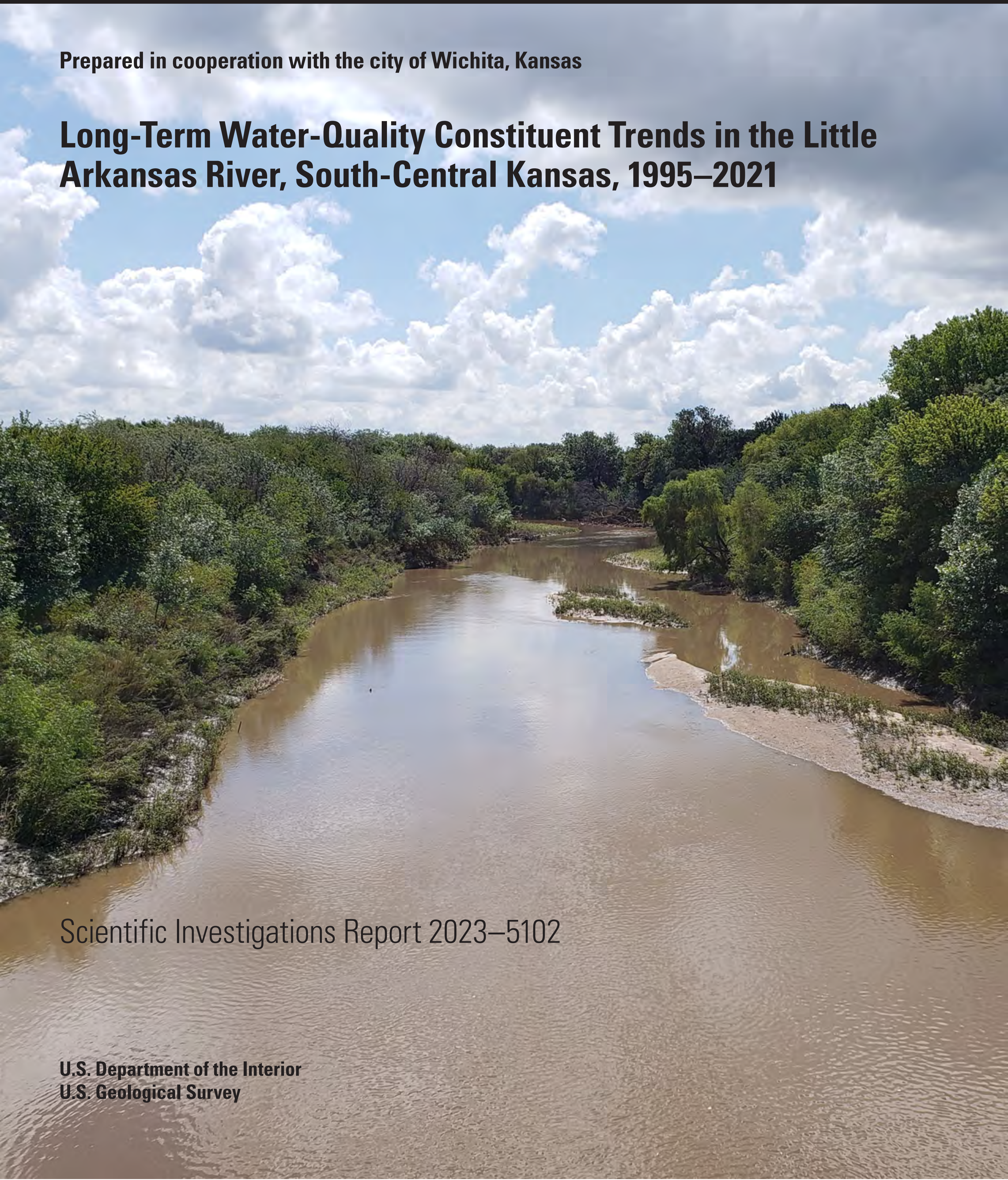

Prepared in cooperation with the city of Wichita, Kansas

Long-Term Water-Quality Constituent Trends in the Little Arkansas River, South-Central Kansas, 1995–2021

Scientific Investigations Report 2023–5102

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

Cover. Photograph showing the Little Arkansas River downstream from the continuous water-quality monitor installation, taken at the Little Arkansas River near Sedgwick, Kansas (U.S. Geological Survey [USGS] site 07144100) on September 17, 2018, by Slade Hackney (USGS hydrologic technician).

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Contents

Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
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)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per year (ft/y)	0.3048	meter per year (m/y)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	metric ton (t)
pound per square mile (lb/mi^2)	0.4536	kilogram per square mile (kg/mi^2)

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

$$°F = (1.8 \times °C) + 32.$$

Supplemental Information

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

Turbidity is given in formazin nephelometric units (FNU).

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

Concentrations of nitrogen species in water are given in milligrams per liter as nitrogen (mg/L as N).

Concentrations of phosphorus species in water are given in milligrams per liter as phosphorus (mg/L as P).

Bacteria densities in water are given in colony forming units per 100 milliliters (cfu/100 mL).

Abbreviations

<	less than
AMLE	absolute maximum likelihood estimation
AMPA	aminomethylphosphonic acid
ASR	aquifer storage and recovery
deethylatrazine	2-chloro-4-isopropylamino-6-amino-*s*-triazine
E. coli	*Escherichia coli*
EGRET	Exploration and Graphics for RivEr Trends
EGRETci	Exploration and Graphics for RivEr Trends Confidence Intervals
EPA	U.S. Environmental Protection Agency
MCL	maximum contaminant level
NPDES	National Pollutant Discharge Elimination System
NWQL	National Water Quality Laboratory
OLS	ordinary least squares
QA/QC	quality assurance and quality control
R^2	coefficient of determination
RPD	relative percentage difference
SMCL	secondary maximum contaminant level
THM	trihalomethane
TKN	total Kjeldahl nitrogen
TMDL	total maximum daily load
USGS	U.S. Geological Survey
WBT	Weighted Regressions on Time, Discharge, and Season bootstrap test
WRTDS	Weighted Regressions on Time, Discharge, and Season

Long-Term Water-Quality Constituent Trends in the Little Arkansas River, South-Central Kansas, 1995–2021

By Mandy L. Stone and Brian J. Klager

Abstract

The *Equus* Beds aquifer and Cheney Reservoir are primary sources for the city of Wichita's current (2023) water supply. The *Equus* Beds aquifer storage and recovery (ASR) project was developed by the city of Wichita in the early 1990s to meet future water demands using the Little Arkansas River as an artificial aquifer recharge water source during above-base-flow conditions. Little Arkansas River water is removed from the river at an ASR Facility intake structure, treated using National Primary Drinking Water Regulations as a guideline, and is infiltrated into the *Equus* Beds aquifer through recharge basins or injected into the aquifer through recharge wells for later use. The U.S. Geological Survey, in cooperation with the city of Wichita, completed this study to quantify and characterize Little Arkansas River water-quality data. Data in this report can be used to evaluate changing conditions, provide science-based information for decision making, and help meet regulatory requirements.

Continuous (hourly) physicochemical properties were measured, and discrete water-quality samples were collected from three Little Arkansas River sites located along the easternmost extent of the *Equus* Beds aquifer during 1995 through 2021 over a range of streamflow conditions. The Little Arkansas River at Highway 50 near Halstead, Kansas, streamgage (U.S. Geological Survey station 07143672; hereafter referred to as the "Highway 50 site") is located upstream from the other two sites, and the Little Arkansas River near Sedgwick, Kans., streamgage (U.S. Geological Survey station 07144100; hereafter referred to as the "Sedgwick site") is located downstream from the other two sites; these two sites bracket most of the easternmost part of the *Equus* Beds aquifer. The Little Arkansas River upstream of ASR Facility near Sedgwick, Kans., streamgage (U.S. Geological Survey station 375350097262800; hereafter referred to as the "Upstream ASR site") is located between the Highway 50 and Sedgwick sites, about 14.7 river miles (mi) downstream from the Highway 50 site, about 1.7 river mi upstream from the Sedgwick site, and immediately upstream from the ASR Facility intake structure. Surrogate models for water-quality constituents of interest (including bromide, dissolved organic carbon, 2-chloro-4-isopropylamino-6-amino-*s*-triazine [deethylatrazine], atrazine, and metolachlor) were updated or developed using continuously measured and concomitant discrete data. These surrogate models, along with previously developed regression models, were used to compute concentrations (at the Highway 50, Sedgwick, and Upstream ASR sites) and loads (at the Highway 50 and Sedgwick sites) during the study period. Federal criteria were used to evaluate water quality. Where applicable, water-quality data were compared to Federal national drinking-water regulations. Flow-normalized water-quality constituent trends were evaluated using Weighted Regressions on Time, Discharge, and Season (WRTDS) statistical models and water-quality trends were described using WRTDS bootstrap tests.

Continuously computed primary ion concentrations were generally larger at the Highway 50 site compared to the Sedgwick site. During the study period, the Federal secondary maximum contaminant level (SMCL) for dissolved solids was exceeded 57 percent of the time at the Highway 50 site and 38 percent of the time at the Sedgwick site. Computed bromide concentrations were larger at the Highway 50 site and exceeded the city of Wichita treatment threshold about 70, 21, and 19 percent of the time at the Highway 50, Sedgwick, and Upstream ASR sites, respectively. Chloride concentrations exceeded the Federal SMCL about 16 percent of the time at the Highway 50 site and did not exceed the SMCL at the Sedgwick site. Continuous arsenic concentrations exceeded the Federal Maximum Contaminant Level (MCL) 9 to 15 percent of the time at the Sedgwick and Highway 50 sites, respectively, during the study. Atrazine concentrations exceeded the Federal MCL 10 percent of the time at the Highway 50 and Sedgwick sites and 14 percent of the time at the Upstream ASR site during the study; computed glyphosate concentrations at the Sedgwick site never exceeded the MCL during the study.

Little Arkansas River flow-normalized primary ion concentrations during 1995 through 2021 generally had downward trends and decreases were generally larger at the Highway 50 site compared to the Sedgwick site. Dissolved solids and chloride concentrations decreased at the Highway 50 and Sedgwick sites. Bromide had no trend at the Highway 50 site and a downward trend at the Sedgwick site. Nitrate plus nitrite and total phosphorus concentrations had upward trends at the Highway 50 site but downward trends at the Sedgwick site, whereas total organic carbon had upward trends at both sites. Nitrate plus nitrite, total nitrogen, total phosphorus, and total

organic carbon fluxes had upward trends at the Highway 50 and Sedgwick sites. Suspended-sediment concentrations had an upward trend at the Highway 50 site and had no trend at the Sedgwick site. Arsenic concentrations had downward trends at the Highway 50 and Sedgwick sites.

About one-quarter to one-half of the Little Arkansas River loads, including nutrients and sediment, were transported during 1 percent of the time during the study. Because streamflows are highly sensitive to climatic variation and an increase of extreme precipitation events in the Great Plains is expected, similar disproportionately large pollutant loading events may increase into the future. Continuous measurement of 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. Continuation of this water-quality monitoring will provide data to characterize changing conditions in the Little Arkansas River and possibly identify new and changing trends. Information in this report allows the city of Wichita to make informed municipal water-supply decisions using past and present water-quality conditions and trends in the watershed.

Introduction

Wichita, in south-central Kansas, is the largest city in the State of Kansas and has a population of about 395,700 (U.S. Census Bureau, 2021). The *Equus* Beds aquifer Wichita well field, constructed in the 1950s, and Cheney Reservoir (fig. 1), constructed in the 1960s, are primary sources for the city of Wichita's current (2023) water supply. An Integrated Local Water Supply Plan was developed by the city of Wichita's Water Utilities Department to address expected water demands through 2050, primarily by artificial recharge of the *Equus* Beds aquifer (City of Wichita, 1993). The *Equus* Beds aquifer storage and recovery (ASR) project diverts water from the Little Arkansas River during above-base-flow conditions, treats it using National Primary Drinking Water Regulations (U.S. Environmental Protection Agency, 2009) as a guideline, and either injects it or recharges it through spreading basins into the *Equus* Beds aquifer for later use to ensure that the city can meet water demand during an extended drought.

The U.S. Geological Survey (USGS), in cooperation with the city of Wichita, completed this study of the Little Arkansas River, which is source water for the *Equus* Beds ASR project, to quantify and characterize Little Arkansas River water-quality conditions. Long-term Little Arkansas River water-quality data were collected from 1995 through 2021 to complete this study objective. Numerous studies summarizing Little Arkansas River water quality have been completed, including Tappa and others (2015), Stone and others (2016), Rasmussen and others (2016), Stone and others (2019), and Stone and Klager (2022).

Equus Beds Aquifer Storage and Recovery Project

The city of Wichita, Kansas, uses the *Equus* Beds aquifer as a primary municipal water-supply source. *Equus* Beds aquifer water levels have decreased substantially (Hansen and others, 2014; Whisnant and others, 2015; Klager, 2016) because historically, irrigator, industrial, and municipal pumpage volume exceeded the natural aquifer recharge rate. The Wichita well field is susceptible to saltwater (including chloride) contamination from the Arkansas River and intrusion from existing upgradient plumes near Burrton, Kansas, caused by oil field evaporation pits remaining from the 1930s (Whittemore, 2007; Klager and others, 2014). The *Equus* Beds ASR project was created by the city of Wichita to help meet future water demands.

The *Equus* Beds ASR project currently (2023) consists of two coexisting phases:

1. Phase I began in 2007 and has the capacity to capture 10 million gallons per day (Mgal/d) of Little Arkansas River water and indirect streambank-diversion well water for recharge activity with water injection in four wells and two recharge basins. Directly diverted stream water is treated using membrane filtration and advanced oxidation to reduce sediment and remove organic material before being recharged through the two recharge basins; streambank-diversion well pumped water is not treated further before recharge through the injection wells or basins (Garinger and others, 2011).

2. Phase II began in 2013 and includes a 30-Mgal/d surface-water treatment facility, a 60-Mgal/d river intake facility equipped to divert 30 Mgal/d and treat 15 Mgal/d, eight recharge-injection wells, and a recharge basin. The facility capacity of 30 Mgal/d requires a streamflow of about 100 cubic feet per second (ft^3/s) or greater at the Little Arkansas River near Sedgwick, Kans., streamgage (USGS station 07144100; hereafter referred to as the "Sedgwick site"; fig. 1) to operate. Water is directly diverted from the Little Arkansas River at the intake structure when streamflow exceeds about 100 ft^3/s at this site. The city of Wichita has a National Pollutant Discharge Elimination System (NPDES) permit (Kansas Permit number I-LA24-PO01; Federal Permit number KS0099694) to discharge waste from the ASR phase II surface-water treatment facility to the Little Arkansas River.

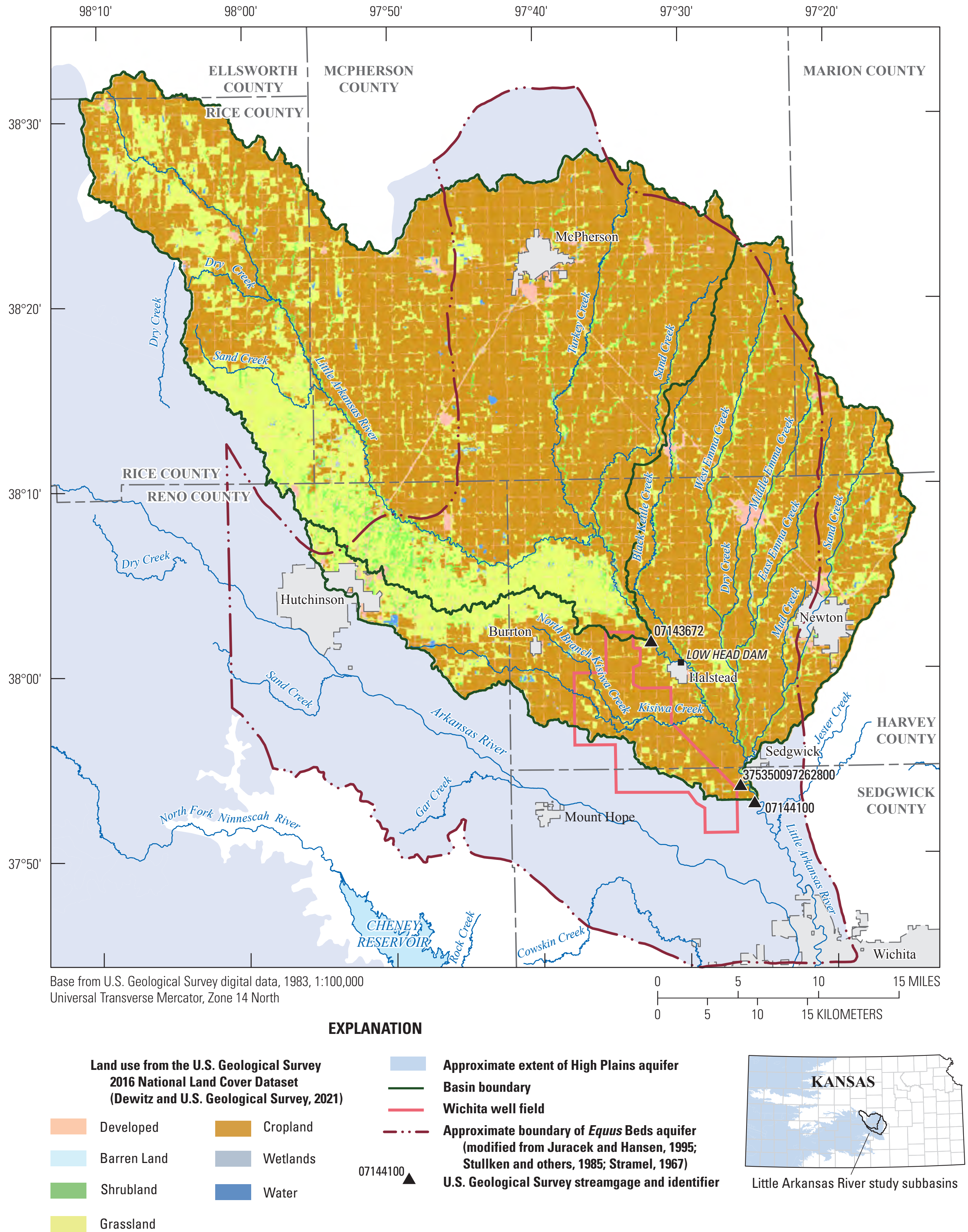


Figure 1. Location of the study area near Wichita, south-central Kansas.

The ASR facilities have an operational period of April 15 through October 15 to avoid freezing conditions. The total amount of phase I and II recharge water was about 5.1 billion gallons during 2007 through 2021. More information about the city of Wichita ASR project is available at https://wichitaasr.org/.

Purpose and Scope

The purpose of this report is to document Little Arkansas River water quantity and quality; document the development and update of regression models that establish relations between continuous and discrete water-quality data; and characterize and quantify water-quality concentrations, loads, and trends during 1995 through 2021 for primary ions, nutrient and carbon species, sediment, indicator bacteria, trace elements, and pesticides. Water-quality constituents of interest were selected because of their relevance to water-supply or water-quality issues in the *Equus* Beds aquifer and the Little Arkansas River. Data from this report can be used to document surface-water quality, quantify potential pollutants, evaluate changing conditions, identify environmental factors affecting surface water, provide science-based information for decision making, and help meet regulatory monitoring requirements. Nationally, the methods and results presented in this report provide guidance and perspective for aquifer recharge projects conducted elsewhere.

Description of Study Area and Background Information

The study area is located in south-central Kansas northwest of Wichita (fig. 1). This study has three study sites along the Little Arkansas River. The Little Arkansas River at Highway 50 near Halstead, Kans., streamgage (USGS station 07143672; hereafter referred to as the “Highway 50 site,” fig. 1) is located upstream from the other sites. The Sedgwick site (fig. 1) is located downstream from the other sites. These two sites bracket a substantial portion of the easternmost part of the *Equus* Beds aquifer. The Little Arkansas River upstream of ASR Facility near Sedgwick, Kans., streamgage (USGS station 375350097262800; hereafter referred to as the “Upstream ASR site,” fig. 1) is located between the Highway 50 and Sedgwick sites, about 14.7 river miles (mi) downstream from the Highway 50 site, about 1.7 river mi upstream from the Sedgwick site, and immediately upstream from the ASR Facility intake structure (not shown). The contributing drainage areas for the Highway 50 and Sedgwick sites are about 685 square miles (mi^2) and about 1,165 mi^2, respectively.

The Little Arkansas River has a contributing drainage area of about 1,266 mi^2 (Albert and Stramel, 1966) of primarily agricultural land that produces mainly corn, sorghum, soybeans, and wheat (Kansas Department of Agriculture, 2021). About 65 percent of the Little Arkansas River watershed is cultivated crops and hay (U.S. Geological Survey, 2019). Fertilizers (such as nitrogen and phosphorus; U.S. Department of Agriculture, 2022) and herbicides (such as atrazine, glyphosate, and metolachlor; Kansas Rural Center, 2018) are commonly applied in the drainage basin. Cattle and hogs are the primary livestock raised in the area (Kansas Department of Agriculture, 2021). Long-term mean annual precipitation (1900 through 2021) in the study area, based on data recorded near Mount Hope, Kans. (fig. 1; National Oceanic and Atmospheric Administration, 2022), was 30.3 inches (table 1). Mean annual precipitation was 33.5 inches during the study period (1995 through 2021; table 1). Rock formations in the Little Arkansas River watershed are not well exposed because of low topographic relief and high erodability; rocks appearing at the land surface include the Wellington Formation and the Ninnescah shale of Permian age. Unconsolidated deposits of clay, silt, sand, and gravel also appear at the surface (Lane and Miller, 1965). Soils in the watershed range from clay and silty clay to sandy silt in the northern part; have developed from loess and alluvial deposits in the northern and central parts that range from clay to silty sand; and have developed from alluvium of Recent age in the southern part that range from clay to fine sand (Albert and Stramel, 1966).

The Kansas Department of Health and Environment has listed several streams in the Little Arkansas River watershed as impaired waterways under section 303(d) of the 1972 Clean Water Act (Kansas Department of Health and Environment, 2022). Section 303(d) of the 1972 Clean Water Act requires States to identify water bodies with impaired water quality and the pollutants causing the impairments. Impairments for streams in or near the study area drainage basin include arsenic, chloride, and nitrate for water supply; dissolved oxygen, selenium, total suspended solids, atrazine, total phosphorus, biology (nutrients and oxygen demand impact on aquatic life), and sediment for aquatic life; and *Escherichia coli* (*E. coli*) bacteria for recreation (Kansas Department of Health and Environment, 2022). Major pollutants of concern for the Little Arkansas River watershed include atrazine, sediment, nutrients, and *E. coli* bacteria (Kansas State University Research and Extension and others, 2018).

A total maximum daily load (TMDL) is the maximum amount of a pollutant allowed in a water body while still meeting water-quality standards and are developed for each impairment-causing pollutant to determine reduction targets and management plans for reducing pollutants. The Little Arkansas River has defined TMDLs for atrazine (Kansas Department of Health and Environment, 2008), nutrients and oxygen demand (biology; Kansas Department of Health and Environment, 2000b), sediment (Kansas Department of Health and Environment, 2000a), chloride (Kansas Department of Health and Environment 2006b), fecal coliform bacteria (Kansas Department of Health and Environment, 2000c), total suspended solids (Kansas Department of Health and Environment, 2014), total phosphorus and pH (Kansas Department of Health and Environment, 2019), and total phosphorus and dissolved oxygen (Kansas Department of Health and Environment, 2021).

Table 1. Annual total and mean annual precipitation during 1995 through 2021, and mean annual precipitation during 1900 through 2021 at the "MT HOPE" (Global Historical Climatology Network–Daily USC00145539) station.

[Data are from National Oceanic and Atmospheric Administration (2022)]

Year or period	Total precipitation, in inches
1995	38.3
1996	32.7
1997	32.4
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
2020	28.3
2021	32.7
Mean annual during 1995 through 2021	33.5
Mean annual during 1900 through 2021	30.3

Recent Investigations

The city of Wichita and USGS cooperative efforts began in the 1920s as the city began its water-supply development (Stone, 2017). Since 1995, the USGS has completed several studies to quantify and characterize *Equus* Beds aquifer and Little Arkansas River water quality. *Equus* Beds aquifer studies have indicated that the amount of aquifer water volume has recovered since the historic 1993 low because of less pumping, more natural recharge, and ASR (Klager, 2016). The chloride plume near Burrton, Kans., moves about 0.6 foot per day eastward toward the Wichita well field regardless of pumping (Klager and others, 2014). Recharge activity has not resulted in substantial effects on *Equus* Beds aquifer water quality, at least partially because the total amount of water recharged is small (Tappa and others, 2015; Stone and others, 2016, 2019). Major recent Little Arkansas River findings include the following:

1. Little Arkansas River water-quality data were collected before (1995 through 2006) and concurrent with (2007 through 2012) ASR phase I activity as part of an effort to quantify effects that may be related to ASR phase I recharge (Tappa and others, 2015). Water-quality constituents of concern did not increase substantially and were likely more affected by climatological and natural processes than artificial recharge. Little Arkansas River sulfate concentrations rarely exceeded the Federal secondary maximum contaminant level (SMCL; 250 milligrams per liter [mg/L]), and chloride concentrations exceeded the Federal SMCL (250 mg/L) about 20 percent of the time, primarily during minimal flow conditions. Little Arkansas River nitrate concentrations rarely exceeded the Federal maximum contaminant level (MCL; 10 mg/L), and arsenic concentrations exceeded the Federal MCL (10 micrograms per liter [µg/L]) about 19 percent of the time, primarily during low-flow conditions. Little Arkansas River dissolved iron and manganese concentrations exceeded their Federal SMCLs (300 µg/L and 50 µg/L, respectively) in about 5 and 50 percent of discretely collected samples, respectively. Atrazine exceeded the Federal MCL (3.0 µg/L) about 28 percent of the time, mostly during the late spring to early fall. Large densities of coliform bacterial indicators (total coliform, fecal coliform, and *E. coli*) were detected in most Little Arkansas River samples (Tappa and others, 2015).

2. A hydrobiological monitoring program was developed and implemented to measure the effects of ASR phase II activity on Little Arkansas River water quality using data collected pre-ASR phase II implementation (2011 through 2012) and post-ASR phase II onset (2013 through 2014; Stone and others, 2016). Little Arkansas River water-quality constituent concentrations were controlled by hydrology rather than phase II ASR activity. Post-ASR nitrate and sediment concentrations were smaller than pre-ASR likely because of larger streamflows, and post-ASR organic carbon concentrations were larger than pre-ASR likely because of larger streamflows and runoff conditions. Pre- and post-ASR habitat, macroinvertebrate community, and fish community scores or metrics were similar (Stone and others, 2016).

3. Little Arkansas River water-quality data were collected during 2001 through 2016 to evaluate constituents of concern for aquifer recharge activity and compare water-quality data to their respective Federal criteria and to establish baseline conditions before further implementation of ASR (Stone and others, 2019). Little Arkansas River water-quality constituent concentrations did not increase in comparison to sampling that preceded (1995 through 2012) the study. Less than 1 percent of chloride and nitrate, 7 percent of dissolved iron, 48 percent of dissolved manganese, 12 percent of dissolved arsenic, and 39 percent of atrazine detections in Little Arkansas River samples exceeded Federal primary or secondary drinking-water criteria. None of the Little Arkansas River samples exceeded the Federal sulfate criterion, and every sample had detections of total coliform bacteria during the study (Stone and others, 2019).

4. Previously developed surrogate regression models used to continuously compute Little Arkansas River water-quality concentrations or densities of constituents of interest in real time were updated using data collected during 1998 through 2019 (Stone and Klager, 2022). Surrogate relations allow the concentrations or densities of many potential constituents of concern, including chloride, nutrients, sediment, bacteria, and atrazine to be estimated in near real time and characterized during conditions and time scales that would not be otherwise possible. Little Arkansas River real-time computations of water-quality constituents are available at the USGS National Real-Time Water Quality website (https://nrtwq.usgs.gov). 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; and streamflow and water temperature were explanatory variables for dissolved arsenic (Stone and Klager, 2022).

Methods

Data collection followed protocols (Ziegler and Combs, 1997; Stone and others, 2012) developed for the *Equus* Beds ASR project. In addition to Ziegler and Combs (1997) and Stone and others (2012), numerous studies detailing Little Arkansas River water-quality sampling, processing, and analysis have been completed, including Ziegler and others (2010), Tappa and others (2015), Stone and others (2016), Stone and others (2019), and Stone and Klager (2022).

Data Collection

Continuous streamflow and physicochemical data and discrete water-quality data were collected from three surface-water sites along the Little Arkansas River over a range of streamflow conditions during 1995 through 2021 to evaluate water-quality conditions. Water-quality data were collected from the Highway 50, Sedgwick, and Upstream ASR sites to quantify water-quality constituents of interest, develop or update previously published water-quality surrogate relations, compute water-quality constituent concentrations and loads, and identify water-quality constituent trends during 1995 through 2021. Data collected by the USGS are stored in the USGS National Water Information System (NWIS) database (U.S. Geological Survey, 2023).

Continuous Streamflow and Gage Height Measurements

Continuous (1-hour maximum interval) streamflow was measured at the Highway 50 and Sedgwick sites and continuous (1-hour maximum interval) gage height (stream stage) was measured at the Upstream ASR site. Streamflow has been measured at the Highway 50 and Sedgwick sites since May 1995 and November 1993, respectively. Gage height was measured at the Upstream ASR site since April 2011. Streamflow and gage height were measured using standard USGS methods (Sauer and Turnipseed, 2010; Turnipseed and Sauer, 2010; Painter and Loving, 2015).

Continuous Water-Quality Monitoring

Continuous (1-hour maximum interval) water-quality physicochemical properties were measured at the Highway 50, Sedgwick, and Upstream ASR sites. Water-quality physicochemical properties measured included water temperature, specific conductance, pH, dissolved oxygen, turbidity, and nitrate plus nitrite. Water-quality monitors were installed near the centroid of the stream cross section at the Highway 50 and Sedgwick sites and on the right streambank (facing downstream) at the Upstream ASR site. The Highway 50, Sedgwick, and Upstream ASR sites were equipped with a YSI Incorporated 6600 Extended Deployment System water-quality monitor (YSI Incorporated, 2012a) in May 1998, April 1998, and April 2011, respectively, to continuously (60-minute interval) measure water temperature, specific conductance, pH, dissolved oxygen (YSI Clark cell or optical dissolved oxygen sensors), and turbidity (YSI 6026 or 6136 turbidity sensors). Nitrate sensors (HACH Nitratax plus sc; HACH Company, 2014) were installed at the Highway 50, Sedgwick, and Upstream ASR sites in February 2017, March 2012, and March 2016, respectively.

Some equipment was upgraded throughout the duration of the project. YSI 6026 turbidity sensors were initially installed at the Highway 50 and Sedgwick sites in October 1998 and September 1998, respectively. YSI 6136 turbidity sensors were installed at the Highway 50, Sedgwick, and Upstream ASR sites in January 2007, July 2004, and April 2011, respectively. A YSI EXO2 water-quality monitor (YSI Incorporated, 2012b) equipped with water temperature, specific conductance, pH, dissolved oxygen, and YSI EXO turbidity sensors was installed in January 2017 at the Highway 50 site, in September 2014 at the Sedgwick site, and in October 2015 at the Upstream ASR site. YSI 6026 and YSI 6136 turbidity sensors were deployed concurrently at the Highway 50 and Sedgwick sites during July 2004 through August 2005 and July 2004 through January 2006, respectively. YSI 6136 and YSI EXO turbidity sensors were deployed concurrently at the Highway 50, Sedgwick, and Upstream ASR sites during January 2017 through May 2019, September 2014 through March 2015 (and again March 2017 through July 2019), and May 2017 through July 2019, respectively, to compare turbidity sensor measurements. Water-quality monitors were maintained following standard USGS procedures (Wagner and others, 2006; Pellerin and others, 2013; Bennett and others, 2014; Rasmussen and others, 2014).

Discrete Water-Quality Data Collection

Discrete surface-water-quality samples were collected at the three study sites across a range of streamflows. Samples were collected using primarily depth- and width-integrated sample collection techniques at the Highway 50 and Sedgwick sites and either single vertical or grab-dip techniques at the Upstream ASR site (U.S. Geological Survey, 2006; Rasmussen and others, 2014). Discrete water-quality constituent datasets used in this report were selected based on the following criteria:

1. relevance as constituents of concern for either the *Equus* Beds aquifer or the Little Arkansas River (for example, constituents with Federal or other criteria),
2. relevance as constituents of concern for water treatment processes (for example, bromide, organic carbon, and pesticides), and
3. a history of detections in Little Arkansas River water samples (for pesticide datasets; appendix 1.5 in Stone and others, 2019).

Discrete water-quality samples were analyzed for primary ions (hardness, dissolved solids, calcium, magnesium, potassium, sodium, bromide, chloride, fluoride, silica, and sulfate), nutrient and carbon species (ammonia plus organic nitrogen, nitrate plus nitrite, total phosphorus, and dissolved and total organic carbon), sediment (suspended solids and suspended-sediment concentration), indicator bacteria (*E. coli* and fecal coliforms), trace elements (iron and arsenic), pesticides (including deethylatrazine, atrazine, and metolachlor), and absorbance and color at all study sites. Total nitrogen values were computed by summing ammonia plus organic nitrogen and nitrate plus nitrite values. Discrete samples collected at the Sedgwick site included additional nutrients (ammonia, nitrate, nitrite, orthophosphate, and dissolved phosphorus), strontium, and pesticides (including aminomethylphosphonic acid [AMPA] and glyphosate). 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), Tappa and others (2015), and Stone and Klager (2022). Indicator bacteria analyses were done using methods described by the U.S. Environmental Protection Agency (2000a, 2006a, 2006b) and Myers and others (2014). AMPA and glyphosate were analyzed following methods described in Meyer and others (2009).

Primary ions, nutrients, organic carbon, and trace element samples were analyzed by the Wichita Municipal Water and Wastewater Laboratory and the USGS National Water Quality Laboratory (NWQL; 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, Kans.). Pesticides were analyzed by the USGS NWQL, with the exception of AMPA and glyphosate, which were analyzed by the USGS Kansas Organic Geochemistry Research Laboratory.

Data Analysis

Water-chemistry data were summarized for the Little Arkansas River for the period 1995 through 2021. Surrogate models for water-quality constituents of interest were updated or developed using continuously measured and concomitant discrete data and were used to compute concentrations and loads during the study period. Federal criteria were used to evaluate water quality. Where applicable, water-quality data were compared to U.S. Environmental Protection Agency (EPA) national drinking-water regulations (U.S. Environmental Protection Agency, 2009). Water-quality trends during the study period also were evaluated.

Continuous and Discrete Water Chemistry Data Analysis

Duration curves were used to summarize continuously measured or select computed Little Arkansas River water-quality data. Duration curves are cumulative distribution functions and were constructed using hourly values to evaluate and compare frequency and magnitude characteristics at the Highway 50, Sedgwick, and Upstream ASR sites during the study period. Duration curves are indicative of the percentage of time that specified conditions were equaled or exceeded, or the frequency of exceedance (Searcy, 1959). The Weibull formula (Weibull, 1939; Helsel and others, 2020) was used for plotting position.

Some water-quality constituents had censored values. Summary statistics for constituents that had censored values were calculated using regression on order statistics (Helsel and Cohn, 1988) for datasets with sample sizes less than (<) 50 and having as much as 80 percent censored data and for datasets with sample sizes greater than or equal to 50 and having as much as 50 percent censored data (Helsel, 2005; Bolks and others, 2014). Summary statistics for constituents that had censored values were calculated using maximum likelihood estimation (Helsel and Cohn, 1988) for datasets that had sample sizes greater than or equal to 50 and having between 50 and 80 percent censored data (Helsel, 2005; Bolks and others, 2014). Summary statistics were not computed when greater than 80 percent of data were censored. Statistical summaries were computed using the censtats function in R (version 4.1.3) programming language (R Core Team, 2021).

Surrogate Regression Model Development

Surrogate models were newly developed for constituents of interest at the three study sites and included models for bromide (all sites), dissolved organic carbon (all sites), total organic carbon (Upstream ASR site), 2-chloro-4-isopropylamino-6-amino-*s*-triazine (deethylatrazine; all sites), acetochlor (Upstream ASR site), AMPA (Sedgwick site), atrazine (Upstream ASR site), glyphosate (Sedgwick site), and metolachlor (all sites). Surrogate models for atrazine at the Highway 50 and Sedgwick sites were updated from previously published models (Stone and Klager, 2022). Surrogate models were not developed for water-quality constituents of interest that had datasets with greater than 20 percent left-censored data. Additional streamflow-based or gage-height-based models were developed to compute estimates of concentrations or densities during periods when concomitant continuous surrogate measurements were unavailable.

Regression models were developed using ordinary least squares (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 bromide, deethylatrazine, acetochlor, and metolachlor.

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 recorded streamflow, water temperature, specific conductance, pH, dissolved oxygen, YSI EXO turbidity, and nitrate plus nitrite measurements. Periodic functions (seasonal components as 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 (Mallows, 1973) 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). Models with the following criteria were selected:

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 a cosine seasonality variable was included in the model, both variables were 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 fit 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 were 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). 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 overestimate the certainty of the model. Data points that 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.

Continuous Water-Quality Constituent Concentration and Load Computation

Daily concentrations of selected primary ions (hardness, dissolved solids, calcium, sodium, bromide, chloride, and sulfate), nutrient and carbon species (ammonia plus organic nitrogen, total phosphorus, dissolved organic carbon, and total organic carbon), indicator bacteria (*E. coli* and fecal coliform bacteria), arsenic, sediment (suspended solids and suspended-sediment concentration), and pesticides (deethylatrazine, acetochlor, AMPA, atrazine, glyphosate, and metolachlor) were computed using previously developed (Christensen and others, 2003; Rasmussen and others, 2016; Stone and Klager, 2022) and newly developed models during 1998 through 2021. Daily mean values were used to compute water-quality constituent concentrations because of missing instantaneous streamflow data and periods of missing water-quality data.

Daily concentrations of hardness, dissolved solids, calcium, sodium, chloride, sulfate, and arsenic were computed at the Highway 50 and Sedgwick sites using surrogate models developed by Stone and Klager (2022). Water-quality constituent models that used turbidity measurements as a surrogate were developed using different turbidity sensors (YSI 6026, YSI 6136, or YSI EXO) and included ammonia plus organic nitrogen, total phosphorus, total organic carbon, *E. coli* bacteria, fecal coliform bacteria, suspended solids, and suspended-sediment concentration. Christensen and others (2003) developed models using continuous YSI 6026 turbidity measurements, Rasmussen and others (2016) developed surrogate relation models using continuous YSI 6136 turbidity measurements, and Stone and Klager (2022) developed surrogate relation models using continuous YSI EXO turbidity measurements at the Highway 50 and Sedgwick sites. Computed continuous concentrations or densities of ammonia plus organic nitrogen, total phosphorus, *E. coli* bacteria, fecal coliform bacteria, suspended solids, and suspended-sediment concentrations at the Highway 50 and Sedgwick sites were developed using a combination of previously published models by Christensen and others (2003; YSI 6026 turbidity sensor), Rasmussen and others (2016; YSI 6136 turbidity sensor), and Stone and Klager (2022; YSI EXO turbidity sensor) that used continuous turbidity sensor measurements. Computed continuous total organic carbon concentrations at the Highway 50 and Sedgwick sites were developed using a combination of previously published models by Rasmussen and others (2016; YSI 6136 turbidity sensor) and Stone and Klager (2022; YSI EXO turbidity sensor) according to continuous turbidity sensor measurements (Christensen and others [2003] did not include a total organic carbon model). Continuous total organic carbon at the Upstream ASR site was computed using the newly developed surrogate model and continuous YSI EXO turbidity sensor data. Continuous bromide, deethylatrazine, atrazine, and metolachlor concentrations were computed at the Highway 50, Sedgwick, and Upstream ASR sites using newly developed models. Continuous acetochlor concentrations were computed for the Upstream ASR site, and continuous AMPA and glyphosate concentrations were computed for the Sedgwick site. Previously published (Stone and Klager, 2022) and newly developed streamflow-based or gage-height-based surrogate models were used to compute continuous water-quality constituent concentrations when continuous water-quality data were unavailable. The streamflow-based or gage-height-based computed constituent concentrations were shifted to the primary water-quality values computed using a surrogate regression model directly preceding and following the streamflow-based or gage-height-based computed concentrations following Porterfield (1972) to align computed concentration differences among model types.

Loads were computed at the Highway 50 and Sedgwick sites for selected water-quality constituents, including those that have TMDLs. Chloride, nitrate plus nitrite, ammonia plus organic nitrogen, total phosphorus, dissolved organic carbon, total organic carbon, suspended solids, suspended-sediment concentration, *E. coli* bacteria, fecal coliform bacteria, and atrazine loads were computed during 1999 (the first full year of water-quality monitor measurements) through 2021. Water-quality constituent loads, with the exception of indicator bacteria, were calculated in tons per day. *E. coli* and fecal coliform bacteria were calculated in trillions of colony-forming units per day. Loads were computed by multiplying regression model-computed daily concentrations or densities (in milligrams per liter, micrograms per liter, or colony forming units per 100 milliliters) by daily streamflow (cubic feet per second) and a unit conversion factor of 0.0027 (for constituents measured in concentrations of milligrams per liter), $2.7\text{x}10^{-6}$ (for constituents measured in concentrations of micrograms per liter), or $2.45\text{x}10^{-5}$ (for constituents measured in densities of colony forming units per 100 milliliters). Annual loads were computed by summing the daily loads. Annual yields (in pounds or trillions of colony-forming units per square mile) were calculated by dividing the annual loads by the contributing drainage area at the Highway 50 (685 mi^2) and Sedgwick (1,165 mi^2) sites.

Water-Quality Constituent Trends

Water-quality constituent trends were analyzed at the Highway 50 and Sedgwick sites for discrete datasets that did not have more than 50 percent censored data (Hirsch and De Cicco, 2015) and were not associated with strong seasonality (for example, pesticides [Gilliom, 2007; Ryberg and York, 2020]) and included primary ions (hardness, dissolved solids, calcium, magnesium, potassium, sodium, bromide, chloride, fluoride, silica, and sulfate), nutrient and carbon species (ammonia [Sedgwick site only], nitrate plus nitrite, total nitrogen, nitrate [Sedgwick site only], nitrite [Sedgwick site only], orthophosphate [Sedgwick site only], dissolved phosphorus [Sedgwick site only], total phosphorus, dissolved organic carbon, and total organic carbon), sediment (suspended solids and suspended-sediment concentration), indicator bacteria (*E. coli* and fecal coliform bacteria), and trace elements. Water-quality constituent trends were analyzed using the R package

Exploration and Graphics for RivEr Trends (EGRET; Hirsch and De Cicco, 2015). The Weighted Regressions on Time, Discharge, and Season model (WRTDS; Hirsch and others, 2010; Hirsch and De Cicco, 2015) was run using the EGRET package for long-term flow-normalized water-quality concentration and flux computations and trends. Annual water-quality concentrations and fluxes were estimated using WRTDS with Kalman filtering (WRTDS–K; described in Zhang and Hirsch, 2019). WRTDS–K generally produces more accurate concentration and flux results than the standard WRTDS method (Zhang and Hirsch, 2019). Lee and others (2019) tested 13 methods for computing annual water-quality constituent loads and determined WRTDS–K was the most accurate.

The Exploration and Graphics for RivEr Trends Confidence Intervals (EGRETci) package was used to quantify WRTDS model uncertainty using a WRTDS bootstrap test (WBT; Hirsch and others, 2015). Hirsch and others (2015) developed WBT trend likelihood descriptive statement definitions (table 2) to provide a method to classify water-quality trends into categories ranging from highly unlikely to highly likely. Water-quality concentrations, flow-normalized concentrations, fluxes, and flow-normalized fluxes were computed annually. Changes in annual flow-normalized concentrations and fluxes were computed at the Highway 50 and Sedgwick sites for three periods:

1. the entire 26- or 27-year study period during 1995 (Sedgwick site) or 1996 (Highway 50 site) through 2021,
2. the 11- or 12-year period before ASR (phase I) operation during 1995 (Sedgwick site) or 1996 (Highway 50 site) through 2006, and
3. the 15-year period after ASR (phase I) operation onset during 2007 through 2021 (Highway 50 and Sedgwick sites).

Quality Assurance and Quality Control

OLS regression was analyzed on concurrent YSI 6026/YSI 6136 (Highway 50 and Sedgwick sites) and YSI 6136/YSI EXO (Highway 50, Sedgwick, and Upstream ASR sites) turbidity sensor measurements for comparisons. The OLS regressions show the relation between the YSI 6026 and YSI 6136 turbidity sensors explained 96 to 97 percent of the variance in turbidity measurements and the relation between the YSI 6136 and YSI EXO turbidity sensors explained 98 to 99 percent of the variance in turbidity measurements (appendix 1). YSI 6136 turbidity sensor measurements were, on average, 46 to 53 percent smaller than YSI 6026 turbidity sensor measurements and 14 to 22 percent larger than YSI EXO turbidity sensor measurements (appendix 2).

Quality-assurance and quality-control (QA/QC) samples were collected to identify, quantify, and document bias and variability in data that may have resulted from collecting, processing, handling, and analyzing samples (U.S. Geological Survey, 2006). QA/QC samples collected for this study included replicate, blank, and standard reference samples for discretely collected water-quality samples. Replicate sample relative percentage difference (RPD) was computed by dividing the difference between replicate pairs by the mean and multiplying that value by 100 for a value that represents the percentage difference between replicate pairs (Zar, 1999). RPDs were not computed 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).

Comparison of field cross-sectional measurements collected during discrete sampling throughout the range of streamflow conditions at the Highway 50 and Sedgwick sites verified minimal bias in continuous data owing to sensor location within the stream cross section. Median RPDs

Table 2. Weighted Regressions on Time, Discharge, and Season bootstrap test trend likelihood descriptive statement definitions (Hirsch and others, 2015).

[≥, greater than or equal to; ≤, less than or equal to; <, less than; >, greater than]

Range of posterior mean estimate of increasing trend probability values	Upward trend descriptors	Downward trend descriptors
≥0.95 and ≤1.0	Highly likely	Highly unlikely
≥0.90 and <0.95	Very likely	Very unlikely
≥0.66 and <0.90	Likely	Unlikely
>0.33 and <0.66	About as likely as not	About as likely as not
>0.1 and ≤0.33	Unlikely	Likely
>0.05 and ≤0.1	Very unlikely	Very likely
≥0 and ≤0.05	Highly unlikely	Highly likely

between continuous in situ and average cross-sectional field water-quality monitor measurements from Highway 50 and Sedgwick sites were <4 percent, except for turbidity, which had a median RPDs of 8 percent. Cross-sectional field measurements were not collected at the Upstream ASR site owing to physical site characteristics and safety concerns; instead, the concomitant field measurement was made near the in situ water-quality monitor. Median RPDs between Upstream ASR site continuous in situ and field water-quality monitor measurements were <3 percent, except for turbidity measurements, which had a median RPD of 8 percent.

Continuous data collected during the study period generally required corrections (such as computations to account for instrument fouling or calibration drift) of <10 percent from the original value. Continuous data were missing or deleted because of equipment malfunction, excessive sensor fouling, and extreme low-flow conditions. During the study period, 2 to 4 percent of the streamflow record and 1 percent of the gage height record, 3 to 10 percent of the water temperature record, 5 to 12 percent of the specific conductance record, 3 to 11 percent of the pH record, 6 to 10 percent of the dissolved oxygen and nitrate plus nitrite records, and 6 to 15 percent of the turbidity record were missing or deleted from study sites (table 3).

About 10 percent of discrete water-quality samples were QA/QC samples. Sequential, split, and concurrent replicate water-quality samples were collected during the study period over a range of streamflows and gage heights among the sampling sites. Replicate comparisons included 772 primary ion pairs, 520 nutrient and carbon species pairs, 102 sediment pairs, 109 indicator bacteria pairs, 110 trace element pairs, 474 pesticide pairs, and 79 absorbance and color pairs (appendix 3). Median replicate pair RPDs were <5 percent for primary ions and nutrient and carbon species, <10 percent for sediment and absorbance and color, <15 percent for pesticides, and less than or equal to 20 percent for indicator bacteria and trace elements (appendix 3). The RPD values generally were largest when the values were at or near the laboratory reporting level.

Blank samples were collected to measure the magnitude of contaminant concentration introduced into samples during sampling, processing, and analytical procedures (U.S. Geological Survey, 2006). Blank samples consisted of deionized water, inorganic blank water, or pesticide-grade blank water depending on analysis type. During 1995 through 2021, 142 blank samples were collected for this study. Primary ion blank detections were in 5 percent of primary ion blank results and all individual primary ions detections were <10 percent (appendix 3); detections were generally at or near the detection limit. Nutrients and carbon were detected in 9 percent of blank samples and were generally at or near the detection limit. Individual nutrient and carbon detections were <10 percent, except for ammonia (16 percent), nitrate plus nitrite (17 percent), dissolved organic carbon (47 percent), and total organic carbon (30 percent; appendix 3). Generally, dissolved and total organic carbon detections were at or near the detection limit; some organic carbon detections were traced to potentially contaminated blank water used for the samples. Indicator bacteria were not detected, and one trace element (iron) was detected in 1 percent of blank samples (appendix 3). Pesticides were detected in 1 percent of blank samples and detections were at or near the detection limit (appendix 3). Absorbance and color samples had four (6 percent) detections that were at or near the detection limit (appendix 3).

Little Arkansas River Long-Term Water Quality

Continuous measurement of physicochemical properties in near-real time allowed characterization of Little Arkansas River water during conditions and time scales that would not have been possible otherwise and served as a complement to discrete water-quality sampling. Continued data collection during different flow and seasonal conditions can be used to characterize water-quality conditions and potentially identify new and changing trends. Surface-water physicochemical properties and water-quality constituents that frequently exceeded EPA Federal drinking water-quality criteria and those that are of potential interest or concern for artificial recharge operations are discussed in this report to characterize the quality of potential recharge water.

Little Arkansas River Continuous Streamflow

Stream ecosystem structure and function are largely affected by streamflow (Allan and others, 2021). Annual differences in streamflow are primarily attributed to differences in precipitation. The *Equus* Beds ASR project operations are limited to above-base-flow conditions. Streamflow at the Highway 50 and Sedgwick sites ranged from <1 to 13,900 ft^3/s and <1 to 19,000 ft^3/s, respectively, during 1995 through 2021 (table 3). Mean streamflows during the study period were 217 and 361 ft^3/s at the Highway 50 and Sedgwick sites, respectively (table 3). The ASR phase II water treatment facility requires a minimum streamflow of about 100 ft^3/s at the Sedgwick site to operate. During the study period, 100 ft^3/s was exceeded about 31 percent of the time (fig. 2*A*). Little Arkansas River streamflow values during 1995 through 2021 at the Sedgwick site did not exceed previously reported ranges (Tappa and others, 2015; Stone and Klager, 2022; table 3). Streamflow and gage height maxima were during May 2019 at the Highway 50, Sedgwick, and Upstream ASR sites.

Little Arkansas River Continuous Water Quality

Water temperature affects physical, chemical, and biological processes. Kansas water-quality criteria require that discharges to streams not change water temperature more than 3 degrees Celsius (°C) above or below natural conditions or

Table 3. Summary statistics for continuously (hourly) measured physicochemical properties for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672, 1995–2021); Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100, 1995–2021); and Little Arkansas River upstream of ASR Facility near Sedgwick, Kans. (Upstream ASR; USGS station 375350097262800, 2011–21).

[Continuous real-time water-quality data are available on the U.S. Geological Survey National Real-Time Water-Quality website (https://nrtwq.usgs.gov/ks); *n*, number of measurements; USGS, U.S. Geological Survey; pcode, parameter code; <, less than; --, not applicable]

Site	*n*	Minimum	Maximum	Mean	Median	Percent missing or deleted data
Streamflow, in cubic feet per second (USGS pcode 00060) or gage height, in feet (USGS pcode 00065)						
Highway 50 (streamflow)[a]	229,998	<1	13,900	217	23	2
Sedgwick (streamflow)[b]	226,573	<1	19,000	361	56	4
Upstream ASR (gage height)[c]	93,062	3.5	30	5.8	4.8	1
Water temperature, in degrees Celsius (USGS pcode 00010)						
Highway 50[d]	199,223	<1	35.2	14.9	15.4	4
Sedgwick[e]	202,365	<1	35.5	15.2	15.7	3
Upstream ASR[f]	86,643	<1	36.6	15.8	16.4	10
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius (USGS pcode 00095)						
Highway 50[d]	196,816	57	2,980	916	921	5
Sedgwick[e]	195,778	48	1,910	743	763	6
Upstream ASR[f]	83,251	63	1,910	719	760	12
pH (USGS pcode 00400)						
Highway 50[d]	197,721	6.1	9.6	--	8.0	5
Sedgwick[e]	201,371	6.4	9.2	--	8.0	3
Upstream ASR[f]	84,131	6.6	9.3	--	8.0	11
Dissolved oxygen, in milligrams per liter (USGS pcode 00300)						
Highway 50[d]	194,439	0.3	22.8	9.5	9.0	6
Sedgwick[d]	197,729	0.1	24.3	9.9	9.5	5
Upstream ASR[f]	84,446	0.4	21.4	9.3	9.0	10
Turbidity, in formazin nephelometric units (USGS pcode 63680)						
Highway 50[g]	191,295	0.3	2,110	89	33	6
Sedgwick[h]	182,299	0.1	2,010	84	27	11
Upstream ASR[i]	79,884	1.4	1,280	57	25	15
Nitrate plus nitrite, in milligrams per liter as nitrogen (USGS pcode 99133)						
Highway 50[j]	40,154	<0.01	8.3	0.9	0.6	6
Sedgwick[k]	77,627	<0.01	11	1.1	0.9	10
Upstream ASR[l]	45,764	0.01	6.3	1.1	1.0	10

[a]Streamflow data collected during May 1995 through December 2021.

[b]Streamflow data collected during January 1995 through December 2021.

[c]Gage height data collected during April 2011 through December 2021.

[d]Data collected during May 1998 through December 2021.

[e]Data collected during April 1998 through December 2021.

[f]Data collected during April 2011 through December 2021.

[g]Data collected using a YSI 6026 turbidity sensor during October 1998 through December 2006, a YSI 6136 turbidity sensor during January 2007 through January 2017, and an EXO turbidity sensor during February 2017 through December 2021.

[h]Data collected using a YSI 6026 turbidity sensor during September 1998 through June 2004, a YSI 6136 turbidity sensor during July 2004 through August 2014, and an EXO turbidity sensor during September 2014 through December 2021.

[i]Data collected using a YSI 6136 turbidity sensor during April 2011 through October 2015 and an EXO turbidity sensor during November 2015 through December 2021.

[j]Data collected during February 2017 through December 2021.

[k]Data collected during March 2012 through December 2021.

[l]Data collected during March 2016 through December 2021.

raise the water temperature above 32 °C (Kansas Department of Health and Environment, 2018). Mean study period water temperatures at the Highway 50, Sedgwick, and Upstream ASR sites were 14.9 °C, 15.2 °C, and 15.8 °C, respectively (table 3). Water temperatures at the Highway 50, Sedgwick, and Upstream ASR sites exceeded 32 °C <1 percent of the time (fig. 2*B*).

Specific conductance is an indirect measure of dissolved solids in water (Hem, 1992). Specific conductance measurements are commonly used as surrogates for primary ions at the Highway 50 and Sedgwick sites (Christensen and others, 2003; Rasmussen and others, 2016; Stone and Klager, 2022). Mean Little Arkansas River specific conductance was 916, 743, and 719 microsiemens per centimeter at 25 °C (µS/cm at 25 °C) during the study period at the Highway 50, Sedgwick, and Upstream ASR sites, respectively (table 3). Minimum continuous specific conductance at the Upstream ASR site was in May 2016 and was about 20 µS/cm at 25 °C less than previously reported by Stone and others (2016; table 3). Specific conductance was between about 500 and 1,000 µS/cm at 25 °C during most of the study period at all three study sites and varied more at the Highway 50 site (fig. 2*C*).

pH is a measure of the effective hydrogen ion concentration and is useful to evaluate chemical and biological reactions in water (Hem, 1992; U.S. Geological Survey, 2021). Kansas aquatic life-support criteria require that pH in streams measure between 6.5 and 8.5 standard units (Kansas Department of Health and Environment, 2018). The 2010 through 2014, 2015 through 2019, and current (2020 through 2025) NPDES permits (Kansas permit number: I-LA24-PO01; Federal permit number: KS0099694) for the ASR phase II treatment facility state that the effluent limits for pH are 6.0 to 9.0 standard units. Little Arkansas River median pH during the study period was 8.0 for all three study sites (table 3). pH was below the Kansas aquatic life-support criterion of 6.5 <1 percent of the time at the Highway 50 and Sedgwick sites and was above the 8.5 criterion 3 percent of the time at all three study sites during the study period (fig. 2*D*).

Dissolved oxygen is important for the survival and growth of aquatic organisms and is used as an indicator of stream health; concentrations of dissolved oxygen in surface water primarily are related to photosynthesis, respiration, atmospheric reaeration, and water temperature (U.S. Geological Survey, 2020). Kansas aquatic life-support criteria require that dissolved oxygen concentrations are not <5.0 mg/L (Kansas Department of Health and Environment, 2018). Little Arkansas River mean dissolved oxygen concentrations during the study period were 9.5, 9.9, and 9.3 mg/L at the Highway 50, Sedgwick, and Upstream ASR sites, respectively (table 3). Dissolved oxygen concentrations were below the Kansas aquatic life-support criterion of 5.0 mg/L about 3 to 4 percent of the time at the study sites during 1995 through 2021 (fig. 2*E*). Minimum dissolved oxygen measurements at the Upstream ASR site were 1 mg/L less than previously reported (Stone and others, 2016) and were during June and July 2016.

Turbidity is caused by suspended and dissolved matter such as clay, silt, dissolved organic material, plankton and other microscopic organisms, organic acids, and dyes. Turbidity measurements are commonly used as surrogates for unfiltered nutrient and carbon species, sediment, and bacteria at the Highway 50 and Sedgwick sites (Christensen and others, 2003; Rasmussen and others, 2016; Stone and Klager, 2022). EPA guidelines for turbidity (based on reference conditions that are determined as the 25th percentiles of all compiled nutrient data for that ecoregion) list 22.13 nephelometric turbidity units (a reporting unit equivalent to formazin nephelometric units [Anderson, 2005]) as the criterion for level III ecoregion 27 (central Great Plains) streams, which includes the Little Arkansas River (U.S. Environmental Protection Agency, 2001a). Mean Little Arkansas River turbidity measurements during the study period at the Highway 50, Sedgwick, and Upstream ASR sites were 89, 84, and 57 formazin nephelometric units (FNUs), respectively (table 3). The EPA level III ecoregion 27 guideline of 22.13 nephelometric turbidity units (presented here as a benchmark for comparison because of relative differences in turbidity sensor measurements) was exceeded about 63, 56, and 54 percent of the time at the Highway 50, Sedgwick, and Upstream ASR sites, respectively, during the study period (fig. 2*F*).

Large concentrations of inorganic nitrogen compounds, such as nitrate plus nitrite, may be toxic to aquatic organisms. Large nitrate concentrations in drinking water can impair the oxygen-carrying capacity of hemoglobin in humans (Camargo and Alonso, 2006). The EPA guidelines for nitrate plus nitrite as nitrogen list 0.19 mg/L as the criterion for level III ecoregion 27 streams (U.S. Environmental Protection Agency, 2001a). The EPA Federal MCL for nitrate in drinking water is 10 mg/L as nitrogen, which is the concentration above which methemoglobinemia, or blue baby syndrome, may happen in infants (U.S. Environmental Protection Agency, 2009). Mean Little Arkansas River nitrate plus nitrite measurements at the Highway 50, Sedgwick, and Upstream ASR sites were 0.9, 1.1, and 1.1 mg/L, respectively (table 3). The EPA level III ecoregion 27 guideline of 0.19 mg/L was exceeded at the Highway 50, Sedgwick, and Upstream ASR sites 84, 96, and 99 percent of the time, respectively, during the study period (fig. 2*G*). The EPA nitrate MCL of 10 mg/L was not exceeded at the Highway 50 and Upstream ASR sites and was exceeded <1 percent of the time at the Sedgwick site (table 3, fig. 2*G*). Continuous nitrate plus nitrite measurements at the Highway 50 site exceeded the range previously reported (Stone and Klager, 2022) by 2.6 mg/L (table 3) and were during February 2021. Continuous nitrate plus nitrite concentrations at the Upstream ASR site have not been previously reported. Maximum nitrate plus nitrite concentrations were during February 2021 and minimum nitrate plus nitrite concentrations were during August 2016 at all three study sites.

All Little Arkansas River continuously measured water-quality constituents at the Sedgwick site fell within historic extremes. Little Arkansas River water temperature and pH

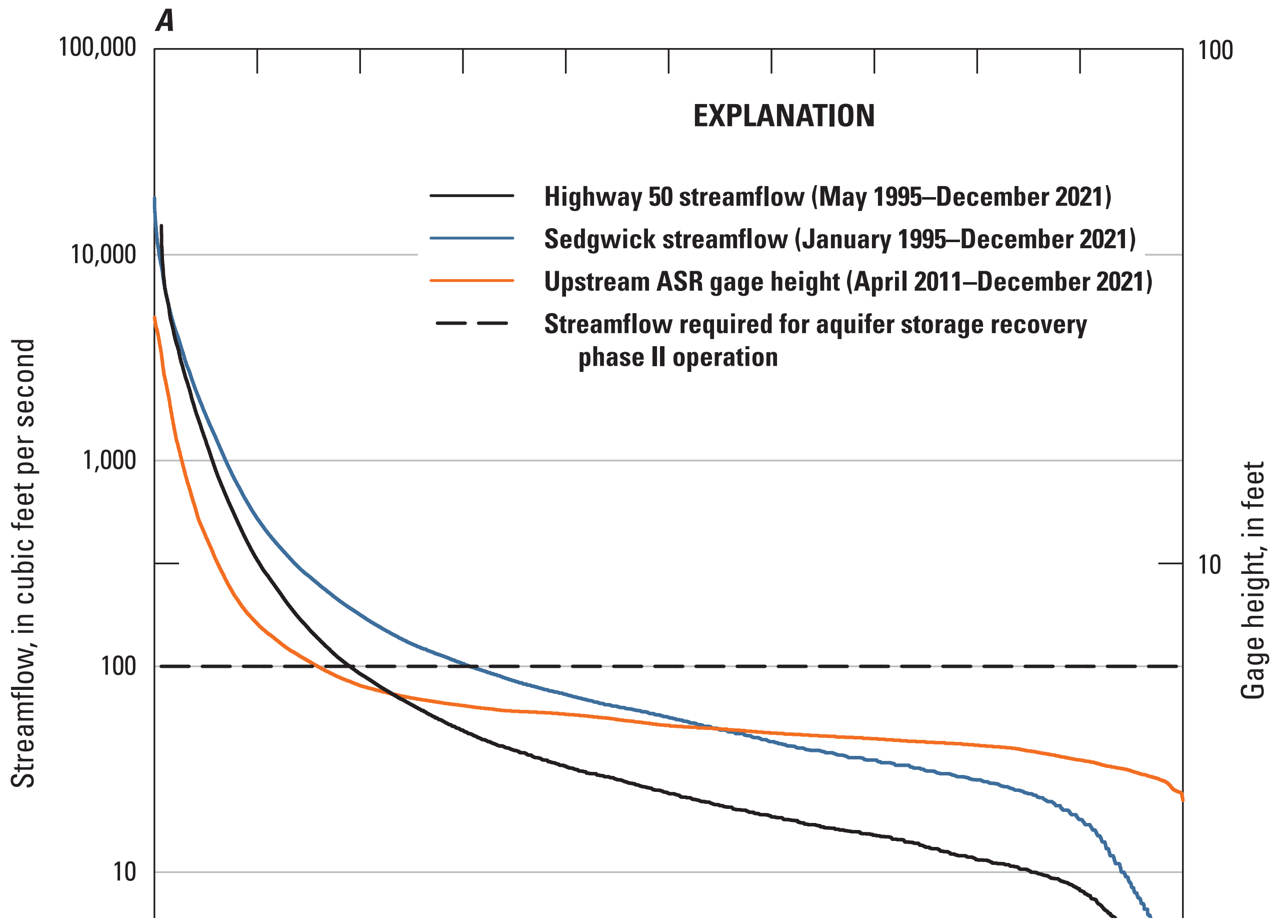
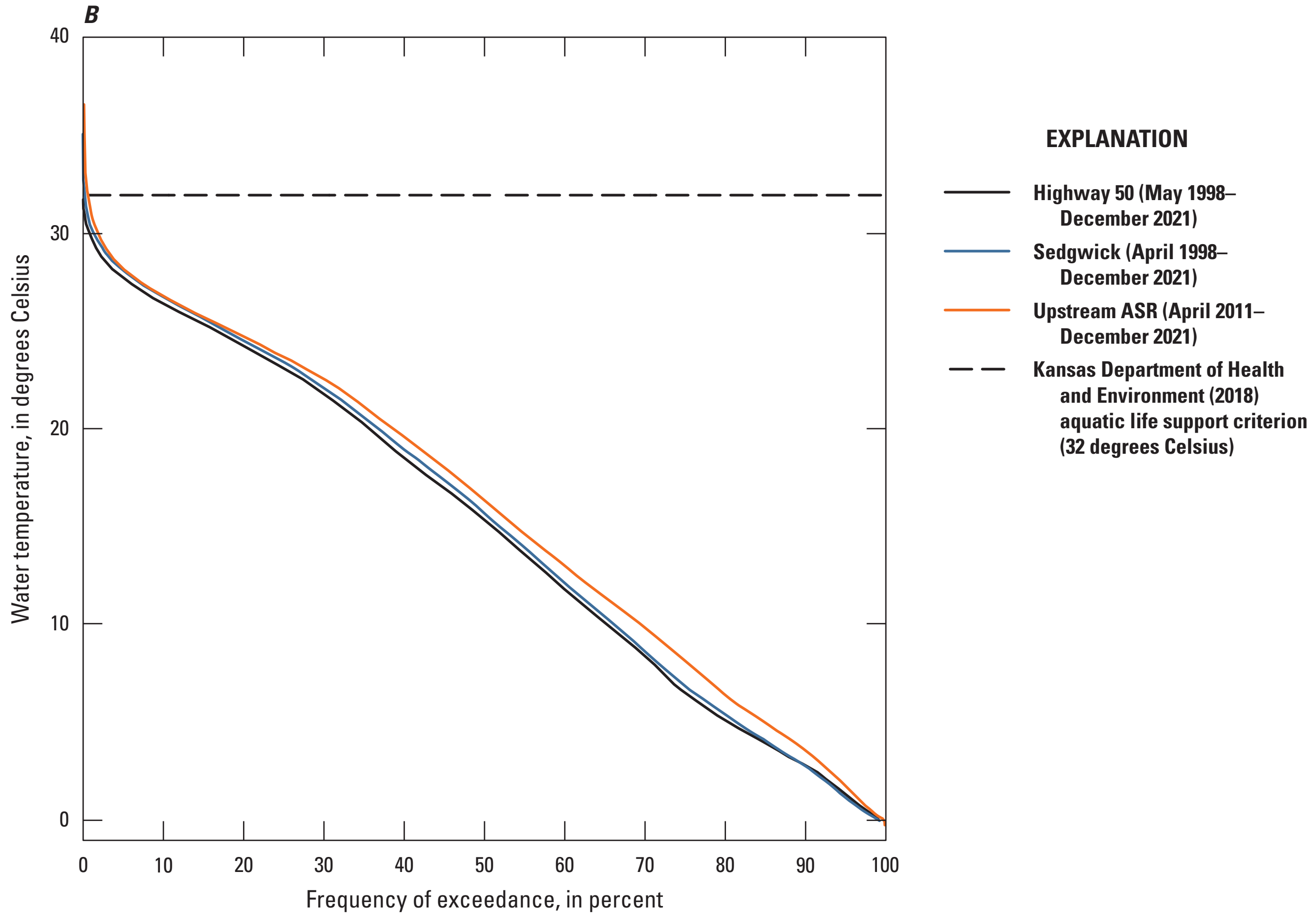


Figure 2. Duration curves for continuously (hourly) measured physicochemical properties for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672, 1995–2021); Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100, 1995–2021); and Little Arkansas River upstream of ASR Facility near Sedgwick, Kans. (Upstream ASR; USGS station 375350097262800, 2011–21). *A*, Streamflow or gage height. *B*, Water temperature. *C*, Specific conductance. *D*, pH. *E*, Dissolved oxygen. *F*, Turbidity. *G*, Nitrate plus nitrite.



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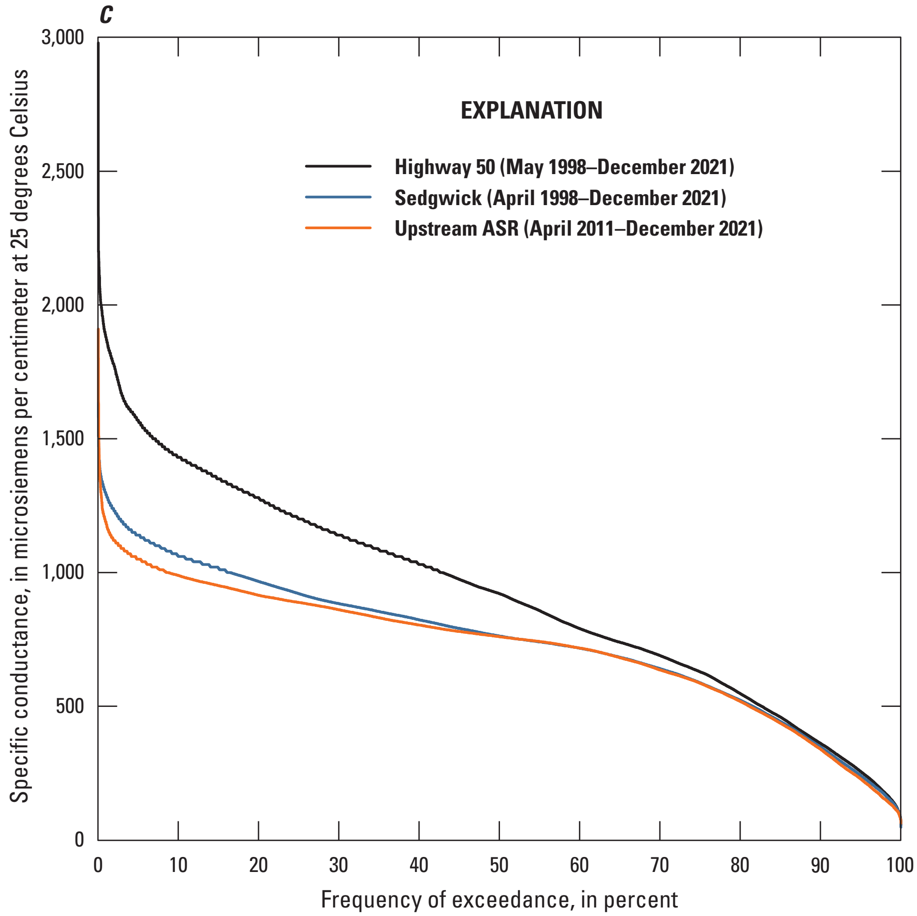

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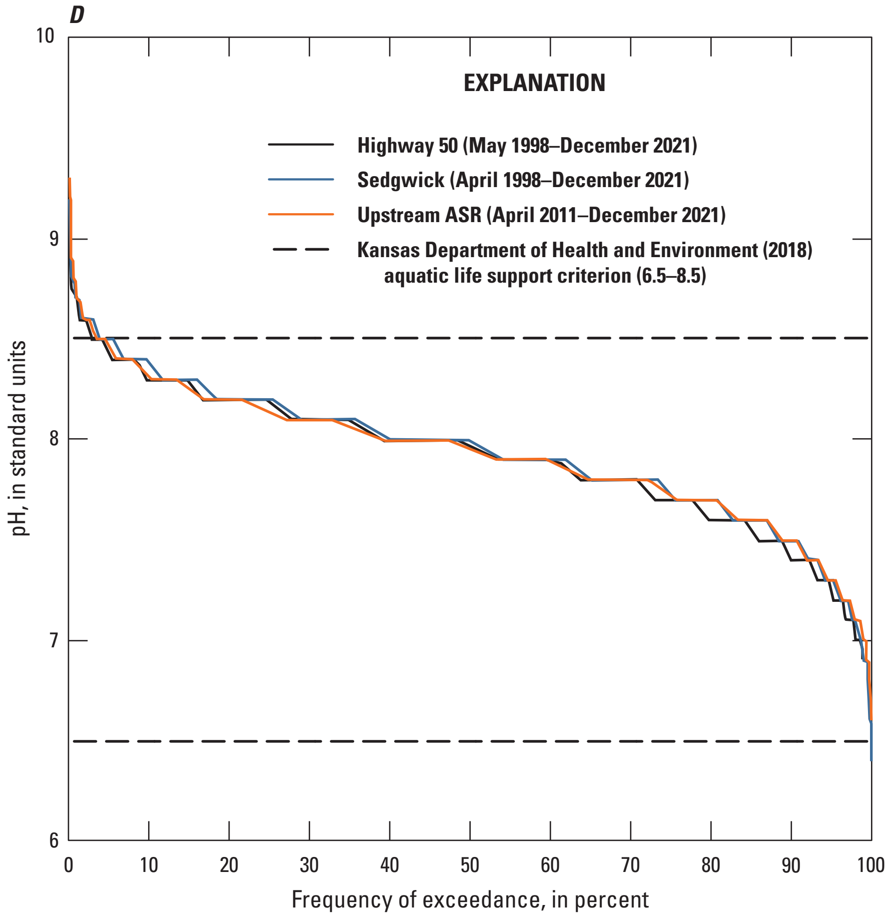

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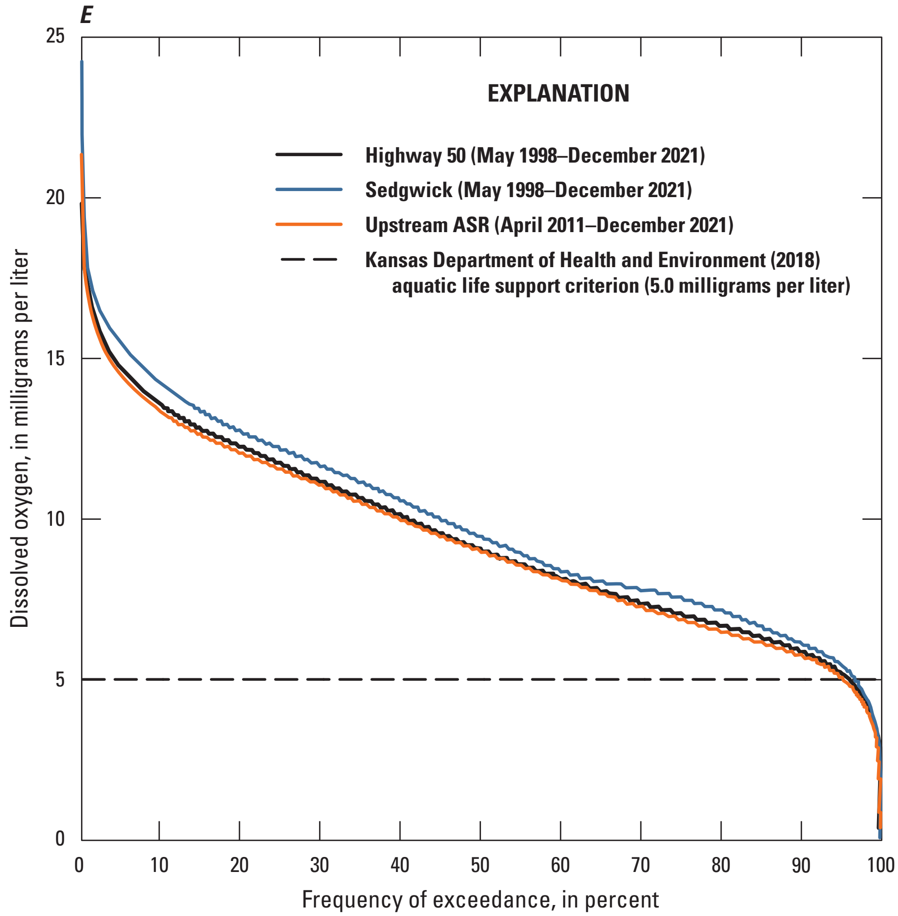

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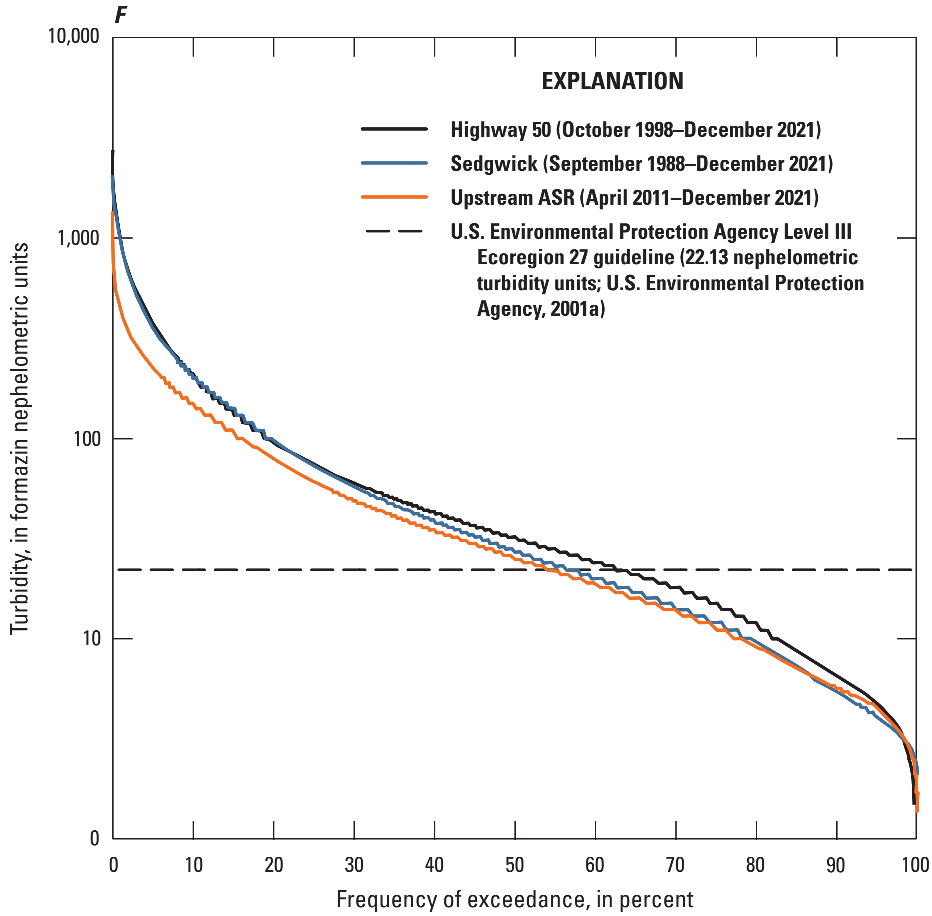

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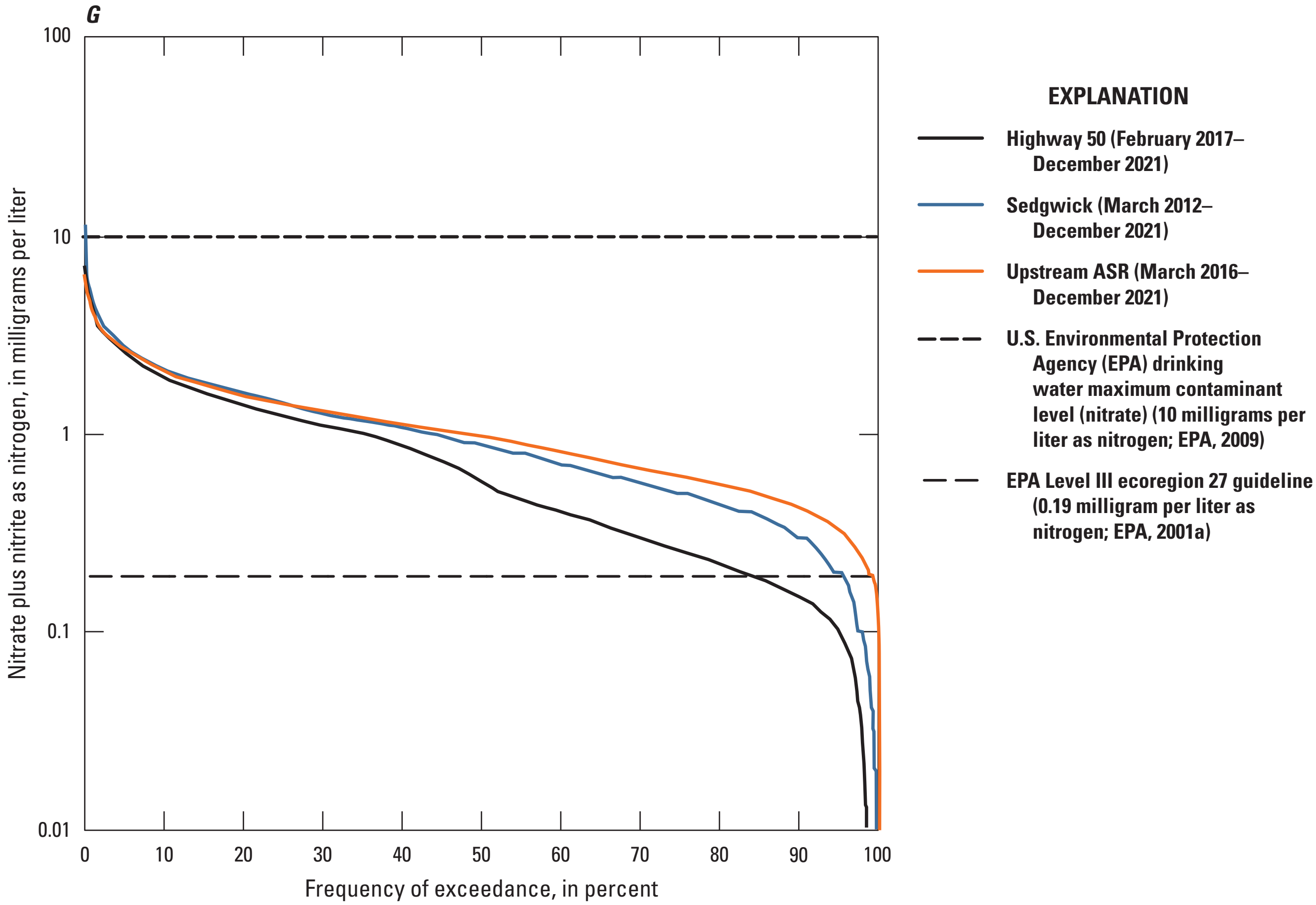

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values at the Highway 50, Sedgwick, and Upstream ASR sites during this study did not exceed ranges previously reported (Tappa and others, 2015; Stone and others, 2016; Stone and Klager, 2022; table 3). Little Arkansas River specific conductance, dissolved oxygen, and turbidity values did not exceed ranges previously reported at the Highway 50 and Sedgwick sites (Tappa and others, 2015; Stone and others, 2016; Stone and Klager, 2022; table 3). Minimum continuous specific conductance and dissolved oxygen values at the Upstream ASR site were less than previously reported by Stone and others (2016; table 3) and maximum nitrate plus nitrate values at the Highway 50 site exceeded the range previously reported (Stone and Klager, 2022).

Little Arkansas River Discrete Water Quality

Discrete stream-water samples were used to describe Little Arkansas River water-quality conditions during 1995 through 2021. Water-quality constituents that frequently exceeded EPA drinking water-quality criteria and those that are of potential interest or concern for ASR operations are discussed in this section of the report to characterize source water for *Equus* Beds ASR efforts. Select Little Arkansas River discrete water-quality datasets at the Highway 50, Sedgwick, and Upstream ASR sites were used with concomitant continuously measured physicochemical parameters to develop new surrogate relations. In addition, select Little Arkansas River discrete water-quality datasets for the Highway 50 and Sedgwick sites were used to evaluate water-quality trends during 1995 through 2021.

Ions

Primary dissolved ions come from decomposing rocks and soils and generally include calcium, magnesium, sodium, potassium, bicarbonate, carbonate, chloride, and sulfate ions (Hem, 1992). Primary ions are a constituent of concern in drinking water because large concentrations of ions may cause physiological effects, unpalatable mineral tastes, and greater costs owing to corrosion or additional treatment needs (U.S. Environmental Protection Agency, 2009). The EPA established National Secondary Drinking Water Regulations that set nonmandatory water-quality standards. The EPA does not enforce SMCLs because they were established as guidelines to assist public water-supply systems in managing their drinking water for aesthetic considerations such as taste, color, and odor (U.S. Environmental Protection Agency, 2009). Several primary ions have EPA SMCLs and include dissolved solids, chloride, fluoride, and sulfate (U.S. Environmental Protection Agency, 2009).

The EPA dissolved solids SMCL is 500 mg/L (U.S. Environmental Protection Agency, 2009), and discrete samples exceeded the SMCL at all three study sites (table 4). Dissolved solids concentrations exceeded the SMCL in 45, 29, and 23 percent of samples at the Highway 50, Sedgwick, and Upstream ASR sites, respectively. Mean dissolved solids concentrations during the study period ranged from 344 mg/L at the Upstream ASR site to 463 mg/L at the Highway 50 site (table 4). Dissolved solids ranges at the Highway 50 and Sedgwick sites did not exceed the ranges previously reported (Tappa and others, 2015; Stone and Klager, 2022; table 4). The dissolved solids minimum at the Upstream ASR site was 26 percent less than the minimum previously reported (Stone and others, 2016) and were in May 2019 (table 4).

Bromide is a constituent of concern for the Little Arkansas River. Bromide is not a risk to human health; however, during drinking-water decontamination, bromide reacts with natural organic matter present in source water and chemical disinfectants to create brominated disinfection byproducts, including bromate. The EPA has classified bromate (Federal MCL of 0.01 mg/L) as a probable human carcinogen (U.S. Environmental Protection Agency, 2009). Bromate is formed when ozone used to disinfect drinking water reacts with naturally occurring bromide in source water (U.S. Environmental Protection Agency, 2001b). The city of Wichita uses a threshold of 0.3 mg/L for bromide as a treatment standard. Bromide concentrations exceeded the treatment threshold of 0.3 mg/L at all three study sites (table 4). Bromide concentrations exceeded the treatment threshold in 38, 19, and 17 percent of samples at the Highway 50, Sedgwick, and Upstream ASR sites, respectively. Mean bromide concentrations at the Highway 50, Sedgwick, and Upstream ASR sites during the study period were 0.32, 0.18, and 0.17 mg/L, respectively (table 4). Bromide ranges at the Highway 50 and Sedgwick sites did not exceed the ranges previously reported (Tappa and others, 2015; Stone and others, 2019; table 4).

The EPA SMCL for chloride and sulfate is 250 mg/L (U.S. Environmental Protection Agency, 2009). Mean chloride concentrations during the study period at the Highway 50, Sedgwick, and Upstream ASR sites were 129, 67, and 61 mg/L, respectively (table 4). Little Arkansas River chloride concentrations exceeded the Federal SMCL at the Highway 50 and Sedgwick sites, but the SMCL was not exceeded at the Upstream ASR site during the study (table 4). Chloride concentrations exceeded the SMCL in 14 and <1 percent of samples at the Highway 50 and Sedgwick sites, respectively. Sulfate concentrations exceeded the Federal SMCL at the Highway 50 site in <1 percent of samples but not the Sedgwick or Upstream ASR sites during the study (table 4). Chloride concentration ranges during this study at the Highway 50 and Sedgwick sites did not exceed previously reported ranges (Tappa and others, 2015; Stone and Klager, 2022). The chloride minimum at the Upstream ASR site was less than the range previously reported (Stone and others, 2016) and were in May 2019 (table 4). Sulfate concentration ranges at the Highway 50 and Sedgwick sites did not exceed the previously reported range (Tappa and others, 2015). The sulfate minimum at the Upstream ASR site was less than the range previously reported (Stone and others, 2016) and were in May 2019 (table 4).

Nutrients and Carbon Species

Nutrients, such as nitrogen and phosphorus species, in water are closely related to agricultural activities because of their presence in fertilizers and animal waste. Nutrients are a pollutant of concern in the Little Arkansas River (Kansas State University Research and Extension and others, 2018). Nitrogen is present as ammonia, nitrate, nitrite, and as part of organic compounds. The EPA level III ecoregion 27 guideline for ammonia plus organic nitrogen (organic nitrogen; as nitrogen) is 0.52 mg/L (U.S. Environmental Protection Agency, 2001a) and was exceeded at all study sites (table 4). Ammonia plus organic nitrogen concentrations exceeded the guideline in 92, 90, and 98 percent of samples at the Highway 50, Sedgwick, and Upstream ASR sites, respectively. During the study period, mean ammonia plus organic nitrogen (as nitrogen) concentrations ranged from 1.4 mg/L (Sedgwick site) to 1.8 mg/L (Highway 50 site; table 4). Ammonia plus organic nitrogen values at the Highway 50 site did not exceed previously reported ranges (Tappa and others, 2015; Stone and Klager, 2022). Ammonia plus organic nitrogen values at the Sedgwick and Upstream ASR sites exceeded previously reported ranges (Stone and others, 2016; Stone and Klager, 2022; table 4) by 3 and 18 percent, respectively, and maximum values at both sites were in February 2020. Mean nitrate plus nitrite (as nitrogen) concentrations ranged from 0.87 mg/L (Highway 50 site) to 1.2 mg/L (Sedgwick site; table 4). Nitrate plus nitrite values during the study period at the Highway 50 and Sedgwick sites did not exceed previously reported ranges (Tappa and others, 2015; Stone and Klager, 2022), but the Upstream ASR site minimum did (Stone and others, 2016; table 4) in May 2019.

The EPA level III ecoregion 27 guideline for total phosphorus of 0.09 mg/L (U.S. Environmental Protection Agency, 2001a) was exceeded in all samples at all three study sites with the exception of one sample at the Sedgwick site (table 4). Discrete sample total phosphorus (as phosphorus) means were 0.70 at the Highway 50 and Sedgwick sites and 0.80 mg/L at the Upstream ASR site for the study period (table 4).

Table 4. Discrete sample water-quality constituent summary statistics for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; USGS station 07143672, 1995–2021); near Sedgwick, Kans. (Sedgwick; USGS station 07144100, 1995–2021); and upstream of ASR Facility near Sedgwick, Kans. (Upstream ASR; USGS station 375350097262800, 2011–21).

[Summary statistics were not computed when more than 80 percent of data were censored; USGS; U.S. Geological Survey; *n*, number of measurements; µg/L QSE, microgram per liter as quinine sulfate equivalents; $CaCO_3$, calcium carbonate; <, less than; --, not applicable; SiO_2, silicon dioxide; *E. coli*, *Escherichia coli*; UV, ultraviolet; nm, nanometer; absorbance units/cm, absorbance units per centimeter]

Water-quality constituent	USGS parameter code	Percent censored data	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Physicochemical water-quality constituents												
Highway 50												
Streamflow, in cubic feet per second	00061	0	378	0.10	10,500	737	69.0	1,566	80.5	2.1	20.7	582
pH, in standard units	00400	0	312	6.2	8.7	7.6	7.6	0.4	0.02	0.05	7.3	7.9
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	00095	0	312	64	3,550	764	678	512	29.0	0.7	297	1,116
Water temperature, in degrees Celsius	00010	0	312	0.0	27.9	15.0	16.7	8.05	0.46	0.54	7.2	22.2
Dissolved oxygen, in milligrams per liter	00300	0	307	2.5	16.2	8.0	7.6	2.7	0.16	0.3	5.9	10.0
Turbidity, in formazin nephelometric units	63680	0	238	3	1,610	242	120	301	19.5	1.24	28.9	332
Sedgwick												
Streamflow, in cubic feet per second	00061	0	528	1.40	16,100	1,083.0	95.8	2,470	107.0	2.3	33.9	560
pH, in standard units	00400	0	426	6.0	8.6	7.7	7.8	0.4	0.02	0.05	7.5	8.0
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	00095	0	437	54	1,419	619	681	317	15.2	0.5	303	857
Water temperature, in degrees Celsius	00010	0	423	-0.2	28.4	15.9	17.3	8.20	0.40	0.51	8.8	23.5
Dissolved oxygen, in milligrams per liter	00300	0	422	0.8	15.0	8.1	7.4	2.7	0.13	0.3	6.0	10.2
Turbidity, in formazin nephelometric units	63680	0	384	3	2,090	155	55.0	252	12.8	1.62	20.0	169

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[Summary statistics were not computed when more than 80 percent of data were censored; USGS; U.S. Geological Survey; *n*, number of measurements; µg/L QSE, microgram per liter as quinine sulfate equivalents; $CaCO_3$, calcium carbonate; <, less than; --, not applicable; SiO_2, silicon dioxide; *E. coli*, *Escherichia coli*; UV, ultraviolet; nm, nanometer; absorbance units/cm, absorbance units per centimeter]

Water-quality constituent	USGS parameter code	Percent censored data	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Upstream ASR												
pH, in standard units	00400	0	96	6.9	8.8	7.8	7.9	0.4	0.04	0.05	7.5	8.0
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	00095	0	96	83	1,293	582	641	305	31.1	0.5	274	794
Water temperature, in degrees Celsius	00010	0	96	0.2	27.4	17.7	19.6	7.60	0.78	0.43	11.8	24.3
Dissolved oxygen, in milligrams per liter	00300	0	96	1.1	17.7	7.4	6.9	3.0	0.30	0.4	5.5	9.0
Turbidity, in formazin nephelometric units	63680	0	95	5	582	127	67.6	138	14.2	1.09	23.0	182
Ions and Silica												
Highway 50												
Hardness, milligrams per liter as $CaCO_3$	00900	0	278	21	584	231	232	144	8.6	0.62	90	350
Dissolved solids, in milligrams per liter	70300	0	278	66	1,960	463	441	289	17	0.62	192	679
Calcium, in milligrams per liter	00915	0	278	6.5	174	73	73	46	2.7	0.63	27	111
Magnesium, in milligrams per liter	00925	0	278	1.2	36	12	11	7.4	0.44	0.62	4.8	18
Potassium, in milligrams per liter	00935	0	278	3.3	18	7.8	7.9	2.2	0.13	0.28	6.3	9.3
Sodium, in milligrams per liter	00930	0	278	2.1	498	69	57	59	3.5	0.85	20	108
Bromide, in milligrams per liter	71870	4	203	<0.02	1.7	0.32	0.18	0.33	0.02	1.0	0.09	0.46
Chloride, in milligrams per liter	00940	<1	279	<5	932	129	99	115	--	--	34	195
Fluoride, in milligrams per liter	00950	<1	206	<0.02	2.7	0.26	0.24	0.19	--	--	0.19	0.29
Silica, in milligrams per liter as SiO_2	00955	0	203	5.2	24	14	14	4.2	0.29	0.30	11	17
Sulfate, in milligrams per liter	00945	4	278	<5	312	35	32	28	--	--	14	52

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[Summary statistics were not computed when more than 80 percent of data were censored; USGS; U.S. Geological Survey; *n*, number of measurements; µg/L QSE, microgram per liter as quinine sulfate equivalents; $CaCO_3$, calcium carbonate; <, less than; --, not applicable; SiO_2, silicon dioxide; *E. coli*, *Escherichia coli*; UV, ultraviolet; nm, nanometer; absorbance units/cm, absorbance units per centimeter]

Water-quality constituent	USGS parameter code	Percent censored data	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
					Sedgwick							
Hardness, milligrams per liter as $CaCO_3$	00900	0	386	16	487	216	246	109	5.5	0.50	102	303
Dissolved solids, in milligrams per liter	70300	0	385	65	839	384	422	179.9	9.2	0.46	208	521
Calcium, in milligrams per liter	00915	0	386	4.7	138	66	75	33	1.7	0.50	31	93
Magnesium, in milligrams per liter	00925	0	386	1.0	35	12	14	6.2	0.31	0.51	5.7	17
Potassium, in milligrams per liter	00935	<1	386	3.7	15	6.9	6.8	1.9	--	--	5.5	8.1
Sodium, in milligrams per liter	00930	0	386	1.5	132	47	48	30	1.5	0.63	20	65
Bromide, in milligrams per liter	71870	6	220	<0.02	0.98	0.18	0.13	0.15	--	--	0.06	0.24
Chloride, in milligrams per liter	00940	1	392	<5	315	67	57	52	--	--	29	93
Fluoride, in milligrams per liter	00950	0	350	0.10	0.82	0.29	0.28	0.09	0.01	0.32	0.22	0.33
Silica, in milligrams per liter as SiO_2	00955	0	340	3.1	24	14	14	3.9	0.21	0.27	11	17
Sulfate, in milligrams per liter	00945	3	392	<5	211	45	50	27	--	--	19	65
					Upstream ASR							
Hardness, milligrams per liter as $CaCO_3$	00900	0	64	30	367	189	199	108	13	0.57	80	288
Dissolved solids, in milligrams per liter	70300	0	64	60	735	344	371	183	23	0.53	160	484
Calcium, in milligrams per liter	00915	0	64	9.2	114	58	58	33	4.2	0.58	25	89
Magnesium, in milligrams per liter	00925	0	64	1.7	21	10	11	5.9	0.74	0.57	4.6	16
Potassium, in milligrams per liter	00935	0	64	4.2	14	7.7	7.7	2.2	0.27	0.28	5.7	9.3
Sodium, in milligrams per liter	00930	0	64	2.5	134	42	43	31	3.9	0.74	12	58
Bromide, in milligrams per liter	71870	5	64	<0.04	0.58	0.17	0.15	0.13	--	--	0.06	0.25
Chloride, in milligrams per liter	00940	0	64	4.2	242	61	48	52	6.5	0.85	16	86

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[Summary statistics were not computed when more than 80 percent of data were censored; USGS; U.S. Geological Survey; *n*, number of measurements; µg/L QSE, microgram per liter as quinine sulfate equivalents; $CaCO_3$, calcium carbonate; <, less than; --, not applicable; SiO_2, silicon dioxide; *E. coli*, *Escherichia coli*; UV, ultraviolet; nm, nanometer; absorbance units/cm, absorbance units per centimeter]

Water-quality constituent	USGS parameter code	Percent censored data	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Upstream ASR—Continued												
Fluoride, in milligrams per liter	00950	0	64	0.10	0.61	0.30	0.27	0.11	0.01	0.38	0.23	0.36
Silica, in milligrams per liter as SiO_2	00955	0	64	6.6	24	14	15	4.3	0.53	0.30	12	17
Sulfate, in milligrams per liter	00945	4	3	<5	88	37	34	24	3.1	0.66	14	60
Nutrient and carbon species												
Highway 50												
Ammonia plus organic nitrogen, in milligrams per liter as nitrogen	00625	0	188	0.27	9.0	1.8	1.5	1.4	0.10	0.78	0.76	2.3
Nitrate plus nitrite, in milligrams per liter as nitrogen	00631	15	274	<0.02	5.4	0.87	0.71	0.94	--	--	0.13	1.2
Total nitrogen, in milligrams per liter as nitrogen	00625+ 00631	22	188	0.29	11	2.7	2.2	2.1	--	--	0.98	0.37
Total phosphorus, in milligrams per liter as phosphorus	00665	0	189	0.14	3.1	0.70	0.61	0.44	0.03	0.63	0.39	0.88
Dissolved organic carbon, in milligrams per liter	00681	0	86	2.4	17	7.9	7.8	3.9	0.42	0.49	4.2	10
Total organic carbon, in milligrams per liter	00680	0	160	2.8	52	13	11	8.7	0.69	0.67	6.8	17
Sedgwick												
Ammonia, in milligrams per liter as nitrogen	00608	24	368	<0.01	0.86	0.09	0.05	0.12	--	--	0.02	0.11
Ammonia plus organic nitrogen, in milligrams per liter as nitrogen	00625	0	332	0.26	6.1	1.4	1.1	0.94	0.05	0.65	0.76	1.9
Nitrate plus nitrite, in milligrams per liter as nitrogen	00631	3	400	<0.02	12	1.2	0.91	1.2	--	--	0.45	1.5

Table 4. Discrete sample water-quality constituent summary statistics for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; USGS station 07143672, 1995–2021); near Sedgwick, Kans. (Sedgwick; USGS station 07144100, 1995–2021); and upstream of ASR Facility near Sedgwick, Kans. (Upstream ASR; USGS station 375350097262800, 2011–21).—Continued

[Summary statistics were not computed when more than 80 percent of data were censored; USGS; U.S. Geological Survey; *n*, number of measurements; µg/L QSE, microgram per liter as quinine sulfate equivalents; $CaCO_3$, calcium carbonate; <, less than; --, not applicable; SiO_2, silicon dioxide; *E. coli*, *Escherichia coli*; UV, ultraviolet; nm, nanometer; absorbance units/cm, absorbance units per centimeter]

Water-quality constituent	USGS parameter code	Percent censored data	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Sedgwick—Continued												
Total nitrogen, in milligrams per liter as nitrogen	00625+ 00631	3	331	0.52	11	2.5	2.1	1.6	--	--	1.3	3.1
Nitrate, in milligrams per liter as nitrogen	00618	3	334	<0.01	9.4	1.0	0.83	1.0	--	--	0.40	1.3
Nitrite, in milligrams per liter as nitrogen	00613	18	335	<0.001	1.5	0.04	0.02	0.10	--	--	0.01	0.05
Orthophosphate, in milligrams per liter as phosphorus	00671	0	335	0.04	1.6	0.42	0.39	0.19	0.01	0.47	0.29	0.50
Dissolved phosphorus, in milligrams per liter as phosphorus	00666	0	368	0.06	2.0	0.41	0.39	0.20	0.01	0.48	0.30	0.50
Total phosphorus, in milligrams per liter as phosphorus	00665	0	335	0.07	2.1	0.70	0.67	0.30	0.02	0.43	0.49	0.85
Dissolved organic carbon, in milligrams per liter	00681	<1	258	<0.23	16	6.6	5.9	3.2	--	--	4.0	8.4
Total organic carbon, in milligrams per liter	00680	0	175	0.59	36	12	11	7.2	0.54	0.59	5.8	17
Upstream ASR												
Ammonia plus organic nitrogen, in milligrams per liter as nitrogen	00625	0	64	0.37	4.0	1.7	1.5	0.87	0.11	0.53	0.94	2.1
Nitrate plus nitrite, in milligrams per liter as nitrogen	00631	3	94	<0.02	4.8	1.1	0.82	1.0	--	--	0.39	1.5
Total nitrogen, in milligrams per liter as nitrogen	00625+ 00631	3	64	0.61	7.7	2.7	2.2	1.6	--	--	1.5	3.5
Total phosphorus, in milligrams per liter as phosphorus	00665	0	64	0.29	1.5	0.80	0.78	0.26	0.03	0.33	0.65	0.93
Dissolved organic carbon, in milligrams per liter	00681	0	85	2.9	14	7.7	6.9	3.5	0.38	0.45	4.5	11
Total organic carbon, in milligrams per liter	00680	0	84	3.5	28	12	11	6.2	0.67	0.53	6.3	15

Table 4. Discrete sample water-quality constituent summary statistics for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; USGS station 07143672, 1995–2021); near Sedgwick, Kans. (Sedgwick; USGS station 07144100, 1995–2021); and upstream of ASR Facility near Sedgwick, Kans. (Upstream ASR; USGS station 375350097262800, 2011–21).—Continued

[Summary statistics were not computed when more than 80 percent of data were censored; USGS; U.S. Geological Survey; *n*, number of measurements; µg/L QSE, microgram per liter as quinine sulfate equivalents; $CaCO_3$, calcium carbonate; <, less than; --, not applicable; SiO_2, silicon dioxide; *E. coli*, *Escherichia coli*; UV, ultraviolet; nm, nanometer; absorbance units/cm, absorbance units per centimeter]

Water-quality constituent	USGS parameter code	Percent censored data	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Sediment												
Highway 50												
Suspended solids, in milligrams per liter	00530	6	242	<4	2,790	264	96	417	--	--	43	302
Suspended-sediment concentration, in milligrams per liter	80154	0	196	4.0	3,270	400	190	559	40	1.4	64	485
Sedgwick												
Suspended solids, in milligrams per liter	00530	5	296	<4	1,670	219	91	285	--	--	33	282
Suspended-sediment concentration, in milligrams per liter	80154	0	339	2.0	1,870	232	82	327	18	1.4	35	290
Upstream ASR												
Suspended solids, in milligrams per liter	00530	2	64	<15	885	184	102	206	--	--	53	234
Suspended-sediment concentration, in milligrams per liter	80154	0	62	18	1,430	246	138	298	38	1.2	60	298
Indicator bacteria												
Highway 50												
E. coli, in colony forming units per 100 milliliters	90902	2	169	<1	26,000	2,000	640	3,700	--	--	190	2,200
Fecal coliforms, in colony forming units per 100 milliliters	31625	3	269	<20	3,000,000	14,000	590	180,000	--	--	170	2,400
Sedgwick												
E. coli, in colony forming units per 100 milliliters	90902	2	184	1	47,000	3,400	610	7,400	--	--	80	3,300
Fecal coliforms, in colony forming units per 100 milliliters	31625	3	258	<1	10,000	4,500	600	11,000	--	--	100	3,400

Table 4. Discrete sample water-quality constituent summary statistics for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; USGS station 07143672, 1995–2021); near Sedgwick, Kans. (Sedgwick; USGS station 07144100, 1995–2021); and upstream of ASR Facility near Sedgwick, Kans. (Upstream ASR; USGS station 375350097262800, 2011–21).—Continued

[Summary statistics were not computed when more than 80 percent of data were censored; USGS; U.S. Geological Survey; *n*, number of measurements; µg/L QSE, microgram per liter as quinine sulfate equivalents; $CaCO_3$, calcium carbonate; <, less than; --, not applicable; SiO_2, silicon dioxide; *E. coli*, *Escherichia coli*; UV, ultraviolet; nm, nanometer; absorbance units/cm, absorbance units per centimeter]

Water-quality constituent	USGS parameter code	Percent censored data	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Upstream ASR												
E. coli, in colony forming units per 100 milliliters	90902	2	55	8	30,000	2,500	540	5,100	--	--	100	2,000
Fecal coliforms, in colony forming units per 100 milliliters	31625	5	63	18	34,000	3,300	910	6,400	--	--	180	2,600
Trace elements												
Highway 50												
Iron, in micrograms per liter	01046	50	278	<5	864	63	25	109	--	--	5.6	50
Arsenic, in micrograms per liter	01000	2	200	<1	16	5.4	4.8	3.0	--	--	3.1	6.6
Sedgwick												
Iron, in micrograms per liter	01046	34	386	<4	621	78	31	120	--	--	11	54
Strontium, in micrograms per liter	01080	0	2 deeth- ylat- razine 73	53	1,278	455	515	237	14	0.52	222	632
Arsenic, in micrograms per liter	01000	1	339	<1	16	5.8	5.1	2.8	--	--	3.7	7.6
Upstream ASR												
Iron, in micrograms per liter	01046	42	64	<5	1,137	137	50	167	--	--	50	209
Arsenic, in micrograms per liter	01000	0	63	1.5	27	7.7	5.9	5.2	0.66	0.68	3.9	9.6
Pesticides												
Highway 50												
2-Chloro-4-isopropylamino-6-amino-*s*-triazine (deethylatrazine), in micrograms per liter	04040	11	227	<0.006	2.69	0.350	0.166	0.460	--	--	0.048	0.495
2-Ethyl-6-methylaniline, in micrograms per liter	61620	97	86	<0.005	0.014	--	--	--	--	--	--	--
3,4-Dichloroaniline, in micrograms per liter	61625	83	86	<0.004	0.127	--	--	--	--	--	--	--

Table 4. Discrete sample water-quality constituent summary statistics for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; USGS station 07143672, 1995–2021); near Sedgwick, Kans. (Sedgwick; USGS station 07144100, 1995–2021); and upstream of ASR Facility near Sedgwick, Kans. (Upstream ASR; USGS station 375350097262800, 2011–21).—Continued

[Summary statistics were not computed when more than 80 percent of data were censored; USGS; U.S. Geological Survey; *n*, number of measurements; µg/L QSE, microgram per liter as quinine sulfate equivalents; $CaCO_3$, calcium carbonate; <, less than; --, not applicable; SiO_2, silicon dioxide; *E. coli*, *Escherichia coli*; UV, ultraviolet; nm, nanometer; absorbance units/cm, absorbance units per centimeter]

Water-quality constituent	USGS parameter code	Percent censored data	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Highway 50—Continued												
4-Chloro-2-methylphenol, in micrograms per liter	61633	84	86	<0.003	0.031	--	--	--	--	--	--	--
Acetochlor, in micrograms per liter	49260	55	233	<0.002	8.68	0.321	0.025	0.940	--	--	0.020	0.139
Alachlor, in micrograms per liter	46342	67	233	<0.002	28.0	0.260	0.025	1.890	0.124	7.25	0.004	0.027
Atrazine, in micrograms per liter	39632	1	216	<0.05	46.2	3.89	1.31	6.23	--	--	0.210	5.09
Carbofuran, in micrograms per liter	82674	83	63	<0.003	0.930	--	--	--	--	--	--	--
Cyanazine, in micrograms per liter	04041	96	183	<0.004	0.340	--	--	--	--	--	--	--
Desulfinylfipronil amide, in micrograms per liter	62169	93	86	<0.003	<0.086	--	--	--	--	--	--	--
Desulfinylfipronil, in micrograms per liter	62170	66	86	<0.004	0.014	0.006	0.006	0.002	--	--	0.005	0.006
Fipronil sulfide, in micrograms per liter	62167	87	86	<0.004	<0.008	--	--	--	--	--	--	--
Hexazinone, in micrograms per liter	04025	96	84	<0.008	0.295	--	--	--	--	--	--	--
Metolachlor, in micrograms per liter	39415	12	233	<0.014	39.4	2.08	0.530	3.75	--	--	0.070	2.50
Metribuzin, in micrograms per liter	82630	75	201	<0.004	0.770	0.042	0.025	0.086	--	--	0.008	0.025
Prometon, in micrograms per liter	04037	58	227	<0.006	0.320	0.026	0.025	0.030	--	--	0.010	0.025
Prometryn, in micrograms per liter	04036	98	186	<0.005	0.120	--	--	--	--	--	--	--
Simazine, in micrograms per liter	04035	70	227	<0.005	1.59	0.027	0.025	0.106	--	--	0.005	0.025

Table 4. Discrete sample water-quality constituent summary statistics for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; USGS station 07143672, 1995–2021); near Sedgwick, Kans. (Sedgwick; USGS station 07144100, 1995–2021); and upstream of ASR Facility near Sedgwick, Kans. (Upstream ASR; USGS station 375350097262800, 2011–21).—Continued

[Summary statistics were not computed when more than 80 percent of data were censored; USGS; U.S. Geological Survey; *n*, number of measurements; µg/L QSE, microgram per liter as quinine sulfate equivalents; $CaCO_3$, calcium carbonate; <, less than; --, not applicable; SiO_2, silicon dioxide; *E. coli*, *Escherichia coli*; UV, ultraviolet; nm, nanometer; absorbance units/cm, absorbance units per centimeter]

Water-quality constituent	USGS parameter code	Percent censored data	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
					Sedgwick							
Tebuthiuron, in micrograms per liter	82670	72	118	<0.01	0.243	0.026	0.014	0.034	--	--	0.012	0.025
2,6-Diethylaniline, in micrograms per liter	82660	99	135	<0.002	<0.004	--	--	--	--	--	--	--
2-Chloro-4-isopropylamino-6-amino-*s*-triazine (deethylatrazine), in micrograms per liter	04040	6	263	<0.006	2.40	0.394	0.215	0.469	--	--	0.065	0.530
2-Ethyl-6-methylaniline, in micrograms per liter	61620	96	115	<0.005	0.010	--	--	--	--	--	--	--
3,4-Dichloroaniline, in micrograms per liter	61625	63	115	<0.004	0.480	0.014	0.004	0.053	--	--	0.003	0.007
4-Chloro-2-methylphenol,in micrograms per liter	61633	79	115	<0.003	0.045	0.006	0.004	0.006	--	--	0.003	0.008
Acetochlor, in micrograms per liter	49260	53	268	<0.002	17.9	0.380	0.025	1.40	--	--	0.025	0.145
Alachlor, in micrograms per liter	46342	57	268	<0.002	3.50	0.127	0.025	0.387	--	--	0.004	0.050
Aminomethylphosphonic acid (AMPA), in micrograms per liter	62649	0	140	0.290	4.30	1.44	1.40	0.742	0.063	0.516	0.798	2.00
Atrazine, in micrograms per liter	39632	2	247	<0.025	31.0	3.55	1.25	5.42	--	--	0.269	4.51
Carbofuran, in micrograms per liter	82674	86	51	<0.003	0.191	--	--	--	--	--	--	--
Cyanazine, in micrograms per liter	04041	96	187	<0.004	0.260	--	--	--	--	--	--	--
Desulfinylfipronil amide, in micrograms per liter	62169	94	115	<0.004	<0.086	--	--	--	--	--	--	--
Desulfinylfipronil, in micrograms per liter	62170	37	115	<0.003	0.010	0.006	0.006	0.002	--	--	0.004	0.006

Table 4. Discrete sample water-quality constituent summary statistics for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; USGS station 07143672, 1995–2021); near Sedgwick, Kans. (Sedgwick; USGS station 07144100, 1995–2021); and upstream of ASR Facility near Sedgwick, Kans. (Upstream ASR; USGS station 375350097262800, 2011–21).—Continued

[Summary statistics were not computed when more than 80 percent of data were censored; USGS; U.S. Geological Survey; *n*, number of measurements; µg/L QSE, microgram per liter as quinine sulfate equivalents; $CaCO_3$, calcium carbonate; <, less than; --, not applicable; SiO_2, silicon dioxide; *E. coli*, *Escherichia coli*; UV, ultraviolet; nm, nanometer; absorbance units/cm, absorbance units per centimeter]

Water-quality constituent	USGS parameter code	Percent censored data	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
					Sedgwick—Continued							
Fipronil sulfide, in micrograms per liter	62167	71	115	<0.002	0.010	0.006	0.006	0.002	--	--	0.006	0.008
Glyphosate, in micrograms per liter	62722	0	141	0.050	7.80	0.970	0.560	1.24	0.104	1.28	0.240	1.20
Hexazinone, in micrograms per liter	04025	92	114	<0.008	<0.088	--	--	--	--	--	--	--
Metolachlor, in micrograms per liter	39415	7	268	<0.016	15.9	1.77	0.480	2.70	--	--	0.080	2.44
Metribuzin, in micrograms per liter	82630	78	233	<0.004	0.439	0.032	0.025	0.051	--	--	0.006	0.025
Prometon, in micrograms per liter	04037	51	263	<0.012	0.460	0.026	0.021	0.038	--	--	0.010	0.025
Prometryn, in micrograms per liter	04036	98	220	<0.005	<0.5	--	--	--	--	--	--	--
Simazine, in micrograms per liter	04035	65	263	<0.005	0.370	0.024	0.024	0.033	--	--	0.007	0.025
Tebuthiuron, in micrograms per liter	82670	79	135	<0.01	0.597	0.030	0.014	0.072	--	--	0.014	0.014
					Upstream ASR							
2,6-Diethylaniline, in micrograms per liter	82660	98	54	<0.006	<0.008	--	--	--	--	--	--	--
2-Chloro-4-isopropylamino-6-amino-*s*-triazine (deethylatrazine), in micrograms per liter	04040	0	54	0.014	1.52	0.297	0.177	0.325	0.044	1.09	0.071	0.396
2-Ethyl-6-methylaniline, in micrograms per liter	61620	89	54	<0.01	0.011	--	--	--	--	--	--	--
3,4-Dichloroaniline, in micrograms per liter	61625	57	54	<0.006	0.033	0.008	0.004	0.007	--	--	0.004	0.010
4-Chloro-2-methylphenol, in micrograms per liter	61633	76	54	<0.005	0.021	0.006	0.006	0.004	--	--	0.004	0.008

Table 4. Discrete sample water-quality constituent summary statistics for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; USGS station 07143672, 1995–2021); near Sedgwick, Kans. (Sedgwick; USGS station 07144100, 1995–2021); and upstream of ASR Facility near Sedgwick, Kans. (Upstream ASR; USGS station 375350097262800, 2011–21).—Continued

[Summary statistics were not computed when more than 80 percent of data were censored; USGS; U.S. Geological Survey; *n*, number of measurements; µg/L QSE, microgram per liter as quinine sulfate equivalents; $CaCO_3$, calcium carbonate; <, less than; --, not applicable; SiO_2, silicon dioxide; *E. coli*, *Escherichia coli*; UV, ultraviolet; nm, nanometer; absorbance units/cm, absorbance units per centimeter]

Water-quality constituent	USGS parameter code	Percent censored data	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Upstream ASR—Continued												
Acetochlor, in micrograms per liter	49260	9	54	<0.01	10.5	0.982	0.202	1.98	--	--	0.025	0.763
Alachlor, in micrograms per liter	46342	80	54	<0.008	0.063	0.008	0.004	0.010	--	--	0.004	0.004
Atrazine, in micrograms per liter	39632	0	54	0.044	19.1	3.47	1.50	4.68	0.64	1.35	0.294	5.02
Desulfinylfipronil amide, in micrograms per liter	62169	94	54	<0.086	<0.086	--	--	--	--	--	--	--
Desulfinylfipronil, in micrograms per liter	62170	31	54	<0.012	0.010	0.006	0.006	0.002	--	--	0.005	0.006
Fipronil sulfide, in micrograms per liter	62167	56	54	<0.012	<0.016	0.006	0.006	0.002	--	--	0.004	0.008
Hexazinone, in micrograms per liter	04025	70	54	<0.008	0.035	0.008	0.006	0.006	--	--	0.006	0.006
Metolachlor, in micrograms per liter	39415	0	54	0.019	12.1	1.77	0.464	2.78	0.379	1.58	0.096	2.65
Metribuzin, in micrograms per liter	82630	67	54	<0.008	0.486	0.044	0.010	0.086	--	--	0.006	0.041
Prometon, in micrograms per liter	04037	19	54	<0.012	0.105	0.014	0.010	0.014	--	--	0.007	0.015
Prometryn, in micrograms per liter	04036	96	54	<0.006	<0.01	--	--	--	--	--	--	--
Simazine, in micrograms per liter	04035	54	54	<0.006	0.067	0.013	0.006	0.014	--	--	0.0037	0.014
Tebuthiuron, in micrograms per liter	82670	83	54	<0.01	<0.16	--	--	--	--	--	--	--

Table 4. Discrete sample water-quality constituent summary statistics for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; USGS station 07143672, 1995–2021); near Sedgwick, Kans. (Sedgwick; USGS station 07144100, 1995–2021); and upstream of ASR Facility near Sedgwick, Kans. (Upstream ASR; USGS station 375350097262800, 2011–21).—Continued

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Water-quality constituent	USGS parameter code	Percent censored data	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Absorbance and color												
Highway 50												
UV absorbance at 254 nm, in absorbance units/cm	50624	0	67	0.06	1.08	0.42	0.31	0.31	0.04	0.74	0.13	0.68
UV organic constituent absorbance at 280 nm, in absorbance units/cm	61726	0	67	0.04	0.85	0.33	0.24	0.25	0.03	0.76	0.10	0.54
Color, in platinum cobalt units	00080	0	61	10	300	109	75	90	12	0.8	30	200
Sedgwick												
UV absorbance at 254 nm, in absorbance units/cm	50624	0	196	0.03	1.09	0.28	0.18	0.23	0.02	0.82	0.10	0.41
UV organic constituent absorbance at 280 nm, in absorbance units/cm	61726	0	196	0.02	0.86	0.22	0.14	0.19	0.01	0.84	0.07	0.32
Color, in platinum cobalt units	00080	0	96	15	400	107	75	92	9	0.9	30	175
Upstream ASR												
UV absorbance at 254 nm, in absorbance units/cm	50624	0	85	0.07	1.09	0.38	0.28	0.27	0.03	0.71	0.13	0.64
UV organic constituent absorbance at 280 nm, in absorbance units/cm	61726	0	85	0.05	0.86	0.30	0.21	0.22	0.02	0.73	0.10	0.50
Color, in platinum cobalt units	00080	0	84	15	350	97	55	84	9	0.9	30	150

Total phosphorus values did not exceed previously reported ranges (Tappa and others, 2015; Stone and Klager, 2022) at the Highway 50 and Sedgwick sites, but did exceed previously reported minimum and maximum values (Stone and others, 2016) by 0.20 and 0.04 mg/L, respectively, at the Upstream ASR site (table 4). The minimum total phosphorus value (0.29 mg/L) at the Upstream ASR site was in December 2019 and the maximum (1.5 mg/L) was in May 2021.

An important artificial recharge concern is the introduction of potentially reactive organic material into an aquifer (Aiken, 2002). Mean dissolved organic carbon concentrations were 7.9, 6.6, and 7.7 mg/L at the Highway 50, Sedgwick, and Upstream ASR study sites, respectively, during the study period (table 4). Dissolved organic carbon values did not exceed previously reported ranges (Tappa and others, 2015; Stone and others, 2019) at the Highway 50 and Sedgwick sites, but did exceed previously reported minimum and maximum values (Stone and others, 2016) by 0.80 and 0.70 mg/L, respectively, at the Upstream ASR site (table 4). The minimum dissolved organic carbon value (2.9 mg/L) was in January 2018 and the maximum (14 mg/L) was in June 2016 at the Upstream ASR site. Mean total organic carbon concentrations were 13 mg/L at the Highway 50 site and 12 mg/L at the Sedgwick and Upstream ASR sites (table 4). Total organic carbon concentrations during the study period at the Highway 50 site did not exceed previously reported ranges (Tappa and others, 2015; Stone and Klager, 2022). The maximum total organic carbon value (36 mg/L) at the Sedgwick site exceeded the range of previously reported values (Tappa and others, 2015; Stone and Klager, 2022) by 4.0 mg/L and were in February 2020. The minimum and maximum total organic carbon values at the Upstream ASR site exceeded the range of previously reported values (Stone and others, 2016) by 1.6 and 5.4 mg/L, respectively, and were in August 2019 and January 2018, respectively (table 4).

Sediment

Sediment is a naturally occurring constituent that is also a pollutant of concern in the Little Arkansas River (Kansas State University Research and Extension and others, 2018). Suspended solids and suspended-sediment concentration are two analytes typically used to describe concentrations of suspended solid-phase material in surface water. Suspended-sediment concentration is a better measure for natural water than suspended solids (Gray and others, 2000), but suspended solids are required for TMDLs. Suspended solids represent suspended solids material and may consist of organic or inorganic material. Suspended solids originate from sources that include algae, decaying vegetation, runoff, discharges (for example, industrial or wastewater), and physical degradation of geologic formations. The amount of suspended solids in a sample is equal to the dry weight of organic and inorganic solids filtered from a subsample of the original sample. Suspended-sediment concentration is the measure of the dry weight of the organic and inorganic sediment in a full sample volume of a water-sediment mixture (Guy, 1969). Suspended sediment may consist of clay, silt, sand, or organic material. Mean Little Arkansas River suspended-solids concentrations were 264, 219, and 184 mg/L at the Highway 50, Sedgwick, and Upstream ASR sites, respectively, during the study period (table 4). Suspended-solids concentrations during the study period did not exceed previously reported ranges (Tappa and others, 2015; Stone and Klager, 2022) at the Highway 50 and Sedgwick sites. The maximum suspended-solids value at the Upstream ASR site exceeded the previously reported value (Stone and others, 2016) by 357 mg/L and was in May 2021 (table 4). Mean suspended-sediment concentrations at the Highway 50, Sedgwick, and Upstream ASR sites were 400, 232, and 246 mg/L, respectively (table 4). Suspended-sediment concentration during the study period at the Highway 50 and Sedgwick sites did not exceed previously reported ranges (Tappa and others, 2015; Stone and Klager, 2022). The maximum suspended-sediment concentration at the Upstream ASR site exceeded the previously reported value (Stone and others, 2016) by 706 mg/L and was in May 2021 (table 4).

Indicator Bacteria

E. coli and fecal coliform bacteria are types of coliform bacteria that are generally specific to fecal material from humans and other homeotherms and are commonly used as pathogen indicators (Myers and others, 2014). *E. coli* and fecal coliform bacteria presence indicates potentially contaminated water by human or animal wastes and presence of other harmful bacteria or viruses (Dufour and others, 1981; Dufour, 1984). The State of Kansas *E. coli* criteria for publicly accessible (Class B) Kansas streams with flows of at least 1 ft^3/s require that the geometric mean of at least five samples collected during separate 24-hour periods within a 30-day period not exceed 262 colony forming units per 100 milliliters (cfu/100 mL) for primary contact during April 1 through October 31 of each year and 2,358 cfu/100 mL during November 1 through March 31 (Kansas Department of Health and Environment, 2011, 2017, 2018). Little Arkansas River *E. coli* and fecal coliform medians ranged from 540 to 640 cfu/100 mL and 590 to 910 cfu/100 mL, respectively, at the three study sites during the study period (table 4). *E. coli* densities exceeded the primary contact Class B criteria of 262 cfu/100 mL at all sites (table 4). *E. coli* densities exceeded the primary contact Class B criteria of 262 cfu/100 mL in 67, 60, and 62 percent of samples at the Highway 50, Sedgwick, and Upstream ASR sites, respectively. *E. coli* densities at the Highway 50 site were within ranges previously reported (Tappa and others, 2015; Stone and Klager, 2022); the maximum *E. coli* densities at the Sedgwick and Upstream ASR sites exceeded previously reported ranges (Stone and others, 2016; Stone and Klager, 2022) by 1,300 and 11,000 cfu/100 mL, respectively, and were in October 2021 (table 4). Fecal coliform densities at the Highway 50 and Sedgwick sites during the study were within previously reported ranges (Tappa and others, 2015; Stone and Klager,

2022) during the study (table 4). The maximum fecal coliform density at the Upstream ASR site exceeded the maximum previously reported value (Stone and others, 2016; table 4) by 16,000 cfu/100 mL and were in June 2016.

Trace Elements

Dissolved concentrations of particular interest in the Little Arkansas River include iron and arsenic. Iron in water is derived from rocks and soils (Hem, 1992). Excessive concentrations of iron in water cause unpalatability because of odor, a metallic taste, and rusty color. The EPA Federal SMCL for iron is 300 µg/L (U.S. Environmental Protection Agency, 2009) and was exceeded in 5, 7, and 9 percent of samples at the Highway 50, Sedgwick, and Upstream ASR sites, respectively, during the study period (table 4). Mean study site iron concentrations ranged from 63 to 137 µg/L (table 4). Iron concentrations at the Highway 50 and Sedgwick sites did not exceed the ranges previously reported (Tappa and others, 2015; Stone and others, 2019). The maximum iron concentrations at the Upstream ASR site exceeded the previously reported range (Stone and others, 2016) by 807 µg/L and were during August 2019 (table 4).

Arsenic is present naturally in clay layers associated with iron sulfide minerals (Hem, 1992) and is a health concern in drinking water because it causes skin damage, affects the circulatory system, and increases the risk of cancer (U.S. Environmental Protection Agency, 2009). The EPA Federal MCL for arsenic is 10 µg/L (U.S. Environmental Protection Agency, 2009) and was exceeded in 10 percent of samples at the Highway 50 and Sedgwick site and 25 percent of samples at the Upstream ASR site (table 4). Mean arsenic concentrations were 5.4, 5.8, and 7.7 µg/L at the Highway 50, Sedgwick, and Upstream ASR sites during the study period (table 4). Arsenic concentrations were within the ranges previously reported (Tappa and others, 2015; Stone and others, 2019) at the Highway 50 and Sedgwick sites (table 4). The minimum arsenic concentration was 1.6 µg/L less than the range previously reported (Stone and others, 2016; table 4) at the Upstream ASR site and was in May 2019.

Pesticides

Pesticides enter streams from field application and through irrigation return flow and surface runoff in agricultural landscapes. Pesticides that were detected in greater than one-half of the collected samples at any of the three study sites included 2-chloro-4-isopropylamino-6-amino-*s*-triazine (deethylatrazine, a degradation product of the atrazine molecule), acetochlor (applied herbicide), AMPA (a chemical that results from the breakdown of glyphosate), atrazine (applied herbicide), desulfinylfipronil (a degradation product of the fipronil [applied insecticide] molecule), glyphosate (applied herbicide), metolachlor (applied herbicide), and prometon (applied herbicide; table 4). Mean deethylatrazine concentrations during the study period were 0.350, 0.394, and 0.297 µg/L at the Highway 50, Sedgwick, and Upstream ASR sites, respectively, and maxima did not exceed previously reported ranges (Stone and others, 2019; table 4). Mean acetochlor concentrations at the Highway 50, Sedgwick, and Upstream ASR sites were 0.321, 0.380, and 0.982 µg/L, respectively (table 4). Acetochlor maxima exceeded the ranges previously reported (Stone and others, 2016, 2019) by 3.01, 12.2, and 6.14 µg/L at the Highway 50, Sedgwick, and Upstream ASR sites, respectively. AMPA and glyphosate were analyzed for the Sedgwick site only, were detected in all of the samples collected during the study, and mean concentrations were 1.44 and 0.970 µg/L, respectively (table 4). The AMPA maxima exceeded the range previously reported (Stone and others, 2019) by 1.6 µg/L, but glyphosate concentrations were within previously reported ranges (Stone and others, 2019; table 4). Mean study period metolachlor concentrations were 2.08 µg/L at the Highway 50 site and 1.77 µg/L at the Sedgwick and Upstream ASR sites (table 4). Metolachlor maxima at the Highway 50, Sedgwick, and Upstream ASR sites exceeded the ranges previously reported (Stone and others, 2016, 2019; table 4) by 24.4, 0.9, and 5.28 µg/L, respectively.

Atrazine is an herbicide commonly used on corn and sorghum, which are crops grown in the study area. Atrazine can cause cardiovascular system or reproductive problems in humans (U.S. Environmental Protection Agency, 2009). Previous (2010 through 2014 and 2015 through 2019) NPDES permits (Kansas permit number: I-LA24-PO01; Federal permit number: KS0099694) for the ASR phase II treatment facility required that atrazine be monitored monthly while the facility was operating. The EPA MCL for atrazine is 3.0 µg/L (U.S. Environmental Protection Agency, 2009) and was exceeded in 34, 36, and 37 percent of discrete samples at the Highway 50, Sedgwick, and Upstream ASR sites, respectively (table 4). Mean atrazine concentrations were 3.89, 3.55, and 3.47 µg/L during the study period at Highway 50, Sedgwick, and Upstream ASR sites, respectively. Atrazine concentrations during the study were within previously reported ranges (Tappa and others, 2015; Stone and others, 2016; Stone and Klager, 2022) at all study sites (table 4).

Regression Models for Selected Constituents

New Little Arkansas River regression models were developed for bromide, dissolved organic carbon, deethylatrazine, and metolachlor at all three study sites; new total organic carbon, acetochlor, and atrazine models were developed for the Upstream ASR site; and new AMPA and glyphosate models were developed for the Sedgwick site. Additional streamflow-based or gage-height-based models were developed to compute concentration and load estimates for constituents of interest when concomitant continuous data were unavailable. These 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 table 5 for newly developed models. Atrazine models at the Highway 50 and Sedgwick sites were updated from previously published models (Stone and Klager, 2022). Regression model archive summaries are presented in appendixes 4 (Highway 50), 5 (Sedgwick), and 6 (Upstream ASR). Continuously measured physicochemical properties that were included as surrogates in final models for this study were specific conductance and YSI EXO turbidity (table 5). Selected regression models used to compute real-time water-quality concentrations are available at the USGS National Real-Time Water-Quality website (https://nrtwq.usgs.gov).

Specific conductance was the sole explanatory variable for bromide at all three study sites (table 5). Specific conductance was positively related to bromide because specific conductance measures the capacity of water to conduct an electrical current and is related to the concentration of ionized substances in water (Hem, 1992). The amount of variance explained by bromide models ranged from 72 percent at the Sedgwick site to 89 percent at the Upstream ASR site (table 5).

YSI EXO turbidity was the sole explanatory variable for total organic carbon at the Upstream ASR site and, in combination with seasonal variables, was an explanatory variable for all modeled pesticides (table 5). Turbidity was positively related to total organic carbon because total organic carbon contains organic material, which is a substantial component of total suspended solids (Hem, 1992). Turbidity was also the sole explanatory variable for total organic carbon at the Highway 50 and Sedgwick sites in previously developed models (Stone and Klager, 2022). The amount of variance explained by the Upstream ASR total organic carbon model was 82 percent (table 5). YSI EXO turbidity was positively related to deethylatrazine, atrazine, and metolachlor at all three study sites; acetochlor at the Upstream ASR site; and AMPA and glyphosate at the Sedgwick site (table 5), likely because pesticides, similar to sediment, are typically transported during runoff conditions. The amount of variance in deethylatrazine concentrations explained by regression models ranged from 64 percent at the Highway 50 site to 77 percent at the Upstream ASR site (table 5). The acetochlor model at the Upstream ASR site explained 75 percent of the variance in acetochlor concentrations (table 5). The amount of variance explained by the Sedgwick site AMPA and glyphosate models was 76 and 59 percent, respectively (table 5). Previously published atrazine models at the Highway 50 and Sedgwick sites (Christensen and others, 2003; Rasmussen and others, 2016; Stone and Klager, 2022) included specific conductance and seasonal components as explanatory variables; the most recently published atrazine models (Stone and Klager, 2022) explained 41 percent of the variance at the Highway 50 site and 54 percent of the variance at the Sedgwick site. The updated atrazine models at the Highway 50 and Sedgwick sites using YSI EXO turbidity as a surrogate explained 58 percent (a 17-percent increase from the most recently published model) and 69 percent (a 15-percent increase from the most recently published model) of the variance, respectively, and the newly developed Upstream ASR atrazine model explained 78 percent of the variance (table 5). The amount of variance explained by the newly developed metolachlor models ranged from 64 percent at the Highway 50 site to 87 percent at the Upstream ASR site (table 5).

Computed Select Water-Quality Constituents

Continuous water-quality concentrations were computed for select constituents using regression models and continuously measured physicochemical parameters. Continuous water-quality concentrations were computed for hardness, dissolved solids, calcium, sodium, bromide, chloride, sulfate, ammonia plus organic nitrogen, total phosphorus, total organic carbon, *E. coli* bacteria, fecal coliform bacteria, suspended solids, suspended-sediment concentration, arsenic, deethylatrazine, acetochlor, atrazine, glyphosate, and metolachlor. Concentration data were useful for evaluating the water-quality conditions of the Little Arkansas River as well as calculating selected water-quality constituent loads.

Primary Ions

The primary components of dissolved solids come from decomposing rocks and soils. Concentrations of dissolved solids in streams may increase because of atmospheric deposition, sewage inputs, industrial effluent, and agricultural and urban runoff (Hem, 1992). Dissolved solids often are used as a general indicator of salinity or water quality, and large concentrations are undesirable in drinking water because of possible physiological effects, strong mineral tastes, increased treatment costs, and corrosion of plumbing (U.S. Environmental Protection Agency, 2009). Dissolved solids commonly exceeded the EPA SMCL in the *Equus* Beds aquifer (Ziegler and others, 2010; Tappa and others, 2015; Stone and others, 2019). Computed primary components of dissolved solids (hardness, calcium, sodium, bromide, and chloride), with the exception of sulfate, were larger at the Highway 50 site compared to the Sedgwick site (table 6; fig. 3*A–D*). Computed dissolved solids concentrations during the study period ranged from 60 to 1,592 mg/L at the Highway 50 site and 53 to 929 mg/L at the Sedgwick site; mean computed dissolved solids concentrations were 546 and 447 mg/L at the Highway 50 and Sedgwick site, respectively (table 6). During the study period, the EPA SMCL for dissolved solids of 500 mg/L was exceeded 57 percent of the time at the Highway 50 site and 38 percent of the time at the Sedgwick site (fig. 3*A*).

Bromide is a constituent of interest because of its potential for conversion to brominated organics of concern through drinking-water treatment processes. Bromate, a known carcinogen, can form during the disinfection of bromide-containing water that involves an oxidation process to kill pathogens (Xie, 2003; U.S. Environmental Protection Agency, 2009). Mean continuously computed bromide concentration during

Table 5. Regression models and summary statistics for continuous water quality constituent computations for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; USGS station 07143672, 1995–2021); near Sedgwick, Kans. (Sedgwick; USGS station 07144100, 1995–2021); and upstream of ASR Facility near Sedgwick, Kans. (Upstream ASR; USGS station 375350097262800, 2011–21).

[R^2, coefficient of determination; *MSE*, mean square error; *RMSE*, root mean square error; *RSE,* residual standard error; *MSPE*, model standard percentage error; *n*, number of discrete samples; mg/L, milligram per liter; USGS, U.S. Geological Survey; log, base 10 logarithm; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; --, not applicable; <, less than; Q, streamflow in cubic feet per second; sin, sine; π, pi; D, day of year; cos, cosine; ASR, aquifer storage and recovery; GH, gage height in feet; TBY, YSI EXO Smart Sensor turbidity in formazin nephelometric units; µg/L, microgram per liter]

Regression model	Model archival summary appendix	R^2	Adjusted R^2	Pseudo R^2	*MSE*	*RMSE*	*RSE*	Average *MSPE*	Bias correction factor (Duan, 1983)	Discrete data: Model dataset date range	Discrete data: *n*	Discrete data: Percent left-censored data	Discrete data: Range of values in variable measurements	Discrete data: Mean	Discrete data: Median
Bromide (Br), mg/L (USGS parameter code 71870)															
Highway 50															
log(Br) = 1.273log(SC) − 4.183	4.1	--	--	0.78	--	--	0.2240	--	1.10	May 1998–October2021	188	4	Br: <0.02–1.72 SC: 76–2,062	0.32 697	0.19 597
log(Br) = −0.2945log(Q) + 0.2079sin(2πD/365) + 0.0407cos(2πD/365) − 0.1205	4.2	--	--	0.42	--	--	0.3645	--	1.35	May 1995–October 2021	200	4	Br: <0.02–1.72 Q: 1–11,000	0.31 836	0.18 90
Sedgwick															
log(Br) = 1.168log(SC) − 4.045	5.1	--	--	0.72	--	--	0.2111	--	1.11	November 1998–August 2021	203	7	Br: <0.02–0.98 SC: 96–1,295	0.17 577	0.13 619
log(Br) = −0.2216log(Q) + 0.1903sin(2πD/365) + 0.1316cos(2πD/365) − 0.4010	5.2	--	--	0.42	--	--	0.3070	--	1.26	March 1995–August 2021	214	7	Br: <0.02–0.98 Q: 1.4–15,000	0.17 1,280	0.13 111
Upstream ASR															
log(Br) = 1.269log(SC) − 4.304	6.1	--	--	0.89	--	--	0.1370	--	1.04	April 2011–October 2021	59	5	Br: <0.04–0.58 SC: 88–1,270	0.17 557	0.14 575
log(Br) = −1.3321log(GH) + 0.24578sin(2πD/365) + 0.0134cos(2πD/365) + 0.1627	6.2	--	--	0.68	--	--	0.2428	--	1.15	April 2011–October 2021	62	5	Br: <0.04–0.58 GH: 3.63–29.4	0.16 8.24	0.15 6.00
Total organic carbon (TOC), mg/L (USGS parameter code 00680)															
Upstream ASR															
log(TOC) = 0.434log(TBY) + 0.212	6.5	0.82	0.82	--	0.0128	0.1130	0.1157	26	1.03	April 2016–October 2021	44	0	TOC: 3.53–28.3 TBY: 4.1–467	13 142	13 106
log(TOC) = 0.824log(GH) + 0.31	6.6	0.56	0.56	--	0.0259	0.1610	0.1631	38	1.07	April 2011–October 2021	81	0	TOC: 3.53–28.3 GH: 3.63–25.7	12 7.93	11 5.73
2-Chloro-4-isopropylamino-6-amino-*s*-triazine (deethylatrazine; 2CTRI), µg/L (USGS parameter code 04040)															
Highway 50															
log(2CTRI) = 0.606log(TBY) + 0.1207sin(2πD/365) − 0.4175cos(2πD/365) − 2.35	4.5	--	--	0.64	--	--	0.4013	--	1.39	March 2017–August 2021	37	8	2CTRI: <0.014–1.31 TBY: 4.0–1,039	0.18 181	0.09 39
log(2CTRI) = 0.1567log(Q) + 0.1608sin(2πD/365) − 0.5222cos(2πD/365) − 1.383	4.6	--	--	0.42	--	--	0.4920	--	1.81	May 1995–August 2021	224	11	2CTRI: <0.006–2.69 Q: <1–11,000	0.33 820	0.17 93

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Regression model	Model archival summary appendix	R^2	Adjusted R^2	Pseudo R^2	*MSE*	*RMSE*	*RSE*	Average *MSPE*	Bias correction factor (Duan, 1983)	Discrete data: Model dataset date range	*n*	Percent left-censored data	Range of values in variable measurements	Mean	Median
Sedgwick															
log(2CTRI) = 0.5937log(TBY) + 0.2523sin(2πD/365) − 0.3438cos(2πD/365) − 2.21	5.5	--	--	0.72	--	--	0.3521	--	1.32	December 2014–August 2021	46	9	2CTRI: <0.014–1.4 TBY: 3.6–702	0.24 155	0.12 80
log(2CTRI) = 0.2130log(Q) + 0.1815sin(2πD/365) − 0.5958cos(2πD/365) − 1.528	5.6	--	--	0.55	--	--	0.4232	--	1.51	March 1995–August 2021	250	5	2CTRI: <0.0145–2.4 Q: 1.4–15,000	0.33 1,412	0.17 141
Upstream ASR															
log(2CTRI) = 0.522log(TBY) + 0.309sin(2πD/365) − 0.276cos(2πD/365) − 1.91	6.7	0.81	0.77	--	0.0534	0.2310	0.2442	56	1.12	May 2016–August 2021	20	0	2CTRI: 0.020–1.24 TBY: 13.6–467	0.33 166	0.24 141
log(2CTRI) = 0.533log(GH) + 0.345sin(2πD/365) − 0.458cos(2πD/365) − 1.54	6.8	0.48	0.45	--	0.1459	0.3820	0.3897	100	1.39	April 2011–August 2021	52	0	2CTRI: 0.014–1.52 GH: 3.63–29.7	0.30 8.62	0.18 5.52
Acetochlor (ACE), µg/L (USGS parameter code 49260)															
Upstream ASR															
log(ACE) = 0.7185log(TBY) + 0.2005sin(2πD/365) − 0.77546cos(2πD/365) − 2.16	6.9	--	--	0.75	--	--	0.4209	--	1.48	May 2016–August 2021	21	5	ACE: <0.072–6.74 TBY: 9.9–467	1.24 159	0.70 138
log(ACE) = 1.684log(GH) + 0.1443sin(2πD/365) − 0.7289cos(2πD/365) − 2.62	6.10	--	--	0.45	--	--	0.7138	--	3.25	April 2011–August 2021	52	8	ACE: <0.01–10.5 GH: 3.63–29.7	0.86 8.62	0.20 5.52
Aminomethylphosphonic acid (AMPA), µg/L (USGS parameter code 62649)															
Sedgwick															
log(AMPA) = 0.165log(TBY) − 0.0931sin(2πD/365) − 0.209cos(2πD/365) − 0.222	5.7	0.76	0.76	--	0.0149	0.1220	0.1231	28	1.04	October 2014–July 2021	117	0	AMPA: 0.29–4.30 TBY: 2.7–603	1.42 66	1.30 27
log(AMPA) = 0.056log(Q) − 0.0932sin(2πD/365) − 0.271cos(2πD/365) − 0.11	5.8	0.70	0.69	--	0.0185	0.1360	0.1370	32	1.05	June 2002–July 2021	138	0	AMPA: 0.29–4.30 Q: 12–16,100	1.44 796	1.40 74

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Regression model	Model archival summary appendix	R^2	Adjusted R^2	Pseudo R^2	*MSE*	*RMSE*	*RSE*	Average *MSPE*	Bias correction factor (Duan, 1983)	Discrete data: Model dataset date range	*n*	Percent left-censored data	Range of values in variable measurements	Mean	Median
Atrazine (ATR), µg/L (USGS parameter code 39632)															
Highway 50															
log(ATR) = 0.721log(TBY) + 0.405sin(2πD/365) − 0.38cos(2πD/365) − 1.7	4.7	0.62	0.58	--	0.2809	0.5300	0.5454	154	1.90	March 2017–August 2021	37	0	ATR: 0.018–15.4 TBY: 4.0–1,040	2.44 181	0.64 39
Sedgwick															
log(ATR) = 0.779log(TBY) + 0.385sin(2πD/365) − 0.278cos(2πD/365) − 1.62	5.9	0.71	0.69	--	0.1910	0.4370	0.4475	119	1.50	December 2014–August 2021	44	0	ATR: 0.031–30.1 TBY: 3.6–702	2.93 139	0.96 61
Upstream ASR															
log(ATR) = 0.646log(TBY) + 0.556sin(2πD/365) − 0.243cos(2πD/365) − 1.22	6.11	0.81	0.78	--	0.0992	0.3150	0.3341	79	1.23	May 2016–August 2021	19	0	ATR: 0.061–14.2 TBY: 13.6–467	2.67 157	3.66 138
log(ATR) = 0.759log(GH) + 0.58sin(2πD/365) − 0.51cos(2πD/365) − 0.94	6.12	0.47	0.44	--	0.3025	0.5500	0.5611	164	1.96	April 2011–August 2021	52	0	ATR: 0.044–19.1 GH: 3.63–29.7	3.50 8.62	1.50 5.52
Glyphosate (GLY), µg/L (USGS parameter code 62722)															
Sedgwick															
log(GLY) = 0.402log(TBY) − 0.0594sin(2πD/365) − 0.229cos(2πD/365) − 0.97	5.10	0.60	0.59	--	0.0767	0.2770	0.2794	68	1.23	October 2014–July 2021	118	0	GLY: 0.05–7.6 TBY: 2.7–603	0.84 66	0.50 27
log(GLY) = 0.215log(Q) − 0.0698sin(2πD/365) − 0.388cos(2πD/365) − 0.83	5.11	0.67	0.64	--	0.0906	0.3010	0.3032	156	1.67	June 2022–July 2021	139	0	GLY: 0.05–7.8 Q: 12–16,100	0.97 791	0.55 76
Metolachlor (MET), µg/L (USGS parameter code 39415)															
Highway 50															
log(MET) = 0.812log(TBY) + 0.17sin(2πD/365) − 0.647cos(2πD/365) − 2.13	4.8	0.67	0.64	--	0.2841	0.5330	0.5485	156	1.67	March 2017–August 2021	37	0	MET: 0.009–13.2 TBY: 4.0–1,040	1.72 181	0.26 39

Table 5. Regression models and summary statistics for continuous water quality constituent computations for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; USGS station 07143672, 1995–2021); near Sedgwick, Kans. (Sedgwick; USGS station 07144100, 1995–2021); and upstream of ASR Facility near Sedgwick, Kans. (Upstream ASR; USGS station 375350097262800, 2011–21).—Continued

[R^2, coefficient of determination; *MSE*, mean square error; *RMSE*, root mean square error; *RSE,* residual standard error; *MSPE*, model standard percentage error; *n*, number of discrete samples; mg/L, milligram per liter; USGS, U.S. Geological Survey; log, base 10 logarithm; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; --, not applicable; <, less than; Q, streamflow in cubic feet per second; sin, sine; π, pi; D, day of year; cos, cosine; ASR, aquifer storage and recovery; GH, gage height in feet; TBY, YSI EXO Smart Sensor turbidity in formazin nephelometric units; µg/L, microgram per liter]

Regression model	Model archival summary appendix	R^2	Adjusted R^2	Pseudo R^2	*MSE*	*RMSE*	*RSE*	Average *MSPE*	Bias correction factor (Duan, 1983)	Discrete data					
										Model dataset date range	*n*	Percent left-censored data	Range of values in variable measurements	Mean	Median
Highway 50—Continued															
log(MET) = 0.3974log(Q) + 0.1198sin(2πD/365) − 0.9058cos(2πD/365) − 1.6131	4.9	--	--	0.60	--	--	0.6265	--	2.31	May 1995–August 2021	230	12	MET: <0.02–39.4 Q: <1–11,000	1.8 805	0.5 88
Sedgwick															
log(MET) = 0.729log(TBY) + 0.108sin(2πD/365) − 0.649cos(2πD/365) − 1.93	5.12	0.74	0.72	--	0.2016	0.4490	0.4596	123	1.54	December 2014–August 2021	45	0	MET: 0.009–14.7 TBY: 3.6–702	1.81 155	0.43 75
log(MET) = 0.3534log(Q) + 0.0721sin(2πD/365) − 0.9242cos(2πD/365) − 1.61	5.13	--	--	0.61	--	--	0.5675	--	2.15	March 1995–August 2021	255	7	MET: <0.02–15.88 Q: 1.4–15,000	1.7 1,388	0.5 144
Upstream ASR															
log(MET) = 0.768log(TBY) + 0.279sin(2πD/365) − 0.888cos(2πD/365) − 1.97	6.13	0.89	0.87	--	0.0692	0.2630	0.2790	65	1.15	May 2016-August 2021	19	0	MET: 0.069–12.1 TBY: 13.6–467	3.09 174	1.88 144
log(MET) = 1.54log(GH) + 0.2sin(2πD/365) − 0.708cos(2πD/365) − 2.04	6.14	0.53	0.50	--	0.3283	0.5730	0.5846	174	1.94	April 2011–August 2021	52	0	MET: 0.021–12.1 GH: 3.63–29.7	1.80 8.62	0.46 5.52

Table 6. Summary statistics for continuously (daily) computed regression-model water-quality constituents for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672, 1998–2021); near Sedgwick, Kans. (Sedgwick; USGS station 07144100, 1998–2021); and upstream of ASR Facility near Sedgwick, Kans. (Upstream ASR; USGS station 375350097262800, 2011–21).

[Continuous real-time water-quality data are available on the U.S. Geological Survey National Real-Time Water-Quality website (https://nrtwq.usgs.gov/ks); *n*, number of measurements; $CaCO_3$, calcium carbonate; USGS, U.S. Geological Survey; pcode, parameter code; <, less than]

Site	Date range	*n*	Minimum	Maximum	Mean	Median
Hardness, in milligrams per liter as $CaCO_3$ (USGS pcode 00900)						
Highway 50	May 1988–December 2021	8,431	25	921	281	278
Sedgwick	April 1998–December 2021	8,619	23	631	259	262
Dissolved solids, in milligrams per liter (USGS pcode 70300)						
Highway 50	May 1988–December 2021	8,431	60	1,592	546	546
Sedgwick	April 1998–December 2021	8,619	53	929	447	456
Calcium, in milligrams per liter (USGS pcode 00915)						
Highway 50	May 1988–December 2021	8,431	7.3	300	88	87
Sedgwick	April 1998–December 2021	8,619	6.9	196	77	78
Sodium, in milligrams per liter (USGS pcode 00930)						
Highway 50	May 1988-December 2021	8,431	3.3	394	82	78
Sedgwick	April 1998-December 2021	8,619	2.5	161	58	58
Bromide, in milligrams per liter (USGS pcode 71870)						
Highway 50	May 1988–December 2021	8,431	0.02	1.43	0.44	0.43
Sedgwick	April 1998–December 2021	8,619	0.02	0.56	0.23	0.23
Upstream ASR	April 2011–December 2021	3,913	0.01	0.61	0.22	0.23
Chloride, in milligrams per liter (USGS pcode 00940)						
Highway 50	May 1988–December 2021	8,431	6.0	669	156	148
Sedgwick	April 1998–December 2021	8,619	3.9	219	81	81
Sulfate, in milligrams per liter (USGS pcode 00945)						
Highway 50	May 1988–December 2021	8,431	4.0	131	42	42
Sedgwick	April 1998–December 2021	8,619	3.0	166	55	55
Ammonia plus organic nitrogen, in milligrams per liter (USGS pcode 00625)						
Highway 50	October 1998–December 2021	8,382	0.09	5.76	1.10	0.88
Sedgwick	September 1998–December 2021	8,488	0.32	5.04	1.14	0.95
Total phosphorus, in milligrams per liter (USGS pcode 00665)						
Highway 50	October 1998–December 2021	8,382	0.07	1.80	0.47	0.39
Sedgwick	September 1998–December 2021	8,488	0.30	1.53	0.61	0.56
Total organic carbon, in milligrams per liter (USGS pcode 00680)						
Highway 50	July 2004–December 2021	6,280	0.8	41	9.2	7.8
Sedgwick	July 2004–December 2021	6,345	2.3	31	8.3	7.1
Upstream ASR	October 2015–December 2021	2,249	2.2	35	8.1	6.7
Suspended solids, in milligrams per liter (USGS pcode 00530)						
Highway 50	October 1998–December 2021	8,381	<1	1,949	101	43
Sedgwick	September 1998–December 2021	8,483	2	1,379	94	38
Suspended-sediment concentration, in milligrams per liter (USGS pcode 80154)						
Highway 50	October 1998–December 2021	8,380	<1	2,598	134	59
Sedgwick	September 1998–December 2021	8,267	3	2,261	129	47

Table 6. Summary statistics for continuously (daily) computed regression-model water-quality constituents for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672, 1998–2021); near Sedgwick, Kans. (Sedgwick; USGS station 07144100, 1998–2021); and upstream of ASR Facility near Sedgwick, Kans. (Upstream ASR; USGS station 375350097262800, 2011–21).—Continued

[Continuous real-time water-quality data are available on the U.S. Geological Survey National Real-Time Water-Quality website (https://nrtwq.usgs.gov/ks); *n*, number of measurements; $CaCO_3$, calcium carbonate; USGS, U.S. Geological Survey; pcode, parameter code; <, less than]

Site	Date range	*n*	Minimum	Maximum	Mean	Median
Escherichia coli bacteria, in colony forming units per 100 milliliters (USGS pcode 90902)						
Highway 50	October 1998–December 2021	8,382	1	12,000	800	330
Highway 50	Months of April–October during October 1998–October 2021	4,842	1	11,000	1,000	470
Highway 50	Months of November–March during November 1998–December 2021	3,540	13	12,000	500	140
Sedgwick	September 1998–December 2021	8,488	5	31,000	980	230
Sedgwick	Months of April–October during September 1998–October 2021	4,955	17	24,000	1,200	380
Sedgwick	Months of November–March during November 1998–December 2021	3,533	5	31,000	610	83
Fecal coliform bacteria, in colony forming units per 100 milliliters (USGS pcode 31625)						
Highway 50	October 1998–December 2021	8,382	0	23,000	1,200	420
Sedgwick	September 1998–December 2021	8,488	5	37,000	1,300	310
Arsenic, in micrograms per liter (USGS pcode 01000)						
Highway 50	May 1988–December 2021	8,511	1.40	24	6.8	6.1
Sedgwick	April 1998–December 2021	8,307	1.56	22	6.4	5.8
2-Chloro-4-isopropylamino-6-amino-*s*-triazine, in micrograms per liter (USGS pcode 04040)						
Highway 50	January 2017–December 2021	1,801	0.005	0.654	0.094	0.059
Sedgwick	September 2014–December 2021	2,667	0.006	0.758	0.109	0.055
Upstream ASR	October 2015–December 2021	2,249	0.008	0.858	0.130	0.078
Acetochlor, in micrograms per liter (USGS pcode 49260)						
Upstream ASR	October 2015–December 2021	2,249	0.003	9.15	0.433	0.107
Aminomethylphosphonic acid, in micrograms per liter (USGS pcode 62649)						
Sedgwick	September 2014–December 2021	2,667	0.425	2.82	1.19	1.06
Atrazine, in micrograms per liter (USGS pcode 39632)						
Highway 50	January 2017–December 2021	1,801	0.034	12.0	1.10	0.507
Sedgwick	September 2014–December 2021	2,667	0.030	11.6	1.12	0.446
Upstream ASR	October 2015–December 2021	2,249	0.042	16.9	1.49	0.617
Glyphosate, in micrograms per liter (USGS pcode 62722)						
Sedgwick	September 2014–December 2021	2,667	0.108	5.81	0.662	0.514
Metolachlor, in micrograms per liter (USGS pcode 39415)						
Highway 50	January 2017–December 2021	1,801	0.008	7.86	0.660	0.261
Sedgwick	September 2014–December 2021	2,667	0.008	6.81	0.612	0.183
Upstream ASR	October 2015–December 2021	2,249	0.002	13.4	0.802	0.149

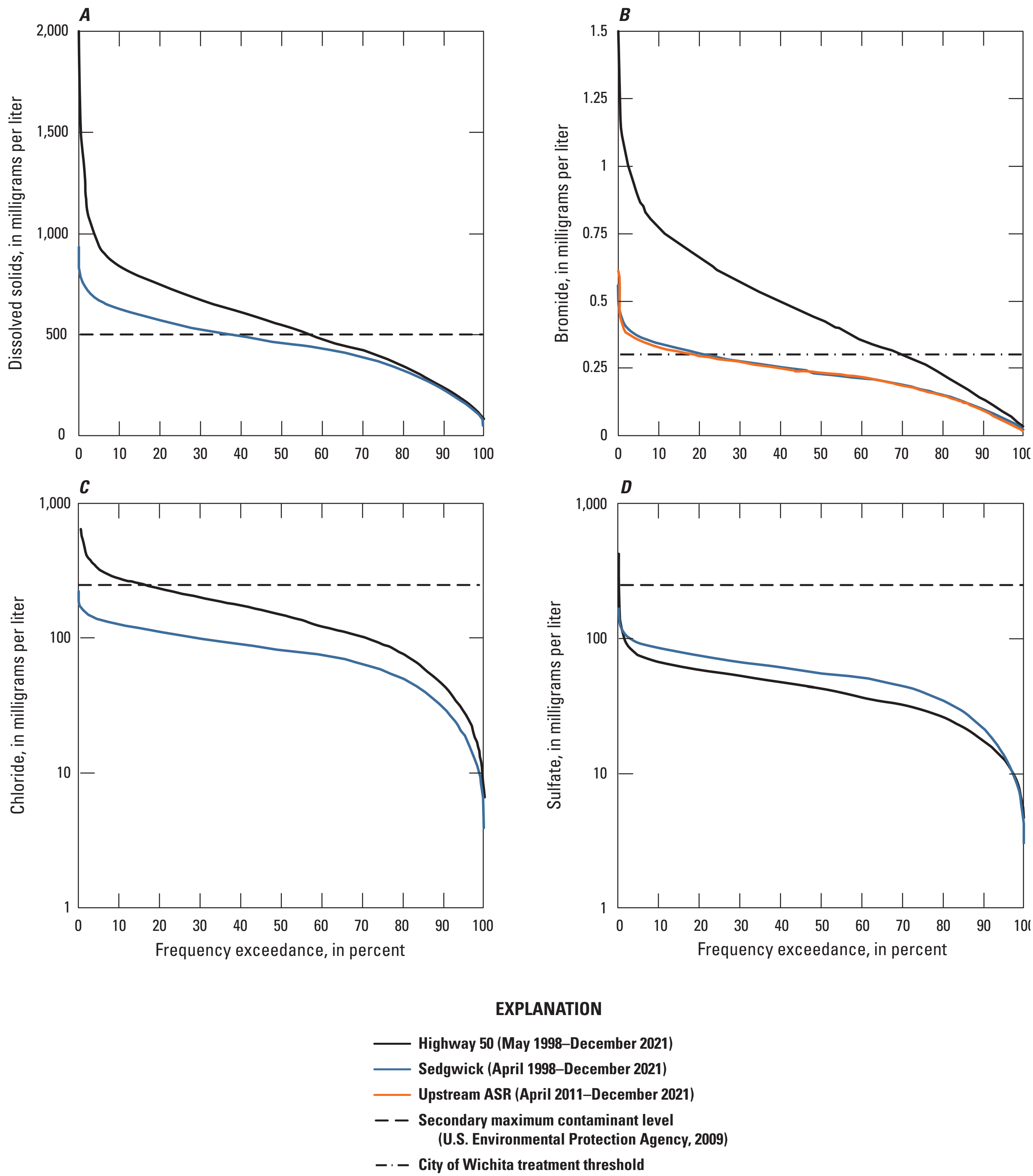


Figure 3. Duration curves for continuously (hourly) computed water-quality constituents for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672, 1998–2021); near Sedgwick, Kans. (Sedgwick; USGS station 07144100, 1998–2021); and upstream of ASR Facility near Sedgwick, Kans. (Upstream ASR; USGS station 375350097262800, 2011–2021). *A*, Dissolved solids. *B*, Bromide. *C*, Chloride. *D*, Sulfate.

the study period was 0.44, 0.23, and 0.22 mg/L at the Highway 50, Sedgwick, and Upstream ASR sites, respectively (table 6). Computed bromide concentrations were larger at the Highway 50 site and exceeded the city of Wichita treatment threshold of 0.3 mg/L about 70, 21, and 19 percent of the time at the Highway 50, Sedgwick, and Upstream ASR sites, respectively (fig. 3*B*).

Chloride is of particular concern in the *Equus* Beds aquifer because of the chloride plume upgradient from the city of Wichita's well field, which was estimated to be moving toward the well field at a rate of as much as 400 feet per year from 1990 through 2008. The plume is expected to continue moving toward the well field regardless of pumping in the area (Klager and others, 2014). Chloride concentrations significantly increased in two shallow monitoring wells near the phase II recharge basin after the onset of artificial recharge, and the increases likely were caused by treated and artificially recharged surface water (Stone and others, 2016). Large chloride concentrations (100 to 500 mg/L) are common in the western part of the study area and along the Arkansas River (fig. 1; Ziegler and others, 2010; Klager and others, 2014; Tappa and others, 2015; Stone and others, 2019). Mean Arkansas River chloride concentration was about 600 mg/L during 1988 through 1991 (Myers and others, 1996) and about 500 mg/L during 1997 through 2006 between Hutchinson and Maize, Kans. (Kansas Department of Health and Environment, 2006a). Little Arkansas River chloride sources include contamination from past oil and gas activity near McPherson, Kans., and industrial and municipal waste-water discharges (Leonard and Kleinschmidt, 1976; Kansas Department of Health and Environment, 2006a; Schmidt and others, 2007; Whittemore, 2007). Continuously computed chloride concentrations during the study period were larger at the Highway 50 site (mean: 156 mg/L) compared to the Sedgwick site (mean: 81 mg/L; table 6; fig. 3*C*). Chloride concentrations exceeded the EPA SMCL of 250 mg/L about 16 percent of the time at the Highway 50 site and did not exceed the SMCL at the Sedgwick site (table 6; fig. 3*C*).

Natural sources of sulfate in surface water and groundwater are rock weathering, oxidation of sulfide minerals, and biological processes (Hem, 1992). Anthropogenic sources of sulfate in water include atmospheric deposition from coal and petroleum combustion products (Hem, 1992) and irrigation return flows. Mean sulfate concentrations during the study period were 42 and 55 mg/L at the Highway 50 and Sedgwick sites, respectively (table 6). Computed sulfate concentrations never exceeded the EPA SMCL of 250 mg/L (table 6; fig. 3*D*).

Nutrients and Carbon

Nutrients, particularly nitrogen and phosphorus, have been identified as a primary cause of water-quality and biological degradation in the Midwest and the Nation (U.S. Environmental Protection Agency, 2000b, 2006c; Kansas Department of Health and Environment, 2004; Dubrovsky and others, 2010; Munn and others, 2018). Dissolved and particulate organic carbon are primary food sources for aquatic food webs. Organic carbon is of interest for ASR operation because of its role in THM formation during the water treatment process. THMs are disinfection byproducts that are formed when naturally existing inorganic and organic materials in water react with the disinfectants chlorine and chloramine (U.S. Environmental Protection Agency, 2005). THMs can cause liver, kidney, and central nervous system problems and are carcinogens (Pyne and others, 1996; U.S. Environmental Protection Agency, 2005). Excessive organic carbon in recharge water may lead to arsenic mobilization in groundwater owing to decreased oxygen from microbial respiration of organic carbon (U.S. Environmental Protection Agency, 2023).

Computed ammonia plus organic nitrogen concentrations were similar at the Highway 50 and Sedgwick sites during the study (table 6; fig. 4*A*). Mean computed ammonia plus organic nitrogen concentrations were 1.10 mg/L at the Highway 50 site and 1.14 mg/L at the Sedgwick site during the study period (table 6). Ammonia plus organic nitrogen concentrations exceeded the EPA level III ecoregion 27 guideline of 0.52 mg/L about 85 percent of the time at the Highway 50 site and 93 percent of the time at the Sedgwick site (fig. 4*A*). Total phosphorus concentrations were generally larger at the Sedgwick site (table 6; fig. 4*B*). Mean continuously computed total phosphorus concentrations were 0.47 mg/L at the Highway 50 site and 0.61 mg/L at the Sedgwick site (table 6). Total phosphorus concentrations during the study period exceeded the EPA level III ecoregion 27 guideline of 0.09 mg/L nearly 100 percent of the time at the Highway 50 site and 100 percent of the time at the Sedgwick site (fig. 4*B*). Continuous total organic carbon concentrations were generally larger at the Highway 50 site (table 6, fig. 4*C*). Mean total organic carbon concentrations were 9.2 mg/L at the Highway 50 site, 8.3 mg/L at the Sedgwick site, and 8.1 mg/L at the Upstream ASR site (table 6).

Sediment

Continuously computed suspended solids and suspended-sediment concentration ranges and means were similar between the Highway 50 and Sedgwick sites during the study (table 6; fig. 5). Mean suspended solids concentrations were 101 mg/L at the Highway 50 site and 94 mg/L at the Sedgwick site (table 6). Mean suspended-sediment concentrations were 134 and 129 mg/L at the Highway 50 and Sedgwick sites, respectively (table 6).

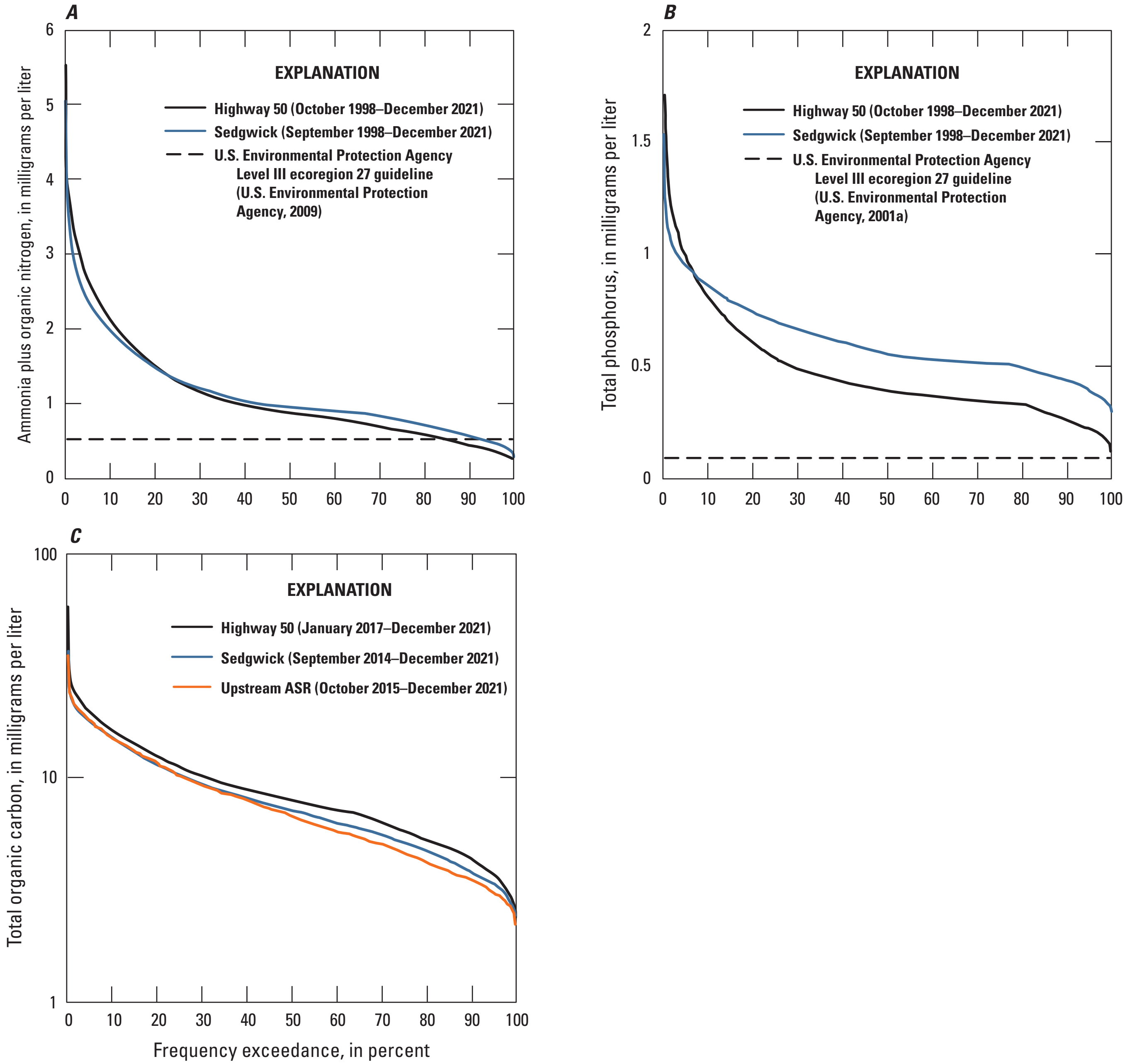


Figure 4. Duration curves for continuously (hourly) computed water-quality constituents for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672, 1998–2021); near Sedgwick, Kans. (Sedgwick; USGS station 07144100, 1998–2021); and upstream of ASR Facility near Sedgwick, Kans. (Upstream ASR; USGS station 375350097262800, 2015–21). *A*, Ammonia plus organic nitrogen. *B*, Total phosphorus. *C*, Total organic carbon.

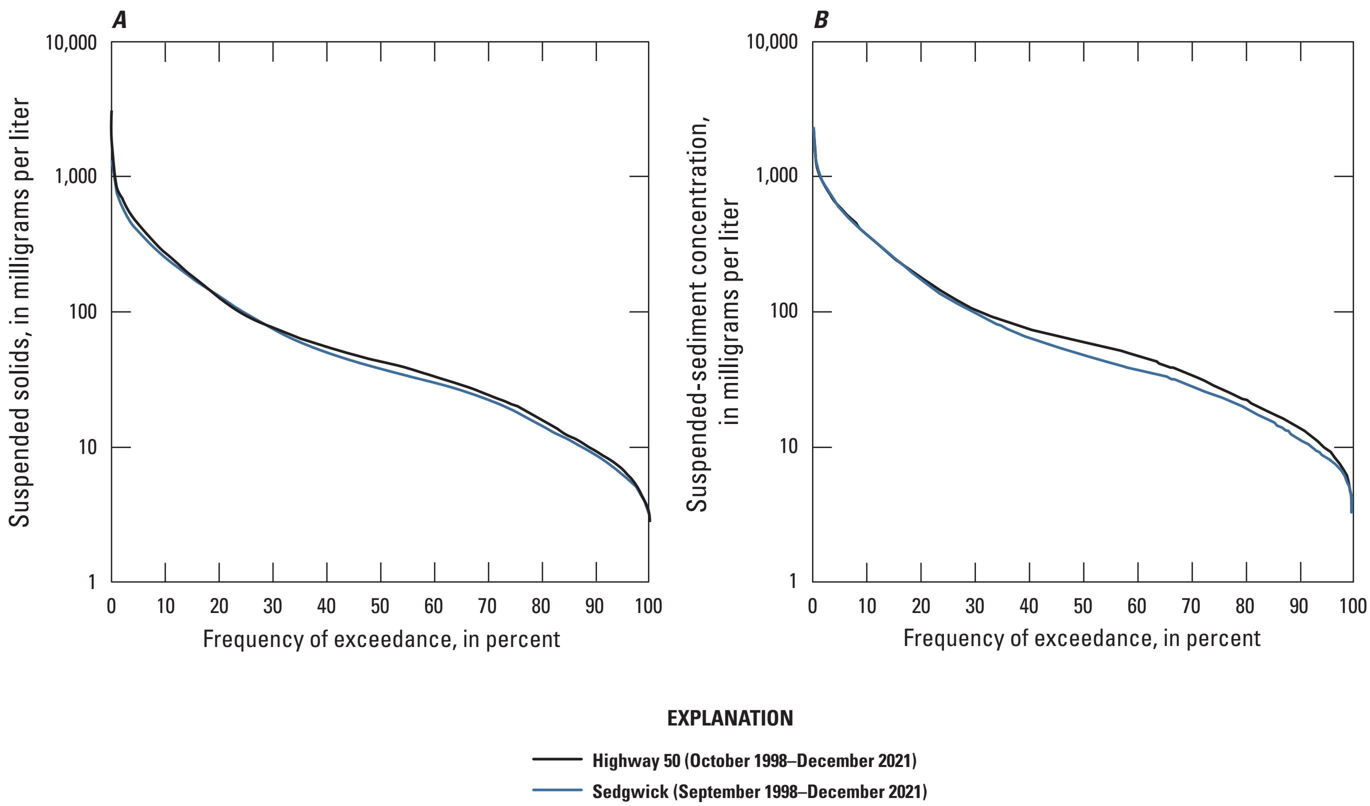


Figure 5. Duration curves for continuously (hourly) computed water-quality constituents for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1998–2021. *A*, Suspended solids, *B*, Suspended-sediment concentration.

Indicator Bacteria

Continuously computed *E. coli* and fecal coliform bacteria density means were larger at the Sedgwick site during the study period (table 6, fig. 6*A*). Median study period *E. coli* densities were 330 cfu/100 mL at the Highway 50 site and 230 cfu/100 mL at the Sedgwick site (table 6). *E. coli* densities exceeded the Kansas Department of Health and Environment primary contact criterion for Class B recreation of 262 cfu/100 mL during April 1 through October 31 (Kansas Department of Health and Environment, 2017) 84 percent of the time at the Highway 50 site and 62 percent of the time at the Sedgwick site during the months of April through October (fig. 6*B*). *E. coli* densities exceeded the Kansas Department of Health and Environment primary contact criterion for Class B recreation during November 1 through March 31 and secondary contact criterion for Class A recreation of 2,358 cfu/100 mL 5 percent of the time at the Highway 50 site and 6 percent of the time at the Sedgwick site during the months of November through March (fig. 6*C*). Median fecal coliform bacteria densities were 420 and 310 cfu/100 mL at the Highway 50 and Sedgwick sites, respectively (table 6).

Arsenic mobility is generally controlled by adsorption and desorption reactions and solid-phase precipitation and dissolution reactions (Hem, 1992; Hinkle and Polette, 1999; Smedley and Kinniburgh, 2002; McMahon and Chapelle, 2008); these processes are affected by pH, oxidation/reduction reactions, and competing anion presence, all of which could be altered because of artificial recharge activities. The EPA Federal MCL for arsenic is 10 µg/L (U.S. Environmental Protection Agency, 2009). Arsenic is a constituent of concern in the *Equus* Beds aquifer and commonly is present in concentrations that exceed the MCL (Ziegler and others, 2010; Tappa and others, 2015; Stone and others, 2019). Dissolved arsenic concentrations in two shallow monitoring wells near the ASR phase II recharge basin increased significantly after the onset of phase II ASR activity (Stone and others, 2016). Continuously computed arsenic concentrations were generally similar between the Highway 50 and Sedgwick sites during the study period (table 6; fig. 7*A*). Mean arsenic concentrations were 6.8 µg/L at the Highway 50 site and 6.4 µg/L at the Sedgwick site (table 6). Continuous arsenic concentrations exceeded the Federal MCL 15 percent of the time at the Highway 50 site and 9 percent of the time at the Sedgwick site (fig. 7*A*).

Atrazine and glyphosate are pesticides that are commonly detected at the Little Arkansas sites (Ziegler and others, 2010; Tappa and others, 2015; Stone and others, 2016, 2019; Stone and Klager, 2022). The EPA MCL is 3.0 µg/L for atrazine and 700 µg/L for glyphosate, and both compounds can cause

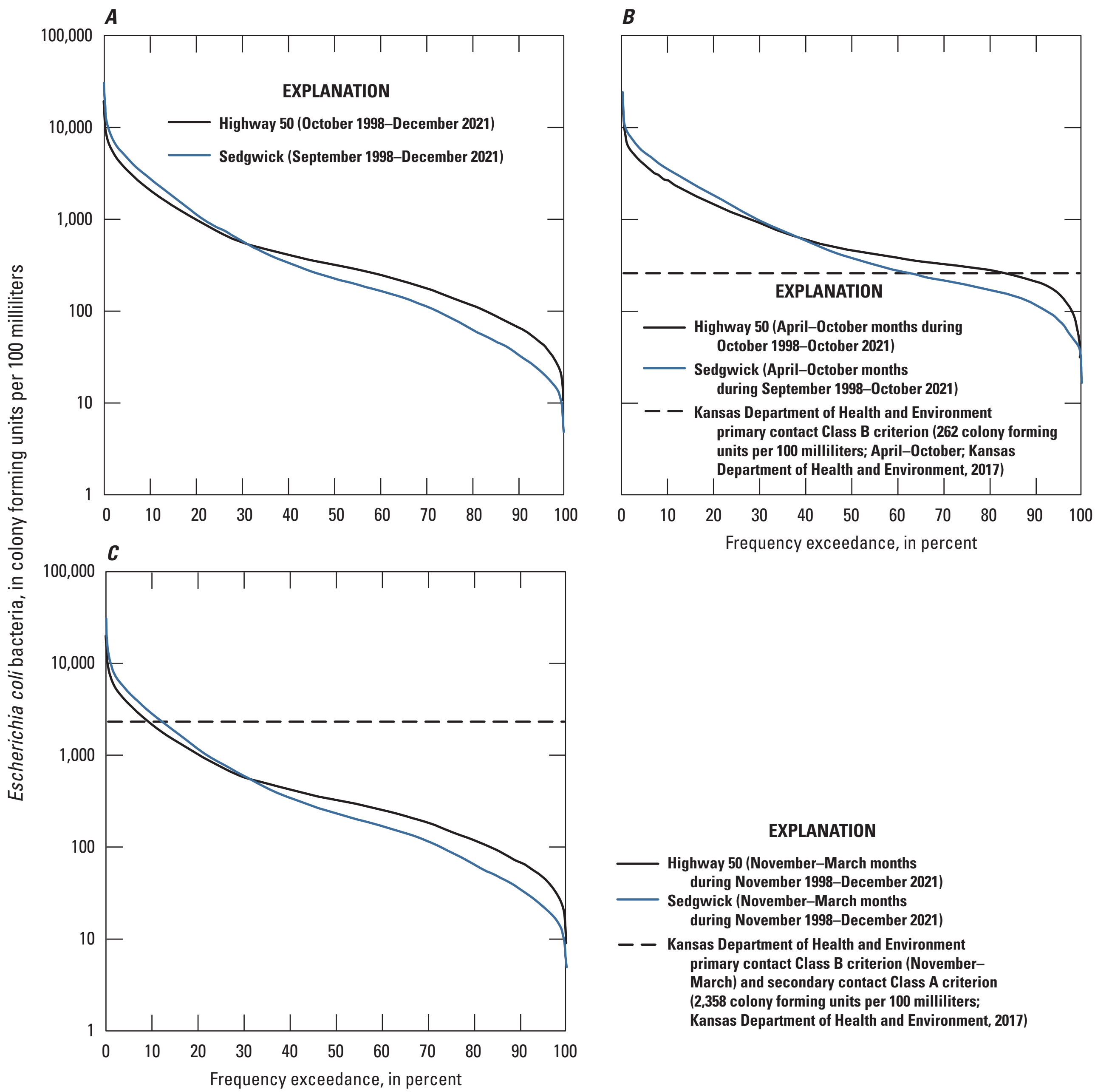


Figure 6. Duration curves for continuously (hourly) computed *Escherichia coli* bacteria densities for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1998–2021. *A*, *Escherichia coli* bacteria densities for the entire study period. *B*, *Escherichia coli* bacteria densities, April–October. *C*, *Escherichia coli* bacteria densities, November–March.

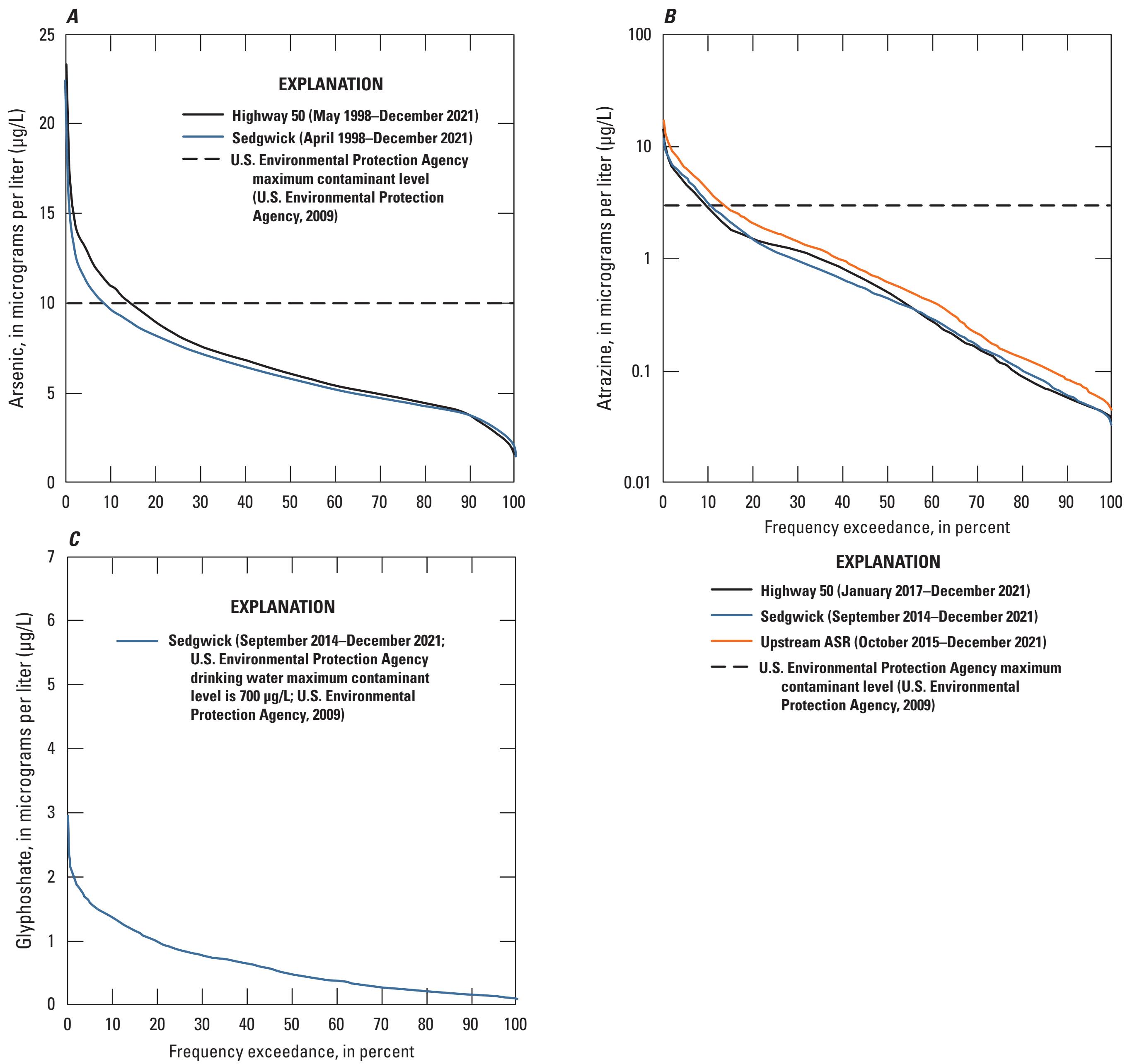


Figure 7. Duration curves for continuously (hourly) computed water-quality constituents for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672, 1998–2021); Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100, 1998–2021); and Little Arkansas River upstream of ASR Facility near Sedgwick, Kans. (Upstream ASR; USGS station 375350097262800, 2015–21). *A*, Arsenic. *B*, Atrazine. *C*, Glyphosate.

reproductive difficulties in humans (U.S. Environmental Protection Agency, 2009). Continuously computed atrazine concentrations were largest at the Upstream ASR site (table 6; fig. 7*B*). Mean computed atrazine concentrations at the Highway 50, Sedgwick, and Upstream ASR sites were 1.10 µg/L, 1.12 µg/L, and 1.49 µg/L, respectively (table 6). Atrazine concentrations exceeded the MCL 10 percent of the time at the Highway 50 and Sedgwick sites and 14 percent of the time at the Upstream ASR site during the study (fig. 7*B*). Computed glyphosate at the Sedgwick site ranged from 0.108 to 5.81 µg/L during the study period and never exceeded the MCL (table 6; fig. 7*C*).

Computed Water-Quality Constituent Loads and Yields

Annual streamflow volume was smallest in 2006 and largest in 2019 (table 7, fig. 8*A*). The smallest annual streamflow volume was 9,330 acre-feet (acre-ft) at the Highway 50 site and 22,700 acre-ft at the Sedgwick site (table 7). The largest streamflow volume was 419,000 acre-ft at the Highway 50 site and 725,000 acre-ft at the Sedgwick site (table 7). Kansas experienced several record-breaking hydrologic conditions during 2019, including the most precipitation within a month on record (Davis, 2020).

Agricultural practices in the watershed, including fertilizer application, likely contributed a substantial amount of the Little Arkansas River nitrate plus nitrite load during the study period. Nitrate plus nitrite loads were computed during 2018 through 2021 at the Highway 50 site and 2013 through 2021 at the Sedgwick site. Mean annual nitrate plus nitrite loads at the Highway 50 and Sedgwick sites were 403 and 599 tons, respectively (table 7). The total nitrate plus nitrite loads were 1,610 tons at the Highway 50 site and 5,390 tons at the Sedgwick site (table 7). The nitrate plus nitrite load was largest in 2019 at the Highway 50 (694 tons) and Sedgwick (1,470 tons) sites (fig. 8*B*, table 7). Nitrate plus nitrite yield was 2,030 pounds per square mile (lbs/mi^2) at the Highway 50 site and 2,520 lbs/mi^2 at the Sedgwick site in 2019 (table 7). Mean annual ammonia plus organic nitrogen loads at the Highway 50 and Sedgwick sites were 457 and 704 tons, respectively (table 7). Ammonia plus organic nitrogen loads for 1999 through 2021 were 10,500 tons at the Highway 50 site and 16,200 tons at the Sedgwick site (table 7). Ammonia plus organic nitrogen loads at both Little Arkansas River study sites were smallest in 2006 and largest in 2019 (fig. 8*C*, table 7). The ammonia plus organic nitrogen load in 2019 was 1,340 tons (13 percent of total load) at the Highway 50 site and 1,870 tons (12 percent of total load) at the Sedgwick site (fig. 8*C*, table 7).

Agricultural practices in the watershed also likely contributed a substantial amount of the Little Arkansas River total phosphorus load during the study period. In Kansas, about 75 to 90 percent of phosphorus movement into surface water is particulate phosphorus associated with soil erosion and transport (Devlin and others, 2000). Total phosphorus is listed as an impairment for aquatic life in the study area (Kansas Department of Health and Environment, 2022). Mean annual total phosphorus loads at the Highway 50 and Sedgwick sites were 178 and 292 tons, respectively (table 7). The total phosphorus load during 1999 through 2021 was 4,090 tons at the Highway 50 site and 6,710 tons at the Sedgwick site (table 7). Annual total phosphorus loads at the Highway 50 and Sedgwick sites were smallest in 2006 and largest in 2019 (fig. 8*D*, table 7). Total phosphorus load in 2019 was 519 tons (13 percent of total load) at the Highway 50 site and 808 tons (12 percent of total load) at the Sedgwick site (fig. 8*D*, table 7). Total phosphorus yield was 1,520 lbs/mi^2 at the Highway 50 site and 1,390 lbs/mi^2 at the Sedgwick site in 2019 (table 7). Total phosphorus yields for this study during 1999 through 2019 were 12,000 lbs/mi^2 at the Highway 50 site and 11,500 lbs/mi^2 at the Sedgwick site (table 7).

Mean annual total organic carbon loads at the Highway 50 and Sedgwick sites were 3,340 and 5,210 tons, respectively (table 7). The total organic carbon load during 2005 through 2021 was 56,800 tons at the Highway 50 site and 88,500 at the Sedgwick site (fig. 8*E*, table 7). Annual total organic carbon loads at both Little Arkansas River sites were smallest in 2006 and largest in 2019 (fig. 8*E*, table 7). Annual total organic carbon loads at the Highway 50 and Sedgwick sites were 119 and 266 tons in 2006, respectively, and 10,400 tons and 15,100 tons in 2019, respectively (fig. 8*E*, table 7). Mean annual total organic carbon yields at the Highway 50 and Sedgwick sites were 9,760 and 8,940 lbs/mi^2, respectively (table 7). Little Arkansas River total organic carbon yield was 30,300 lbs/mi^2 at the Highway 50 site and 25,900 lbs/mi^2 at the Sedgwick site in 2019 (table 7).

Kansas reservoirs are continually losing storage capacity because of sedimentation (Kansas Water Office, 2022). Suspended solids are listed as an impairment for aquatic life in the study area (Kansas Department of Health and Environment, 2022). Mean suspended-solids loads at the Highway 50 and Sedgwick sites were 77,000 and 108,000 tons, respectively (table 8). Little Arkansas River suspended-solids load during 1999 through 2021 was 1,770,000 tons at the Highway 50 site and 2,480,000 tons at the Sedgwick site (fig. 8*F*, table 8). Annual suspended-solids loads at both Little Arkansas River sites were smallest in 2006 and largest in 2019 (fig. 8*F*, table 8). Annual suspended-solids loads at the Highway 50 and Sedgwick sites were 2,550 and 3,770 tons in 2006, respectively, and 234,000 and 271,000 tons in 2019, respectively (fig. 8*F*, table 8). Mean annual suspended-solids yields at the Highway 50 and Sedgwick sites were 224,000 and 185,000 lbs/mi^2, respectively (table 8). Little Arkansas River suspended-solids yields were 683,000 lbs/mi^2 at the Highway 50 site and 466,000 lbs/mi^2 at the Sedgwick site in 2019 (table 8).

Mean annual suspended-sediment loads at the Highway 50 and Sedgwick sites were 102,000 and 177,000 tons, respectively (table 8). The total Little Arkansas River suspended-sediment load during 1999 through 2021 was 2,340,000 tons

Table 7. Computed annual streamflow volumes and water-quality constituent loads and yields for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.

[--, not applicable. All loads and yields are estimated. Water-quality constituent loads are expressed in tons and yields are expressed in pounds per square mile. Streamflow volumes are expressed in acre-feet and yields are expressed in acre-feet per acre]

Year	Load		Yield	
	Highway 50	Sedgwick	Highway 50	Sedgwick
Streamflow				
1995	264,000	504,000	0.60	0.68
1996	81,000	117,000	0.18	0.16
1997	135,000	243,000	0.31	0.33
1998	261,000	311,000	0.60	0.42
1999	251,000	369,000	0.57	0.49
2000	173,000	277,000	0.39	0.37
2001	177,000	272,000	0.40	0.36
2002	96,100	155,000	0.22	0.21
2003	150,000	238,000	0.34	0.32
2004	126,000	219,000	0.29	0.29
2005	138,000	301,000	0.32	0.40
2006	9,330	22,700	0.02	0.03
2007	280,000	349,000	0.64	0.47
2008	134,000	246,000	0.31	0.33
2009	202,000	319,000	0.46	0.43
2010	125,000	248,000	0.28	0.33
2011	12,700	29,400	0.03	0.04
2012	15,600	40,400	0.04	0.05
2013	245,000	402,000	0.56	0.54
2014	73,700	123,000	0.17	0.17
2015	118,000	242,000	0.27	0.32
2016	211,000	321,000	0.48	0.43
2017	120,000	221,000	0.27	0.30
2018	142,000	252,000	0.32	0.34
2019	419,000	725,000	0.96	0.97
2020	70,200	120,000	0.16	0.16
2021	110,000	214,000	0.25	0.29
Total load or yield	4,140,000	6,880,000	9.44	9.23
Mean annual load or yield	153,000	255,000	0.35	0.34
Chloride				
1995	--	--	--	--
1996	--	--	--	--
1997	--	--	--	--
1998	--	--	--	--
1999	17,600	16,500	51,400	28,300
2000	13,700	13,500	40,100	23,200
2001	12,200	10,800	35,600	18,500
2002	6,170	6,400	18,000	11,000

Table 7. Computed annual streamflow volumes and water-quality constituent loads and yields for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.—Continued

[--, not applicable. All loads and yields are estimated. Water-quality constituent loads are expressed in tons and yields are expressed in pounds per square mile. Streamflow volumes are expressed in acre-feet and yields are expressed in acre-feet per acre]

Year	Load		Yield	
	Highway 50	Sedgwick	Highway 50	Sedgwick
Chloride—Continued				
2003	10,100	9,680	29,600	16,600
2004	7,730	8,000	22,600	13,700
2005	9,170	10,500	26,800	18,100
2006	1,610	2,430	4,690	4,180
2007	10,500	9,870	30,800	16,900
2008	13,500	13,000	39,300	22,300
2009	14,700	14,100	42,800	24,200
2010	7,600	8,390	22,200	14,400
2011	2,290	2,710	6,680	4,650
2012	1,680	2,470	4,890	4,250
2013	6,830	7,530	20,000	12,900
2014	4,930	5,520	14,400	9,480
2015	6,160	8,570	18,000	14,700
2016	9,750	10,600	28,500	18,200
2017	8,840	10,200	25,800	17,400
2018	5,620	7,220	16,400	12,400
2019	18,400	20,000	53,600	34,300
2020	7,550	8,440	22,100	14,500
2021	6,950	8,710	20,300	15,000
Total load or yield	204,000	215,000	595,000	369,000
Mean annual load or yield	8,870	9,350	25,900	16,000
Nitrate plus nitrite as nitrogen				
1995	--	--	--	--
1996	--	--	--	--
1997	--	--	--	--
1998	--	--	--	--
1999	--	--	--	--
2000	--	--	--	--
2001	--	--	--	--
2002	--	--	--	--
2003	--	--	--	--
2004	--	--	--	--
2005	--	--	--	--
2006	--	--	--	--
2007	--	--	--	--
2008	--	--	--	--
2009	--	--	--	--
2010	--	--	--	--
2011	--	--	--	--

Table 7. Computed annual streamflow volumes and water-quality constituent loads and yields for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.—Continued

[--, not applicable. All loads and yields are estimated. Water-quality constituent loads are expressed in tons and yields are expressed in pounds per square mile. Streamflow volumes are expressed in acre-feet and yields are expressed in acre-feet per acre]

Year	Load		Yield	
	Highway 50	Sedgwick	Highway 50	Sedgwick
Nitrate plus nitrite as nitrogen—Continued				
2012	--	--	--	--
2013	--	401	--	688
2014	--	227	--	390
2015	--	489	--	840
2016	--	590	--	1,010
2017	--	652	--	1,120
2018	370	584	1,080	1,000
2019	694	1,470	2,030	2,520
2020	205	338	599	580
2021	339	641	991	1,100
Total load or yield	1,610	5,390	4,700	9,250
Mean annual load or yield	403	599	1,180	1,030
Ammonia plus organic nitrogen				
1995	--	--	--	--
1996	--	--	--	--
1997	--	--	--	--
1998	--	--	--	--
1999	865	1,180	2,520	2,020
2000	545	737	1,590	1,260
2001	696	1,050	2,030	1,810
2002	363	528	1,060	907
2003	563	768	1,640	1,320
2004	420	683	1,230	1,170
2005	413	934	1,210	1,600
2006	16	37	47	64
2007	793	1,070	2,310	1,830
2008	456	782	1,330	1,340
2009	587	1,050	1,710	1,800
2010	297	638	866	1,090
2011	35	74	103	128
2012	56	133	163	229
2013	452	847	1,320	1,450
2014	211	334	615	574
2015	407	616	1,190	1,060
2016	544	812	1,590	1,390
2017	382	591	1,120	1,010
2018	484	656	1,410	1,130

Table 7. Computed annual streamflow volumes and water-quality constituent loads and yields for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.—Continued

[--, not applicable. All loads and yields are estimated. Water-quality constituent loads are expressed in tons and yields are expressed in pounds per square mile. Streamflow volumes are expressed in acre-feet and yields are expressed in acre-feet per acre]

Year	Load		Yield	
	Highway 50	Sedgwick	Highway 50	Sedgwick
Ammonia plus organic nitrogen—Continued				
2019	1,340	1,870	3,920	3,210
2020	247	298	722	512
2021	350	549	1,020	942
Total load or yield	10,500	16,200	30,700	27,800
Mean annual load or yield	457	704	1,330	1,210
Total phosphorus				
1995	--	--	--	--
1996	--	--	--	--
1997	--	--	--	--
1998	--	--	--	--
1999	311	436	907	749
2000	188	291	548	499
2001	274	366	800	629
2002	136	191	398	328
2003	213	283	621	486
2004	173	272	504	467
2005	158	358	460	615
2006	6.0	19	17	32
2007	316	439	921	754
2008	167	318	488	546
2009	231	412	675	707
2010	132	297	384	510
2011	12	32	35	55
2012	19	49	54	85
2013	215	460	627	789
2014	90	150	262	258
2015	149	280	435	481
2016	233	352	679	604
2017	146	251	427	431
2018	183	281	533	482
2019	519	808	1,520	1,390
2020	91	128	265	220
2021	136	235	396	404
Total load or yield	4,090	6,710	12,000	11,500
Mean annual load or yield	178	292	522	500

Table 7. Computed annual streamflow volumes and water-quality constituent loads and yields for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.—Continued

[--, not applicable. All loads and yields are estimated. Water-quality constituent loads are expressed in tons and yields are expressed in pounds per square mile. Streamflow volumes are expressed in acre-feet and yields are expressed in acre-feet per acre]

Year	Load		Yield	
	Highway 50	Sedgwick	Highway 50	Sedgwick
	Total organic carbon			
1995	--	--	--	--
1996	--	--	--	--
1997	--	--	--	--
1998	--	--	--	--
1999	--	--	--	--
2000	--	--	--	--
2001	--	--	--	--
2002	--	--	--	--
2003	--	--	--	--
2004	--	--	--	--
2005	3,190	7,220	9,320	12,400
2006	119	266	348	457
2007	6,430	7,680	18,800	13,200
2008	3,370	5,830	9,830	10,000
2009	4,700	7,460	13,700	12,800
2010	2,690	5,020	7,850	8,610
2011	247	528	722	907
2012	376	856	1,100	1,470
2013	4,460	7,340	13,000	12,600
2014	1,810	2,660	5,290	4,560
2015	3,010	5,240	8,770	9,000
2016	4,730	6,510	13,800	11,200
2017	2,940	4,740	8,570	8,140
2018	3,710	5,290	10,800	9,080
2019	10,400	15,100	30,300	25,900
2020	1,870	2,410	5,470	4,130
2021	2,700	4,380	7,900	7,520
Total load or yield	56,800	88,500	166,000	152,000
Mean annual load or yield	3,340	5,210	9,760	8,940

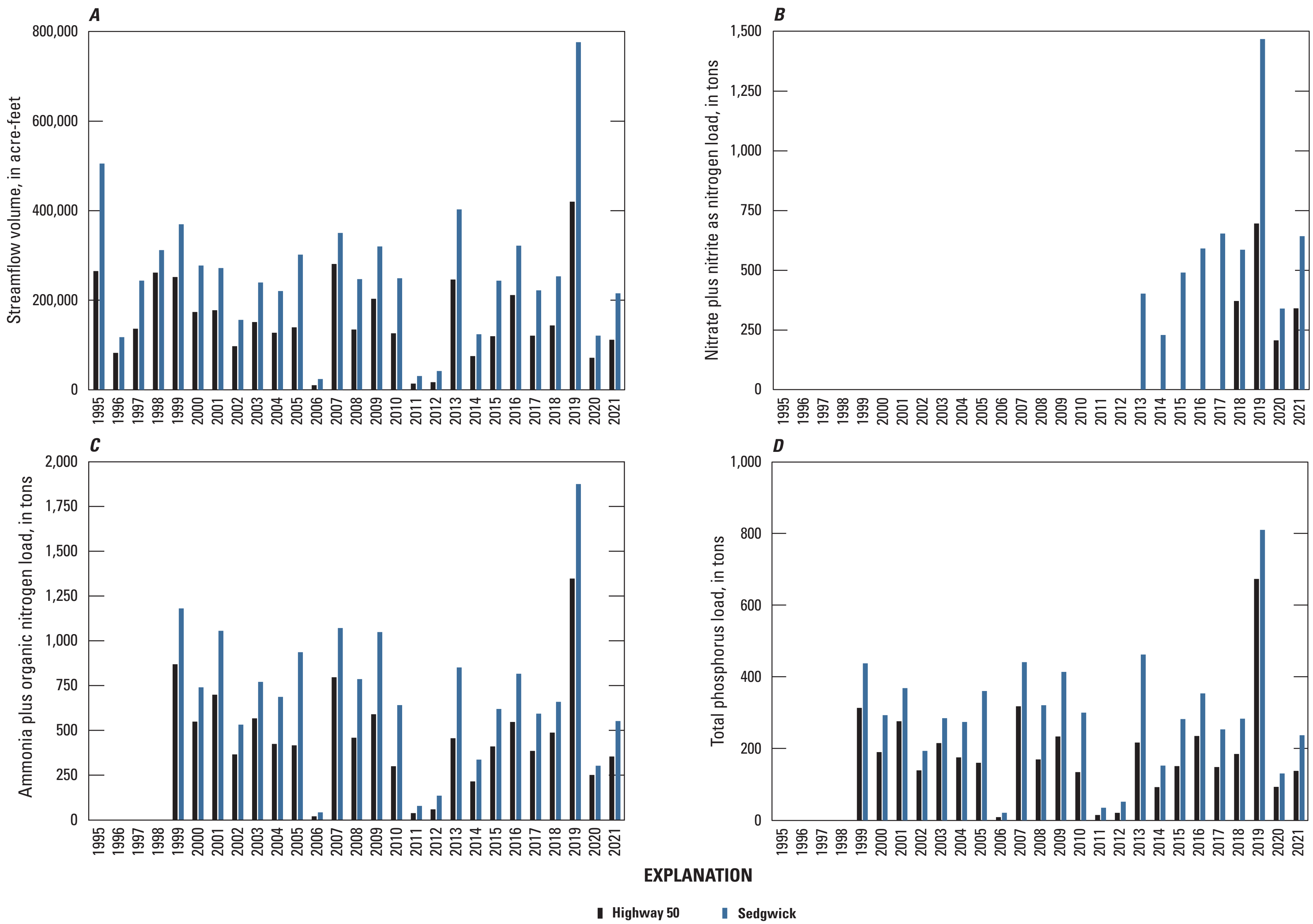


Figure 8. Yearly water-quality constituent loads for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021. *A*, Streamflow. *B*, Nitrate plus nitrite as nitrogen. *C*, Ammonia plus organic nitrogen. *D*, Total phosphorus. *E*, Total organic carbon. *F*, Suspended solids. *G*, Suspended sediment.

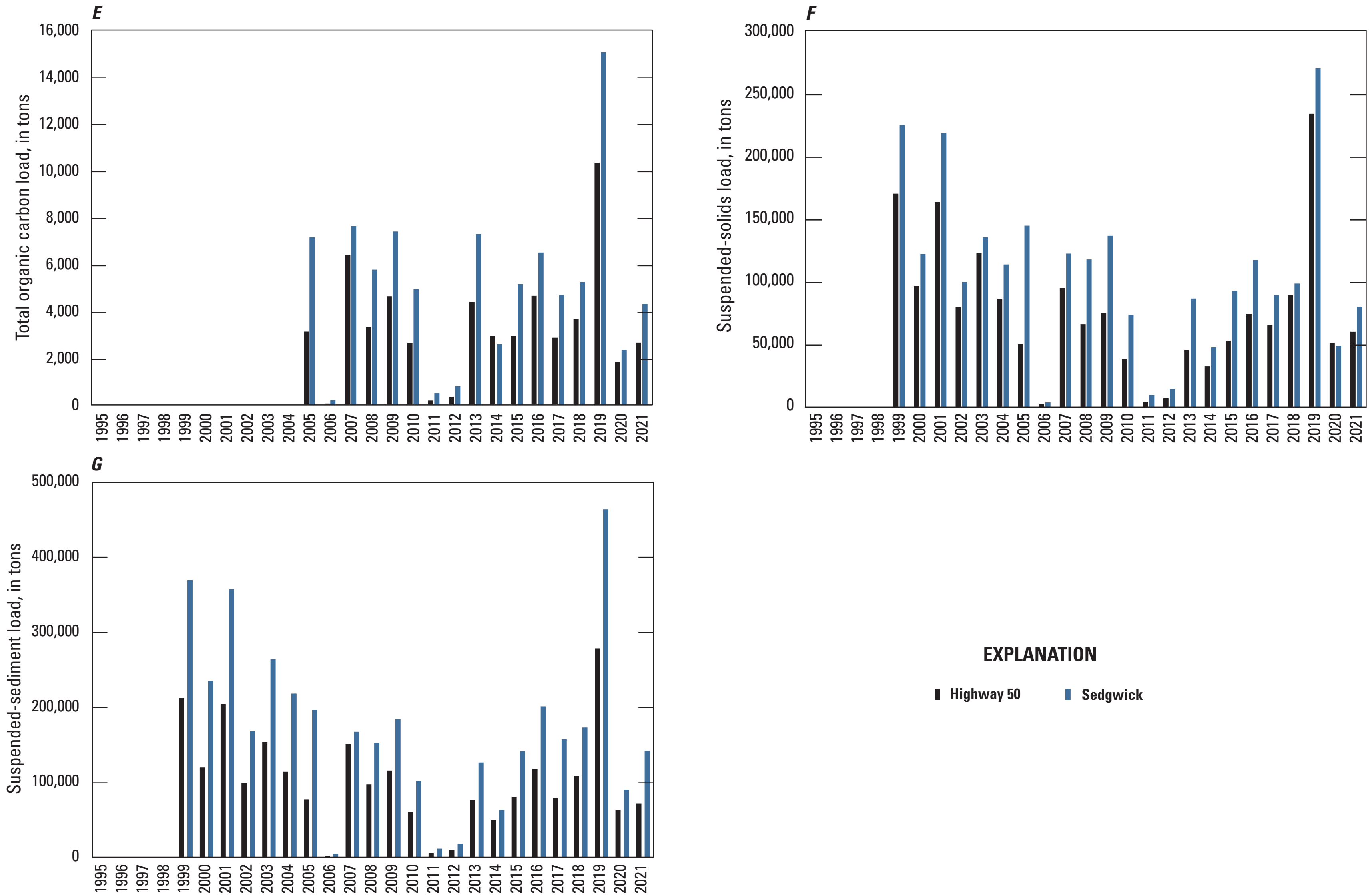


Figure 8. Yearly water-quality constituent loads for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021. *A*, Streamflow. *B*, Nitrate plus nitrite as nitrogen. *C*, Ammonia plus organic nitrogen. *D*, Total phosphorus. *E*, Total organic carbon. *F*, Suspended solids. *G*, Suspended sediment.—Continued

Table 8. Computed annual water-quality constituent loads and yields for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.

[--, not applicable. All loads and yields are estimated. Water-quality constituent loads are expressed in tons and yields are expressed in pounds per square mile, except for bacteria. Bacteria loads are expressed in trillions of colony forming units and yields are expressed in trillions of colony forming units per square mile]

Year	Load		Yield	
	Highway 50	Sedgwick	Highway 50	Sedgwick
		Suspended solids		
1995	--	--	--	--
1996	--	--	--	--
1997	--	--	--	--
1998	--	--	--	--
1999	171,000	226,200	498,000	388,000
2000	96,300	122,000	281,000	210,000
2001	164,000	219,000	478,000	376,000
2002	79,300	100,000	231,000	172,000
2003	123,000	136,000	360,000	234,000
2004	86,900	115,000	254,000	197,000
2005	50,400	145,000	147,000	249,000
2006	2,550	3,770	7,460	6,460
2007	95,400	123,000	278,000	211,000
2008	66,500	118,000	194,300	203,000
2009	75,000	137,000	219,000	236,000
2010	38,700	74,000	113,000	127,000
2011	4,180	9,740	12,200	16,700
2012	6,830	14,600	19,900	25,100
2013	45,500	86,900	133,000	149,000
2014	33,100	48,300	96,700	82,900
2015	52,700	93,100	154,000	160,000
2016	74,000	118,000	216,000	202,000
2017	65,400	89,700	191,000	154,000
2018	90,100	99,200	263,000	170,000
2019	234,000	271,000	683,000	466,000
2020	51,300	49,300	150,000	84,600
2021	60,300	80,500	176,000	138,000
Total load or yield	1,770,000	2,480,000	5,160,000	4,260,000
Mean annual load or yield	77,000	108,000	224,000	185,000
		Suspended-sediment concentration		
1995	--	--	--	--
1996	--	--	--	--
1997	--	--	--	--
1998	--	--	--	--
1999	212,000	369,000	619,000	634,000
2000	120,000	235,000	349,000	403,000
2001	204,000	357,000	595,000	613,000
2002	98,700	168,000	288,000	289,000

Table 8. Computed annual water-quality constituent loads and yields for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.—Continued

[--, not applicable. All loads and yields are estimated. Water-quality constituent loads are expressed in tons and yields are expressed in pounds per square mile, except for bacteria. Bacteria loads are expressed in trillions of colony forming units and yields are expressed in trillions of colony forming units per square mile]

Year	Load		Yield	
	Highway 50	Sedgwick	Highway 50	Sedgwick
Suspended-sediment concentration—Continued				
2003	153,000	264,000	447,000	454,000
2004	114,000	219,000	333,000	376,000
2005	76,800	197,000	224,000	337,700
2006	2,010	4,610	5,870	7,920
2007	151,000	167,000	440,000	287,000
2008	97,100	152,000	283,000	262,000
2009	116,000	183,000	339,000	314,000
2010	60,600	102,000	177,000	176,000
2011	5,740	11,800	16,800	20,300
2012	9,560	18,100	27,900	31,100
2013	77,200	126,000	226,000	217,000
2014	49,800	64,000	145,000	110,000
2015	80,000	193,000	234,000	331,000
2016	114,000	201,000	332,000	345,000
2017	78,300	157,000	229,000	270,000
2018	109,000	173,000	317,000	297,000
2019	279,000	464,000	814,000	797,000
2020	63,300	90,700	185,000	156,000
2021	71,600	142,000	209,000	244,000
Total load or yield	2,340,000	4,060,000	6,840,000	6,970,000
Mean annual load or yield	102,000	177,000	297,000	303,000
Escherichia coli bacteria				
1995	--	--	--	--
1996	--	--	--	--
1997	--	--	--	--
1998	--	--	--	--
1999	13,200	21,100	19	31
2000	7,310	11,100	11	16
2001	13,000	22,000	19	32
2002	6,200	10,000	9.0	15
2003	9,640	13,900	14	20
2004	6,840	12,800	10	19
2005	3,930	22,000	5.7	32
2006	115	272	0.2	0.4
2007	7,400	16,100	11	24
2008	5,280	18,500	7.7	27
2009	5,850	19,500	8.5	28
2010	3,000	9,370	4.4	14

Table 8. Computed annual water-quality constituent loads and yields for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.—Continued

[--, not applicable. All loads and yields are estimated. Water-quality constituent loads are expressed in tons and yields are expressed in pounds per square mile, except for bacteria. Bacteria loads are expressed in trillions of colony forming units and yields are expressed in trillions of colony forming units per square mile]

Year	Load		Yield	
	Highway 50	Sedgwick	Highway 50	Sedgwick
		Escherichia coli bacteria—Continued		
2011	330	1,520	0.5	2.2
2012	539	2,100	0.8	3.1
2013	3,450	9,690	5.0	14
2014	2,610	6,940	3.8	10
2015	4,130	19,600	6.0	29
2016	5,750	12,400	8.4	18
2017	4,040	9,810	5.9	14
2018	5,500	10,600	8.0	15
2019	14,400	28,200	21	41
2020	3,080	5,610	4.5	8.2
2021	3,720	10,400	5.4	15
Total load or yield	129,000	294,000	190	430
Mean annual load or yield	5,610	12,800	8.3	19
		Fecal coliform bacteria		
1995	--	--	--	--
1996	--	--	--	--
1997	--	--	--	--
1998	--	--	--	--
1999	23,400	25,700	34	38
2000	12,700	13,500	18	20
2001	24,100	27,100	35	40
2002	11,200	12,200	16	18
2003	17,600	17,000	26	25
2004	12,100	16,000	18	23
2005	5,850	29,700	8.5	43
2006	178	322	0.3	0.5
2007	10,900	21,100	16	31
2008	7,840	23,500	11	34
2009	8,670	25,100	13	37
2010	4,440	12,300	6.5	18
2011	489	1,930	0.7	2.8
2012	799	2,700	1.2	3.9
2013	5,080	13,000	7.4	19
2014	3,870	8,940	5.7	13
2015	6,120	17,700	8.9	26
2016	8,530	19,000	12	28
2017	5,990	15,000	8.7	22
2018	8,360	16,400	12	24

Table 8. Computed annual water-quality constituent loads and yields for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.—Continued

[--, not applicable. All loads and yields are estimated. Water-quality constituent loads are expressed in tons and yields are expressed in pounds per square mile, except for bacteria. Bacteria loads are expressed in trillions of colony forming units and yields are expressed in trillions of colony forming units per square mile]

Year	Load		Yield	
	Highway 50	Sedgwick	Highway 50	Sedgwick
Fecal coliform bacteria—Continued				
2019	21,400	43,600	31	64
2020	4,910	8,850	7.2	13
2021	5,480	13,100	8.0	19
Total load or yield	210,000	384,000	310	560
Mean annual load or yield	9,130	16,700	14	24
Atrazine				
1995	--	--	--	--
1996	--	--	--	--
1997	--	--	--	--
1998	--	--	--	--
1999	--	--	--	--
2000	--	--	--	--
2001	--	--	--	--
2002	--	--	--	--
2003	--	--	--	--
2004	--	--	--	--
2005	--	--	--	--
2006	--	--	--	--
2007	--	--	--	--
2008	--	--	--	--
2009	--	--	--	--
2010	--	--	--	--
2011	--	--	--	--
2012	--	--	--	--
2013	--	--	--	--
2014	--	--	--	--
2015	--	1.3	--	3.8
2016	--	1.4	--	4.0
2017	--	1.6	--	4.8
2018	0.19	0.37	0.56	1.1
2019	2.9	4.9	8.5	14
2020	0.42	0.68	1.2	2.0
2021	0.63	1.10	1.8	3.2
Total load or yield	4.2	11	12	33
Mean annual load or yield	1.0	1.6	3.0	4.8

at the Highway 50 site and 4,060,000 tons at the Sedgwick site (fig. 8*G*, table 8). Annual suspended-sediment loads at both Little Arkansas River sites were smallest in 2006 and largest in 2019 (fig. 8*G*, table 8). Annual suspended-sediment loads at the Highway 50 and Sedgwick sites were 2,010 and 4,610 tons in 2006, respectively, and 279,000 and 464,000 tons in 2019, respectively (fig. 8*G*, table 8). Mean annual suspended-sediment yields at the Highway 50 and Sedgwick sites were 297,000 and 303,000 lbs/mi^2, respectively (table 8). Little Arkansas River suspended-sediment yield was 814,000 lbs/mi^2 at the Highway 50 site and 797,000 lbs/mi^2 at the Sedgwick site in 2019 (table 8).

About one-quarter to one-half of the study period loads, including nutrients and sediment, were transported during 1 percent of the time during the study (with the exception of chloride loads, which were about one-tenth). About 38 to 40 percent of the total Little Arkansas River suspended-sediment load at the Highway 50 and Sedgwick sites during 1999 through 2021 was transported in the top 1 percent of loading days during high-flow events. Similar studies of the nearby North Fork Ninnescah River have also demonstrated that high-flow events are the main carriers for sediment (Stone and others, 2015; Kramer and others, 2021). Because streamflows are highly sensitive to climatic variation and change (Carlisle and others, 2019) and an increase of extreme precipitation events in the Great Plains is expected (Shafer and others, 2014; Conant and others, 2018; Kloesel and others, 2018), similar disproportionately large pollutant loading events may increase in the future.

Weighted Regressions on Time, Discharge, and Season Models

Little Arkansas River water-quality data collected during 1995 (Sedgwick site) or 1996 (Highway 50 site) through 2021 were analyzed for temporal trends and included primary ions, nutrient and carbon species, sediment, indicator bacteria, and trace elements. Changes in annual flow-normalized water-quality concentrations and fluxes were computed for the entire study period (1995 or 1996 through 2021), the period before ASR (phase I) operation onset (1995 or 1996 through 2006; hereafter referred to as “before ASR”), and the period after ASR (phase I) onset (2007 through 2021; hereafter referred to as “after ASR”). The delineation of trend periods does not indicate that ASR activities were the causes of water-quality trends and were selected solely as a convenient way of organizing trend reporting. WRTDS annual mean water-quality constituent concentrations and fluxes are presented in appendixes 7 and 8. WRTDS model evaluation and WBT output for each water-quality constituent are provided in appendixes 9 (Highway 50 site) and 10 (Sedgwick site). Estimated mean annual concentrations with flow-normalized trendlines and 90-percent confidence intervals are presented in figures 9 through 13; larger confidence intervals at the beginning and end of the study period are because of larger streamflow and time uncertainty (Hirsch and others, 2015). Flow-normalized values indicate the overall water-quality constituent trend for the time period irrespective of annual streamflow variability and water-quality trend results incorporate the trend direction uncertainty among years; large flow-normalized water-quality constituent concentration and flux percentage changes may not be reflected in the trend results. WRTDS-estimated yearly water-quality constituent loads are provided in appendix 11.

Primary Ion Trends

Little Arkansas River flow-normalized primary ion concentrations during 1995 through 2021 (fig. 9*A–K*) generally had downward trends based on categories defined by Hirsch and others (2015; table 2); percent decreases in flow-normalized concentrations were generally larger at the Highway 50 site (table 8). Dissolved solids, potassium, sodium, chloride, and fluoride flow-normalized concentrations (fig. 9*B*, *E*, *F*, *H, I*) were very likely or highly likely to have downward trends at both sites (table 9). Dissolved solids mean annual concentrations decreased by 30 percent (Highway 50 site) and 15 percent (Sedgwick site); sodium concentrations decreased by 49 percent (Highway 50 site) and 32 percent (Sedgwick site); and chloride concentrations decreased by 54 percent (Highway 50 site) and 43 percent (Sedgwick site) during the study period (table 9). Hardness, calcium, and magnesium flow-normalized concentrations (fig. 9*A*, *C*, *D*) had downward trends at the Highway 50 site and no trend at the Sedgwick site for the entire study period (table 9). Bromide and silica flow-normalized concentrations (fig. 9*G*, *J*) exhibited no trend at the Highway 50 site and downward trends at the Sedgwick site from 1995 through 2021 (table 9). Bromide concentrations decreased by 68 percent at the Highway 50 site and 45 percent at the Sedgwick site during the study period (table 9). Flow-normalized sulfate concentrations (fig. 9*K*) during the entire study period exhibited a downward trend (and a decrease of 10 percent) at the Highway 50 site and an upward trend (and an increase of 7 percent) at the Sedgwick site (table 9).

Hardness, calcium, magnesium, silica, and sulfate flow-normalized concentrations had before-ASR downward trends and after-ASR upward trends at both study sites, whereas potassium, sodium, chloride, and fluoride flow-normalized concentrations had downward trends at each site for both periods (table 9). Dissolved solids flow-normalized concentrations had a before-ASR downward trend and no trend after ASR at the Highway 50 site. At the Sedgwick site, dissolved solids flow-normalized concentrations had a before-ASR downward trend and an after-ASR upward trend (table 9). Bromide flow-normalized concentrations had no trend before ASR at the Highway 50 site and after ASR at the Sedgwick site and a downward trend after ASR at the Highway 50 site and before ASR at the Sedgwick site (table 9).

Little Arkansas River flow-normalized primary ion fluxes during 1995 through 2021 generally had downward trends (table 9). Dissolved solids, potassium, sodium, bromide,

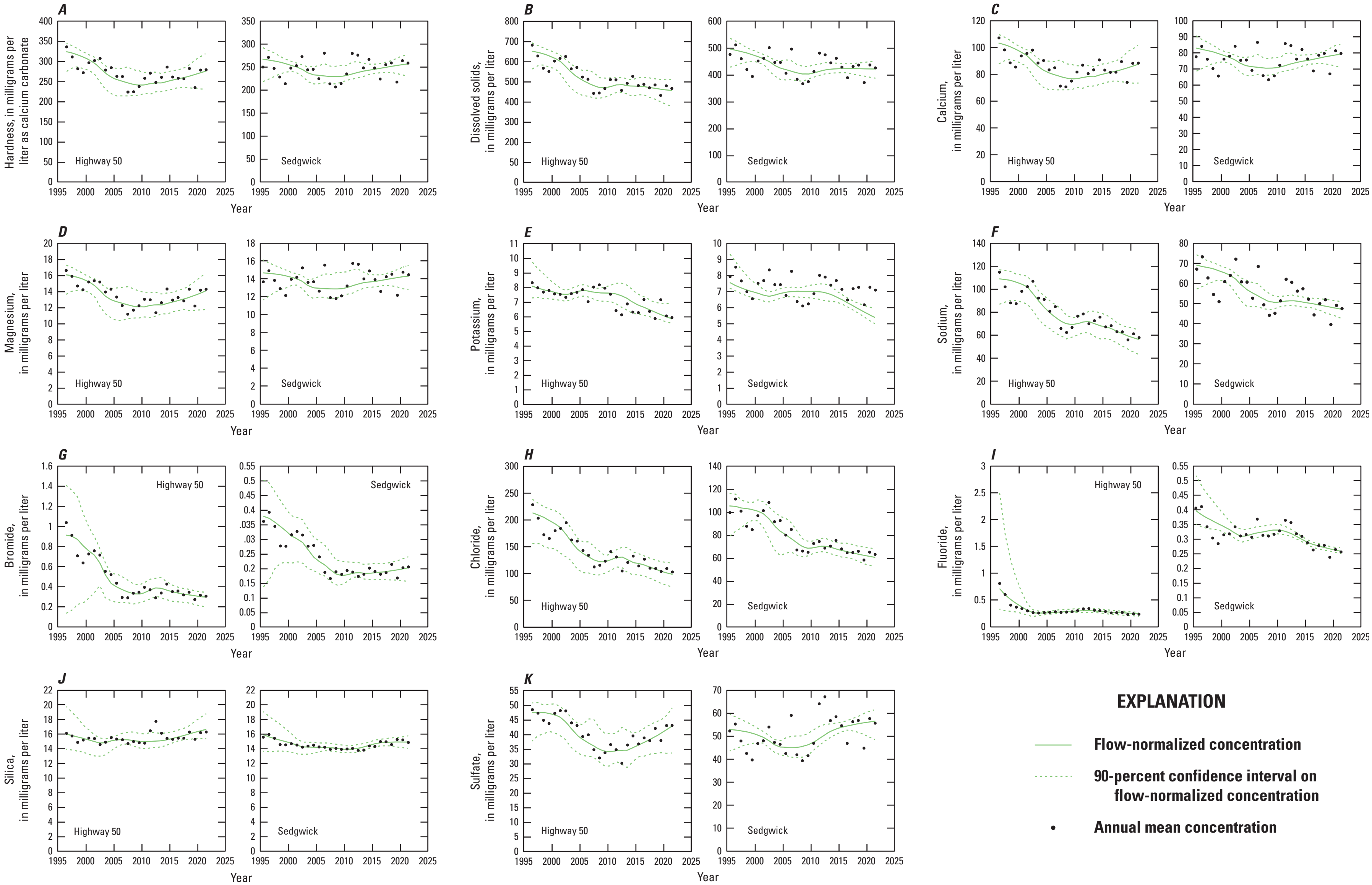


Figure 9. Weighted Regressions on Time, Discharge, and Season annual mean concentrations with flow-normalized concentration trend and 90-percent confidence interval for constituents at the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021. *A*, Hardness. *B*, Dissolved solids. *C*, Calcium. *D*, Magnesium. *E*, Potassium. *F*, Sodium. *G*, Bromide. *H*, Chloride. *I*, Fluoride. *J*, Silica. *K*, Sulfate.

Table 9. Weighted Regressions on Time, Discharge, and Season bootstrap test and trend change summary results for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.

[$CaCO_3$, calcium carbonate; USGS, U.S. Geological Survey; mg/L, milligram per liter; --, not applicable; tons/yr, tons per year]

Site	Time period	Flow-normalized concentration					Flow-normalized flux				
		Trend direction	Trend probability	Likelihood descriptor	Concentration change	Percent concentration change	Trend direction	Trend probability	Likelihood descriptor	Flux change	Percent flux change
Hardness as $CaCO_3$ (USGS parameter code 00900)											
Highway 50	1996–2021	Downward	0.876	Downward trend is likely	−51 mg/L	−16	--	0.668	Downward trend is about as likely as not	−1,078 tons/yr	−5
	1996–2006	Downward	0.985	Downward trend is highly likely	−75.3 mg/L	−23	Downward	0.876	Downward trend is likely	−3,611 tons/yr	−16
	2007–21	Upward	0.777	Upward trend is likely	28.3 mg/L	12	Upward	0.738	Upward trend is likely	2,476 tons/yr	13
Sedgwick	1995–2021	--	0.569	Downward trend is about as likely as not	−10.6 mg/L	−4	Upward	0.777	Upward trend is likely	1,799 tons/yr	5
	1995–2006	Downward	0.926	Downward trend is very likely	−37.4 mg/L	−14	Downward	0.837	Downward trend is likely	−4,499 tons/yr	−12
	2007–21	Upward	0.946	Upward trend is very likely	27.9 mg/L	12	Upward	0.975	Upward trend is highly likely	6,143 tons/yr	19
Dissolved solids (USGS parameter code 70300)											
Highway 50	1996–2021	Downward	0.995	Downward trend is highly likely	−198 mg/L	−30	Downward	0.728	Downward trend is likely	−6,259 tons/yr	−12
	1996–2006	Downward	0.895	Downward trend is highly likely	−161 mg/L	−25	Downward	0.866	Downward trend is likely	−7,457 tons/yr	−15
	2007–21	--	0.639	Downward trend is about as likely as not	−23.7 mg/L	−5	--	0.569	Upward trend is about as likely as not	1,108 tons/yr	3
Sedgwick	1995–2021	Downward	0.946	Downward trend is very likely	−75 mg/L	−15	Downward	0.767	Downward trend is likely	−3,875 tons/yr	−5
	1995–2006	Downward	0.955	Downward trend is highly likely	−84.1 mg/L	−17	Downward	0.936	Downward trend is very likely	−10,083 tons/yr	−13
	2007–21	Upward	0.748	Upward trend is likely	15.3 mg/L	4	Upward	0.936	Upward trend is very likely	6,591 tons/yr	10

Table 9. Weighted Regressions on Time, Discharge, and Season bootstrap test and trend change summary results for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.—Continued

[$CaCO_3$, calcium carbonate; USGS, U.S. Geological Survey; mg/L, milligram per liter; --, not applicable; tons/yr, tons per year]

Site	Time period	Flow-normalized concentration					Flow-normalized flux				
		Trend direction	Trend probability	Likelihood descriptor	Concentration change	Percent concentration change	Trend direction	Trend probability	Likelihood descriptor	Flux change	Percent flux change
Calcium (USGS parameter code 00915)											
Highway 50	1996–2021	Downward	0.886	Downward trend is likely	−16.7 mg/L	−16	--	0.609	Downward trend is about as likely as not	−277 tons/yr	−4
	1996–2006	Downward	0.985	Downward trend is highly likely	−24.2 mg/L	−23	Downward	0.876	Downward trend is likely	−1,139 tons/yr	−16
	2007–21	Upward	0.777	Upward trend is likely	8.74 mg/L	11	Upward	0.757	Upward trend is likely	845 tons/yr	14
Sedgwick	1995–2021	--	0.609	Downward trend is about as likely as not	−3.79 mg/L	−5	Upward	0.797	Upward trend is likely	640 tons/yr	6
	1995–2006	Downward	0.946	Downward trend is very likely	−12.1 mg/L	−15	Downward	0.847	Downward trend is likely	−1,403 tons/yr	−13
	2007–21	Upward	0.946	Upward trend is very likely	8.71 mg/L	12	Upward	0.975	Upward trend is very likely	2,005 tons/yr	20
Magnesium (USGS parameter code 00925)											
Highway 50	1996–2021	Downward	0.797	Downward trend is likely	−2.18 mg/L	−13	Downward	0.688	Downward trend is likely	−80 tons/yr	−6
	1996–2006	Downward	0.985	Downward trend is highly likely	−3.64 mg/L	−23	Downward	0.827	Downward trend is likely	−182 tons/yr	−14
	2007–21	Upward	0.787	Upward trend is likely	1.65 mg/L	13	--	0.639	Upward trend is about as likely as not	9.9 tons/yr	9
Sedgwick	1995–2021	--	0.540	Downward trend is about as likely as not	−0.351 mg/L	−2	Upward	0.678	Upward trend is likely	56 tons/yr	3
	1995–2006	Downward	0.866	Downward trend is likely	−1.82 mg/L	−12	Downward	0.807	Downward trend is likely	−239 tons/yr	−11
	2007–21	Upward	0.896	Upward trend is likely	1.49 mg/L	12	Upward	0.946	Upward trend is very likely	1,043 tons/yr	15

Table 9. Weighted Regressions on Time, Discharge, and Season bootstrap test and trend change summary results for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.—Continued

[$CaCO_3$, calcium carbonate; USGS, U.S. Geological Survey; mg/L, milligram per liter; --, not applicable; tons/yr, tons per year]

Site	Time period	Flow-normalized concentration					Flow-normalized flux				
		Trend direction	Trend probability	Likelihood descriptor	Concentration change	Percent concentration change	Trend direction	Trend probability	Likelihood descriptor	Flux change	Percent flux change
Potassium (USGS parameter code 00935)											
Highway 50	1996–2021	Downward	0.995	Downward trend is highly likely	−2.2 mg/L	−27	Downward	0.708	Downward trend is likely	−71 tons/yr	−4
	1996–2006	Downward	0.748	Downward trend is likely	−0.314 mg/L	−4	--	0.668	Upward trend is about as likely as not	68 tons/yr	4
	2007–21	Downward	0.985	Downward trend is highly likely	−1.8 mg/L	−23	Downward	0.896	Downward trend is likely	−153 tons/yr	−8
Sedgwick	1995–2021	Downward	0.995	Downward trend is highly likely	−2.11 mg/L	−28	Downward	0.975	Downward trend is highly likely	−352 tons/yr	−12
	1995–2006	Downward	0.936	Downward trend is very likely	−0.522 mg/L	−7	Downward	0.906	Downward trend is very likely	−140 tons/yr	−5
	2007–21	Downward	0.995	Downward trend is highly likely	−1.6 mg/L	−23	Downward	0.906	Downward trend is very likely	−220 tons/yr	−8
Sodium (USGS parameter code 00930)											
Highway 50	1996–2021	Downward	0.995	Downward trend is highly likely	−53.6 mg/L	−49	Downward	0.936	Downward trend is very likely	−1,771 tons/yr	−28
	1996–2006	Downward	0.985	Downward trend is highly likely	−34.3 mg/L	−31	Downward	0.946	Downward trend is very likely	−1,559 tons/yr	−25
	2007–21	Downward	0.946	Downward trend is very likely	−16 mg/L	−22	--	0.599	Downward trend is about as likely as not	−187 tons/yr	−4
Sedgwick	1995–2021	Downward	0.995	Downward trend is highly likely	−22.1 mg/L	−32	Downward	0.896	Downward trend is likely	−1,872 tons/yr	−23
	1995–2006	Downward	0.965	Downward trend is highly likely	−15.5 mg/L	−22	Downward	0.886	Downward trend is likely	−1,709 tons/yr	−21
	2007–21	Downward	0.886	Downward trend is likely	−4.93 mg/L	−9	--	0.530	Downward trend is about as likely as not	−46 tons/yr	−1

Table 9. Weighted Regressions on Time, Discharge, and Season bootstrap test and trend change summary results for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.—Continued

[$CaCO_3$, calcium carbonate; USGS, U.S. Geological Survey; mg/L, milligram per liter; --, not applicable; tons/yr, tons per year]

Site	Time period	Flow-normalized concentration					Flow-normalized flux				
		Trend direction	Trend probability	Likelihood descriptor	Concentration change	Percent concentration change	Trend direction	Trend probability	Likelihood descriptor	Flux change	Percent flux change
Bromide (USGS parameter code 71870)											
Highway 50	1996–2021	--	0.639	Downward trend is about as likely as not	−0.628 mg/L	−68	Downward	0.718	Downward trend is likely	−25 tons/yr	−50
	1996–2006	--	0.629	Downward trend is about as likely as not	−0.558 mg/L	−60	Downward	0.698	Downward trend is likely	−23 tons/yr	−46
	2007–21	Downward	0.698	Downward trend is likely	−0.0472 mg/L	−14	--	0.649	Downward trend is about as likely as not	−0.83 tons/yr	−3
Sedgwick	1995–2021	Downward	0.767	Downward trend is likely	−0.17 mg/L	−45	Downward	0.886	Downward trend is likely	−26 tons/yr	−51
	1995–2006	Downward	0.757	Downward trend is likely	−0.161 mg/L	−43	Downward	0.787	Downward trend is likely	−20 tons/yr	−35
	2007–21	--	0.569	Upward trend is about as likely as not	0.00731 mg/L	4	Downward	0.896	Downward trend is likely	−6.8 tons/yr	−20
Chloride (USGS parameter code 00940)											
Highway 50	1996–2021	Downward	0.995	Downward trend is highly likely	−116 mg/L	−54	Downward	0.886	Downward trend is likely	−3,340 tons/yr	−27
	1996–2006	Downward	0.965	Downward trend is highly likely	−84.1 mg/L	−39	Downward	0.975	Downward trend is highly likely	−4,145 tons/yr	−33
	2007–21	Downward	0.866	Downward trend is likely	−26.7 mg/L	−21	--	0.649	Upward trend is about as likely as not	857 tons/yr	10
Sedgwick	1995–2021	Downward	0.975	Downward trend is highly likely	−45.1 mg/L	−43	Downward	0.896	Downward trend is likely	−3,675 tons/yr	−27
	1995–2006	Downward	0.906	Downward trend is very likely	−28.8 mg/L	−27	Downward	0.886	Downward trend is likely	−3,445 tons/yr	−26
	2007–21	Downward	0.965	Downward trend is highly likely	−12.5 mg/L	−17	--	0.52	Upward trend is about as likely as not	106 tons/yr	1

Table 9. Weighted Regressions on Time, Discharge, and Season bootstrap test and trend change summary results for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.—Continued

[$CaCO_3$, calcium carbonate; USGS, U.S. Geological Survey; mg/L, milligram per liter; --, not applicable; tons/yr, tons per year]

Site	Time period	Flow-normalized concentration					Flow-normalized flux				
		Trend direction	Trend probability	Likelihood descriptor	Concentration change	Percent concentration change	Trend direction	Trend probability	Likelihood descriptor	Flux change	Percent flux change
Fluoride (USGS parameter code 00950)											
Highway 50	1996–2021	Downward	0.995	Downward trend is highly likely	−0.449 mg/L	−65	Downward	0.847	Downward trend is likely	−11 tons/yr	−22
	1996–2006	Downward	0.995	Downward trend is highly likely	−0.424 mg/L	−61	Downward	0.827	Downward trend is likely	−7.9 tons/yr	−16
	2007–21	Downward	0.946	Downward trend is very likely	−0.0324 mg/L	−12	Downward	0.847	Downward trend is likely	−3.7 tons/yr	−9
Sedgwick	1995–2021	Downward	0.995	Downward trend is highly likely	−0.138 mg/L	−35	Downward	0.886	Downward trend is likely	−8.8 tons/yr	−12
	1995–2006	Downward	0.936	Downward trend is very likely	−0.074 mg/L	−19	Upward	0.965	Upward trend is highly likely	9.4 tons/yr	13
	2007–21	Downward	0.995	Downward trend is highly likely	−0.0671 mg/L	−21	Downward	0.995	Downward trend is highly likely	−20 tons/yr	−24
Silica (USGS parameter code 00955)											
Highway 50	1996–2021	--	0.649	Upward trend is about as likely as not	0.546 mg/L	3	--	0.579	Upward trend is about as likely as not	148 tons/yr	6
	1996–2006	Downward	0.718	Downward trend is likely	−0.829 mg/L	−5	--	0.470	Upward trend is about as likely as not	127 tons/yr	5
	2007–21	Upward	0.876	Upward trend is likely	1.4 mg/L	9	--	0.450	Downward trend is about as likely as not	−25 tons/yr	−1
Sedgwick	1995–2021	Downward	0.817	Downward trend is likely	−0.932 mg/L	−6	--	0.480	Downward trend is about as likely as not	−61 tons/yr	−1
	1995–2006	Downward	0.906	Downward trend is very likely	−1.7 mg/L	−11	--	0.540	Downward trend is about as likely as not	−129 tons/yr	−3
	2007–21	Upward	0.866	Upward trend is likely	0.802 mg/L	6	--	0.589	Downward trend is about as likely as not	−400 tons/yr	−1

Table 9. Weighted Regressions on Time, Discharge, and Season bootstrap test and trend change summary results for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.—Continued

[$CaCO_3$, calcium carbonate; USGS, U.S. Geological Survey; mg/L, milligram per liter; --, not applicable; tons/yr, tons per year]

Site	Time period	Flow-normalized concentration					Flow-normalized flux				
		Trend direction	Trend probability	Likelihood descriptor	Concentration change	Percent concentration change	Trend direction	Trend probability	Likelihood descriptor	Flux change	Percent flux change
Sulfate (USGS parameter code 00945)											
Highway 50	1996–2021	Downward	0.718	Downward trend is likely	−4.93 mg/L	−10	--	0.589	Downward trend is about as likely as not	−305 tons/yr	−8
	1996–2006	Downward	0.946	Downward trend is very likely	−10.8 mg/L	−23	Downward	0.847	Downward trend is likely	−784 tons/yr	−21
	2007–21	Upward	0.827	Upward trend is likely	7.01 mg/L	19	Upward	0.807	Upward trend is likely	583 tons/yr	20
Sedgwick	1995–2021	Upward	0.847	Upward trend is likely	3.8 mg/L	7	Upward	0.767	Upward trend is likely	587 tons/yr	9
	1995–2006	Downward	0.856	Downward trend is likely	−8.17 mg/L	−15	Downward	0.698	Downward trend is likely	−709 tons/yr	−11
	2007–21	Upward	0.985	Upward trend is highly likely	11.8 mg/L	26	Upward	0.946	Upward trend is very likely	1,355 tons/yr	24

chloride, and fluoride flow-normalized study period fluxes had downward trends at both study sites (table 9). Hardness, calcium, and sulfate flow-normalized fluxes had no trend at the Highway 50 site and an upward trend at the Sedgwick site for the study period (table 9). Magnesium flow-normalized flux had a study period downward trend at the Highway 50 site and an upward trend for the Sedgwick site and silica flow-normalized flux for the study period had no trend at either site (table 9).

Nutrient and Carbon Species Trends

Little Arkansas River flow-normalized nutrient and carbon species concentrations during 1995 through 2021 (fig. 10*A–K*) generally had downward trends, and concentration percent decreases were generally larger at the Sedgwick site (table 10). Flow-normalized ammonia plus organic nitrogen concentrations during 2000 through 2021 (fig. 10*B*) had downward trends that were highly likely at both sites; ammonia plus organic nitrogen concentrations decreased by 18 percent at the Highway 50 site and 23 percent at the Sedgwick site (table 10). Nitrate plus nitrite flow-normalized concentrations during the study period (fig. 10*C*) had an upward trend at the Highway 50 site and a downward trend at the Sedgwick site; both trends were highly likely (table 10). Flow-normalized total nitrogen concentrations during 2000 through 2021 (fig. 10*D*) had no trend at the Highway 50 site and a downward trend at the Sedgwick site; total nitrogen concentrations decreased by 1 percent at the Highway 50 site and 38 percent at the Sedgwick site (table 10). Ammonia, nitrate, and nitrite flow-normalized concentrations during the study period (fig. 10*A*, *E*, *F*) had downward trends at the Sedgwick site; of these, ammonia had a downward trend that was highly likely (table 10). Ammonia plus organic nitrogen flow-normalized concentrations had a before-ASR upward trend and an after-ASR downward trend at both sites (table 10). Nitrate plus nitrite flow-normalized concentrations had before- and after-ASR upward trends at the Highway 50 site, no before-ASR trend at the Sedgwick site, and an after-ASR downward trend at the Sedgwick site (table 10). Total nitrogen flow-normalized concentrations had before-ASR trends that were upward for the Highway 50 site and downward for the Sedgwick site and after-ASR trends that were downward at both sites (table 10). Ammonia and nitrate flow-normalized concentrations at the Sedgwick site had no trend before ASR and a downward trend after ASR (table 10). Nitrite concentrations at the Sedgwick site had a downward trend before and after ASR (table 10).

Flow-normalized orthophosphate concentrations had no trend before ASR and a downward trend after ASR at the Sedgwick site (table 10). Flow-normalized dissolved phosphorus concentrations had a downward trend before ASR and after ASR at the Sedgwick site (table 10). Flow-normalized total phosphorus concentrations for the study period (2000 through 2021 for the Highway 50 site and 1995 through 2021 for the Sedgwick site; fig. 10*I*) had a likely upward trend at the Highway 50 site and a likely downward trend at the Sedgwick site (table 10). Orthophosphate and dissolved phosphorus flow-normalized concentrations for the study period (fig. 10*G*, *H*) had downward trends that were either very or highly likely (table 10). Flow-normalized total phosphorus concentrations had a before-ASR upward trend and an after-ASR downward trend at both sites (table 10).

Dissolved organic carbon flow-normalized concentrations at the Highway 50 and Sedgwick sites during 2010 through 2021 (fig. 10*J*) had downward trends that were very likely or highly likely (table 10). Dissolved organic carbon concentrations decreased by 20 percent at the Highway 50 site and 43 percent at the Sedgwick site during 2010 through 2021 (table 10). Total organic carbon flow-normalized concentrations during the study period (fig. 10*K*) had upward trends that were highly likely at both study sites. Total organic carbon concentrations increased 53 percent at the Highway 50 site and 52 percent at the Sedgwick site during the study period (table 10). Total organic carbon flow-normalized concentrations had a before-ASR upward trend and an after-ASR downward trend at both sites (table 10).

Little Arkansas River flow-normalized nutrient and carbon species fluxes during 1995 through 2021 generally had upward trends (table 10). Ammonia plus organic nitrogen flow-normalized fluxes during the study period had an upward trend at the Highway 50 site and no trend at the Sedgwick site (table 10). Nitrate plus nitrite fluxes during the study period had upward trends at both sites and increased 77 percent at the Highway 50 site and 53 percent at the Sedgwick site (table 10). Study period flow-normalized total nitrogen fluxes had no trend at the Highway 50 site and an upward trend at the Sedgwick site (table 10). Study period ammonia and nitrate fluxes had upward trends and the nitrite flux had a downward trend at the Sedgwick site (table 10). Before- and after-ASR ammonia plus organic nitrogen fluxes had no trends at the Highway 50 site and had upward and downward trends, respectively, at the Sedgwick site (table 10). Before-ASR nitrate plus nitrite fluxes had upward trends at both sites and after-ASR nitrate plus nitrite fluxes had no trend at the Highway 50 site and an upward trend at the Sedgwick site (table 10). Before- and after-ASR total nitrogen flow-normalized fluxes had upward trends and no trends, respectively, at both sites (table 10). Sedgwick site ammonia flow-normalized fluxes had an upward trend before ASR and a downward trend after ASR. Nitrate fluxes at the Sedgwick site had no before-ASR trend and an after-ASR upward trend. Nitrite fluxes at the Sedgwick site had downward trends for both time periods (table 10).

Study period flow-normalized total phosphorus fluxes had upward trends at both study sites (table 10). Sedgwick site orthophosphate and dissolved phosphorus fluxes during the study period had an upward trend and no trend, respectively (table 10). Orthophosphate fluxes increased by 57 percent during the study period at the Sedgwick site (table 10). Total phosphorus flow-normalized fluxes had upward trends at both sites before ASR; after-ASR total phosphorus fluxes

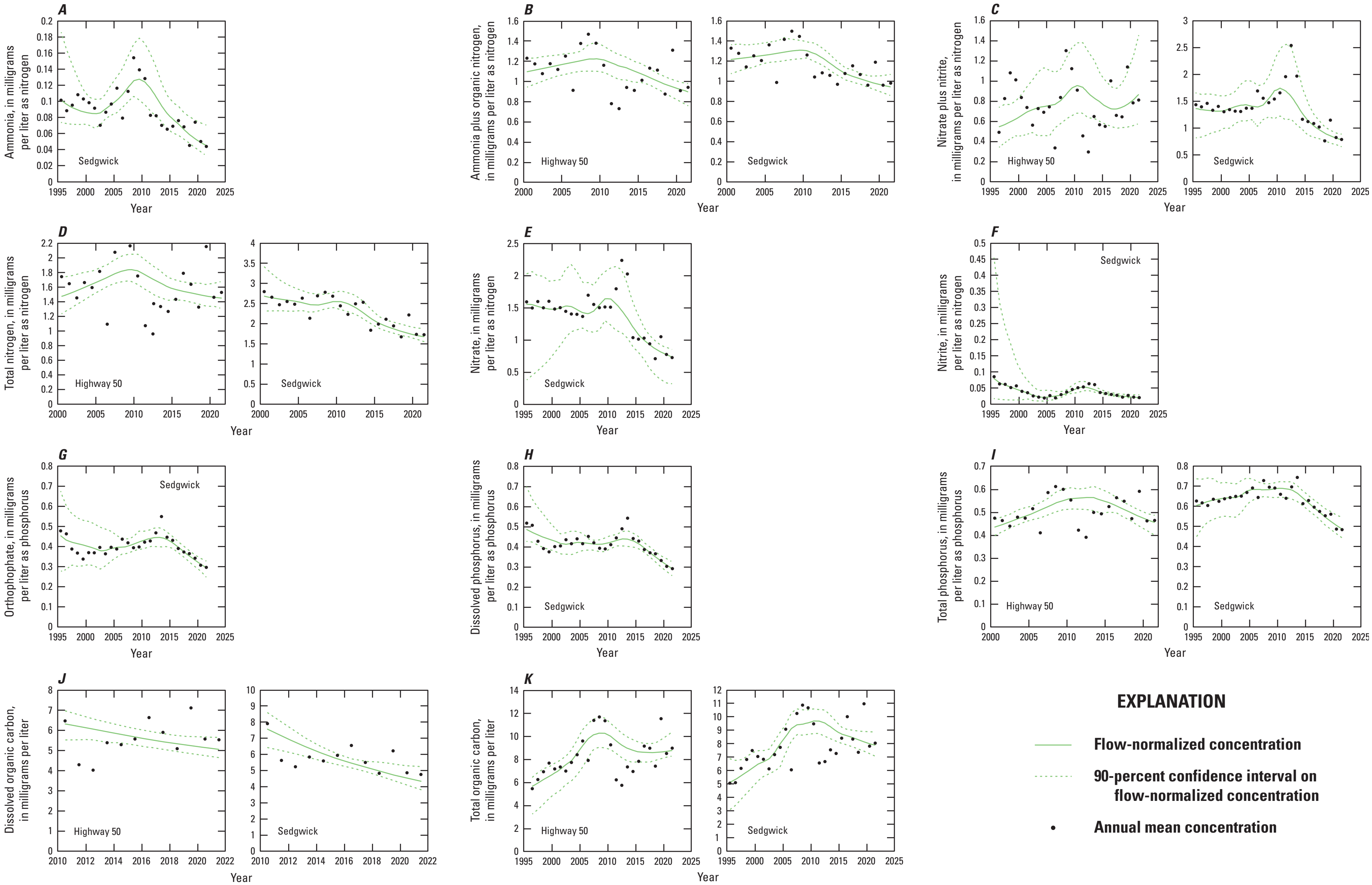


Figure 10. Weighted Regressions on Time, Discharge, and Season annual mean concentrations with flow-normalized concentration trend and 90-percent confidence interval for constituents at the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021. *A*, Ammonia. *B*, Ammonia plus organic nitrogen. *C*, Nitrate plus nitrite. *D*, Total nitrogen. *E*, Nitrate. *F*, Nitrite. *G*, Orthophosphate. *H*, Dissolved phosphorus. *I*, Total phosphorus. *J*, Dissolved organic carbon. *K*, Total organic carbon.

Table 10. Weighted Regressions on Time, Discharge, and Season bootstrap test and trend change summary results for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.

[USGS, US Geological Survey; mg/L, milligram per liter; yr, year; --, not applicable; cfu/100 mL, colony forming units per 100 milliliters]

Site	Time period	Flow-normalized concentration					Flow-normalized flux				
		Trend direction	Trend probability	Likelihood descriptor	Concentration change	Percent concentration change	Trend direction	Trend probability	Likelihood descriptor	Flux change	Percent flux change
Ammonia (USGS parameter code 00608)											
Sedgwick	1995–2021	Downward	0.985	Downward trend is highly likely	−0.0563 mg/L	−56	Upward	0.708	Upward trend is likely	4.5 tons/yr	11
	1996–2006	--	0.629	Upward trend is about as likely as not	0.00795 mg/L	8	Upward	0.946	Upward trend is very likely	15 tons/yr	37
	2007–21	Downward	0.985	Downward trend is highly likely	−0.0735 mg/L	−62	Downward	0.787	Downward trend is likely	−12 tons/yr	−22
Ammonia plus organic nitrogen (USGS parameter code 00625)											
Highway 50	2000–21	Downward	0.965	Downward trend is highly likely	−0.199 mg/L	−18	Upward	0.688	Upward trend is likely	35 tons/yr	8
	2000–06	Upward	0.837	Upward trend is likely	0.0934 mg/L	9	--	0.490	Downward trend is about as likely as not	−0.097 tons/yr	<1
	2007–21	Downward	0.985	Downward trend is highly likely	−0.307 mg/L	−26	--	0.639	Upward trend is about as likely as not	36 tons/yr	9
Sedgwick	2000–21	Downward	0.995	Downward trend is highly likely	−0.275 mg/L	−23	--	0.569	Downward trend is about as likely as not	−23 tons/yr	−3
	2000–06	Upward	0.698	Upward trend is likely	0.0625 mg/L	5	Upward	0.748	Upward trend is likely	20 tons/yr	3
	2007–21	Downward	0.995	Downward trend is highly likely	−0.349 mg/L	−27	Downward	0.777	Downward trend is likely	−42 tons/yr	−5

Table 10. Weighted Regressions on Time, Discharge, and Season bootstrap test and trend change summary results for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.—Continued

[USGS, US Geological Survey; mg/L, milligram per liter; yr, year; --, not applicable; cfu/100 mL, colony forming units per 100 milliliters]

Site	Time period	Flow-normalized concentration					Flow-normalized flux				
		Trend direction	Trend probability	Likelihood descriptor	Concentration change	Percent concentration change	Trend direction	Trend probability	Likelihood descriptor	Flux change	Percent flux change
Nitrate plus nitrite (USGS parameter code 00631)											
Highway 50	1996–2021	Upward	0.965	Upward trend is highly likely	0.326 mg/L	60	Upward	0.946	Upward trend is very likely	130 tons/yr	77
	1996–2006	Upward	0.975	Upward trend is highly likely	0.227 mg/L	42	Upward	0.995	Upward trend is highly likely	127 tons/yr	75
	2007–21	Upward	0.757	Upward trend is likely	0.0622 mg/L	8	--	0.332	Upward trend is about as likely as not	2.3 tons/yr	1
Sedgwick	1995–2021	Downward	0.965	Downward trend is highly likely	−0.587 mg/L	−43	Upward	0.936	Upward trend is very likely	191 tons/yr	53
	1995–2006	--	0.649	Upward trend is about as likely as not	0.0261 mg/L	2	Upward	0.936	Upward trend is very likely	114 tons/yr	32
	2007–21	Downward	0.975	Downward trend is highly likely	−0.654 mg/L	−46	Upward	0.728	Upward trend is likely	79 tons/yr	17
Total nitrogen (USGS parameter codes 00625+00631)											
Highway 50	2000–21	--	0.460	Downward trend is about as likely as not	−0.0219 mg/L	−1	--	0.629	Upward trend is about as likely as not	46 tons/yr	7
	2000–06	Upward	0.985	Upward trend is highly likely	0.259 mg/L	18	Upward	0.767	Upward trend is likely	30 tons/yr	5
	2007–21	Downward	0.936	Downward trend is very likely	−0.331 mg/L	−19	--	0.421	Upward trend is about as likely as not	10 tons/yr	2
Sedgwick	2000–21	Downward	0.995	Downward trend is highly likely	−1.02 mg/L	−38	Upward	0.748	Upward trend is likely	66 tons/yr	6
	2000–06	Downward	0.837	Downward trend is likely	−0.199 mg/L	−7	Upward	0.847	Upward trend is likely	58 tons/yr	5
	2007–21	Downward	0.995	Downward trend is highly likely	−0.798 mg/L	−32	--	0.500	Upward trend is about as likely as not	10 tons/yr	1

Table 10. Weighted Regressions on Time, Discharge, and Season bootstrap test and trend change summary results for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.—Continued

[USGS, US Geological Survey; mg/L, milligram per liter; yr, year; --, not applicable; cfu/100 mL, colony forming units per 100 milliliters]

Site	Time period	Flow-normalized concentration					Flow-normalized flux				
		Trend direction	Trend probability	Likelihood descriptor	Concentration change	Percent concentration change	Trend direction	Trend probability	Likelihood descriptor	Flux change	Percent flux change
Nitrate (USGS parameter code 00618)											
Sedgwick	1995–2021	Downward	0.817	Downward trend is likely	−0.798 mg/L	−52	Upward	0.688	Upward trend is likely	−71 tons/yr	−1
	1995–2006	--	0.510	Downward trend is about as likely as not	−0.128 mg/L	−8	--	0.441	Downward trend is about as likely as not	−24 tons/yr	−5
	2007–21	Downward	0.985	Downward trend is highly likely	−0.712 mg/L	−49	Upward	0.748	Upward trend is likely	19 tons/yr	4
Nitrite (USGS parameter code 00613)											
Sedgwick	1995–2021	Downward	0.886	Downward trend is likely	−0.0606 mg/L	−75	Downward	0.708	Downward trend is likely	−22 tons/yr	−64
	1995–2006	Downward	0.906	Downward trend is very likely	−0.0555 mg/L	−69	Downward	0.688	Downward trend is likely	−15 tons/yr	−44
	2007–21	Downward	0.916	Downward trend is very likely	−0.00803 mg/L	−29	Downward	0.767	Downward trend is likely	−5.0 tons/yr	−29
Orthophosphate (USGS parameter code 00671)											
Sedgwick	1995–2021	Downward	0.926	Downward trend is very likely	−0.149 mg/L	−33	Upward	0.975	Upward trend is highly likely	57 tons/yr	57
	1995–2006	--	0.619	Downward trend is about as likely as not	−0.0521 mg/L	−12	Upward	0.995	Upward trend is highly likely	41 tons/yr	41
	2007–21	Downward	0.995	Downward trend is highly likely	−0.103 mg/L	−26	Upward	0.688	Upward trend is likely	9.9 tons/yr	7
Dissolved phosphorus (USGS parameter code 00666)											
Sedgwick	1995–2021	Downward	0.995	Downward trend is highly likely	−0.188 mg/L	−39	--	0.649	Upward trend is about as likely as not	19 tons/yr	15
	1995–2006	Downward	0.946	Downward trend is very likely	−0.0666 mg/L	−14	--	0.460	Upward trend is about as likely as not	3.0 tons/yr	2
	2007–21	Downward	0.995	Downward trend is highly likely	−0.119 mg/L	−29	Upward	0.738	Upward trend is likely	12 tons/yr	9

Table 10. Weighted Regressions on Time, Discharge, and Season bootstrap test and trend change summary results for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.—Continued

[USGS, US Geological Survey; mg/L, milligram per liter; yr, year; --, not applicable; cfu/100 mL, colony forming units per 100 milliliters]

Site	Time period	Flow-normalized concentration					Flow-normalized flux				
		Trend direction	Trend probability	Likelihood descriptor	Concentration change	Percent concentration change	Trend direction	Trend probability	Likelihood descriptor	Flux change	Percent flux change
Total phosphorus (USGS parameter code 00665)											
Highway 50	2000–21	Upward	0.738	Upward trend is likely	0.0226 mg/L	5	Upward	0.718	Upward trend is likely	19 tons/yr	12
	2000–06	Upward	0.985	Upward trend is highly likely	0.0744 mg/L	17	Upward	0.698	Upward trend is likely	5.3 tons/yr	3
	2007–21	Downward	0.975	Downward trend is highly likely	−0.0666 mg/L	−13	--	0.649	Upward trend is about as likely as not	13 tons/yr	8
Sedgwick	1995–2021	Downward	0.807	Downward trend is likely	−0.119 mg/L	−20	Upward	0.827	Upward trend is likely	23 tons/yr	8
	1995–2006	Upward	0.847	Upward trend is likely	0.0769 mg/L	13	Upward	0.985	Upward trend is highly likely	40 tons/yr	14
	2007–21	Downward	0.995	Downward trend is highly likely	−0.194 mg/L	−29	Downward	0.777	Downward trend is likely	−18 tons/yr	−5
Dissolved organic carbon (USGS parameter code 00681)											
Highway 50	2010–21	Downward	0.926	Downward trend is very likely	−1.25 mg/L	−20	Downward	0.965	Downward trend is highly likely	−732 tons/yr	−31
Sedgwick	2010–21	Downward	0.995	Downward trend is highly likely	−3.24 mg/L	−43	Downward	0.906	Downward trend is very likely	−855 tons/yr	−24
Total organic carbon (USGS parameter code 00680)											
Highway 50	1996–2021	Upward	0.995	Upward trend is highly likely	3.02 mg/L	53	Upward	0.995	Upward trend is highly likely	2,247 tons/yr	125
	1996–2006	Upward	0.995	Upward trend is highly likely	4.07 mg/L	71	Upward	0.995	Upward trend is highly likely	1,588 tons/yr	88
	2007–21	Downward	0.817	Downward trend is likely	−1.4 mg/L	−14	Upward	0.698	Upward trend is likely	363 tons/yr	10
Sedgwick	1995–2021	Upward	0.985	Upward trend is highly likely	2.71 mg/L	52	Upward	0.995	Upward trend is highly likely	4,134 tons/yr	162
	1995–2006	Upward	0.995	Upward trend is highly likely	3.93 mg/L	76	Upward	0.995	Upward trend is highly likely	3,034 tons/yr	119
	2007–21	Downward	0.946	Downward trend is very likely	−1.49 mg/L	−16	Upward	0.748	Upward trend is likely	709 tons/yr	12

Table 10. Weighted Regressions on Time, Discharge, and Season bootstrap test and trend change summary results for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.—Continued

[USGS, US Geological Survey; mg/L, milligram per liter; yr, year; --, not applicable; cfu/100 mL, colony forming units per 100 milliliters]

Site	Time period	Flow-normalized concentration					Flow-normalized flux				
		Trend direction	Trend probability	Likelihood descriptor	Concentration change	Percent concentration change	Trend direction	Trend probability	Likelihood descriptor	Flux change	Percent flux change
Suspended solids (USGS parameter code 00530)											
Highway 50	1996–2021	Downward	0.698	Downward trend is likely	−14.5 mg/L	−12	Upward	0.698	Upward trend is likely	10,207 tons/yr	13
	1996–2006	Downward	0.708	Downward trend is likely	−9.97 mg/L	−8	--	0.540	Downward trend is about as likely as not	−2,111 tons/yr	−3
	2007–21	--	0.609	Downward trend is about as likely as not	−5.94 mg/ L	−5	--	0.658	Upward trend is about as likely as not	16,314 tons/yr	23
Sedgwick	1995–2021	--	0.500	Upward trend is about as likely as not	5.6 mg/L	5	Upward	0.827	Upward trend is likely	40,929 tons/yr	29
	1995–2006	--	0.639	Upward trend is about as likely as not	5.46 mg/L	5	--	0.559	Upward trend is about as likely as not	1,108 tons/yr	1
	2007–21	--	0.490	Upward trend is about as likely as not	3.46 mg/L	3	Upward	0.876	Upward trend is likely	47,047 tons/yr	35
Suspended-sediment concentration (USGS parameter code 80154)											
Highway 50	1998–2021	Upward	0.688	Upward trend is likely	10 mg/L	8	Upward	0.807	Upward trend is likely	35,131 tons/yr	29
	1998–2006	Upward	0.975	Upward trend is highly likely	39.8 mg/L	31	--	0.540	Downward trend is about as likely as not	−12,688 tons/yr	−10
	2007–21	Downward	0.886	Downward trend is likely	−38.8 mg/L	−22	Upward	0.767	Upward trend is likely	49,824 tons/yr	47
Sedgwick	1998–2021	--	0.530	Downward trend is about as likely as not	−9.54 mg/L	−7	--	0.589	Upward trend is about as likely as not	493 tons/yr	<1
	1998–2006	Upward	0.728	Upward trend is likely	10.2 mg/L	7	--	0.658	Downward trend is about as likely as not	−28,307 tons/yr	−13
	2007–21	Downward	0.767	Downward trend is likely	−18.4 mg/L	−12	Upward	0.807	Upward trend is likely	36,244 tons/yr	19

Table 10. Weighted Regressions on Time, Discharge, and Season bootstrap test and trend change summary results for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.—Continued

[USGS, US Geological Survey; mg/L, milligram per liter; yr, year; --, not applicable; cfu/100 mL, colony forming units per 100 milliliters]

Site	Time period	Flow-normalized concentration					Flow-normalized flux				
		Trend direction	Trend probability	Likelihood descriptor	Concentration change	Percent concentration change	Trend direction	Trend probability	Likelihood descriptor	Flux change	Percent flux change
Escherichia coli (USGS parameter code 90902)											
Highway 50	2001–21	Downward	0.787	Downward trend is likely	−467 cfu/100 mL	−41	--	0.540	Upward trend is about as likely as not	1,545x10^{12} cfu/yr	21
	2001–06	--	0.609	Downward trend is about as likely as not	−154 cfu/100 mL	−13	Downward	0.688	Downward trend is likely	−1,007x10^{12} cfu/yr	−14
	2007–21	Downward	0.936	Downward trend is very likely	−320 cfu/100 mL	−32	--	0.609	Upward trend is about as likely as not	2,640x10^{12} cfu/yr	42
Sedgwick	2001–21	Downward	0.827	Downward trend is likely	−704 cfu/100 mL	−39	--	0.658	Upward trend is about as likely as not	842x10^{12} cfu/yr	4
	2001–06	Downward	0.738	Downward trend is likely	−287 cfu/100 mL	−16	--	0.579	Downward trend is about as likely as not	−2,519x10^{12} cfu/yr	−10
	2007–21	Downward	0.777	Downward trend is likely	−392 cfu/100 mL	−26	Upward	0.777	Upward trend is likely	4,095x10^{12} cfu/yr	20
Fecal coliforms (USGS parameter code 31625)											
Highway 50	1996–2021	Downward	0.718	Downward trend is likely	−1,559 cfu/100 mL	−67	--	0.649	Downward trend is about as likely as not	−7,586x10^{12} cfu/yr	−47
	1996–2006	--	0.649	Downward trend is about as likely as not	−959 cfu/100 mL	−41	--	0.609	Downward trend is about as likely as not	−7,418x10^{12} cfu/yr	−46
	2007–21	Downward	0.936	Downward trend is very likely	−562 cfu/100 mL	−43	Downward	0.688	Downward trend is likely	−98x10^{12} cfu/yr	−1
Sedgwick	1995–2021	--	0.579	Upward trend is about as likely as not	220 cfu/100 mL	22	--	0.639	Downward trend is about as likely as not	−4,143x10^{12} cfu/yr	−14
	1995–2006	Upward	0.995	Upward trend is highly likely	1,060 cfu/100 mL	106	Upward	0.797	Upward trend is likely	8,452x10^{12} cfu/yr	28
	2007–21	Downward	0.965	Downward trend is highly likely	−742 cfu/100 mL	−38	Downward	0.748	Downward trend is likely	−6,558x10^{12} cfu/yr	−20

Table 10. Weighted Regressions on Time, Discharge, and Season bootstrap test and trend change summary results for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.—Continued

[USGS, US Geological Survey; mg/L, milligram per liter; yr, year; --, not applicable; cfu/100 mL, colony forming units per 100 milliliters]

Site	Time period	Flow-normalized concentration					Flow-normalized flux				
		Trend direction	Trend probability	Likelihood descriptor	Concentration change	Percent concentration change	Trend direction	Trend probability	Likelihood descriptor	Flux change	Percent flux change
Iron (USGS parameter code 01046)											
Highway 50	1996–2021	Upward	0.955	Upward trend is highly likely	47.8 µg/L	318	Upward	0.985	Upward trend is highly likely	83 tons/yr	467
	1996–2006	Upward	0.975	Upward trend is highly likely	9.27 µg/L	62	Downward	0.718	Downward trend is likely	−3.0 tons/yr	−17
	2007–21	Upward	0.906	Upward trend is very likely	34 µg/L	118	Upward	0.985	Upward trend is highly likely	82 tons/yr	459
Sedgwick	1995–2021	Upward	0.916	Upward trend is very likely	17.9 µg/L	69	--	0.550	Upward trend is about as likely as not	23 tons/yr	42
	1995–2006	--	0.589	Upward trend is about as likely as not	1.14 µg/L	4	Downward	0.698	Downward trend is likely	−23 tons/yr	−42
	2007–21	Upward	0.916	Upward trend is very likely	12.5 µg/L	40	Upward	0.906	Upward trend is very likely	38 tons/yr	92
Strontium (USGS parameter code 01080)											
Sedgwick	1995–2021	Downward	0.866	Downward trend is likely	−38.7 µg/L	−11	Downward	0.718	Downward trend is likely	−35 tons/yr	−32
	1995–2006	Downward	0.946	Downward trend is very likely	−139 µg/L	−23	Downward	0.748	Downward trend is likely	−45 tons/yr	−40
	2007–21	Upward	0.985	Upward trend is highly likely	104 µg/L	24	Upward	0.936	Upward trend is very likely	11 tons/yr	17
Arsenic (USGS parameter code 01000)											
Highway 50	1996–2021	Downward	0.876	Downward trend is likely	−0.751 µg/L	−11	--	0.658	Downward trend is about as likely as not	−0.0162 tons/yr	−2
	1996–2006	Downward	0.847	Downward trend is likely	−0.765 µg/L	−11	Downward	0.856	Downward trend is likely	−0.12 tons/yr	−16
	2007–21	--	0.480	Upward trend is about as likely as not	0.075 µg/L	1	Upward	0.926	Upward trend is very likely	0.103 tons/yr	17

Table 10. Weighted Regressions on Time, Discharge, and Season bootstrap test and trend change summary results for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.—Continued

[USGS, US Geological Survey; mg/L, milligram per liter; yr, year; --, not applicable; cfu/100 mL, colony forming units per 100 milliliters]

Site	Time period	Flow-normalized concentration					Flow-normalized flux				
		Trend direction	Trend probability	Likelihood descriptor	Concentration change	Percent concentration change	Trend direction	Trend probability	Likelihood descriptor	Flux change	Percent flux change
Arsenic (USGS parameter code 01000)—Continued											
Sedgwick	1995–2021	Downward	0.777	Downward trend is likely	−0.91 µg/L	−14	--	0.649	Downward trend is about as likely as not	−0.12 tons/yr	−10
	1995–2006	Downward	0.678	Downward trend is likely	−0.553 µg/L	−8	Downward	0.718	Downward trend is likely	−0.11 tons/yr	−8
	2007–21	--	0.658	Downward trend is about as likely as not	−0.629 µg/L	−5	--	0.619	Downward trend is about as likely as not	−0.021 tons/yr	−2

had no trend at the Highway 50 site and a downward trend at the Sedgwick site (table 10). Sedgwick site flow-normalized orthophosphate fluxes before and after ASR had upward trends (table 10). Dissolved phosphorus fluxes at the Sedgwick site had no before-ASR trend and an upward trend after ASR (table 10).

Flow-normalized dissolved organic carbon fluxes during the study period had downward trends at the Highway 50 and Sedgwick sites with respective decreases of 31 and 24 percent (table 10). Total organic carbon fluxes during the study period had upward trends that were highly likely at both sites. Total organic carbon fluxes increased by 125 percent at the Highway 50 site and 162 percent at the Sedgwick site during the study period (table 10). Both sites had total organic carbon fluxes with upward trends for the before- and after-ASR time periods (table 10).

Sediment Trends

Little Arkansas River sediment concentration and flux trends were generally inconsistent among study sites and time periods (fig. 11; table 10). Little Arkansas River flow-normalized suspended-solids concentrations during the study period (fig. 11*A*) had a downward trend at the Highway 50 site and no trend at the Sedgwick site; suspended-solids concentrations decreased 12 percent at the Highway 50 site and increased 5 percent at the Sedgwick site (table 10). Study period flow-normalized suspended-sediment concentrations (fig. 11*B*) had an upward trend at the Highway 50 site and no trend at the Sedgwick site; suspended-sediment concentrations increased 8 percent at the Highway 50 site and decreased 7 percent at the Sedgwick site (table 10). Suspended-solids concentrations had a downward trend at the Highway 50 site and no trend at the Sedgwick site during the before-ASR period (table 10). Suspended-solids concentrations had no trends at either site during the after-ASR period (table 10). Suspended-sediment concentrations had upward trends during the before-ASR period and downward trends during the after-ASR period at both sites (table 10). Suspended-solids fluxes increased 13 and 29 percent and suspended-sediment fluxes increased 29 and <1 percent at the Highway 50 and Sedgwick sites, respectively, during the study period (table 10). Both sites had suspended-solids and suspended-sediment flow-normalized fluxes that had no trend before ASR and upward trends after ASR, except for Highway 50 after ASR, which had no trend (table 10).

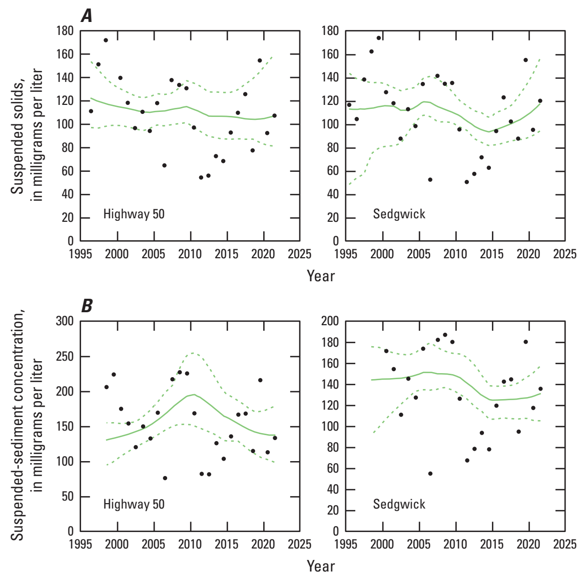
Indicator Bacteria Trends

Little Arkansas River flow-normalized indicator bacteria densities during 1995 through 2021 (fig. 12) generally had downward trends, whereas flow-normalized indicator bacteria flux trends were not evident (table 10). Flow-normalized *E. coli* bacteria densities during the study period (fig. 12*A*) had downward trends that decreased by about 40 percent at both sites (table 10). Study period fecal coliform densities (fig. 12*B*) had a downward trend at the Highway 50 site and no trend at the Sedgwick site (table 10). Before-ASR flow-normalized *E. coli* densities had no trend at the Highway 50 site and had a downward trend at the Sedgwick site; after-ASR *E. coli* densities had downward trends at both sites (table 10). Flow-normalized fecal coliform densities before ASR had no trend at the Highway 50 site and had an upward trend at the Sedgwick site (table 10). After-ASR fecal coliform densities had a downward trend at both sites (table 10). There were no trends in flow-normalized indicator bacteria fluxes during the study period at either study site (table 10). Before-ASR *E. coli* bacteria density fluxes had a downward trend at the Highway 50 site and no trend at the Sedgwick site; after-ASR *E. coli* bacteria density fluxes had no trend at the Highway 50 site and an upward trend at the Sedgwick site (table 10). Before-ASR fecal coliform bacteria density fluxes had no trend at the Highway 50 site and an upward trend at the Sedgwick site; after-ASR fecal coliform bacteria density fluxes had downward trends at both sites (table 10).

Trace Element Trends

Flow-normalized dissolved iron concentrations during the study period (fig. 13*A*) had upward trends at both study sites; iron concentrations increased 318 percent at the Highway 50 site and 69 percent at the Sedgwick site (table 10). Dissolved iron concentrations during the before ASR time period had an upward trend at the Highway 50 site and no trend at the Sedgwick site; dissolved iron concentrations at both sites had upward trends during the after-ASR period (table 10). Sedgwick site flow-normalized dissolved strontium concentrations (fig. 13*B*) had a downward trend during the entire study and before-ASR time periods, and an upward trend during the after-ASR time period (table 10). Flow-normalized dissolved arsenic concentrations during the entire study (fig. 13*C*) and before-ASR periods had downward trends at both sites and dissolved arsenic concentrations had no trend at either site during the after-ASR time period (table 10). Dissolved arsenic concentrations decreased 11 percent at the Highway 50 site and 14 percent at the Sedgwick site during the study period (table 10).

Flow-normalized dissolved iron fluxes during the study period had an upward trend at the Highway 50 site and no trend at the Sedgwick site; before-ASR dissolved iron fluxes had downward trends at both sites; after-ASR dissolved iron fluxes had an upward trend at the Highway 50 site and downward trend at the Sedgwick site (table 10). Flow-normalized dissolved strontium fluxes at the Sedgwick site during the study period and before ASR had a downward trend and after ASR had an upward trend (table 10). Flow-normalized dissolved arsenic fluxes had no trend during the study period at both sites; arsenic fluxes had downward trends for the before-ASR time period at both sites; arsenic fluxes during the after-ASR time period had an upward trend at the Highway 50 site and no trend at the Sedgwick site (table 10).



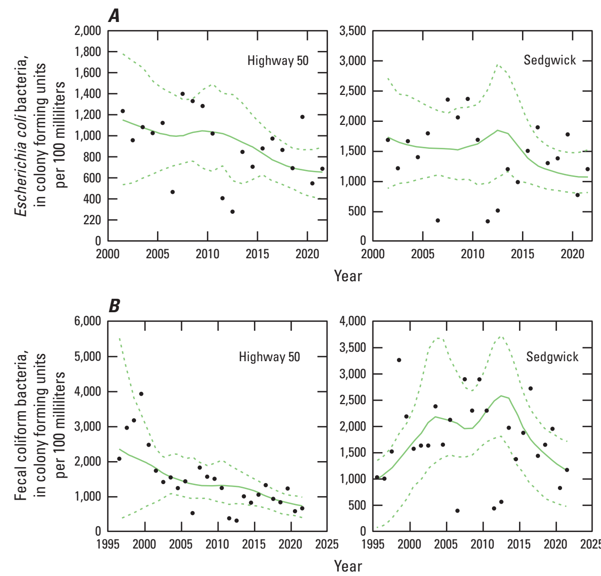
EXPLANATION

Flow-normalized concentration

90-percent confidence interval on flow-normalized concentration

Annual mean concentration

Figure 11. Weighted Regressions on Time, Discharge, and Season annual mean concentrations with flow-normalized concentration trend and 90-percent confidence interval for constituents at the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021. *A*, Suspended solids. *B*, Suspended-sediment concentration.



EXPLANATION

Flow-normalized concentration

90-percent confidence interval on flow-normalized concentration

Annual mean concentration

Figure 12. Weighted Regressions on Time, Discharge, and Season annual mean concentrations with flow-normalized concentration trend and 90-percent confidence interval for constituents at the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021. *A*, *Escherichia coli* bacteria. *B*, Fecal coliform bacteria.

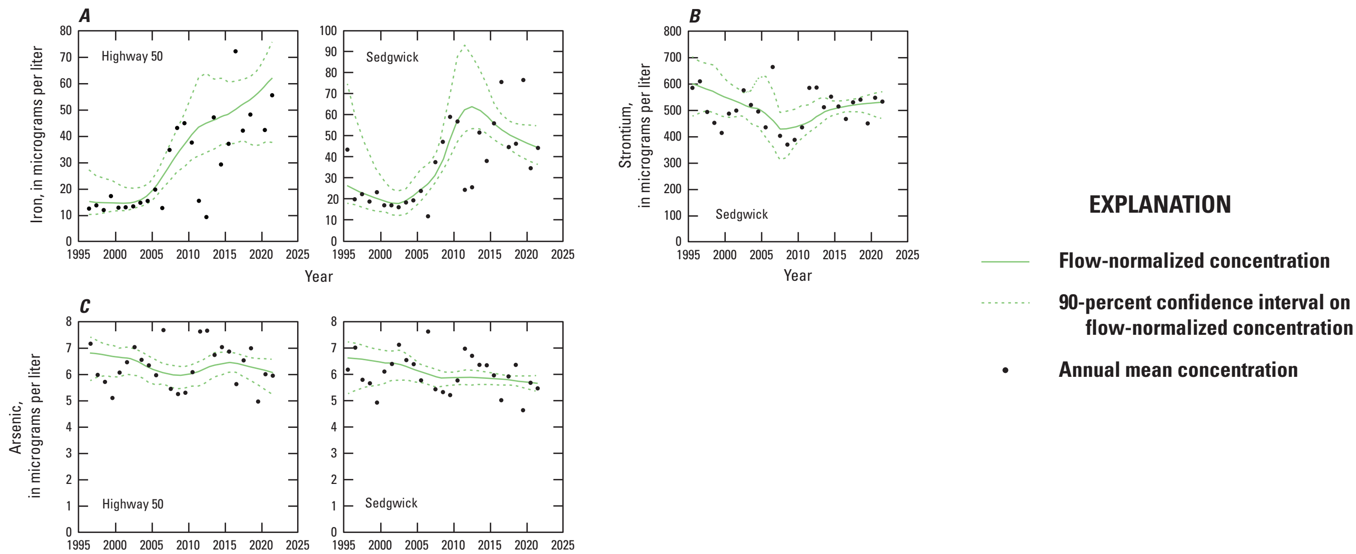


Figure 13. Weighted Regressions on Time, Discharge, and Season annual mean concentrations with flow-normalized concentration trend and 90-percent confidence interval for constituents at the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021. *A*, Iron. *B*, Strontium. *C*, Arsenic.

Several studies have used statistical approaches based on weighted regressions to characterize flow-normalized annual water-quality constituent concentrations and fluxes in U.S. streams (Hirsch and others, 2010; Medalie and others, 2012; Moyer and others, 2012; Murphy and others, 2013; Hickman and Hirsch, 2017; Oelsner and others, 2017; Murphy and Sprague, 2019; Murphy, 2020; Ryberg and others, 2020; Barr and Kalkhoff, 2021; Domagalski and others, 2021; Kramer and others, 2021; Flickinger and Shephard, 2022). Within Kansas, the Little Arkansas River and Arkansas River had downward trends for dissolved solids and chloride concentrations during several time periods during 1972 through 2012 (Oelsner and others, 2017). Arkansas River nitrate concentrations had upward trends for the time periods 1982 through 2012 and 1992 through 2012 (Oelsner and others, 2017). Arkansas River total nitrogen concentrations had a downward trend for the period 1992 through 2012 (Oelsner and others, 2017). Little Arkansas River orthophosphate concentrations had an upward trend for the period 2002 through 2012 (Oelsner and others, 2017). Arkansas River sites had downward total phosphorus concentration trends for earlier time periods (1972 through 2012, 1982 through 2012, and 1992 through 2012) and upward total phosphorus concentrations for the time periods 2002 through 2012 (Oelsner and others, 2017). Several sites in Kansas, including sites along the Verdigris River and Kansas River, had dissolved solids, chloride, and nitrate concentrations with downward trends, and total phosphorus concentrations with upward trends during time periods between 1972 through 2012 (Oelsner and others, 2017). The nearby North Fork Ninnescah River (inflow to Cheney Reservoir, fig. 1) had downward nitrate plus nitrite and upward orthophosphate, total phosphorus, total organic carbon, suspended solids, and suspended-sediment concentration trend probabilities during 1999 through 2019 (Kramer and others, 2021). Future *Equus* Beds aquifer and Little Arkansas River research efforts would benefit from trend analysis during targeted flow conditions to assess drivers of long-term water-quality concentration changes.

Summary

The *Equus* Beds aquifer and Cheney Reservoir are primary sources for the city of Wichita's current (2023) water supply. The *Equus* Beds aquifer storage and recovery (ASR) project was developed by the city of Wichita to help meet future water demands using Little Arkansas River as an artificial aquifer recharge water source during above-base-flow conditions. Little Arkansas River water is removed from the river at an ASR Facility intake structure, treated using National Primary Drinking Water Regulations as a guideline, and is infiltrated into the *Equus* Beds aquifer through recharge basins or injected into the aquifer through recharge wells for later use. The U.S. Geological Survey, in cooperation with the city of Wichita, completed this study to document Little Arkansas River water quantity and quality; document the development and update of regression models that establish relations between continuous and discrete water-quality data; and to characterize and quantify water-quality concentrations, loads, and trends during 1995 through 2021 for primary ions, nutrient and carbon species, sediment, indicator bacteria, trace elements, and pesticides. Water-quality constituents of interest were selected because of their relevance to water-supply or water-quality issues in the *Equus* Beds aquifer and the Little Arkansas River. Data from this report are important because they can be used to document surface-water quality, quantify potential pollutants, evaluate changing conditions, identify environmental factors affecting surface water, provide science-based information for decision making, and help meet regulatory monitoring requirements.

The Little Arkansas River has a contributing drainage area of primarily agricultural land (producing mainly corn, sorghum, soybeans, and wheat); fertilizers and herbicides are commonly applied in the drainage basin. Several streams in the Little Arkansas River watershed are listed as impaired waterways; impairments include arsenic, chloride, nutrients, sediment, and bacteria. The Little Arkansas River has defined total maximum daily loads for atrazine, nutrients, suspended solids and sediment, fecal coliform bacteria, and total phosphorus.

Data were collected from three sites along the Little Arkansas River. The upstream Little Arkansas River at Highway 50 near Halstead, Kansas, streamgage (U.S. Geological Survey station 07143672; hereafter referred to as the “Highway 50 site”) and downstream Little Arkansas River near Sedgwick, Kans., streamgage (U.S. Geological Survey station 07144100; hereafter referred to as the “Sedgwick site”) bracket a substantial portion of the easternmost part of the *Equus* Beds aquifer. The Little Arkansas River upstream from the ASR Facility near Sedgwick, Kans., streamgage (U.S. Geological Survey station 375350097262800; hereafter referred to as the “Upstream ASR site”) is located between the Highway 50 and Sedgwick sites, about 14.7 river miles (mi) downstream from the Highway 50 site, about 1.71 river mi upstream from the Sedgwick site, and immediately upstream from the ASR Facility intake structure. The contributing drainage areas for the Highway 50 and Sedgwick sites are about 685 square miles (mi^2) and 1,165 mi^2, respectively.

Continuous (hourly) streamflow and physicochemical parameters (water temperature, specific conductance, pH, dissolved oxygen, turbidity, and nitrate plus nitrite) and discrete water-quality data (primary ions [hardness, dissolved solids, calcium, magnesium, potassium, sodium, bromide, chloride, fluoride, silica, and sulfate], nutrient and carbon species [ammonia plus organic nitrogen, nitrate plus nitrite, total phosphorus, and dissolved and total organic carbon], sediment [suspended solids and suspended-sediment concentration], indicator bacteria [*Escherichia coli* and fecal coliform bacteria], trace elements [iron and arsenic], and pesticides [deethylatrazine, atrazine, and metolachlor]) were collected over a range of streamflows during 1995 through 2021. Surrogate models for water-quality constituents of interest (including bromide, dissolved organic carbon, deethylatrazine, atrazine, and metolachlor) were updated or developed using continuously measured and concomitant discrete data and were used, along with previously developed regression models, to compute concentrations (at the Highway 50, Sedgwick, and Upstream ASR sites) and loads (at the Highway 50 and Sedgwick sites) during the study period. Federal criteria were used to evaluate water quality. Where applicable, water-quality data were compared to Federal national drinking-water regulations. Flow-normalized water-quality constituent trends were evaluated using Weighted Regressions on Time, Discharge, and Season; statistical models and water-quality trends were described using Weighted Regressions on Time, Discharge, and Season bootstrap tests.

The ASR phase II water treatment facility requires a minimum streamflow of about 100 cubic feet per second at the Sedgwick site to operate, and this operational guideline was exceeded about 31 percent of the time during the study; streamflow maxima were during May 2019. Water temperature exceeded the Kansas criterion less than 1 percent of the time. pH was below the Kansas aquatic life-support criterion less than 1 percent of the time and exceeded the upper criterion 3 percent of the time. Dissolved oxygen concentrations were below the Kansas aquatic life-support criterion about 3 to 4 percent of the time; dissolved oxygen minima were during June and July 2016. Continuous nitrate plus nitrite concentrations exceeded the EPA level III ecoregion 27 guideline 84 to 99 percent of the time and the nitrate maximum contaminant level (MCL) was exceeded less than 1 percent of the time.

Continuously measured physicochemical properties that were included as surrogates in final regression models for this study were specific conductance, and YSI EXO turbidity. Specific conductance was the sole explanatory variable for bromide; turbidity was the sole explanatory variable for total organic carbon, and turbidity and seasonal components were explanatory variables for pesticides, including deethylatrazine, atrazine, and metolachlor.

Computed primary constituents of dissolved solids (hardness, calcium, sodium, bromide, and chloride), with the exception of sulfate, were larger at the Highway 50 site compared to the Sedgwick site. During the study period, the EPA secondary maximum contaminant level (SMCL) for dissolved solids (500 milligrams per liter [mg/L]) was exceeded 57 percent of the time at the Highway 50 site and 38 percent of the time at the Sedgwick site. Computed bromide concentrations were larger at the Highway 50 site and exceeded the city of Wichita treatment threshold (0.3 mg/L) about 70, 21, and 19 percent of the time at the Highway 50, Sedgwick, and Upstream ASR sites, respectively. Chloride concentrations exceeded the EPA SMCL (250 mg/L) about 16 percent of the time at the Highway 50 site and did not exceed the SMCL at the Sedgwick site. Computed sulfate concentrations never exceeded the EPA SMCL (250 mg/L) at any site during the study.

Ammonia plus organic nitrogen concentrations exceeded the EPA level III ecoregion 27 guideline (0.52 mg/L) about 85 percent of the time at the Highway 50 site and 93 percent of the time at the Sedgwick site. Total phosphorus concentrations were generally larger at the Sedgwick site and exceeded the EPA level III ecoregion 27 guideline (0.09 mg/L) nearly 100 percent of the time at the Highway 50 and Sedgwick sites. Continuously computed suspended solids and suspended-sediment concentration ranges and means were similar between the Highway 50 and Sedgwick sites during the study.

Escherichia coli bacteria densities exceeded the Kansas Department of Health and Environment primary contact guideline (262 colony forming units per 100 milliliters [cfu/100 mL] during April 1 through October 31) 84 to 62 percent of the time and exceeded the Kansas Department of Health and Environment secondary contact guideline (2,358 cfu/100 mL during November 1 through March 31) 5 to 6 percent of the time during the study for the associated periods of time. Continuous arsenic concentrations exceeded the Federal MCL (10 micrograms per liter [µg/L]) 9 to 15 percent of the time during the study. Atrazine concentrations exceeded the MCL (3 µg/L) 10 percent of the time at the Highway 50 and Sedgwick sites and 14 percent of the time at the Upstream ASR site during the study; computed glyphosate concentrations at the Sedgwick site never exceeded the MCL (700 µg/L) during the study.

Annual streamflow volume was smallest in 2006 and largest in 2019 at all sites; as such, nearly all computed water-quality constituent loads were largest in 2019 and smallest in 2006. Agricultural practices in the watershed, including fertilizer application, likely contributed a substantial amount of the Little Arkansas River nitrate plus nitrite and phosphorus loads during the study period. Nitrate plus nitrite loads were computed during 2018 through 2021 at the Highway 50 site and 2013 through 2021 at the Sedgwick site; the total nitrate plus nitrite loads were 1,610 tons at the Highway 50 site and 5,390 tons at the Sedgwick site. Ammonia plus organic nitrogen loads for 1999 through 2021 were 10,500 tons at the Highway 50 site and 16,200 tons at the Sedgwick site. The total phosphorus load during 1999 through 2021 was 4,090 tons at the Highway 50 site and 6,710 tons at the Sedgwick site. The ammonia plus organic nitrogen load during 2005 through 2021 was 56,800 tons at the Highway 50 site and 88,500 tons at the Sedgwick site. Little Arkansas River suspended-solids load during 1999 through 2021 was 1,770,000 tons at the Highway 50 site and 2,480,000 tons at the Sedgwick site. The Little Arkansas River total suspended-sediment load during 1999 through 2021 was 2,340,000 tons at the Highway 50 site and 4,060,000 tons at the Sedgwick site. About 40 percent of the total Little Arkansas River suspended-sediment load at both the Highway 50 and Sedgwick sites during 1999 through 2021 was transported in the top 1 percent (about 80) of loading days.

Little Arkansas River flow-normalized primary ion concentrations during 1995 through 2021 generally had downward trends and percent decreases in concentrations were generally larger at the Highway 50 site. Dissolved solids, potassium, sodium, chloride, and fluoride flow-normalized concentrations had downward trends that were very likely or highly likely at both sites during the study period. Dissolved solids concentrations decreased by 30 percent (Highway 50 site) and 15 percent (Sedgwick site); sodium concentrations decreased by 49 percent (Highway 50 site) and 32 percent (Sedgwick site); and chloride concentrations decreased by 54 percent (Highway 50 site) and 43 percent (Sedgwick site) during the study period. Bromide and silica flow-normalized concentrations had no trend at the Highway 50 site and a downward trend at the Sedgwick site during the study period. Flow-normalized sulfate concentrations during the study period had a downward trend (and a decrease of 10 percent) at the Highway 50 site and an upward trend (and an increase of 7 percent) at the Sedgwick site. Little Arkansas River flow-normalized primary ion fluxes generally had downward trends. Dissolved solids, potassium, sodium, bromide, chloride, and fluoride flow-normalized study period fluxes had downward trends at both study sites.

Little Arkansas River flow-normalized nutrient and carbon species concentrations during 1995 through 2021 generally had downward trends, and concentration percent decreases were generally larger at the Sedgwick site. Flow-normalized ammonia plus organic nitrogen concentrations during the study had downward trends at both sites that were highly likely; ammonia plus organic nitrogen concentrations decreased by 18 percent at the Highway 50 site and 23 percent at the Sedgwick site. Nitrate plus nitrite concentrations had an upward trend at the Highway 50 site and downward trend at the Sedgwick site; both trends were highly likely. Flow-normalized total phosphorus concentrations for the study period (2000 through 2021 for the Highway 50 site and 1995 through 2021 for the Sedgwick site) had an upward trend at the Highway 50 site and a downward trend at the Sedgwick site. Orthophosphate and dissolved phosphorus concentrations had downward trend probabilities that were either very or highly likely at the Sedgwick site. Dissolved organic carbon concentrations at the Highway 50 and Sedgwick sites during 2010 through 2021 had downward trends that were very or highly likely. Dissolved organic carbon concentrations decreased by 20 percent at the Highway 50 site and 43 percent at the Sedgwick site. Total organic carbon concentrations had upward trends that were highly likely at both study sites; total organic carbon concentrations increased about 50 percent at both sites. Little Arkansas River flow-normalized nutrient and carbon species fluxes during the study period generally had upward trends. Nitrate plus nitrite fluxes had upward trends at both sites and increased 77 percent at the Highway 50 site and 53 percent at the Sedgwick site. Total phosphorus fluxes had upward trends at both study sites. Dissolved organic carbon fluxes had downward trends at the Highway 50 and Sedgwick sites and decreases of 31 percent at the Highway 50 site and 24 percent at the Sedgwick site. Total organic carbon fluxes had upward trends that were highly likely at both sites; total organic carbon fluxes increased by 125 percent at the Highway 50 site and 162 percent at the Sedgwick site.

Little Arkansas River sediment concentration and flux trends were generally inconsistent among study sites and time periods. Suspended-solids concentrations during the study period had a downward trend at the Highway 50 site and no trend at the Sedgwick site; suspended-solids concentrations decreased 12 percent at the Highway 50 site and increased

5 percent at the Sedgwick site. Study period flow-normalized suspended-sediment concentrations had an upward trend at the Highway 50 site and no trend at the Sedgwick site; suspended-sediment concentrations increased 8 percent at the Highway 50 site and decreased 7 percent at the Sedgwick site. Indicator bacteria densities generally had downward trend probabilities during the study period, whereas flow-normalized indicator bacteria flux trends were not evident. Dissolved iron concentrations during the study period had upward trends at both study sites; iron concentrations increased 318 percent at the Highway 50 site and 69 percent at the Sedgwick site. Dissolved arsenic concentrations during the entire study had downward trends at both sites and arsenic concentrations decreased 11 percent at the Highway 50 site and 14 percent at the Sedgwick site.

About one-quarter to one-half of the study period loads, including nutrients and sediment, were transported during 1 percent of the time during the study. About 38 to 40 percent of the total Little Arkansas River suspended-sediment load at the Highway 50 and Sedgwick sites during 1999 through 2021 was transported in the top 1 percent of loading days. Because streamflows are highly sensitive to climatic variation and an increase of extreme precipitation events in the Great Plains is expected, similar disproportionately large pollutant loading events may increase into the future. Continuous measurement of 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. Continuation of this water-quality monitoring will provide data to characterize changing conditions in the Little Arkansas River and possibly identify new and changing trends. Information in this report allows the city of Wichita to make informed municipal water-supply decisions on past and present water-quality conditions and trends in the watershed.

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Appendix 1. Turbidity Sensor Relations

Figure 1.1 is available for download at https://doi.org/10.3133/sir20235102 (U.S. Geological Survey, 2023).

Figure 1.1. Relations between turbidity sensors, 2004–19. *A*, YSI 6026 (YSI_{6026}) and YSI 6136 (YSI_{6136}) at the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672). *B*, YSI_{6136} and YSI EXO (YSI_{EXO}) at Highway 50. *C*, YSI_{6026} and YSI_{6136} at the Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100). *D*, YSI_{6136} and YSI_{EXO} at Sedgwick. *E*, YSI_{6136} and YSI_{EXO} at the Little Arkansas River upstream of ASR Facility near Sedgwick, Kans. (USGS station 375350097262800).

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Appendix 2. Turbidity Sensor Comparisons

Table 2.1 is available for download at https://doi.org/10.3133/sir20235102 (U.S. Geological Survey, 2023).

Table 2.1. Summary statistics for continuously (hourly) measured turbidity data measured with different sensors at the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672); Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100); and Little Arkansas River upstream of ASR Facility near Sedgwick, Kans. (Upstream ASR; USGS station 375350097262800), 2004–19.

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Appendix 3. Quality Assurance and Quality Control Summary

Table 3.1 is available for download at https://doi.org/10.3133/sir20235102 (U.S. Geological Survey, 2023).

Table 3.1. Relative percentage differences for discrete replicate pairs and detection percentages for blank discrete water-quality samples for the Little Arkansas River sites near Sedgwick, Kansas (U.S. Geological Survey station 07144100), 1995–2021.

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U.S. Geological Survey, 2023, USGS water data for the Nation: U.S. Geological Survey National Water Information System database, accessed August 2022 at https://doi.org/10.5066/F7P55KJN.

Appendix 4. Surrogate Regression Model Archive Summaries for the Little Arkansas River at Highway 50 near Halstead, Kansas (U.S. Geological Survey station 07143672)

Appendix 4 is available for download at https://doi.org/10.3133/sir20235102 (U.S. Geological Survey, 2023).

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Appendix 5. Surrogate Regression Model Archive Summaries for the Little Arkansas River near Sedgwick, Kansas (U.S. Geological Survey station 07144100)

Appendix 5 is available for download at https://doi.org/10.3133/sir20235102 (U.S. Geological Survey, 2023).

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U.S. Geological Survey, 2023, USGS water data for the Nation: U.S. Geological Survey National Water Information System database, accessed August 2022 at https://doi.org/10.5066/F7P55KJN.

Appendix 6. Surrogate Regression Model Archive Summaries for the Little Arkansas River upstream of ASR Facility near Sedgwick, Kansas (U.S. Geological Survey station 375350097262800)

Appendix 6 is available for download at https://doi.org/10.3133/sir20235102 (U.S. Geological Survey, 2023).

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Appendix 7. Weighted Regressions on Time, Discharge, and Season Concentrations

Tables 7.1–7.3 are available for download at https://doi.org/10.3133/sir20235102 (U.S. Geological Survey, 2023).

Table 7.1. Weighted Regressions on Time, Discharge, and Season estimated mean, flow-normalized, and generalized mean concentrations for primary ions at the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.

Table 7.2. Weighted Regressions on Time, Discharge, and Season estimated mean, flow-normalized, and generalized mean concentrations for nutrients and carbon species at the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.

Table 7.3. Weighted Regressions on Time, Discharge, and Season estimated mean, flow-normalized, and generalized mean concentrations or densities for sediment, indicator bacteria, and trace elements at the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.

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U.S. Geological Survey, 2023, USGS water data for the Nation: U.S. Geological Survey National Water Information System database, accessed August 2022 at https://doi.org/10.5066/F7P55KJN.

Appendix 8. Weighted Regressions on Time, Discharge, and Season Fluxes

Tables 8.1–8.3 are available for download at https://doi.org/10.3133/sir20235102 (U.S. Geological Survey, 2023).

Table 8.1. Weighted Regressions on Time, Discharge, and Season estimated mean, flow-normalized, and generalized mean fluxes for primary ions at the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.

Table 8.2. Weighted Regressions on Time, Discharge, and Season estimated mean, flow-normalized, and generalized mean fluxes for nutrients and carbon species at the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.

Table 8.3. Weighted Regressions on Time, Discharge, and Season estimated mean, flow-normalized, and generalized mean fluxes for sediment, indicator bacteria, and trace elements at the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1995–2021.

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Appendix 9. Weighted Regressions on Time, Discharge, and Season Graphical Output at station 07143672

Appendix 9 is available for download at https://doi.org/10.3133/sir20235102 (U.S. Geological Survey, 2023).

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U.S. Geological Survey, 2023, USGS water data for the Nation: U.S. Geological Survey National Water Information System database, accessed August 2022 at https://doi.org/10.5066/F7P55KJN.

Appendix 10. Weighted Regressions on Time, Discharge, and Season Graphical Output at station 07144100

Appendix 10 is available for download at https://doi.org/10.3133/sir20235102 (U.S. Geological Survey, 2023).

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U.S. Geological Survey, 2023, USGS water data for the Nation: U.S. Geological Survey National Water Information System database, accessed August 2022 at https://doi.org/10.5066/F7P55KJN.

Appendix 11. Weighted Regressions on Time, Discharge, and Season Estimated Yearly Water-Quality Constituent Loads

Table 11.1 is available for download at https://doi.org/10.3133/sir20235102 (U.S. Geological Survey, 2023).

Table 11.1. Weighted Regressions on Time, Discharge, and Season estimated yearly water-quality constituent loads at the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672) and near Sedgwick, Kans. (Sedgwick; USGS station 07144100), 1998–2021.

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