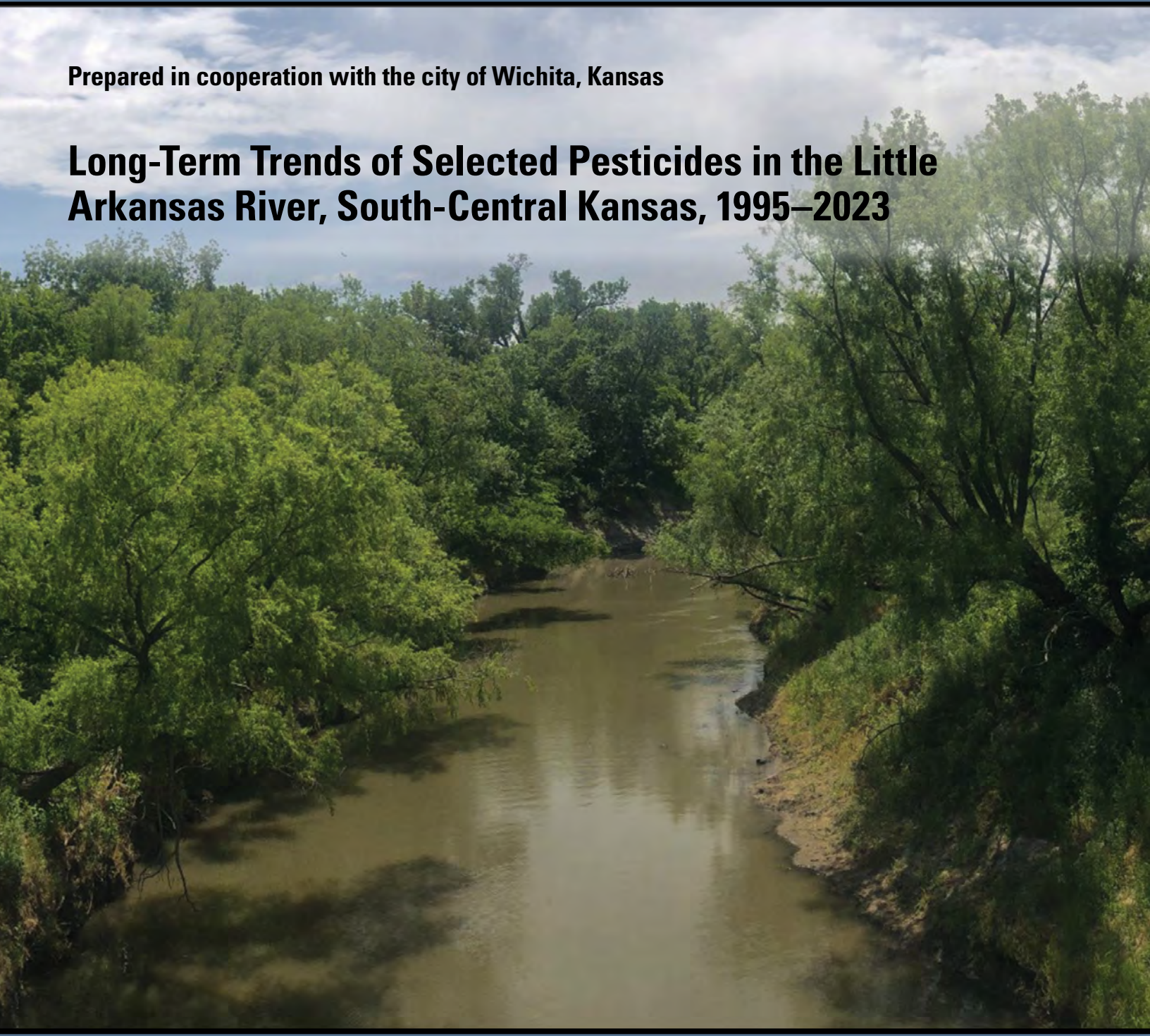
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Long-Term Trends of Selected Pesticides in the Little Arkansas River, South-Central Kansas, 1995–2023



Scientific Investigations Report 2026–5016

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

Front cover. Photograph showing the Little Arkansas River in south-central Kansas, taken near Highway 50 on May 14, 2026, by Clark Taylor, U.S. Geological Survey.

Back cover. Photograph showing the Little Arkansas River in south-central Kansas, taken near Sedgwick on May 18, 2026, by Clark Taylor, U.S. Geological Survey.

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By Mandy L. Stone and Brian J. Klager

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	0.003785	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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

$$°F = (1.8 \times °C) + 32.$$

Supplemental Information

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

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).

Abbreviations

<	less than
AIC	Aikake's Information Criterion
AMPA	aminomethylphosphonic acid
ASR	aquifer storage and recovery
BMP	best management practice
EPA	U.S. Environmental Protection Agency
GCMS	gas chromatography/mass spectrometry
LTFA	long-term flow anomalies
MCL	maximum contaminant level
MTFA	mid-term flow anomalies
NWQL	U.S. Geological Survey National Water Quality Laboratory
QA/QC	quality assurance and quality control
R^2	coefficient of determination
RPD	relative percentage difference
STFA	short-term flow anomalies
TMDL	total maximum daily load
USGS	U.S. Geological Survey
WDFN	U.S. Geological Survey Water Data for the Nation
WRTDS	Weighted Regressions on Time, Discharge, and Season

Long-Term Trends of Selected Pesticides in the Little Arkansas River, South-Central Kansas, 1995–2023

By Mandy L. Stone and Brian J. Klager

Abstract

The eastern part of the High Plains Aquifer, herein called the *Equus* beds aquifer, is currently a primary source of water (2026) for the city of Wichita, Kansas. The *Equus* Beds Aquifer Storage and Recovery Project was developed in the early 1990s to meet future water demands by using the Little Arkansas River as an artificial aquifer recharge water source during above-base-flow conditions in the river. Little Arkansas River water is diverted at an intake structure, treated following National Primary Drinking Water Regulations as a guideline, and delivered to the aquifer through recharge basins or injection wells for later use. The U.S. Geological Survey, in cooperation with the city of Wichita, completed the study described in this report to quantify and characterize Little Arkansas River water-quality data. Data in this report can be used to evaluate changing conditions in aquifer recharge source water, provide science-based information for decision making, and help meet regulatory monitoring requirements.

Continuous streamflow, specific conductance, turbidity, and discrete atrazine data were collected from two Little Arkansas River study sites and discrete glyphosate and aminomethylphosphonic acid was collected from one of the two Little Arkansas River study sites from 1995 to 2023 to evaluate water-quality conditions and assess pesticide trends. Pesticide trends in the herbicides atrazine and glyphosate and the herbicide-associated compound aminomethylphosphonic acid (a glyphosate degradate) were evaluated using the R package seawaveQ.

Pesticides modeled with the seawaveQ R package had increasing and decreasing trends during the study period, depending on the individual pesticide and if there were strong seasonal patterns; larger estimated concentrations occurring in late spring and early summer. Modeled atrazine concentrations exceeded the Federal maximum contaminant level of 3 micrograms per liter about 8 percent of the time at both study sites. Atrazine had a nonsignificant increasing trend (98 percent) at the Highway 50 site and a nonsignificant decreasing trend (31 percent) at the downstream Sedgwick site during the study period. Glyphosate and aminomethylphosphonic acid trends were not evident at the Sedgwick site during the study period.

Introduction

Wichita is the largest city in the State of Kansas and has a population of about 396,120 (U.S. Census Bureau, 2023). The eastern part of the High Plains aquifer is informally and commonly called the *Equus* beds aquifer (Wilmarth, 1938). The *Equus* beds aquifer Wichita well field and the Cheney Reservoir (fig. 1) are currently (2026) primary sources of water for the city of Wichita. An Integrated Local Water Supply Plan was developed by Wichita's Water Utilities Department to specify expected water demands through 2050, primarily considering the artificial recharge of the *Equus* beds aquifer to meet future needs (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 the National Primary Drinking Water Regulations (U.S. Environmental Protection Agency, 2009) as a guideline, and either injects or recharges it into the *Equus* beds aquifer through spreading basins for later use to help ensure water demands are met during an extended drought.

The U.S. Geological Survey (USGS), in cooperation with the city of Wichita, completed the study of the Little Arkansas River (source water for the *Equus* Beds ASR project) as detailed in this report to quantify and characterize Little Arkansas River pesticide conditions, including trends. Long-term Little Arkansas River pesticide data were collected from 1995 through 2023 to complete this study objective. Previous studies summarizing Little Arkansas River water quality, including pesticides in the river include Tappa and others (2015), Stone and others (2016, 2019), and Stone and Klager (2022, 2023).

Equus Beds Aquifer Storage and Recovery Project

The city of Wichita, Kansas, uses the *Equus* beds aquifer as a primary municipal water-supply source. Water levels in the aquifer have decreased substantially since predevelopment (before 1940) because historical irrigator, industrial, and municipal pumpage rates exceeded the natural aquifer recharge rate (Hansen and others, 2014; Whisnant

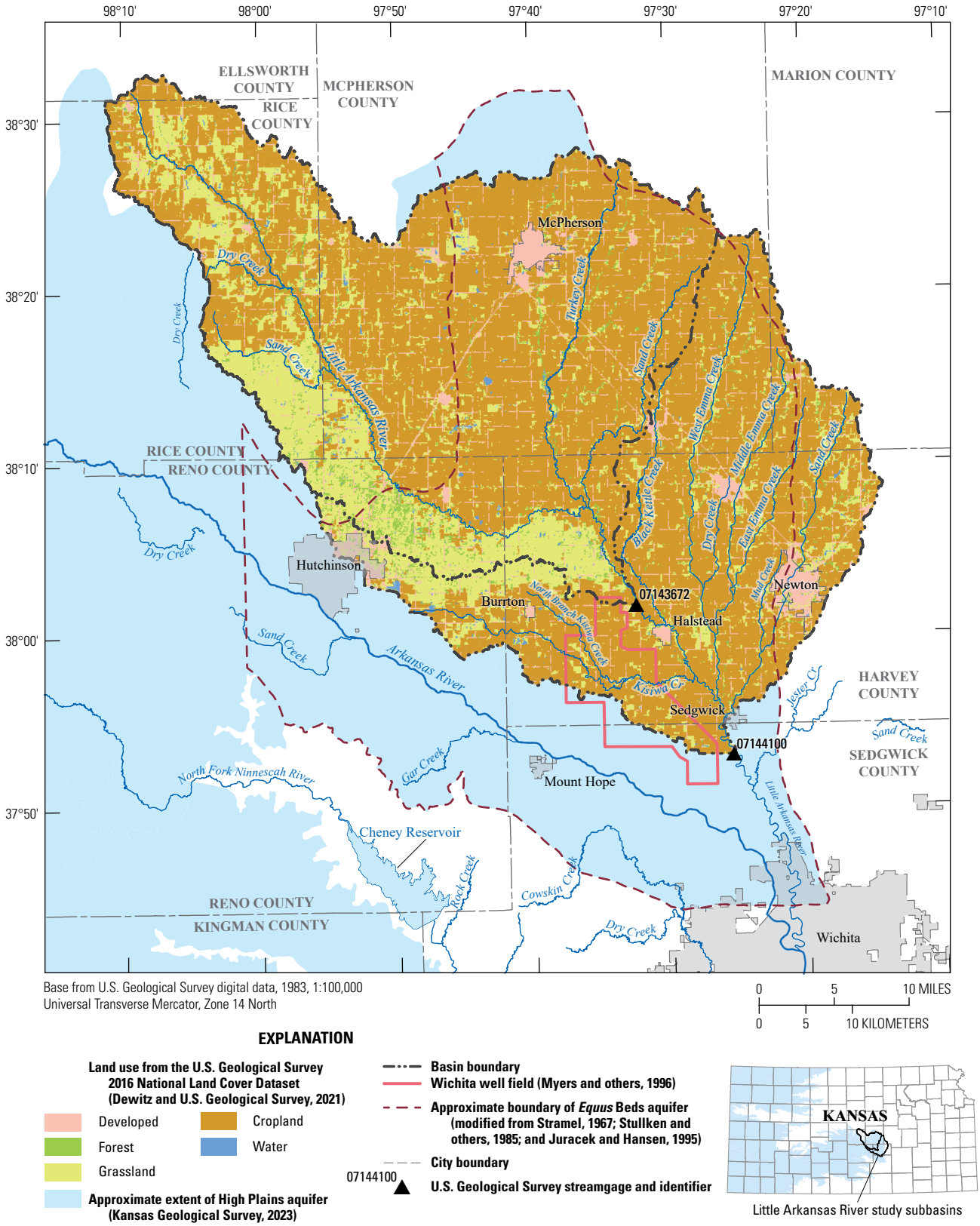


Figure 1. Map showing the location of the study area in south-central Kansas near the city of Wichita. Land use data from Dewitz and U.S. Geological Survey (2021). Approximate boundary of *Equus* beds aquifer modified from Stramel (1967), Stullken and others (1985), and Juracek and others (1996). Approximate extent of High Plains aquifer from Kansas Geological Survey (2023). Wichita well field boundary data from Myers and others (1996).

and others, 2015; Klager, 2016). The Wichita well field, located in the center of the *Equus* beds aquifer boundary (fig. 1), is susceptible to saltwater, which includes chloride, contamination from the Arkansas River and intrusion from existing upgradient plumes near Burrton, Kansas, that are 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 and currently (2026) consists of two coexisting phases (phases I and II); information about the project is available at https://wichitaasr.org. Phase I began in 2007 and included capturing Little Arkansas River water and indirect streambank-diversion well water to be injected into four wells and two recharge basins. Phase II includes the treatment of surface water and the construction of river intake facilities, recharge-injection wells, and a recharge basin. Phase II operations began in 2013 and require a minimum streamflow of about 100 cubic feet per second (ft^3/s) at the Little Arkansas River near Sedgwick, Kans., streamgage (USGS station 07144100; hereafter referred to as the "Sedgwick site"; fig. 1) for the river intake facility to operate. At this flow threshold, Little Arkansas River water is directly diverted at the river intake structure. The city of Wichita has a National Pollutant Discharge Elimination System permit (Kansas Permit number I–LA24–PO01; Federal Permit number KS0099694) that allows the city to discharge waste associated with sediment and filtrates from the ASR phase II surface-water treatment facility to the Little Arkansas River (Kansas Department of Health and Environment, 2020). The total amount of phase I and II recharge water was about 5.3 billion gallons from 2007 to 2023 (Mike Jacobs and Logan Walker, City of Wichita, written commun., 2024).

Purpose and Scope

The purpose of this report is to characterize Little Arkansas River pesticide occurrence and trends from 1995 through 2023 as part of efforts to characterize and quantify water-quality of ASR source water. Initial efforts to quantify Little Arkansas River water-quality constituent trends using Weighted Regressions on Time, Discharge, and Season (WRTDS) were published by Stone and Klager (2023), but the study did not include pesticides because WRTDS was not the appropriate method to analyze them. Data from this report can be used to document surface-water quality, quantify potential pollutants, evaluate changing conditions, identify environmental factors affecting surface-water pesticide concentrations, provide science-based information for decision making, and help meet regulatory monitoring requirements. The methods and results in this report can provide guidance and perspective for aquifer recharge projects that are in progress or in development elsewhere and can inform national efforts to characterize the effects of pesticide use on environmental conditions.

Description of Study Area and Background Information

The study area is in south-central Kansas, northwest of Wichita (fig. 1). This study had two 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 the upstream site. The Sedgwick site (USGS station 07144100; fig. 1) is about 16.4 river miles downstream from the Highway 50 site. These two sites bracket a substantial area of the easternmost part of the *Equus* beds aquifer. 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 (U.S. Geological Survey, 2019).

The Little Arkansas River has a contributing drainage area of about 1,300 mi^2 (U.S. Geological Survey, 2019) consisting of primarily agricultural land that produces mainly corn, sorghum, soybeans, and wheat (Kansas Department of Agriculture, 2023). About 65 percent of the land of the Little Arkansas River drainage basin is cultivated crops and hay (U.S. Geological Survey, 2019). Fertilizers (such as nitrogen and phosphorus; U.S. Department of Agriculture, 2024) and herbicides (such as atrazine and glyphosate; Pistora, 2018) are commonly applied in the drainage basin. Cattle and hogs are the primary livestock raised in the area (Kansas Department of Agriculture, 2023). Long-term mean annual precipitation (1900 through 2023) in the study area, based on data recorded near Mount Hope, Kans. (fig. 1; National Oceanic and Atmospheric Administration, 2024), was 30.3 inches (table 1). Mean annual precipitation was 32.9 inches during the study period (1995 through 2023; table 1).

The Kansas Department of Health and Environment has listed several streams in the Little Arkansas River drainage basin as impaired waterways under section 303(d) of the 1972 Clean Water Act (Kansas Department of Health and Environment, 2024). Section 303(d) of the 1972 Clean Water Act requires States to identify water bodies with impaired water quality and the associated pollutants causing the impairments. Creeks located within the Little Arkansas River drainage basin include Emma Creek near Sedgwick, Kisiwa Creek near Halstead, Little Arkansas River at Alta Mills, Little Arkansas River at Wichita, Sand Creek near Sedgwick, and Turkey Creek near Alta Mills, and these creeks all have atrazine impairments (Kansas Department of Health and Environment, 2024).

A total maximum daily load (TMDL) is the maximum amount of a pollutant allowed in a water body according to water-quality standards. TMDLs are developed primarily by individual States under the Clean Water Act for impairment-causing pollutants for the purpose of developing reduction targets and management plans (U.S. Environmental Protection Agency, 2022). The Little Arkansas River has defined TMDLs for atrazine (Kansas Department of Health and Environment, 2008).

Table 1. Annual total precipitation for 1995 to 2023 and mean annual precipitation for the periods 1995 through 2023 and 1900 through 2023 at the National Oceanic and Atmospheric Administration, National Centers for Environmental Information station "MOUNT HOPE" in Mount Hope, Kansas (network identification: GHCN–Daily:USC00145539).

[Data from the National Oceanic and Atmospheric Administration (2024). GHCN, Global Historical Climatology Network; USC, United States Climate]

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
2022	24.5
2023	24.5
Mean annual precipitation for the period 1995 through 2023	32.9
Mean annual precipitation for the period 1900 through 2023	30.3

Atrazine is a major pollutant of concern for the Little Arkansas River drainage basin (Kansas State University Research and Extension and others, 2018). The city of Wichita has partnered with the Little Arkansas River Kansas Watershed Restoration and Protection Strategy Atrazine Management Program in an effort to implement atrazine-related best management practices (BMPs) in the Little Arkansas River drainage basin with the goal of reducing atrazine in targeted drainage basin areas (Kansas State University Research and Extension and others, 2018). As part of the Little Arkansas River Kansas Watershed Restoration and Protection Strategy Atrazine Management Program, several incentivized BMPs have been implemented in targeted Little Arkansas River drainage basins since 2006 (for example, the drainage basins of Turkey, Emma, and Sand [near Sedgwick] Creeks; fig. 1, drainage basins not shown) in an effort to reach the goal of reducing atrazine in these drainage basins to below 3 micrograms per liter (µg/L) with no seasonal spikes (Kansas State University Research and Extension and others, 2018). Ninety-four BMPs were implemented in the Little Arkansas River drainage basin in or by 2023; some of these practices included early, post-emergent, and split atrazine application; reduced soil-applied atrazine rate; and utilization of no atrazine (Kansas State University Agricultural Experiment Station and Cooperative Extension Service, 2024).

Related Investigations

The cooperative efforts of the city of Wichita and the USGS began when the city started to develop its water supplies in the 1920s by developing a local well field and USGS installing a streamgage; USGS investigations related to the *Equus* Beds Aquifer Storage and Recovery Project is the most recent example of longstanding cooperation dating back to the 1920s (Stone, 2017). Recharge activity has not been shown to substantially affect *Equus* beds aquifer water quality, at least partially, because the total amount of water recharged is small (Ziegler and others, 2010; Tappa and others, 2015; Stone and others, 2016, 2019). Within the study area, pesticides are commonly detected in surface and groundwater and sometimes exceed Federal criteria, particularly in surface water (Ziegler and others, 1999, 2001, 2010; Tappa and others, 2015; Stone and others, 2016, 2019; Stone and Klager, 2022, 2023). Major findings related to previous Little Arkansas River investigations include the following:

1. Little Arkansas River and *Equus* beds aquifer water-quality data were collected from 1995 through 1998 to describe preliminary effects of ASR on *Equus* beds aquifer water quality (Ziegler and others, 1999). Little Arkansas River water alachlor, atrazine, cyanazine, and metolachlor concentrations commonly exceeded their respective Federal criterion of 2 µg/L maximum contaminant level (MCL), 3 µg/L (MCL), 1 µg/L health advisory level (the concentration of a contaminant in drinking water below which adverse health effects

are not anticipated to happen), and 70 µg/L health advisory level, respectively. Alachlor, cyanazine, and metolachlor were detected in some groundwater samples, but did not exceed Federal criteria. Atrazine was defined as a constituent of concern for ASR because its concentrations frequently exceeded the MCL of 3 µg/L (U.S. Environmental Protection Agency, 2009) in Little Arkansas River samples. Atrazine was detected in the groundwater samples of nearly all sampling sites, but concentrations were smaller than those of Little Arkansas River water samples and less than the Federal MCL.

2. Little Arkansas River and *Equus* beds aquifer baseline water quality from 1995 through 2005 was characterized prior to full-scale ASR implementation (Ziegler and others, 2010). Atrazine was the most commonly detected pesticide in the study area, and regression-computed surface-water atrazine concentrations exceeded the Federal MCL of 3 µg/L about 27 percent of the time, primarily during late spring to early fall. Atrazine was also detected in about 55 percent of shallow aquifer well samples, indicating infiltration from field application; however, these atrazine sample concentrations were substantially smaller than the MCL. Alachlor was the only pesticide other than atrazine that was frequently detected in surface-water samples, and measurements of alachlor exceeded the Federal MCL of 2 µg/L, but exceedances were rare.

3. Little Arkansas River water-quality data were collected before (1995 through 2006) and concurrent with (2007 through 2012) ASR phase I recharge 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 because of the recharge and were more likely affected by climatological and natural processes. Regression-computed atrazine concentrations exceeded the Federal MCL (3 µg/L) 24 to 28 percent of the time during the study, mostly during the late spring to early fall. Alachlor was the only pesticide other than atrazine that was frequently detected in surface water samples, and 2.4 percent of the samples had concentrations that exceeded the Federal MCL of 2 µg/L (U.S. Environmental Protection Agency, 2009).

4. A 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 phase II surface-water atrazine concentrations were larger than pre-ASR concentrations, likely because of greater streamflow and runoff conditions. Atrazine concentrations exceeded the Federal MCL in about 20 to 25 percent of pre-ASR samples and 38 to 50 percent of post-ASR samples. Alachlor was detected in pre- and post-ASR surface-water samples, but post-ASR concentrations were generally smaller than pre-ASR concentrations. Little Arkansas River alachlor concentrations never exceeded the Federal MCL during the study.

5. Little Arkansas River water-quality data were collected from 2001 through 2016 to evaluate constituents of concern from aquifer recharge activity, to 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 in this study did not increase in comparison with those previously reported by Tappa and others (2015). Thirty-nine percent of atrazine detections in Little Arkansas River samples exceeded the MCL. Atrazine was detected in about 58 percent of shallow (depth to water-level range: 1.42 to 60.3 feet below land surface) *Equus* beds aquifer index wells, but concentrations never exceeded the Federal MCL. Atrazine concentrations in shallow aquifer index wells were generally largest in the northwest part of the study area near the North Branch Kisiwa Creek (fig. 1). Pesticides that were detected in less than 20 percent of *Equus* beds aquifer samples and did not exceed their MCLs included alachlor, carbofuran, glyphosate, and simazine. Herbicides such as atrazine, deethylatrazine, and metolachlor were detected in 20 percent of samples from shallow index wells.

6. 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 from 1998 through 2019 (Stone and Klager, 2022). Surrogate relations allow the concentrations or densities of many potential constituents of concern, including atrazine, to be estimated in near real-time and to be characterized during conditions and timescales that would not be otherwise possible. Specific conductance and seasonal components were explanatory variables for atrazine concentrations, and atrazine was negatively correlated with specific conductance.

7. Little Arkansas River water quantity and quality were documented, and long-term water-quality trends were quantified using data collected from 1995 through 2021 (Stone and Klager, 2023). Surrogate regression models were developed or updated for the pesticides deethylatrazine, acetochlor, aminomethylphosphonic acid (AMPA), atrazine, glyphosate, and metolachlor using continuously measured turbidity, seasonal variables, and concomitant discrete data, and were

used to compute long-term concentrations and loads. Continuously computed atrazine concentrations exceeded the Federal MCL 10 to 14 percent of the time, but continuously computed glyphosate concentrations never exceeded the MCL during the study.

Methods

Data were collected following protocols developed for the *Equus* Beds ASR project (Ziegler and Combs, 1997; Stone and others, 2012). 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, 2019), and Stone and Klager (2022, 2023).

Data Collection

Continuous streamflow and physicochemical data as well as discrete water-quality data were collected from two surface-water sites (Highway 50 and Sedgwick) along the Little Arkansas River during a range of streamflow conditions from 1995 through 2023 to evaluate water-quality conditions. The water-quality data were used to quantify pesticides of interest and identify pesticide constituent trends from 1995 through 2023. Data collected by the USGS are accessible in the USGS Water Data for the Nation (WDFN) website (U.S. Geological Survey, 2024). Datasets used in this report are available in the associated USGS data release (Stone, 2026).

Continuous Streamflow Measurements and Water-Quality Monitoring

Continuous (1-hour maximum interval) streamflow was measured at the Highway 50 and Sedgwick sites using standard USGS methods (Sauer and Turnipseed, 2010; Turnipseed and Sauer, 2010). Physicochemical properties affecting water quality were continuously measured (1-hour maximum interval) at the Highway 50 and Sedgwick sites. Physicochemical properties that were measured included specific conductance and turbidity. Specific conductance and turbidity have been used as surrogates for pesticide concentrations at the Highway 50 and Sedgwick sites (Christensen and others, 2003; Rasmussen and others, 2016; Stone and Klager, 2022, 2023). Water-quality monitors were installed near the centroid of the stream cross section. The Highway 50 and Sedgwick sites were equipped with a YSI Incorporated 6600 Extended Deployment System water-quality monitor (YSI Incorporated, 2012a) in May and April 1998, respectively, to continuously (60-minute interval) measure specific conductance. Turbidity sensors were added to the water-quality monitors in October and September 1998, respectively. Water-quality monitors were maintained following standard USGS procedures (Wagner and others, 2006).

Some equipment was upgraded during the project. The YSI 6026 turbidity sensors installed at the Highway 50 and Sedgwick sites in October 1998 were replaced with YSI 6136 turbidity sensors in January 2007 and July 2004, respectively. A YSI EXO2 water-quality monitor (YSI Incorporated, 2012b) equipped with specific conductance and YSI EXO turbidity sensors was installed in January 2017 at the Highway 50 site and in September 2014 at the Sedgwick site. The YSI 6026 and YSI 6136 turbidity measurements were converted to YSI EXO2 turbidity measurement values using conversion factors developed from side-by-side sensor measurements documented in figure 1.1 and table 2.1 in Stone and Klager (2023).

Discrete Pesticide Data Collection

Discrete surface-water-quality samples were collected at the two study sites during a range of streamflow conditions and seasons. Samples were primarily collected using depth- and width-integrated sample collection techniques (U.S. Geological Survey, 2006) and are coded in WDFN as either equal-width increment “EWI” or “Multiple verticals” under “SampleCollectionMethod_IdentifierContext.” Discrete water-quality samples were analyzed for pesticides at both study sites. Specific pesticides were included in this report because they had a documented history of frequently being detected in Little Arkansas River water samples at study sites (table 1.5 in Stone and others, 2019, and table 4 in Stone and Klager, 2023). Discrete samples collected at the Sedgwick site were additionally analyzed for glyphosate and AMPA. Pesticide collection and analyses 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, 2023). Water-quality samples were analyzed for atrazine by the USGS National Water Quality Laboratory (NWQL) using a gas chromatography/mass spectrometry (GCMS) method using NWQL schedule 2003 (for samples collected from 1995 through September 2017) or 2033 (for samples collected from November 2017 through 2023) and the Method identifier “GCM35” (“ResultAnalyticalMethod_Identifier” in WDFN). Atrazine was isolated from filtered water samples by solid-phase extraction and analyzed using capillary-column GCMS with selected-ion monitoring (Zaugg and others, 1995). Atrazine samples analyzed using NWQL schedule 2003 had detection and reporting limits of 0.004 µg/L and 0.007 µg/L, respectively, for samples collected from 1995 through September 2010 and detection and reporting limits of 0.004 µg/L and 0.008 µg/L, respectively, for samples collected from October 2010 through September 2017. Atrazine samples analyzed using NWQL schedule 2033 had detection and reporting limits of 0.004 µg/L and 0.008 µg/L, respectively, for samples collected from October 2017

through December 2019 and detection and reporting limits of 0.001 µg/L and 0.008 µg/L, respectively, for samples collected during January 2020 through December 2023. Water-quality samples were analyzed for glyphosate and AMPA by the USGS Organic Geochemistry Research Laboratory using a liquid chromatography/tandem mass spectrometry method (WDFN "ResultAnalyticalMethod_Identifier" of either "LCM41" or "LCM57") as described in Meyer and others (2009). Glyphosate and AMPA had detection and reporting limits of 0.01 µg/L and 0.02 µg/L, respectively.

Data Compilation and Analysis

County-level data for pesticide use in the Little Arkansas River were summarized for the period 1992 through 2019. Federal criteria were used to evaluate water quality. Where applicable, water-quality data were also evaluated using U.S. Environmental Protection Agency (EPA) national drinking-water regulations (U.S. Environmental Protection Agency, 2009). Pesticide trends during the study period were also evaluated. Datasets used in this report are available in the associated USGS data release (Stone, 2026).

Continuous and Discrete Water-Chemistry Data Analysis

Continuous streamflow, specific conductance, and turbidity values were obtained using the dataRetrieval package (De Cicco and others, 2025) in the R (version 4.3.0) programming language (R Core Team, 2023) to get unit (hourly) values. Duration curves were used to summarize these 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 and Sedgwick sites during the study period. Duration curves indicate 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 to plot position. Statistical summaries of discrete pesticide data were computed with the Regression on Order Statistics method using the censtats function from the NADA package (Lee, 2020) in the R (version 4.3.0) programming language (R Core Team, 2023).

Annual Pesticide-Use Estimation in the Drainage Basin

Agricultural pesticide-use data were summed for 1992 through 2019 using data from Baker and Stone (2013), Stone (2013), and Wieben (2019, 2021) for selected pesticides. Estimation methods to get data for county-level pesticide use are described in Thelin and Stone (2013). These data include two annual estimates called Epest-low and Epest-high that are variations on estimates that treat missing data differently (Thelin and Stone, 2013). Epest-low considers missing-use reports to be zero use, and Epest-high estimates consider missing-use reports based on surrounding area use (Thelin and Stone, 2013). The 2018 and 2019 use estimates are currently (2026) considered preliminary (Wieben, 2021). Epest-high estimates were used in this report for simplification.

Annual agricultural pesticide use in the Highway 50 and Sedgwick site drainage basins was calculated from 2001 to 2019 by proportioning Epest-high county-level pesticide use estimates to the cropland in each county for counties having any land area in the study drainage basins. A geographic information system was used to estimate cultivated cropland in square miles for Kansas, study drainage basin counties (Ellsworth, Rice, McPherson, Marion, Reno, Harvey, and Sedgwick), study drainage basin areas, and parts of counties within the study drainage basin areas. Cultivated cropland data were downloaded from the USGS National Land Cover Database (Dewitz and U.S. Geological Survey, 2021) for the years 2001, 2004, 2006, 2008, 2011, 2013, 2016, 2019, and 2021. Cultivated cropland area for years in between (2002, 2003, 2005, 2007, 2009, 2010, 2012, 2014, 2015, 2017, 2018, and 2020) were estimated using linear interpolation. Estimated drainage basin pesticide use in study drainage basins was computed as the proportion of cropland in each county that was contained in the drainage basin.

Pesticide Trends

Trends for atrazine (herbicide) were analyzed at the Highway 50 and Sedgwick sites. Trends for glyphosate (herbicide) and AMPA (a degradation product of glyphosate) were analyzed at the Sedgwick site. Pesticide trends were analyzed using SEAWAVE-Q, a parametric regression model that uses a seasonal wave (seawave), adjusts for streamflow (Q), and uses other ancillary variables (Ryberg and Vecchia, 2013; Ryberg and York, 2020). Although discrete pesticide samples collected within 1 to 7 days of each other are typically screened to prevent autocorrelation using SEAWAVE-Q, these occasional samples were retained in the datasets for analysis in this report. The SEAWAVE-Q model is specifically designed for analyzing seasonal- and flow-related variability and trends in pesticide concentration. SEAWAVE-Q is capable of robustly fitting seasonal patterns of pesticides. In addition to including seasonality and streamflow as variables, the SEAWAVE-Q model allows for other continuously measured physicochemical parameters, such as daily mean specific conductance and turbidity, to be included as surrogate variables; however, if daily mean surrogate variable data were missing on a sample day, then those sample data were not used in the model. For SEAWAVE-Q analysis, continuous daily streamflow values were obtained using the importDVs function from the waterData package (Ryberg and Vecchia, 2012) in the R (version 4.3.0) programming language (R Core Team, 2023). Flow anomaly variables were obtained using the compAnom function from the waterData package (Ryberg and

Vecchia, 2012) in the R (version 4.3.0) programming language (R Core Team, 2023). Specific conductance and turbidity values were obtained using the dataRetrieval package (De Cicco and others, 2025) in the R (version 4.3.0) programming language (R Core Team, 2023) to pull unit (hourly) values and then compute daily means from the unit values.

SEAWAVE-Q models that included (1) only seasonality and streamflow variables and (2) seasonality and streamflow variables, daily mean specific conductance, and daily mean turbidity variables were developed for comparison. Three dimensionless streamflow anomalies were included in the SEAWAVE-Q models to account for flow-related pesticide concentration variability: short-term (day-to-day) flow anomaly (STFA), mid-term (30- to 365-day) flow anomaly (MTFA), and long-term (greater than 365 days) flow anomaly (LTFA). Option 1 from the compAnom function of the waterData package (Ryberg and Vecchia, 2012) was selected, which calculated the 1-day, 30-day, and 1-year anomalies for STFA, MTFA, and LTFA, respectively. The Restricted Cubic Spline model option (for long trend periods) and the default 4 knots were selected to model pesticide trends. The SEAWAVE-Q models were fitted to the pesticide data using the seawaveQ (Ryberg and York, 2020) package in the R (version 4.3.0) programming language (R Core Team, 2023). Models were selected that minimized Aikake's Information Criterion (AIC; Akaike, 1974) and maximized the coefficient of determination (R^2). AIC is the model deviance plus two times the number of fitted coefficients, and R^2 is the fraction of the variance explained by regression (Helsel and others, 2020). Pesticide loads were computed using daily SEAWAVE-Q model-computed concentration estimates that were corrected for retransformation bias. Percentage change in starting and ending pesticide concentrations is the trend expressed as a percentage in net change during the period of record (Ryberg and York, 2020). Descriptive statements of trend likelihood were used to assign trend likelihood categories following the methods of Hirsch and others (2015) for water-quality constituent trend analysis using a WRTDS model bootstrap test using the SEAWAVE-Q trend likelihoods and thresholds defined in Hirsch and others (2015).

Quality Assurance and Quality Control

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 and blank samples for discretely collected water-quality samples. Relative percentage difference (RPD) of replicate samples was computed by dividing the absolute value of 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).

Pesticide concentrations reported by NWQL are not corrected for recovery (a measure of how much of a known amount of pesticide is successfully extracted and detected). Martin and others (2009) and Martin and Eberle (2011) provided recovery information from pesticide samples collected from 1992 through 2010 that were analyzed by GCMS using NWQL schedules 2003 and 2033. Modeled temporal changes in recovery for atrazine ranged from about 90 percent in 1992, to about 100 percent in 2006 (Martin and others, 2009), and to about 110 percent in 2010 (Martin and Eberle, 2011). Atrazine concentrations were not adjusted for temporal recovery in this study, but temporal changes in recovery during the study period may have introduced bias in the atrazine data.

Comparisons of cross-sectional measurements collected during discrete sampling throughout the range of streamflow conditions at the Highway 50 and Sedgwick sites verified that there was minimal bias in the continuous data owing to sensor location within the stream cross section. Median RPDs between continuous in situ and average cross-sectional field water-quality monitor measurements from Highway 50 and Sedgwick sites combined were 1 percent for specific conductance and 8 percent for turbidity. Continuous data collected during the study period generally required corrections (such as computations to account for instrument fouling or calibration drift) of less than (<) 10 percent of 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, 5 percent of the specific conductance record, and 6 to 7 percent of the turbidity record were missing or deleted from the datasets for each study site (table 2).

About 10 percent of discrete water-quality samples were QA/QC samples. Sequential, split, and concurrent replicate water-quality samples were collected at the sampling sites during the study period over a range of streamflow conditions. Replicate water-quality samples included 36 pesticide pairs (app. 1, table 1.1). Median replicate pair RPDs for pesticides were less than or equal to 7 percent during the study (table 1.1). 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 pesticide-grade blank water. From 1995 through 2023, 19 atrazine blank samples and 10 glyphosate and AMPA blank samples were collected for this study. Atrazine was detected in 11 percent of blank samples, but detections were at or near the detection limit (table 1.1). Glyphosate and AMPA were not detected in blank samples (table 1.1).

Long-Term Water Quality, Pesticide Use, and Pesticide Trends in the Little Arkansas River

Continuous, near real-time measurement of physicochemical properties enabled characterization of the Little Arkansas River under conditions and at time scales that would not otherwise have been attainable, and these measurements served as surrogates for pesticide modeling. Continued data collection during different flow and seasonal conditions can be used to further characterize water-quality conditions and potentially identify new and changing trends. Surface-water physicochemical properties and water-quality constituents related to pesticide concentrations were used to assess pesticide trends and characterize the quality of any potential recharge water. Discrete stream-water samples were used to describe Little Arkansas River pesticide concentrations from 1995 through 2023. Results of discrete samples measuring pesticides at the Highway 50 and Sedgwick sites on the Little Arkansas River contained in datasets were used with concomitant continuously measured physicochemical parameters (streamflow, specific conductance, and turbidity) to evaluate pesticide trends from 1995 through 2023.

Little Arkansas River Continuous Streamflow, Specific Conductance, and Turbidity

Annual differences in streamflow are primarily attributed to differences in precipitation. Operation of the *Equus* Beds ASR project is only done during above-base-flow conditions in the Little Arkansas River. Streamflow at the Highway 50 and Sedgwick sites ranged from <1 to 13,900 ft^3/s and from <1 to 18,960 ft^3/s, respectively, from 1995 through 2023 (table 2). Mean streamflows during the study period were 207 and 333 ft^3/s at the Highway 50 and Sedgwick sites, respectively (table 2). The ASR phase II water treatment facility at the Sedgwick site requires a minimum streamflow of about 100 ft^3/s to operate. During the study period, 100 ft^3/s was exceeded about 28 percent of the time at the Sedgwick site (fig. 2*A*). Little Arkansas River streamflow values from 1995 through 2023 at the Sedgwick site did not exceed previously reported values from 1995 through 2021 (Tappa and others, 2015; Stone and Klager, 2022, 2023; table 2). Streamflow was highest in May 2019 at the Highway 50 and Sedgwick sites.

Specific conductance is an indirect measure of dissolved solids in water (Hem, 1992). Specific conductance measurements have been commonly used as surrogates, often along with seasonal components, for atrazine at the Highway 50 and Sedgwick sites; specific conductance is

Table 2. Summary statistics for continuously (hourly) measured physicochemical properties in the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey station 07143672), and near Sedgwick, Kansas (Sedgwick; U.S. Geological Survey station 07144100), 1995–2023.

[*n*, number of measurements; <, less than]

Site	*n*	Minimum	Maximum	Mean	Median	Percentage missing or deleted data
Streamflow, in cubic feet per second						
Highway 50 (streamflow)[a]	245,192	<1	13,900	207	22	2
Sedgwick (streamflow)[b]	253,487	<1	18,960	333	52	4
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius						
Highway 50[c]	212,841	57	2,980	903	897	5
Sedgwick[d]	213,045	48	1,910	742	761	5
Turbidity, in formazin nephelometric units[e]						
Highway 50[f]	207,673	0.2	1,292	55	22	6
Sedgwick[g]	206,787	0.1	1,140	56	21	7

[a]Streamflow data collected from May 1995 through December 2023.

[b]Streamflow data collected from January 1995 through December 2023.

[c]Specific conductance data collected from May 1998 through December 2023.

[d]Specific conductance data collected from April 1998 through December 2023.

[e]YSI 6026 and 6136 turbidity sensor data converted to EXO turbidity sensor data using site-specific coefficients in Stone and Klager (2023).

[f]Turbidity data collected using a YSI 6026 turbidity sensor from October 1998 through December 2006, a YSI 6136 turbidity sensor from January 2007 through January 2017, and an EXO turbidity sensor from February 2017 through December 2023.

[g]Turbidity data collected using a YSI 6026 turbidity sensor from September 1998 through June 2004, a YSI 6136 turbidity sensor from July 2004 through August 2014, and an EXO turbidity sensor from September 2014 through December 2023.

inversely related to atrazine concentrations (Christensen and others, 2003; Rasmussen and others, 2016; Stone and Klager, 2022), which may be because larger streamflows dilute specific conductance (Rasmussen and others, 2016) and transport atrazine by runoff (Gilliom and others, 2006). Little Arkansas River mean specific conductance was 903 and 742 microsiemens per centimeter at 25 degrees Celsius during the study period at the Highway 50 and Sedgwick sites, respectively (table 2). Little Arkansas River specific conductance values from 1995 through 2023 did not exceed previously reported ranges from 1995 through 2021 (Tappa and others, 2015; Stone and Klager, 2022, 2023; table 2) at either study site. Specific conductance was between about 500 and 1,000 microsiemens per centimeter during most of the study period at the study sites and varied more at the Highway 50 site (fig. 2*B*).

Turbidity is caused by suspended and dissolved matter such as clay, silt, fine divided organic material, plankton and other microscopic organisms, organic acids, and dyes. Turbidity measurements, along with seasonal components, were previously used as surrogates for atrazine, deethylatrazine, acetochlor, and metolachlor at the

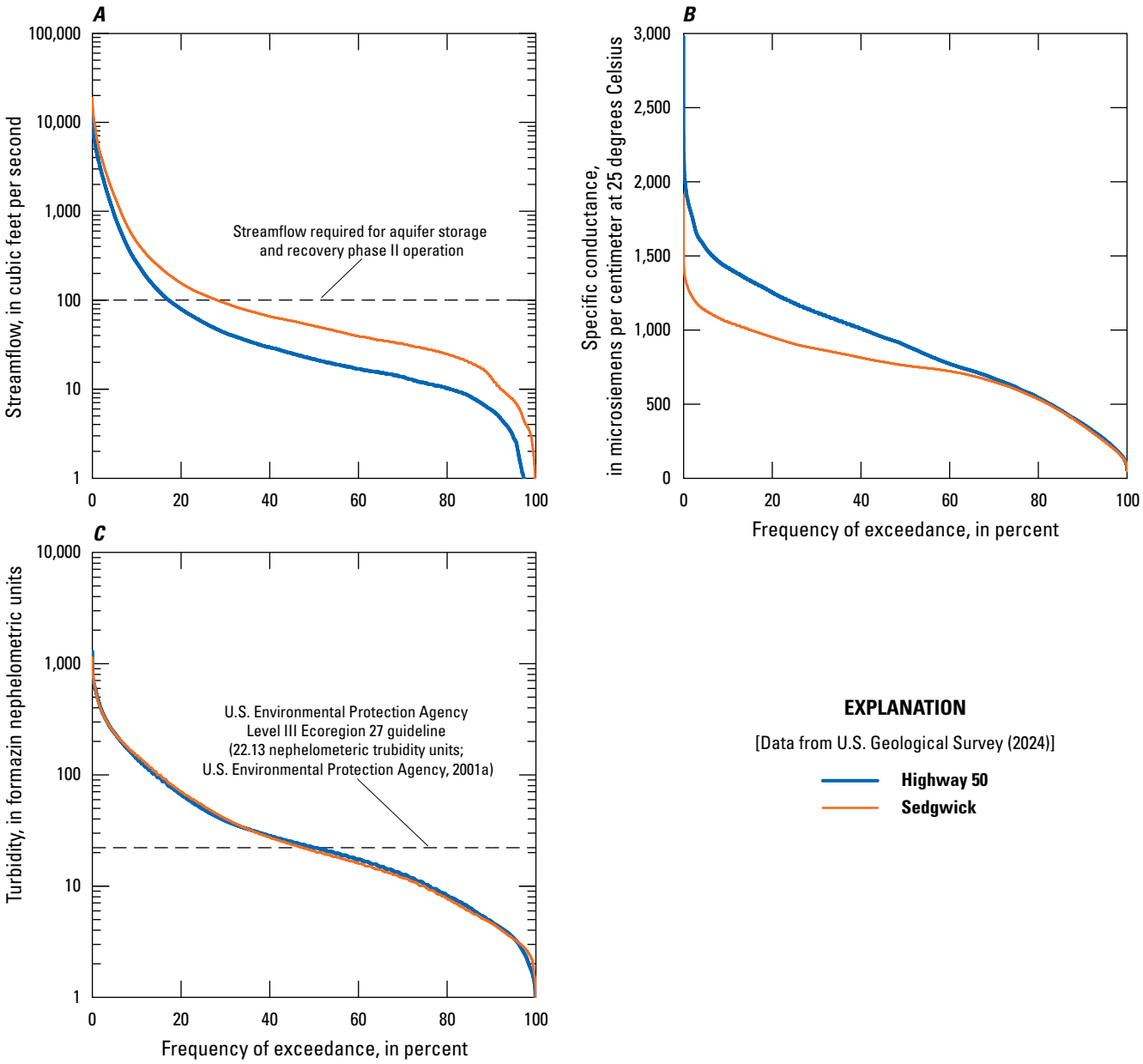


Figure 2. Graphs showing duration curves for continuously (hourly) measured physicochemical properties in the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672, 1995–2021), and near Sedgwick, Kansas (Sedgwick; USGS station 07144100, 1995–2021). *A*, Streamflow. *B*, Specific conductance. *C*, Turbidity. Data are stored in the USGS Water Data for the Nation website (U.S. Geological Survey, 2024).

Highway 50 and Sedgwick sites and AMPA and glyphosate at the Sedgwick site (Stone and Klager, 2023). 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, 2001). Little Arkansas River mean turbidity measurements during the study period at the Highway 50 and Sedgwick sites were 55 and 56 formazin nephelometric units, respectively (table 2). The EPA guidelines for turbidity (22.13) (presented here as a benchmark for comparison because of relative differences in turbidity sensor measurements) were exceeded about 54 and 50 percent of the time at the Highway 50 and Sedgwick sites, respectively, during the study period (fig. 2*C*).

Little Arkansas River Discrete Pesticide Data

Pesticides enter streams from field applications, through irrigation return flow, and from surface runoff in agricultural landscapes. Annual pesticide summaries, including the annual number of samples, are in appendix 2, table 2.1.

Atrazine

Atrazine is a chlorinated triazine synthetic herbicide used to selectively control annual broadleaf weeds and grasses before and after they emerge (Pohanish, 2015). Atrazine is also commonly used on corn and sorghum, which are crops commonly grown in the study area. Atrazine can cause cardiovascular and reproductive problems in humans (U.S. Environmental Protection Agency, 2009). The National Pollutant Discharge Elimination System ASR phase II treatment facility (Kansas permit number: I–LA24–PO01; Federal permit number: KS0099694) required monthly atrazine monitoring during facility operation for the periods 2010–14 and 2015–19. Atrazine affects aquatic plant communities and there is a potential for chronic risk to aquatic invertebrates, amphibians, and fish in areas where atrazine use is substantial (U.S. Environmental Protection Agency, 2016).

Atrazine was detected in all discrete samples collected at the study sites (table 3, table 2.1). The Federal MCL for atrazine is 3 µg/L (U.S. Environmental Protection Agency, 2009) and was exceeded in discrete samples from the Highway 50 and Sedgwick sites (table 3), primarily in the months of May and June. Mean atrazine was 4.05 µg/L and 3.36 µg/L at the Highway 50 and Sedgwick sites, respectively, and concentrations did not exceed previously reported ranges from 1995 through 2021 (Tappa and others, 2015; Stone and others, 2016, 2019; Stone and Klager, 2022, 2023) at either site during the study period (table 3).

Glyphosate and Aminomethylphosphonic Acid

Glyphosate is a broad-spectrum herbicide used to control annual and perennial plants (Pohanish, 2015). Glyphosate can cause kidney problems and reproductive difficulties in humans (U.S. Environmental Protection Agency, 2009). AMPA is a chemical that results from the breakdown of glyphosate. The largest glyphosate and AMPA concentrations were during May, June, and July of the study. The EPA MCL for glyphosate is 700 µg/L (U.S. Environmental Protection Agency, 2009). Glyphosate and AMPA were detected in all the samples collected during the study but were analyzed only for the Sedgwick site. During the study period, glyphosate concentrations ranged from 0.050 to 7.80 µg/L, and AMPA concentrations ranged from 0.290 to 4.30 µg/L (table 3). Mean concentrations of glyphosate and AMPA were 0.934 and 1.45 µg/L, respectively (table 3); these concentrations are substantially larger than the median annual averages (0.09 µg/L and 0.35 µg/L, respectively) for Midwest streams during 2015 through 2017 (Medalie and others, 2020). Glyphosate and AMPA concentration ranges reported in this study did not exceed the ranges previously reported (Stone and Klager, 2023; table 3).

Estimated Pesticide Use in Study Drainage Basin

Data for pesticide use and crop area in the study drainage basin are in appendixes 3–7, figures 7.1 and tables 3.1–6.2, data for pesticide use in Kansas and the study drainage basin counties from 1992 through 2019 are in tables 3.1, 3.2, 3.3, and figure 4.1, crop-area data from 2001 through 2021 are in table 5.1 and 5.2, and data for drainage basin pesticide use from 2001 through 2019 are in figure 7.1 and tables 6.1 and 6.2. Atrazine and glyphosate are the pesticides with the largest use in Kansas and the study drainage basin counties from 1992 through 2019 (Stone, 2013; Baker and Stone, 2013; Wieben, 2019, 2021). Atrazine use was about 79 percent larger in the Sedgwick drainage basin than the Highway 50 drainage basin and was variable from 2001 to 2019 (fig. 7.1*A*, tables 6.1 and 6.2), whereas atrazine use in Kansas as a whole generally increased from 1992 to 2019 (tables 3.1, 3.2, 3.3, and fig. 4.1). Glyphosate use in the Sedgwick site drainage basin had a substantial increase from 2001 through 2019 of about 300 percent (high estimate; fig. 7.1*B*, tables 6.1 and 6.2). Glyphosate use in Kansas increased substantially from 1992 to 2019; the increase was about 30-fold from 298,605 kilograms in 1992 to 9,438,361 kilograms in 2019 (tables 3.1, 3.2, 3.3, and fig. 4.1).

Table 3. Water-quality constituent summary statistics from discrete samples from the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and near Sedgwick, Kansas (Sedgwick; USGS station 07144100), 1995–2023. Data are stored in the USGS Water Data for the Nation website (U.S. Geological Survey, 2024).—Left

[USGS, U.S. Geological Survey; *n*, number of measurements; EPA, U.S. Environmental Protection Agency; PDWR, Primary Drinking Water Regulations; MCL, maximum contaminant level; --, no data]

Water-quality constituent	USGS parameter code	USGS observed property	*n*	Minimum
Physicochemical water-quality constituents				
Highway 50				
Streamflow, in cubic feet per second	00061	Discharge, instantaneous	243	0.11
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	00095	Specific conductance, water, unfiltered, normalized to 25 degrees Celsius	172	77
Turbidity, in formazin nephelometric units	63680	Turbidity (nephelometry), monochrome near-infrared (NIR) light-emitting diode (LED) light source (780 nanometers to 900 nanometers), detection angle 87.5 degrees to 92.5 degrees	143	4
Sedgwick				
Streamflow, in cubic feet per second	00061	Discharge, instantaneous	409	1.40
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	00095	Specific conductance, water, unfiltered, normalized to 25 degrees Celsius	317	54
Turbidity, in formazin nephelometric units	63680	Turbidity (nephelometry), monochrome near-infrared (NIR) light-emitting diode (LED) light source (780 nanometers to 900 nanometers), detection angle 87.5 degrees to 92.5 degrees	289	3
Pesticides				
Highway 50				
Atrazine (herbicide), in micrograms per liter	39632	Atrazine, water, filtered, recoverable	131	0.018
Sedgwick				
Atrazine (herbicide), in micrograms per liter	39632	Atrazine, water, filtered, recoverable	146	0.020
Glyphosate (herbicide), in micrograms per liter	62722	Glyphosate, water, filtered, recoverable	171	0.050
Aminomethylphosphonic acid (AMPA, herbicide glyphosate degradate), in micrograms per liter	62649	Aminomethylphosphonic acid (AMPA), water, filtered, recoverable	170	0.290

Table 3. Water-quality constituent summary statistics from discrete samples from the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and near Sedgwick, Kansas (Sedgwick; USGS station 07144100), 1995–2023. Data are stored in the USGS Water Data for the Nation website (U.S. Geological Survey, 2024). —Right

[USGS, U.S. Geological Survey; *n*, number of measurements; EPA, U.S. Environmental Protection Agency; PDWR, Primary Drinking Water Regulations; MCL, maximum contaminant level; --, no data]

Water-quality constituent	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile	EPA PDWR MCL[a]
Physicochemical water-quality constituents									
Highway 50									
Streamflow, in cubic feet per second	10,500	737	73.0	1,584	102.0	2.1	20.1	643	--
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	2,020	670	572	432	33.1	0.7	291	972	--
Turbidity, in formazin nephelometric units	1,610	267	126	326	27.4	1.22	32.6	380	--
Sedgwick									
Streamflow, in cubic feet per second	16,100	1,107.0	95.3	2,550	127.0	2.3	33.0	511	--
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	1,350	597	682	295	16.6	0.5	308	805	--
Turbidity, in formazin nephelometric units	2,090	149	47.2	258	15.3	1.73	18.0	150	--
Pesticides									
Highway 50									
Atrazine (herbicide), in micrograms per liter	30.0	4.05	1.37	5.98	0.522	1.48	0.216	5.53	3
Sedgwick									
Atrazine (herbicide), in micrograms per liter	30.1	3.36	1.22	5.15	0.426	1.53	0.186	4.66	3
Glyphosate (herbicide), in micrograms per liter	7.80	0.934	0.550	1.17	0.090	1.25	0.225	1.20	700
Aminomethylphosphonic acid (AMPA, herbicide glyphosate degradate), in micrograms per liter	4.30	1.45	1.40	0.761	0.058	0.526	0.808	2.00	--

[a]U.S. Environmental Protection Agency (2009).

SEAWAVE-Q Models, Computed Concentrations, and Trends

SEAWAVE-Q was used to develop models, compute continuous concentrations, and assess trends for atrazine at the Highway 50 and Sedgwick study sites and glyphosate and AMPA at the Sedgwick site only. SEAWAVE-Q trend analysis output is shown in appendix 8, figures 8.1–8.4. SEAWAVE-Q models that used streamflow as the sole explanatory variable had 4 to 49 percent larger AIC values and the same or smaller generalized R^2 values than models that used specific conductance and turbidity as additional potential explanatory variables (table 4); discussion about SEAWAVE-Q models is focused on models that used additional explanatory variables. Pesticide loads are in appendixes 9 and 10, table 9.1 and figure 10.1. Trend results are presented using a likelihood-categorization approach as an alternative to null-hypothesis significance testing following the methods of Hirsch and others (2015). The likelihood-categorization approach provides more intuitive information about the certainty of a trend estimate by presenting a probability category of a trend direction. This approach avoids concluding that there is no trend associated with nonsignificant probability values; for example, trend results where the null hypothesis is not rejected may still be indicative of increasing or decreasing trends.

Atrazine

Atrazine is consistently one of the most frequently detected pesticides in the Nation's rivers and streams (Gilliom, 2007; Stone and others, 2014; Stackpoole and others, 2021; Shoda and others, 2026). The SEAWAVE-Q models using streamflow and additional timeseries data selected for atrazine included explanatory variables streamflow, turbidity, STFA, MTFA, and LTFA at the Highway 50 site and streamflow, specific conductance, turbidity, STFA, MTFA, and LTFA at the Sedgwick site (table 4). The amount of variance explained by the SEAWAVE-Q atrazine models was 64 to 66 percent (table 4). Surrogate regression models for atrazine at the Highway 50 and Sedgwick sites published in Stone and Klager (2023) included turbidity and seasonal components as explanatory variables, and the amount of variance explained by these models was 58 to 69 percent at the Highway 50 and Sedgwick sites, respectively.

SEAWAVE-Q computed atrazine concentrations ranged from 0.006 to 20.6 µg/L with a mean of 0.954 µg/L from October 1998 through December 2023 at the Highway 50 site and from 0.051 to 21.1 µg/L with a mean of 1.15 µg/L from September 1998 through December 2023 at the Sedgwick site (table 5). SEAWAVE-Q computed atrazine concentrations exceeded the Federal MCL of 3.0 µg/L about 8 percent of the time at both study sites from 1998 to 2023 (fig. 3), and this typically happened at both sites during May and June. SEAWAVE-Q computed atrazine concentrations for this study had relatively similar maxima (within 5 percent) and relatively smaller means (21 to 36 percent smaller) and MCL exceedances (25 percent smaller) than those computed previously using surrogate regression models (Stone and Klager, 2023) during the same periods. SEAWAVE-Q computed atrazine concentrations at the Highway 50 site ranged from 0.041 to 12.0 µg/L (mean=0.699 µg/L) and exceeded the Federal MCL about 3 percent of the time in comparison with previously published surrogate regression-computed atrazine concentrations that ranged from 0.034 to 12.0 µg/L (mean=1.10 µg/L) and exceeded the Federal MCL about 10 percent of the time from 2017 through 2021 (table 5; Stone and Klager, 2023). SEAWAVE-Q computed atrazine concentrations at the Sedgwick site ranged from 0.088 to 12.1 µg/L (mean=0.883 µg/L) and exceeded the Federal MCL about 4 percent of the time in comparison with previously published surrogate regression-computed atrazine concentrations that ranged from 0.030 to 11.6 µg/L (mean=1.12 µg/L) and exceeded the Federal MCL about 10 percent of the time from 2014 through 2021 (table 5; Stone and Klager, 2023).

Atrazine trends were inconsistent between study sites. Atrazine had an increasing trend at the Highway 50 site that was highly likely to occur and a decreasing trend at the Sedgwick site that was likely to occur during the study period; neither of these trends were statistically significant (table 6, fig. 4*A*, *B*). However, the atrazine trend at the Sedgwick site did not appear to follow atrazine use, which did not change substantially in the study drainage basin from 2001 to 2019 (figs. 7.1*A*, 8.2). Atrazine concentrations increased by 98 percent at the Highway 50 site and decreased by 31 percent at the Sedgwick site from 1998 through 2023 (table 6). Atrazine concentrations showed a strong seasonal pattern (fig. 4*A*, *B*), with larger estimated concentrations happening in late spring and early summer. Decreasing atrazine trend results at the Sedgwick site during this study are consistent with the decreasing atrazine trend results at most of the sites studied for national pesticide trend assessments (Ryberg and others, 2014; Ryberg and Gilliom, 2015; Oelsner and others, 2017; Shoda and others, 2026). Differences in long-term water-quality constituent trend directions between the Highway 50 and Sedgwick sites are not uncommon (Stone and Klager, 2022). Sulfate, nitrate plus nitrite, and total phosphorus had different concentration trend directions at the study sites from 1996 to 2021. Sulfate had a decreasing trend at the Highway 50 site and an increasing trend at the Sedgwick site; nitrate plus nitrite and total phosphorus had increasing trends at the Highway 50 site and decreasing trends at the Sedgwick site (Stone and Klager, 2022).

Kansas has been underrepresented in efforts that have quantified pesticide trends in rivers and streams across the Nation and regionally (Sullivan and others, 2009; Ryberg and others, 2010, 2014; Oelsner and others, 2017) until recently (Shoda and others, 2026). Atrazine trend results in this study generally follow those found across the Nation (Ryberg and others, 2014; Ryberg and Gilliom, 2015; Oelsner and others, 2017; Shoda and others, 2026). Average atrazine

Table 4. SEAWAVE-Q (Ryberg and Vecchia, 2013; Ryberg and York, 2020) model summaries for samples taken at the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey station 07143672), and near Sedgwick, Kansas (Sedgwick; U.S. Geological Survey station 07144100), 1996–2023. Data are from Stone (2026).

[Dates given in month/day/year. *n*, number of samples; AIC, Akaike's information criterion (Akaike, 1974); R^2, coefficient of determination; KS, Kansas; Q, streamflow; STFA, short-term flow anomalies; MTFA, mid-term flow anomalies; LTFA, long-term flow anomalies; SC, specific conductance; TBY, turbidity]

Modeled pesticide	Explanatory variables	Start date	End date	*n*	AIC	Generalized R^2
Little Arkansas River at Highway 50 near Halstead, KS (07143672) streamflow-only model						
Atrazine	Q, STFA, MTFA, LTFA	5/14/1996	8/30/2023	126	208	0.62
Little Arkansas River at Highway 50 near Halstead, KS (07143672) streamflow and additional timeseries model						
Atrazine	Q, TBY, STFA, MTFA, LTFA	11/6/1998	8/30/2023	116	186	0.64
Little Arkansas River near Sedgwick, KS (07144100) streamflow-only model						
Atrazine	Q, STFA, MTFA, LTFA	3/19/1996	8/31/2023	141	202	0.66
Glyphosate	Q, STFA, MTFA, LTFA	3/13/2015	12/7/2023	148	36	0.68
Aminomethyl-phosphonic acid (AMPA)	Q, STFA	4/10/2014	12/7/2023	170	−209	0.75
Little Arkansas River near Sedgwick, KS (07144100) streamflow and additional timeseries model						
Atrazine	Q, SC, TBY, STFA, MTFA, LTFA	11/5/1998	8/31/2023	134	190	0.66
Glyphosate	Q, SC, TBY, STFA, MTFA, LTFA	4/17/2015	12/7/2023	138	24	0.72
Aminomethyl-phosphonic acid (AMPA)	Q, SC	4/10/2014	12/7/2023	162	−218	0.78

Table 5. Summary statistics for continuously (daily) computed SEAWAVE-Q (Ryberg and Vecchia, 2013; Ryberg and York, 2020) pesticides for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey station 07143672), and near Sedgwick, Kansas (Sedgwick; U.S. Geological Survey station 07144100), 1998–2023. Data are from Stone (2026).

[*n*, number of measurements]

Site	Date range	*n*	Minimum	Maximum	Mean	Median
Atrazine (herbicide), in micrograms per liter						
Highway 50	October 1998–December 2023	8,780	0.006	20.6	0.954	0.203
Highway 50	January 2017–December 2021	1,810	0.041	12.0	0.699	0.179
Sedgwick	September 1998–December 2023	8,742	0.051	21.1	1.15	0.282
Sedgwick	September 2014–December 2021	2,428	0.088	12.1	0.883	0.266
Glyphosate (herbicide), in micrograms per liter						
Sedgwick	March 2015–December 2023	3,059	0.073	4.04	0.528	0.314
Sedgwick	March 2015–December 2021	2,335	0.073	4.0	0.543	0.326
Aminomethylphosphonic acid (AMPA, degradation product of herbicide glyphosate), in micrograms per liter						
Sedgwick	March 2014–December 2023	3,441	0.337	3.45	1.18	0.975
Sedgwick	September 2014–December 2021	2,544	0.337	3.30	1.14	0.951

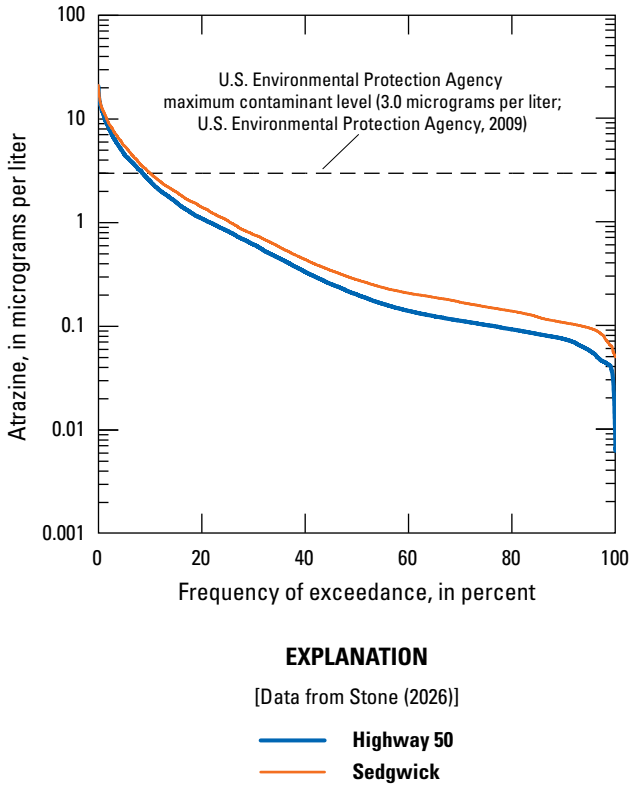


Figure 3. Graph showing duration curves for continuously (daily) computed SEAWAVE-Q (Ryberg and Vecchia, 2013; Ryberg and York, 2020) atrazine concentrations in the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey station 07143672), and near Sedgwick, Kansas (Sedgwick; U.S. Geological Survey station 07144100), 1998–2023. Data are from Stone (2026).

concentrations at the Little Arkansas River study sites were commonly substantially greater (tables 3 and 5) in comparison with those reported by Ryberg and others (2017), and both measured and model-computed atrazine concentrations in this study exceeded the MCL more frequently. National atrazine trends were assessed in Ryberg and others (2014), Ryberg and Gilliom (2015) and Oelsner and others (2017) using SEAWAVE-Q. Pesticides that were used predominately in agricultural settings, such as atrazine, had similar riverine concentration and use trends and represent pesticide application in agricultural settings (Ryberg and others, 2014). Ryberg and others (2014) found that instream atrazine concentration trends were generally consistent with use trends, which declined from 2003 to 2010. Ryberg and Gilliom (2015) found decreasing atrazine trends at most sites in the Mississippi River region from 1992 to 2010. Oelsner and others (2017) found increasing atrazine trends at 21 sites and decreasing atrazine trends at 53 sites across the United States from 1992 to 2012. Breitmeyer and others (2026) described atrazine trends that were decreasing at 60 percent and increasing at 40 percent of 45 sites across the conterminous United States during 2013–22; 2 of the 45 study sites were in Kansas, included the Sedgwick site, and had nonsignificant increasing atrazine trends during 2013–22 (Breitmeyer and others, 2026).

Although both study sites had strong seasonal patterns and interannual variability in their atrazine concentrations, atrazine concentrations regularly (about 8 percent of the time) exceeded 3 µg/L over the study period (fig. 3). Despite the lack of significant changes in atrazine concentrations over time at the Little Arkansas River study sites, trend analysis during targeted flow conditions could help identify the drivers of long-term water quality, including changes in pesticide concentrations. Given the challenges associated with quantifying BMP effectiveness, future study efforts in the Little Arkansas River drainage basin could be focused on smaller drainage basins in the study area and include consistent and long-term discrete pesticide sampling and accompanying in situ water-quality monitoring to better quantify BMP effectiveness.

Glyphosate and Aminomethylphosphonic Acid

Glyphosate is one of the most widely used herbicides in the United States and worldwide, and its use has increased substantially since its introduction in 1974, particularly after the introduction of glyphosate-resistant crops (Richmond, 2018; Duke, 2020). Glyphosate use is expected to continue to increase in the United States (Richmond, 2018). The selected SEAWAVE-Q glyphosate model in this study used streamflow, specific conductance, turbidity, STFA, MTFA, and LTFA as explanatory variables, and the amount of variance explained by the SEAWAVE-Q model was 72 percent (generalized R^2 of 0.72; table 4). A previously developed glyphosate surrogate regression model used for the Sedgwick site used turbidity and seasonal components as explanatory variables and had an adjusted R^2 value of 0.59 (Stone and Klager, 2023). SEAWAVE-Q computed glyphosate concentrations for this study had relatively smaller minima (32 percent smaller), maxima (30 percent smaller), and mean concentrations (20 percent smaller) than those computed previously with surrogate regression models (Stone and Klager, 2023) during similar periods (March 2015 through December 2021 for this study [table 5] compared with September 2014 through December 2021 for Stone and Klager [2023]). Previously published surrogate regression-computed glyphosate concentrations ranged from 0.108 to 5.81 µg/L (mean=0.662 µg/L) from September 2014 through December 2021 at the Sedgwick site (Stone and Klager, 2023). Computed glyphosate concentrations for this study ranged from 0.073 to 4.04 µg/L with a mean value of 0.528 µg/L from 2015 to 2023 (table 5). Larger computed glyphosate concentrations occurred during June and July. Computed glyphosate concentrations at the Sedgwick site never exceeded the Federal MCL of 700 µg/L during the study (table 5; fig. 5*A*).

Table 6. SEAWAVE-Q (Ryberg and Vecchia, 2013; Ryberg and York, 2020) model trend test results for pesticides in the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey station 07143672), and near Sedgwick, Kansas (Sedgwick; U.S. Geological Survey station 07144100), 1995–2023. Data are from Stone (2026).

[USGS, U.S. Geological Survey; *p*, probability; Q, discharge; TBY, turbidity; STFA, short-term flow anomalies; MTFA, mid-term flow anomalies; LTFA, long-term flow anomalies; SC, specific conductance]

Modeled pesticide	USGS parameter code	Explanatory variables	Starting concentration (in micrograms per liter)	Ending concentration (in micrograms per liter)	Percentage change in starting and ending concentration	*p*-value	Trend likelihood	Trend likelihood descriptor (Hirsch and others, 2015)	Trend direction
				Highway 50					
Atrazine	39632	Q, TBY, STFA, MTFA, LTFA	0.386	0.765	98	0.10	0.95	Highly likely	Increasing
				Sedgwick					
Atrazine	39632	Q, SC, TBY, STFA, MTFA, LTFA	1.555	1.069	−31	0.61	0.70	Likely	Decreasing
Glyphosate	62722	Q, SC, TBY, STFA, MTFA, LTFA	1.931	1.689	−13	0.86	0.57	About as likely as not	Decreasing
Aminomethylphosphonic acid (AMPA)	62649	Q, SC	2.424	2.324	−4	0.86	0.57	About as likely as not	Decreasing

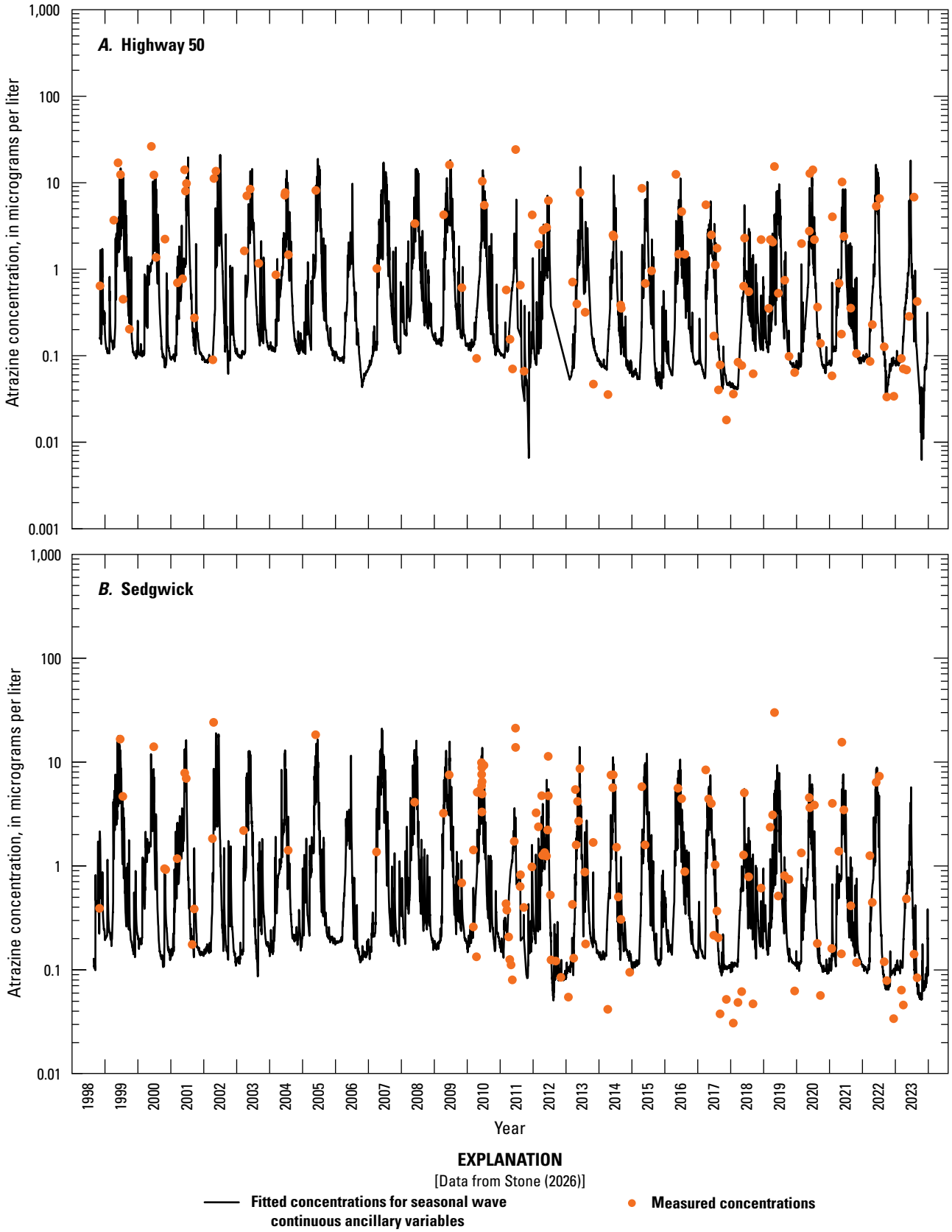
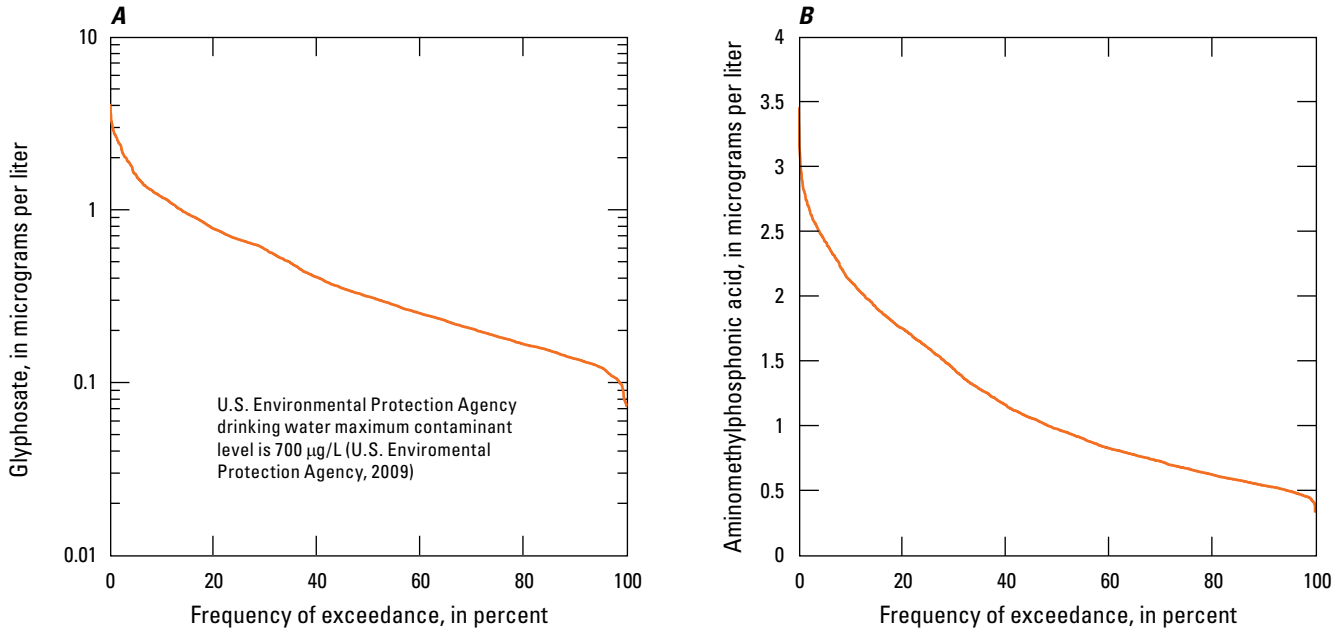


Figure 4. Graphs showing SEAWAVE-Q (Ryberg and Vecchia, 2013; Ryberg and York, 2020) trend analysis output of measured and fitted atrazine concentrations and trend line for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey station 07143672), and near Sedgwick, Kansas (Sedgwick; U.S. Geological Survey station 07144100), 1998–2023. *A*, Highway 50. *B*, Sedgwick. Data are from Stone (2026).



Data from Stone (2026)

Figure 5. Graphs showing duration curves for continuously (daily) computed SEAWAVE-Q (Ryberg and Vecchia, 2013; Ryberg and York, 2020) pesticide concentrations in the Little Arkansas River near Sedgwick, Kansas (Sedgwick; U.S. Geological Survey station 07144100), 2015–23. *A*, Glyphosate. *B*, Aminomethylphosphonic acid (AMPA). Data are from Stone (2026).

The AMPA model in this study included streamflow and specific conductance as explanatory variables, and the amount of variance in AMPA concentration explained by the model was 78 percent (table 4). Stone and Klager (2023) developed an AMPA surrogate relation for the Sedgwick site using turbidity and seasonal variables as explanatory variables; the amount of variance in AMPA concentrations explained by this (Stone and Klager, 2023) previously developed AMPA model was 76 percent. SEAWAVE-Q model-computed AMPA concentrations for this study ranged from 0.337 to 3.45 µg/L and had a mean of 1.18 µg/L during March 2014 through December 2023 (table 5). SEAWAVE-Q computed AMPA concentrations for this study had relatively smaller minimum values (20 percent smaller), larger maximum values (22 percent larger), and similar average values (<1 percent) than those computed previously using surrogate regression models for the same period (September 2014 through December 2021; Stone and Klager, 2023). Previously published surrogate regression-computed AMPA concentrations ranged from 0.425 to 2.82 µg/L (mean=1.19 µg/L) during September 2014 through December 2021 at the Sedgwick site (Stone and Klager, 2023).

Trends in glyphosate and AMPA concentrations were not detected; decreasing trends were about as likely as not to occur and were not significant (table 6). No substantial glyphosate use changes were detected during the coinciding years of available glyphosate use data and trend analysis (2015–19); however, from 1992 through 2019, the Sedgwick drainage basin counties had substantial glyphosate use increases (app. 7 and 8, figs. 7.1*B*, 8.3) and so did Kansas as a whole (app. 4 and 5, fig. 4.1 and tables 5.1 and 5.2). The measured and computed glyphosate concentrations showed a strong seasonal pattern, with larger estimated concentrations in early summer months of June and July (fig. 6*A*). AMPA concentrations decreased by 4 percent from 2014 to 2023 (table 6, fig. 6*B*).

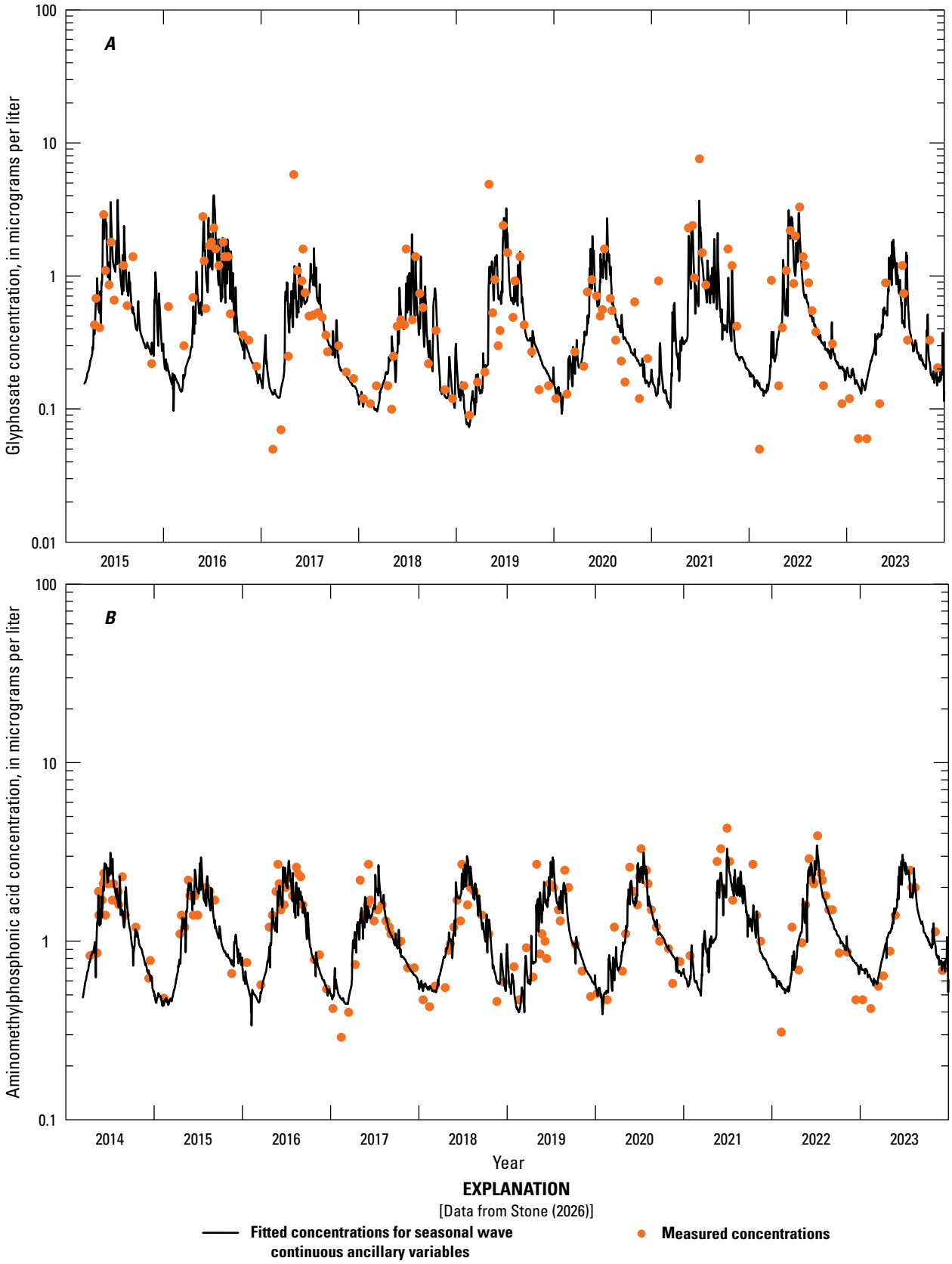


Figure 6. Graphs showing SEAWAVE-Q (Ryberg and Vecchia, 2013; Ryberg and York, 2020) trend analysis output of measured and fitted pesticide concentrations and a trend line for the Little Arkansas River near Sedgwick, Kansas (Sedgwick; U.S. Geological Survey station 07144100), 2015–23. *A*, Glyphosate. *B*, Aminomethylphosphonic acid (AMPA). Data are from Stone (2026).

Summary

The *Equus* beds aquifer and Cheney Reservoir are currently (2025) primary sources of water for the city of Wichita. The *Equus* Beds Aquifer Storage and Recovery Project was developed in the early 1990s to meet the future water demands of the city of Wichita using the Little Arkansas River as an artificial aquifer recharge source when the river had above-base-flow conditions. Little Arkansas River water is removed from an aquifer storage and recovery facility intake structure, treated according to National Primary Drinking Water Regulations, and infiltrated into the 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. The purpose of this report is to document Little Arkansas River water quality and to characterize and quantify pesticide trends from 1995 through 2023. 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. The methods and results in this report can provide guidance and perspective for aquifer recharge projects done nationally.

The study area is in south-central Kansas northwest of Wichita with two study sites along the Little Arkansas River: the Little Arkansas River at Highway 50 near the Halstead, Kans., streamgage (U.S. Geological Survey station 07143672; hereafter referred to as the "Highway 50 site") located about 16.4 river miles upstream from the Little Arkansas River near the Sedgwick, Kansas, streamgage (U.S. Geological Survey station 07144100; hereafter referred to as the "Sedgwick site"). These two sites bracket a substantial part of the easternmost area of the *Equus* beds aquifer. Land use in the study area is primarily agricultural, and herbicides are commonly applied. The Kansas Department of Health and Environment has listed several streams in the Little Arkansas River drainage basin as having atrazine impairments.

Continuous streamflow, specific conductance, turbidity, and discrete pesticide data were collected over a range of streamflow conditions from the two Little Arkansas River study sites from 1995 through 2023 to evaluate water-quality conditions. Duration curves were used to summarize continuously measured Little Arkansas River water-quality data. Annual agricultural pesticide use for the Highway 50 and Sedgwick site drainage basins was calculated by proportioning previously published county-level pesticide-use estimates to the cropland in each county for counties having any land area in the study drainage basins.

Pesticide trends in samples from the Highway 50 and Sedgwick sites were analyzed for atrazine (herbicide) and in samples at the Sedgwick site for glyphosate (herbicide) and aminomethylphosphonic acid (degradation product of herbicide glyphosate). Pesticide trends were analyzed using SEAWAVE-Q, a parametric regression model that uses a seasonal wave, an adjustment for streamflow, and other ancillary variables. Pesticide loads were computed using daily SEAWAVE-Q model-computed concentration estimates.

The aquifer storage and recovery phase II water treatment facility requires a minimum streamflow of about 100 cubic feet per second (ft^3/s) to operate at the Sedgwick site; this operational guideline was exceeded about 28 percent of the time. Streamflow reached its maxima (13,900 ft^3/s at the Highway 50 site and 18,960 ft^3/s at the Sedgwick site) in May 2019. Little Arkansas River continuous specific conductance values measured in this study did not exceed previously reported ranges. The study sites had measurements that exceeded the EPA level III ecoregion 27 guideline of 22.13 nephelometric turbidity units about half the time during the study period.

Concentration ranges of discrete pesticide samples did not exceed previously reported ranges, but did exceed EPA guidelines during the late spring and early summer months. Atrazine was detected in all discrete samples from the study sites and frequently exceeded the Federal maximum contaminant level (MCL) of 3.0 micrograms per liter. The Federal MCL for glyphosate was not exceeded in discrete samples at either site during the study.

Pesticide concentrations had strong seasonal patterns and larger model-computed pesticide concentrations and associated criteria exceedances occurred during late spring and early summer. Modeled pesticides had increasing and decreasing trends during the study, although no trends were statistically significant. Computed atrazine concentrations exceeded the Federal MCL of 3.0 micrograms per liter about 8 percent of the time at both study sites. Atrazine was very likely to have had an increasing trend at the Highway 50 site (98 percent change) and a decreasing trend at the Sedgwick site (−31 percent change) during the study period. Atrazine use varied in the study drainage basins, whereas atrazine use in Kansas generally increased during the study period. Model-computed glyphosate concentrations at the Sedgwick site never exceeded, and were often orders of magnitude below, the Federal MCL of 700 micrograms per liter during the study. Glyphosate and aminomethylphosphonic acid trends were not evident during the study, and no substantial glyphosate use changes occurred during the coinciding years of available glyphosate use data and trend analysis (2015–19); however, glyphosate use substantially increased (300 percent) in the Sedgwick drainage basin from 1992 through 2019.

Continuous measurement of physicochemical properties related to pesticides in near real-time enabled characterization of the Little Arkansas River surface water under conditions and time scales that would not otherwise have been attainable and served as a complement to discrete water-quality sampling. Continuing to monitor water quality in the Little Arkansas River could provide data that characterize evolving conditions in the river to possibly identify new and changing trends. Information in this report will help the city of Wichita make informed municipal water-supply decisions using past and present data of water-quality conditions and trends in the drainage basin.

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Appendix 1. Quality Assurance and Quality Control

Table 1.1. Relative percentage differences for discrete replicate pairs and detection percentages for blank discrete water-quality samples from Little Arkansas River sites near Sedgwick, Kansas, 1995–2023. Data are stored in the U.S. Geological Survey Water Data for the Nation website (U.S. Geological Survey, 2024).

[*n*, number of measurement pairs; blank *n*, number of blank measurements; det *n*, number of detections in blanks; det %, detection percentage in blanks]

Water-quality constituent	Relative percentage difference					Blanks		
	n	Minimum	Maximum	Mean	Median	Blank *n*	Det *n*	Det %
Organic compounds								
Atrazine, in micrograms per liter	16	0	12	5	4	19	2	11
Glyphosate, in micrograms per liter	10	0	14	7	7	10	0	0
Aminomethylphosphonic acid, in micrograms per liter	10	0	25	9	7	10	0	0

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Appendix 2. Annual Discrete Pesticide Summary Statistics

Table 2.1. Annual water-quality constituent summary statistics from discrete samples from the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672), and near Sedgwick, Kansas (Sedgwick; USGS station 07144100), 1995–2023. Data are stored in the USGS Water Data for the Nation website (U.S. Geological Survey, 2024).

[*n*, number of samples; med, median; --, not applicable]

Year	Atrazine						Glyphosate			Aminomethylphosphonic acid (AMPA)		
	Highway 50			Sedgwick			Sedgwick			Sedgwick		
	n	Mean	Med	*n*	Mean	Med	*n*	Mean	Med	*n*	Mean	Med
1995	4	8.41	1.79	4	1.20	0.595	0	--	--	0	--	--
1996	2	3.43	3.43	2	0.052	0.157	0	--	--	0	--	--
1997	4	11.6	11.0	1	22.1	22.1	0	--	--	0	--	--
1998	4	5.31	1.66	1	0.392	0.392	0	--	--	0	--	--
1999	5	7.22	3.69	2	10.7	10.7	0	--	--	0	--	--
2000	4	10.6	7.27	3	5.32	0.944	0	--	--	0	--	--
2001	6	5.61	4.39	5	3.32	1.18	0	--	--	0	--	--
2002	3	8.30	11.2	2	13.0	13.0	0	--	--	0	--	--
2003	4	4.58	4.35	1	2.20	2.20	0	--	--	0	--	--
2004	4	4.30	4.33	1	1.42	1.42	0	--	--	0	--	--
2005	1	8.15	8.15	1	18.4	18.4	0	--	--	0	--	--
2006	0	--	--	0	--	--	0	--	--	0	--	--
2007	1	1.02	1.02	1	1.37	1.37	0	--	--	0	--	--
2008	1	3.37	3.37	1	4.12	4.12	0	--	--	0	--	--
2009	3	6.99	4.26	3	3.83	3.23	0	--	--	0	--	--
2010	3	5.33	5.50	13	5.28	5.27	0	--	--	0	--	--
2011	7	4.28	0.576	16	2.60	0.389	0	--	--	0	--	--
2012	5	2.81	2.830	13	2.58	1.35	0	--	--	0	--	--
2013	6	1.92	0.554	11	2.36	1.60	0	--	--	0	--	--
2014	5	1.13	0.385	8	2.90	1.01	21	1.60	0.980	21	1.57	1.70
2015	3	3.42	0.958	2	3.71	3.71	19	0.820	0.660	19	1.36	1.40
2016	4	5.03	3.06	4	5.77	5.04	21	1.16	1.20	21	1.61	1.60
2017	8	1.40	0.645	9	2.09	0.369	18	0.782	0.425	18	1.22	1.25
2018	8	0.742	0.317	8	0.994	0.338	18	0.437	0.320	17	1.17	1.10
2019	8	2.68	0.637	8	4.76	0.778	18	0.894	0.410	18	1.29	0.980
2020	7	4.91	2.20	6	2.28	2.50	18	0.486	0.415	18	1.46	1.20
2021	8	2.25	0.522	8	2.89	0.903	10	0.975	1.35	10	1.45	2.35
2022	7	1.78	0.127	7	2.24	0.447	17	0.942	0.880	17	1.62	1.50
2023	6	1.29	0.189	5	0.164	0.084	11	0.377	0.205	11	1.15	0.880

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Appendix 3. Total Pesticide Use

Table 3.1. Estimated pesticide use in Kansas and selected counties in Kansas, 1992–2001. Data are from Baker and Stone (2013), Stone (2013), and Wieben (2019, 2021).

[Epest-high, method estimates missing-use reports based on surrounding area use (Thelin and Stone, 2013).]

Land area	Pesticide use (Epest-high) in kilograms									
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
					Atrazine					
Ellsworth County	16,999	9,643	16,538	15,263	17,957	19,522	19,364	24,450	17,546	15,064
Harvey County	24,922	28,656	33,925	38,050	42,909	33,659	41,452	29,584	38,808	40,542
McPherson County	62,549	22,946	51,866	42,660	43,827	55,932	45,339	57,608	44,805	42,597
Marion County	74,880	32,310	62,893	44,091	49,463	54,283	46,854	58,864	43,438	37,883
Reno County	29,113	29,988	37,752	42,028	55,622	37,815	45,877	32,954	44,506	46,212
Rice County	62,780	25,606	52,433	40,400	45,274	52,368	46,618	58,020	40,691	35,715
Sedgwick County	24,799	26,546	34,647	41,172	40,070	34,867	37,116	28,872	41,062	42,417
Study drainage basin counties	296,043	175,694	290,053	263,664	295,122	288,445	282,620	290,351	270,855	260,429
All Kansas counties	2,883,268	2,503,395	2,570,226	2,735,848	3,370,325	3,372,783	3,101,544	3,643,967	3,578,149	3,333,710
					Glyphosate					
Ellsworth County	1,446	720	3,258	2,292	1,925	3,178	5,015	6,685	5,082	7,508
Harvey County	2,488	635	1,588	2,095	8,026	7,911	8,399	14,322	23,920	32,451
McPherson County	2,330	1,647	5,766	4,467	2,456	5,551	10,739	19,018	15,184	30,760
Marion County	2,585	1,451	4,425	3,673	2,263	3,781	9,036	16,909	12,305	27,324
Reno County	6,139	1,476	2,845	2,278	13,401	10,426	10,463	14,084	22,206	29,901
Rice County	2,794	1,157	4,864	4,181	2,863	4,719	10,137	18,168	14,354	23,449
Sedgwick County	4,833	1,270	2,104	2,286	10,109	9,757	10,519	14,108	19,514	30,523
Study drainage basin counties	22,614	8,355	24,848	21,272	41,042	45,322	64,308	103,293	112,565	181,916
All Kansas counties	298,605	237,732	432,505	312,022	623,875	874,192	973,452	1,599,382	1,682,794	2,196,106

Table 3.2. Estimated pesticide use in Kansas and selected counties in Kansas, 2002–11. Data are from Baker and Stone (2013), Stone (2013), and Wieben (2019, 2021).

[Epest-high, method estimates missing-use reports based on surrounding area use (Thelin and Stone, 2013).]

Land area	Pesticide use (Epest-high) in kilograms									
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
					Atrazine					
Ellsworth County	14,392	17,541	15,423	13,202	12,484	12,711	12,551	14,805	12,624	13,893
Harvey County	27,960	46,426	44,570	32,522	25,447	34,180	42,400	23,678	39,823	42,588
McPherson County	52,805	46,240	39,638	48,684	29,468	32,430	33,260	41,757	33,595	24,675
Marion County	48,452	42,962	36,243	48,079	28,384	30,119	35,024	40,810	32,777	24,654
Reno County	31,364	50,573	50,103	33,432	30,944	40,248	44,055	28,902	38,387	40,024
Rice County	49,112	43,148	37,921	48,444	26,215	30,210	34,483	43,607	30,114	26,728
Sedgwick County	27,921	49,670	45,013	32,856	27,610	36,830	40,199	26,319	37,793	29,278
Study drainage basin counties	252,007	296,558	268,911	257,218	180,551	216,728	241,972	219,878	225,113	201,841
All Kansas counties	3,105,363	3,328,462	3,029,990	3,054,601	2,456,201	2,405,286	3,205,097	2,568,440	2,833,326	3,099,548
					Glyphosate					
Ellsworth County	7,570	8,465	8,734	15,793	9,451	18,089	15,915	27,276	15,982	26,935
Harvey County	18,687	21,722	24,268	41,692	36,902	44,598	63,873	65,237	124,069	94,805
McPherson County	35,758	28,411	26,134	64,769	30,434	63,529	67,053	93,330	56,100	83,414
Marion County	33,844	25,766	22,528	62,579	30,082	55,711	67,737	90,640	57,277	86,916
Reno County	19,420	19,627	26,286	42,489	35,893	51,090	67,829	67,841	131,297	101,269
Rice County	27,547	24,930	25,521	63,308	31,568	56,394	62,323	91,635	50,634	72,985
Sedgwick County	19,555	25,499	25,154	41,808	37,123	46,702	57,992	58,252	119,767	78,020
Study drainage basin counties	162,380	154,419	158,625	332,439	211,453	336,113	402,722	494,210	555,126	544,343
All Kansas counties	2,345,387	2,430,883	2,880,693	4,497,068	3,615,072	4,711,864	5,658,414	6,471,165	7,210,018	7,038,855

Table 3.3. Estimated pesticide use in Kansas and selected counties in Kansas, 2012–19. Data are from Baker and Stone (2013), Stone (2013), and Wieben (2019, 2021).

[Epest-high, method estimates missing-use reports based on surrounding area use (Thelin and Stone, 2013).]

Land area	Pesticide use (Epest-high) in kilograms								
	2012	2013	2014	2015	2016	2017	2018	2019	1992–2019
Atrazine									
Ellsworth County	15,861	21,749	20,061	20,724	26,925	23,528	27,344	11,976	480,139
Harvey County	50,701	39,408	26,334	25,881	28,470	33,275	37,375	62,017	1,015,561
McPherson County	23,968	26,369	36,819	36,858	44,466	48,580	40,954	23,690	1,134,383
Marion County	24,376	25,581	35,012	28,517	34,351	44,554	34,395	20,408	1,119,657
Reno County	41,659	45,561	29,143	38,509	37,066	39,780	46,583	56,205	1,124,404
Rice County	26,199	30,611	38,582	42,766	54,308	59,344	59,843	28,109	1,169,646
Sedgwick County	41,875	41,687	26,744	32,189	31,117	32,583	35,349	58,489	1,005,087
Study drainage basin counties	224,637	230,966	212,695	225,444	256,702	281,644	281,843	260,894	7,048,876
All Kansas counties	3,293,352	3,864,088	3,329,926	4,079,849	4,227,655	5,310,372	5,170,435	4,591,681	94,046,887
Glyphosate									
Ellsworth County	36,555	38,727	49,851	57,599	45,908	44,965	40,567	41,429	546,917
Harvey County	130,489	105,515	93,529	96,626	95,050	66,534	105,227	133,767	1,464,424
McPherson County	100,615	78,238	146,046	126,448	119,680	121,803	111,388	116,997	1,568,064
Marion County	96,031	76,980	130,916	103,038	114,370	107,824	102,842	116,649	1,465,481
Reno County	136,073	116,034	102,463	118,122	94,841	83,705	142,604	126,342	1,596,444
Rice County	88,429	74,369	118,329	119,779	105,365	115,809	110,138	103,536	1,429,283
Sedgwick County	112,988	101,371	88,175	98,076	95,637	69,872	108,524	132,696	1,422,233
Study drainage basin counties	701,180	591,234	729,309	719,688	670,851	610,511	721,289	771,417	9,492,845
All Kansas counties	8,165,998	8,200,774	8,610,369	9,433,957	8,874,819	9,348,166	9,430,145	9,438,361	127,592,672

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Appendix 4. Total Pesticide Use

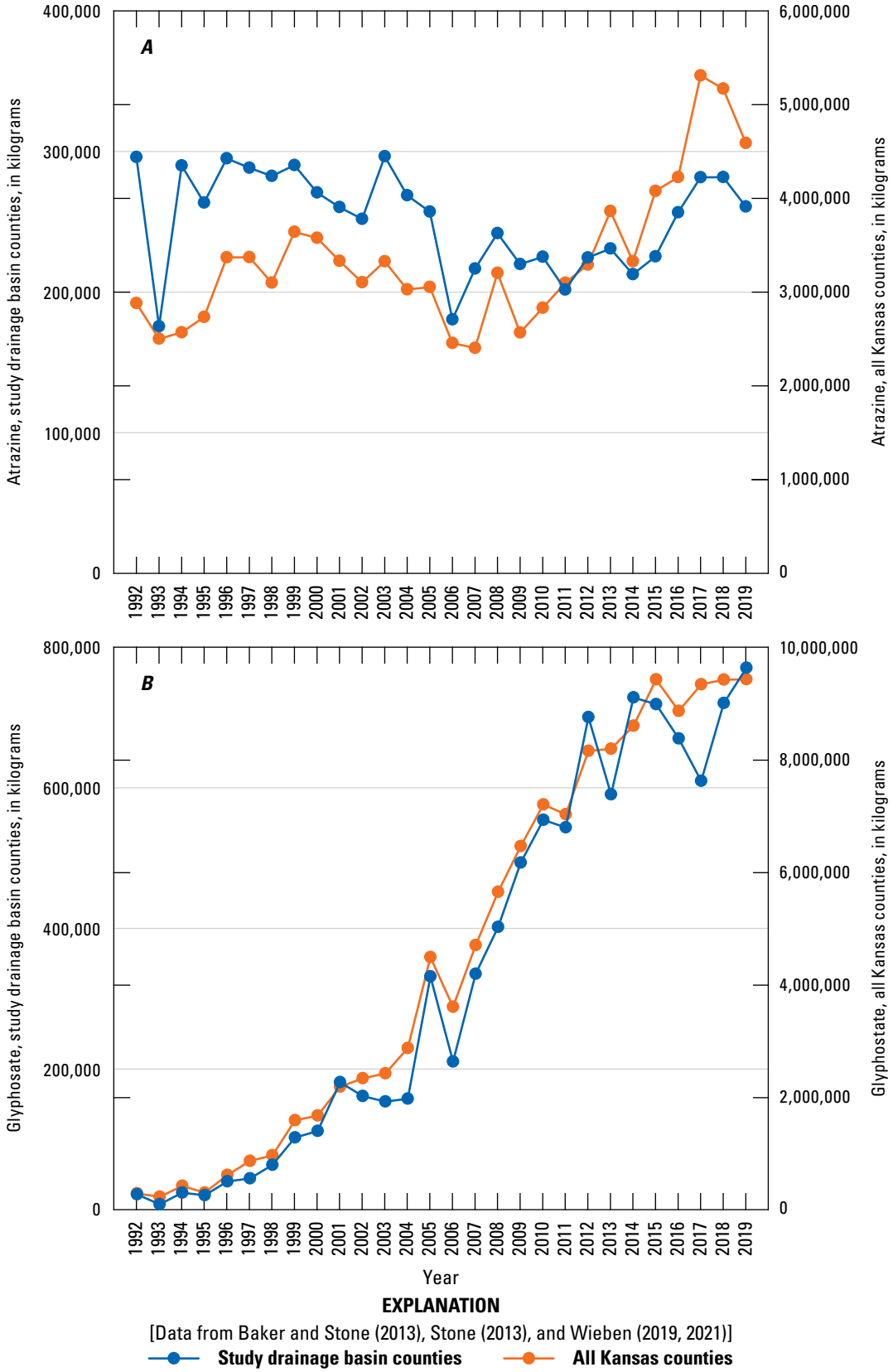


Figure 4.1. Graphs showing pesticide use in Kansas and study drainage basin counties in Kansas from 1992 to 2019. *A*, Atrazine. *B*, Glyphosate. Data are from Baker and Stone (2013), Stone (2013), and Wieben (2019, 2021).

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Baker, N.T., and Stone, W.W., 2013, Preliminary estimates of annual agricultural pesticide use for counties of the conterminous United States, 2010–11: U.S. Geological Survey Open-File Report 2013–1295, 2 p., 14 supplemental tables. [Also available at https://doi.org/10.3133/ofr20131295.]

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Appendix 5. Drainage Basin Crop Data

Table 5.1. Drainage basin cultivated crop area, 2001–10, in Kansas; selected counties in Kansas; the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672); and near Sedgwick, Kansas (Sedgwick; USGS station 07144100). Data are from the USGS National Land Cover website (Dewitz and U.S. Geological Survey, 2021).

Land area	Cultivated crop land area in square miles									
	2001[a]	2002[b]	2003[b]	2004[a]	2005[b]	2006[a]	2007[b]	2008[a]	2009[b]	2010[b]
Kansas	36,146	36,189	36,233	36,276	36,343	36,409	36,461	36,512	36,620	36,728
Ellsworth County	243	243	244	244	244	244	243	243	243	243
Harvey County	365	365	365	366	366	366	366	367	367	367
McPherson County	573	574	574	574	574	574	574	574	574	574
Marion County	451	451	451	451	452	452	452	452	452	452
Reno County	655	655	654	654	652	650	650	650	651	653
Rice County	470	470	470	470	470	471	471	471	472	472
Sedgwick County	508	507	506	505	503	502	501	500	500	500
Highway 50 drainage basin	505	505	505	505	505	505	505	505	505	505
Ellsworth County within Highway 50 drainage basin	4.27	4.27	4.27	4.27	4.27	4.27	4.27	4.27	4.27	4.27
Harvey County within Highway 50 drainage basin	35.7	35.8	35.8	35.9	35.9	35.9	36.0	36.0	36.0	36.0
McPherson County within Highway 50 drainage basin	341	341	341	341	341	341	341	341	340	340
Marion County within Highway 50 drainage basin	0	0	0	0	0	0	0	0	0	0
Reno County within Highway 50 drainage basin	26.2	26.2	26.2	26.2	26.2	26.3	26.3	26.3	26.3	26.4
Rice County within Highway 50 drainage basin	97.9	97.9	97.9	97.9	97.9	98.0	98.0	98.0	98.1	98.2
Sedgwick County within Highway 50 drainage basin	0	0	0	0	0	0	0	0	0	0
Sedgwick drainage basin	850	850	850	850	850	850	850	850	850	851
Ellsworth County within Sedgwick drainage basin	4.27	4.27	4.27	4.27	4.27	4.27	4.27	4.27	4.27	4.27
Harvey County within Sedgwick drainage basin	259	259	259	259	259	259	259	259	259	259
McPherson County within Sedgwick drainage basin	416	416	416	416	416	416	416	416	416	416
Marion County within Sedgwick drainage basin	26.4	26.4	26.4	26.4	26.5	26.6	26.6	26.7	26.7	26.7
Reno County within Sedgwick drainage basin	40.7	40.7	40.7	40.7	40.6	40.5	40.5	40.5	40.6	40.7
Rice County within Sedgwick drainage basin	97.9	97.9	97.9	97.9	97.9	98.0	98.0	98.0	98.1	98.2
Sedgwick County within Sedgwick drainage basin	6.19	6.14	6.09	6.04	6.05	6.05	6.05	6.05	6.04	6.03

[a]Data from NLCD and can be found at https://www.mrlc.gov/data.

[b]Data estimated using linear interpolation.

Table 5.2. Drainage basin cultivated crop area, 2011–21, in Kansas; selected counties in Kansas; the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672); and near Sedgwick, Kansas (Sedgwick; USGS station 07144100). Data are from the USGS National Land Cover website (Dewitz and U.S. Geological Survey, 2021).

Land area	Cultivated crop land area in square miles										
	2011[a]	2012[b]	2013[a]	2014[b]	2015[b]	2016[a]	2017[b]	2018[b]	2019[a]	2020[b]	2021[a]
Kansas	36,836	36,963	37,090	37,175	37,260	37,344	37,374	37,403	37,433	37,352	37,272
Ellsworth County	243	243	243	244	244	244	244	244	244	242	239
Harvey County	368	368	368	368	368	369	369	369	369	368	367
McPherson County	574	574	574	574	574	574	574	574	574	571	568
Marion County	452	452	453	451	450	449	449	450	450	447	443
Reno County	654	656	657	659	661	662	664	665	666	661	656
Rice County	472	472	473	473	474	474	475	475	475	473	471
Sedgwick County	500	500	500	501	501	502	501	501	501	498	496
Highway 50 drainage basin	505	505	506	506	506	506	506	506	506	504	502
Ellsworth County within Highway 50 drainage basin	4.27	4.27	4.27	4.28	4.29	4.30	4.30	4.30	4.30	4.27	4.23
Harvey County within Highway 50 drainage basin	36.0	36.0	36.0	36.1	36.1	36.1	36.1	36.1	36.2	36.0	35.9
McPherson County within Highway 50 drainage basin	340	340	340	340	340	340	340	340	340	339	337
Marion County within Highway 50 drainage basin	0	0	0	0	0	0	0	0	0	0	0
Reno County within Highway 50 drainage basin	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.2	25.9
Rice County within Highway 50 drainage basin	98.3	98.5	98.7	99.0	99.3	99.6	99.7	99.7	99.8	99.0	98.2
Sedgwick County within Highway 50 drainage basin	0	0	0	0	0	0	0	0	0	0	0
Sedgwick drainage basin	851	851	851	852	852	852	852	853	853	849	846
Ellsworth County within Sedgwick drainage basin	4.27	4.27	4.27	4.28	4.29	4.30	4.30	4.30	4.30	4.27	4.23
Harvey County within Sedgwick drainage basin	259	259	259	259	259	260	260	260	260	259	258
McPherson County within Sedgwick drainage basin	416	416	416	415	415	415	415	415	415	414	412

Table 5.2. Drainage basin cultivated crop area, 2011–21, in Kansas; selected counties in Kansas; the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey [USGS] station 07143672); and near Sedgwick, Kansas (Sedgwick; USGS station 07144100). Data are from the USGS National Land Cover website (Dewitz and U.S. Geological Survey, 2021).—Continued

Land area	Cultivated crop land area in square miles										
	2011[a]	2012[b]	2013[a]	2014[b]	2015[b]	2016[a]	2017[b]	2018[b]	2019[a]	2020[b]	2021[a]
Marion County within Sedgwick drainage basin	26.7	26.7	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.7	26.7
Reno County within Sedgwick drainage basin	40.7	40.8	40.9	40.9	41.0	41.0	41.0	41.0	41.0	40.4	39.8
Rice County within Sedgwick drainage basin	98.3	98.5	98.7	99.0	99.3	99.6	99.7	99.7	99.8	99.0	98.2
Sedgwick County within Sedgwick drainage basin	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.01	5.99

[a]Data from NLCD and can be found at https://www.mrlc.gov/data.

[b]Data estimated using linear interpolation.

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Appendix 6. Proportionate Drainage Basin Pesticide Use

Table 6.1. Pesticide use estimates for Kansas and selected Kansas counties proportioned to the cropland in each county for counties having any land area in the study drainage basins within the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey station 07143672), and near Sedgwick, Kansas (Sedgwick; U.S. Geological Survey station 07144100), drainage basins and county boundaries, 2001–10. Data are from Stone (2026).

[Epest-high method estimates missing-use reports based on surrounding area use (Thelin and Stone, 2013). USGS, U.S. Geological Survey]

Land area	Pesticide use (Epest-high) in kilograms									
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Atrazine (USGS parameter code 39632)										
Ellsworth County within Highway 50 drainage basin	265	253	307	270	231	218	223	221	260	222
Harvey County within Highway 50 drainage basin	28,768	2,742	4,554	4,372	3,190	2,496	3,362	4,159	2,323	3,906
McPherson County within Highway 50 drainage basin	25,350	31,370	27,470	23,548	28,922	17,506	19,266	19,759	24,734	19,899
Reno County within Highway 50 drainage basin	1,848	1,255	2,026	2,007	1,343	1,252	1,629	1,783	1,168	1,552
Rice County within Highway 50 drainage basin	7,439	10,230	8,988	7,899	10,091	5,455	6,286	7,175	9,063	6,265
Ellsworth County within Sedgwick drainage basin	265	253	307	270	231	218	223	221	260	222
Harvey County within Sedgwick drainage basin	28,768	19,840	32,943	31,540	23,014	18,008	24,187	29,923	16,710	28,104
McPherson County within Sedgwick drainage basin	30,925	38,270	33,512	28,727	35,283	21,356	23,503	24,105	30,263	24,347
Marion County within Sedgwick drainage basin	2,218	2,836	2,515	2,122	2,819	1,670	1,772	2,069	2,411	1,936
Reno County within Sedgwick drainage basin	2,871	1,949	3,147	3,118	2,082	1,928	2,508	2,745	1,802	2,393
Rice County within Sedgwick drainage basin	7,439	10,230	8,988	7,899	10,091	5,455	6,286	7,175	9,063	6,265
Sedgwick County within Sedgwick drainage basin	517	338	598	538	395	333	445	486	318	456
Highway 50 drainage basin county total	63,670	45,850	43,344	38,096	43,777	26,927	30,765	33,096	37,548	31,845
Sedgwick drainage basin county total	73,003	73,716	82,009	74,214	73,914	48,968	58,925	66,723	60,827	63,723
Glyphosate (USGS parameter code 62722)										
Ellsworth County within Highway 50 drainage basin	132	133	148	153	276	165	318	280	479	281
Harvey County within Highway 50 drainage basin	23,027	1,833	2,131	2,380	4,089	3,620	4,387	6,265	6,399	12,170

Table 6.1. Pesticide use estimates for Kansas and selected Kansas counties proportioned to the cropland in each county for counties having any land area in the study drainage basins within the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey station 07143672), and near Sedgwick, Kansas (Sedgwick; U.S. Geological Survey station 07144100), drainage basins and county boundaries, 2001–10. Data are from Stone (2026).—Continued

[Epest-high method estimates missing-use reports based on surrounding area use (Thelin and Stone, 2013). USGS, U.S. Geological Survey]

Land area	Pesticide use (Epest-high) in kilograms									
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
	Glyphosate (USGS parameter code 62722)—Continued									
McPherson County within Highway 50 drainage basin	18,306	21,243	16,878	15,526	38,478	18,080	37,741	39,835	55,283	33,230
Reno County within Highway 50 drainage basin	1,196	777	786	1,053	1,707	1,452	2,067	2,744	2,741	5,308
Rice County within Highway 50 drainage basin	4,884	5,738	5,193	5,316	13,187	6,568	11,734	12,967	19,045	10,534
Ellsworth County within Sedgwick drainage basin	132	133	148	153	276	165	318	280	479	281
Harvey County within Sedgwick drainage basin	23,027	13,260	15,414	17,173	29,503	26,114	31,560	45,077	46,039	87,558
McPherson County within Sedgwick drainage basin	22,332	25,915	20,591	18,941	46,941	22,057	46,042	48,596	67,640	40,658
Marion County within Sedgwick drainage basin	1,599	1,981	1,508	1,319	3,669	1,770	3,279	4,001	5,354	3,383
Reno County within Sedgwick drainage basin	1,858	1,207	1,221	1,636	2,646	2,236	3,183	4,226	4,231	8,183
Rice County within Sedgwick drainage basin	4,884	5,738	5,193	5,316	13,187	6,568	11,734	12,967	19,045	10,534
Sedgwick County within Sedgwick drainage basin	372	237	307	301	503	447	564	702	704	1,444
Highway 50 drainage basin County total	47,545	29,723	25,136	24,428	57,738	29,886	56,247	62,092	83,947	61,523
Sedgwick drainage basin County total	54,204	48,470	44,382	44,838	96,725	59,358	96,679	115,849	143,492	152,042

Table 6.2. Pesticide use estimates for Kansas and selected Kansas counties proportioned to the cropland in each county for counties having any land area in the study drainage basins within the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey station 07143672), and near Sedgwick, Kansas (Sedgwick; U.S. Geological Survey station 07144100), drainage basins and county boundaries, 2011–19. Data are from Stone (2026).

[Epest-high method estimates missing-use reports based on surrounding area use (Thelin and Stone, 2013). USGS, U.S. Geological Survey]

Land area	Pesticide use (Epest-high) in kilograms									
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2001–19
	Atrazine (USGS parameter code 39632)									
Ellsworth County within Highway 50 drainage basin	244	279	382	352	364	474	415	482	211	5,673
Harvey County within Highway 50 drainage basin	4,166	4,960	3,855	2,583	2,539	2,785	3,255	3,656	6,084	93,756
McPherson County within Highway 50 drainage basin	14,616	14,197	15,619	21,809	21,832	26,338	28,775	24,259	14,032	419,303
Reno County within Highway 50 drainage basin	1,622	1,683	1,838	1,172	1,544	1,484	1,588	1,856	2,236	30,884
Rice County within Highway 50 drainage basin	5,567	5,467	6,388	8,075	8,959	11,411	12,456	12,561	5,906	155,680
Ellsworth County within Sedgwick drainage basin	244	279	382	352	364	474	415	482	211	5,673
Harvey County within Sedgwick drainage basin	29,974	35,683	27,735	18,534	18,215	20,060	23,446	26,335	43,698	496,718
McPherson County within Sedgwick drainage basin	17,883	17,370	19,110	26,620	26,648	32,148	35,123	29,610	17,128	511,933
Marion County within Sedgwick drainage basin	1,456	1,440	1,513	2,081	1,698	2,050	2,659	2,048	1,215	38,530
Reno County within Sedgwick drainage basin	2,491	2,591	2,836	1,809	2,389	2,296	2,456	2,872	3,460	47,743
Rice County within Sedgwick drainage basin	5,567	5,467	6,388	8,075	8,959	11,411	12,456	12,561	5,906	155,680
Sedgwick County within Sedgwick drainage basin	353	504	502	321	387	373	392	425	703	8,383
Highway 50 drainage basin county total	26,215	26,586	28,082	33,992	35,239	42,493	46,489	42,814	28,470	705,296
Sedgwick drainage basin county total	57,967	63,335	58,467	57,792	58,661	68,814	76,947	74,332	72,321	1,264,659

Table 6.2. Pesticide use estimates for Kansas and selected Kansas counties proportioned to the cropland in each county for counties having any land area in the study drainage basins within the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey station 07143672), and near Sedgwick, Kansas (Sedgwick; U.S. Geological Survey station 07144100), drainage basins and county boundaries, 2011–19. Data are from Stone (2026).—Continued

[Epest-high method estimates missing-use reports based on surrounding area use (Thelin and Stone, 2013). USGS, U.S. Geological Survey]

Land area	Pesticide use (Epest-high) in kilograms									
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2001–19
	Glyphosate (USGS parameter code 62722)									
Ellsworth County within Highway 50 drainage basin	473	642	681	874	1,013	809	792	715	730	9,095
Harvey County within Highway 50 drainage basin	9,274	12,765	10,322	9,175	9,479	9,299	6,509	10,295	13,123	156,542
McPherson County within Highway 50 drainage basin	49,409	59,598	46,343	86,508	74,899	70,891	72,148	65,979	69,302	889,675
Reno County within Highway 50 drainage basin	4,103	5,497	4,680	4,120	4,736	3,797	3,341	5,683	5,027	60,816
Rice County within Highway 50 drainage basin	15,200	18,454	15,518	24,767	25,093	22,140	24,308	23,117	21,753	285,518
Ellsworth County within Sedgwick drainage basin	473	642	681	874	1,013	809	792	715	730	9,095
Harvey County within Sedgwick drainage basin	66,724	91,839	74,262	65,826	68,006	66,973	46,880	74,143	94,253	983,631
McPherson County within Sedgwick drainage basin	60,453	72,920	56,702	105,591	91,421	86,528	88,063	80,533	84,589	1,086,511
Marion County within Sedgwick drainage basin	5,134	5,673	4,554	7,779	6,136	6,827	6,436	6,125	6,947	83,475
Reno County within Sedgwick drainage basin	6,302	8,463	7,223	6,359	7,327	5,874	5,169	8,792	7,778	93,915
Rice County within Sedgwick drainage basin	15,200	18,454	15,518	24,767	25,093	22,140	24,308	23,117	21,753	285,518
Sedgwick County within Sedgwick drainage basin	939	1,360	1,221	1,060	1,178	1,147	840	1,304	1,594	16,224
Highway 50 drainage basin county total	78,460	96,956	77,544	125,444	115,219	106,935	107,098	105,789	109,935	1,401,646
Sedgwick drainage basin county total	155,226	199,351	160,161	212,256	200,175	190,298	172,487	194,730	217,645	2,558,369

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Appendix 7. Proportionate Drainage Basin Pesticide Use

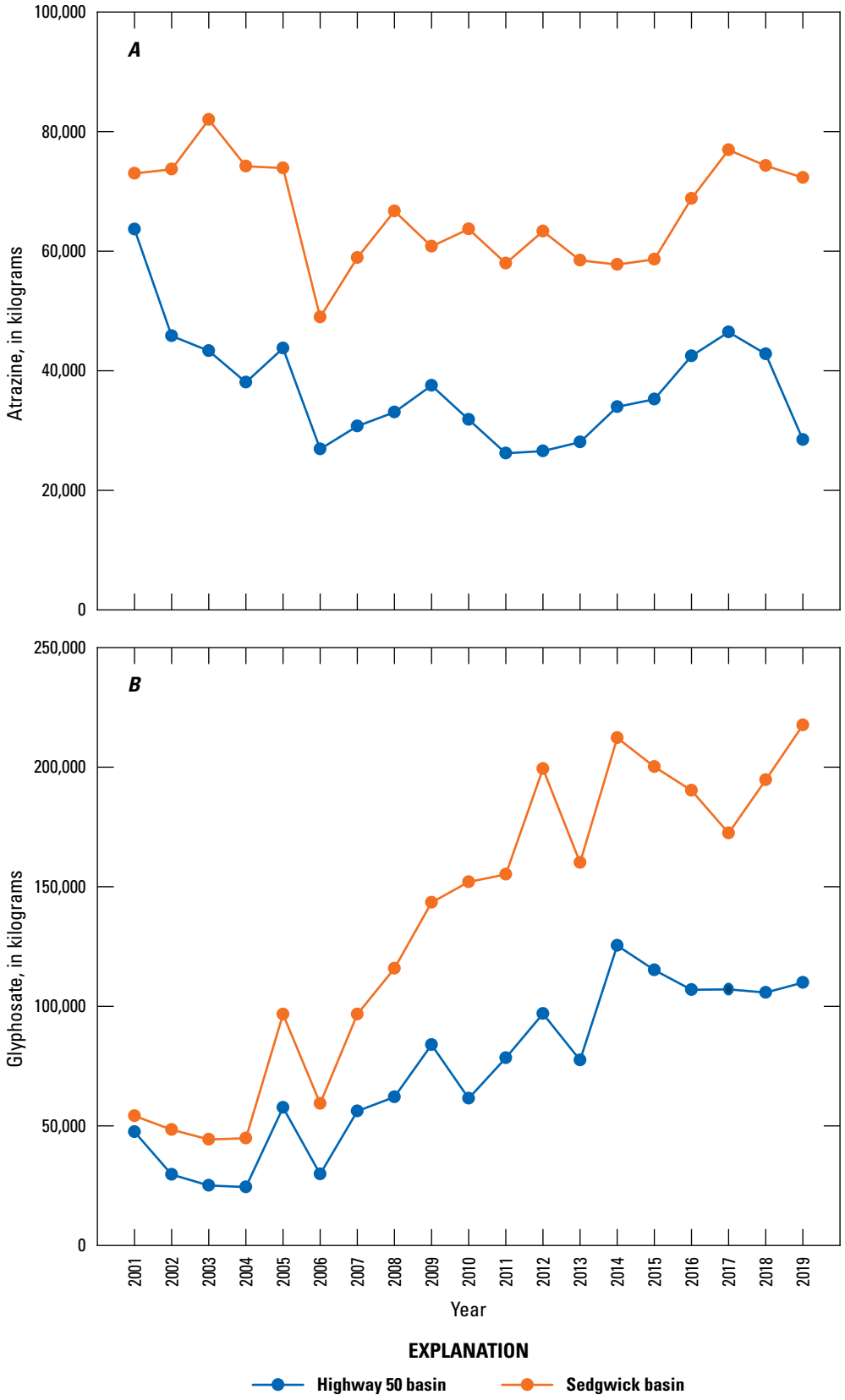


Figure 7.1. Graphs showing estimated total pesticide use for the study drainage basins within the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey station 07143672), and near Sedgwick, Kansas (Sedgwick; U.S. Geological Survey station 07144100), drainage basins from 2001 to 2019. *A*, Atrazine. *B*, Glyphosate. Data are from Stone (2026).

Reference Cited

Stone, M.L., 2026, Selected pesticide concentrations and trends and drainage basin pesticide use in the Little Arkansas River, south-central Kansas, 1995–2023: U.S. Geological Survey data release, https://doi.org/10.5066/P14CZVK4.

Appendix 8. SEAWAVE-Q Trend Output

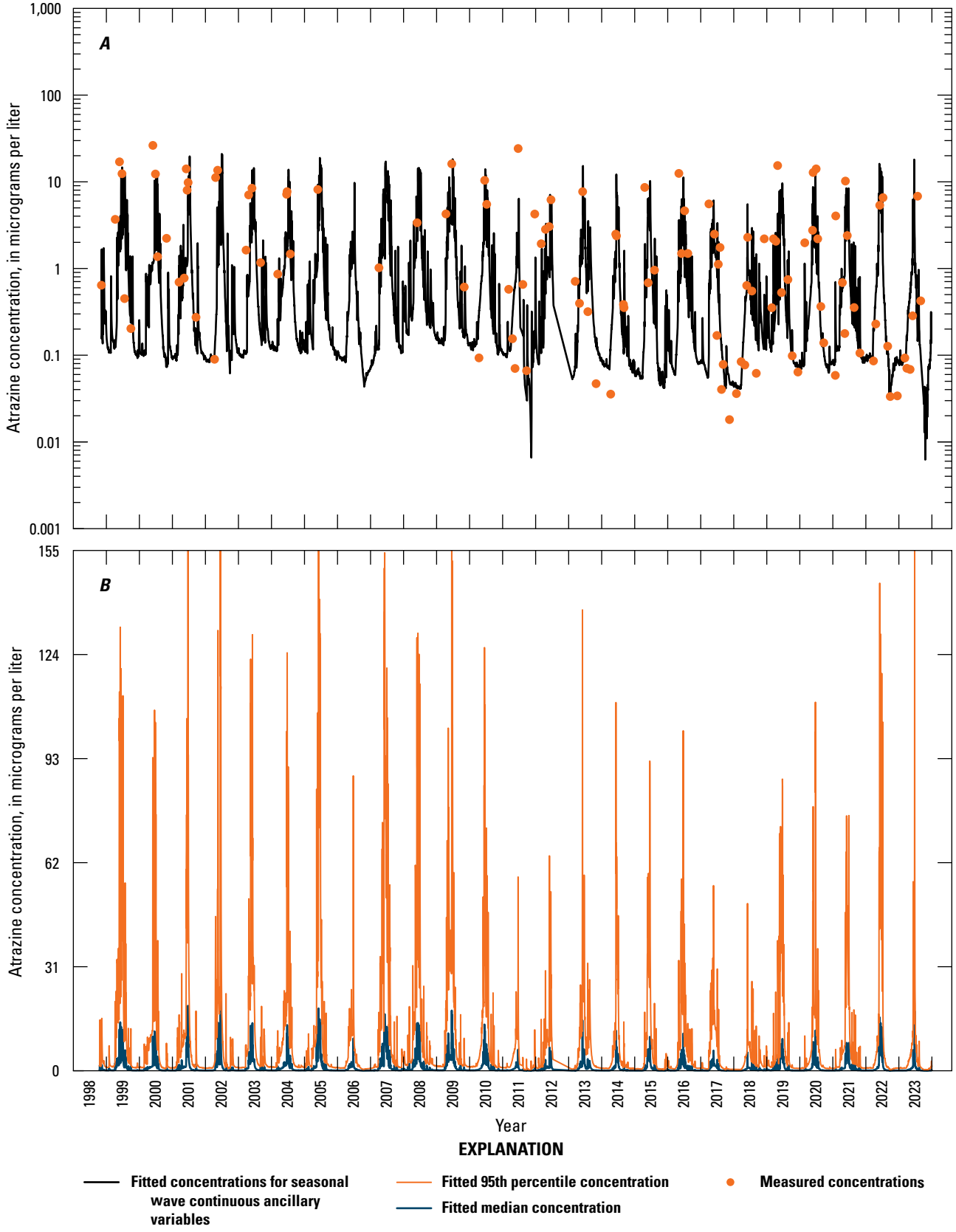


Figure 8.1. Graphs showing SEAWAVE-Q (Ryberg and Vecchia, 2013; Ryberg and York, 2020) trend analysis output for atrazine in the Little Arkansas River at Highway 50 near Halstead, Kansas (U.S. Geological Survey station 07143672), from 1998 to 2023. *A*, Measured and fitted pesticide concentrations and trend line. *B*, Fitted median concentrations and 95th percentile concentrations. *C*, Fitted versus measured concentrations. *D*, Fitted concentrations versus standardized residuals. *E*, Annual standardized residuals. *F*, Monthly standardized residuals. Data are from Stone (2026).

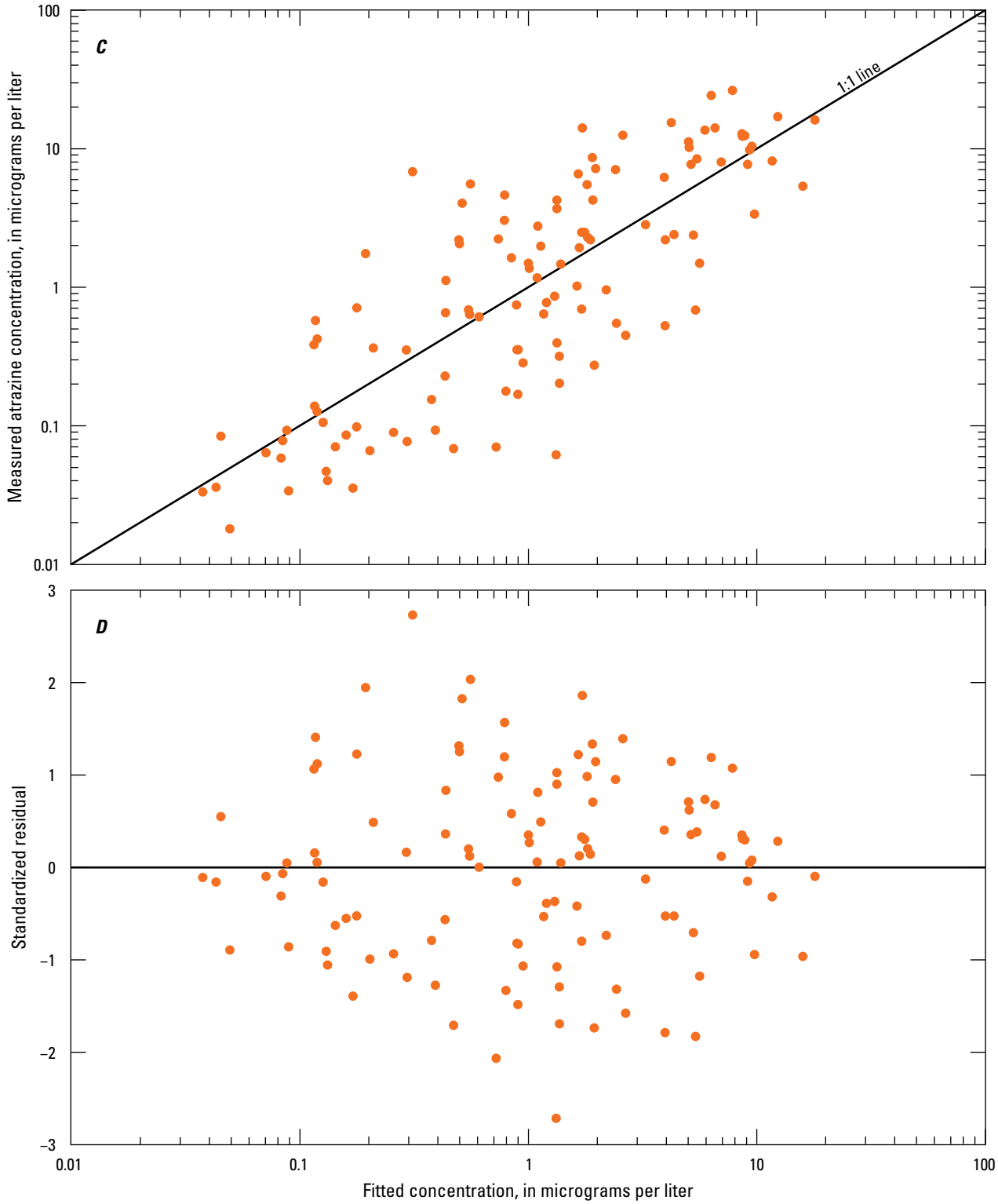


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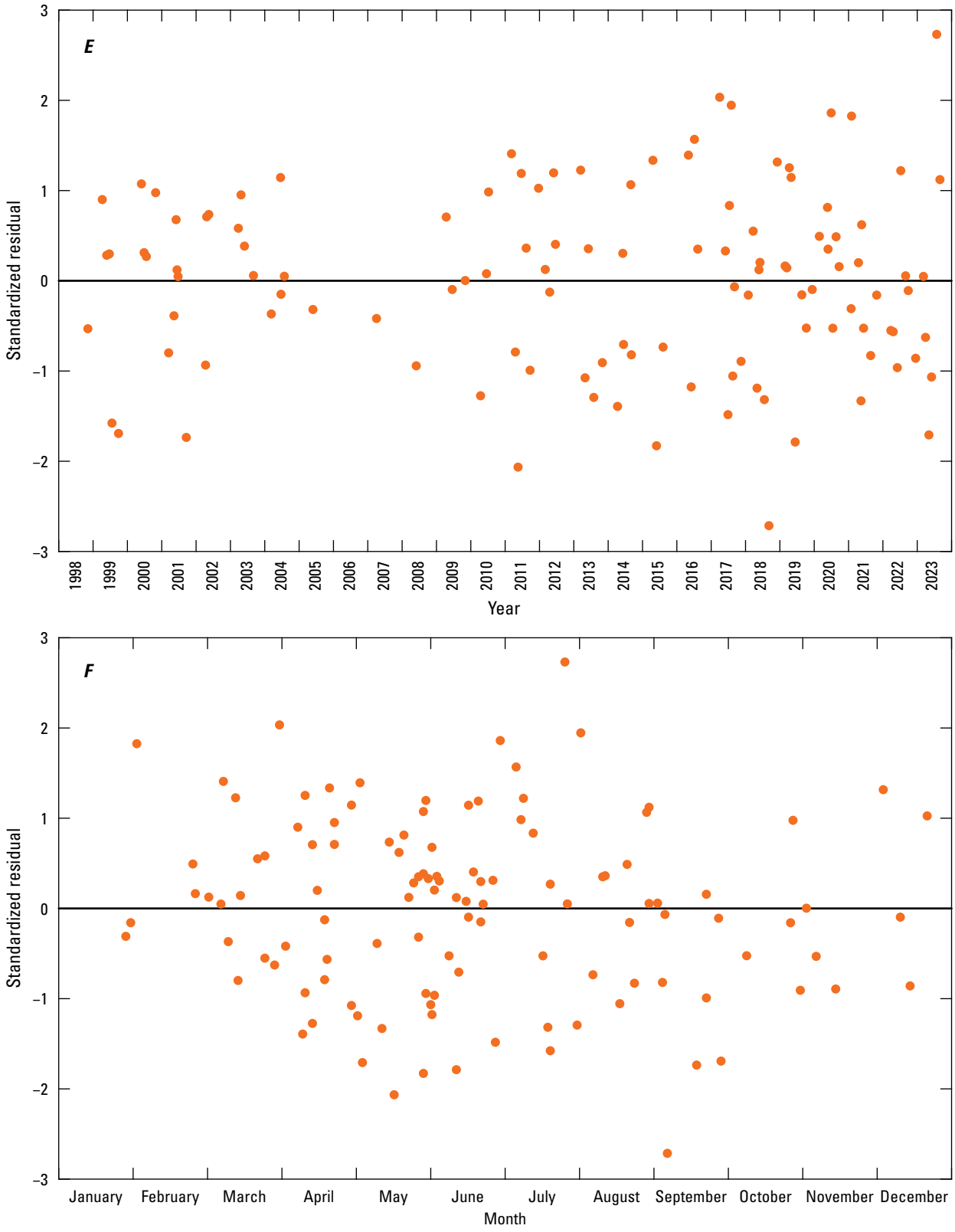


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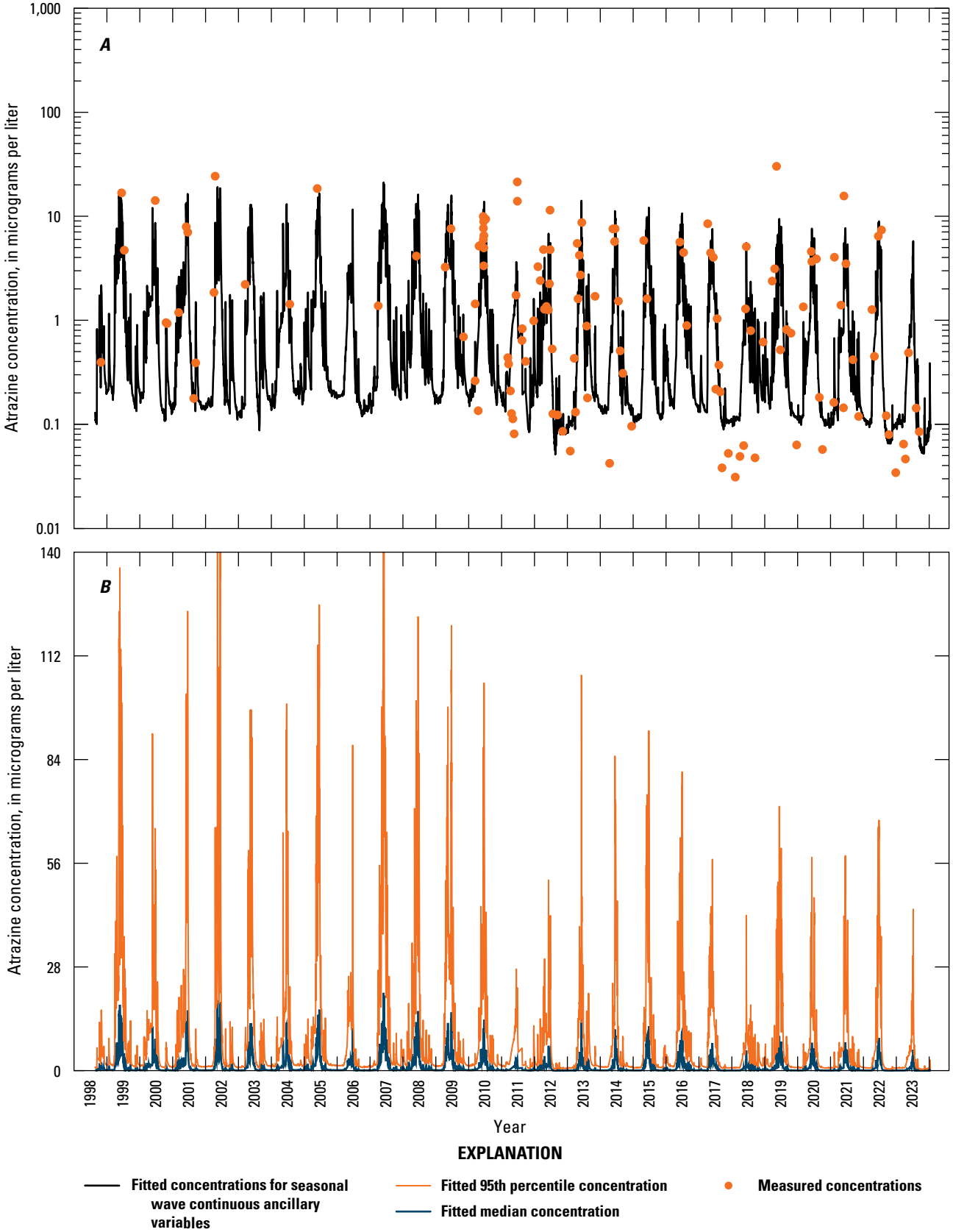


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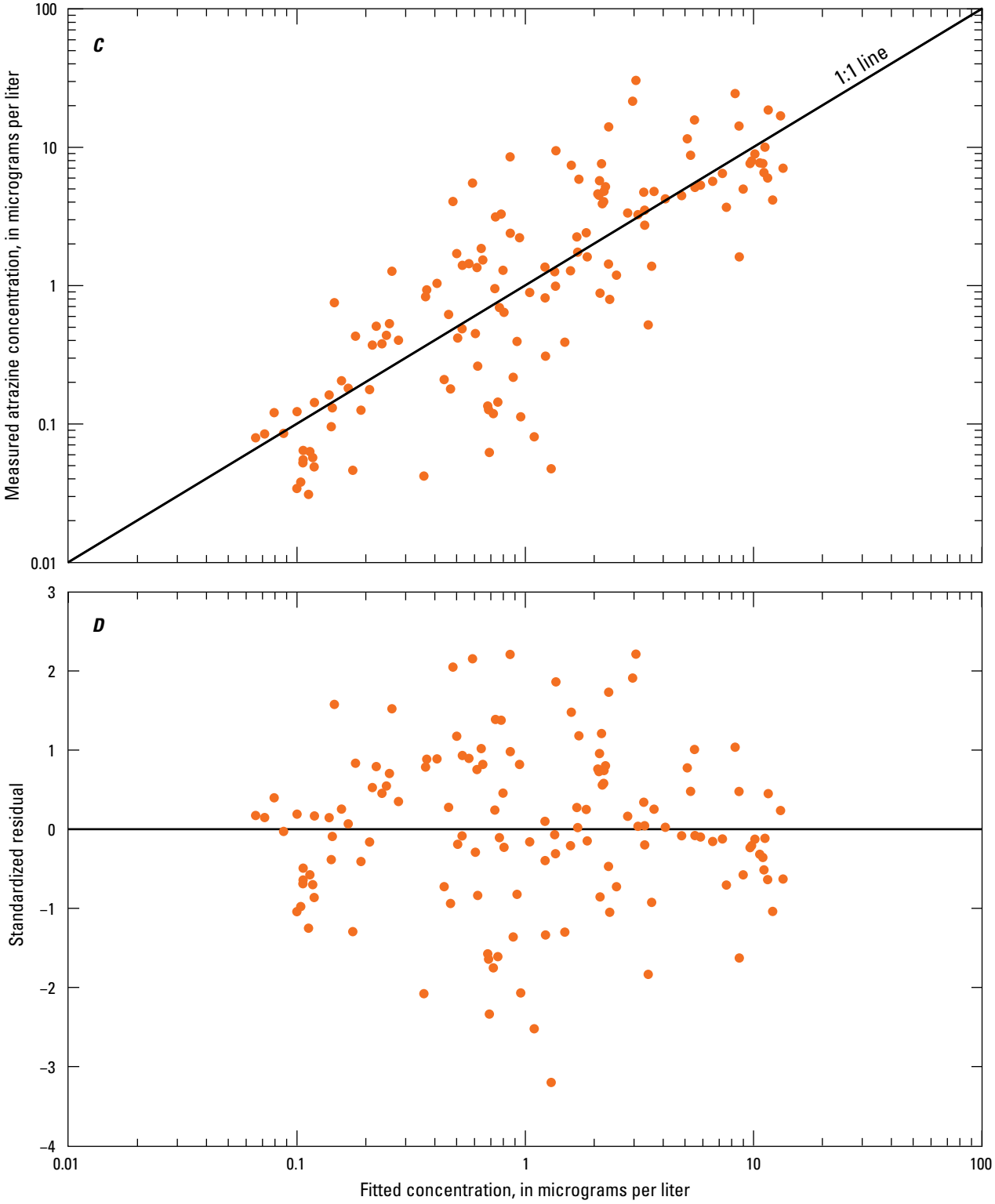


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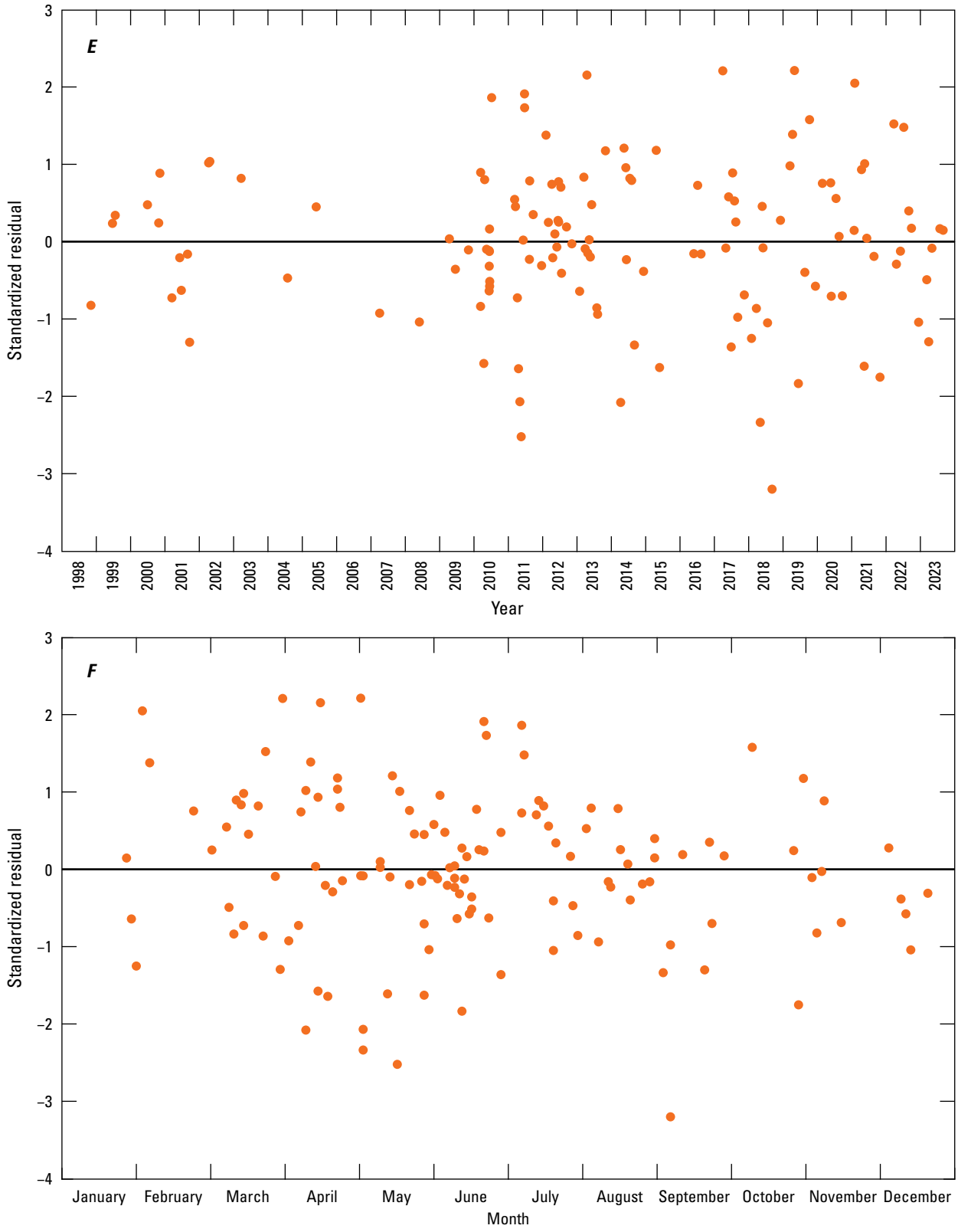


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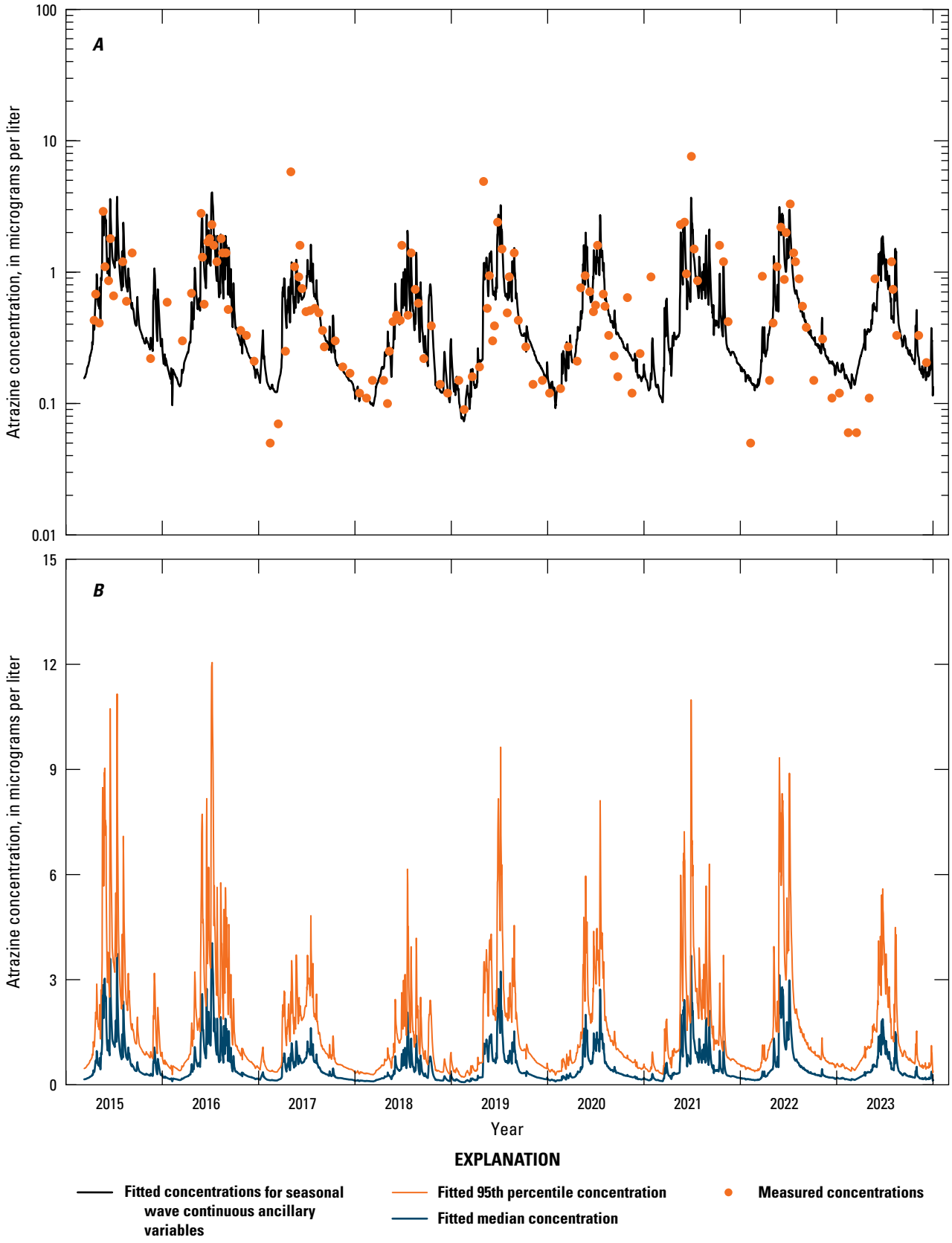


Figure 8.3. Graphs showing SEAWAVE-Q (Ryberg and Vecchia, 2013; Ryberg and York, 2020) trend analysis output for glyphosate in the Little Arkansas River near Sedgwick, Kansas (U.S. Geological Survey station 07144100), from 2015 to 2023. *A*, Measured and fitted pesticide concentrations and trend line. *B*, Fitted median and 95th percentile concentrations. *C*, Fitted versus measured concentrations. *D*, Fitted concentration versus standardized residuals. *E*, Annual standardized residuals. *F*, Monthly standardized residuals. Data are from Stone (2026).

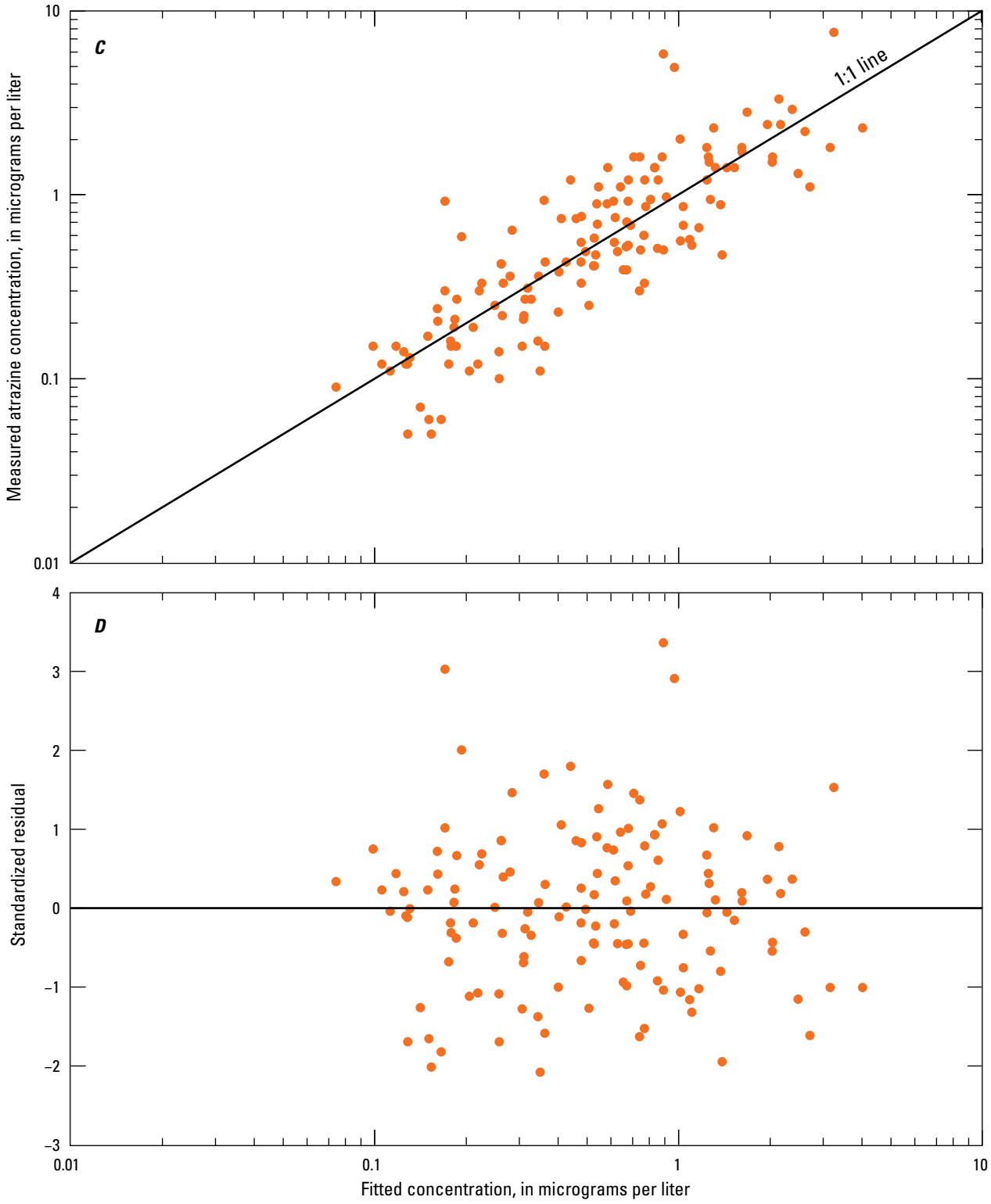


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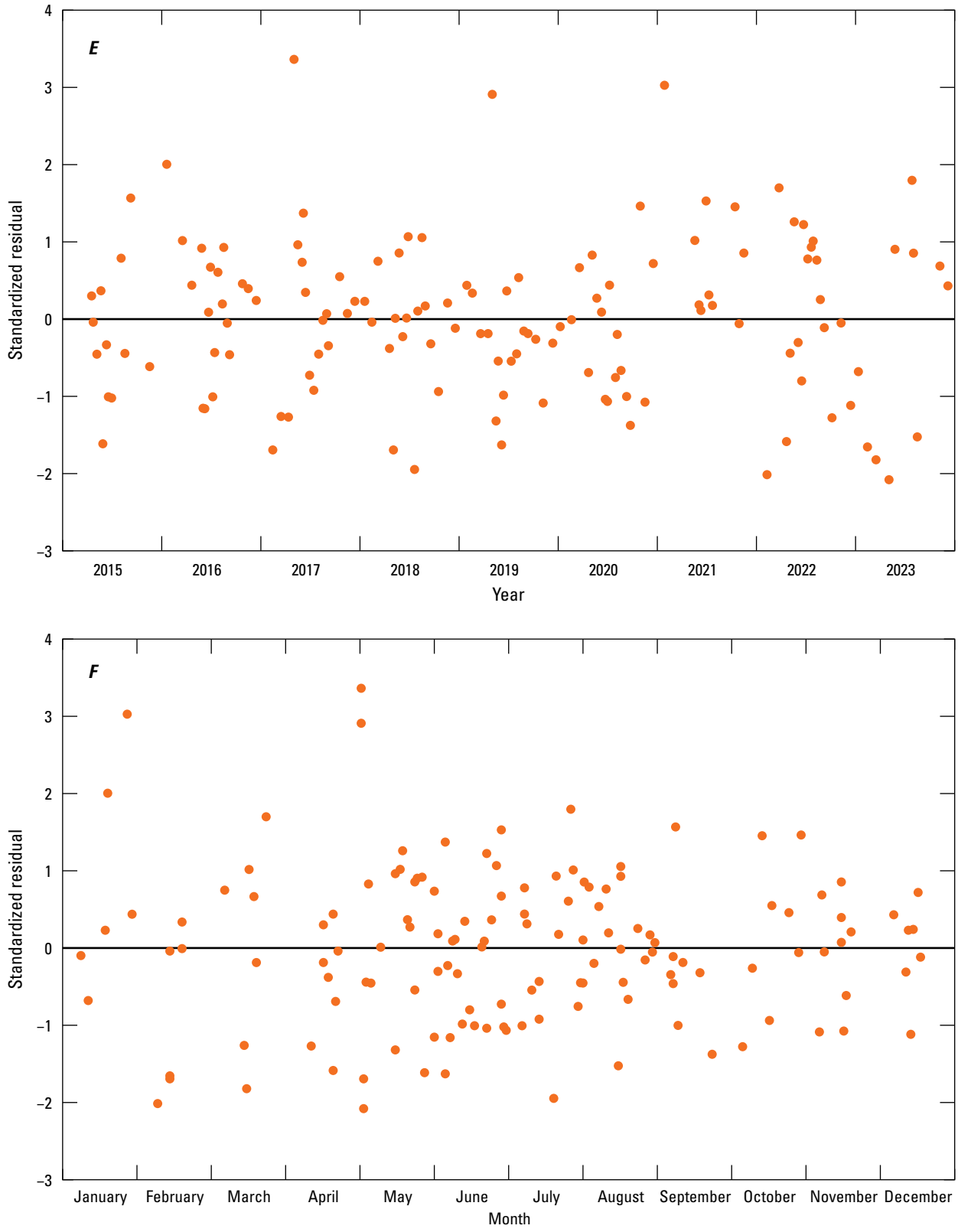


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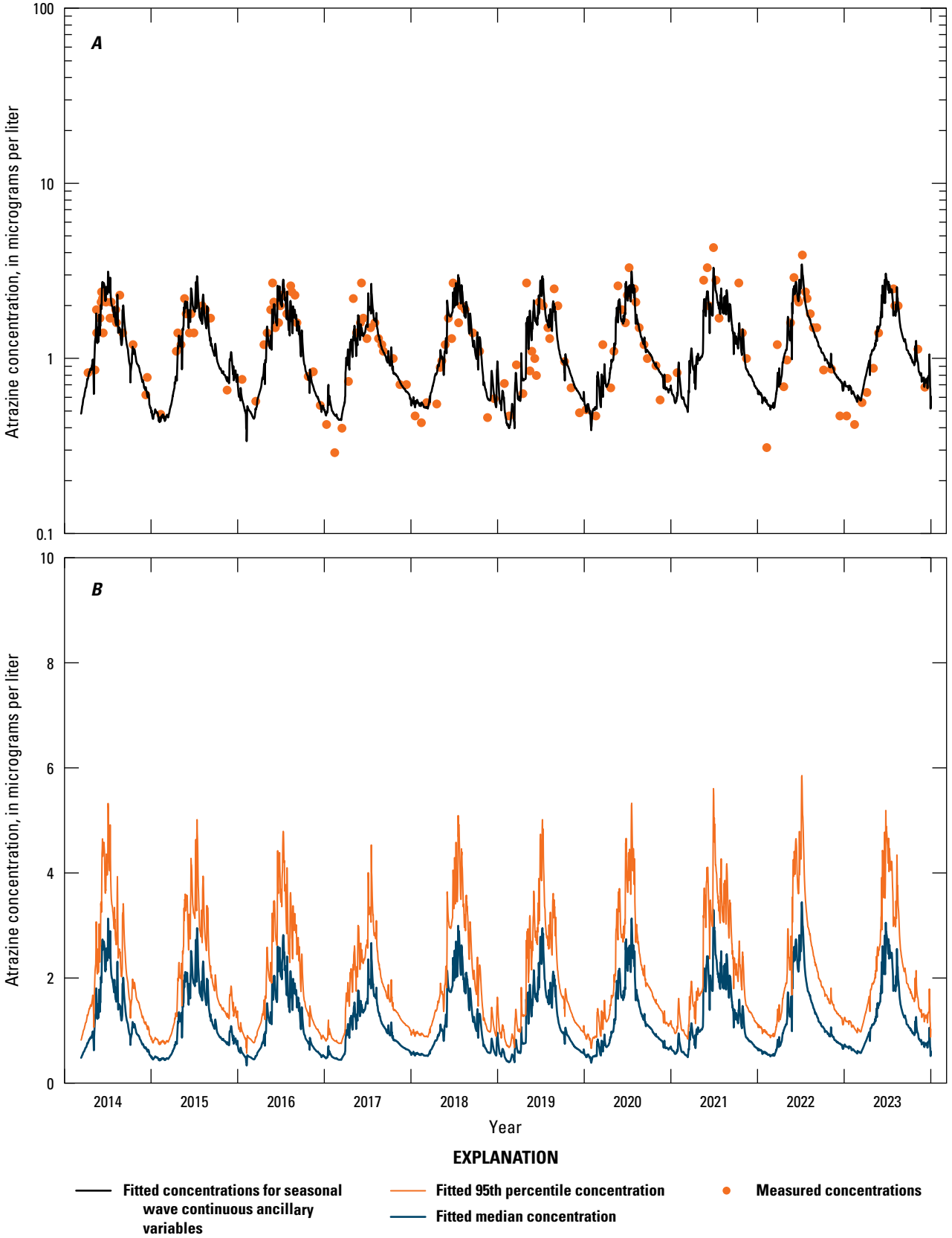


Figure 8.4. Graphs showing SEAWAVE-Q (Ryberg and Vecchia, 2013; Ryberg and York, 2020) trend analysis output for Aminomethylphosphonic acid (AMPA) in the Little Arkansas River near Sedgwick, Kansas (U.S. Geological Survey station 07144100), from 2015 to 2023. *A*, Measured and fitted pesticide concentrations and trend line. *B*, Fitted median and 95th percentile concentrations. *C*, Fitted versus measured concentrations. *D*, Fitted concentration versus standardized residuals. *E*, Annual standardized residuals. *F*, Monthly standardized residuals. Data are from Stone (2026).

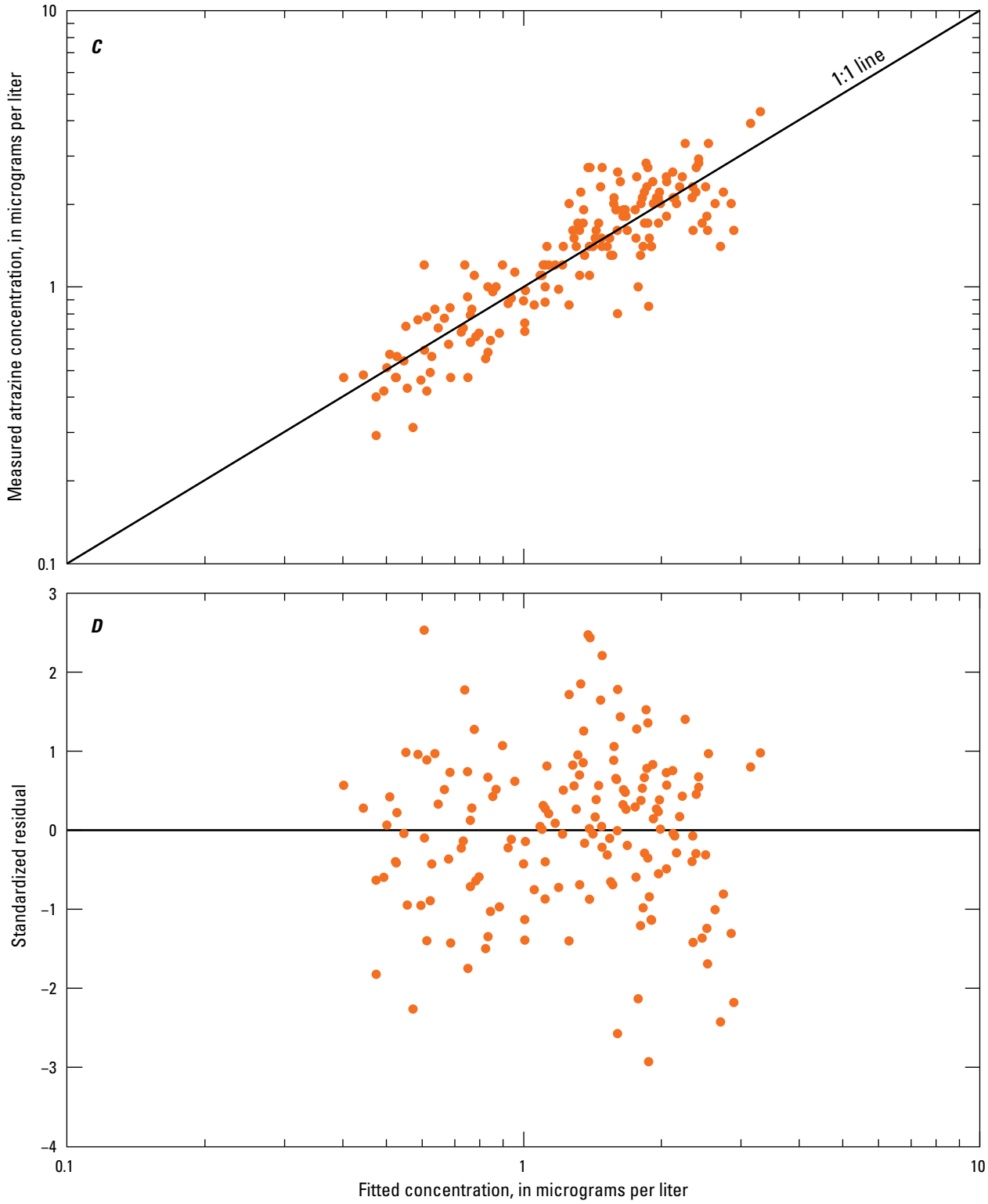


Figure 8.4. Graphs showing SEAWAVE-Q (Ryberg and Vecchia, 2013; Ryberg and York, 2020) trend analysis output for Aminomethylphosphonic acid (AMPA) in the Little Arkansas River near Sedgwick, Kansas (U.S. Geological Survey station 07144100), from 2015 to 2023. *A*, Measured and fitted pesticide concentrations and trend line. *B*, Fitted median and 95th percentile concentrations. *C*, Fitted versus measured concentrations. *D*, Fitted concentration versus standardized residuals. *E*, Annual standardized residuals. *F*, Monthly standardized residuals. Data are from Stone (2026).—Continued

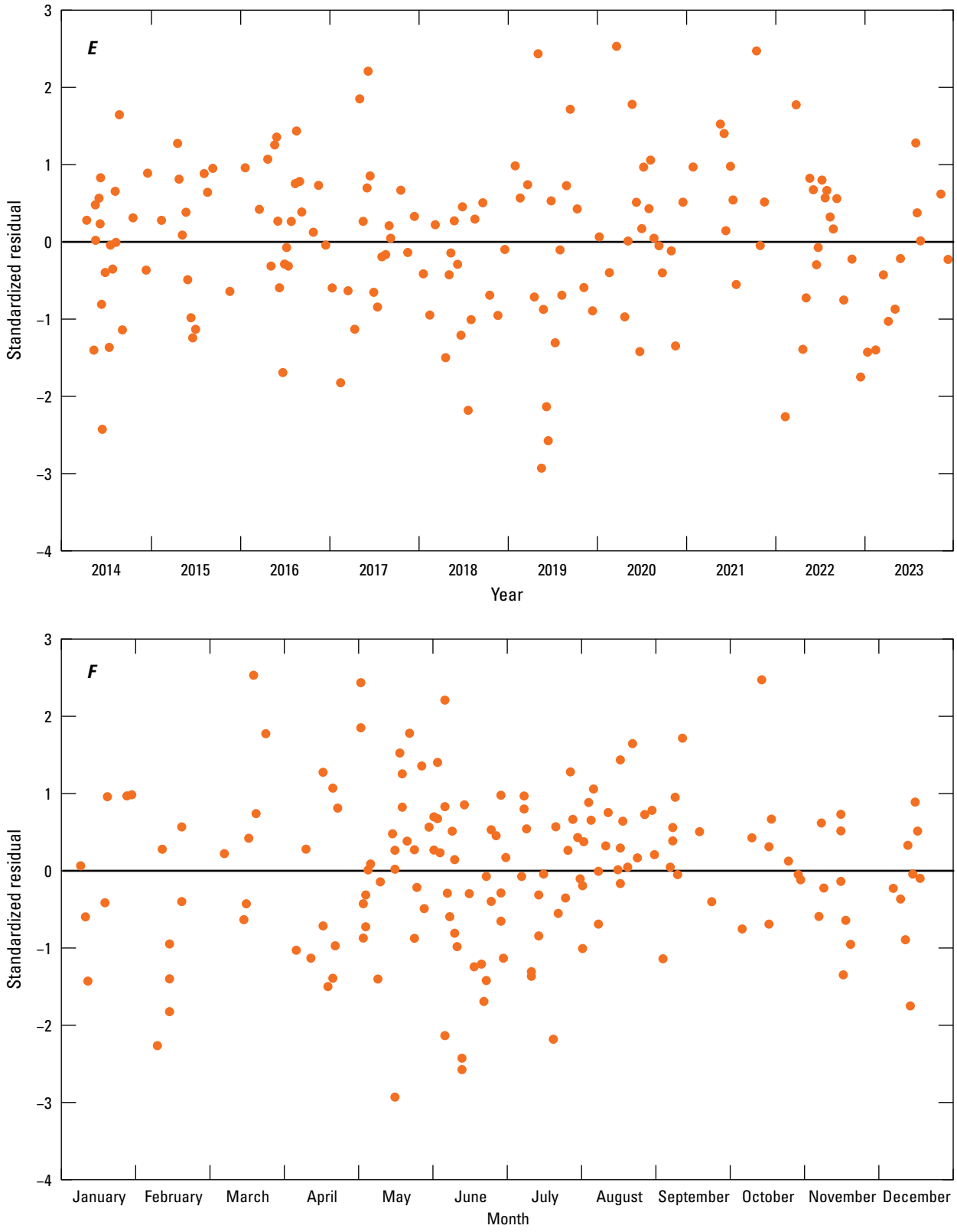


Figure 8.4. Graphs showing SEAWAVE-Q (Ryberg and Vecchia, 2013; Ryberg and York, 2020) trend analysis output for Aminomethylphosphonic acid (AMPA) in the Little Arkansas River near Sedgwick, Kansas (U.S. Geological Survey station 07144100), from 2015 to 2023. *A*, Measured and fitted pesticide concentrations and trend line. *B*, Fitted median and 95th percentile concentrations. *C*, Fitted versus measured concentrations. *D*, Fitted concentration versus standardized residuals. *E*, Annual standardized residuals. *F*, Monthly standardized residuals. Data are from Stone (2026). —Continued

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Appendix 9. SEAWAVE-Q Computed Pesticide Loads

Table 9.1. SEAWAVE-Q (Ryberg and Vecchia, 2013; Ryberg and York, 2020) computed pesticide loads for the Little Arkansas River at Highway 50 near Halstead, Kansas (Highway 50; U.S. Geological Survey station 07143672) and near Sedgwick, Kansas (Sedgwick; U.S. Geological Survey station 07144100), 1995–2021. Data are from Stone (2026).

[All loads are estimated and are expressed in kilograms. --, not applicable]

Year	Atrazine (herbicide) load, in kilograms		Glyphosate (herbicide) load, in kilograms	Aminomethylphosphonic acid (AMPA, degradation product of herbicide glyphosate) load, in kilograms
	Highway 50	Sedgwick	Sedgwick	Sedgwick
1995	--	--	--	--
1996	--	--	--	--
1997	--	--	--	--
1998	--	--	--	--
1999	1,261	2,437	--	--
2000	362	571	--	--
2001	804	1,792	--	--
2002	786	1,588	--	--
2003	501	1,130	--	--
2004	329	635	--	--
2005	1,045	2,227	--	--
2006	31	69	--	--
2007	1,655	3,354	--	--
2008	535	1,122	--	--
2009	1,262	2,471	--	--
2010	706	1,397	--	--
2011	10.4	30	--	--
2012	28	79	--	--
2013	491	646	--	--
2014	362	763	--	--
2015	439	1,477	--	508
2016	530	1,310	977	876
2017	241	693	202	308
2018	114	193	204	372
2019	1,162	2,123	1,194	1,432
2020	278	340	132	225
2021	485	827	380	468
2022	625	842	390	379
2023	32	24	14.1	30
Total load	14,080	28,140	3,490	4,600

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Ryberg, K.R., and Vecchia, A.V., 2013, seawaveQ—An R package providing model and utilities for analyzing trends in chemical concentrations in streams with a seasonal wave (seawave) and adjustment for streamflow (Q) and other ancillary variables: U.S. Geological Survey Open-File Report 2013–1255, 13 p., 3 apps. [Also available at https://doi.org/10.3133/ofr20131255.]

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Appendix 10. SEAWAVE-Q Computed Pesticide Loads

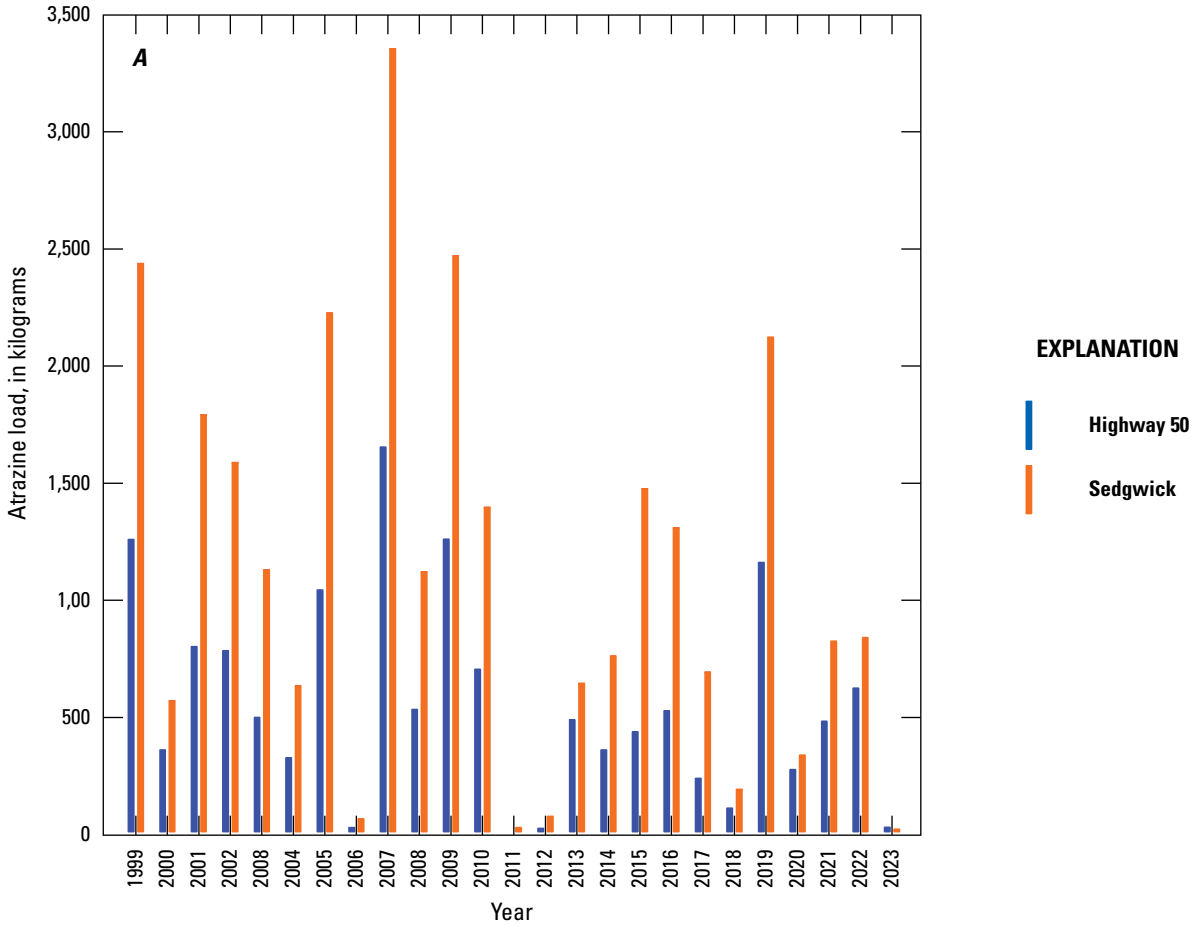


Figure 10.1. Graphs showing SEAWAVE-Q (Ryberg and Vecchia, 2013; Ryberg and York, 2020) computed pesticide loads in the Little Arkansas River at Highway 50 near Halstead, Kansas (Hwy 50; U.S. Geological Survey station 07143672) and near Sedgwick, Kansas (Sedgwick; U.S. Geological Survey station 07144100), from 1995 to 2023. *A*, Atrazine. *B*, Glyphosate. *C*, Aminomethylphosphonic acid (AMPA). Data are from Stone (2026).

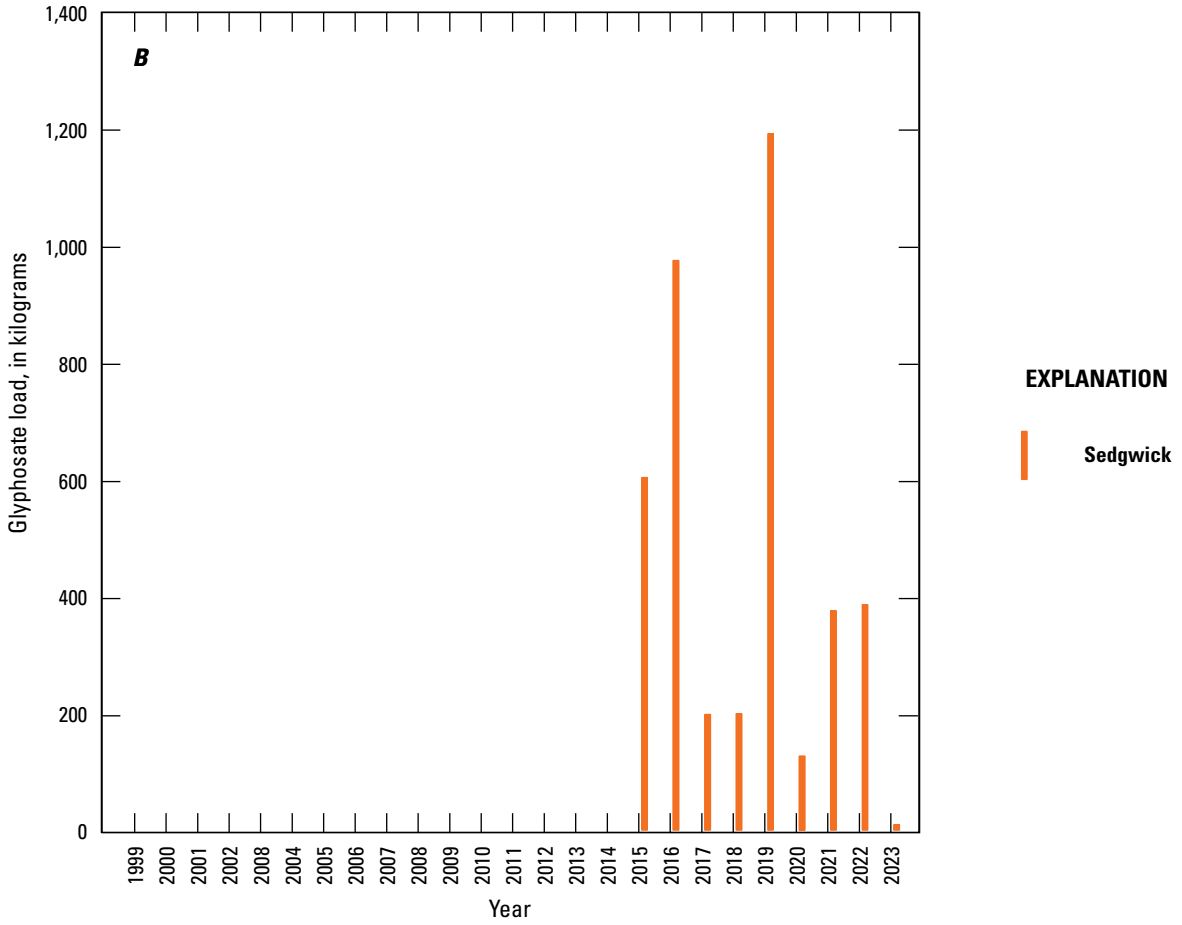


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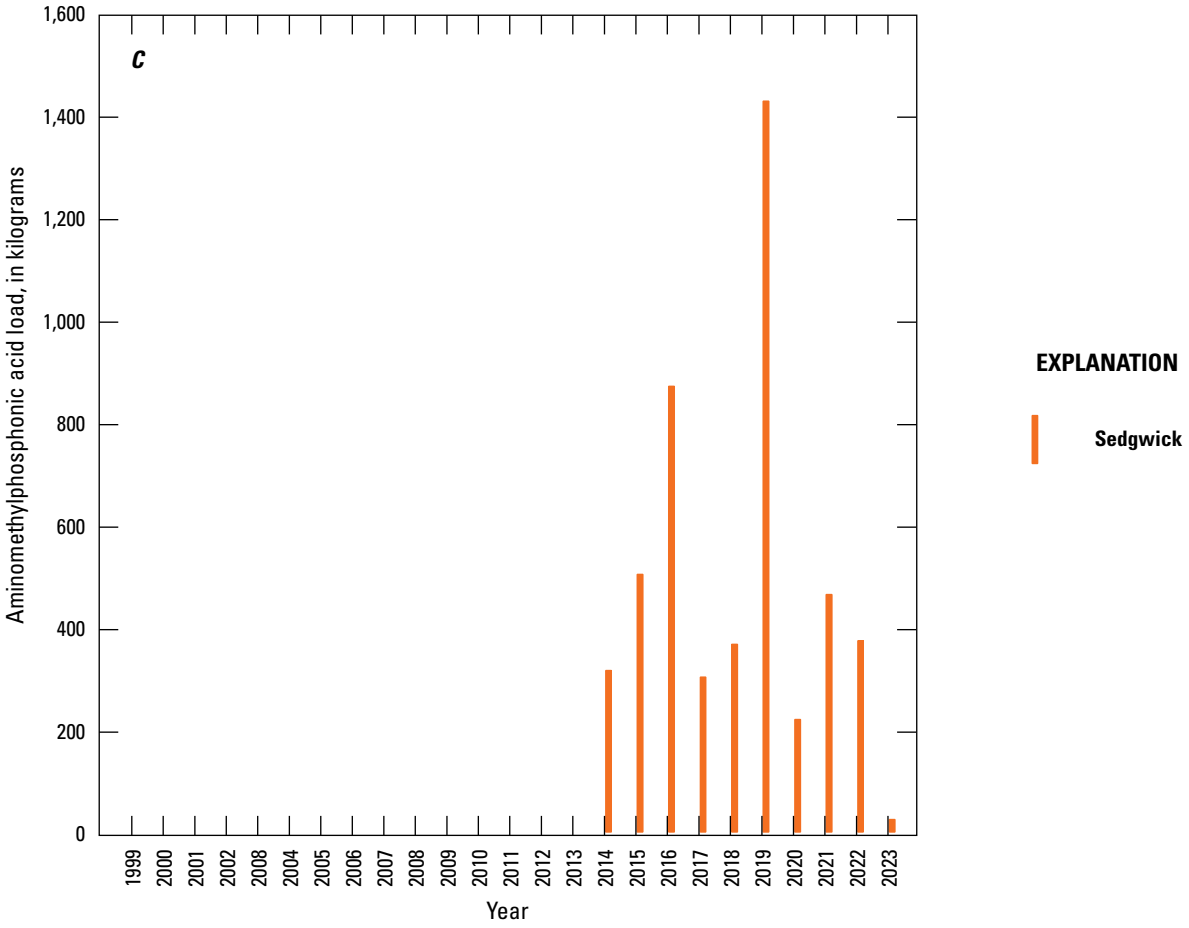


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