

Prepared in cooperation with the City of Wichita, Kansas

# Effects of Aquifer Storage and Recovery Activities on Water Quality in the Little Arkansas River and *Equus* Beds Aquifer, South-Central Kansas, 2011–14

Scientific Investigations Report 2016–5042

**Cover.** Photograph showing the Little Arkansas River near Sedgwick, Kansas, May 2012, by Mandy Stone, U.S. Geological Survey.

# **Effects of Aquifer Storage and Recovery Activities on Water Quality in the Little Arkansas River and *Equus* Beds Aquifer, South-Central Kansas, 2011–14**

By Mandy L. Stone, Jessica D. Garrett, Barry C. Poulton, and Andrew C. Ziegler

Prepared in cooperation with the City of Wichita, Kansas

Scientific Investigations Report 2016–5042

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

**U.S. Department of the Interior**  
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U.S. Geological Survey, Reston, Virginia: 2016

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Suggested citation:

Stone, M.L., Garrett, J.D., Poulton, B.C., and Ziegler, A.C., 2016, Effects of aquifer storage and recovery activities on water quality in the Little Arkansas River and *Equus* Beds aquifer, south-central Kansas, 2011–14: U.S. Geological Survey Report 2016–5024, 88 p., <http://dx.doi.org/10.3133/sir20165042>.

ISSN 2328-0328 (online)

## Contents

Acknowledgments .....	xii
Abstract .....	1
Introduction.....	2
Overview of the <i>Equus</i> Beds Aquifer Storage and Recovery Project.....	3
Purpose and Scope .....	4
Description of Study Area and Background Information.....	4
Recent Investigations .....	6
Methods.....	6
Data Collection.....	7
Continuous Water-Quality Monitoring.....	7
Discrete Water-Quality Samples.....	8
Streambed-Sediment Samples.....	8
Habitat Assessment .....	9
Macroinvertebrates .....	9
Fish .....	9
Data Analysis.....	10
Water Chemistry Data .....	10
Macroinvertebrate Data.....	11
Fish Data.....	11
Geochemical Modeling.....	12
Quality Assurance and Quality Control .....	12
Water Chemistry Data.....	12
Streambed Sediment Data .....	18
Macroinvertebrate Data.....	18
Effects of Aquifer Storage and Recovery Activities on Water Quality in the Little Arkansas River and <i>Equus</i> Beds Aquifer .....	18
Surface Water Physicochemical and Biological Conditions of the Little Arkansas River Upstream and Downstream from the Aquifer Storage and Recovery Facility.....	18
Streamflow.....	19
Water Quality of Stream Water and Releases.....	19
Continuous Water-Quality of Stream Water and Releases .....	19
Discrete Water-Quality of Stream Water and Releases .....	25
Dissolved and Suspended Solids, Major Ions, and Suspended Sediment .....	25
Nutrients.....	28
Trace Elements and Associated Compounds.....	30
Coliform Bacteria and Viral Indicators.....	32
Biological Activity Reaction Tests .....	34
Organic Compounds.....	34
Streambed-Sediment Chemistry .....	35
Habitat Assessment .....	38
Macroinvertebrates .....	40
Macroinvertebrate Community Composition .....	41

Macroinvertebrate Metrics .....	41
Fish Community Composition and Metrics .....	48
Groundwater Environmental Conditions .....	51
Groundwater Quality .....	51
Continuous Groundwater Quality .....	51
Discrete Groundwater Quality .....	58
Solids and Primary Ions .....	58
Nutrients and Organic Carbon .....	58
Indicator Bacteria .....	58
Trace Elements .....	62
Pesticides .....	62
Brominated and Chlorinated Organic Compounds .....	62
Radioactive Chemistry .....	62
Geochemical Effects .....	62
Summary and Conclusions .....	70
References Cited .....	73
Appendix 1. Water-Quality Data of the Little Arkansas River and <i>Equus</i> Beds Aquifer, Aquifer Storage and Recovery Project, South-Central Kansas, 2011–14 .....	84
Appendix 2. S+® Output of Regression Model Development and Graphs from Simple Linear Regression Analysis .....	85

## Figures

1. Maps showing study area and locations of monitoring wells for the city of Wichita, Kansas, <i>Equus</i> Beds aquifer storage and recovery project .....	3
2. Graph showing duration curve for hourly measured streamflow for the Little Arkansas River near Sedgwick, Kansas, January 2011 through December 2014 .....	19
3. Graphs showing duration curves for hourly measured constituents for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, and the Little Arkansas River near Sedgwick, Kansas, March 2011 through December 2014 .....	20
4. Graph showing relations between sensor and laboratory measured nitrate plus nitrite for the Little Arkansas River near Sedgwick, Kansas, March 2012 through December 2014 .....	22
5. Graphs showing duration curves for hourly measured or computed constituents for the Little Arkansas River near Sedgwick, Kansas, January 2011 through December 2014 .....	23
6. Graphs showing relations between discrete and computed constituents using regression models for the Little Arkansas River near Sedgwick, Kansas, March 2012 through December 2014 .....	24
7. Graphs showing relation between discrete and computed constituents using models developed in Rasmussen and others (2016) for the Little Arkansas River near Sedgwick, Kansas, January 2011 through December 2014 .....	25
8. Diagrams showing mean relative abundances of macroinvertebrate functional feeding groups for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, and the Little Arkansas River near Sedgwick, Kansas, May 2011 through August 2014 .....	42

9.	Diagrams showing mean relative abundances of macroinvertebrate behavioral groups for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, and the Little Arkansas River near Sedgwick, Kansas, May 2011 through August 2014. ....	43
10.	Diagrams showing mean relative abundances of macroinvertebrate tolerance groups for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, and the Little Arkansas River near Sedgwick, Kansas, May 2011 through August 2014. ....	44
11.	Graphs showing mean macroinvertebrate aquatic life-support metrics for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, and the Little Arkansas River near Sedgwick, Kansas, April 2011 through August 2014.....	49
12.	Diagrams showing mean fish feeding group percentage of total abundance for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, and the Little Arkansas River near Sedgwick, Kansas, September 2011 and 2012 and September 2013 and August 2014.....	52
13.	Diagrams showing mean fish tolerance group percentage of total abundance for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, and the Little Arkansas River near Sedgwick, Kansas, September 2011 and 2012 and September 2013 and August 2014. ....	53
14.	Graphs showing groundwater conditions continuously monitored or measured in wells near infiltration basin, 2011 through 2014.....	55
15.	Graphs showing saturation indices of minerals calculated for stream water and groundwater samples collected from monitoring wells near the infiltration basin, 2011 through 2014 .....	68
16.	Graphs showing pH of minerals calculated for groundwater samples collected from monitoring wells near the infiltration basin, 2011 through 2014 .....	69

## Appendix Figures

2-1.	S+® output of regression model development using chromophoric dissolved organic matter as the explanatory variable for dissolved organic carbon from the Little Arkansas River near Sedgwick, Kansas, 2009 through 2012 .....	85
2-2.	S+® output graphs from simple linear regression analysis from the Little Arkansas River near Sedgwick, Kansas, 2012 through 2014.....	86
2-3.	S+® output of regression model development using chromophoric dissolved organic matter and turbidity as explanatory variables for total organic carbon from the Little Arkansas River near Sedgwick, Kansas, 2009 through 2012 .....	87
2-4.	S+® output graphs from simple linear regression analysis using turbidity and log-transformed chromophoric dissolved organic matter as explanatory variables for total organic carbon concentrations from the Little Arkansas River near Sedgwick, Kansas, 2012 through 2014 .....	88

## Tables

1. Volumes of discharge from the Little Arkansas River aquifer storage and recovery facility and streamflow volumes from the Little Arkansas River near Sedgwick, Kansas, May 2013 through September 2014 .....	5
2. Total and mean annual precipitation during 2011 through 2014, and mean annual precipitation during 1900 through 2014 at the “Newton 2 SW” station.....	5
3. Summary statistics for continuously measured physicochemical properties and computed water-quality constituents of interest for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, Little Arkansas River near Sedgwick, Kansas, and discharge from the Little Arkansas River aquifer storage and recovery facility near Sedgwick, Kansas, March 2011 through December 2014.....	13
4. Discretely collected dissolved and suspended solids, primary ions, and suspended sediment summary statistics for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, Little Arkansas River near Sedgwick, Kansas, and discharge from the Little Arkansas River aquifer storage and recovery facility near Sedgwick, Kansas, March 2011 through September 2014.....	27
5. Discretely collected nutrient and carbon summary statistics for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, Little Arkansas River near Sedgwick, Kansas, and discharge from the Little Arkansas River aquifer storage and recovery facility near Sedgwick, Kansas, March 2011 through September 2014.....	29
6. Discretely collected trace element and associated compound summary statistics for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, Little Arkansas River near Sedgwick, Kansas, and discharge from the Little Arkansas River aquifer storage and recovery facility near Sedgwick, Kansas, March 2011 through September 2014.....	31
7. Discretely collected viral and bacteria summary statistics for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, Little Arkansas River near Sedgwick, Kansas, and discharge from the Little Arkansas River aquifer storage and recovery facility near Sedgwick, Kansas, March 2011 through September 2014.....	33
8. Discretely collected pesticide summary statistics for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, Little Arkansas River near Sedgwick, Kansas, and discharge from the Little Arkansas River aquifer storage and recovery facility near Sedgwick, Kansas, March 2011 through September 2014.....	36
9. Streambed-sediment nutrients, carbon, and trace element summary statistics for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, Little Arkansas River near Sedgwick, Kansas, and discharge from the Little Arkansas River Aquifer Storage and Recovery facility near Sedgwick, Kansas, April 2011 through April 2013 and July through September 2014 .....	37
10. Streambed-sediment organic wastewater indicator compound summary statistics for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, Little Arkansas River near Sedgwick, Kansas, and discharge from the Little Arkansas River aquifer storage and recovery facility near Sedgwick, Kansas, April 2011 through April 2013 and July through September 2014 ....	39



11. Habitat assessment scores for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, and Little Arkansas River near Sedgwick, Kansas, during August 2011 and September 2014 .....	40
12. List of five most dominant macroinvertebrate taxa for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, and Little Arkansas River near Sedgwick, Kansas, April 2011 through April 2013 and September 2013 through August 2014.....	41
13. Mean selected macroinvertebrate metric values and Kansas Department of Health and Environment aquatic-life-support status for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, and Little Arkansas River near Sedgwick, Kansas, April 2011 through April 2013 and September 2013 through August 2014.....	45
14. Criteria for four macroinvertebrate metrics used in Kansas to evaluate aquatic-life-support status of streams.....	48
15. Mean fish community summary statistics for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, and Little Arkansas River near Sedgwick, Kansas, September 2011 and 2012 and September 2013 and August 2014.....	50
16. Mean selected fish community metrics for the Little Arkansas River upstream from the aquifer storage and recovery facility and the Little Arkansas River near Sedgwick, Kansas, during September 2011 and 2012 and September 2013 and August 2014.....	51
17. Physicochemical properties for sites near the recharge basin near Sedgwick, Kansas before, during, and after artificial recharge and at the Little Arkansas River near Sedgwick, Kansas, summary of daily statistics from continuously measured data .....	54
18. Discretely collected solids and primary ions summary statistics for groundwater samples at sites near the recharge basin near Sedgwick, Kansas, before and after artificial recharge .....	59
19. Discretely collected nutrient and carbon summary statistics for groundwater samples at sites near the recharge basin near Sedgwick, Kansas, before and after artificial recharge.....	60
20. Discretely collected bacteria summary statistics for groundwater samples at sites near the recharge basin near Sedgwick, Kansas, before and after artificial recharge.....	61
21. Discretely collected trace element summary statistics for groundwater samples at sites near the recharge basin near Sedgwick, Kansas, before and after artificial recharge.....	63
22. Discretely collected pesticides summary statistics for groundwater samples at sites near the recharge basin near Sedgwick, Kansas, before and after artificial recharge.....	64
23. Discretely collected brominated and chlorinated organic compounds and radioactivity summary statistics for groundwater samples at sites near the recharge basin near Sedgwick, Kansas, before and after artificial recharge.....	65
24. Saturation indices for select minerals for groundwater samples collected at sites near the recharge basin near Sedgwick, Kansas, before and after artificial recharge.....	67

## Appendix Tables

1-1.	Discretely collected constituents from the residual basin aquifer storage and recovery treatment plant near Sedgwick, Kansas, diverted water at the Sedgwick recharge site, Kansas, and treated source water at the high service pump station, July 2012 through September 2014 .....	84
1-2.	Sample collection dates and streamflow conditions for discrete water-quality samples collected at surface-water sites, the residuals return line site, and groundwater well sites, March 2011 through September 2014 .....	84
1-3.	High flow summary statistics for continuously measured physicochemical properties and computed water-quality constituents of interest for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, the Little Arkansas River near Sedgwick, Kansas, discharge from the Little Arkansas River aquifer storage and recovery facility near Sedgwick, Kansas, January 2011 through December 2014.....	84
1-4.	Regression models and summary statistics for continuous dissolved and total organic carbon concentration computations for the Little Arkansas River near Sedgwick, Kansas, March 2012 through September 2014.....	84
1-5.	Dissolved and total organic carbon datasets using chromophoric dissolved organic matter and turbidity as explanatory variables for the Little Arkansas River near Sedgwick, Kansas, 2012 through 2014 .....	84
1-6.	Discretely collected during high flow condition water-quality constituent summary statistics for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, the Little Arkansas River near Sedgwick, Kansas, and discharge from the Little Arkansas River aquifer storage and recovery facility near Sedgwick, Kansas, March 2011 through September 2014 .....	84
1-7.	Discrete organic material characterization data for samples collected at the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, the Little Arkansas River near Sedgwick, Kansas, and discharge from the Little Arkansas River aquifer storage and recovery facility near Sedgwick, Kansas, March 2011 through September 2014.....	84
1-8.	Macroinvertebrate taxa abundances identified for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, and the Little Arkansas River near Sedgwick, Kansas, April 2011 through August 2014 .....	84
1-9.	Seasonal and annual mean selected macroinvertebrate metric values and Kansas Department of Health and Environment aquatic life-support status for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas, and the Little Arkansas River near Sedgwick, Kansas, April 2011 through August 2014.....	84
1-10.	Constituents analyzed but not detected in groundwater samples for sites near the recharge basin near Sedgwick, Kansas, January 2011 to December 2014.....	84

## Conversion Factors

[International System of Units to U.S. customary units]

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
micrometer ( $\mu\text{m}$ )	0.001	millimeter (mm)
meter (m)	1.094	yard (yd)
Area		
square kilometer ( $\text{km}^2$ )	0.3861	square mile ( $\text{mi}^2$ )
Mass		
gram (g)	0.03527	ounce, avoirdupois (oz)

Temperature in degrees Celsius ( $^{\circ}\text{C}$ ) may be converted to degrees Fahrenheit ( $^{\circ}\text{F}$ ) as follows:

$$^{\circ}\text{F} = (1.8 \times ^{\circ}\text{C}) + 32.$$

## Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ( $\mu\text{S}/\text{cm}$  at  $25^{\circ}\text{C}$ ).

Concentrations of chemical constituents in water are given in either milligrams per liter ( $\text{mg}/\text{L}$ ) or micrograms per liter ( $\mu\text{g}/\text{L}$ ).

Concentrations of water-quality constituents are given in colony forming units per 100 milliliters ( $\text{cfu}/100 \text{ mL}$ ), colonies per 100 milliliters ( $\text{col}/100 \text{ mL}$ ), most probable number per 100 milliliters ( $\text{mpn}/100 \text{ mL}$ ), or plaque forming units per 100 milliliters ( $\text{pfu}/100 \text{ mL}$ ).

Concentrations of streambed-sediment constituents are given in milligrams per kilogram ( $\text{mg}/\text{kg}$ ).

Activities for radioactive constituents in water are given in picocuries per liter ( $\text{pCi}/\text{L}$ ).

Flow rate is given in cubic feet per second ( $\text{ft}^3/\text{s}$ ) or million gallons per day ( $\text{Mgal}/\text{d}$ ).

Volume is given in million gallons ( $\text{Mgal}$ ).

Aquifer storage volume is given in billion gallons ( $\text{Bgal}$ ).

Turbidity is given in formazin nephelometric units ( $\text{FNU}$ ).

Precipitation is given in inches (in.).

## Abbreviations

1Q	first quartile
3Q	third quartile
ASR	aquifer storage and recovery
BART	Biological Activity Reaction Test
CDOM	chromophoric (colored) dissolved organic matter
Df	degrees of freedom
DOC	dissolved organic carbon
CIAT	2-Chloro-4-isopropylamino-6-amino- <i>s</i> -triazine
CV	coefficient of variation
<i>E. coli</i>	<i>Escherichia coli</i>
EPA	U.S. Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, and Trichoptera
F Value	explained variance divided by unexplained variance
FID	floating intercedent device
GIS	geographic information system
h	hour
HBMP	hydrobiological monitoring program
IBI	Index of Biotic Integrity
ILWS	Integrated Local Water Supply
KDHE	Kansas Department of Health and Environment
LOG <sub>10</sub>	log <sub>10</sub>
Max	maximum
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
Min	minimum
NPDES	National Pollutant Discharge Elimination System
NWQL	National Water Quality Laboratory
ORP	oxidation-reduction potential
OWC	organic wastewater-indicator compound
PEC	probable effect concentration
Post-ASR	May 2013 through December 2014
Pre-ASR	January 2011 through April 2013
Pr(F)	probability value of an F-test

$\Pr(> t )$	probability of observing a test statistic that follows a Student's t distribution if the null hypothesis is supported
$p$ -value extreme	probability of observing a test statistic that is as extreme or more than currently observed assuming that the null hypothesis is true
QA/QC	quality assurance and quality control
$R^2$	coefficient of determination
Residual standard error	square root of residual sum of squares divided by degrees of freedom
RMSE	root mean square error
ROS	regression on order statistics
RPD	relative percentage difference
SI	saturation index
SMCL	secondary maximum contaminant level
Sum of Sq	sum of squares
t value	coefficient divided by its standard error
TBY	turbidity
THM	trihalomethane
TMDL	total maximum daily load
TOC	total organic carbon
USGS	U.S. Geological Survey

## Acknowledgments

The authors thank Mike Jacobs, Deb Ary, and Scott Macey of the city of Wichita; and Tim Boese and the Groundwater Management District 2 staff for technical assistance and providing data and information about the *Equus* Beds aquifer storage and recovery project. The authors also thank Terryl Pajor, Vernon Strasser, and the laboratory staff at the city of Wichita Municipal Water and Wastewater Laboratory for laboratory analyses. The authors greatly appreciate the efforts of Jeff Conley, Aaron Austin, Ryan Waters, Jessica Mounts, Mark Van Scoyoc, and other personnel from the Kansas Department of Wildlife, Parks and Tourism who helped with fish sampling.

The authors thank the U.S. Geological Survey staff that assisted with data collection, analysis, and interpretation, including Billy Justus, Trudy Bennett, Carlen Collins, Beatrice Richie, Barb Dague, John Rosendale, and Chelsea Paxson. Brian Kelly of the Missouri Water Science Center and Teresa Rasmussen of the Kansas Water Science Center provided helpful reviews that contributed to technical and editorial clarity of the report.

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By Mandy L. Stone, Jessica D. Garrett, Barry C. Poulton, and Andrew C. Ziegler

## Abstract

The *Equus* Beds aquifer in south-central Kansas is a primary water source for the city of Wichita. The *Equus* Beds aquifer storage and recovery (ASR) project was developed to help the city of Wichita meet increasing current (2016) and future water demands. The *Equus* Beds ASR project pumps water out of the Little Arkansas River during above-base flow conditions, treats it using drinking-water quality standards as a guideline, and recharges it into the *Equus* Beds aquifer for later use. Phase II of the *Equus* Beds ASR project currently (2016) includes a river intake facility and a surface-water treatment facility with a 30 million gallon per day capacity. Water diverted from the Little Arkansas River is delivered to an adjacent presedimentation basin for solids removal. Subsequently, waste from the surface-water treatment facility and the presedimentation basin is returned to the Little Arkansas River through a residuals return line. The U.S. Geological Survey, in cooperation with the city of Wichita, developed and implemented a hydrobiological monitoring program as part of the ASR project to characterize and quantify the effects of aquifer storage and recovery activities on the Little Arkansas River and *Equus* Beds aquifer water quality.

Data were collected from 2 surface-water sites (one upstream and one downstream from the residuals return line), 1 residuals return line site, and 2 groundwater well sites (each having a shallow and deep part): the Little Arkansas River upstream from the ASR facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), about 0.03 mile (mi) upstream from the residuals return line site; the Little Arkansas River near Sedgwick, Kans. (downstream surface-water site 07144100), about 1.68 mi downstream from the residuals return line site; discharge from the Little Arkansas River ASR facility near Sedgwick, Kansas (residuals return line site 375348097262800); 25S 01 W 07BCCC01 SMW–S11 near CW36 (MW–7 shallow groundwater well site 375327097285401); 25S01 W 07BCCC02 DMW–S10 near CW36 (MW–7 deep groundwater well site 375327097285402); 25S 01W 07BCCA01 SMW–S13 near CW36 (MW–8 shallow groundwater

well site 375332097284801); and 25S 01W 07BCCA02 DMW–S14 near CW36 (MW–8 deep groundwater well site 375332097284802). The U.S. Geological Survey, in cooperation with the city of Wichita, assessed the effects of the ASR Phase II facility residuals return line discharges on stream quality of the Little Arkansas River by measuring continuous physicochemical properties and collecting discrete water-quality and sediment samples for about 2 years pre- (January 2011 through April 2013) and post-ASR (May 2013 through December 2014) Phase II facility operation upstream and downstream from the ASR Phase II facility. Additionally, habitat variables were quantified and macroinvertebrate and fish communities were sampled upstream and downstream from the ASR Phase II facility during the study period. To assess the effects of aquifer recharge on *Equus* Beds groundwater quality, continuous physicochemical properties were measured and discrete water-quality samples were collected before and during the onset of Phase II aquifer recharge in two (shallow and deep) groundwater wells.

Little Arkansas River streamflow was about 10 times larger after the facility began operating because of greater rainfall. Residuals return line release volumes were a very minimal proportion (0.06 percent) of downstream streamflow volume during the months the ASR facility was operating. Upstream and downstream continuously measured water temperature and dissolved oxygen median differences were smaller post-ASR than pre-ASR. Turbidity generally was smaller at the downstream site throughout the study period and decreased at both sites after the ASR Phase II facility began discharging despite a median residuals return line turbidity that was about an order of magnitude larger than the median turbidity at the downstream site. Upstream and downstream continuously measured turbidity median differences were larger post-ASR than pre-ASR. Median post-ASR continuously measured nitrite plus nitrate and continuously computed total suspended solids and suspended-sediment concentrations were smaller than pre-ASR likely because of higher streamflows and dilution; whereas, median continuously computed dissolved and total organic carbon concentrations were larger likely because of higher streamflows and runoff conditions.

None of the discretely measured water-quality constituents (dissolved and suspended solids, primary ions, suspended sediment, nutrients, carbon, trace elements, viral and bacterial indicators, and pesticides) in surface water were significantly different between the upstream and downstream sites after the ASR Phase II facility began discharging; however, pre-ASR calcium, sodium, hardness, manganese, and arsenate concentrations were significantly larger at the upstream site, which indicates that some water-quality conditions at the upstream and downstream sites were more similar post-ASR. Most of the primary constituents that make up dissolved solids decreased at both sites after the ASR Phase II facility began operation. Discretely collected total suspended solids concentrations were similar between the upstream and downstream sites before the facility began operating but were about 27 percent smaller at the downstream site after the facility began operating, despite the total suspended solids concentrations in the residuals return line being 15 times larger than the downstream site.

Overall habitat scores were indicative of suboptimal conditions upstream and downstream from the ASR Phase II facility throughout the study period. Substrate fouling and sediment deposition mean scores indicated marginal conditions at the upstream and downstream sites during the study period, demonstrating that sediment deposition was evident pre- and post-ASR and no substantial changes in these habitat characteristics were noted after the ASR Phase II facility began discharging. Macroinvertebrate community composition (evaluated using functional feeding, behavioral, and tolerance metrics) generally was similar between sites during the study period. Fewer macroinvertebrate metrics were significant between the upstream and downstream sites post-ASR (6) than pre-ASR (14), which suggests that macroinvertebrate communities were more similar after the ASR facility began discharging. Upstream-downstream comparisons in macroinvertebrate aquatic-life-support metrics had no significant differences for the post-ASR time period and neither site was fully supporting for any of the Kansas Department of Health and Environment aquatic-life-support metrics (Macroinvertebrate Biotic Index; Kansas Biotic Index with tolerances for nutrients and oxygen-demanding substances; Ephemeroptera, Plecoptera, and Trichoptera [EPT] richness; and percentage of EPT species). Overall, using macroinvertebrate aquatic life-support criteria from the Kansas Department of Health and Environment, upstream and downstream sites were classified as partially supporting before and after the onset of ASR facility operations. Fish community trophic status and tolerance groups generally were similar among sites during the study period. Fish community Little Arkansas River Basin Index of Biotic Integrity scores at the upstream and downstream sites were indicative of fair-to-good conditions before the facility began operating and decreased to fair conditions after the facility began operating.

Groundwater physicochemical changes concurrent with the beginning of recharge operations at the Sedgwick basin were more pronounced in shallow groundwater. No constituent concentrations in the pre-recharge period in comparison to the post-recharge period increased to concentrations exceeding

drinking water regulations; however, nitrate decreased significantly from a pre-recharge exceedance of the U.S. Environmental Protection Agency maximum contaminant level to a post recharge nonexceedance. Shallow groundwater chemical concentrations or rates of detection increased after artificial recharge began for the ions potassium, chloride, and fluoride; phosphorus and organic carbon species; trace elements barium, manganese, nickel, arsenate, arsenic, and boron; agricultural pesticides atrazine, metolachlor, metribuzin, and simazine; organic disinfection byproducts bromodichloromethane and trichloromethane; and gross beta levels. Additionally, water temperature, and pH were larger after recharge began; and total solids and slime-forming bacteria concentrations and densities were smaller. Total solids, nitrate, and selenium significantly decreased; and potassium, chloride, nickel, arsenic, fluoride, phosphorus and carbon species, and gross beta levels significantly increased in shallow groundwater after artificial recharge. Results of biological activity reaction tests indicated that water quality microbiology was different before and after artificial recharge began; at times, these differences may lead to changes in dominant bacterial populations that, in turn, may lead to formation and expansion in populations that may cause bioplugging and other unwanted effects. Calcite, iron (II) hydroxide, hydroxyapatite, and similar minerals, had shifts in saturation indices that generally were from undersaturation toward equilibrium and, in some cases, toward oversaturation. These shifts toward neutral saturation indices might suggest reduced weathering of the minerals present in the *Equus* Beds aquifer. Chemical weathering in the shallow parts of the aquifer may be accelerated because of the increased water temperatures and the system is more vulnerable to clogged pores and mineral dissolution as the equilibrium state is affected by recharge and withdrawal. When oversaturation is indicated for iron minerals, plugging of aquifer materials may happen.

## Introduction

The city of Wichita's water supply currently (2016) comes from two primary sources: (1) Cheney Reservoir and (2) the Wichita *Equus* Beds aquifer (fig. 1) well field, which was first constructed in the 1950s (Ziegler and others, 2001). The city of Wichita's Water Utilities Department developed an Integrated Local Water Supply (ILWS) Plan because future water demands are expected to exceed current supply (City of Wichita, 1993). A primary component of the ILWS Plan is to increase the city of Wichita's available water supply for their future water demands through 2050 by artificial recharge of the *Equus* Beds aquifer (City of Wichita, 1993). The *Equus* Beds aquifer storage and recovery (ASR) project, as part of the ILWS Plan, pumps water out of the Little Arkansas River during above-base flow conditions, treats it according to National Primary Drinking Water Regulations (U.S. Environmental Protection Agency, 2009), and injects it into the *Equus* Beds aquifer. The U.S. Geological Survey (USGS), in cooperation



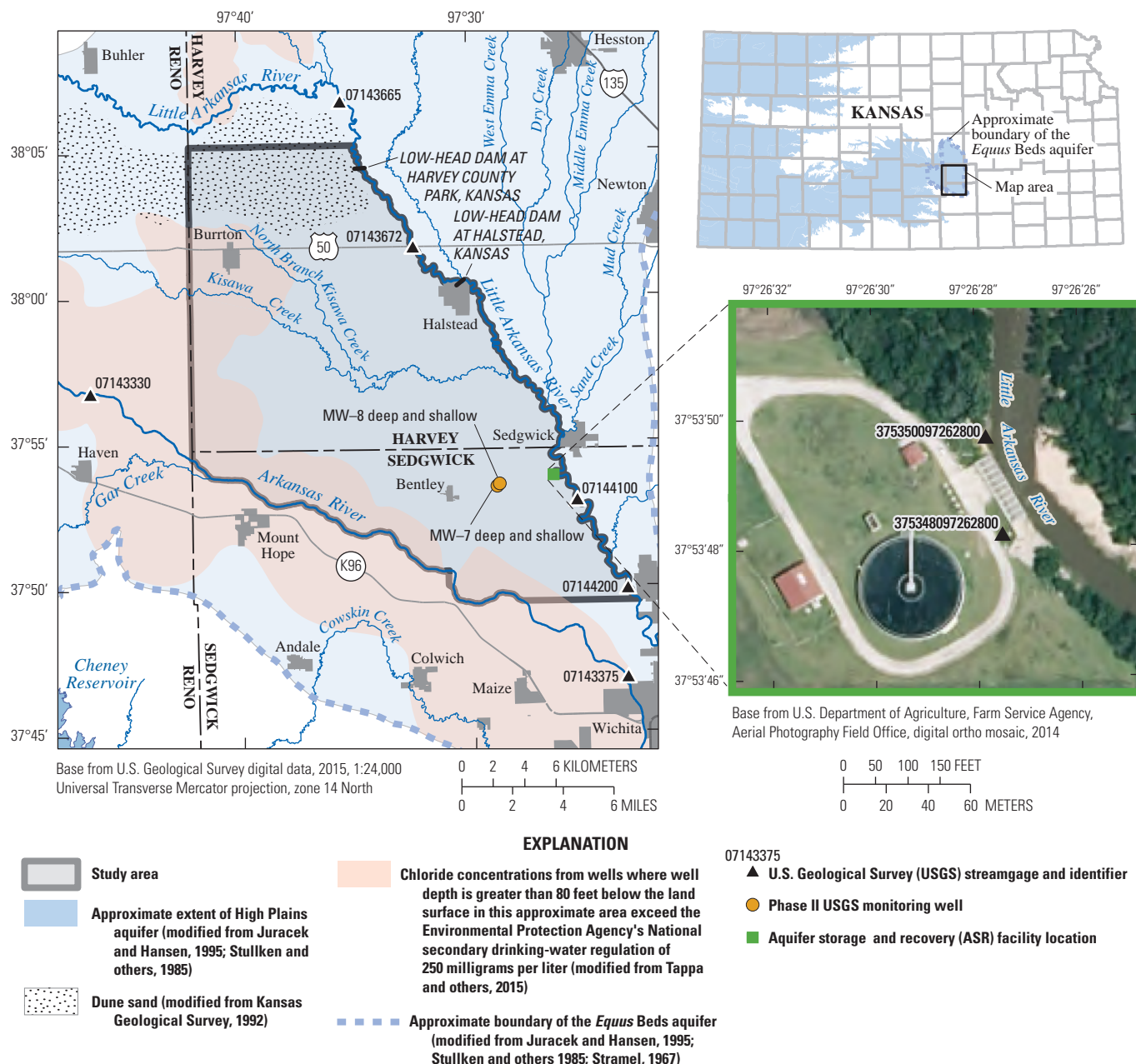
with the city of Wichita, developed and implemented a hydrobiological monitoring program (HBMP) as part of the mitigation described in City of Wichita, Department of Water and Sewer (2003) for the ILWS Plan (now part of the ASR project).

The USGS, in cooperation with the city of Wichita, completed a study to assess the effects of ASR project activities on the Little Arkansas River and the *Equus* Beds aquifer (fig. 1). The primary objective of this study was to establish baseline conditions before expanded implementation for aquifer recharge and to evaluate changes that may be related to the recharge program. To complete this objective, physical, chemical, and biological data were collected from the Little Arkansas River and the *Equus* Beds aquifer before and after the ASR

Phase II facility began operation to quantify and characterize water-quality relative to before recharge conditions and to compare to water-quality and biological criteria.

### Overview of the *Equus* Beds Aquifer Storage and Recovery Project

The city of Wichita, Kansas, uses the *Equus* Beds aquifer as a primary municipal water supply source. The volume of water that has been pumped out of parts of the *Equus* beds aquifer has exceeded its natural recharge rate; as such, water levels in the aquifer have decreased substantially (Whisnant



**Figure 1.** Study area and locations of monitoring wells for the city of Wichita, Kansas, *Equus* Beds aquifer storage and recovery (ASR) project.

and others, 2015; Hansen and others, 2014). The aquifer is susceptible to saltwater contamination from the Arkansas River (fig. 1) and saltwater intrusion from existing upgradient contamination plumes caused by oil field evaporation pits remaining from the 1930s (Whittemore, 2007; Klager and others, 2014). The *Equus* Beds ASR project, along with increased reliance on Cheney Reservoir, will help the city of Wichita meet increasing future water demands. The ASR project will also inhibit saltwater encroachment into the Wichita well field (not shown) (Ziegler and others, 2010; Klager and others, 2014).

The *Equus* Beds ASR project consists of four phases of construction. Phase I construction was completed in 2006, with a designed capacity to capture 10 million gallons per day (Mgal/d) of above-base flow water diverted directly from the Little Arkansas River and indirectly through streambank diversion wells for recharge. Phase I recharge activity began in 2007 with water injection in four wells and two recharge basins; Phase I recharge activity is currently (2016) ongoing with intermittent pauses as a result of low flows on the Little Arkansas River. Directly diverted stream water is treated to reduce sediment and remove organic materials before being recharged to the aquifer through the two recharge basins; water pumped from streambank diversion wells does not receive additional treatment before being recharged to the aquifer through the Phase I injection wells or recharge basins (Garinger, 2011).

Phase II activity began in 2009 with construction of a 30 Mgal/d surface-water treatment facility and a 60 Mgal/d river intake facility currently (2016) equipped to divert 30 Mgal/d and treat 15 Mgal/d, drilling of seven new recharge injection wells, and creation of a third recharge basin. The Phase II ASR facility began operating in May 2013 and is currently (2016) ongoing. The city of Wichita has a National Pollutant Discharge Elimination System (NPDES) permit to discharge waste from the ASR Phase II surface water treatment facility to the Little Arkansas River. The city of Wichita was appropriated a 60 Mgal/d diversion when permit requirements are met (Kansas Department of Agriculture and Kansas Geological Survey, 2015). The Phase II ASR facility diversion permit requires that 30 cubic feet per second (ft<sup>3</sup>/s) or greater is maintained in the Little Arkansas River at the streamgage at Valley Center, Kans. (site 07144200; fig. 1). The current Phase II ASR facility capacity of 30 Mgal/d (46.4 ft<sup>3</sup>/s) requires a streamflow of about 100 ft<sup>3</sup>/s or greater at the USGS streamgage near Sedgwick, Kansas (site 07144100; fig. 1); Phase II water is directly diverted from the Little Arkansas River at the intake structure when streamflow exceeds about 100 ft<sup>3</sup>/s at this site. The ASR facilities have an operational period of April 15 through October 15 because of climatological restrictions related to the potential for freezing conditions.

Intake structure pumps deliver water to an adjacent presedimentation basin for solids removal. Water from the presedimentation basin is subsequently treated (the main processes are membrane ultrafiltration and advanced oxidation) at the surface-water treatment facility and then recharged directly into infiltration basins and wells. A summary table of gallons of water recharged for each month during Phase II is available

at <http://ks.water.usgs.gov/water-recharge#phase2>. A residuals return line conveys residuals from the surface water treatment facility and from the presedimentation basin back to the Little Arkansas River; delays between river water withdrawal and releases to the river may last as much as 5 hours. The city of Wichita's original NPDES permit to discharge waste from the ASR Phase II surface water treatment facility through the residuals return line to the Little Arkansas River was effective during January 1, 2010, through December 31, 2014, and the city of Wichita currently has a NPDES permit dated May 1, 2015, through December 31, 2015. The ASR total residuals return line volume during 2013 through 2014 was about 600 million gallons (table 1). More information about the city of Wichita ASR project is available at <http://www.wichita.gov/Government/Departments/PWU/Pages/PublicWaterSupply.aspx>.

## Purpose and Scope

The purpose of this report is to document baseline and postoperational conditions upstream and downstream from the Phase II surface-water diversion, treatment, and infiltration facilities on the Little Arkansas River before and after facility operations began in May 2013 and describe effects of aquifer recharge on river water quality (including biology) and groundwater quality in comparison to relevant drinking water and biological criteria. The data in this report will be used to establish baseline conditions before expanded implementation of artificial aquifer recharge and to evaluate changes that may be related to the recharge program. In addition, data from this report will be used to document stream and groundwater quality, evaluate changing conditions, identify environmental factors affecting streams and groundwater, provide science-based information for decision-making, and help meet regulatory monitoring requirements. Physical, chemical, and biological conditions during March 2011 through December 2014, using sample data collected from two primary sites, upstream and downstream from the ASR facility, and geochemical modeling are described in this report. Streamflow, continuously and discretely collected water-quality, streambed-sediment, macroinvertebrate, fish, and habitat data were collected to quantify and characterize conditions in the Little Arkansas River. Water-quality data collected from two groundwater sites are also summarized in this report. Results presented in this report also contribute to the understanding of potential effects related to ASR activities throughout the Nation.

## Description of Study Area and Background Information

The study area is in south-central Kansas (fig. 1). The Little Arkansas River drainage basin is about 3,107 square kilometers of primarily agricultural (corn, sorghum, soybeans, and wheat) land. Fertilizers (such as nitrogen and phosphorus) and herbicides (such as alachlor and atrazine) are commonly applied in the drainage basin (Kansas Department of

**Table 1.** Volumes of discharge from the Little Arkansas River aquifer storage and recovery facility (residuals return line site 375348097262800) and streamflow volumes from the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), May 2013 through September 2014.

[See figure 1 for site locations. Data were provided by the city of Wichita.]

Time period	Volume (gallon)		Downstream surface-water site volume from the residuals return line site (percent)
	Residuals return line site	Downstream surface-water site	
May 2013	4,376,517	2,203,809,235	0.20
June 2013	12,681,174	2,813,025,142	0.45
July 2013	3,160,602	19,279,500,570	0.02
August 2013	23,500,358	100,659,358,070	0.02
September 2013	9,879,790	1,409,797,575	0.70
May 2014	5,577,225	1,326,622,586	0.42
June 2014	15,138,362	20,160,222,942	0.08
July 2014	12,816,712	3,285,525,627	0.39
August 2014	45,129	630,685,853	0.01
September 2014	12,350,376	10,065,903,335	0.12
Total 2013–2014	99,526,247	161,834,450,935	0.06

Agriculture, 2015). Cattle and hogs are the primary livestock raised in the area (Kansas Department of Agriculture, 2015). Long-term mean annual precipitation (1900 through 2014) in the study area, based on data recorded near Newton, Kans., was 31.1 inches (in.) (table 2). During the study period (2011 through 2014) mean annual precipitation was 29.4 in. (table 2).

The study area is underlain by the *Equus* Beds aquifer, which is part of the easternmost extent of the larger High Plains aquifer (fig. 1). The *Equus* Beds aquifer is named for Pleistocene horse fossils in its sediments. The *Equus* Beds aquifer is about 300 feet (ft) thick and consists of alluvial deposits

**Table 2.** Total and mean annual precipitation during 2011 through 2014, and mean annual precipitation during 1900 through 2014 at the “Newton 2 SW” station (Global Historical Climatology Network USC00145744).

[Data from Global Historical Climatology Network, 2015. Values for years in ranges are mean annual precipitation, whereas values for 1 year are total annual precipitation]

Year or time period	Total or mean annual precipitation (inch)
2011	19.9
2012	25.4
2013	41.0
2014	31.5
2011 through 2014	29.4
2011 through 2012	22.6
2013 through 2014	36.2
1900 through 2014	31.1

of sand and gravel interbedded with clay or silt and is an important source of groundwater because of its water quality, shallow depth to the water table, and large saturated thickness (Williams and Lohman, 1949). Groundwater in the study area generally moves to the east except where the hydraulic gradient is altered by pumping wells and near a low-head dam on the Little Arkansas River at Halstead, Kansas (fig. 1; Whisnant and others, 2015). The city of Wichita well field is one of the primary sources of water for the city and surrounding area, and numerous irrigation wells also withdraw aquifer water within the boundaries (not shown) of *Equus* Beds Groundwater Management District Number 2 (GMD2; *Equus* Beds Groundwater Management District No. 2, 1990), which contain the study area boundary. Water withdrawals exceeding natural recharge of the *Equus* Beds aquifer have resulted in water-level declines of as much as 50 ft and exacerbated the threat of saltwater contamination (Hansen and Aucott, 2003, 2010; Hansen, 2007; Klager and others, 2014).

Consequently, the city of Wichita’s Water Utilities Department developed an ILWS Plan that was implemented in 1993. The goal of the ASR project, as part of the ILWS Plan, is to increase the city of Wichita’s available water supply for their future water demands through 2050 by artificial recharge of the *Equus* Beds aquifer using water from the Little Arkansas River above minimum flow requirements (City of Wichita, 1993; Warren and others, 1995). Phase I recharge of the ASR project began in 2007, and Phase II expansion became operational in 2013. Phase II of the ASR project includes a water intake structure along the Little Arkansas River, a presedimentation basin, a surface water treatment facility, and a residuals return line. The facility operational period is April 15 through October 15 when streamflow exceeds 100 ft<sup>3</sup>/s.

The Kansas Department of Health and Environment (KDHE) 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, 2014a). Impairments for streams in or near the study area include arsenic and chloride for water supply; dissolved oxygen, selenium, total suspended solids, atrazine, copper, total phosphorus, biology, and biology/sediment for aquatic life; and *Escherichia coli* (*E. coli*) bacteria for recreation (Kansas Department of Health and Environment, 2014a, 2014b). Main pollutants of concern listed in the Little Arkansas River Watershed Restoration and Protection Strategy (WRAPS) were atrazine, sediment, nutrients, and fecal coliform bacteria (Kansas State University Research and Extension: Kansas Center for Agricultural Resources and the Environment, 2011). The Little Arkansas River has total maximum daily loads (TMDLs) for atrazine; effect on aquatic life by nutrients, sediment, and low dissolved oxygen; chloride; fecal coliform bacteria; and total suspended solids (Kansas Department of Health and Environment, 2000b, 2000c, 2000d, 2006, 2008b, and 2014b).

## Recent Investigations

Kelly and others (2013) and Klager and others (2014) developed Wichita well field numerical groundwater models. Kelly and others (2013) characterized groundwater flow and quantified artificial recharge in the *Equus* Beds aquifer. The Kelly and others (2013) model can be used for the following: quantify artificial and natural recharge, well pumping, and streamflow change effects on groundwater; simulate changes in water withdrawals, water levels caused by drought or pumping, and natural and artificial aquifer recharge; and simulate chloride movement throughout the aquifer and evaluate the effects of withdrawal and injection scenarios on chloride transport. Klager and others (2014) simulated chloride transport scenarios in the *Equus* Beds aquifer between the Arkansas and Little Arkansas Rivers (fig. 1) near the Wichita *Equus* Beds aquifer well field. Simulated scenario results indicated that the chloride plume near Burrton, Kans., originating from previous oil and gas activities will continue moving eastward toward the well field regardless of pumping in that area. Eastward movement of the Burrton chloride plume could be slowed by additional recharge at Phase I sites. Decreasing pumping along the Arkansas River or increasing water levels in the aquifer may slow chloride movement and prevent further encroachment into the southern part of the well field area.

Hansen and others (2014) and Whisnant and others (2015) documented water levels and storage volumes in the *Equus* Beds aquifer. Water levels in the aquifer during 1993 through 2015 increased in the central part of the *Equus* Beds aquifer study area as a result of the city of Wichita decreasing water use by 40 percent since an all-time low in water levels happened in 1993. Storage volumes in the aquifer were determined to be about 95 percent of the total aquifer storage

(Hansen and others, 2014; Whisnant and others, 2015); and the 1993 to 1995 recovery of storage volume previously lost from predevelopment to 1993 was about 46 percent (Whisnant and others, 2015).

Tappa and others (2015) summarized Little Arkansas River and *Equus* Beds aquifer (fig. 1) water quality before (1995 through 2006) and concurrent with (2007 through 2012) ASR Phase I recharge by defining water quality using measured and regression-computed data. Computed chloride concentrations in the Little Arkansas River exceeded the Federal secondary maximum contaminant level (SMCL) of 250 milligrams per liter (mg/L) about 20 percent of the time, primarily during minimal flow conditions. Groundwater chloride concentrations exceeded the SMCL between 6 and 7 percent of shallow and deep samples, primarily near Burrton, Kans., and along the Arkansas River. Few surface-water nitrate concentrations exceeded the Federal maximum contaminant level (MCL) of 10 mg/L. Groundwater nitrate concentrations exceeded the MCL in 16 percent of shallow samples and rarely in deep samples. Several trace elements including arsenic, iron, and manganese often exceeded drinking-water criteria.

Phase I recharge activities did not result in substantial effects on groundwater quality in the *Equus* Beds aquifer study area, likely because the total amount of recharged water is small (1 billion gallons) compared to aquifer storage volume (greater than [ $>$ ] 990 billion gallons in winter 2012; Tappa and others, 2015). Artificial recharge at Phase I recharge locations likely slowed eastward movement of the Burrton chloride plume. Water-quality constituents of concern (primary ions, nutrients, trace elements, triazine herbicides, and indicator bacteria) did not increase substantially and were likely more affected by climatological (for example, natural recharge by precipitation) and natural processes (for example, geochemical reactions and metabolic and decay rates) than artificial recharge. Arsenic remained a constituent of concern because of natural, persistent concentrations exceeding the Federal MCL of 10 micrograms per liter ( $\mu\text{g/L}$ ), particularly in the deeper aquifer.

## Methods

Data collection efforts followed protocols (Stone and others, 2012) developed for the HBMP project. A total of 2 surface-water sites along the Little Arkansas River, 1 site inside the residuals return line, and 2 groundwater wells (each having a shallow and deep part) were established to quantify and characterize environmental and biological responses to Phase II residuals return line discharge and groundwater recharge activities: the Little Arkansas River upstream from the ASR facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), about 0.03 mile (mi) upstream from the residuals return line site; the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), about

1.68 mi downstream from the residuals return line site; discharge from the Little Arkansas River ASR facility (residuals return line site 375348097262800); 25S 01 W 07BCCC01 SMW-S11 near CW36 (MW-7 shallow groundwater well site 375327097285401); 25S01 W 07BCCC02 DMW-S10 near CW36 (MW-7 deep groundwater well site 375327097285402); 25S 01W 07BCCA01 SMW-S13 near CW36 (MW-8 shallow groundwater well site 375332097284801); and 25S 01W 07BCCA02 DMW-S14 near CW36 (MW-8 deep groundwater well site 375332097284802). Although the upstream surface-water site is near the residuals return line site discharge, water quality should be minimally affected at this site because of residuals returns being discharged during higher streamflow conditions; residuals returns discharged are assumed to move downstream under these conditions. Three sites (not shown) were established to provide data for ASR Phase II facility operations: the residual basin ASR treatment plant near Sedgwick, Kansas (site 375330097290200); diverted water at the Sedgwick recharge site, Kansas (site 375331097285301); and treated source water at the high service pump station, Kansas (site 375338097290800), which is part of the ASR treatment facility. Data collected by the USGS are stored in the USGS National Water Information System (NWIS) database (U.S. Geological Survey, 2016).

## Data Collection

Continuous and discrete water-quality data were collected at surface-water sites upstream and downstream from the ASR Phase II facility, inside the ASR Phase II residuals return line, and in the shallow and deep parts of two groundwater wells associated with ASR Phase II recharge activities. Discrete water-quality data also were collected from the ASR treatment facility residual basin, diverted water at the Sedgwick recharge site, and treated source water at the ASR treatment facility high service pump station to aid in ASR Phase II facility operations; these data are presented in appendix table 1-1 and are not otherwise discussed in this report. Streambed sediment samples were collected at surface-water sites upstream and downstream from the ASR Phase II facility and inside the ASR Phase II residuals return line. Habitat, macroinvertebrate, and fish data were collected upstream and downstream from the ASR Phase II facility. Data collected by the USGS anytime during January 2011 through April 2013 (hereafter referred to as pre-ASR) and May 2013 through December 2014 (hereafter referred to as post-ASR) were used to evaluate the environmental and biological conditions upstream and downstream from the ASR Phase II residuals return line site discharges to the Little Arkansas River before and after the onset of facility operations.

## Continuous Water-Quality Monitoring

Detailed method descriptions for continuous water-quality monitoring for the USGS Kansas Water Science Center (KSWSC) are presented in Bennett and others (2014) and Putnam and Hansen (2014). Continuous streamflow data were measured at the downstream surface-water site (07144100, fig. 1). Continuous water-quality data were collected from the upstream (375350097262800) and downstream surface-water sites and the shallow and deep parts of the aquifer from groundwater well sites MW-7 (375327097285401 and 375327097285402, respectively) and MW-8 (375332097284801 and 375332097284802, respectively) (fig. 1). A streamgage and continuous monitoring site was established and has been operational at the downstream site since 1998 (fig. 1). Streamflow was measured using standard USGS methods (Sauer and Turnipseed, 2010; Turnipseed and Sauer, 2010). Continuous water-quality monitors were installed at the upstream surface-water site in April 2011 and in the residuals return line in August 2011; although no continuous data were collected from the residuals return line until the ASR facility began operating in 2013, the monitor was installed in August 2011 for operational testing given the novel installation location. An additional continuous monitor was installed at the downstream surface-water site in March 2012 to quantify stream cross-sectional differences (for example, mixing). All continuously monitored sites were equipped with YSI 6600EDS water-quality monitors that measured specific conductance, pH, water temperature, dissolved oxygen (YSI optical dissolved oxygen sensor), and turbidity (YSI 6136 optical turbidity sensor). A nitrate sensor (HACH® Nitratax plus sc) and a Turner Designs Cyclops-7™ chromophoric (or colored) dissolved organic matter (CDOM) sensor were installed at the downstream surface-water site in March 2012. The nitrate sensor does not differentiate between nitrate and nitrite (Pellerin and others, 2013); therefore, all nitrate sensor data include nitrite and are reported as nitrate plus nitrite concentrations in this report.

Some equipment was upgraded throughout the life of the project. YSI 600OMS water-quality monitors were installed in the shallow parts of groundwater wells MW-7 (on the southwest corner of the surface recharge basin) and MW-8 (on the northeast corner of the surface recharge basin, about 180 meters [m] away from MW-7) during July 2011 through June 2014 and the deep parts during October 2012 through June 2014. YSI 600OMS monitors were equipped with specific conductance, pH/oxidation-reduction potential (ORP), temperature, and dissolved oxygen (YSI optical dissolved oxygen sensor) sensors. Xylem EXO1 water-quality monitors were installed in the shallow parts of both groundwater wells in June through December 2014. Xylem EXO1 monitors were equipped with specific conductance, pH/ORP, water temperature, and dissolved oxygen sensors. Continuously collected ORP data were not evaluated in this report.

Surface-water monitors were installed near the centroid of the stream cross section to best represent conditions across

the width of the stream and were maintained in accordance with standard USGS procedures (Wagner and others, 2006; Rasmussen and others, 2008; Pellerin and others, 2013; Bennett and others, 2014). Groundwater monitors were in the well screen and were maintained in accordance with standard USGS procedures (Wagner and others, 2006; Bennett and others, 2014). Continuous streamflow, water level, and water-quality data were recorded at hourly intervals. Continuous data are available at <http://waterdata.usgs.gov/ks/nwis>.

## Discrete Water-Quality Samples

About eight surface-water discrete water-quality samples were collected annually at each site during a range of Little Arkansas River (fig. 1) streamflows during 2011 through 2014 (appendix table 1–2) following USGS equal width increment (EWI) methods (U.S. Geological Survey, 2006; Rasmussen and others, 2014; Putnam and Hansen, 2014). Surface-water samples were analyzed for dissolved and suspended solids, primary ions, suspended sediment, nutrients (nitrogen and phosphorus species), organic carbon, trace elements, arsenic speciation, fecal and viral indicator bacteria, volatile organic compounds, and pesticides. Groundwater samples were collected about biannually at each site during 2011 through 2014 (appendix table 1–2) and were analyzed for the same constituents as surface-water samples except for suspended sediment.

Analyses for physicochemical properties and concentrations of dissolved and suspended solids, primary ions, nutrients, organic carbon, trace elements, coliform bacteria, volatile organic compounds, and pesticides used methods described by Ziegler and Combs (1997), Ziegler and others (1999), Ziegler and others (2010), and Tappa and others (2015). Arsenic speciation data were collected and analyzed using methods described in Garbarino and others (2002). Fecal and viral indicator bacteria analyses were done using methods described by Myers and others (2014), Bushon (2003), and the U.S. Environmental Protection Agency (2000a, 2001b, 2006a, 2006b, 2006c, and 2006d). Reported values may be denoted as estimated (E) for some constituents when values are reported outside of instrument calibration range, performance of the analyte does not meet acceptable method-specific criteria, or if there were matrix interferences. Values reported with the E qualifier are considered firm detections, although the precision of the value is frequently less than that of values without this qualifier (Childress and others, 1999).

Methods used to analyze biological activity reaction tests (BART) are described by Droycon Bioconcepts, Inc. (2004). The BART for iron-related and sulfate-reducing bacteria were used to evaluate the potential for aquifer material plugging and well fouling. The BART is a semiquantitative assessment of the select bacterial community in the sample using a bacteria-specific nutrient medium and a floating intercedent device (FID) that acts as a barrier to oxygen diffusion into the sample thereby creating at least three distinct environments for bacterial growth. Aerobic bacteria grow in the oxygen-rich environment above the FID, and anaerobic bacteria grow in the anoxic

environment beneath the FID; facultative anaerobes grow at the oxidation-reduction (redox) front at the interface of the two environments. The iron-related bacteria BART (IRB–BART) uses a ferric-iron nutrient media for select growth of iron-related bacteria, and the sulfate-reducing bacteria BART (SRB–BART) uses a short-chain fatty-acid culture medium for the growth of sulfate-reducing bacteria. Distinct reactions defined by color and other visual properties indicate the bacteria type present in the water sample. The order in which these reactions happen (reaction pattern signature) and the time to the first reaction indicate which bacteria are dominant and provide an estimate of the number of bacteria in the water sample.

Samples were analyzed by the city of Wichita Municipal Water and Wastewater Laboratory (Wichita, Kansas), the USGS National Water Quality Laboratory (Denver, Colorado), and the USGS Organic Geochemistry Research Laboratory (Lawrence, Kans.). Suspended-sediment concentration was analyzed at the USGS Iowa Sediment Laboratory, Iowa City, Iowa, according to methods described in Guy (1969). Samples were analyzed by ALS Environmental Laboratories in Fort Collins, Colo., for alpha and gross beta radioactivity (U.S. Environmental Protection Agency and Environmental Monitoring and Support Laboratory, 1980). Further information regarding data-collection methods, preservation, sample holding times, analytical methods, and reporting levels are presented in Ziegler and Combs (1997) and Stone and others (2012). Discrete water-quality data are available at <http://waterdata.usgs.gov/ks/nwis>.

## Streambed-Sediment Samples

Streambed-sediment samples were collected once annually during 2011 through 2014 at the upstream and downstream surface-water sites (375350097262800 and 07144100, respectively [fig. 1]) after at least 1 week without any substantial streamflow events and in 2014 from the residuals return line. Samples were collected into a large glass container, homogenized, passed through a 63 micrometer ( $\mu\text{m}$ ) sieve, split into aliquots for different laboratories, and either shipped chilled (Shelton and Capel, 1994; Radtke, 2005) for nitrogen and wastewater compound analysis or allowed to air dry as required by the laboratory for about 2 weeks before shipping for analysis. Analysis was done only on the fraction of the sediment sample with particles less than ( $<$ ) 63  $\mu\text{m}$  in diameter (silt and clay size) to minimize sediment-size effects on chemical concentrations. A detailed description of streambed sediment sampling is presented in Stone and others (2012).

Sediment carbon, nutrient, and trace element analyses were completed at the USGS Sediment Chemistry Laboratory, Atlanta, Georgia, using digestion (Horowitz and others, 2001) on samples collected in 2011. Test America Laboratories (Denver, Colo.) analyzed sediment nitrogen (nitrate plus nitrite and total Kjeldahl nitrogen) in 2012 and 2013 and RTI Laboratories Incorporated (Livonia, Michigan) analyzed sediment nitrogen in 2014 according to methods presented in

O'Dell (1993a and 1993b) and U.S. Environmental Protection Agency (1983). Sediment trace elements and total phosphorus were analyzed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) 4-acid digestion by the USGS Crustal Geophysics and Geochemistry Science Center (Denver, Colo.) in 2012, 2013, and 2014 following methods by Taggart (2002). Sediment carbon, sulfur, and selenium were analyzed by the USGS Central Mineral and Environmental Resources Science Center (Denver, Colo.) in 2012, 2013, and 2014 following methods detailed in Brown and Curry (2002a and 2002b), Brown and others (2002), and Hageman and others (2002). Organic wastewater-indicator compounds were analyzed at the USGS National Water Quality Laboratory (NWQL) using methods described by Burkhardt and others (2006). These methods are sensitive to submicrogram per kilogram ( $\mu\text{g}/\text{kg}$ ) levels.

## Habitat Assessment

Habitat assessments were completed in August 2011 and September 2014 at the surface-water sites upstream (375350097262800) and downstream (07144100; fig. 1) from the ASR Phase II facility. A total of 14 habitat assessment variables, described in detail in Stone and others (2012), were used in this study to integrate data for three general habitat categories: channel, streambank/riparian, and instream aquatic. Variables measured in the channel category include indicators of overall channel morphology such as channel slope and sinuosity. Variables included in the streambank/riparian category provide information on organic material sources, bank conditions, and the degree of disturbance in the riparian zone. Variables in the instream aquatic category provide information on the availability of cover and substrate materials and the stream's capacity for meeting basic physical requirements for support of a diverse and well-balanced aquatic community. Each habitat variable was scored on a scale of 1 (poor conditions) to 12 (optimal conditions).

Habitat data were evaluated at two hierarchical scales (stream segment and stream reach) using a classification system proposed by Frissell and others (1986) and slightly modified by the National Water-Quality Assessment (NAWQA) program (Fitzpatrick and others, 1998). Segment-scale data also were obtained from geographic information system (GIS) coverages, topographic maps, and aerial photographs. A stream segment was defined as a section of stream that is relatively homogeneous with respect to physical, chemical, and biological properties and generally bounded by tributary junctions, point-source discharges, or other features that might be expected to change stream properties (Fitzpatrick and others, 1998). The upstream boundaries of stream segments were defined by a change in stream order and the downstream boundaries of stream segments were defined as 50 m downstream from the downgradient boundary of the reach. Stream reaches were defined as the section of the stream where a streamgage was located and where biological sampling happened. The reaches included at least two riffle-pool sequences

or at least two runs where current velocity was greater than in pools to capture habitat diversity that is representative of the segment. The same geographical stream segments and reaches were assessed in 2011 and 2014.

## Macroinvertebrates

Macroinvertebrate sampling events were completed during spring to late summer and were determined to some extent by hydrologic stability. Macroinvertebrates were collected at the upstream and downstream sites (375350097262800 and 07144100 [fig. 1], respectively) within the same 24-hour period in April, July, and August 2011; May, June, and September 2012; April and September 2013; and June and August 2014 after 1 week without substantial streamflow events. Triplicate samples were collected from three continuous reaches at each site in April and August 2011, May and September 2012, September 2013, and June 2014 to more accurately compare differences among sites while accounting for within-site variability. Macroinvertebrate sampling reaches were selected to maximize diversity of available habitat types and similarity of habitat types between sites. Sampling reaches were approximately 50 to 100 m upstream from the upstream and downstream surface-water sites. Individual sampling reaches were about 120 m in length. Macroinvertebrate samples were collected following semiquantitative protocols described in detail in Stone and others (2012) that were developed based on KDHE's protocols (Kansas Department of Health and Environment, 2000a), which have been used for stream evaluations in water-quality monitoring studies within the state (Poulton and others, 2007; Rasmussen, T.J., and others, 2009, 2012; Graham and others, 2010, 2014). Two independent 100-organism subsamples were collected at each sampling site with a rectangular framed aquatic kick net (23 centimeters [cm] by 46 cm, 530  $\mu\text{m}$  mesh netting) from multiple habitat types. Organisms were picked and counted onsite by two scientists simultaneously for 1 hour and later pooled into one 200-organism sample. Samples were preserved in 80 percent ethanol and shipped to the USGS NWQL for taxonomic identification and enumeration following methods described by Moulton and others (2000). Macroinvertebrate data are available in the USGS BioData Database at <https://aquatic.biodata.usgs.gov>.

## Fish

Fish communities were sampled yearly at the upstream and downstream sites (375350097262800 and 07144100 [fig. 1], respectively) within the same 24-hour period in September 2011, 2012, and 2013 and August 2014. Fish sampling protocols were adapted from U.S. Environmental Protection Agency (EPA) and USGS protocols (Barbour and others, 1999; Moulton and others, 2002). Two complementary methods were used for fish sampling: electrofishing and seining. Electrofishing was done in two separate passes of the stream reach using a backpack electrofisher. Electrofishing crews

consisted of a minimum of three people: the person electrofishing and at least two crew members to collect stunned fish with dip nets. Fish collected from the first pass were identified and processed before the second electrofishing pass was made and were released outside of the sampling reach. After electrofishing, five to seven seine hauls were made with a 15-ft, 3/16-in. mesh size minnow seine. The first 30 individuals of each species were weighed to the nearest gram (g) with an electronic portable scale and measured (total length) to the nearest millimeter (mm) with a fish measuring board. Stone and others (2012) provide additional fish sampling protocol detail. Fish data are available in the USGS BioData Database at <https://aquatic.biodata.usgs.gov>.

## Data Analysis

Water chemistry, macroinvertebrate, and fish data were analyzed to quantify and compare stream water and groundwater quality pre- and post-ASR Phase II facility operation. Pre- and post-ASR surface water, groundwater, and macroinvertebrate data were compared using nonparametric statistical methods. Macroinvertebrate and fish community metrics were computed. Stream and groundwater data were geochemically modeled.

## Water Chemistry Data

Water-quality conditions at the upstream and downstream surface-water sites (375350097262800 and 07144100 [fig. 1], respectively) pre- and post-ASR Phase II facility operation were compared during all streamflow conditions, including during streamflow conditions under which the facility could have been (pre-ASR) or could be (post-ASR) operating (for example, flow conditions of 100 ft<sup>3</sup>/s or greater). Comparison of upstream and downstream continuous and discrete water-quality data pre- and post-ASR during these higher streamflow conditions were included to allow comparisons between sites and time periods under similar streamflows and addresses limitations of upstream and downstream comparisons under different streamflow conditions. Water chemistry data comparisons to specifically assess ASR facility discharge effects between time periods with substantially different streamflows may be complicated because of streamflow influences on water quality. Sample pairs at similar pre- and post-ASR streamflows were compared; however, there were too few sample pairs for a robust statistical analysis; therefore, comparisons between overall pre- and post-ASR water chemistry data sets include limitations because of streamflow effects; higher streamflow conditions can dilute some water-quality constituent concentrations or have larger sediment-associated constituent concentrations from runoff. These streamflow-related dilution or runoff conditions may not allow detection of ASR discharge effects on stream water chemistry.

Duration curves were used to compare continuously collected surface-water data during all flow conditions.

Duration curves are cumulative distribution functions and were constructed using hourly values to evaluate and compare frequency and magnitude characteristics upstream and downstream from the ASR Phase II facility before and after facility operation began (Rasmussen and Ziegler, 2003; Rasmussen and others, 2005). Duration curves are indicative of the percentage of time that specified conditions were equaled or exceeded, or the frequency of exceedance (Maidment, 1993). The Weibull formula (Helsel and Hirsch, 2002) was used for plotting position. Streamflow and water-quality condition duration curves are available for the upstream and downstream surface-water sites for the period of record at <http://nrtwq.usgs.gov/ks/>.

Statistical differences in water-quality constituent pairs for the upstream and downstream surface-water sites pre- and post-ASR were determined. Paired samples were considered to be samples collected during the same 24-hour period from both sites during similar flow conditions. To avoid false-positive quantification of a constituent, low concentrations are left-censored and reported as “less than” values by the laboratory (Childress and others, 1999). Several water-quality constituents had left-censored values. Summary statistics (means and medians) for constituents that had left-censored values were calculated using regression on order statistics (ROS; Helsel and Cohn, 1988). The ROS is recommended for datasets with sample sizes <50 and having as much as 80 percent censored data (Helsel, 2005). Summary statistics were not computed when >80 percent of data were left-censored. For constituent pairs that did not contain left-censored data, a two-sided nonparametric Wilcoxon signed-rank test (Helsel and Hirsch, 2002; Sokal and Rohlf, 2012) was used to statistically compare paired values from the upstream and downstream surface-water sites. For constituent pairs that contained left-censored data, a two-sided paired Prentice generalized Wilcoxon test (Kalbfleisch and Prentice, 2002) was used to statistically compare values among sites. Upstream and downstream constituent pairs with severe (>50 percent; Helsel and Hirsch, 2002) censoring were not statistically compared because the selected comparison test would have little power to detect differences in central values with datasets that have severe censoring (near 50 percent or greater; Helsel, 1990). The Wilcoxon tests determine if the median difference between paired values is significantly different than zero. Statistical significance for both analyses was set at a *p*-value of <0.05 and was completed using R 3.0.1 (R Core Team, 2013).

Similarly, summary statistics for groundwater samples were calculated using ROS (means) and maximum likelihood estimation (MLE, for medians) for handling datasets with values reported above maximum detection (right censored), below lower detection limit or laboratory reporting level (left-censored), and for multiple levels of detection. A generalized Wilcoxon test of unpaired samples was used for a two-sided test of differences between samples before and after the beginning of artificial recharge in May 2013. Statistical summaries of groundwater samples were computed using R 3.2.0 (R Core Team, 2015) and the *smwrQW* package (Lorenz, 2015).



Continuous (hourly) total suspended solids and suspended sediment concentration data were computed for the upstream and downstream surface-water sites before and after the onset of Phase II ASR facility operation using regression models developed in Rasmussen and others (in press). New regression models were developed as part of this report using simple linear (ordinary least squares) regression analyses to establish relations between discretely sampled dissolved and total organic carbon and concurrent continuously measured physicochemical properties (Helsel and Hirsch, 2002; Rasmussen and others, 2008; Rasmussen, P.P., and others, 2009). Untransformed and  $\log_{10}$  transformations (log-transformed) were used for discrete dissolved and total organic carbon concentrations and continuously measured water-quality properties. The methods used for the development of models and quantifying uncertainty are described in detail in Rasmussen, P.P., and others (2009) and Stone and Graham (2014). Data were analyzed using TIBCO Spotfire S+® 8.1 for Windows® statistical software (TIBCO Software, Inc., 2008).

Continuous data corresponding to each discrete sample were determined from time-series datasets by using time-weighted averages of continuous data values recorded immediately before, during, and after sample collection. Concurrent instream continuous measurements were used to correspond with discrete dissolved and total organic carbon measurements as described in Rasmussen, P.P., and others (2009). All continuously measured physical properties and seasonal components (sine and cosine variables) were tested for significance for each response variable. Outliers in discrete samples were identified and removed as described in Rasmussen, P.P., and others (2009). Five outliers were removed from dissolved and total organic carbon datasets because of large heterogeneity in corresponding turbidity measurements of cross-sectional data recorded during discrete sampling.

Regression models were evaluated based on diagnostic statistics (coefficient of determination [ $R^2$ ]; Mallow's  $C_p$ ; root mean square error [ $RMSE$ ]; prediction error sum of squares [ $PRESS$ ]), patterns in residual plots, and the range and distribution of discrete and continuous data (Helsel and Hirsch, 2002). Models were selected that maximized the amount of variance in the response variable that was explained by the model (multiple  $R^2$  for models with one explanatory variable and adjusted  $R^2$  for models with more than one explanatory variable), maximized fit to the data (Mallow's  $C_p$ ), and minimized heteroscedasticity (irregular scatter) in the residual plots and uncertainty associated with computed values ( $RMSE$  and  $PRESS$ ). Variance inflation factor (VIF) was used to measure collinearity (the exact or approximate linear relation between variables; Marquardt, 1970). Model simplicity was additionally considered for selection because, as more variables are included in a model, the likelihood that the variability of the system is not being described by the sampling dataset increases. Variables were included if  $p$ -values were significant ( $<0.05$ ). Significant ( $p$ -value $<0.05$ ) additional explanatory variables were included in models if their retention increased the amount of variance explained by 10 percent or more,

decreased Mallow's  $C_p$ , and minimized heteroscedasticity in residual plots.

Mean square error ( $MSE$ ) and  $RMSE$  were calculated for each model to assess the variance between predicted and observed values (Helsel and Hirsch, 2002). Model standard percentage error ( $MSPE$ ) was calculated as a percentage of the  $RMSE$  (Hardison, 1969). A bias correction factor ( $BCF$ ) was calculated for models with logarithmically transformed response variables (Duan, 1983) because transformation of estimated values back into original units results in a low-biased estimate (Helsel and Hirsch, 2002).

## Macroinvertebrate Data

Macroinvertebrate community metrics were calculated using the Invertebrate Data Analysis System v. 5.0.28 (IDAS) developed for NAWQA (Cuffney, 2003). Among the large number of indicator metrics this program calculates ( $>100$ ), metrics were selected that have been used for evaluating aquatic life in Kansas streams as part of previous studies (Rasmussen and others, 2008; Rasmussen and others, 2012; Graham and others, 2014; Graham and others, 2010; Huggins and Moffet, 1988) and are recommended by the EPA Rapid Bioassessment Protocols (RBPs; Barbour and others, 1999). During analysis with IDAS, rare taxa were not deleted, lowest practical taxonomic levels were used, and taxonomic ambiguities were resolved by retaining ambiguous taxa. Four KDHE aquatic life-support metrics (Macroinvertebrate Biotic Index, Davenport and Kelly, 1983; Kansas Biotic Index, Huggins and Moffet, 1988; Ephemeroptera, Plecoptera, and Trichoptera [EPT] taxa richness, Lenat and Penrose, 1996; and relative abundance of EPT taxa, Lenat and Penrose, 1996) were used to calculate multimetric aquatic life-support scores for each site. Statistical differences in each of the macroinvertebrate community composition metrics between the upstream and downstream surface-water sites (375350097262800 and 07144100 [fig. 1], respectively) before and after the onset of ASR Phase II facility operation were determined with the two-sided nonparametric Wilcoxon signed-rank test as described in the "Water Chemistry Data" section for discrete water-quality constituents.

## Fish Data

Fish metrics were selected that represent those used in several State evaluation programs and those known to be sensitive and reliable for quantifying stream degradation. Average fish metrics were calculated for the upstream and downstream surface-water sites (375350097262800 and 07144100 [fig. 1], respectively) pre- and post-ASR. Fish species were classified into feeding and tolerance groups as described in Barbour and others (1999). Shannon's diversity index was calculated by quantifying the proportion of an individual species relative to the total number of species in the sample and multiplying that proportion by its natural log, then summing these values across species and multiplying by -1 (Brower and others,

1998). Index of Biotic Integrity (IBI) scores that were specific to the Little Arkansas River Basin (not shown) were calculated as described in Lydy and others (2000). Little Arkansas River Basin IBI scores were calculated using 12 metrics that represent the structure and function of fish assemblages in the Little Arkansas River basin (Lydy and others, 2000).

## Geochemical Modeling

Changes in groundwater chemistry and microbiological dominance and growth as a result of artificial recharge and water withdrawals may result in precipitation or dissolution of minerals causing physical plugging or changes in the aquifer properties as can changes in microbiology that may cause bioplugging. Mineral precipitation could adversely affect water yield by clogging aquifer pores, and dissolution of certain minerals may release harmful constituents like arsenic into the aquifer. To describe the potential for precipitation and dissolution of various minerals, PHREEQC (Parkhurst and Appelo, 2013) geochemical modeling software, executed in R (R Core Team, 2015; Charlton and Parkhurst, 2011) with the wateq4f.dat database file derived from Ball and Nordstrom (1991) and distributed with the PHREEQC software (Parkhurst and Appelo, 2013), was used to calculate ion speciation and saturation indices for discrete groundwater and stream water samples. Input for PHREEQC computations included discrete sample data for water temperature, pH, alkalinity, water level, and dissolved concentrations of oxygen, calcium, magnesium, sodium, potassium, chloride, sulfate, nitrite, nitrate, orthophosphate, fluoride, silica, arsenic, iron, and manganese.

For a solution near equilibrium, indicated as a saturation index (SI) value near zero, the given mineral may precipitate and dissolve to maintain balance. Positive SI values indicate oversaturation and the potential for the mineral to precipitate. Conversely, negative SI values indicate the potential for mineral dissolution. In addition to the equilibrium state, described by the SI, additional factors affect precipitation and dissolution reactions, including kinetics and the presence of the mineral at available reaction sites. A mineral SI is calculated as the log of the ion-activity product of a solution (water sample), divided by the solubility product ( $K_{sp}$ ) for the mineral, such as for calcite ( $\text{CaCO}_3$ ):

$$SI = \text{Log} \frac{[\text{Ca}^{2+}][\text{CO}_3^{2-}]}{K_{sp(\text{calcite})}} \quad (1)$$

Where

$[\text{Ca}^{2+}]$  is the activity of the calcium ion;  
 $[\text{CO}_3^{2-}]$  is the activity of the carbonate ion; and  
 $K_{sp(\text{calcite})}$  is the solubility product of calcite.

## Quality Assurance and Quality Control

Quality assurance and quality control (QA/QC) samples routinely were collected to identify, quantify, and document bias and variability in data that resulted from collecting, processing, handling, and analyzing samples (U.S. Geological Survey, 2006). The QA/QC samples included replicate, blank, and standard reference samples for discretely collected water-quality and streambed-sediment constituents. Triplicate QA/QC samples were collected for macroinvertebrates. Relative percentage difference (RPD) was used to evaluate differences in analyte concentrations detected in replicate water and streambed-sediment samples. The RPD was calculated by dividing the difference between replicate pairs by the mean and multiplying that value by 100, creating a value that represents the percent difference between replicate samples (Zar, 1999). The coefficient of variation (CV) was used to evaluate differences in macroinvertebrate community metrics because more than two samples can be included in the calculations. The CV was calculated by dividing the standard deviation by the mean and multiplying that value by 100, creating a value that represents the percent variation between replicate samples (Zar, 1999).

## Water Chemistry Data

The specific conductance, pH, water temperature, and dissolved oxygen sensors have wide ranges of operation (for example, pH sensors measure from 0 to 14 units; Wagner and others, 2000 and 2006) that were not exceeded in this study. The manufacturer specifications for the YSI 6136 optical turbidity sensor indicate the maximum is 1,000 formazin nephelometric units (FNU). Individual turbidity sensors differ in actual maximum readings. The maximum turbidity reading recorded at all sites was 1,410 FNU at the residuals return line site (table 3; 375348097262800, fig. 1). The maximum turbidity readings for the upstream and downstream surface-water sites (375350097262800 and 07144100 [fig. 1], respectively) were 1,280 FNU and 1,250 FNU, respectively (table 3). Less than 0.01 percent of turbidity data at the upstream and downstream surface-water sites exceeded 1,000 FNU and about 7 percent of residuals return line site turbidity data exceeded 1,000 FNU. Data that exceeded the maximum operation value were retained in datasets and classified as poor.

Comparison of field cross-sectional measurements collected during high and low flow conditions at the surface-water sites, the additional continuous monitor data at the downstream surface-water site, and field measurements at the residuals return line site provided verification that bias in continuous data because of monitor location within the stream cross-section or residuals return line was minimal. The RPDs between continuous and field monitors were <3 percent except turbidity. Turbidity had median RPDs of <8 percent at all study sites compared to cross-sectional field data. Larger differences between continuous and field monitor values commonly happened when conditions were changing rapidly.

**Table 3.** Summary statistics for continuously (hourly) measured physicochemical properties and computed water-quality constituents of interest for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), and discharge from the Little Arkansas River aquifer storage and recovery facility (residuals return line site 375348097262800) near Sedgwick, Kansas, March 2011 through December 2014.

[Continuous real-time water-quality data are available on the U.S. Geological Survey National Real-Time Water Quality Web site at <http://nrtwq.usgs.gov>. Data collected hourly. *n*, number of measurements; ft<sup>3</sup>/s, cubic foot per second; <, less than; pre, March 2011 through April 2013; ASR, aquifer storage and recovery; post, May 2013 through December 2014; μS/cm at 25 °C, microsiemen per centimeter at 25 degrees Celsius; —, not applicable; °C, degrees Celsius; mg/L, milligram per liter; FNU, formazin nephelometric units; NO<sub>3</sub>+NO<sub>2</sub>, nitrate plus nitrite; N, nitrogen; CDOM, chromophoric (colored) dissolved organic material; ppb, part per billion; QSE, quinine sulfate equivalent]

Continuous variable	Data collection period	<i>n</i>	Minimum	Maximum	Mean	Median	Missing or deleted data (percent)
<b>Streamflow (ft<sup>3</sup>/s)</b>							
All data							
Downstream surface-water site	January 2011 through December 2014	35,064	<1	16,735	206	31	<1
Pre-ASR data							
Downstream surface-water site	January 2011 through April 2013	20,424	<1	2,094	44	14	<1
Post-ASR							
Downstream surface-water site	May 2013 through December 2014	14,640	1.0	16,735	431	39	<1
<b>Specific conductance (μS/cm at 25 °C)</b>							
All data							
Upstream surface-water site	April 2011 through December 2014	27,824	107	1,910	776	801	15
Downstream surface-water site	January 2011 through December 2014	31,349	83	1,910	777	798	11
Pre-ASR data							
Upstream surface-water site	April 2011 through April 2013	13,750	153	1,910	759	773	24
Downstream surface-water site	January 2011 through April 2013	17,695	148	1,910	769	775	13
Post-ASR data							
Upstream surface-water site	May 2013 through December 2014	14,074	107	1,830	792	848	4
Downstream surface-water site	May 2013 through December 2014	13,654	86	1,630	787	838	7
Residuals return line site <sup>1</sup>	May 2013 through December 2014	1,727	46	1,890	348	268	—
<b>pH (standard units)</b>							
All data							
Upstream surface-water site	April 2011 through December 2014	28,260	6.7	9.3	8.0	8.0	14
Downstream surface-water site	January 2011 through December 2014	33,053	6.6	9.1	8.0	8.0	6
Pre-ASR data							
Upstream surface-water site	April 2011 through April 2013	14,352	6.7	9.3	8.1	8.0	21
Downstream surface-water site	January 2011 through April 2013	18,413	7.1	9.1	8.0	8.0	10

**Table 3.** Summary statistics for continuously (hourly) measured physicochemical properties and computed water-quality constituents of interest for the Little Arkansas River upstream surface-water site from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), and discharge from the Little Arkansas River aquifer storage and recovery facility (residuals return line site 375348097262800) near Sedgwick, Kansas, March 2011 through December 2014.—Continued

[Continuous real-time water-quality data are available on the U.S. Geological Survey National Real-Time Water Quality Web site at <http://nrtwq.usgs.gov>. Data collected hourly. *n*, number of measurements; ft<sup>3</sup>/s, cubic foot per second; pre, March 2011 through April 2013; ASR, aquifer storage and recovery; post, May 2013 through December 2014; μS/cm at 25 °C, microsiemen per centimeter at 25 degrees Celsius; —, not applicable; °C, degrees Celsius; mg/L, milligram per liter; FNU, formazin nephelometric units; NO<sub>3</sub>+NO<sub>2</sub>, nitrate plus nitrite; N, nitrogen; CDOM, chromophoric (colored) dissolved organic material; ppb, part per billion; QSE, quinine sulfate equivalent]

Continuous variable	Data collection period	<i>n</i>	Minimum	Maximum	Mean	Median	Missing or deleted data (percent)
pH (standard units)—Continued							
Post-ASR data							
Upstream surface-water site	May 2013 through December 2014	13,908	6.7	9.0	7.9	7.9	5
Downstream surface-water site	May 2013 through December 2014	14,640	6.6	8.9	7.9	8.0	<1
Residuals return line site <sup>1</sup>	May 2013 through December 2014	1,803	6.6	8.4	7.4	7.4	—
Water temperature (°C)							
All data							
Upstream surface-water site	April 2011 through December 2014	28,427	<1	36.6	15.9	16.8	13
Downstream surface-water site	January 2011 through December 2014	33,053	<1	35.5	14.8	14.9	6
Pre-ASR data							
Upstream surface-water site	April 2011 through April 2013	14,353	<1	36.6	15.4	15.4	21
Downstream surface-water site	January 2011 through April 2013	18,413	<1	35.5	13.6	12.4	10
Post-ASR data							
Upstream surface-water site	May 2013 through December 2014	14,074	<1	35.3	16.4	19.0	4
Downstream surface-water site	May 2013 through December 2014	14,640	<1	34.4	16.2	18.4	<1
Residuals return line site <sup>1</sup>	May 2013 through December 2014	1,809	9.8	27.1	21.9	22.6	—
Dissolved oxygen (mg/L)							
All data							
Upstream surface-water site	April 2011 through December 2014	28,425	1.4	21.4	9.4	9.1	13
Downstream surface-water site	January 2011 through December 2014	33,055	1.6	24.3	10.2	10.2	6
Pre-ASR data							
Upstream surface-water site	April 2011 through April 2013	14,351	1.6	21.4	9.5	9.3	21
Downstream surface-water site	January 2011 through April 2013	18,415	2.5	24.3	10.7	10.8	10

**Table 3.** Summary statistics for continuously (hourly) measured physicochemical properties and computed water-quality constituents of interest for the Little Arkansas River upstream surface-water site from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), and discharge from the Little Arkansas River aquifer storage and recovery facility (residuals return line site 375348097262800) near Sedgwick, Kansas, March 2011 through December 2014.—Continued

[Continuous real-time water-quality data are available on the U.S. Geological Survey National Real-Time Water Quality Web site at <http://nrtwq.usgs.gov>. Data collected hourly. *n*, number of measurements; ft<sup>3</sup>/s, cubic foot per second; pre, March 2011 through April 2013; ASR, aquifer storage and recovery; post, May 2013 through December 2014;  $\mu\text{S}/\text{cm}$  at 25 °C, microsiemen per centimeter at 25 degrees Celsius; —, not applicable; °C, degrees Celsius; mg/L, milligram per liter; FNU, formazin nephelometric units; NO<sub>3</sub>+NO<sub>2</sub>, nitrate plus nitrite; N, nitrogen; CDOM, chromophoric (colored) dissolved organic material; ppb, part per billion; QSE, quinine sulfate equivalent]

Continuous variable	Data collection period	<i>n</i>	Minimum	Maximum	Mean	Median	Missing or deleted data (percent)
<b>Dissolved oxygen (mg/L)—Continued</b>							
Post-ASR data							
Upstream surface-water site	May 2013 through December 2014	14,074	1.4	19.4	9.2	8.9	4
Downstream surface-water site	May 2013 through December 2014	14,640	1.6	24.0	9.6	9.4	<1
Residuals return line site <sup>1</sup>	May 2013 through December 2014	1,758	2.5	10.8	7.6	7.8	—
<b>Turbidity (FNU)</b>							
All data							
Upstream surface-water site	April 2011 through December 2014	27,578	2.1	1,280	54	30	16
Downstream surface-water site	January 2011 through December 2014	32,670	1.1	1,250	47	26	7
Pre-ASR data							
Upstream surface-water site	April 2011 through April 2013	14,113	5.4	1,170	60	33	22
Downstream surface-water site	January 2011 through April 2013	18,348	2.9	880	50	29	10
Post-ASR data							
Upstream surface-water site	May 2013 through December 2014	13,465	2.1	1,280	47	24	8
Downstream surface-water site	May 2013 through December 2014	14,322	1.1	1,250	43	19	2
Residuals return line site <sup>1</sup>	May 2013 through December 2014	1,776	11	1,410	561	380	—
<b>NO<sub>3</sub>+NO<sub>2</sub> (mg/L) as N</b>							
All data							
Downstream surface-water site	March 2012 through December 2014	21,959	<0.01	11.50	1.17	0.90	12
Pre-ASR data							
Downstream surface-water site	March 2012 through April 2013	7,419	<0.01	11.50	1.59	1.42	27
Post-ASR data							
Downstream surface-water site	May 2013 through December 2014	14,540	<0.01	7.66	0.95	0.80	<1

**Table 3.** Summary statistics for continuously (hourly) measured physicochemical properties and computed water-quality constituents of interest for the Little Arkansas River upstream surface-water site from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), and discharge from the Little Arkansas River aquifer storage and recovery facility (residuals return line site 375348097262800) near Sedgwick, Kansas, March 2011 through December 2014.—Continued

[Continuous real-time water-quality data are available on the U.S. Geological Survey National Real-Time Water Quality Web site at <http://nrtwq.usgs.gov>. Data collected hourly. *n*, number of measurements; ft<sup>3</sup>/s, cubic foot per second; pre, March 2011 through April 2013; ASR, aquifer storage and recovery; post, May 2013 through December 2014; μS/cm at 25 °C, microsiemen per centimeter at 25 degrees Celsius; —, not applicable; °C, degrees Celsius; mg/L, milligram per liter; FNU, formazin nephelometric units; NO<sub>3</sub>+NO<sub>2</sub>, nitrate plus nitrite; N, nitrogen; CDOM, chromophoric (colored) dissolved organic material; ppb, part per billion; QSE, quinine sulfate equivalent]

Continuous variable	Data collection period	<i>n</i>	Minimum	Maximum	Mean	Median	Missing or deleted data (percent)
<b>CDOM (ppb QSE)</b>							
All data							
Downstream surface-water site <sup>2</sup>	March 2012 through December 2014	11,059	15	338	104	104	55
Pre-ASR data							
Downstream surface-water site <sup>2</sup>	March 2012 through April 2013	4,782	15	199	72	59	51
Post-ASR data							
Downstream surface-water site <sup>2</sup>	May 2013 through December 2014	6,277	55	338	129	129	57
<b>Computed dissolved organic carbon (mg/L)</b>							
All data							
Downstream surface-water site <sup>3</sup>	March 2012 through December 2014	11,059	1.42	17.2	6.61	6.72	55
Pre-ASR data							
Downstream surface-water site <sup>3</sup>	March 2012 through April 2013	4,782	1.42	11.3	4.89	4.26	51
Post-ASR data							
Downstream surface-water site <sup>3</sup>	May 2013 through December 2014	6,277	4.02	17.2	7.93	7.95	57
<b>Computed total organic carbon (mg/L)</b>							
All data							
Downstream surface-water site <sup>4</sup>	March 2012 through December 2014	11,059	0.13	50.0	8.95	7.93	55
Pre-ASR data							
Downstream surface-water site <sup>4</sup>	March 2012 through April 2013	4,782	0.13	39.7	6.93	6.05	51
Post-ASR data							
Downstream surface-water site <sup>4</sup>	May 2013 through December 2014	6,277	4.21	50.0	10.48	9.52	57
<b>Computed total suspended solids (mg/L)</b>							
All data							
Downstream surface-water site <sup>5</sup>	January 2011 through December 2014	32,670	2	1,646	63	36	7
Pre-ASR data							
Downstream surface-water site <sup>5</sup>	January 2011 through April 2013	18,348	4	1,212	67	39	10

**Table 3.** Summary statistics for continuously (hourly) measured physicochemical properties and computed water-quality constituents of interest for the Little Arkansas River upstream surface-water site from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), and discharge from the Little Arkansas River aquifer storage and recovery facility (residuals return line site 375348097262800) near Sedgwick, Kansas, March 2011 through December 2014.—Continued

[Continuous real-time water-quality data are available on the U.S. Geological Survey National Real-Time Water Quality Web site at <http://nrtwq.usgs.gov>. Data collected hourly. *n*, number of measurements; ft<sup>3</sup>/s, cubic foot per second; pre, March 2011 through April 2013; ASR, aquifer storage and recovery; post, May 2013 through December 2014;  $\mu\text{S}/\text{cm}$  at 25 °C, microsiemen per centimeter at 25 degrees Celsius; —, not applicable; °C, degrees Celsius; mg/L, milligram per liter; FNU, formazin nephelometric units; NO<sub>3</sub>+NO<sub>2</sub>, nitrate plus nitrite; N, nitrogen; CDOM, chromophoric (colored) dissolved organic material; ppb, part per billion; QSE, quinine sulfate equivalent]

Continuous variable	Data collection period	<i>n</i>	Minimum	Maximum	Mean	Median	Missing or deleted data (percent)
Computed total suspended solids (mg/L)—Continued							
Post-ASR data							
Downstream surface-water site <sup>5</sup>	May 2013 through December 2014	14,322	1	1,727	57	25	2
Computed suspended-sediment concentration (mg/L)							
All data							
Downstream surface-water site <sup>6</sup>	January 2011 through December 2014	32,670	2	1,876	78	44	7
Pre-ASR data							
Downstream surface-water site <sup>6</sup>	January 2011 through April 2013	18,348	6	1,416	81	48	10
Post-ASR data							
Downstream surface-water site <sup>6</sup>	May 2013 through December 2014	14,322	2	1,876	75	34	2

<sup>1</sup>Intermittent hourly data during May 2013 through December 2014.

<sup>2</sup>Data temperature- and turbidity-corrected following Downing and others (2012).

<sup>3</sup>Computed using regression model and hourly CDOM data.

<sup>4</sup>Computed using regression model and hourly CDOM and turbidity data.

<sup>5</sup>Computed using regression model in Rasmussen and others (2016) and hourly turbidity and temperature data.

<sup>6</sup>Computed using regression model in Rasmussen and others (2016) and hourly turbidity data.

Median RPDs between the two in-place continuous monitors at the downstream surface-water site for specific conductance, pH, water temperature, and dissolved oxygen were <3 percent except for turbidity, which was 6 percent. Continuous data during the study period generally required corrections (such as computations to account for instrument fouling or calibration drift) of <10 percent, which classifies the data-quality rating as good according to established guidelines (Wagner and others, 2006). During the study period, <1 percent of the streamflow record and 16 percent or less of the specific conductance, water temperature, dissolved oxygen, turbidity, and nitrate plus nitrite records were missing or deleted (table 3) because of equipment malfunction, excessive sensor fouling, and low-flow conditions. A total of 55 percent of the CDOM record was missing or deleted, primarily because of equipment malfunction and subsequent lengthy repair times as well as low-flow conditions (table 3). The CDOM data

were temperature- and turbidity-corrected following protocols described by Downing and others (2012).

About 10 percent of discrete water-quality samples were QA/QC samples. Sequential, split, and concurrent replicate water-quality samples were collected during the study period among the sampling sites over a range of streamflow conditions. Replicate pairs with a RPD within 10 percent were considered acceptable for inorganic constituents (Ziegler and Combs, 1997). Replicate pairs with a RPD within 20 percent were considered acceptable for nutrient and organic constituents and RPDs within 50 percent were considered acceptable for bacterial analysis. All inorganic constituent replicate pairs had median RPDs that were <10 percent except for arsenite (12 percent). All nutrient and organic constituent replicate pairs had median RPDs that were less than or equal to ( $\leq$ ) 10 percent. All bacteria constituent replicate pairs had median RPDs that were <20 percent except for *E. coli* (21 percent).

Blank samples were collected to measure the magnitude of contaminant concentration that might have been introduced into samples as a result of sampling, processing, and analytical procedures (U.S. Geological Survey, 2006). Blank samples consisted of deionized water, inorganic blank water, or pesticide-grade blank water depending on analyses. During 2011 through 2014, 16 blank samples were collected. Filtered and unfiltered organic carbon samples had the largest number of detections, however, nearly all carbon detections were near the laboratory reporting level. Detections for ammonia and *E. coli* coliphage were also at, or near, the laboratory reporting level or method detection limit. Fluoride had two detections and beryllium and thallium each had one detection out of eight samples.

Standard reference samples were analyzed by the Wichita Municipal Water and Wastewater laboratory and submitted to the USGS Branch of Quality Systems at least annually and oftentimes biannually for laboratory performance evaluation. Standard reference sample data is available at <https://bqs.usgs.gov/srs/>. Reported values usually were within 10 percent of the most probable value during 2011 through 2014. Median percent differences between laboratory results and most probable values indicated that laboratory data generally were consistent and unbiased.

## Streambed Sediment Data

Approximately 30 percent of streambed-sediment samples were QA/QC samples and included split and concurrent replicates. Median replicate pairs for nutrients, carbon, and trace elements had RPDs that were <10 percent except for antimony (13 percent). Most organic wastewater-indicator compound data were below either the laboratory reporting level or reported as estimated concentrations. Where concentrations were measured or estimated, the RPD ranged from 0 to 40 percent for the upstream and downstream surface-water and residuals return line sites (37535009726280, 07144100, and 375348097262800 [fig. 1], respectively) (median=12 percent). Poor replication and large RPD values are likely because of the low detection levels for these compounds and matrix interference conditions.

## Macroinvertebrate Data

Concurrent replicate macroinvertebrate samples were collected in triplicate at the upstream and downstream surface-water sites (375350097262800 and 07144100 [fig. 1], respectively) during April and August 2011, May and September 2012, September 2013, and June 2014. The CVs for macroinvertebrate metrics ranged from 0 percent to 173 percent (median=26 percent;  $n=780$ ); however, 67 percent of metric comparisons had CVs <40 percent. Metric comparisons with CVs >100 percent (8 percent of metric comparisons) were caused by rare taxa (consisting of <10 percent of the overall community) present in some of the replicate samples but not others. Metrics affected by rare taxa included percent

abundance of Trichoptera, percent abundance and richness of Orthocladinae Chironomidae, percent abundance and richness of Tanytarsini Chironomidae, percent abundance of non-Chironomidae Diptera, percent abundance of Mollusca and Crustacea, percent abundance and richness of Bivalvia, and percent abundance and richness of Oligochaeta. Additional variability sources likely were habitat differences among the sampling locations at each site. Large variances in some macroinvertebrate community metrics are often observed because of natural spatial variation, which can preclude statistical detection of minimal differences among sites (Miller and others, 2008).

## Effects of Aquifer Storage and Recovery Activities on Water Quality in the Little Arkansas River and *Equus* Beds Aquifer

The city of Wichita's HBMP presented the opportunity to quantify and characterize Little Arkansas River stream quality above and below the ASR facility as well as *Equus* Beds aquifer (fig. 1) groundwater quality in response to ASR activities. Continuous measurement and computation of physicochemical properties in real time allowed characterization during conditions and time scales that would not have been possible otherwise and served as a complement to discrete water-quality sampling as well as biological monitoring. Similar future data collection efforts will provide data during different conditions, identify new and changing trends, and allow more powerful statistical analyses.

## Surface Water Physicochemical and Biological Conditions of the Little Arkansas River Upstream and Downstream from the Aquifer Storage and Recovery Facility

Evaluated physicochemical conditions included stream-flow, stream-water chemistry, and streambed-sediment chemistry. Conditions were evaluated at three sites: upstream and downstream from the ASR Phase II facility (surface-water sites 375350097262800 and 07144100 [fig. 1], respectively) and the residuals return line site (375348097262800, fig. 1). Evaluated physical and biological conditions included habitat and macroinvertebrate and fish communities upstream and downstream from the ASR Phase II facility. Data collected during January 2011 through December 2014 were used to evaluate differences upstream and downstream from the ASR Phase II facility pre- and post-ASR. The facility operated intermittently May through September 2013 and May through September (except August) 2014.



### Streamflow

Stream ecosystem structure and function are largely affected by streamflow (Allan and Castillo, 2007). Annual differences in streamflow can be attributed to differences in precipitation. There was a large difference in precipitation during pre-ASR compared to post-ASR: mean annual precipitation was 22.6 in. during 2011 through 2012 and 36.2 in. during 2013 through 2014 (table 2). Duration curves, which graphically represent the relation between streamflow magnitude and frequency during a period, were computed for the downstream surface-water site (fig. 1). Hourly streamflow ranged from <1 ft<sup>3</sup>/s to 2,094 ft<sup>3</sup>/s pre-ASR and 1.0 ft<sup>3</sup>/s to 16,735 ft<sup>3</sup>/s post-ASR (table 3; fig. 2). Streamflow was about 10 times larger post-ASR than pre-ASR because of larger post-ASR precipitation (table 3, fig. 2). During May 2013 through December 2014, streamflow exceeded 100 ft<sup>3</sup>/s about 20 percent of the time (fig. 2). During the facility operational period (April 15 through October 15) in 2013 and 2014, streamflow exceeded 100 ft<sup>3</sup>/s about 30 percent of the time. Residuals return line site (375348097262800, fig. 1) release volumes included a very minimal proportion (0.06 percent) of downstream streamflow volume during the months the ASR facility was operating during 2013 and 2014.

### Water Quality of Stream Water and Releases

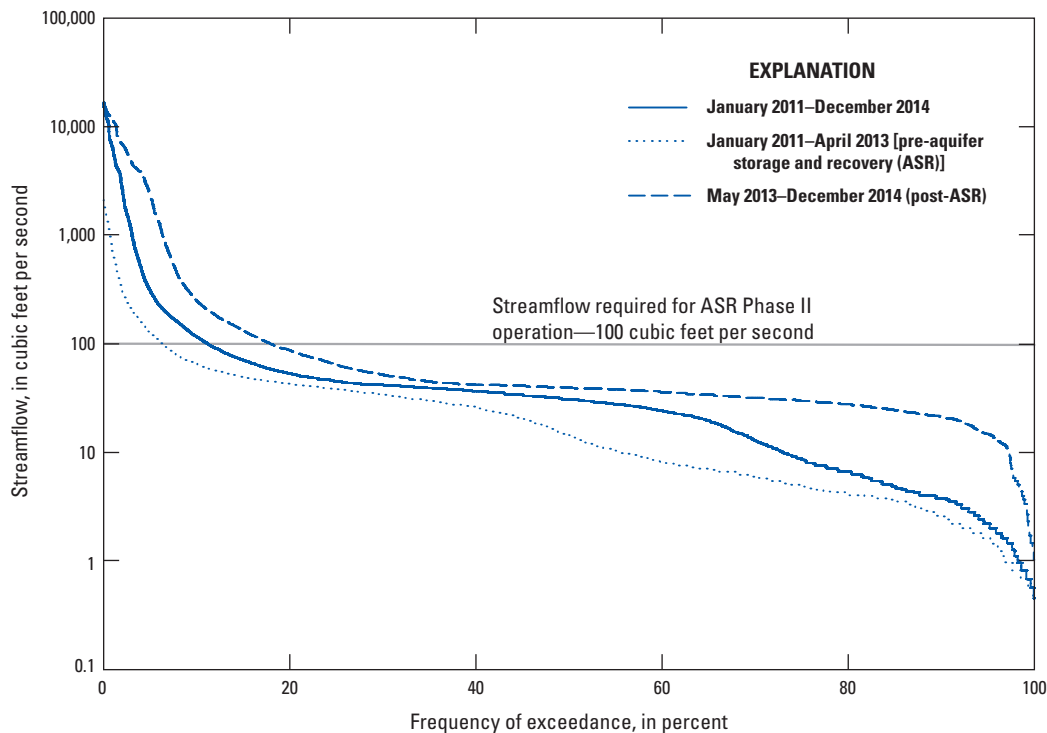
Continuous and discrete water-quality data were collected at the upstream and downstream surface-water sites (375350097262800 and 07144100 [fig. 1], respectively) and

in the residuals return line site (375348097262800, fig. 1) and were used to evaluate stream-water chemistry pre- and post-ASR. The following sections describe continuously measured and discretely collected water-quality constituents of stream water and ASR residuals return line site (375348097262800, fig. 1) releases.

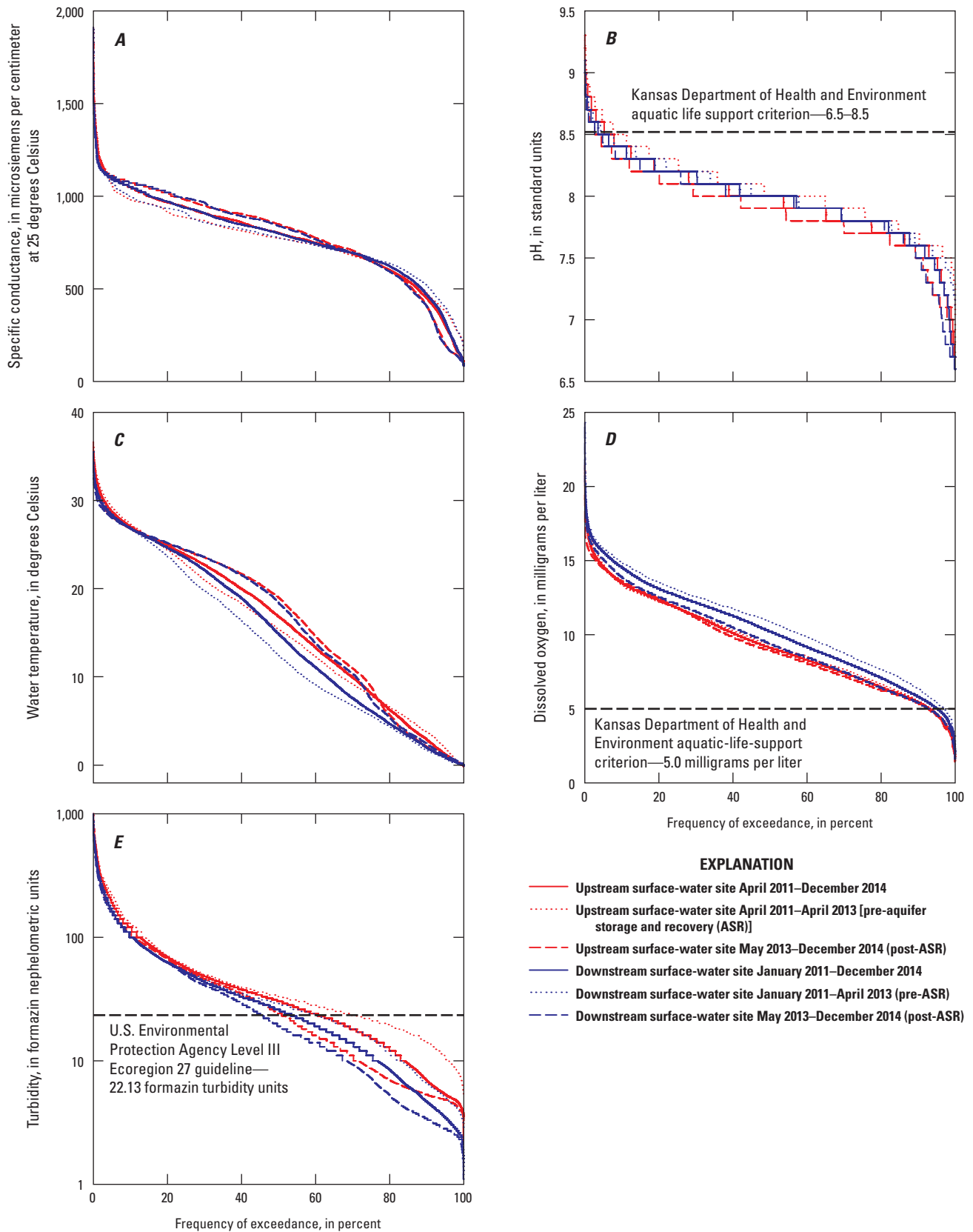
### Continuous Water-Quality of Stream Water and Releases

Data from continuously measured and computed physicochemical properties were used to describe water-quality conditions at the upstream and downstream surface-water sites (375350097262800 and 07144100 [fig. 1], respectively) pre- and post-ASR. Continuously measured physicochemical properties in the residuals return line site (375348097262800, fig. 1) were also used to quantify residuals return line site water quality. Continuously measured water-quality data included specific conductance, pH, water temperature, dissolved oxygen, turbidity, and nitrate plus nitrite. Continuously computed water-quality data included total and dissolved organic carbon, total suspended solids, and suspended-sediment concentration. Continuous physicochemical property data during higher flow conditions (>100 ft<sup>3</sup>/s) under which the ASR facility could have been (pre-ASR) or could be (post-ASR) operating are presented in appendix table 1–3. Continuous physicochemical property data collected under higher flow conditions were not substantially different between sites and are not discussed further in this report.

Specific conductance is an indirect measure of dissolved solids in water (Hem, 1992). Specific conductance was similar



**Figure 2.** Duration curve for hourly measured streamflow for the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), January 2011 through December 2014.



**Figure 3.** Duration curves for hourly measured constituents for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), and the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), March 2011 through December 2014. *A*, specific conductance; *B*, pH; *C*, water temperature; *D*, dissolved oxygen; and, *E*, turbidity.

upstream and downstream from the ASR Phase II facility during the study period. Median pre-ASR hourly specific conductance was 773 microsiemens per centimeter at 25 degrees Celsius ( $\mu\text{S}/\text{cm}$  at 25 °C) at the upstream surface-water site and 775  $\mu\text{S}/\text{cm}$  at 25 °C at the downstream surface-water site (table 3). Median post-ASR hourly specific conductance was 848  $\mu\text{S}/\text{cm}$  at 25 °C at the upstream surface-water site and 838  $\mu\text{S}/\text{cm}$  at 25 °C at the downstream surface-water site (table 3). Upstream and downstream surface-water site median specific conductance was similar pre- and post-ASR: median values at the upstream and downstream surface-water sites varied by <1 percent pre-ASR and 1.2 percent post-ASR (fig. 3A; table 3). Median residuals return line site specific conductance (268  $\mu\text{S}/\text{cm}$  at 25 °C) was about 68 percent less than the downstream surface-water site (table 3).

pH is a measure of the effective hydrogen ion concentration and often used to evaluate chemical and biological reactions in water (Hem, 1992). Kansas aquatic life-support criteria require that pH in streams not measure less than 6.5 or more than 8.5 standard units (Kansas Department of Health and Environment, 2005). The 2010 through 2014 and current (2015 through 2019) NPDES permits for the ASR Phase II treatment facility state that the effluent (residuals return line site) limits for pH are 6.0 to 9.0. Median pre-ASR hourly pH at the upstream and downstream surface-water sites was 8.0 (table 3). Median post-ASR pH was 7.9 at the upstream surface-water site and 8.0 at the downstream surface-water site (table 3). Upstream and downstream surface-water site median pH was similar pre- and post-ASR: median values above and below the ASR Phase II facility varied by less than 1 percent pre-ASR and 1.3 percent post-ASR (fig. 3B; table 3). Upstream and downstream surface-water site pH was never smaller than 6.6; however, upstream and downstream pre-ASR pH exceeded 8.5 about 8 percent and 4 percent of the time, respectively. Upstream and downstream surface-water site post-ASR pH exceeded 8.5 about 3 percent and 4 percent of the time, respectively (fig. 3B). Residuals return line site pH had a median of 7.4 and never exceeded Kansas aquatic life-support criteria or the ASR Phase II NPDES permit limits during the study period (table 3).

Water temperature affects the solubility of chemicals in water and biological activity. Kansas water-quality criteria require that discharges to streams not change water temperature more than 3 degrees Celsius (°C) above or below natural conditions or raise the water temperature above 32 °C (Kansas Department of Health and Environment, 2005). Median water temperature generally was lower at the downstream surface-water site (fig. 3C; table 3) throughout the study period. Median pre-ASR hourly water temperature was 15.4 °C at the upstream surface-water site and 12.4 °C at the downstream surface-water site (table 3). Median post-ASR water temperature was 19.0 °C at the upstream surface-water site and 18.4 °C at the downstream surface-water site (table 3). Upstream and downstream surface-water site water temperature differences were smaller post-ASR (RPD=3 percent) than pre-ASR (RPD=22 percent); however, the difference in median water

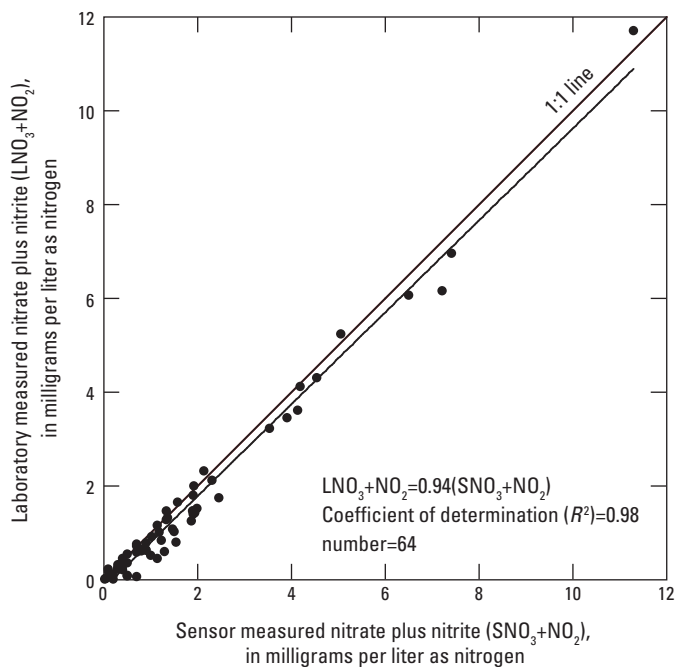
temperature upstream and downstream from the facility was 3 °C or less pre- and post-ASR and did not exceed the KDHE criterion (table 3). Median residuals return line site water temperature was about 23 percent higher than the downstream surface-water site and had a median of 22.6 °C (table 3). Residuals return line site water temperature never reached 32 °C during the study period; as such, ASR Phase II facility discharges did not exceed this criterion (table 3).

Dissolved oxygen is important for aquatic organisms and concentrations in surface water primarily are related to photosynthesis, respiration, atmospheric reaeration, and water temperature (Rounds and others, 2013). Kansas aquatic life-support criteria require that dissolved oxygen concentrations are not less than 5.0 mg/L (Kansas Department of Health and Environment, 2005). Dissolved oxygen was somewhat larger at the downstream surface-water site compared to the upstream surface-water site during the study and decreased slightly at both sites post-ASR (fig. 3D; table 3). Hourly median pre-ASR dissolved oxygen concentrations were 9.3 mg/L at the upstream surface-water site and 10.8 mg/L at the downstream surface-water site. Median post-ASR dissolved oxygen concentrations were 8.9 mg/L at the upstream surface-water site and 9.4 mg/L at the downstream surface-water site (table 3). Upstream and downstream surface-water site dissolved oxygen differences were smaller post-ASR (RPD=5 percent) than pre-ASR (RPD=15 percent). Dissolved oxygen was less than the Kansas aquatic life-support criterion (5.0 mg/L) about 6 percent and 3 percent of the time pre-ASR at the upstream and downstream surface-water sites, respectively, and about 7 percent of the time post-ASR at both sites (fig. 3D). Median residuals return line site dissolved oxygen was about 17 percent smaller than the downstream surface-water site. Residuals return line site dissolved oxygen ranged from 2.5 mg/L to 10.8 mg/L and had a median value of 7.8 mg/L (table 3).

The 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 (NTU; a reporting unit equivalent to FNU [Anderson, 2005]) as the criterion for level III ecoregion 27 (central Great Plains) streams, which includes the Little Arkansas River (U.S. Environmental Protection Agency, 2001a). The guidelines are nonenforceable criteria developed for the protection of water quality, aquatic life, and human health. Turbidity generally was smaller at the downstream surface-water site throughout the study period and decreased at both sites post-ASR (fig. 3E, table 3). Median turbidities throughout the study period varied by no more than 4 to 5 FNU (table 3). Median pre-ASR hourly turbidities were 33 FNU at the upstream surface-water site and 29 FNU at the downstream surface-water site (table 3). Median post-ASR hourly turbidities were 24 FNU and 19 FNU at the upstream and downstream surface-water sites, respectively (table 3). Upstream and downstream surface-water site continuously measured turbidity differences were larger post-ASR (RPD=23 percent) than pre-ASR (RPD=13 percent). Pre-ASR

turbidities exceeded the EPA guideline about 72 percent of the time at the upstream surface-water site and 62 percent of the time at the downstream surface-water site and post-ASR turbidities exceeded the guideline about 52 percent of the time at the upstream surface-water site and 46 percent of the time at the downstream surface-water site (fig. 3E). Median residuals return line site turbidity (380 FNU) was about an order of magnitude (20 times) larger than the downstream surface-water site and ranged from 11 FNU to 1,410 FNU (table 3).

Large concentrations of inorganic nitrogen compounds, such as nitrate plus nitrite, may be toxic to aquatic organisms. Large nitrate concentrations in drinking water can impair the oxygen-carrying capacity of hemoglobin in humans (Camargo and Alonso, 2006). The EPA guidelines for nitrate plus nitrite list 0.19 mg/L as the criterion for level III ecoregion 27 streams (U.S. Environmental Protection Agency, 2001a). The EPA Federal maximum contaminant level (MCL) for nitrate in drinking water is 10 mg/L as nitrogen, which is the concentration above which methemoglobinemia, or blue baby syndrome, may happen in infants (U.S. Environmental Protection Agency, 2009). Sensor- and laboratory-measured nitrate plus nitrite concentrations were strongly correlated ( $R^2=0.98$ ) and the nitrate sensor tended to overestimate nitrate concentrations by about 6 percent (fig. 4). Median pre-ASR hourly nitrate plus nitrite concentration was 1.42 mg/L and post-ASR was 0.80 mg/L (about 44 percent smaller; table 3), likely because of larger post-ASR streamflow and dilution. Nitrate plus nitrite concentrations exceeded the EPA level III ecoregion 27 guideline of 0.19 mg/L about 89 percent of the time pre-ASR



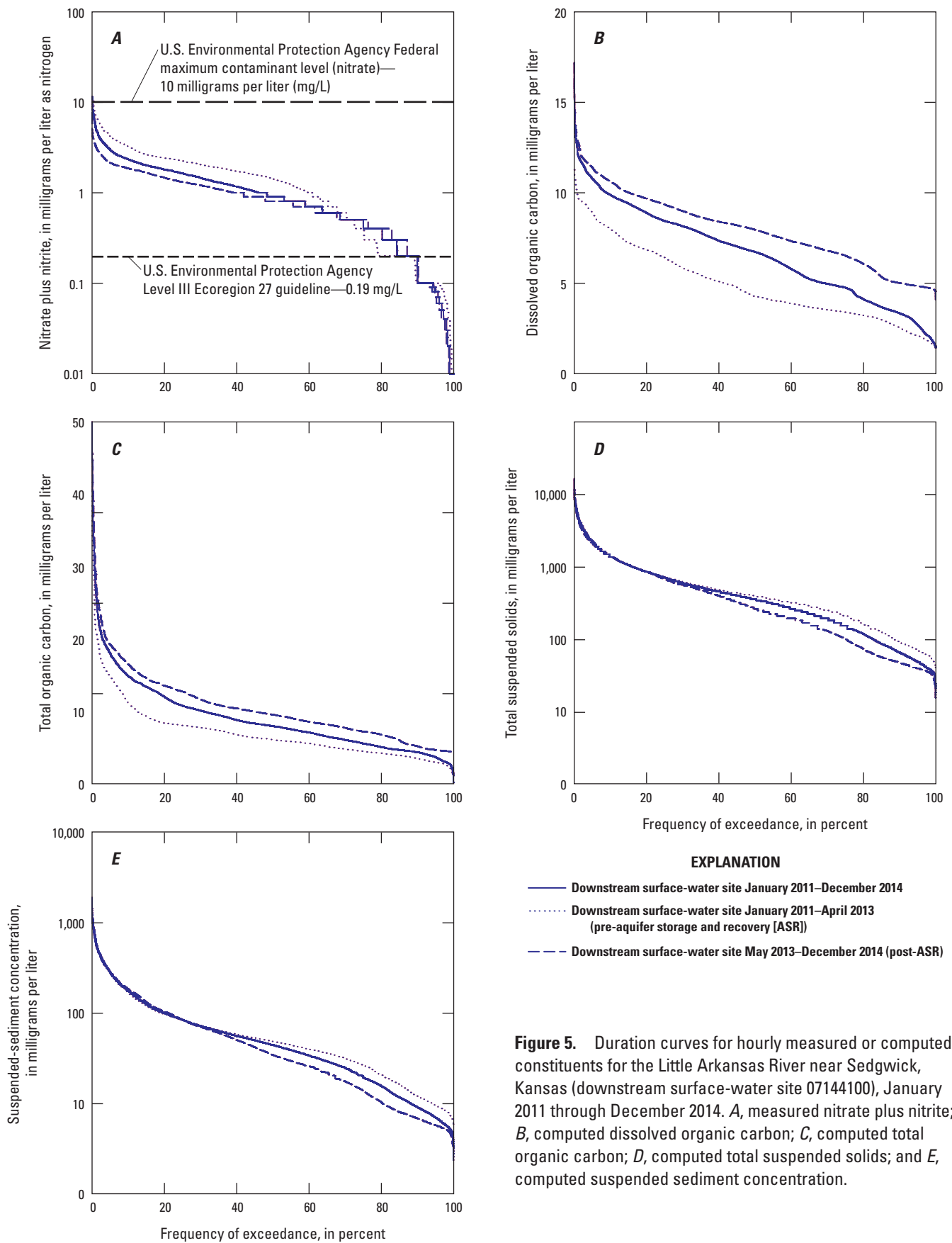
**Figure 4.** Relations between sensor and laboratory measured nitrate plus nitrite for the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), March 2012 through December 2014.

and 90 percent of the time post-ASR (fig. 5A). Nitrate plus nitrite concentrations exceeded the EPA nitrate Federal MCL of 10 mg/L <1 and 0 percent of the time pre- and post-ASR, respectively (fig. 5A).

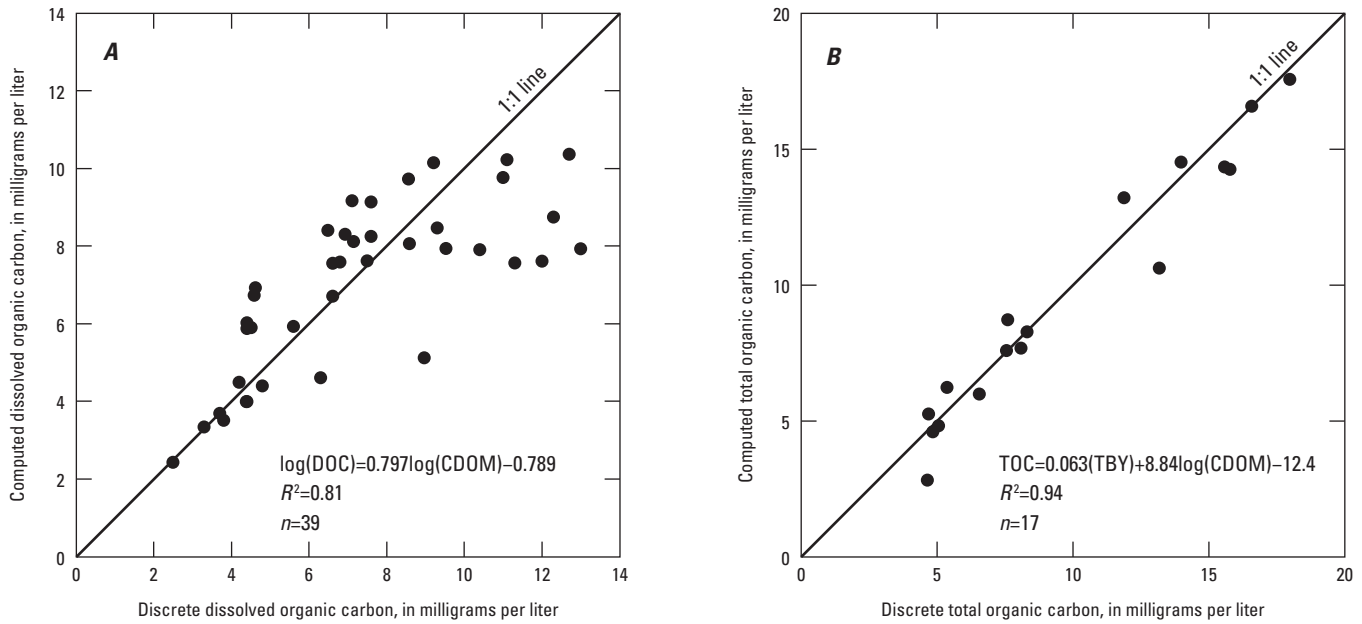
Organic carbon is of interest for ASR operation because of its role in trihalomethane (THM) formation during the water-treatment process. The THMs are disinfection byproducts (DBPs) that are formed when naturally existing inorganic and organic materials in water react with the disinfectants chlorine and chloramine. The THMs can cause liver, kidney, and central nervous system problems and are cancer-causing agents (U.S. Environmental Protection Agency, 2005; Pyne and others, 1996). An additional concern regarding organic carbon concentrations for ASR operations is the potential for decreased oxygen leading to increased arsenic concentrations in groundwater. Organic carbon from surface-water sources has impeded ASR operations in Florida (Mirecki and others, 2013).

Continuous (hourly) dissolved and total organic carbon concentrations were computed based on developed regression models for the downstream surface-water site (appendix tables 1–4 and 1–5 and figs. 2–1 through 2–4). Both carbon models used CDOM sensor data as an explanatory variable and the total organic carbon model also used turbidity as an explanatory variable (figs. 6A and 6B; appendix tables 1–4 and 1–5 and figs. 2–1 through 2–4). The dissolved carbon model explained 81 percent of the variance in dissolved carbon concentrations and the total carbon model explained 94 percent of the variance in total carbon concentrations (figs. 6A and 6B; appendix table 1–4 and figs. 2–1 and 2–3). Computed dissolved and total organic carbon concentrations were about 87 percent and 57 percent larger, respectively, post-ASR (figs. 5B and 5C; table 3), likely because of runoff during larger streamflows during this period. Median computed dissolved organic carbon was 4.26 mg/L pre-ASR and 7.95 mg/L post-ASR (table 3). Median computed total organic carbon pre-ASR was 6.05 mg/L and was 9.52 mg/L post-ASR (table 3).

Total suspended solids and suspended-sediment concentration are two analytes typically used to describe concentrations of suspended solid-phase material in surface water. Studies have shown that total suspended solids is a poorer measure for natural water compared to suspended-sediment concentration (Gray and others, 2000); total suspended solids was measured for this study because it is required for TMDLs. Although the terms often are used interchangeably, the laboratory analytical methods differ. Total suspended solids represent suspended solids material and may consist of organic or inorganic materials. Total suspended solids originate from sources such as algae, decaying vegetation, agricultural and urban runoff, municipal and industrial discharges, and physical degradation of geologic formations. The amount of total suspended solids in a medium is equal to the dry weight of organic and inorganic solids filtered from a subsample of the original. Suspended-sediment concentration is the measure of the dry weight of the organic and inorganic sediment in a



**Figure 5.** Duration curves for hourly measured or computed constituents for the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), January 2011 through December 2014. *A*, measured nitrate plus nitrite; *B*, computed dissolved organic carbon; *C*, computed total organic carbon; *D*, computed total suspended solids; and *E*, computed suspended sediment concentration.



**EXPLANATION**

- DOC Dissolved organic carbon, in milligrams per liter
- CDOM Colored dissolved organic matter
- TOC Total organic carbon, in milligrams per liter
- R<sup>2</sup> Coefficient of determination
- TBY Turbidity, in formazin nephelometric units
- n Number of samples

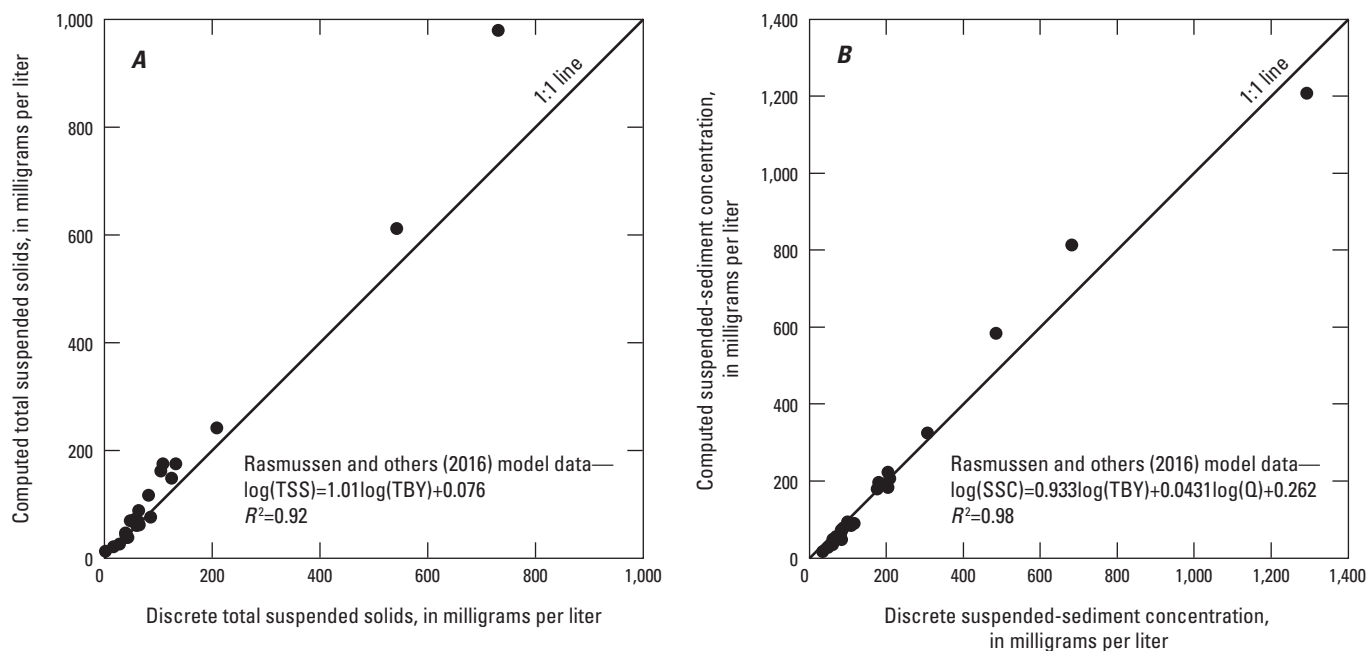
**Figure 6.** Relations between discrete and computed constituents using regression models for the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), March 2012 through December 2014. A, dissolved organic carbon; and, B, total organic carbon.

full sample volume of a water-sediment mixture (Guy, 1969). Suspended sediment may consist of clay, silt, sand, or organic material. Suspended solids and sediment in stream water typically are from erosion and subsequent transport of surface and channel bank soils. Increased suspended sediment in streams reduces light penetration and photosynthesis, smothers benthic habitats, and interferes with feeding activities (Wetzel, 2001). Additionally, suspended particulates provide attachment sites for nutrients, organic compounds, and other potential contaminants. Sediment is a pollutant of concern in the Little Arkansas River drainage basin (Kansas State University Research and Extension: Kansas Center for Agricultural Resources and the Environment, 2011). Sediment is an impairment for aquatic life for streams in or near the study area and the Little Arkansas River drainage basin has a TMDL for total suspended solids (Kansas Department of Health and Environment, 2014a,b). The ASR Phase II treatment facility’s 2010 through 2014 and current (2015 through 2019) NPDES permits state that total suspended solids should be monitored monthly while the facility is operating.

Regression-computed total suspended solids concentrations tended to overestimate total suspended solids concentrations by about 6 percent and regression-computed suspended

sediment concentrations tended to overestimate suspended sediment concentrations by about 19 percent during the study period (fig. 7). Median continuously computed total suspended solids and suspended-sediment concentrations were 36 percent and 29 percent smaller, respectively, post-ASR (figs. 5 D and 5E; table 3), likely because of larger post-ASR streamflow and dilution. Median total suspended solids concentration was 39 mg/L pre-ASR and 25 mg/L post-ASR (table 3). Median suspended-sediment concentration was 48 mg/L pre-ASR and 34 mg/L post-ASR (table 3).

Because facility operations are limited to high flow conditions, water-quality concentrations and physical properties of stream water and residuals return line releases are more indicative of event conditions than the distribution of all continuously collected water-quality data. During events, stream specific conductance, pH, and dissolved oxygen are smaller than during base-flow conditions, and turbidity is larger. Though stream dissolved oxygen tends to be smaller, even below 5 mg/L, residuals return line releases are turbulent and would entrain air, resulting in dissolved oxygen concentrations near saturation. The short delay (as much as 5 hours) between water withdrawals and residual releases could prolong event conditions for specific conductance, pH, and turbidity;



#### EXPLANATION

TSS	Total suspended solids, in milligrams per liter
TBY	Turbidity, in formazin nephelometric units
SSC	Suspended-sediment concentration, in milligrams per liter
Q	Streamflow, in cubic feet per second
$R^2$	Coefficient of determination

**Figure 7.** Relation between discrete and computed constituents using models developed in Rasmussen and others (2016) for the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), January 2011 through December 2014. *A*, total suspended solids; and, *B*, suspended-sediment concentration.

however, effects would likely be localized near the residuals return line outflow.

#### Discrete Water-Quality of Stream Water and Releases

Data from discrete stream-water samples also were used to describe water-quality conditions at the upstream and downstream surface-water sites (375350097262800 and 07144100 [fig. 1], respectively) pre- and post-ASR. Discrete data from residuals return line site (375348097262800, fig. 1) water samples also were used to quantify residuals return line site water quality. Discrete water-quality data collected included dissolved solids and primary ions, nutrients, trace elements, indicator bacteria, and organic compounds. Upstream and downstream surface-water site water-quality variables were statistically compared pre- and post-ASR to determine differences between sites. Discrete water-quality data collected during higher flow conditions ( $>100 \text{ ft}^3/\text{s}$ ) under which the ASR facility could have been (pre-ASR) or could be (post-ASR) operating are presented in appendix table 1–6. No statistical comparisons for discrete water-quality data collected under higher flow conditions were significant and these data are not discussed further in this report.

#### Dissolved and Suspended Solids, Major Ions, and Suspended Sediment

The primary constituents of dissolved solids generally are calcium, magnesium, sodium, potassium, bicarbonate, carbonate, chloride, and sulfate ions. These ions come from decomposing rocks and soils. Concentrations of dissolved solids in stream water may increase because of atmospheric deposition, sewage inputs, industrial effluents, agricultural runoff, and urban runoff (Hem, 1992; Wetzel, 2001). Dissolved solids often are used as a general indicator of salinity or water quality. Large concentrations of dissolved solids are undesirable in drinking water because of possible physiological effects, strong mineral tastes, increased treatment costs, and corrosion in plumbing. The EPA has established National Secondary Drinking Water Regulations that set nonmandatory water-quality standards. The EPA does not enforce these SMCLs; they were established as guidelines to assist public water-supply systems in managing their drinking water for aesthetic considerations such as taste, color, and odor (U.S. Environmental Protection Agency, 2009). The EPA has established a SMCL for dissolved solids in drinking water of 500 mg/L (U.S. Environmental Protection Agency, 2009).

Dissolved solids at the upstream and downstream surface-water sites (375350097262800 and 07144100 [fig. 1], respectively) were 18 percent to 27 percent smaller post-ASR (table 4). Pre-ASR dissolved solids medians at the upstream and downstream surface-water sites were 473 mg/L and 438 mg/L, respectively; post-ASR upstream and downstream surface-water site dissolved solids medians were 345 mg/L and 359 mg/L, respectively (table 4). Upstream and downstream surface-water site dissolved solids differences were smaller post-ASR (RPD=4 percent) than pre-ASR (RPD=8 percent). The median residuals return line site (375348097262800, fig. 1) dissolved solids concentration was 281 mg/L and was about 20 percent smaller than median dissolved solids concentrations at the upstream and downstream surface-water sites post-ASR (table 4). Median dissolved solids concentrations at all sites did not exceed the EPA SMCL; individual samples from all sites, except for the downstream surface-water site post-ASR, occasionally exceeded the EPA SMCL during the study period (table 4).

All the primary constituents of dissolved solids, with the exception of potassium, were smaller at both sites post-ASR compared to pre-ASR (table 4). With the exception of potassium, primary dissolved solids constituents were smaller at the downstream site pre-ASR; with the exception of magnesium, chloride, and sulfate, primary dissolved solids constituents were smaller at the downstream site post-ASR (table 4). Median primary dissolved solids constituent concentrations in the residuals return line, with the exception of potassium, were always at least about 10 percent smaller than median primary dissolved solids constituent concentrations at the upstream and downstream surface-water sites post-ASR (table 4). Median calcium concentrations at the upstream and downstream surface-water sites were 87.0 mg/L and 80.9 mg/L, respectively, pre-ASR and 57.9 mg/L and 56.5 mg/L, respectively, post-ASR (table 4). Median pre-ASR sodium concentrations were 62.0 mg/L at the upstream surface-water site and 52.0 at the downstream surface-water site; median post-ASR sodium concentrations were 43.0 mg/L at the upstream surface-water site and 42.0 mg/L at the downstream surface-water site (table 4). Median calcium and sodium concentrations were significantly larger ( $p$ -value=0.04 and  $p$ -value=0.03, respectively) at the upstream surface-water site pre-ASR and were not significantly different post-ASR (table 4). Carbonate hardness was significantly ( $p$ -value<0.05) smaller at the downstream surface-water site (255 mg/L) compared to the upstream surface-water site (285 mg/L) pre-ASR and was not significantly different post-ASR (table 4). Pre-ASR calcium, sodium, and carbonate hardness concentrations that were significantly different between the upstream and downstream surface-water sites and not significantly different post-ASR indicates that water-quality conditions were more similar between sites after the facility began discharging; however, this result could be because of the higher post-ASR streamflow conditions compared to pre-ASR streamflow conditions.

The EPA SMCL for chloride is 250 mg/L (U.S. Environmental Protection Agency, 2009) and KDHE has established

an aquatic-life-support criterion for chloride of 860 mg/L (Kansas Department of Health and Environment, 2011). Chloride was lower at both surface-water sites post-ASR. Median pre-ASR chloride was 79 mg/L at the upstream surface-water site and 58 mg/L at the downstream surface-water site; median post-ASR chloride was 51 mg/L at the upstream surface-water site and 54 mg/L at the downstream surface-water site (table 4). Median residuals return line site chloride was 44 mg/L (table 4). No chloride samples collected during the study exceeded the EPA SMCL or the KDHE aquatic-life-support criterion (table 4). The EPA has a SMCL for fluoride of 2.0 mg/L (U.S. Environmental Protection Agency, 2009); no fluoride samples collected during the study exceeded the SMCL (table 4). The EPA has a SMCL for sulfate of 250 mg/L (U.S. Environmental Protection Agency, 2009); no sulfate samples collected during the study exceeded this SMCL (table 4).

Discretely collected total suspended solids concentration medians were similar at the upstream and downstream surface-water sites (70 mg/L and 74 mg/L, respectively) pre-ASR and about 27 percent smaller at the downstream surface-water site (upstream median=78 mg/L; downstream median=57 mg/L) post-ASR, despite a median residuals return line total suspended solids concentration (858 mg/L) that was about 15 times larger than the downstream surface-water site (table 4), likely because of dilution. Discretely collected pre-ASR suspended-sediment concentration medians were similar at the upstream (79 mg/L) and downstream (74 mg/L) surface-water sites. Discretely collected post-ASR suspended-sediment concentration medians were larger than pre-ASR concentrations at both sites (upstream median=112 mg/L; downstream median=154 mg/L; table 4), which is contradictory to the continuously computed suspended-sediment concentration medians at the downstream surface-water site that decreased post-ASR (table 3). These differences in suspended-sediment concentration medians highlight the utility of continuous monitoring by capturing temporal variability and the need to continue continuous monitoring as a complement to discrete water-quality sampling. The median residuals return line site suspended-sediment concentration was 1,175 mg/L and was about 10 times greater than the upstream surface-water site and 8 times greater than the downstream surface-water site post-ASR (table 4).

Sodium hypochlorite is used in ASR facility operations to clean filtration membranes and is subsequently dechlorinated. The 2010 through 2014 NPDES permit for the residuals return line requires monthly total residual chlorine monitoring when the facility is operating. The current (2015 through 2019) NPDES permit for the residuals return line limits total residual chlorine (because of aquatic organism sensitivity) to 100 µg/L. Total residual chlorine was not detected in at least 50 percent of upstream surface-water site, downstream surface-water site, or residuals return line site samples during the study period (table 4). Median pre-ASR total residual chlorine was 12 µg/L at the upstream surface-water site and 19 µg/L at the downstream surface-water site (table 4). Two



**Table 4.** Discretely collected dissolved and suspended solids, primary ions, and suspended sediment summary statistics for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), and discharge from the Little Arkansas River aquifer storage and recovery facility (residuals return line site 375348097262800) near Sedgwick, Kansas, March 2011 through September 2014.

[See figure 1 for site locations. Medians in **bold** indicate statistically significant differences (*p*-value less than 0.05) between the upstream and downstream surface-water sites; the upstream and downstream surface-water sites were not statistically compared when greater than 50 percent of data were left-censored. Means and medians were not computed when greater than 80 percent of data were left-censored. pre, March 2011 through April 2013; ASR, aquifer storage and recovery; post, May 2013 through December 2014; *n*, number of measurements; mg/L, milligram per liter; µg/L, microgram per liter; <, less than; --, not applicable; SiO<sub>2</sub>, silicon dioxide; CaCO<sub>3</sub>, calcium carbonate]

Water-quality constituent (unit of measure)	Pre-ASR												Post-ASR																	
	Upstream surface-water site						Downstream surface-water site						Upstream surface-water site					Downstream surface-water site					Residuals return line site							
	Left-censored data (percent)	<i>n</i>	Mini-mum	Maxi-mum	Mean	Median	Left-censored data (percent)	<i>n</i>	Mini-mum	Maxi-mum	Mean	Median	Left-censored data (percent)	<i>n</i>	Mini-mum	Maxi-mum	Mean	Median	Left-censored data (percent)	<i>n</i>	Mini-mum	Maxi-mum	Mean	Median	Left-censored data (percent)	<i>n</i>	Mini-mum	Maxi-mum	Mean	Median
Dissolved solids (mg/L)	0	20	141	735	475	473	0	20	153	666	444	438	0	7	86	517	294	345	0	7	78	497	294	359	0	7	96	817	344	281
Total solids (mg/L)	0	20	342	862	589	560	0	20	376	1,520	615	531	0	6	242	596	468	499	0	6	230	590	460	474	0	7	726	6,750	2,179	1,580
Calcium (mg/L)	0	20	21.6	111	80.0	<b>87.0</b>	0	20	23.1	103	73.7	<b>80.9</b>	0	7	12.7	96.3	48.8	57.9	0	7	10.5	98.3	49.7	56.5	0	7	11.7	79.1	42.3	43.1
Magnesium (mg/L)	0	20	3.4	18.3	14.1	15.5	0	20	3.6	18.7	12.9	14.2	0	7	2.4	17.8	9.6	12.3	0	7	1.9	17.8	9.8	12.7	0	7	2.1	13.1	7.9	7.8
Potassium (mg/L)	0	20	5.0	14.0	7.2	6.5	0	20	4.0	14.0	7.2	7.0	0	7	6.0	10.0	8.0	8.0	0	7	6.0	10.0	7.9	7.0	0	7	6.0	10.0	8.3	9.0
Sodium (mg/L)	0	20	11.9	134	68.8	<b>62.0</b>	0	20	14.1	123	62.5	<b>52.0</b>	0	7	2.5	57.3	30.1	43.0	0	7	2.1	56.2	30.0	42.0	0	7	2.29	191	53.1	34.7
Bromide (mg/L)	0	19	0.1	1	0.2	0.2	0	19	0.1	0.5	0.2	0.2	29	7	<0.04	0.2	0.2	0.2	29	7	<0.04	0.3	0.1	0.1	0	6	0.0	0.3	0.1	0.1
Chloride (mg/L)	0	20	15	240	95	79	0	20	19	226	86	58	0	7	6.6	69	39	51	0	7	5.8	76	41	54	0	7	5.7	210	62	44
Total residual chlorine (µg/L)	80	15	<50	240	42	12	80	15	<50	210	44	19	83	6	<50	80	--	--	50	6	<50	80	54	48	50	6	<50	310	120	50
Flouride (mg/L)	0	20	0.2	0.5	0.4	0.4	0	20	0.2	0.5	0.3	0.4	0	7	0.3	0.6	0.4	0.4	0	7	0.2	0.5	0.3	0.3	0	7	0.1	0.4	0.3	0.3
Silica (mg/L as SiO <sub>2</sub> )	0	20	7.0	23.6	14.4	14.9	0	20	6.5	21.8	14.2	15.3	0	7	9.1	20.1	15.4	16.1	0	7	9.6	20.1	15.0	14.6	0	7	11.3	16.6	13.5	12.7
Sulfate (mg/L)	0	20	11	88	53	59	0	20	12	88	52	55	14	7	<5	57	31	44	14	7	<5	67	36	49	14	7	<5	210	63	40
Carbonate hardness (mg/L as CaCO <sub>3</sub> )	0	20	68	350	258	<b>285</b>	0	20	73	330	237	<b>255</b>	0	7	42	310	162	200	0	7	34	320	164	190	0	7	38	250	137	140
Alkalinity (mg/L as CaCO <sub>3</sub> )	0	20	60	286	210	222	0	20	58	276	197	212	0	7	42	278	146	160	0	7	39	273	145	154	0	7	44	198	106	112
Bicarbonate (mg/L)	0	20	73	350	257	270	0	20	71	340	240	260	0	7	51	340	178	200	0	7	48	330	177	190	0	7	54	240	131	140
Total suspended solids (mg/L)	0	20	14	162	72	70	0	20	11	740	110	74	0	7	48	528	154	78	0	7	48	552	153	57	0	7	259	5,220	1,405	858
Suspended-sediment concentration (mg/L)	0	20	18	241	100	79	0	20	13	1,270	151	74	0	7	45	724	270	112	0	7	58	660	249	154	0	6	286	5,314	1,643	1,175

pre-ASR total residual chlorine samples at each upstream (190 µg/L and 240 µg/L) and downstream (210 µg/L and 170 µg/L) surface-water site exceeded the level established in the 2015 permit during June 2011. Median post-ASR chlorine was 48 µg/L at the downstream surface-water site (table 4). Median residuals return line site total residual chlorine was 50 µg/L, ranged from <50 µg/L to 310 µg/L, and was above the level established in the 2015 draft permit in two samples collected in May 2013 (270 µg/L) and May 2014 (310 µg/L). Total residual chlorine may be present upstream and downstream from the ASR facility because of water treatment discharges to streams in the drainage basin at locations upstream from the study sites. Samples that exceeded the current (2015 through 2019) NPDES permit total residual chlorine limit may be due to interferences during sample analysis (Harp, 2002), or municipal wastewater discharges from upstream sources, or ASR facility treatment.

## Nutrients

Nutrient sources for streams include upstream sources, terrestrial runoff, groundwater, and the atmosphere. Nutrients, including species of nitrogen and phosphorus, are necessary for plant and animal growth but can lead to eutrophication, algal blooms, low dissolved oxygen, fish kills, and taste-and-odor problems when present in excess amounts. Nutrients, particularly nitrogen and phosphorus, have been identified as a primary source of water-quality degradation in Kansas and the Nation (Kansas Department of Health and the Environment, 2004a; U.S. Environmental Protection Agency, 2000c, 2006e).

Nitrogen is present as ammonia, nitrate, nitrite, and as part of organic compounds. Most algae use dissolved forms of inorganic nitrogen (Hem, 1992). Nitrate is the form of nitrogen most easily used by plants and algae and is the most common ion in many oxygen-rich waters because the nitrite ion is easily oxidized. The large increase in use of nitrogen fertilizers on agricultural land in recent decades prompted concern about nitrate concentration increases in surface and groundwater (Hem, 1992). Large nitrate concentrations in drinking water can pose adverse health effects on humans, such as methemoglobinemia, a condition also known as blue baby syndrome. This condition restricts the oxygen-carrying capacity of the blood in infants and may be fatal (Walton, 1951).

There were no substantial differences in discretely collected nitrogen species concentration medians between the upstream and downstream surface-water sites (375350097262800 and 07144100 [fig. 1], respectively) throughout the study period. Median pre-ASR total Kjeldahl nitrogen (ammonia plus organic nitrogen) was 1.25 mg/L at the upstream surface-water site and 1.20 mg/L at the downstream site; median post-ASR total Kjeldahl nitrogen was 1.80 mg/L at the upstream site and 1.85 at the downstream surface-water site (table 5). Median residuals return line site (375348097262800, fig. 1) total Kjeldahl nitrogen was 7.30 mg/L and about 4 times larger than either surface-water site post-ASR (table 5). The EPA guidelines for total Kjeldahl

nitrogen list 0.52 mg/L as the criterion for level III ecoregion 27 streams (U.S. Environmental Protection Agency, 2001a); all samples from all sites exceeded this guideline (table 5).

Median nitrate plus nitrite and nitrate concentrations were smaller at the upstream surface-water site during both pre- and post-ASR and were smaller at both surface-water sites post-ASR likely because of larger post-ASR streamflow and dilution. There was no change in nitrite medians. Median pre-ASR nitrate plus nitrite was 0.74 mg/L at the upstream surface-water site and 0.95 at the downstream surface-water site; median post-ASR nitrate plus nitrite was 0.50 mg/L at the upstream surface-water site and 0.79 at the downstream surface-water site (table 5). The EPA guidelines for nitrate plus nitrite list 0.19 mg/L as the criterion for level III ecoregion 27 streams (U.S. Environmental Protection Agency, 2001a); nitrate plus nitrite samples collected from all sites throughout this study frequently exceeded this guideline. Residuals return line site median nitrate plus nitrite was 1.57 mg/L and was about 3.1 times larger than the upstream surface-water site median and about 2 times larger than the downstream surface-water site median post-ASR (table 5). Pre-ASR nitrate medians were 0.69 mg/L at the upstream surface-water site and 0.88 mg/L at the downstream surface-water site; post-ASR nitrate medians were 0.43 mg/L at the upstream surface-water site and 0.72 mg/L at the downstream surface-water site (table 5). Median residuals return line site nitrate was 1.45 mg/L, never exceeded the Federal MCL of 10 mg/L, and was about 3.4 times than the upstream surface-water site nitrate median and about 100 percent larger than the downstream surface-water site nitrate median (table 5).

Median pre-ASR total nitrogen was similar at both surface-water sites (upstream=2.17 mg/L; downstream=2.15 mg/L), whereas the post-ASR total nitrogen median was about 26 percent larger at the downstream surface-water site (upstream=2.00 mg/L; downstream=2.51 mg/L; table 5). Median residuals return line site total nitrogen was 8.89 mg/L and was about 4.4 times larger than the upstream surface-water site median and about 3.5 times larger than the downstream surface-water site median post-ASR (table 5). The EPA guidelines for total nitrogen list 0.71 mg/L as the criterion for level III ecoregion 27 streams (U.S. Environmental Protection Agency, 2001a); all total nitrogen samples collected throughout this study exceeded this guideline (table 5).

Phosphorus is introduced into the environment by soil and rock mineral breakdown. Most phosphorus in surface water is organically bound and much of the organic phosphorus fraction is in the particulate phase of living cells, primarily algae (Wetzel, 2001). Sources of phosphorus in the Little Arkansas River drainage basin include inorganic phosphates from fertilizer, manure from animal production, and runoff. There were no substantial differences in phosphorus species concentration medians between the upstream and downstream surface-water sites pre- or post-ASR. Phosphorus species were generally smaller at the downstream surface-water site compared to the upstream surface-water site and were larger at both sites post-ASR. Median pre-ASR orthophosphate was

**Table 5.** Discretely collected nutrient and carbon summary statistics for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), and discharge from the Little Arkansas River aquifer storage and recovery facility (residuals return line site 375348097262800) near Sedgwick, Kansas, March 2011 through September 2014.

[See figure 1 for site locations. pre, March 2011 through April 2013; ASR, aquifer storage and recovery; post, May 2013 through December 2014; *n*, number of measurements; mg/L, milligram per liter; N, nitrogen; <, less than; P, phosphorus]

Water-quality constituent (unit of measure)	Pre-ASR												Post-ASR																	
	Upstream surface-water site						Downstream surface-water site						Upstream surface-water site						Downstream surface-water site						Residuals return line site					
	Left-censored data (percent)	<i>n</i>	Mini- mum	Maxi- mum	Mean	Median	Left-censored data (percent)	<i>n</i>	Mini- mum	Maxi- mum	Mean	Median	Left-censored data (percent)	<i>n</i>	Mini- mum	Maxi- mum	Mean	Median	Left-censored data (percent)	<i>n</i>	Mini- mum	Maxi- mum	Mean	Median	Left-censored data (percent)	<i>n</i>	Mini- mum	Maxi- mum	Mean	Median
Total Kjeldahl nitrogen (mg/L as N)	0	20	0.69	1.90	1.28	1.25	0	20	0.79	5.20	1.51	1.20	0	8	0.89	3.40	1.85	1.80	0	8	0.96	3.10	1.87	1.85	0	7	2.60	18.0	8.14	7.30
Ammonia (mg/L as N)	45	20	<0.03	0.36	0.09	0.04	25	20	<0.03	0.38	0.12	0.04	29	7	<0.03	0.34	0.13	0.09	29	7	<0.03	0.37	0.14	0.09	0	7	0.17	1.03	0.46	0.35
Nitrate plus nitrite (mg/L as N)	5	22	<0.02	4.79	1.16	0.74	9	22	<0.02	5.24	1.19	0.95	0	7	0.04	1.80	0.75	0.50	14	7	<0.02	1.74	0.77	0.79	0	7	0.08	2.42	1.52	1.57
Nitrate (mg/L as N)	5	20	<0.01	3.16	0.96	0.69	10	20	<0.01	5.04	1.10	0.88	0	7	0.04	1.76	0.70	0.43	14	7	<0.01	1.70	0.71	0.72	0	7	0.08	2.38	1.44	1.45
Nitrite (mg/L as N)	35	20	<0.01	0.14	0.05	0.04	30	20	<0.01	0.20	0.06	0.04	43	7	<0.01	0.12	0.06	0.04	43	7	<0.01	0.16	0.07	0.04	14	7	<0.01	0.16	0.09	0.10
Total nitrogen (mg/L as N) <sup>1</sup>	0	20	0.87	4.37	2.28	2.17	0	20	0.96	6.59	2.66	2.15	0	7	0.97	4.40	2.37	2.00	0	7	0.97	4.24	2.46	2.51	0	7	3.28	19.96	9.66	8.89
Orthophosphate (mg/L as P)	0	20	0.22	0.94	0.52	0.47	0	20	0.19	1.24	0.44	0.36	0	7	0.37	0.71	0.54	0.55	0	7	0.35	0.80	0.56	0.52	0	7	0.34	0.88	0.56	0.56
Dissolved phosphorus (mg/L as P)	0	20	0.32	1.10	0.55	0.54	0	20	0.23	1.07	0.46	0.41	0	7	0.37	0.72	0.59	0.59	0	7	0.35	1.94	0.73	0.54	0	7	0.35	0.98	0.60	0.56
Total phosphorus (mg/L as P)	0	20	0.49	1.16	0.80	0.77	0	20	0.45	1.58	0.76	0.70	0	8	0.69	1.46	0.94	0.89	0	8	0.69	1.36	0.92	0.89	0	7	0.96	6.76	3.03	2.67
Dissolved organic carbon (mg/L)	0	20	3.7	12.5	6.2	5.4	0	20	2.3	13.7	6.4	5.2	0	8	4.4	13.3	9.2	9.2	0	8	4.2	13.0	9.3	9.7	0	7	6.5	19.4	13.3	14.8
Total organic carbon (mg/L)	0	20	5.1	15.6	8.2	7.1	0	20	4.4	32.4	9.3	7.3	0	8	5.1	22.6	12.3	13.1	0	8	5.1	29.4	13.0	12.3	0	7	8.8	71.6	31.0	23.6

<sup>1</sup>Calculated as the sum of total Kjeldahl nitrogen plus nitrate plus nitrite.

0.47 mg/L at the upstream surface-water site and 0.36 mg/L at the downstream surface-water site (table 5). Median post-ASR orthophosphate was 0.55 mg/L at the upstream surface-water site and 0.52 mg/L at the downstream surface-water site (table 5). Median residuals return line site orthophosphate was 0.56 mg/L and was about 2 and 8 percent larger than median orthophosphate at the upstream and downstream surface-water sites post-ASR, respectively (table 5). Median pre-ASR total phosphorus was 0.77 mg/L at the upstream surface-water site and 0.70 mg/L at the downstream surface-water site; median post-ASR total phosphorus was 0.89 mg/L at both surface-water sites (table 5). Residuals return line site total phosphorus ranged from 0.96 mg/L to 6.76 mg/L and the median was about three times larger (median=2.67 mg/L) than the upstream and downstream surface-water site median phosphorus concentrations post-ASR (table 5). The EPA guidelines for total phosphorus list 0.09 mg/L as the criterion for level III ecoregion 27 streams (U.S. Environmental Protection Agency, 2001a); all samples collected from all sites throughout the study period exceeded this guideline (table 5).

Organic material in natural waters is composed of living and senescent organisms, cellular exudates, and degraded detrital material (Aiken, 2002). An important artificial recharge concern is the introduction of potentially reactive organic material into an aquifer (Aiken, 2002). Organic carbon is a constituent of interest for ASR operation because of its role in THM formation during the water treatment process. Data related to organic material characterization is presented in appendix table 1–7. There were no substantial differences in dissolved or total organic carbon medians between the upstream and downstream surface-water sites pre- or post-ASR. Dissolved and total organic carbon was larger post-ASR likely because of runoff during larger streamflows during this period. Median pre-ASR dissolved organic carbon was 5.4 mg/L at the upstream surface-water site and 5.2 mg/L at the downstream surface-water site; median post-ASR dissolved organic carbon was 9.2 mg/L at the upstream surface-water site and 9.7 mg/L at the downstream surface-water site (table 5). Median residuals return line site dissolved organic carbon was 14.8 mg/L and was about 61 and 53 percent larger than the upstream and downstream surface-water sites post-ASR, respectively (table 5). Pre-ASR total organic carbon was 7.1 mg/L at the upstream surface-water site and 7.3 mg/L at the downstream surface-water site; median post-ASR total organic carbon was 13.1 mg/L at the upstream surface-water site and 12.3 mg/L at the downstream surface-water site (table 5). Median residuals return line site total organic carbon was 23.6 mg/L and was about 80 and 92 percent larger than the upstream and downstream surface-water sites post-ASR, respectively (table 5).

#### Trace Elements and Associated Compounds

Dissolved concentrations of trace elements of particular interest in this report include copper, iron, manganese, and arsenic and associated arsenic species. The 2010 through 2014

NPDES permit for the ASR Phase II treatment facility stated that total recoverable copper should be monitored monthly while the facility was operating; however, total recoverable copper is not listed in the current (2015 through 2019) NPDES permit. Exposure to copper may cause health problems that include stomach distress and liver or kidney damage (U.S. Environmental Protection Agency, 2009). Arsenic is a carcinogen and iron and manganese can give water an undesirable taste and color and can plug groundwater wells. Infiltration of stream water or treated water into the *Equus* Beds aquifer (fig. 1) by artificial recharge operations could affect dissolved arsenic mobility or could stimulate microbial activity and cause iron and manganese precipitation of groundwater.

Sources of copper include corrosion of plumbing systems and erosion of natural deposits (U.S. Environmental Protection Agency, 2009). The EPA Federal SMCL for copper is 1.0 mg/L (1,000 µg/L). At least 80 percent of total copper samples were below the laboratory reporting level in surface-water samples collected during the study period (table 6). Median residuals return line site (375348097262800, fig. 1) total copper was 39 µg/L and ranged from 18 µg/L to 48 µg/L (table 6). No samples collected during the study exceeded the EPA Federal SMCL for copper.

Iron in water is derived from rocks and soils (Hem, 1992). Water having excessive concentrations of iron is unpalatable because of odor, a metallic taste, and rusty color. The EPA Federal SMCL for iron is 300 µg/L (U.S. Environmental Protection Agency, 2009). Iron was not detected in at least 75 percent of pre-ASR surface-water samples and 57 percent of post-ASR surface-water samples (table 6). Pre-ASR iron concentrations ranged from <100 to 200 µg/L at the upstream surface-water site (375350097262800, fig. 1) and <100 to 350 µg/L at the downstream surface-water site (07144100, fig. 1) (table 6). Median post-ASR iron concentrations were 102 µg/L at the upstream surface-water site and 115 µg/L at the downstream surface-water site (table 6). Iron was not detected in about 30 percent of residuals return line site samples; median residuals return line site iron concentration was 140 µg/L and ranged from <100 to 920 µg/L (table 6). Iron concentrations exceeded the EPA SMCL in one pre-ASR sample from the downstream surface-water site and one post-ASR sample from each surface-water site. Iron concentrations exceeded the EPA SMCL in two residuals return line samples.

Manganese originates from rocks and soil (Hem, 1992). The EPA SMCL for manganese is 50 µg/L (U.S. Environmental Protection Agency, 2009). Drinking water consumers may notice a bitter metallic taste, a black to brown color, and black staining on plumbing fixtures at concentrations larger than the SMCL (U.S. Environmental Protection Agency, 2009). Median manganese concentrations were larger at both surface-water sites pre-ASR. Manganese was significantly larger ( $p$ -value=0.02) at the upstream surface-water site (252 µg/L) compared to the downstream surface-water site (170 µg/L) pre-ASR but not post-ASR (table 6). Median post-ASR manganese concentrations were 51 µg/L at the upstream surface-water site, 94 µg/L at the downstream surface-water site, and

**Table 6.** Discretely collected trace element and associated compound summary statistics for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), and discharge from the Little Arkansas River aquifer storage and recovery facility (residuals return line site 375348097262800) near Sedgwick, Kansas, March 2011 through September 2014.

[See figure 1 for site locations. Medians in **bold** indicate statistically significant differences (*p*-value less than 0.05) between the upstream and downstream surface-water sites; the upstream and downstream surface-water sites were not statistically compared when greater than 50 percent of data were left-censored. Means and medians were not computed when greater than 80 percent of data were left-censored. pre, March 2011 through April 2013; ASR, aquifer storage and recovery; post, May 2013 through December 2014; *n*, number of measurements; µg/L, microgram per liter; <, less than; --, not applicable; As, arsenic]

Water-quality constituent (unit of measure)	Pre-ASR												Post-ASR																	
	Upstream surface-water site						Downstream surface-water site						Upstream surface-water site					Downstream surface-water site					Residuals return line site							
	Left-censored data (percent)	<i>n</i>	Minimum	Maximum	Mean	Median	Left-censored data (percent)	<i>n</i>	Minimum	Maximum	Mean	Median	Left-censored data (percent)	<i>n</i>	Minimum	Maximum	Mean	Median	Left-censored data (percent)	<i>n</i>	Minimum	Maximum	Mean	Median	Left-censored data (percent)	<i>n</i>	Minimum	Maximum	Mean	Median
Total copper (µg/L)	81	16	<5	10.0	--	--	94	16	<5	10.0	--	--	100	1	<10	<10	--	--	100	1	<10	<10	--	--	0	4	18	48	36	39
Iron (µg/L)	85	20	<100	200	--	--	75	20	<100	350	59	17	57	7	<100	330	143	102	57	7	<100	310	148	115	29	7	<100	920	281	140
Lead (µg/L)	25	20	<0.1	0.36	0.15	0.13	25	20	<0.1	0.35	0.16	0.13	29	7	<1	0.44	0.15	0.10	71	7	<0.1	0.35	0.12	0.05	0	7	0.12	6.67	1.16	0.22
Manganese (µg/L)	0	20	26	1,480	377	<b>252</b>	0	20	15	708	239	<b>170</b>	0	7	6	187	75	51	0	7	5	168	78	94	0	7	7	445	141	56
Nickel (µg/L)	0	20	1.3	5.4	2.8	2.4	0	20	0.7	5.8	2.7	2.5	0	7	2.6	4.5	3.6	3.8	0	7	2.5	4.5	3.5	3.6	0	7	3.1	6.4	4.2	4.0
Strontium (µg/L)	0	20	132	811	551	575	0	20	142	690	520	605	0	7	76	660	353	483	0	7	57	657	358	474	0	7	65	574	318	298
Arsenic (µg/L)	0	20	5.0	27.3	12.3	10.5	0	20	3.0	15.9	8.5	8.8	0	7	3.1	12.4	8.0	8.5	0	7	3.0	11.3	7.4	8.2	0	7	3.4	6.7	5.1	5.1
Arsenate (µg/L as As)	0	20	3.4	20.1	8.7	<b>7.6</b>	15	20	<1.6	11.5	5.6	<b>5.7</b>	0	8	1.8	11.3	5.3	3.8	0	8	2.2	10.2	5.7	5.2	0	7	2.2	5.4	3.8	3.8
Arsenite (µg/L as As)	85	20	<0.4	1.0	--	--	80	20	<0.4	1.0	0.4	0.3	38	8	<0.2	12.4	1.9	0.5	25	8	<0.2	0.6	0.3	0.3	86	7	<0.2	0.5	--	--
Dimethylarsinate (µg/L as As)	100	20	<0.6	<2	--	--	100	20	<0.6	<2	--	--	100	8	<0.3	<0.6	--	--	88	8	<0.3	0.3	--	--	100	7	<0.3	<0.6	--	--
Monomethylarsonate (µg/L as As)	100	20	<0.8	<3.2	--	--	100	20	<0.8	<3.2	--	--	100	8	<0.8	<3.2	--	--	95	13	<0.8	1.6	--	--	100	7	<3.2	<3.2	--	--
Selenium (µg/L)	0	20	1.0	4.5	2.2	2.0	0	20	0.5	5.3	2.1	1.8	14	7	<0.5	2.9	1.6	1.5	14	7	<0.5	2.7	1.4	1.4	29	7	<0.5	15.1	4.7	1.0

56 µg/L at the residuals return line site (table 6). Manganese concentrations exceeded the SMCL at the upstream and downstream surface-water sites in about 80 percent of pre-ASR samples and 60 percent of post-ASR samples; the residuals return line site exceeded the SMCL in about 40 percent of samples.

Arsenic is present naturally in clay layers associated with iron sulfide minerals (Hem, 1992) and is a health concern in drinking water because it causes skin damage, affects the circulatory system, and increases the risk of cancer (U.S. Environmental Protection Agency, 2009). Arsenic mobility is generally controlled by adsorption and desorption reactions as well as solid-phase precipitation and dissolution reactions (Hem, 1992; Hinkle and Polette, 1999; Smedley and Kinniburgh, 2002; McMahon and Chapelle, 2008). These processes are affected by pH, oxidation/reduction reactions, and competing anion presence, all of which could be altered as a result of artificial recharge activities. The EPA Federal MCL for arsenic is 10 µg/L (U.S. Environmental Protection Agency, 2009). Median arsenic concentrations were 7 to 19 percent larger before the ASR Phase II facility began operating and were similar upstream and downstream after the facility began operating. Median pre-ASR arsenic concentrations were 10.5 µg/L and 8.8 µg/L at the upstream and downstream surface-water sites, respectively (table 6). Median post-ASR arsenic concentrations were 8.5 µg/L and 8.2 µg/L at the upstream and downstream surface-water sites, respectively (table 6). Median residuals return line site arsenic was about 38 percent smaller than the downstream surface-water site. Median arsenic concentration in the residuals return line was 5.1 µg/L and ranged from 3.4 µg/L to 6.7 µg/L (table 6). Arsenic concentrations exceeded the MCL in about 55 and 30 percent of pre-ASR samples for the upstream and downstream surface-water sites, respectively; post-ASR arsenic concentrations exceeded the MCL in about 43 percent of samples for both the upstream and downstream surface-water sites. Arsenic concentrations never exceeded the MCL in the residuals return line site samples during the study.

Arsenic in natural waters is mostly found in the inorganic forms arsenate and arsenite (Smedley and Kinniburgh, 2002). Median pre-ASR arsenate concentrations were larger at both surface-water sites. Pre-ASR arsenate was significantly ( $p$ -value<0.05) larger at the upstream surface-water site (7.6 µg/L) compared to the downstream surface-water site (5.7 µg/L; table 6). Median post-ASR arsenate concentrations were not significantly different between the two surface-water sites (upstream median=3.8 µg/L; downstream median=5.2 µg/L; table 6). Median residuals return line site arsenate was 3.8 µg/L (table 6). Greater than 80 percent of pre-ASR arsenite samples were below the laboratory reporting level at both surface-water sites as well as the residuals return line site (table 6). Median pre- and post-ASR arsenite concentrations were 0.3 µg/L at the downstream surface-water site (table 6). All dimethylarsinate and monomethylarsonate samples were less than the laboratory reporting level at the upstream surface-water site, the downstream surface-water

site pre-ASR, and the residuals return line site (table 6). One dimethylarsinate sample and one monomethylarsonate sample at the downstream surface-water site were at or near the laboratory reporting level post-ASR.

#### Coliform Bacteria and Viral Indicators

*E. coli* and fecal coliform bacteria are types of coliform bacteria that are generally specific to fecal material from humans and other homeotherms and are common types of bacteria used as indicators of pathogens. *E. coli* and fecal coliform presence indicate that water may be contaminated with human or animal wastes, and may indicate that other harmful bacteria or viruses are present (Dufour and others, 1981; Dufour, 1984). These bacteria indicate potential for pathogens that may cause diarrhea, nausea, headaches, and abdominal cramps, and may pose a particular health risk for infants, young children, and people with compromised immune systems (U.S. Environmental Protection Agency, 2009). All indicator bacterial and viral densities were generally larger after the ASR Phase II facility began operating, likely because of runoff during larger streamflows during this period.

The State of Kansas established surface water recreational-use criteria in 2004 for *E. coli*. The criteria for publicly accessible (Class B) Kansas streams with flows of at least 1 ft<sup>3</sup>/s require that the geometric mean of at least five samples collected during separate 24-hour periods within a 30-day period not exceed 262 colony forming units per 100 milliliters (cfu/100 mL) for primary contact during April 1 through October 31 of each year and 2,358 cfu/100 mL at any time of year (Kansas Department of Health and Environment, 2004b and 2011). For the purposes of this report, cfu/100 mL are considered equivalent to colonies per 100 milliliters (col/100 mL). Median pre-ASR *E. coli* bacteria densities were 96 col/100 mL at the upstream surface-water site (375350097262800, fig. 1) and 83 col/100 mL at the downstream surface-water site (07144100, fig. 1); median post-ASR *E. coli* densities were 855 col/100 mL at the upstream surface-water site and 995 col/100 mL at the downstream surface-water site (table 7). Residuals return line site (375348097262800, fig. 1) median *E. coli* density was 9,300 col/100 mL (table 7). The upstream surface-water site *E. coli* densities exceeded 262 col/100 mL in about 33 percent of pre-ASR samples and 75 percent of post-ASR samples; the downstream surface-water site *E. coli* densities exceeded 262 col/100 mL in about 28 percent of pre-ASR samples and about 63 percent of post-ASR samples. All residuals return line site *E. coli* samples exceeded 262 col/100 mL. The upstream and downstream surface-water site *E. coli* densities exceeded 2,358 col/100 mL in about 6 percent of pre-ASR samples and 25 percent of post-ASR samples after facility operation onset. The residuals return line site *E. coli* sample densities exceeded 2,358 col/100 mL in about 71 percent of samples.

The State of Kansas' recreational-use guidelines for Kansas stream water fecal coliform densities are 200 col/100 mL for primary contact (swimming) during April 1 through

**Table 7.** Discretely collected viral and bacteria summary statistics for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), and discharge from the Little Arkansas River aquifer storage and recovery facility (residuals return line site 375348097262800) near Sedgwick, Kansas, March 2011 through September 2014.

[See figure 1 for site locations. pre, March 2011 through April 2013; ASR, aquifer storage and recovery; post, May 2013 through December 2014; *n*, number of measurements; *E. coli*, *Escherichia coli*; col/100 mL, colony per 100 milliliters; mpn/100 mL, most probably number per 100 milliliters; pfu/100 mL, plaque forming unit per 100 milliliters; <, less than; cfu/mL, colony forming unit per milliliter]

Water-quality constituent (unit of measure)	Pre-ASR												Post-ASR																	
	Upstream surface-water site						Downstream surface-water site						Upstream surface-water site						Downstream surface-water site						Residuals return line site					
	Left-censored data (percent)	<i>n</i>	Mini-mum	Maxi-mum	Mean	Median	Left-censored data (percent)	<i>n</i>	Mini-mum	Maxi-mum	Mean	Median	Left-censored data (percent)	<i>n</i>	Mini-mum	Maxi-mum	Mean	Median	Left-censored data (percent)	<i>n</i>	Mini-mum	Maxi-mum	Mean	Median	Left-censored data (percent)	<i>n</i>	Mini-mum	Maxi-mum	Mean	Median
<i>E. coli</i> bacteria (col/100 mL)	0	18	8	19,000	1,240	96	0	18	11	4,100	462	83	0	8	110	8,100	2,185	855	0	8	45	8,000	2,078	995	0	7	700	30,000	14,086	9,300
Fecal coliform bacteria (col/100 mL)	0	20	18	18,000	1,295	200	0	20	12	5,600	681	89	0	8	140	7,000	2,781	1,000	0	8	93	100,000	14,298	1,750	0	7	850	160,000	30,611	4,500
Total coliform bacteria (mpn/100 mL)	0	17	900	150,000	24,641	16,000	0	17	820	77,000	22,789	10,000	0	7	21,000	290,000	110,429	46,000	0	7	19,000	200,000	68,857	37,000	0	5	16,000	240,000	152,000	240,000
<i>E. coli</i> coliphage (pfu/100 mL)	6	18	<1	1,400	155	50	6	18	<1	660	105	45	0	8	3	2,700	577	320	0	8	1	2,500	494	114	0	7	130	17,000	5,773	2,100
Iron-related bacteria (cfu/mL)	0	20	9,000	140,000	32,450	35,000	0	20	9,000	140,000	38,300	35,000	0	8	9,000	35,000	22,000	22,000	0	8	9,000	35,000	22,000	22,000	0	7	9,000	140,000	42,571	35,000
Slime-forming bacteria (cfu/mL)	0	20	66,500	1,800,000	742,475	350,000	0	20	12,500	1,800,000	709,850	350,000	0	8	350,000	1,800,000	712,500	350,000	0	8	350,000	1,800,000	712,500	350,000	0	7	350,000	1,800,000	764,286	350,000
Sulfate-reducing bacteria (cfu/mL)	0	20	1,200	6,800,000	1,155,060	700,000	0	20	5,000	700,000	545,250	700,000	0	8	500	700,000	364,963	400,000	0	8	500	700,000	354,713	359,000	0	7	5,000	700,000	331,857	100,000

October 31 of each year and 2,000 col/100 mL for primary contact during the rest of the year and for secondary contact (boating or wading; Kansas Department of Health and Environment, 2001). Median pre-ASR fecal coliform bacteria densities were 200 col/100 mL at the upstream surface-water site and 89 col/100 mL at the downstream surface-water site, and median post-ASR densities were 1,000 col/100 mL at the upstream surface-water site and 1,750 col/100 mL at the downstream surface-water site (table 7). Median residuals return line site fecal coliform density was 4,500 col/100 mL (table 7). The upstream surface-water site fecal coliform densities exceeded 200 col/100 mL in about 61 percent of pre-ASR samples and 88 percent of post-ASR samples. The downstream surface-water site fecal coliform densities exceeded 200 col/100 mL in about 44 percent of pre-ASR samples and about 63 percent of post-ASR samples. All residuals return line site fecal coliform sample densities exceeded 200 col/100 mL.

The EPA Federal MCL for total coliform bacteria in drinking water is that no greater than 5 percent of samples test positive during 1 month for water systems that collect at least 40 routine samples per month (U.S. Environmental Protection Agency, 2009). If fewer than 40 samples are collected per month, no greater than 1 sample can test positive for total coliform bacteria (U.S. Environmental Protection Agency, 2009). The EPA Federal maximum contaminant level goal (MCLG) for total coliform bacteria in drinking water is 0 col/100 mL. For the purposes of this report, col/100 mL are considered equivalent to most probable number per 100 milliliters (mpn/100 mL). Median pre- and post-ASR total coliform bacteria densities were smaller at the downstream surface-water site. Median pre-ASR total coliform densities were 16,000 mpn/100 mL at the upstream surface-water site and 10,000 mpn/100 mL at the downstream surface-water site (table 7). Median post-ASR total coliform densities were 46,000 mpn/100 mL at the upstream surface-water site and 37,000 mpn/100 mL at the downstream surface-water site (table 7). Median residuals return line site total coliform bacteria density was 240,000 mpn/100 mL (table 7). All samples at all sites tested positive for total coliform bacteria during the study and the minimum pre-ASR density (820 mpn/100 mL) was at the downstream surface-water site.

*E. coli* coliphage virus is an indicator of possible fecal contamination because it infects coliform bacteria. Pre- and post-ASR *E. coli* coliphage densities were generally smaller at the downstream surface-water site. Median pre-ASR *E. coli* coliphage densities were 50 plaque forming units per 100 milliliters (pfu/100 mL) at the upstream surface-water site and 45 pfu/100 mL at the downstream surface-water site (table 7). Median post-ASR *E. coli* coliphage densities were 320 pfu/100 mL at the upstream surface-water site and 114 pfu/100 mL at the downstream surface-water site (table 7). Median residuals return line site *E. coli* coliphage density was 2,100 pfu/100 mL (table 7).

### Biological Activity Reaction Tests

Iron-related, slime-forming, and sulfate-reducing bacteria are a natural part of the environment and multiply in conditions suitable to growth. These bacteria are of interest because they may enter an aquifer through wells or other interaction with the surface. Iron-related bacteria use iron in their metabolism and grow optimally in water with large iron content. Iron-related bacteria tend to colonize on well and pump surfaces, can cause slime and unpleasant odors and tastes, and may deposit iron oxide on surfaces or produce corrosive acids. Many iron-related bacteria can grow in aerobic or anaerobic environments by substituting nitrates for oxygen during metabolism. Slime-forming bacteria can produce extracellular polysaccharide polymers that act as a foundation for biofilm, or slime, formation. The slime supports the growth of iron-related and sulfate-reducing bacteria. Sulfate-reducing bacteria reduce sulfates to obtain energy, primarily in anaerobic and reducing conditions. Hydrogen sulfide is a byproduct of sulfate-reducing bacteria metabolism (Cullimore, 2007).

Median pre-ASR iron-related bacteria densities were 35,000 colony forming units per 100 milliliters (cfu/100 mL) at the upstream and downstream surface-water sites (375350097262800 and 07144100 [fig. 1], respectively) (table 7). Median post-ASR iron-related densities were 22,000 cfu/100 mL at the upstream and downstream surface-water sites (table 7). Median residuals return line site (375348097262800, fig. 1) iron-related bacteria density was 35,000 cfu/100 mL. Median slime-forming bacteria densities were 350,000 cfu/100 mL for all sites and all time periods during the study (table 7). Median sulfate-reducing bacteria was 700,000 cfu/100 mL at the upstream and downstream surface-water sites pre-ASR, and 400,000 cfu/100 mL at the upstream surface-water site and 359,000 cfu/100 mL at the downstream surface-water site post-ASR (table 7). Median residuals return line site sulfate-reducing bacteria density was 100,000 cfu/100 mL (table 7).

### Organic Compounds

Many of the organic compounds detected in surface water and groundwater in the study area are pesticides (Tappa and others, 2015). These organic compounds enter streams or slowly infiltrate into the aquifer from the application on fields or through irrigation return flow and surface runoff. Atrazine is a primary constituent of concern in the study area (Ziegler and others, 1999). Atrazine is an herbicide commonly used on corn and sorghum, which are crops commonly grown in the study area. Atrazine can cause cardiovascular system or reproductive problems in humans (U.S. Environmental Protection Agency, 2009). The EPA MCL in drinking water for atrazine is 3.0 µg/L as an annual average (U.S. Environmental Protection Agency, 2009). The 2010 through 2014 and current (2015 through 2019) NPDES permits for the ASR Phase II treatment facility require that atrazine be monitored monthly while the facility is operating. Atrazine was generally larger at the upstream surface-water site (375350097262800, fig. 1)



and post-ASR. Median atrazine concentrations increased by 361 percent to 393 percent post-ASR, likely because of runoff during larger streamflows during that time period. Median pre-ASR atrazine concentrations were 0.69 µg/L at the upstream surface-water site and 0.58 µg/L at the downstream surface-water site (07144100, fig. 1) (table 8). Median post-ASR atrazine concentrations were 3.18 µg/L at the upstream surface-water site and 2.86 µg/L at the downstream surface-water site (table 8). Median residuals return line atrazine concentration was 2.95 µg/L (table 8). Atrazine concentrations at the upstream surface-water site exceeded the EPA MCL of 3.0 µg/L in about 20 percent of pre-ASR samples and 50 percent of post-ASR samples. Atrazine concentrations at the downstream surface-water site exceeded 3.0 µg/L in about 25 percent and 38 percent of samples pre- and post-ASR, respectively. Residuals return line site (375348097262800, fig. 1) atrazine concentrations exceeded 3.0 µg/L in about 43 percent of samples.

Alachlor is an herbicide used to control weeds in soybeans and was frequently detected in study samples. Alachlor potentially can cause eye, liver, kidney, or spleen problems, anemia, and an increased risk of cancer (U.S. Environmental Protection Agency, 2009). The EPA Federal drinking-water criterion for alachlor is 2 µg/L (U.S. Environmental Protection Agency, 2009). Alachlor was detected less frequently and concentrations were generally smaller at the surface-water sites post-ASR (table 8). Alachlor concentrations never exceeded the EPA drinking-water criterion at any sites during the study period (table 8).

Chlordane is an insecticide that was sold in the United States until 1983. Chlordane can potentially cause liver or nervous system problems and increase the risk of cancer (U.S. Environmental Protection Agency, 2009). The EPA Federal drinking-water criterion for chlordane is 2 µg/L (U.S. Environmental Protection Agency, 2009). Among all sites and samples during the study period, including the residuals return line site, chlordane was only detected at the downstream surface-water site post-ASR in about 50 percent of samples (table 8). Chlordane never exceeded the EPA drinking-water criterion (table 8). Chlordane is no longer required for monitoring in the current (2015 through 2019) NPDES permit.

Glyphosate is an herbicide that can cause kidney problems and reproductive difficulties (U.S. Environmental Protection Agency, 2009). The EPA Federal drinking-water criterion for glyphosate is 700 µg/L (U.S. Environmental Protection Agency, 2009). Glyphosate was not analyzed pre-ASR. Glyphosate was detected in all post-ASR samples. Median post-ASR glyphosate concentrations were 1.600 µg/L at the upstream surface-water site, 1.800 µg/L at the downstream surface-water site, and 0.790 µg/L at the residuals return line site (table 8). Glyphosate never exceeded the EPA drinking-water criterion (table 8).

Simazine is an herbicide that can cause weight loss and changes in blood (U.S. Environmental Protection Agency, 2009). The EPA Federal drinking-water criterion for simazine is 4 µg/L (U.S. Environmental Protection Agency, 2009).

Simazine concentrations were below the laboratory reporting level for about 40 percent of pre-ASR surface-water samples and about 60 percent of post-ASR surface-water samples (table 8). Median pre-ASR simazine concentrations were 0.006 µg/L at the upstream surface-water site and 0.008 µg/L at the downstream surface-water site (table 8). Median post-ASR simazine concentrations were 0.012 µg/L at the upstream surface-water site and 0.009 µg/L at the downstream surface-water site (table 8). Median residuals return line site simazine concentration was 0.010 µg/L (table 8).

## Streambed-Sediment Chemistry

Some compounds are hydrophobic and are associated with sediment; therefore, concentrations of these compounds are larger in sediment than in the overlying water column (Horowitz, 1991). Contaminated sediment can be toxic to benthic organisms, including periphyton and macroinvertebrates, and contaminants may bioaccumulate in fish and mammals (U.S. Environmental Protection Agency, 2000b). Streambed-sediment samples were collected annually at the upstream and downstream surface-water sites (375350097262800 and 07144100 [fig. 1], respectively) during 2011 through 2014 (a total of three pre-ASR samples), and one sediment sample was collected from the residuals return line site in September 2014. All samples were analyzed for nutrients, carbon, trace elements, and organic wastewater-indicator compounds (OWCs). Because there are no set criteria for trace elements or OWCs in sediments, probable effect concentrations (PECs) have been established for some compounds (MacDonald and others, 2000). The PEC represents the concentration of a contaminant in streambed sediment that is expected to adversely affect benthic biota.

Streambed sediment nutrients generally were larger at the downstream surface-water site during the study period and smaller at both surface-water sites post-ASR. Median pre-ASR total nitrogen was 1,500 mg/kg at the upstream surface-water site and 3,003 mg/kg at the downstream surface-water site (table 9). Post-ASR total nitrogen was 1,002 mg/kg at the upstream surface-water site and 1,601 mg/kg at the downstream surface-water site after facility operation onset (table 9). Residuals return line site total nitrogen was 3,203 mg/kg and two times (50 percent) larger than the downstream site (table 9). Median pre-ASR total phosphorus was 1,200 mg/kg at the upstream and downstream surface-water sites and exceeded mean background levels for the conterminous United States (1,000 mg/kg; table 9; Horowitz and Stephens, 2008). Post-ASR total phosphorus concentrations were 910 and 980 mg/kg at the upstream and downstream surface-water sites, respectively (table 9). Residuals return line site total phosphorus was 850 mg/kg and was about 7 to 13 percent smaller than the post-ASR upstream and downstream surface-water site concentrations, respectively (table 9).

Organic and total carbon generally was larger at the downstream surface-water site during the entire study period and larger at both surface-water sites pre-ASR (table 9).

**Table 8.** Discretely collected pesticide summary statistics for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), and discharge from the Little Arkansas River aquifer storage and recovery facility (residuals return line site 375348097262800) near Sedgwick, Kansas, March 2011 through September 2014.

[See figure 1 for site locations. The upstream and downstream surface-water sites were not statistically compared when greater than 50 percent of data were left-censored. Means and medians were not computed when greater than 80 percent of data were left-censored. pre, March 2011 through April 2013; ASR, aquifer storage and recovery; post, May 2013 through December 2014; *n*, number of measurements; µg/L, microgram per liter; <, less than; --, not applicable; EPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level]

Water-quality constituent (unit of measure)	Pre-ASR												Post-ASR																	
	Upstream surface-water site						Downstream surface-water site						Upstream surface-water site					Downstream surface-water site					Residuals return line site							
	Left-censored data (percent)	<i>n</i>	Mini-mum	Maxi-mum	Mean	Median	Left-censored data (percent)	<i>n</i>	Mini-mum	Maxi-mum	Mean	Median	Left-censored data (percent)	<i>n</i>	Mini-mum	Maxi-mum	Mean	Median	Left-censored data (percent)	<i>n</i>	Mini-mum	Maxi-mum	Mean	Median	Left-censored data (percent)	<i>n</i>	Mini-mum	Maxi-mum	Mean	Median
Acetochlor (µg/L)	20	20	<0.01	4.36	0.41	0.02	15	20	<0.01	5.67	0.58	0.03	0	8	0.14	3.42	0.75	0.27	0	8	0.14	2.98	0.70	0.30	0	7	0.03	1.16	0.47	0.20
Atrazine (µg/L) <sup>1</sup>	0	20	0.04	19.10	2.94	0.69	0	20	0.02	21.30	3.03	0.58	0	8	0.20	8.56	3.51	3.18	0	8	0.18	7.56	3.44	2.86	0	7	0.19	11.00	3.35	2.95
Alachlor (µg/L) <sup>2</sup>	55	20	<0.008	0.063	0.012	0.007	45	20	<0.008	0.125	0.018	0.009	88	8	<0.009	0.008	--	--	75	8	<0.008	0.008	0.005	0.004	27	7	0.004	0.031	0.009	0.004
Chlordane (µg/L) <sup>2</sup>	100	18	<0.1	<0.1	--	--	100	18	<0.1	<0.1	--	--	100	2	<0.1	<0.1	--	--	50	2	<0.1	0.05	0.05	0.05	100	4	<0.1	<0.1	--	--
Desulfinylfipronil (µg/L)	0	20	0.003	0.010	0.006	0.006	0	20	0.003	0.010	0.006	0.005	38	8	<0.012	0.005	0.004	0.004	38	8	<0.012	0.006	0.005	0.004	43	7	<0.012	0.006	0.005	0.005
Fipronil sulfide (µg/L)	25	20	<0.012	0.012	0.004	0.004	40	20	<0.012	0.012	0.004	0.004	38	8	<0.012	0.012	0.003	0.004	38	8	<0.012	0.012	0.003	0.004	71	7	<0.012	0.006	0.005	0.006
Glyphosate (µg/L)	--	--	--	--	--	--	--	--	--	--	--	--	0	6	0.590	3.500	1.763	1.600	0	6	0.650	3.500	1.942	1.800	0	3	0.640	3.300	1.577	0.790
Metolachlor (µg/L)	0	20	0.019	3.340	0.622	0.113	0	20	0.014	3.630	0.860	0.101	0	8	0.202	6.820	1.680	0.467	0	8	0.212	6.830	2.098	0.486	0	7	0.105	11.20	2.170	0.297
Prometon (µg/L)	5	20	<0.12	0.030	0.012	0.011	25	20	<0.12	0.031	0.012	0.010	25	8	<0.12	0.105	0.024	0.012	13	8	<0.12	0.132	0.028	0.012	0	7	0.002	0.272	0.063	0.016
Simazine (µg/L) <sup>3</sup>	40	20	<0.006	0.067	0.013	0.006	45	20	<0.006	0.043	0.013	0.008	63	8	<0.006	0.038	0.014	0.012	63	8	<0.006	0.038	0.013	0.009	29	7	<0.006	0.047	0.016	0.010
Triazines (µg/L as atrazine)	15	20	<0.1	19.00	2.29	0.46	5	20	<0.1	12.00	2.37	0.63	0	8	0.28	10.00	3.86	3.35	0	8	0.16	8.30	3.69	3.15	0	7	0.26	12.00	3.56	2.40

<sup>1</sup>EPA MCL of 0.003 µg/L (U.S. Environmental Protection Agency, 2009).

<sup>2</sup>EPA MCL of 0.002 µg/L (U.S. Environmental Protection Agency, 2009).

<sup>3</sup>EPA MCL of 0.004 µg/L (U.S. Environmental Protection Agency, 2009).

**Table 9.** Streambed-sediment nutrients, carbon, and trace element summary statistics for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), and discharge from the Little Arkansas River Aquifer Storage and Recovery facility (residual return line site 375348097262800) near Sedgwick, Kansas, April 2011 through April 2013 and July through September 2014.

[See figure 1 for site locations. Means and medians were not computed when greater than 80 percent of data were left-censored. pre, March 2011 through April 2013; ASR, aquifer storage and recovery; post, May 2013 through December 2014; *n*, number of measurements; mg/kg, milligram per kilogram; --, not applicable; <, less than]

Constituent (unit of measure)	Probable effect concentration <sup>1</sup>	Background concentration <sup>2</sup>	Pre-ASR						Pre-ASR						Post-ASR					
			Upstream surface-water site						Downstream surface-water site						Upstream surface-water site	Downstream surface-water site	Residuals return line site			
			Left-censored data (percent)	<i>n</i>	Minimum	Maximum	Mean	Median	Left-censored data (percent)	<i>n</i>	Minimum	Maximum	Mean	Median						
Nutrients and carbon									Nutrients and carbon											
Total Kjeldahl nitrogen (mg/kg)	--	--	0	1	590	590	--	--	0	1	3,000	3,000	--	--	1,000	1,600	3,200			
Nitrate plus nitrite (mg/kg)	--	--	100	1	<1.6	<1.6	--	--	100	1	<5.2	<5.2	--	--	2	1	3			
Total nitrogen (mg/kg)	--	--	0	3	591	2,900	1,664	1,500	0	3	2,400	3,900	3,101	3,003	1,002	1,601	3,203			
Total phosphorus (mg/kg)	--	1,000	0	3	820	1,600	1,207	1,200	0	3	1,000	1,600	1,267	1,200	910	980	850			
Organic carbon (mg/kg)	--	24,000	0	3	14,000	20,000	16,000	14,000	0	3	18,000	24,000	20,000	18,000	14,000	17,000	23,200			
Total carbon (mg/kg)	--	33,000	0	3	14,000	25,000	18,333	16,000	0	3	20,000	32,000	24,000	20,000	15,000	17,000	23,200			
Total sulfur (mg/kg)	--	800	0	3	500	1,400	833	600	0	3	600	1,300	867	700	2,900	2,700	900			
Trace elements									Trace elements											
Aluminum (mg/kg)	--	59,000	0	3	59,000	61,000	59,667	59,000	0	3	60,000	64,000	62,667	64,000	64,000	64,000	80,200			
Antimony (mg/kg)	--	0.7	0	3	0.7	0.8	0.7	0.7	0	3	0.7	0.9	0.8	0.7	0.8	0.8	1.2			
Arsenic (mg/kg)	33	6.6	0	3	6.0	8.8	7.2	6.8	0	3	6.4	7.8	7.3	7.7	8.3	8.5	11			
Barium (mg/kg)	--	490	0	3	670	800	720	690	0	3	650	740	700	710	660	650	568			
Beryllium (mg/kg)	--	1.8	0	3	1.4	2.0	1.7	1.8	0	3	1.6	2.0	1.8	1.9	1.9	1.9	2.5			
Calcium (mg/kg)	--	18,000	0	3	10,000	22,000	14,667	12,000	0	3	11,000	24,000	16,333	14,000	10,000	10,000	10,300			
Chromium (mg/kg)	111	58	0	3	40	52	47	50	0	3	40	60	52	55	45	10	76			
Cobalt (mg/kg)	--	12	0	3	9.0	10	9.3	9.0	0	3	10	11	10	10	10	10	13			
Copper (mg/kg)	149	20	0	3	16	21	19	19	0	3	19	21	20	21	21	22	32			
Iron (mg/kg)	--	29,000	0	3	24,000	28,000	25,333	24,000	0	3	25,000	29,000	27,333	28,000	27,000	28,000	46,000			
Lead (mg/kg)	128	20	0	3	20	37	26	21	0	3	23	36	28	24	22	23	32			
Lithium (mg/kg)	--	30	0	3	22	29	26	27	0	3	24	32	29	31	28	28	39			
Magnesium (mg/kg)	--	9,000	0	3	5,000	7,000	6,067	6,200	0	3	6,000	7,000	6,533	6,600	7,000	7,400	9,390			
Manganese (mg/kg)	--	840	0	3	620	940	827	920	0	3	770	1,200	1,057	1,200	1,000	1,200	701			
Nickel (mg/kg)	48.6	23	0	3	16	19	18	18	0	3	19	22	20	19	21	22	36			
Potassium (mg/kg)	--	15,000	0	3	18,000	19,000	18,333	18,000	0	3	17,000	20,000	18,333	18,000	18,000	17,000	19,800			
Selenium (mg/kg)	--	0.7	0	3	0.5	0.6	0.6	0.6	0	3	0.7	0.9	0.8	0.7	0.6	0.7	0.6			
Silver (mg/kg)	--	0.2	66	3	<0.25	0.30	0.27	0.25	0	3	<0.25	0.60	0.38	0.30	<0.02	<0.02	<0.5			
Sodium (mg/kg)	--	6,000	0	3	7,500	8,000	7,833	8,000	0	3	7,000	7,000	7,000	7,000	6,900	6,500	2,330			
Strontium (mg/kg)	--	150	0	3	150	200	170	160	0	3	160	210	177	160	150	140	127			
Vanadium (mg/kg)	--	83	0	3	65	78	72	72	0	3	73	83	77	76	78	78	122			
Zinc (mg/kg)	459	91	0	3	73	91	83	86	0	3	87	97	91	88	94	96	131			

<sup>1</sup>From MacDonald and others (2000).

<sup>2</sup>Background concentrations for the conterminous United States from Horowitz and Stephens (2008).

Organic and total carbon did not exceed mean background levels (24,000 mg/kg and 33,000 mg/kg, respectively) for the conterminous United States at any site during the study (table 9). Pre- and post-ASR organic carbon at the upstream surface-water site was 14,000 mg/kg (table 9). Organic carbon at the downstream surface-water site was 18,000 mg/kg pre-ASR and 17,000 mg/kg post-ASR (table 9). Residuals return line site organic carbon concentration was 23,200 mg/kg (table 9). Median pre-ASR total carbon concentrations were 16,000 mg/kg at the upstream surface-water site and 20,000 mg/kg at the downstream surface-water site (table 9). Post-ASR total carbon was 15,000 mg/kg at the upstream surface-water site, 17,000 mg/kg at the downstream surface-water site, and 23,200 mg/kg at the residuals return line site (table 9). Residuals return line site organic and total carbon were about 27 percent larger than the downstream surface-water site.

Streambed sediment trace element concentrations at the surface-water sites generally were similar among sites pre- and post-ASR. Residuals return line site trace element concentrations generally were larger than the downstream surface-water site concentrations, with the exception of barium, manganese, selenium, sodium, and strontium (table 9). No trace element samples from any site exceeded their respective PEC (table 9). Median arsenic, barium, lead, and potassium concentrations from all sites exceeded their respective mean background levels for the conterminous United States during the study period (table 9). Concentrations of streambed trace elements above median background levels may be due to natural variability, local geology, or agricultural land use. Streambed trace element concentrations at the surface-water sites were within the range of previously collected data in the drainage basin (Juracek and Rasmussen, 2008). Most residuals return line site trace element concentrations were within the range of previously collected data in the drainage basin, with the exception of exceedances in aluminum, antimony, iron, nickel, and vanadium (Juracek and Rasmussen, 2008). Median pre-ASR arsenic concentrations were 6.8 mg/kg at the upstream surface-water site and 7.7 mg/kg at the downstream surface-water site (table 9). Post-ASR arsenic concentrations were 8.3 mg/kg at the upstream surface-water site, 8.5 mg/kg at the downstream surface-water site, and 11 mg/kg at the residuals return line site (table 9). Median pre-ASR copper concentrations were 19 and 21 mg/kg at the upstream and downstream surface-water sites, respectively (table 9). Post-ASR copper concentrations were 21 and 22 mg/kg at the upstream and downstream surface-water sites, respectively (table 9). The residual return line site copper concentration was 32 mg/kg (table 9). Median pre-ASR manganese concentrations were 920 mg/kg at the upstream surface-water site and 1,200 mg/kg at the downstream surface-water site (table 9). Post-ASR manganese concentrations were 1,000 mg/kg at the upstream surface-water site, 1,200 mg/kg at the downstream surface-water site, and 701 mg/kg at the residuals return line site (table 9).

Streambed and residuals return line site sediment samples were analyzed for 57 OWCs, 21 of which were detected (table 10). Detected compounds included pesticides, natural organics, polycyclic aromatic hydrocarbons (PAHs), sterols or stanols, flavorings or fragrances, detergents, components of coal tar and asphalt, solvents, disinfectants, and fire retardants. The most frequently detected compounds at all sites during the study period were pesticides, which are used in agricultural activities in the drainage basin. There were no clear patterns in OWC concentrations before and after the ASR Phase II facility began operating, although the downstream surface-water site tended to have larger OWC concentrations compared to the upstream surface-water site throughout the study period (table 10). Of the data that were above the laboratory reporting level, residuals return line OWC concentrations generally were smaller than the downstream surface-water site (table 10).

## Habitat Assessment

Habitat-quality evaluations are a critical part of assessing ecological integrity and integrate several factors that directly or indirectly affect stream water quality and biota (Barbour and others, 1996; Barbour and others, 1999). Habitat degradation is one of the principal stressors affecting diversity and abundance of stream organisms (Karr and others, 1986). Channel, bank, riparian, and aquatic habitat conditions were evaluated before the ASR Phase II facility began operating during August 2011 and after the facility began operating during September 2014.

Mean total habitat scores were indicative of suboptimal conditions at the upstream and downstream surface-water sites (375350097262800 and 07144100 [fig. 1], respectively) during the study period (table 11). Mean channel conditions and characteristics scores were indicative of marginal conditions at the upstream surface-water site pre- and post-ASR and the downstream surface-water site pre-ASR (table 11). The post-ASR mean channel conditions and characteristics score for the downstream surface-water site was indicative of suboptimal conditions (table 11).

Mean bank and riparian conditions scores were indicative of suboptimal conditions at the upstream surface-water site and optimal conditions at the downstream surface-water site during the study period (table 11). Within the bank and riparian category, both surface-water sites generally scored suboptimally for bank stability, canopy cover, and bank/riparian protection and optimally for length and extent of buffers, mean buffer width, and percent altered banks (table 11).

Mean aquatic habitat availability scores were indicative of marginal conditions at the upstream and downstream surface-water sites during the study period (table 11). Within the aquatic habitat availability category, substrate fouling and sediment deposition mean scores indicated marginal conditions at the upstream and downstream surface-water sites during the entire study period (table 11), demonstrating that sediment deposition was evident pre- and post-ASR and no substantial changes were noted after the ASR facility began

**Table 10.** Streambed-sediment organic wastewater indicator compound summary statistics for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), and discharge from the Little Arkansas River aquifer storage and recovery facility (residuals return line site 375348097262800) near Sedgwick, Kansas, April 2011 through April 2013 and July through September 2014.

[See figure 1 for site locations. Means and medians were not computed when greater than 80 percent of data were left-censored. pre, March 2011 through April 2013; ASR, aquifer storage and recovery; post, May 2013 through December 2014; *n*, number of measurements; µg/kg, microgram per kilogram; --, not applicable; <, less than; E, estimated; PAH, polycyclic aromatic hydrocarbon; β, beta]

Constituent (unit of measure)	General use <sup>1</sup>	Probable effect concentration <sup>2</sup>	Pre-ASR												Post-ASR		
			Upstream surface-water site						Downstream surface-water site						Upstream surface- water site	Downstream surface- water site	Residual return line site
			Left- censored data (percent)	<i>n</i>	Minimum	Maximum	Mean	Median	Left- censored data (percent)	<i>n</i>	Minimum	Maximum	Mean	Median			
Carbazole (µg/kg)	Insecticide, manufacturing dyes, explosives, and lubricants	--	33	3	<60	E14	17	14	100	3	<63	<112	--	--	12	14	10
Metolachlor (µg/kg)	Herbicide	--	67	3	<60	4	30	30	67	3	<72	6	33	36	11	12	<76
<i>p</i> -Cresol (µg/kg)	PAH or combustion by-product, wood preservative	--	0	3	E20	320	190	230	0	3	80	E4,900	2,830	3,510	250	190	93
2,6-Dimethylnaphthalene (µg/kg)	PAH or combustion by-product, present in diesel and kerosene	--	0	3	34	E150	82	62	0	3	70	E189	115	86	50	87	13
3-β-Coprostanol (µg/kg)	Sterol or stanol, carnivore fecal indicator	--	67	3	<540	E370	313	300	67	3	<630	E360	345	360	<1,360	E530	E248
3-Methyl-1 <i>H</i> -indole (Skatole) (µg/kg)	Flavoring or fragrance, stench in feces, coal tar	--	0	3	5	12	10	12	0	3	20	E563	206	34	68	83	36
4- <i>tert</i> -Octylphenol diethoxylate (µg/kg)	Nonionic detergent metabolite	--	100	3	<54	<114	--	--	67	3	<63	E25	38	32	<136	<138	<76
9,10-Anthraquinone (µg/kg)	Pesticide, manufacturing dye and textiles, seed treatment, bird repellent	--	33	3	<94	E27	29	27	67	3	<112	E33	49	56	27	E31	<76
Acetophenone (µg/kg)	Fragrance or flavor	--	100	3	<160	<340	--	--	100	3	<190	<340	--	--	<410	<410	E39
Benzo[ <i>a</i> ]pyrene (µg/kg)	PAH or combustion by-product, used in cancer research	1,450	0	3	7	E26	15	11	33	3	<63	E15	19	15	12	17	<76
β-Sitosterol (µg/kg)	Plant sterol	--	0	3	E5,730	E7,200	6,417	6,320	0	3	E5,050	E7,420	5,873	5,150	E2,760	E3,200	E5,210
β-Stigmastanol (µg/kg)	Plant sterol	--	0	3	E760	E990	890	920	0	3	E620	E900	743	710	<1,360	E850	E938
Cholesterol (µg/kg)	Fecal indicator, plant sterol	--	0	3	E2,420	E4,580	3,417	3,250	0	3	E3,790	E6,210	5,140	5,420	E2,840	E4,110	E2,840
<i>d</i> -Limonene (µg/kg)	Fungicide, antimicrobial, antiviral, fragrance in aerosols	--	100	3	<54	<114	--	--	67	3	<63	E30	39	32	<136	<138	E30
Fluoranthene (µg/kg)	Component of coal tar and asphalt	2,230	0	3	27	79	48	38	0	3	26	E48	34	27	33	43	20
Indole (µg/kg)	Pesticide inert ingredient, fragrance in coffee	--	0	3	E140	260	183	150	0	3	240	E480	353	340	850	810	350
Isophorone (µg/kg)	Solvent for lacquer, plastic, oil, silicon, resin	--	100	3	<54	<114	--	--	67	3	<72	E3	32	36	<136	<138	<76
Phenanthrene (µg/kg)	Manufacturing explosives, component of tar, diesel fuel, or crude oil, combustion product	1,170	33	3	<54	E41	28	27	33	3	<63	E27	24	27	20	24	<76
Phenol (µg/kg)	Disinfectant, manufacturing of several products	--	67	3	<54	E80	55	57	33	3	<263	E459	228	132	<415	<451	<190
Pyrene (µg/kg)	Component of coal tar and asphalt	1,520	0	3	21	64	39	33	0	3	20	E40	27	21	23	32	14
Tris(2-butoxyethyl) phosphate (µg/kg)	Fire retardant	--	67	3	<180	E30	97	90	100	3	<190	<340	--	--	<410	<410	<226

<sup>1</sup>Compound uses and sources from Zaugg and others (2006), Lee and others (2005), and Wilkison and others (2006).

<sup>2</sup>From MacDonald and others (2000).

**Table 11.** Habitat assessment scores for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), and Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), during August 2011 and September 2014.

[See figure 1 for site locations. Habitat assessment scores of 10–12 indicate optimal conditions, 7–9 indicate suboptimal conditions, 4–6 indicate marginal conditions, and 1–3 indicate poor conditions. pre, March 2011 through April 2013; ASR, aquifer storage and recovery; post, May 2013 through December 2014]

Habitat variable	Pre-ASR		Post-ASR	
	Upstream surface-water site	Downstream surface-water site	Upstream surface-water site	Downstream surface-water site
Channel conditions and characteristics				
Flow status	4	5	5	6
Channel slope and morphological status	8	7	7	8
Sinuosity	6	5	5	8
Mean channel conditions and characteristics score	6	6	6	7
Bank and riparian conditions				
Bank stability	7	9	6	9
Canopy cover	8	7	7	6
Bank/riparian protection	6	8	7	8
Length and extent of buffers	12	12	12	12
Mean buffer width	10	11	11	11
Percentage of altered banks	12	12	12	12
Mean bank and riparian conditions score	9	10	9	10
Aquatic habitat availability				
Substrate fouling	6	5	5	6
Pool variability	5	5	5	5
Pool substrate composition	8	9	7	8
Sediment deposition	5	6	5	5
Diversity of epifaunal substrate and cover types	8	7	8	6
Mean aquatic habitat availability score	6	6	6	6
Mean total habitat score	8	8	7	8

discharging, although this could be related to higher post-ASR streamflow conditions. Substrate fouling is a measure of periphyton growth and accumulation of fine materials covering substrates. Excessive amounts of accumulation can clog interstitial substrate spaces and lead to a decline in living space for macroinvertebrates and fish. Sediment deposition is a measure of the amount of accumulated sediment as a result of deposition. Large amounts of sediment deposition may indicate a continually changing environment that is unsuitable for organisms. Pool variability scores were indicative of marginal conditions for both surface-water sites during the study period and pool substrate composition scores were indicative of suboptimal conditions for both surface-water sites during the study period (table 11). Diversity of epifaunal substrate and cover types scores were indicative of suboptimal conditions at the upstream surface-water site for the study period and the downstream surface-water site pre-ASR; the post-ASR diversity of epifaunal substrate and cover types score for the downstream surface-water site was indicative of

marginal conditions (table 11). Diversity of epifaunal substrate and cover is a measure of the number and variety of instream habitat and cover types. A wide variety and abundance of good habitat increases overall biotic diversity within the stream reach.

## Macroinvertebrates

Macroinvertebrate community-level responses are commonly used for evaluation of biological conditions, diagnosis of stream impairment sources and causes, restoration activity success measurement, and development of biological criteria in support of water-quality compliance and regulation (Rosenberg and Resh, 1993; Southerland and Stribling, 1995). Macroinvertebrate communities have also been widely used as an indicator of stream quality in agricultural drainage basins (Allan, 2004). Macroinvertebrate community assessments include evaluation of changes in abundance or dominance of ecologically important taxa and sensitive taxa

that have been eliminated or decreased as a result of stream condition changes. More specifically, abundance and diversity values can be used to calculate specific metrics for ecologically important and sensitive taxa that respond to changes in stream condition. These metrics provide diagnostic information related to stressor responses and effects on community function.

**Macroinvertebrate Community Composition**

A total of 229 macroinvertebrate taxa were identified from samples collected at all sites during 2011 through 2014: 193 taxa were present at the upstream surface-water site (375350097262800, fig. 1) and 192 taxa were present at the downstream surface-water site (07144100, fig. 1) (appendix table 1–8). Overall, 193 taxa of insect macroinvertebrates and 36 taxa of non-insect macroinvertebrates were included in the samples. Both surface-water sites contained 41 EPT taxa and 44 midge (Diptera: Chironomidae) taxa. Water boatmen (Hemiptera: Corixidae), including the genus *Trichocorixa* sp., the caddisfly *Nectopsyche candida* (Trichoptera: Leptoceridae), and midges (including *Polypedilum* sp., *Glyptotendipes* sp., *Chironomus* sp., and *Cricotopus/Orthocladius* sp.) were among the most dominant taxa collected at the two Little Arkansas River surface-water sites (table 12). Across sampling dates, there were minor seasonal differences in total richness at the sites, with 151 taxa in April/May, 145 taxa in June/July, and 172 taxa in August/September (appendix tables 1–8 and 1–9).

Macroinvertebrate community composition, including functional feeding, behavioral, and tolerance groups, generally was similar among sites during the study period. Among functional feeding groups, predators and collector-gatherers were the two most abundant groups, collectively made up over 50 percent of the macroinvertebrates at both surface-water sites for pre- and post-ASR (fig. 8). Among macroinvertebrate behavioral groups, most organisms were swimmers and sprawlers, which collectively made up more than 50 percent of the organisms pre-ASR and more than 75 percent post-ASR (fig. 9). Intolerant macroinvertebrates had the lowest

abundance among tolerance groups at both surface-water sites during the duration of the study (fig. 10).

**Macroinvertebrate Metrics**

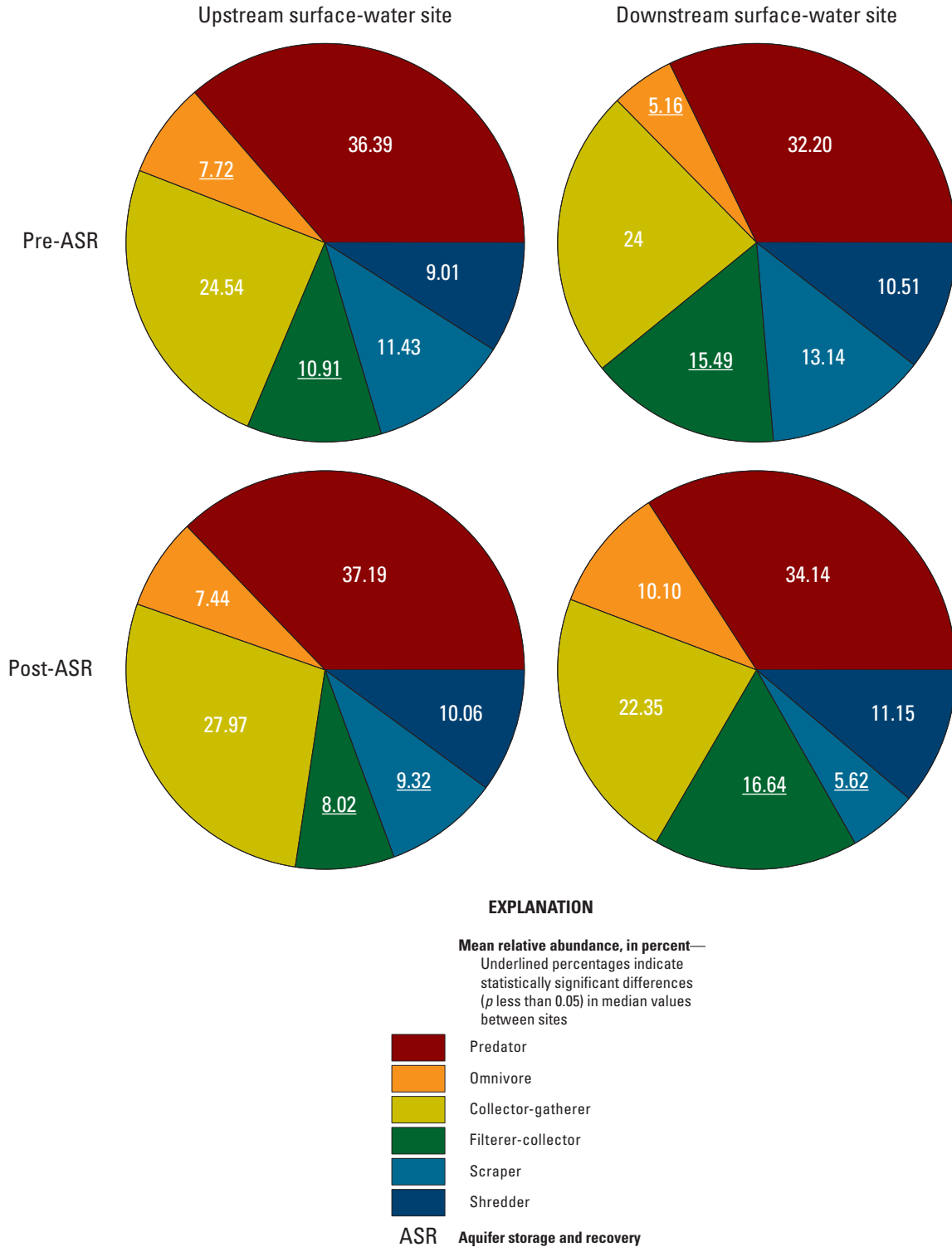
Overall, there were 16 indicator metrics for which significant differences existed between the upstream and downstream surface-water sites (375350097262800 and 07144100 [fig. 1], respectively) (table 13; figs. 8–10). Four relative abundance metrics, three taxa richness metrics, four functional feeding and behavioral group metrics, four tolerance metrics, and one other metric were significant (table 13). There were 14 significantly different macroinvertebrate metrics between the upstream and downstream surface-water sites pre-ASR and 6 significantly different metrics between the two surface-water sites post-ASR, indicating that the two sites are more similar post-ASR, which is likely related to higher post-ASR streamflow conditions. No diversity and evenness indices were significantly different between the upstream and downstream surface-water sites during the study period (table 13). Four indicator metrics were significantly different between upstream and downstream surface-water sites for both pre-ASR and post-ASR time periods and these included percent filterer-collectors (upstream<downstream) and three of the Kansas Biotic Indices (AP, HM, and SA, all upstream>downstream; table 13).

As compared to macroinvertebrates at the upstream surface-water site, the downstream surface-water site pre-ASR had a significantly greater relative abundance of Tanytarsini (a tribe of midges belonging to Chironomidae), Bivalvia, filterer-collectors, and climbers and greater richness of Trichoptera and Tanytarsini (table 13). In contrast, the upstream surface-water site pre-ASR had significantly greater relative abundance of Gastropoda and predators (table 13). As compared to the upstream surface-water site, the downstream surface-water site post-ASR had a significantly greater mean relative abundance of caddisflies (Trichoptera) that was nearly twice that of the upstream surface-water site; however, the downstream surface-water site had significantly greater caddisfly richness than the upstream surface-water site pre-ASR (table 13).

**Table 12.** List of five most dominant macroinvertebrate taxa for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), and Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), April 2011 through April 2013 and September 2013 through August 2014.

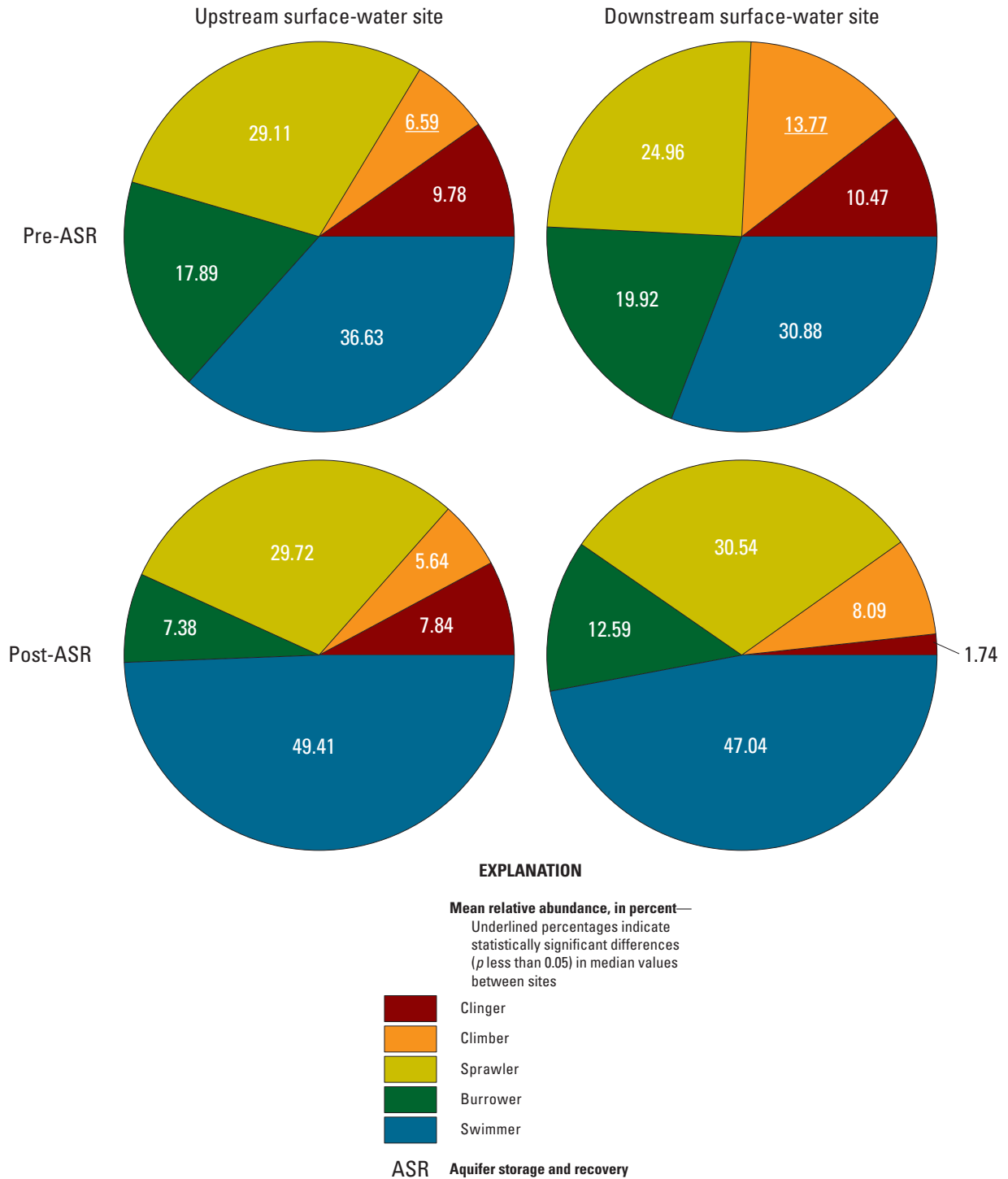
[See figure 1 for site locations. Values in parentheses are percentage of total abundance. pre, March 2011 through April 2013; ASR, aquifer storage and recovery; post, May 2013 through December 2014]

Pre-ASR		Post-ASR	
Upstream surface-water site	Downstream surface-water site	Upstream surface-water site	Downstream surface-water site
<i>Physa</i> sp. (5.1)	<i>Simulium</i> sp. (4.2)	Corixidae (8.3)	<i>Polypedilum</i> sp. (7.1)
Corixidae (4.9)	<i>Cricotopus/Orthocladius</i> sp. (4.2)	<i>Polypedilum</i> sp. (8.2)	<i>Nectopsyche candida</i> (6.7)
<i>Nectopsyche candida</i> (4.6)	<i>Trichochrixa</i> sp. (3.9)	<i>Chironomus</i> sp. (6.8)	<i>Glyptotendipes</i> sp. (6.4)
<i>Polypedilum</i> sp. (4.1)	<i>Paracloeodes minutus</i> (3.9)	<i>Argia</i> sp. (5.3)	<i>Argia</i> sp. (5.3)
<i>Trichocorixa</i> sp. (3.7)	<i>Polypedilum</i> sp. (3.8)	<i>Nectopsyche candida</i> (4.9)	Corixidae (4.6)

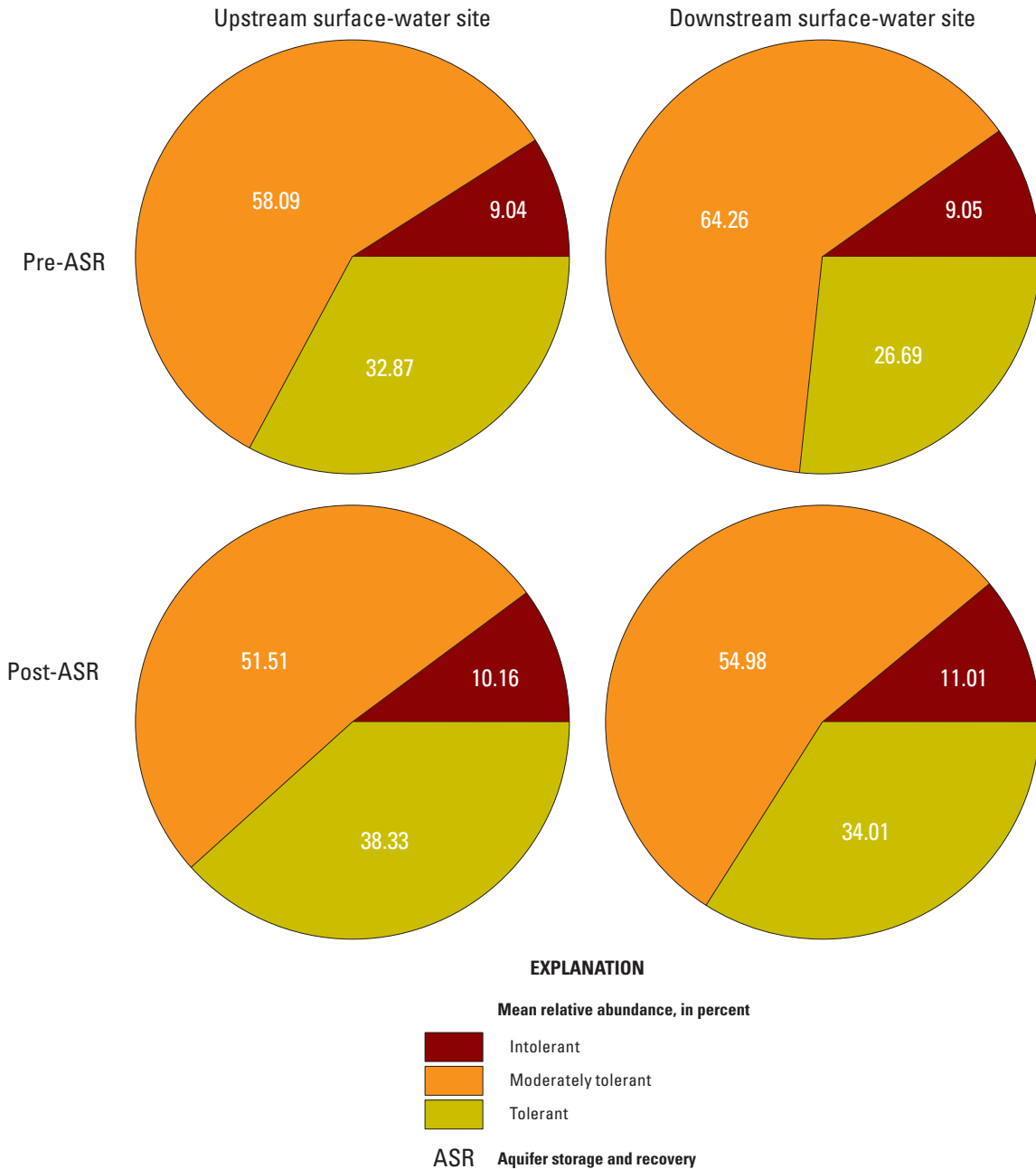


**Figure 8.** Mean relative abundances of macroinvertebrate functional feeding groups for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), and the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), May 2011 through August 2014.





**Figure 9.** Mean relative abundances of macroinvertebrate behavioral groups for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), and the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), May 2011 through August 2014.



**Figure 10.** Mean relative abundances of macroinvertebrate tolerance groups for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), and the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), May 2011 through August 2014.

**Table 13.** Mean selected macroinvertebrate metric values and Kansas Department of Health and Environment aquatic-life-support status for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), and Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), April 2011 through April 2013 and September 2013 through August 2014.

[See figure 1 for site locations. Medians in **bold** indicate statistically significant differences ( $p$ -value less than 0.05) between the upstream and downstream surface-water sites. Values in parentheses are plus or minus 1 standard deviation. pre, March 2011 through April 2013; ASR, aquifer storage and recovery; post, May 2013 through December 2014; EPT, Ephemeroptera, Plecoptera, and Trichoptera; NO, tolerances for nutrients and oxygen-demanding substances; AP, tolerances for agricultural pesticides; HM, tolerances for heavy metals; POC, tolerances for persistent organic compounds; SA, tolerances for salinity; SSS, tolerances for suspended solids and sediments; KBI, Kansas Biotic Index; <, less than]

Metric (unit of measure)	Pre-ASR		Post-ASR	
	Upstream surface-water site	Downstream surface-water site	Upstream surface-water site	Downstream surface-water site
Relative abundance metrics				
Most abundant taxon (percent)	11.90 (3.77)	12.09 (4.85)	13.78 (4.19)	12.77 (3.22)
Five most abundant taxa (percent)	38.27 (5.65)	39.07 (6.95)	41.00 (5.29)	43.54 (8.23)
EPT (percent) <sup>1</sup>	18.21 (9.53)	21.92 (10.31)	23.92 (7.62)	29.68 (13.7)
Ephemeroptera (percent)	10.76 (6.28)	13.40 (5.90)	15.92 (7.05)	15.19 (10.38)
Trichoptera (percent)	7.11 (5.25)	8.32 (5.90)	<b>8.00</b> (5.03)	<b>14.48</b> (10.30)
Odonata (percent)	7.57 (4.95)	10.11 (7.71)	10.36 (3.90)	10.22 (4.17)
Coleoptera (percent)	10.27 (5.73)	12.46 (5.66)	5.46 (2.19)	5.87 (1.64)
Diptera (percent)	33.95 (9.99)	31.89 (15.82)	29.64 (6.51)	28.80 (8.81)
Chironomidae (percent)	28.48 (7.42)	27.74 (11.73)	28.48 (6.53)	27.41 (8.50)
Orthocladinae Chironomidae (percent)	4.58 (7.90)	5.72 (9.66)	0.85 (1.03)	1.78 (2.34)
Tanytarsini Chironomidae (percent)	<b>1.29</b> (1.47)	<b>2.79</b> (2.07)	1.28 (2.08)	2.20 (3.90)
Non-Chironomidae Diptera (percent)	5.46 (4.74)	4.15 (5.42)	1.16 (0.56)	1.38 (0.67)
Noninsects (percent)	12.96 (7.28)	11.55 (5.35)	12.86 (8.30)	12.05 (3.67)
Non-Chironomidae Diptera and noninsects (percent)	18.42 (8.02)	15.70 (4.32)	14.02 (8.80)	13.43 (4.21)
Mollusca and crustacea (percent)	9.74 (6.02)	8.99 (5.85)	9.66 (6.30)	9.54 (3.31)
Gastropoda (percent)	<b>6.00</b> (3.96)	<b>3.92</b> (2.78)	3.53 (3.14)	3.22 (0.84)
Bivalvia (percent)	<b>2.36</b> (1.87)	<b>3.90</b> (4.07)	1.15 (1.25)	0.88 (0.97)
Oligochaeta (percent)	2.78 (2.37)	1.43 (1.64)	1.83 (2.68)	0.59 (1.27)
Taxa richness metrics				
Taxa richness	44.38 (7.51)	46.06 (7.84)	41.57 (6.70)	40.14 (3.67)
EPT richness <sup>1</sup>	6.88 (3.50)	7.88 (3.81)	9.14 (3.08)	8.86 (4.14)
Ephemeroptera richness	4.50 (2.56)	4.94 (2.67)	6.86 (2.48)	6.14 (2.79)
Trichoptera richness	<b>2.06</b> (1.00)	<b>2.69</b> (1.54)	2.29 (1.11)	2.71 (1.38)
Odonata richness	3.50 (1.21)	4.25 (1.98)	3.86 (1.07)	3.14 (1.07)
Coleoptera richness	7.38 (2.94)	8.31 (2.87)	4.29 (1.38)	4.14 (1.07)
Diptera richness	14.50 (3.67)	14.69 (5.22)	11.57 (3.55)	11.43 (1.40)
Chironomidae richness	12.06 (3.64)	13.50 (4.76)	10.29 (3.15)	10.00 (0.82)
Orthocladinae Chironomidae richness	0.94 (1.18)	1.44 (1.36)	0.86 (0.90)	1.29 (0.95)
Tanytarsini Chironomidae richness	<b>0.81</b> (0.66)	<b>1.69</b> (0.95)	0.71 (0.95)	1.14 (1.21)
Non-Chironomidae Diptera richness	<b>2.44</b> (1.63)	<b>1.19</b> (0.91)	1.29 (0.49)	1.43 (0.79)
Noninsect richness	5.25 (2.32)	5.38 (2.42)	6.57 (3.21)	6.29 (1.25)
Non-Chironomidae Diptera and noninsect richness	7.69 (3.42)	6.56 (2.76)	7.86 (3.63)	7.71 (1.38)
Mollusca and crustacea richness	3.19 (1.42)	3.31 (1.89)	4.43 (1.62)	3.86 (1.35)

**Table 13.** Mean selected macroinvertebrate metric values and Kansas Department of Health and Environment aquatic-life-support status for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), and Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), April 2011 through April 2013 and September 2013 through August 2014.—Continued

[See figure 1 for site locations. Medians in **bold** indicate statistically significant differences ( $p$ -value less than 0.05) between the upstream and downstream surface-water sites. Values in parentheses are plus or minus 1 standard deviation. pre, March 2011 through April 2013; ASR, aquifer storage and recovery; post, May 2013 through December 2014; EPT, Ephemeroptera, Plecoptera, and Trichoptera; NO, tolerances for nutrients and oxygen-demanding substances; AP, tolerances for agricultural pesticides; HM, tolerances for heavy metals; POC, tolerances for persistent organic compounds; SA, tolerances for salinity; SSS, tolerances for suspended solids and sediments; KBI, Kansas Biotic Index; <, less than]

Metric (unit of measure)	Pre-ASR		Post-ASR	
	Upstream surface-water site	Downstream surface-water site	Upstream surface-water site	Downstream surface-water site
Taxa richness metrics—Continued				
Gastropoda richness	1.38 (0.81)	1.00 (0.63)	1.43 (0.53)	1.43 (0.79)
Bivalvia richness	1.25 (0.93)	1.44 (0.73)	0.86 (0.69)	0.57 (0.53)
Oligochaeta richness	1.44 (1.03)	0.94 (0.85)	0.86 (0.69)	0.43 (0.79)
Diversity and evenness indices				
Margalef's diversity index	19.86 (2.73)	20.18 (2.67)	18.80 (2.76)	18.36 (1.80)
Manhinick's diversity index	3.60 (0.32)	3.53 (0.32)	3.47 (0.42)	3.45 (0.40)
Simpson's diversity index	0.96 (0.01)	0.95 (0.01)	0.95 (0.01)	0.95 (0.02)
Shannon's diversity index	1.46 (0.07)	1.46 (0.08)	1.43 (0.06)	1.40 (0.08)
Brillouin's diversity index	1.30 (0.07)	1.31 (0.08)	1.27 (0.05)	1.24 (0.06)
Simpson's evenness index	0.97 (0.01)	0.97 (0.01)	0.97 (0.01)	0.97 (0.01)
Brillouin's evenness index	0.90 (0.02)	0.89 (0.03)	0.89 (0.03)	0.88 (0.04)
Shannon's evenness index	0.89 (0.02)	0.88 (0.03)	0.89 (0.02)	0.88 (0.04)
Functional feeding and behavioral groups				
Predators (percent)	<b>36.39</b> (10.56)	<b>32.20</b> (15.13)	37.19 (6.10)	34.14 (10.24)
Omnivores (percent)	7.72 (5.43)	5.16 (4.87)	7.44 (5.23)	10.10 (4.69)
Collector-gatherers (percent)	24.54 (10.81)	23.50 (10.31)	27.97 (4.17)	22.35 (8.00)
Filterer-collectors (percent)	<b>10.91</b> (5.31)	<b>15.49</b> (6.46)	<b>8.02</b> (2.47)	<b>16.64</b> (10.53)
Scrapers (percent)	11.43 (5.91)	13.14 (5.24)	<b>9.32</b> (4.34)	<b>5.62</b> (1.62)
Shredders (percent)	9.01 (4.43)	10.51 (7.97)	10.06 (3.99)	11.15 (1.79)
Clingers (percent)	9.78 (11.42)	10.47 (11.53)	7.84 (7.46)	1.74 (1.65)
Climbers (percent)	<b>6.59</b> (6.34)	<b>13.77</b> (10.74)	5.64 (4.93)	8.09 (6.37)
Sprawlers (percent)	29.11 (12.23)	24.96 (16.87)	29.72 (14.44)	30.54 (14.31)
Burrowers (percent)	17.89 (9.43)	19.92 (11.81)	7.38 (10.09)	12.59 (15.01)
Swimmers (percent)	36.63 (14.54)	30.88 (20.36)	49.41 (19.98)	47.04 (14.08)
Tolerance metrics				
Intolerant (percent)	9.04 (3.97)	9.05 (5.98)	10.16 (5.56)	11.01 (9.43)
Moderately tolerant (percent)	58.09 (10.05)	64.26 (11.70)	51.51 (7.29)	54.98 (11.04)
Tolerant (percent)	32.87 (11.30)	26.69 (14.20)	38.33 (9.74)	34.01 (13.88)
Kansas Biotic Index (NO) <sup>1</sup>	3.07 (0.14)	3.00 (0.14)	3.09 (0.17)	3.08 (0.16)
Kansas Biotic Index (AP)	<b>3.09</b> (0.23)	<b>2.95</b> (0.22)	<b>3.01</b> (0.24)	<b>2.84</b> (0.33)
Kansas Biotic Index (HM)	<b>2.29</b> (0.25)	<b>2.17</b> (0.20)	<b>2.39</b> (0.19)	<b>2.22</b> (0.14)
Kansas Biotic Index (POC)	2.59 (0.16)	2.53 (0.21)	2.43 (0.17)	2.31 (0.35)
Kansas Biotic Index (SA)	<b>3.19</b> (0.14)	<b>3.12</b> (0.11)	<b>3.31</b> (0.11)	<b>3.22</b> (0.15)
Kansas Biotic Index (SSS)	3.28 (0.12)	3.21 (0.14)	3.29 (0.20)	3.19 (0.22)

**Table 13.** Mean selected macroinvertebrate metric values and Kansas Department of Health and Environment aquatic-life-support status for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), and Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), April 2011 through April 2013 and September 2013 through August 2014.—Continued

[See figure 1 for site locations. Medians in **bold** indicate statistically significant differences (*p*-value less than 0.05) between the upstream and downstream surface-water sites. Values in parentheses are plus or minus 1 standard deviation. pre, March 2011 through April 2013; ASR, aquifer storage and recovery; post, May 2013 through December 2014; EPT, Ephemeroptera, Plecoptera, and Trichoptera; NO, tolerances for nutrients and oxygen-demanding substances; AP, tolerances for agricultural pesticides; HM, tolerances for heavy metals; POC, tolerances for persistent organic compounds; SA, tolerances for salinity; SSS, tolerances for suspended solids and sediments; KBI, Kansas Biotic Index; <, less than]

Metric (unit of measure)	Pre-ASR		Post-ASR	
	Upstream surface-water site	Downstream surface-water site	Upstream surface-water site	Downstream surface-water site
Tolerance metrics—Continued				
Intolerant taxa (percent) (KBI-NO <3.0)	18.05 (5.83)	19.93 (3.87)	16.12 (7.14)	12.49 (4.73)
Macroinvertebrate Biotic Index <sup>1</sup>	<b>5.90</b> (0.76)	<b>5.37</b> (0.37)	5.73 (0.82)	5.44 (0.50)
Other metrics				
EPT/Chironomidae ratio	0.69 (0.45)	0.96 (0.55)	0.87 (0.34)	1.27 (0.77)
Orthocladinae Chironomidae/Chironomidae ratio	0.13 (0.22)	0.14 (0.21)	0.03 (0.04)	0.06 (0.06)
Tanytarsini Chironomidae/Chironomidae ratio	0.05 (0.07)	0.11 (0.08)	0.04 (0.06)	0.08 (0.12)
Scraper/filtering collector ratio	1.31 (0.99)	1.12 (0.89)	1.26 (0.68)	0.80 (1.20)
EPT richness/Chironomidae richness ratio	0.57 (0.24)	0.57 (0.19)	0.96 (0.40)	0.89 (0.41)
Orthocladinae Chironomidae richness/Chironomidae richness ratio	0.07 (0.09)	0.09 (0.09)	0.07 (0.07)	0.13 (0.10)
Tanytarsini Chironomidae richness/Chironomidae richness ratio	<b>0.07</b> (0.06)	<b>0.13</b> (0.06)	0.06 (0.09)	0.11 (0.12)

<sup>1</sup>Kansas Department of Health and Environment aquatic life-support metrics.

Scrapers were also significantly greater at the upstream surface-water site, but this difference was only observed during the post-ASR time period (table 13). Filterer-collectors were significantly greater at the downstream surface-water site pre- and post-ASR (table 13).

Several macroinvertebrate indicators for which significant differences existed between upstream and downstream surface-water sites suggest an effect of overall greater flow velocities in the study reach downstream of the ASR facility. Even though flow velocities were not measured throughout the reach at either surface-water site and differences in habitat properties between the sites were of small magnitude (scores for pool substrate composition and flow status slightly larger downstream; table 11), there were more run and glide locations and fewer distinct pools within the reach at the downstream surface-water site. This may partially explain the larger abundance and mean richness of Trichoptera, larger mean Tanytarsini Chironomidae richness, and overall larger abundances of filterer-collectors at the downstream surface-water site (table 13, fig. 8). Similarly, the larger abundances of Gastropods (for example, *Physa* sp.) and water boatmen

(Corixidae; table 12) at the upstream site (tables 12, 13) may reflect a greater predominance of distinct pools at that site because these taxa are more commonly associated with pool margins (Merritt and others, 2008; Thorp and Covich, 2010).

Upstream-downstream surface-water site comparisons of macroinvertebrate aquatic-life-support metrics (table 14) did not reveal any significant differences for either pre- or post-ASR time periods, and neither surface-water site was fully-supporting for any of the four metrics (figs. 11A–11D); however, pre-ASR EPT richness was non-supporting at both surface-water sites, and post-ASR EPT richness was partially-supporting at both surface-water sites (fig. 11C). Pre- and post-ASR values were slightly greater at the upstream surface-water site for the Macroinvertebrate Biotic Index and slightly greater at the downstream surface-water site for the percent EPT metric (figs. 11A and 11D; table 13). Overall, using macroinvertebrate aquatic life-support criteria from the Kansas Department of Health and Environment (2008a), both upstream and downstream surface-water sites were classified as partially supporting pre- and post-ASR (fig. 11E).

**Table 14.** Criteria for four macroinvertebrate metrics used in Kansas to evaluate aquatic-life-support status of streams (Kansas Department of Health and Environment, 2008a).

[KDHE, Kansas Department of Health and Environment; MBI, Microinvertebrate Biotic Index; KBI, Kansas Biotic Index; NO, tolerances for nutrients and oxygen-demanding substances; EPT, Ephemeroptera, Plecoptera, and Trichoptera; <, less than; >, greater than]

KDHE aquatic life-support status	KDHE aquatic life-support score	MBI	KBI-NO	EPT richness	EPT (percent)	Mean KDHE aquatic life-support score
Fully supporting	3	<4.51	<2.61	>12	>48	>2.49
Partially supporting	2	4.51–5.39	2.61–2.99	8–12	31–47	1.5–2.49
Nonsupporting	1	>5.39	>2.99	<8	<31	1.0–1.49

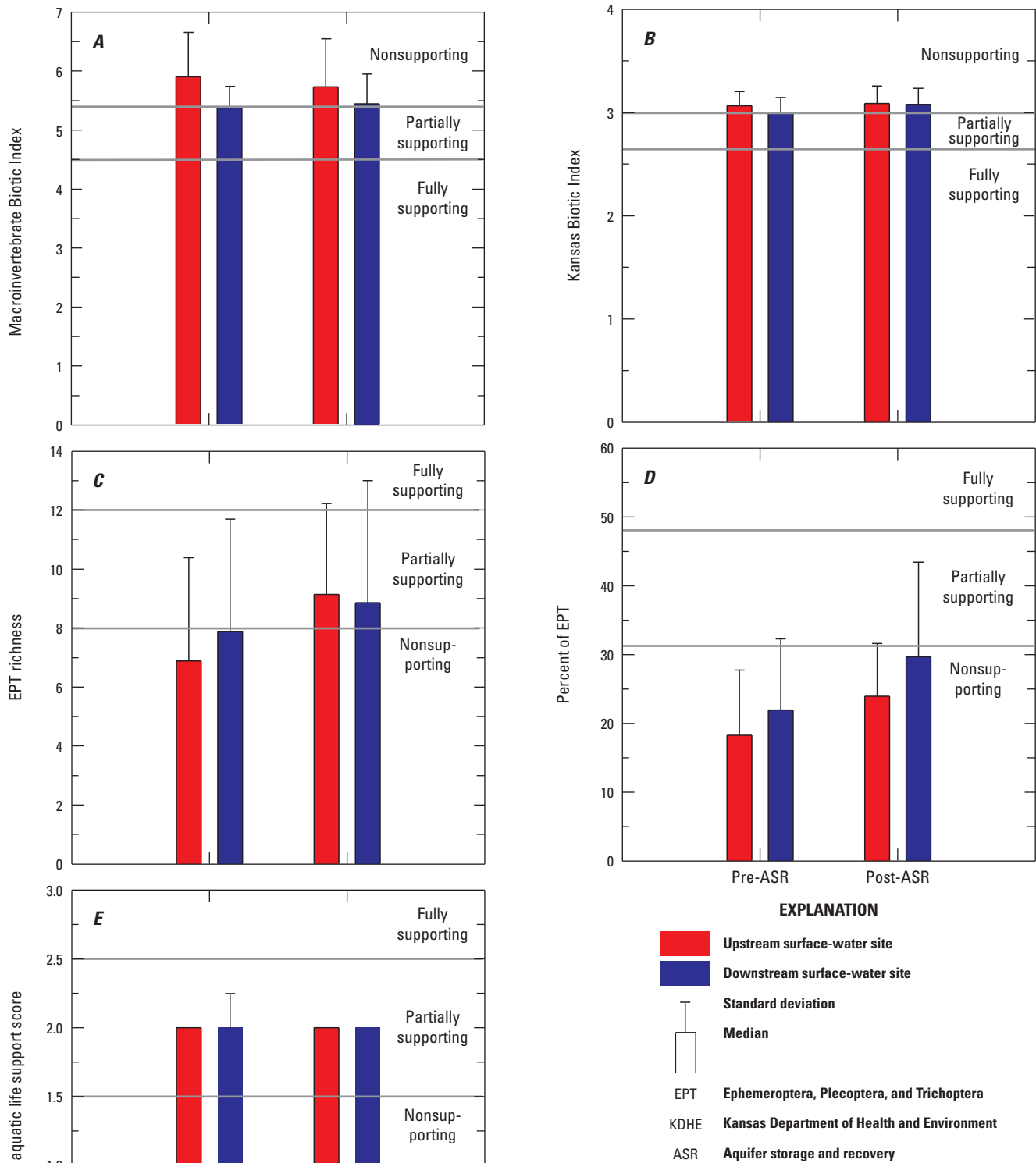
## Fish Community Composition and Metrics

Fish communities can be good indicators of long-term effects and broad habitat conditions because fish can live many years and are mobile (Karr and others, 1986). Fish assemblages include species that comprise a variety of trophic levels and integrate effects of lower trophic levels; therefore, fish community structure is reflective of integrated environmental health (Barbour and others, 1999). Fish metrics calculated with abundance, richness, and diversity data can provide diagnostic information related to ecological condition.

A total of 23 fish taxa were identified from samples collected at all sites during 2011 through 2014 (table 15). Nine taxa belonged to the order Cypriniformes (minnows and carp) and four of the five dominant taxa were shiners (for example, Cyprinidae family) belonging to this order. Nine taxa belonged to the order Perciformes (perch-like fishes) and fish in this order were less common. The red shiner (*Cyprinella lutrensis*) was the dominant species at both surface-water sites (upstream surface-water site 375350097262800 and downstream surface-water site 07144100 [fig. 1]) during the study period, followed by sand shiners (*Notropis stramineus*), western mosquitofish (*Gambusia affinis*), bullhead minnows (*Pimephales vigilax*), and suckermouth minnows (*Phenacobius mirabilis*). Shiners were the most dominant group at both surface-water sites during the entire study period (table 15). The red shiner was the dominant taxon at the upstream surface-water site during the study period (pre-ASR mean=42.38 percent of total abundance; post-ASR mean=80.35 percent of total abundance) and at the downstream surface-water site post-ASR (mean=62.04 percent of total abundance) as well as the second most dominant taxon at the downstream surface-water site pre-ASR (mean=30.86 percent of total abundance; table 15). The sand shiner was the dominant taxon at the downstream surface-water site pre-ASR (mean=33.42 percent of total abundance) as well as the second most dominant taxon at the upstream surface-water site pre-ASR (mean=13.49 percent of total abundance) and at the downstream surface-water site post-ASR (mean=15.18 percent of total abundance; table 15). The bullhead minnow was the second most dominant taxon at the upstream surface-water site post-ASR (mean=5.03 percent of total abundance; table 15).

Pre-ASR mean taxa richness was 14.50 at the upstream surface-water site and 20.00 at the downstream surface-water site and post-ASR mean taxa richness was 16.50 at the upstream surface-water site and 15.00 at the downstream surface-water site (table 16). Fish community trophic status generally was similar among sites during the study period. Omnivores increased and insectivores and piscivores decreased at the upstream and downstream surface-water sites post-ASR. Omnivores were the most dominant feeding group at the upstream site surface-water pre-ASR (mean=58.69 percent of total abundance) and at the upstream and downstream surface-water sites post-ASR (mean=87.42 and 65.16 percent of total abundance, respectively; table 16, fig. 12). Insectivores were dominant at the downstream surface-water site pre-ASR (mean=53.26 percent of total abundance) as well as second most dominant post-ASR (mean=34.06 percent of total abundance). At the upstream surface-water site, insectivores were second most dominant during the study period (pre-ASR mean=38.08 percent of total abundance, post-ASR mean=12.14 percent of total abundance; table 16, fig. 13). Piscivore abundance was minimal (ranged from 0.44 to 5.57 percent of total abundance) at both surface-water sites during the study period (table 16, fig. 12).

Tolerant species increased and intermediately tolerant and intolerant species decreased at both the upstream and downstream surface-water sites post-ASR. Tolerant species made up the greatest percentage of fish communities at the upstream surface-water site pre-ASR (mean=50.72 percent of total abundance; table 16, fig. 13) and at both upstream and downstream surface-water sites post-ASR (mean=85.42 and 65.49 percent of total abundance, respectively; table 16, fig. 13). The downstream surface-water site was dominated by intermediately tolerant species pre-ASR (mean=63.70 percent; table 16, fig. 13). Intermediately tolerant species were second most dominant at the upstream surface-water site pre-ASR (mean=47.83 percent of total abundance) and at the upstream and downstream surface-water sites post-ASR (mean=13.76 and 32.28 percent of total abundance, respectively; table 16, fig. 13). Intolerant species were minimal at both surface-water sites during the study period and means ranged from 0.82 percent of total abundance at the upstream surface-water site post-ASR and 2.69 percent of total abundance at the downstream surface-water site pre-ASR (table 16, fig. 13).



**Figure 11.** Mean macroinvertebrate aquatic life-support metrics for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800) and the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), April 2011 through August 2014. *A*, Macroinvertebrate Biotic Index; *B*, Kansas Biotic Index; *C*, EPT Richness; *D*, Percent of EPT; and *E*, KDHE aquatic life-support score.

**Table 15.** Mean fish community summary statistics for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), and Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), September 2011 and 2012 and September 2013 and August 2014.

[See figure 1 for site locations. Values in parentheses are plus or minus 1 standard deviation. pre, March 2011 through April 2013; ASR, aquifer storage and recovery; post, May 2013 through December 2014]

Species (unit of measure)	Pre-ASR		Post-ASR	
	Upstream surface-water site	Downstream surface-water site	Upstream surface-water site	Downstream surface-water site
Gizzard shad ( <i>Dorosoma cepedianum</i> ) (percent)	0.65 (0.91)	0.57 (0.32)	0.02 (0.03)	0.10 (0.14)
Goldfish ( <i>Carassius auratus</i> ) (percent)	0.08 (0.11)	0.13 (0.06)	0.03 (0.04)	0
Red shiner ( <i>Cyprinella lutrensis</i> ) (percent)	42.38 (17.97)	30.86 (9.18)	80.35 (12.13)	62.04 (13.77)
Common carp ( <i>Cyprinus carpio</i> ) (percent)	1.16 (0.87)	1.15 (0.81)	0.46 (0.07)	2.09 (2.95)
Sand shiner ( <i>Notropis stramineus</i> ) (percent)	13.49 (2.43)	33.42 (9.07)	3.12 (1.88)	15.18 (11.06)
Suckermouth minnow ( <i>Phenacobius mirabilis</i> ) (percent)	8.18 (6.90)	10.18 (6.59)	0.78 (0.61)	1.57 (1.52)
Fathead minnow ( <i>Pimephales promelas</i> ) (percent)	1.91 (0.49)	0.85 (0.50)	0.18 (0.15)	0.33 (0.11)
Bullhead minnow ( <i>Pimephales vigilax</i> ) (percent)	10.56 (8.33)	7.20 (0.79)	5.03 (5.57)	2.88 (3.89)
River carpsucker ( <i>Carpionodes carpio</i> ) (percent)	0.65 (0.91)	0.82 (0.43)	0.32 (0.29)	0.03 (0.05)
Quillback ( <i>Carpionodes cyprinus</i> ) (percent)	0	0.11 (0.09)	0.03 (0.04)	0.03 (0.05)
Black bullhead ( <i>Ameiurus melas</i> ) (percent)	0	0	0.02 (0.03)	0.03 (0.05)
Channel catfish ( <i>Ictalurus punctatus</i> ) (percent)	3.17 (3.05)	4.05 (2.55)	0.37 (0.13)	0.43 (0.44)
Flathead catfish ( <i>Pylodictus olivaris</i> ) (percent)	0.56 (0.80)	0.30 (0.07)	0	0.10 (0.04)
Western mosquitofish ( <i>Gambusia affinis</i> ) (percent)	10.58 (4.48)	3.30 (2.72)	4.86 (0.99)	7.78 (3.05)
Green sunfish ( <i>Lepomis cyanellus</i> ) (percent)	1.98 (0.85)	0.91 (0.55)	2.85 (2.60)	4.18 (0.16)
Orangespotted sunfish ( <i>Lepomis humilis</i> ) (percent)	2.57 (0.01)	3.41 (2.98)	0.40 (0.34)	1.29 (0.09)
Bluegill ( <i>Lepomis macrochius</i> ) (percent)	0.89 (1.25)	0.69 (0.74)	0.30 (0.31)	0.78 (1.10)
Longear sunfish ( <i>Lepomis megalotis</i> ) (percent)	0.70 (0.31)	1.59 (0.06)	0.55 (0.78)	0.95 (1.34)
Largemouth bass ( <i>Micropterus salmoides</i> ) (percent)	0.40 (0.57)	0.08 (0.12)	0.03 (0.04)	0.14 (0.19)
White crappie ( <i>Pomoxis annularis</i> ) (percent)	0	0.15 (0.03)	0	0
Black crappie ( <i>Pomoxis nigromaculatus</i> ) (percent)	0	0.06 (0.09)	0.09 (0.12)	0
Slenderhead darter ( <i>Percina phoxocephala</i> ) (percent)	0.08 (0.11)	0.08 (0.12)	0.20 (0.29)	0.06 (0.09)
Freshwater drum ( <i>Aplodinotus grunniens</i> ) (percent)	0	0.08 (0.12)	0.03 (0.04)	0

Mean percent abundance of the five most abundant species was larger at the upstream surface-water site during the study period and increased at both surface-water sites post-ASR (table 16). Fish community diversity decreased post-ASR at the upstream and downstream surface-water sites. Shannon's diversity index was 1.83 at both sites pre-ASR and decreased to 0.85 at the upstream surface-water site and 1.38 at the downstream surface-water site post-ASR (table 16).

The region-specific Little Arkansas River Basin IBI was developed for fish communities in the Little Arkansas drainage basin by Lydy and others (2000) by regionally modifying an index of biotic integrity that was first used to assess the biotic integrity of Midwestern streams (Karr, 1981; Karr and others, 1986) using reference conditions from the Central Great Plains ecoregion. The Little Arkansas River Basin IBI encompasses taxa richness and composition, tolerance, trophic guild,

abundance, reproductive guild, and individual health and condition (Lydy and others, 2000). The Little Arkansas River Basin IBI was similar among surface-water sites pre-ASR (upstream=46, downstream=47) and post-ASR (upstream=44, downstream=42). The Little Arkansas River Basin IBI integrity class was the same among sites pre- and post-ASR. The pre-ASR Little Arkansas River Basin IBI integrity classes were indicative of fair-to-good conditions and post-ASR decreased to fair conditions at the upstream and downstream surface-water sites (table 16). Although the Little Arkansas River Basin IBI integrity class decreased post-ASR, the decrease could be related to different streamflow conditions post-ASR compared to pre-ASR. These results were within the Little Arkansas River Basin IBI integrity class range for fish assemblages from agricultural streams in the Little Arkansas River drainage basin reported by Eaton and Lydy (2000).



**Table 16.** Mean selected fish community metrics for the Little Arkansas River upstream from the aquifer storage and recovery facility (upstream surface-water site 375350097262800) and the Little Arkansas River (downstream surface-water site 07144100) near Sedgwick, Kansas, during September 2011 and 2012 and September 2013 and August 2014.

[See figure 1 for site locations. Values in parentheses are plus or minus 1 standard deviation. pre, March 2011 through April 2013; ASR, aquifer storage and recovery; post, May 2013 through December 2014]

Metric (unit of measure)	Pre-ASR		Post-ASR	
	Upstream surface-water site	Downstream surface-water site	Upstream surface-water site	Downstream surface-water site
Taxa richness metrics				
Taxa richness	14.50 (4.95)	20.00 (2.83)	16.50 (3.54)	15.00 (4.24)
Trophic status metrics				
Omnivores (percent)	58.69 (6.22)	41.17 (1.50)	87.42 (6.19)	65.16 (12.71)
Insectivores (percent)	38.08 (1.78)	53.26 (0.18)	12.14 (4.73)	34.06 (9.38)
Piscivores (percent)	3.23 (4.44)	5.57 (2.90)	0.44 (0.13)	0.78 (0.40)
Tolerance metrics				
Intolerant (percent)	1.45 (1.07)	2.69 (0.91)	0.82 (0.31)	2.23 (0.09)
Intermediately tolerant (percent)	47.83 (14.49)	63.70 (0.09)	13.76 (7.53)	32.28 (13.92)
Tolerant (percent)	50.72 (15.56)	33.61 (0.82)	85.42 (9.45)	65.49 (16.76)
Little Arkansas River Basin Index of Biotic Integrity <sup>1</sup>	46 (2.83)	47 (4.24)	44 (0.00)	42 (2.83)
Little Arkansas River Basin Index of Biotic Integrity class <sup>1</sup>	Fair-to-good	Fair-to-good	Fair	Fair
Abundance and diversity metrics				
Five most abundant species (percent)	87.18 (9.21)	84.77 (2.46)	94.97 (3.06)	89.39 (4.89)
Shannon’s diversity index	1.83 (0.50)	1.83 (0.17)	0.85 (0.45)	1.38 (0.46)

<sup>1</sup>Index of Biotic Integrity scores were calculated as described in Lydy and others (2000).

## Groundwater Environmental Conditions

Baseline and postoperational groundwater conditions were assessed with continuous and discrete groundwater-quality data and by modeling the geochemical equilibrium state of the aquifer with respect to select minerals.

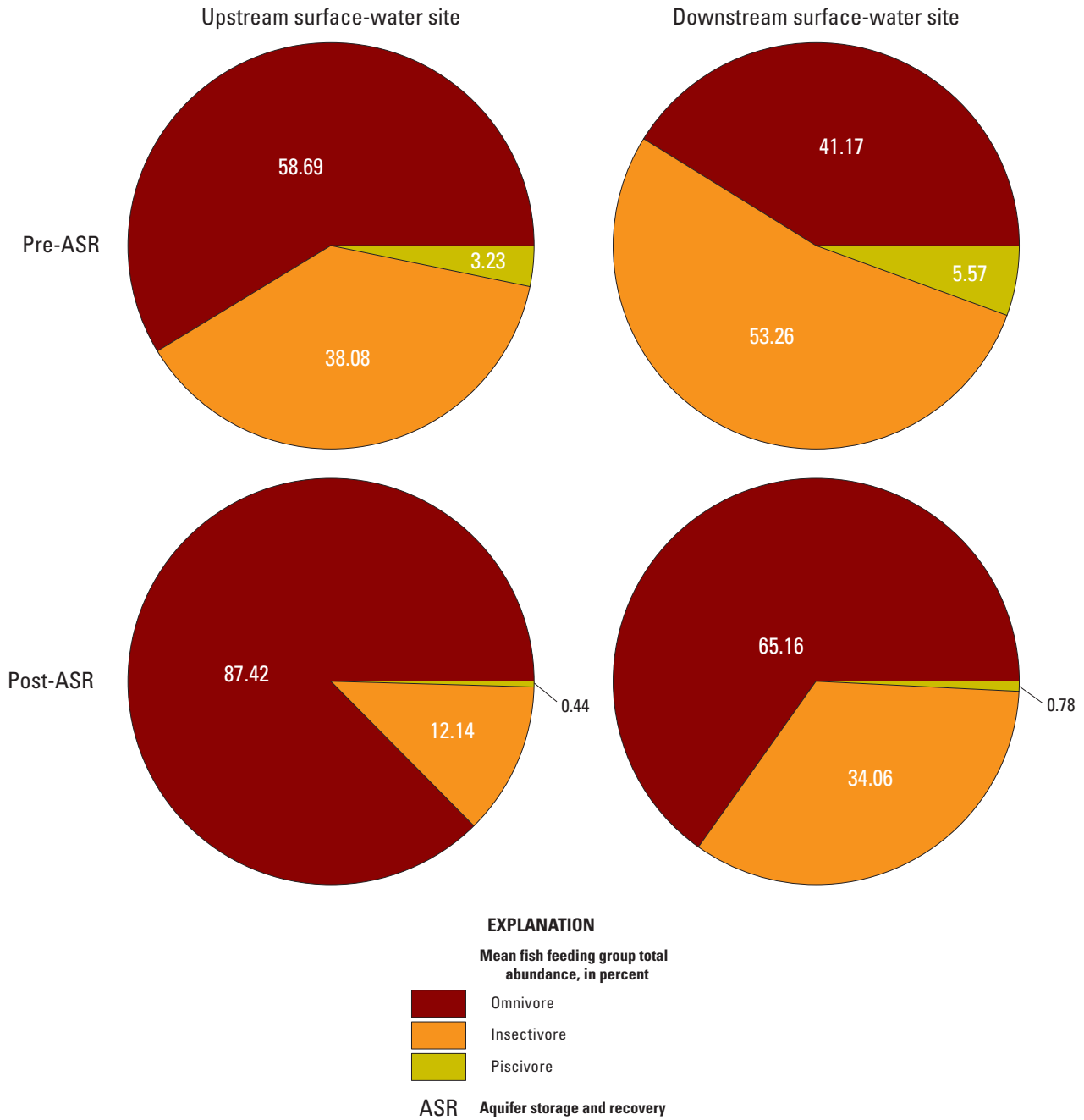
## Groundwater Quality

Continuous and discrete water-quality data collected in four wells near the surface recharge basin near Sedgwick, Kansas (fig. 1) was used to describe conditions before (January 2011 to April 2013), during (May to September 2013 and May to July 2014), and after (October 2013 to April 2014 and August to December 2014) recharge periods. Continuously collected groundwater data included specific conductance, pH, water temperature, and dissolved oxygen. Discretely collected groundwater data included solids and primary ions, nutrients, indicator bacteria, trace elements, pesticides, chlorinated and brominated organic compounds, and radioactive chemistry. The total amount of water recharged at the Sedgwick basin was 356 million gallons during 2013 and 2014.

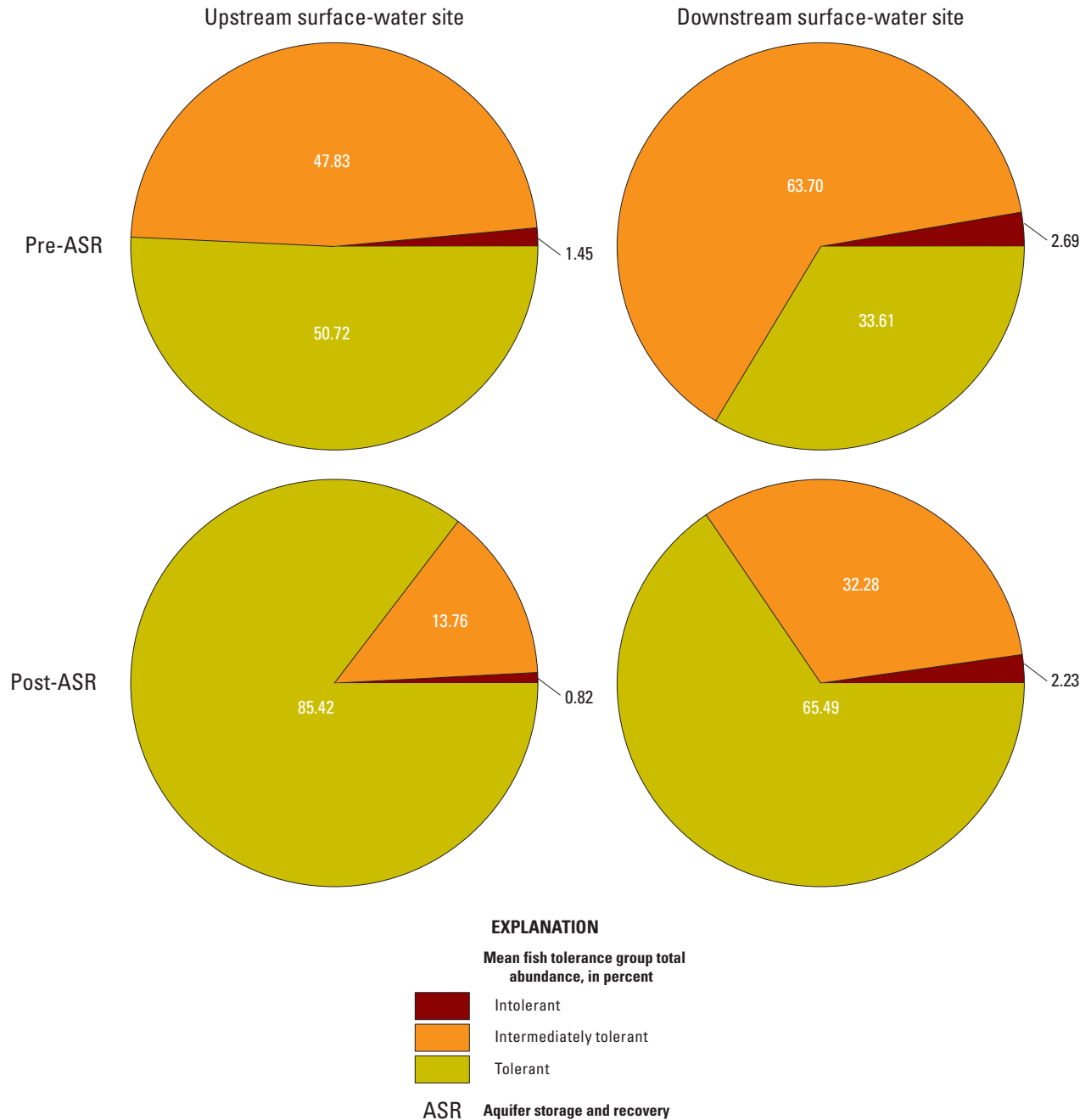
## Continuous Groundwater Quality

Summary statistics of daily water quality (as daily means for dissolved oxygen, specific conductance, and water temperature; median for pH) are listed below. Additionally, water level was monitored October 10, 2012 through 2014, and aquifer withdrawal periods were determined by response in water level to account for multiple pumping sources (table 17, fig. 14A). During 2011 through 2012, the pre-artificial recharge shallow groundwater altitudes varied from about 1,344 to 1,358 ft in a few discrete measurements that were made associated with sample collection. Shallow and deep groundwater levels were within about 1 ft with the shallow water levels higher indicating a downward movement of water. In the post-recharge period during 2013 through 2014, water levels varied from altitudes of about 1,343 to 1,363 ft in response to a nearby pumping well and in response to recharge activities that caused increased elevation (fig. 14A).

Although stream and deep groundwater dissolved oxygen were similar before and after recharge periods, shallow groundwater dissolved oxygen during recharge were more variable in response to artificial and natural recharge. Dissolved oxygen in the MW-7 shallow groundwater well (site 375327097285401) recovered to values similar to before



**Figure 12.** Mean fish feeding group percentage of total abundance for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), and the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), September 2011 and 2012 and September 2013 and August 2014.



**Figure 13.** Mean fish tolerance group percentage of total abundance for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), and the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), September 2011 and 2012 and September 2013 and August 2014.

**Table 17.** Physicochemical properties for sites near the recharge basin near Sedgwick, Kansas before (January 2011 to April 2013), during (May to September 2013 and May to July 2014), and after (October 2013 to April 2014 and August to December 2014) artificial recharge and at the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), summary of daily statistics from continuously measured data.

[See figure 1 for site locations. Continuous real-time water-quality data are available on the U.S. Geological Survey National Real-Time Water Quality Web site at <http://nrtwq.usgs.gov>, mg/L, milligram per liter; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; <math>\leq</math>, less than]

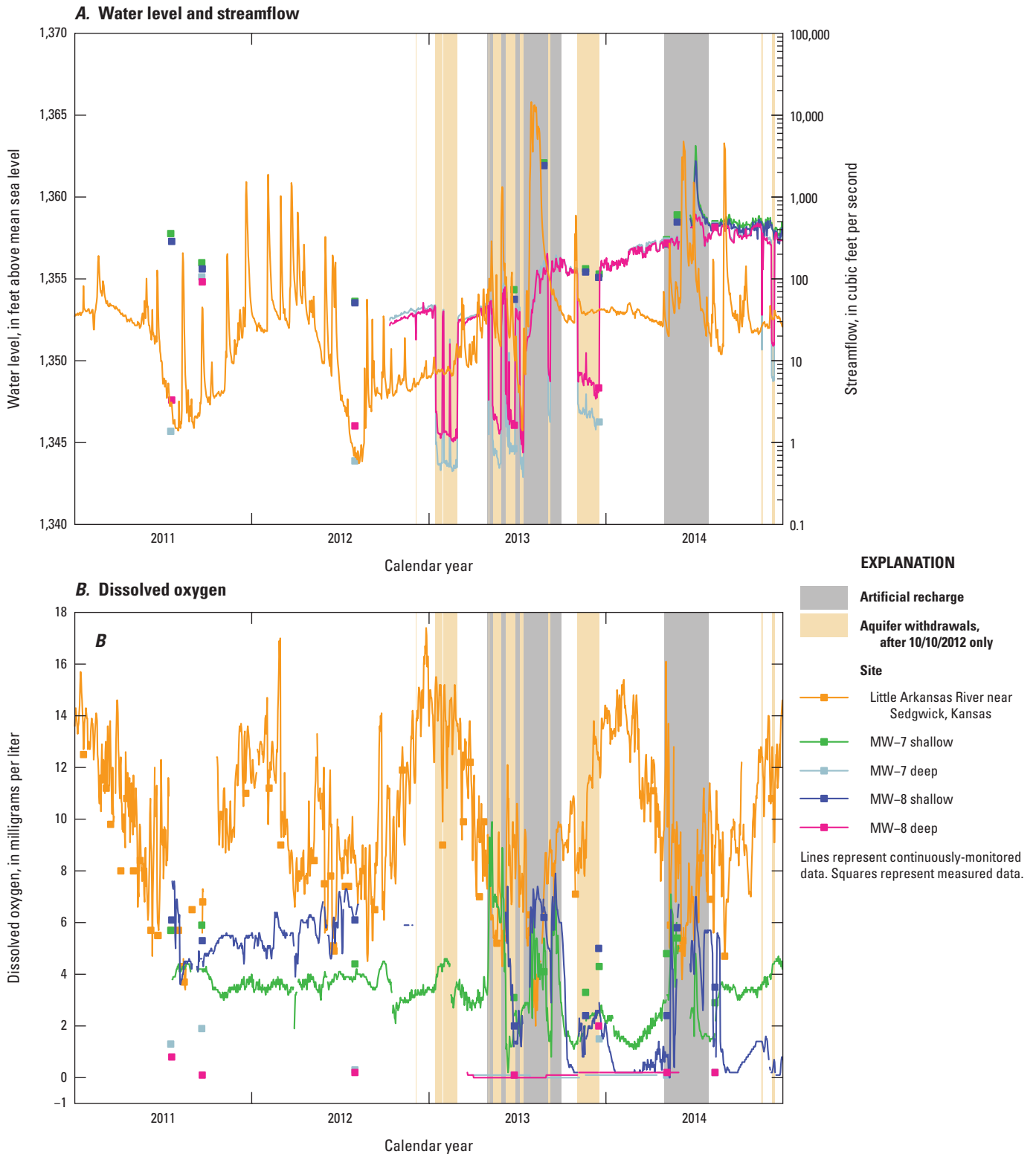
Description	Dissolved oxygen (mg/L)			pH (standard units)			Specific conductance (µS/cm at 25 °C)			Water temperature (°C)		
	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum
Overall	2.0	10.0	17.4	6.6	8.0	8.9	98	799	1,620	0.1	14.6	30.5
During recharge	2.0	7.7	16.1	6.6	7.9	8.6	98	638	1,520	11.6	24.5	30.3
Overall	0.2	3.4	9.9	6.6	6.8	7.5	165	663	902	14.3	16.1	28.3
Before recharge	1.9	3.6	4.6	6.7	6.8	6.9	532	701	767	14.5	15.6	16.2
During recharge	0.2	3.5	9.9	6.7	6.9	7.5	165	470	902	14.3	22.6	28.3
After recharge	1.1	2.4	4.7	6.6	6.8	7.2	333	440	842	19.8	23.2	26.5
During and after recharge	0.2	2.6	9.9	6.6	6.9	7.5	165	444	902	14.3	22.9	28.3
Overall	<0.1	4.6	7.9	6.0	6.7	7.6	139	512	924	14.3	21.9	27.6
Before recharge	3.6	5.5	7.6	6.0	6.5	6.7	380	504	569	14.3	15.6	16.6
During recharge	<0.1	5.2	7.9	6.8	7.0	7.6	139	465	914	19.3	23.0	27.6
After recharge	0.1	0.7	6.0	6.6	6.9	7.4	408	832	924	21.7	22.7	24.1
During and after recharge	<0.1	1.2	7.9	6.6	7.0	7.6	139	580	924	19.3	22.7	27.6
MW-7 Deep	<0.1	0.1	0.2	7.0	7.3	7.5	737	760	804	15.2	15.3	15.3
MW-8 Deep	<0.1	0.1	0.2	7.1	7.2	7.4	689	729	752	15.6	15.7	15.8

Stream

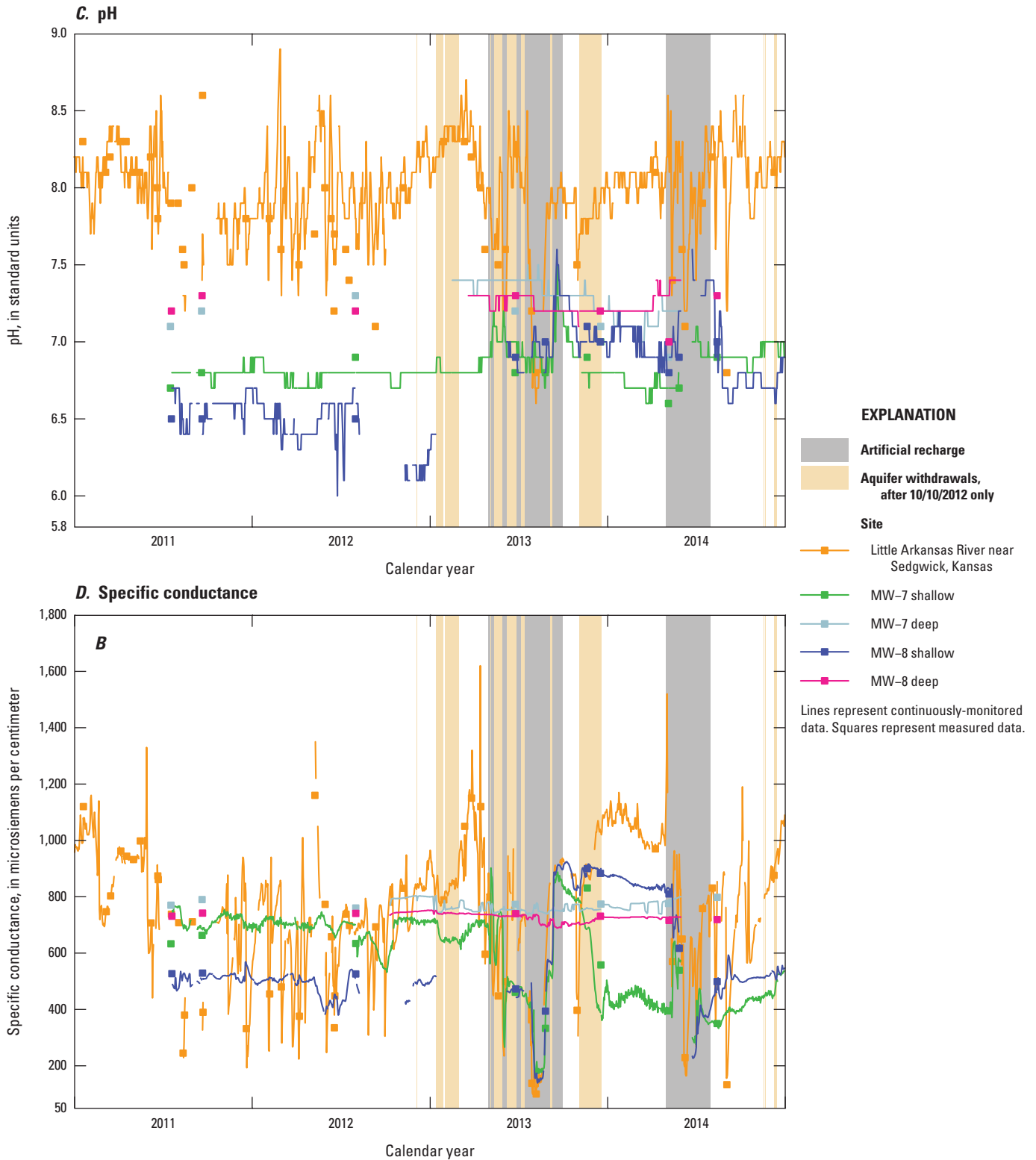
MW-7 shallow well

MW-8 shallow well

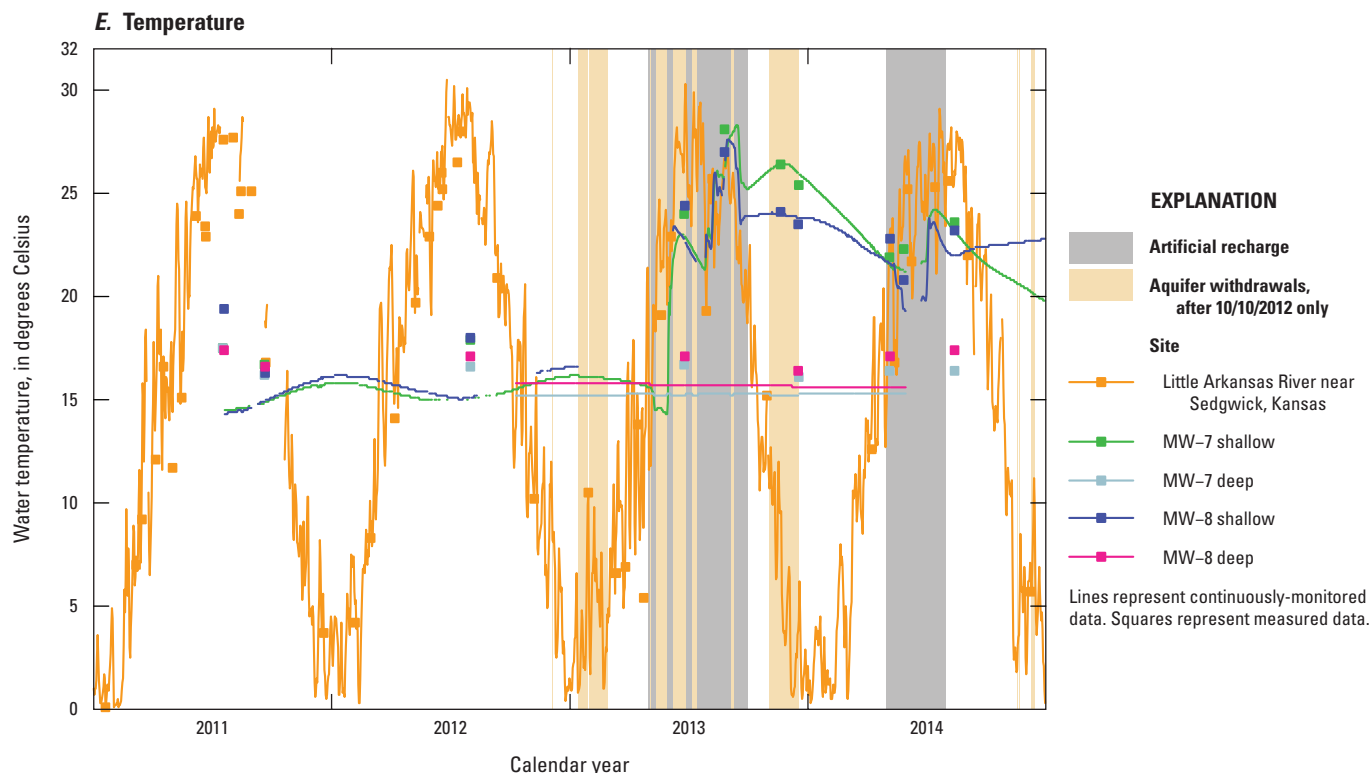
MW-7 and MW-8 deep wells



**Figure 14.** Groundwater conditions continuously monitored or measured in wells near infiltration basin, 2011 through 2014. A, water level and streamflow; B, dissolved oxygen; C, pH; D, specific conductance; and E, water temperature.



**Figure 14.** Groundwater conditions continuously monitored or measured in wells near infiltration basin, 2011 through 2014. *A*, water level and streamflow; *B*, dissolved oxygen; *C*, pH; *D*, specific conductance; and *E*, water temperature.—Continued



**Figure 14.** Groundwater conditions continuously monitored or measured in wells near infiltration basin, 2011 through 2014. *A*, water level and streamflow; *B*, dissolved oxygen; *C*, pH; *D*, specific conductance; and *E*, water temperature.—Continued

recharge, but the MW-8 shallow groundwater well (site 375332097284801) dissolved oxygen was reduced after recharge periods. Stream daily mean dissolved oxygen varied seasonally, peaking in winter and smallest in the summer, around an overall median daily mean of 10.0 mg/L (table 17, fig. 14*B*). Summer low stream dissolved oxygen is coincident with the period of water withdrawals and aquifer recharge. In the MW-7 shallow groundwater well, median dissolved oxygen before, during, and after recharge were 3.6, 3.5, and 2.4 mg/L, respectively. Median daily mean dissolved oxygen in the MW-8 shallow groundwater well was 5.5 mg/L before recharge, 5.2 mg/L during recharge periods, and 0.7 mg/L after each recharge period. Though shallow well median daily mean dissolved oxygen was little changed during recharge periods, the range was higher during recharge than before for both groundwater wells. The MW-7 shallow groundwater well mean dissolved oxygen ranged from 1.9 to 4.6 mg/L, 0.2 to 9.9 mg/L, and 1.1 to 4.7 mg/L before, during, and after recharge, respectively; and the MW-8 shallow groundwater well mean dissolved oxygen ranged from 3.6 to 7.6 mg/L, <0.1 to 7.9 mg/L, and 0.1 to 6.0 mg/L before, during, and after recharge, respectively. Deep groundwater dissolved oxygen was monitored from March 29, 2013, to May 31, 2014, was consistently anoxic, and had a maximum daily mean in both wells of 0.2 mg/L.

Continuously monitored pH in groundwater well sites generally was smaller than stream pH (table 17; fig. 14*C*). Median daily stream pH was 8.0 during 2011 through 2014.

Shallow well pH was monitored from July 21, 2011 through 2014 and the first recharge period began in May 2013. Median pH was 6.8 in the MW-7 shallow groundwater well and differed minimally before the first recharge period (median=6.8) compared to during and after the first recharge period (median=6.9). Median pH was 6.7 in the MW-8 shallow groundwater well and was slightly smaller before the first recharge period (median=6.5) compared to during and after the first recharge period (median=7.0). Deep wells were monitored for continuous pH from March 21, 2013 through May 31, 2014, from just before the first artificial recharge event and into the second artificial recharge period. Median daily pH was 7.3 in the MW-7 deep groundwater well (site 375327097285402, fig. 1) and 7.2 in the MW-8 deep groundwater well (site 375332097284802, fig. 1).

Specific conductance in shallow groundwater wells tended to reflect stream water conditions during recharge periods (table 17, fig. 14*D*). Stream median daily mean specific conductance was 799  $\mu\text{S}/\text{cm}$  at 25 °C. Median daily mean specific conductance was 663  $\mu\text{S}/\text{cm}$  at 25 °C in the MW-7 shallow groundwater well and 512  $\mu\text{S}/\text{cm}$  at 25 °C in the MW-8 shallow groundwater well. Specific conductance in deep wells varied little from the median daily mean of 760  $\mu\text{S}/\text{cm}$  at 25 °C and 729  $\mu\text{S}/\text{cm}$  at 25 °C for MW-7 and MW-8 deep groundwater wells, respectively.

Stream water and deep groundwater temperatures were similar before and after recharge periods but shallow groundwater temperature increased during the first recharge period

and remained higher. Stream withdrawals and aquifer recharge periods were coincident with seasonal high stream daily mean temperatures. Before recharge, the median daily mean temperature in the MW-7 and MW-8 shallow groundwater wells was 15.6 °C. Temperatures in shallow wells increased substantially during the first recharge period and remained higher through the study period, with median daily mean temperatures during and after recharge of 22.9 °C (range=14.3 °C to 28.3 °C) in the MW-7 shallow groundwater well and 22.7 °C in the MW-8 shallow groundwater well. Water temperatures in deep groundwater wells were consistent around median daily means of 15.3 °C and 15.7 °C for the MW-7 and MW-8 deep groundwater wells, respectively (table 17).

### Discrete Groundwater Quality

Data from discrete groundwater well samples were used to describe water-quality conditions in shallow and deep wells before and after recharge periods. Discrete water-quality data collected included dissolved solids and primary ions, nutrients, indicator bacteria, trace elements, pesticides, chlorinated and brominated organic compounds, and radioactive chemistry. Samples from before and after the beginning of artificial recharge were compared for shallow wells and deep wells using a generalized two-sided Wilcoxon test of unpaired samples. Sample counts and censoring levels (laboratory reporting levels) for additional constituents analyzed but not detected are presented in appendix table 1–10.

### Solids and Primary Ions

Solids and the individual ions calcium, magnesium, potassium, sodium, alkalinity, bicarbonate, carbonate, bromide, chloride, fluoride, silica, and sulfate are summarized in table 18. Median total solids significantly decreased, potassium significantly tripled, chloride significantly doubled, and fluoride significantly increased in shallow groundwater after artificial recharge ( $p$ -values <0.05); all other measures of solids and individual ion concentrations were not significantly different before and after recharge began. These significant changes in shallow groundwater concentrations were likely caused by the artificially recharged treated surface water and natural infiltration of precipitation. Deep groundwater samples were not significantly different for any solids or ion concentrations. No solids and primary ion constituent concentrations in the pre-recharge period in comparison to the post-recharge period increased to concentrations exceeding drinking water regulations.

### Nutrients and Organic Carbon

Nitrogen species, except ammonia and nitrite, significantly decreased in shallow groundwater, whereas phosphorus and carbon species significantly increased after artificial recharge (table 19). Ammonia and nitrite datasets had high percentages of left-censored data and were not statistically compared. Median shallow groundwater nitrate before recharge was 10.3 mg/L and exceeded the Federal MCL of 10 mg/L; during

and after recharge median nitrate was 1.06 mg/L. Four of six shallow groundwater samples before recharge began exceeded the MCL of 10 mg/L for nitrate. None of the post-recharge onset nitrate samples exceeded the MCL. Median shallow groundwater orthophosphate and dissolved phosphorus concentrations were similar and increased after recharge began from 0.04 and 0.06 mg/L to 0.17 and 0.18 mg/L, respectively. Total carbon was predominantly in dissolved forms and median shallow groundwater total carbon and dissolved carbon increased after recharge began from 0.5 to 1.3 mg/L, respectively. Of all deep groundwater nutrients and carbon constituents, only dissolved carbon was statistically ( $p$ -value <0.05) different before and after recharge in deep groundwater but increased minimally from 0.4 to 0.6 mg/L after recharge began. These statistical increases following recharge remain within the range of concentrations for total organic carbon throughout the aquifer (Tappa and others, 2015).

### Indicator Bacteria

Bacteria and indicators had datasets with severe left-censoring and some also contained right-censored data. All *E. coli* and fecal coliform bacteria densities were below the method detection limits (<1 mpn/100 mL and <1 col/100 mL, respectively), except for one deep well *E. coli* sample that was at the method detection limit after the onset of recharge (table 20). The EPA Federal MCL in drinking water for total coliform bacteria is that no more than 5 percent of samples test positive during 1 month for water systems that collect at least 40 routine samples per month (U.S. Environmental Protection Agency, 2009). If fewer than 40 samples are collected per month, only 1 sample can test positive for total coliform bacteria (U.S. Environmental Protection Agency, 2009). The EPA Federal MCLG in drinking water for total coliform bacteria is 0 col/100 mL. For the purposes of this report, col/100 mL are considered equivalent to mpn/100 mL. Total coliform bacteria densities were within the range of densities throughout the aquifer (Tappa and others, 2015). Total coliform bacteria detections were smaller after recharge onset. Total coliform bacteria densities exceeded the EPA MCLG in 83 percent of shallow groundwater samples before recharge and 50 percent after recharge began. Total coliform bacteria densities exceeded the EPA MCLG in 50 percent of deep groundwater samples prior to recharge and 38 percent after recharge onset. Median shallow groundwater slime-forming bacteria before recharge was 1,080,000 cfu/100 mL and was significantly smaller ( $p$ -value=0.03) after the onset of artificial recharge (median=208,000 cfu/100 mL; table 20). Deep groundwater sulfate-reducing bacteria increased from a median of <1 to 1,200 cfu/100 mL after artificial recharge began, although the pre-recharge sample dataset was severely censored. Results of biological activity reaction tests indicated that water quality microbiology was different before and after artificial recharge began; at times, these differences may lead to changes in dominant bacterial populations that, in turn, may lead to formation and expansion in populations that may cause bioplagging and other unwanted effects.



**Table 18.** Discretely collected solids and primary ions summary statistics for groundwater samples at sites near the recharge basin near Sedgwick, Kansas, before (January 2011 to April 2013) and after (May 2013 to December 2014) artificial recharge.

[Medians in **bold** indicate significant differences (*p*-value less than 0.05) between before and after recharge. Censoring levels are for all samples. The before and after groundwater samples were not statistically compared when greater than 50 percent of data were left-censored. Means and medians were not computed when greater than 80 percent of data were left-censored. *n*, number of measurements; mg/L, milligram per liter; CaCO<sub>3</sub>, calcium carbonate; --, not applicable; <, less than; SiO<sub>2</sub>, silicon dioxide]

Water-quality constituent (unit of measure)	Before recharge					After recharge						
	Left-censored data (percent)	<i>n</i>	Minimum	Maximum	Mean	Median	Left-censored data (percent)	<i>n</i>	Minimum	Maximum	Mean	Median
Shallow groundwater												
Dissolved solids (mg/L)	0	6	329	413	369	364	0	14	205	522	340	298
Hardness (mg/L as CaCO <sub>3</sub> )	0	6	171	251	219	216	0	14	114	316	194	176
Suspended solids (mg/L)	83	6	<4	5	--	--	100	14	<4	<4	--	--
Total solids (mg/L)	0	4	340	424	383	<b>384</b>	0	4	216	298	267	<b>276</b>
Calcium (mg/L)	0	6	53.5	79.5	68.7	67.8	0	14	35.1	96.9	60.7	54.9
Magnesium (mg/L)	0	6	9.05	12.8	11.3	11.3	0	14	6.16	17.8	10.3	9.3
Potassium (mg/L)	0	6	2	3	3	<b>3</b>	0	14	5	12	9	<b>9</b>
Sodium (mg/L)	0	6	29.7	47.6	36.7	34.2	0	14	15.3	64.4	38.6	34.2
Alkalinity (mg/L as CaCO <sub>3</sub> )	0	6	142	192	166	165	0	14	88.0	228	149	136
Bicarbonate (mg/L)	0	6	170	230	200	200	0	14	110	280	182	165
Bromide (mg/L)	0	4	0.1	0.1	0.1	0.1	0	14	0.1	0.3	0.2	0.1
Chloride (mg/L)	0	6	23	32	27	<b>26</b>	0	14	23	110	62	<b>55</b>
Fluoride (mg/L)	0	6	0.3	0.5	0.4	<b>0.4</b>	0	14	0.2	0.8	0.6	<b>0.6</b>
Silica (mg/L as SiO <sub>2</sub> )	0	6	16.5	20.6	18.5	18.5	0	14	15.0	19.6	17.3	17.1
Sulfate (mg/L)	0	6	54	64	58	58	0	14	19	72	45	43
Deep groundwater												
Dissolved solids (mg/L)	0	6	442	477	456	448	0	8	427	492	453	450
Hardness (mg/L as CaCO <sub>3</sub> )	0	6	191	251	223	217	0	8	211	253	228	227
Suspended solids (mg/L)	100	6	<4	<4	--	--	100	8	<4	<4	--	--
Total solids (mg/L)	0	4	460	486	474	474	0	2	464	490	477	477
Calcium (mg/L)	0	6	57.2	75.9	67.1	65.0	0	8	63.3	76.6	68.6	68.2
Magnesium (mg/L)	0	6	11.5	15.0	13.3	13.2	0	8	12.6	14.8	13.5	13.5
Potassium (mg/L)	0	6	3	3	3	<b>3</b>	0	8	3	3	3	<b>3</b>
Sodium (mg/L)	0	6	67	92	82	85	0	8	75	82	78	78
Alkalinity (mg/L as CaCO <sub>3</sub> )	0	6	248	262	257	260	0	8	258	268	262	262
Bicarbonate (mg/L)	0	6	300	320	315	320	0	8	320	330	321.25	320
Bromide (mg/L)	33	6	<0.02	0.1	0.1	0.1	0	8	0.1	0.1	0.1	0.1
Chloride (mg/L)	0	6	44	63	54	55	0	8	40	67	52	52
Fluoride (mg/L)	0	6	0.4	0.5	0.5	0.5	0	8	0.4	1.0	0.6	0.5
Silica (mg/L as SiO <sub>2</sub> )	0	6	21.6	27.2	24.9	25.0	0	8.0	23.8	27.4	25.4	25.3
Sulfate (mg/L)	0	6	57	64	61	61	0	8	56	66	60	61

**Table 19.** Discretely collected nutrient and carbon summary statistics for groundwater samples at sites near the recharge basin near Sedgwick, Kansas, before (January 2011 to April 2013) and after (May 2013 to December 2014) artificial recharge.

[Medians in **bold** indicate significant differences ( $p$ -value less than 0.05) between before and after recharge. Censoring levels are for all samples. The before and after groundwater samples were not statistically compared when greater than 50 percent of data were left-censored. Means and medians were not computed when greater than 80 percent of data were left-censored.  $n$ , number of measurements; mg/L, milligram per liter; N, nitrogen; <, less than; --, not applicable; P, phosphorus]

Water-quality constituent (unit of measure)	Before recharge					After recharge						
	Left-censored data (percent)	$n$	Minimum	Maximum	Mean	Median	Left-censored data (percent)	$n$	Minimum	Maximum	Mean	Median
Shallow groundwater												
Ammonia (mg/L as N)	83	6	<0.03	0.04	--	--	71	14	<0.01	0.04	0.03	0.02
Nitrate plus nitrite (mg/L as N)	0	6	3.64	11.6	8.73	<b>10.3</b>	0	14	0.41	3.94	1.36	<b>1.06</b>
Nitrate (mg/L as N)	0	6	3.64	11.6	8.73	<b>10.3</b>	0	14	0.41	3.94	1.36	<b>1.06</b>
Nitrite (mg/L as N)	100	6	<0.01	<0.01	--	--	93	14	<0.001	0.02	--	--
Orthophosphate (mg/L as P)	0	6	0.03	0.05	0.04	<b>0.04</b>	0	14	0.06	0.33	0.18	<b>0.17</b>
Dissolved phosphorus (as above for shallow groundwater)	0	6	0.05	0.07	0.06	<b>0.06</b>	0	14	0.06	0.30	0.17	<b>0.18</b>
Dissolved organic carbon (mg/L)	0	4	0.4	0.6	0.5	<b>0.5</b>	0	14	0.6	3.2	1.6	<b>1.3</b>
Total organic carbon (mg/L)	0	4	0.41	0.54	0.49	<b>0.50</b>	0	14	0.62	3.14	1.64	<b>1.30</b>
Deep groundwater												
Ammonia (mg/L as N)	67	6	<0.03	0.03	0.02	0.02	88	8	<0.03	0.03	--	--
Nitrate plus nitrite (mg/L as N)	0	6	0.04	2.44	1.22	1.10	0	8	0.07	2.11	1.07	1.09
Nitrate (mg/L as N)	0	6	0.04	2.41	1.20	1.06	0	8	0.07	2.05	1.04	1.06
Nitrite (mg/L as N)	67	6	<0.01	0.07	0.02	0.01	50	8	<0.01	0.07	0.06	0.04
Orthophosphate (mg/L as P)	67	6	<0.02	0.02	0.01	0.01	75	8	<0.02	0.04	0.02	0.02
Dissolved phosphorus (as above for shallow groundwater)	33	6	<0.03	0.05	0.03	0.04	75	8	<0.03	0.03	0.02	0.02
Dissolved organic carbon (mg/L)	0	4	0.4	0.5	0.4	<b>0.4</b>	0	8	0.5	0.9	0.6	<b>0.6</b>
Total organic carbon (mg/L)	0	4	0.37	0.63	0.46	0.43	0	8	0.49	0.63	0.57	0.56

**Table 20.** Discretely collected bacteria summary statistics for groundwater samples at sites near the recharge basin near Sedgwick, Kansas, before (January 2011 to April 2013) and after (May 2013 to December 2014) artificial recharge.

[Medians in **bold** indicate significant differences (p-value less than 0.5) between before and after recharge. All bacteria are left-censored at one unit. The before and after groundwater samples were not statistically compared when greater than 50 percent of data were left- or right-censored. Means and medians were not computed when greater than 80 percent of data were left- or right-censored. *n*, number of measurements; *E. coli*, *Escherichia coli*; mpn/100 mL, most probable number per 100 milliliters; <, less than; --, not applicable; col/100 mL, colony per 100 milliliters; >, greater than; pfu/100 mL, plaque forming unit per 100 milliliters; cfu/mL, colony forming unit per milliliter]

Water-quality constituent (unit of measure)	Before recharge						After recharge					
	Left-censored data (percent)	<i>n</i>	Minimum	Maximum	Mean	Median	Left-censored data (percent)	<i>n</i>	Minimum	Maximum	Mean	Median
Shallow groundwater												
<i>E. coli</i> bacteria (mpn/100 mL)	100	6	<1	<1	--	--	100	14	<1	<1	--	--
Fecal coliform bacteria (col/100 mL)	100	6	<1	<1	--	--	100	14	<1	<1	--	--
Total coliform bacteria (mpn/100 mL)	17	6	<1	>200	109	41	50	14	<1	>200	40	10
<i>E. coli</i> coliphage (pfu/100 mL)	75	4	<1	1	1	1	100	14	<1	<1	--	--
Iron-related bacteria (cfu/mL)	0	4	9,000	9,000	9,000	9,000	0	14	150	35,000	15,600	9,000
Slime-forming bacteria (cfu/mL)	0	4	350,000	1,800,000	1,080,000	<b>1,080,000</b>	7.1	14	<1	1,800,000	299,000	<b>208,000</b>
Sulfate-reducing bacteria (cfu/mL)	50	4	<1	5,000	1,650	600	57	14	<1	18,000	1,830	<1
Deep groundwater												
<i>E. coli</i> bacteria (mpn/100 mL)	100	6	<1	<1	--	--	88	8	<1	1	--	--
Fecal coliform bacteria (col/100 mL)	100	6	<1	<1	--	--	100	8	<1	<1	--	--
Total coliform bacteria (mpn/100 mL)	50	6	<1	18	4	<1	63	8	<1	34	8	<1
<i>E. coli</i> coliphage (pfu/100 mL)	100	4	<1	<1	--	--	100	8	<1	<1	--	--
Iron-related bacteria (cfu/mL)	50	4	<1	9,000	9,000	4,500	0	8	150	35,000	11,400	5,650
Slime-forming bacteria (cfu/mL)	0	4	12,500	1,800,000	544,000	181,000	13	8	<1	1,800,000	359,000	181,000
Sulfate-reducing bacteria (cfu/mL)	75	4	<1	200	200	<1	0	8	500	100,000	14,200	1,200

## Trace Elements

Metals and other trace elements detected include aluminum, barium, cadmium, lead, manganese, nickel, strontium, thallium, vanadium, zinc, arsenate, arsenic, boron, and selenium. Arsenite, beryllium, chromium, copper, cyanide, iron, mercury, and silver were not detected in groundwater samples during the study (appendix table 1–10). Shallow groundwater barium, manganese, nickel, arsenate, arsenic, and boron concentrations increased, whereas strontium and selenium decreased after recharge onset (table 21). Shallow groundwater nickel and arsenic significantly increased after the beginning of the first recharge period (table 21). Shallow groundwater median arsenic concentrations increased from 0.9  $\mu\text{g/L}$  before recharge to 1.7  $\mu\text{g/L}$  after recharge onset (table 21). The increase in arsenic concentrations is likely because of the recharged surface water, but arsenic remained about 6 times smaller than the EPA MCL of 10  $\mu\text{g/L}$ . None of the shallow or deep groundwater sample arsenic concentrations exceeded the MCL during the study. Shallow groundwater selenium medians decreased significantly from 11 to 1.9  $\mu\text{g/L}$  (table 21). Deep groundwater manganese, nickel, arsenate, and selenium increased, whereas strontium, arsenic, and boron decreased after recharge onset (table 21). Pre- and post-recharge deep groundwater manganese medians exceeded the EPA SMCL of 50  $\mu\text{g/L}$  and significantly increased from 88  $\mu\text{g/L}$  before recharge to 216  $\mu\text{g/L}$  after recharge onset (table 21). Deep groundwater nickel medians significantly doubled after recharge onset (table 21). Significant manganese and nickel increases in deep groundwater are unlikely related to recharge activities.

## Pesticides

Pesticides detected in shallow groundwater samples included acetochlor, atrazine, metolachlor, metribuzin, and simazine. These pesticides, along with detected degradation compounds and total triazines, are summarized in table 22. Undetected analytes included many additional pesticides and degradation compounds that are summarized in appendix table 1–10. Atrazine and the triazine degradate 2-Chloro-4-isopropylamino-6-amino-*s*-triazine (CIAT) were the only pesticides detected before recharge. Atrazine was detected prior to recharge in one shallow well sample at the laboratory reporting level. Shallow groundwater atrazine concentrations increased after recharge began to a median of 0.035  $\mu\text{g/L}$ . Comparison summary statistics were not computed for most pesticides because of datasets with severe censoring. With the exception of CIAT, no pesticides were detected in deep groundwater during the study period. The CIAT was present in all but one of the samples from the deep groundwater wells (MW-7 deep, site 375327097285402), but concentrations were not significantly different before and after recharge. All concentrations of pesticides were less than drinking water regulatory criteria before and after artificial recharge.

## Brominated and Chlorinated Organic Compounds

Though residual chlorine from the water treatment process was not detected in groundwater samples, brominated and chlorinated organic compounds, such as trihalomethanes (THM), are summarized in table 23 for compounds detected in groundwater or appendix table 1–10 for compounds analyzed but not detected. Most statistical comparisons for these compounds having datasets with severe censoring were not computed. Detection frequencies increased after recharge in shallow groundwater samples for bromodichloromethane and trichloromethane, but detection frequencies decreased in deep groundwater for bromodichloromethane, dibromochloromethane, tribromomethane, trichloromethane, and THM.

## Radioactive Chemistry

Alpha radioactivity and gross beta radioactivity are summarized in table 23. Alpha radioactivity (Th-230 curve) was detected but not different before compared with after the beginning of recharge, and the maximum level in all samples tested (5.7 picocuries per liter [pCi/L]; table 23) was below the EPA MCL of 15 pCi/L (U.S. Environmental Protection Agency, 2005). Gross beta radioactivity (Cs-137 curve) significantly increased in shallow and deep groundwater samples; median shallow groundwater well values increased from 3.1 to 13.2 pCi/L and median deep well values increased from 3.1 to 5.8 pCi/L (table 23). The maximum sample gross beta radioactivity was 18 pCi/L, which was below a screening level of the 50 pCi/L, above which EPA may require testing for individual beta-emitting species (U.S. Environmental Protection Agency, 2005).

## Geochemical Effects

To determine if changes in groundwater quality might affect mineral precipitation and dissolution, discrete samples were assessed for a change in saturation index (SI), particularly near or across the equilibrium threshold of SI near zero. A mineral SI is calculated as the log of the ion-activity product of a water sample, divided by the solubility product ( $K_{sp}$ ) for the mineral and indicates the extent of disequilibrium with respect to the mineral (Parkhurst and Appelo, 2013). Equilibrium state only describes the potential for precipitation (positive SI) and dissolution (negative SI), but reaction kinetics and interaction among other constituents also affect whether minerals precipitate or dissolve. Therefore, a mineral is of particular interest if it has relatively short reaction times (fast kinetics) and if the SI changes across equilibrium during the study period, as did calcite, chalcedony, dolomite, aqueous iron (III) hydroxide, hydroxyapatite, and rhodochrosite. Saturation equilibrium for many minerals is closely and positively related to pH across the range of sample conditions.

In assessing changes in the aquifer during recharge, SI values that were strongly and consistently negative (such as gypsum) or positive (such as quartz) for groundwater samples before and after artificial recharge indicate no change in

**Table 21.** Discretely collected trace element summary statistics for groundwater samples at sites near the recharge basin near Sedgwick, Kansas, before (January 2011 to April 2013) and after (May 2013 to December 2014) artificial recharge.

[Medians in bold indicate significant differences (*p*-value less than 0.05) between before and after recharge; the before and after groundwater samples were not statistically compared when greater than 50 percent of data were left-censored. Means and medians were not computed when greater than 80 percent of data were left-censored. *n*, number of measurements; µg/L, microgram per liter; <, less than; --, not applicable]

Water-quality constituent (unit of measure)	Before recharge						After recharge					
	Left-censored data (percent)	<i>n</i>	Minimum	Maximum	Mean	Median	Left-censored data (percent)	<i>n</i>	Minimum	Maximum	Mean	Median
Shallow groundwater												
Aluminum (µg/L)	100	4	<20	<20	--	--	100	14	<20	<20	--	--
Barium (µg/L)	0	4	93	164	112	96	0	14	74	274	156	150
Cadmium (µg/L)	100	4	<0.05	<0.05	--	--	57	14	<0.05	0.11	0.06	0.05
Lead (µg/L)	50	4	<0.1	0.1	--	--	93	14	<0.1	0.1	--	--
Manganese (µg/L)	100	4	<5	<5	--	--	71	14	<5	15	2.2	3.0
Nickel (µg/L)	0	4	0.4	1.8	1.1	<b>1.2</b>	0	14	0.8	3.8	2.2	<b>2.0</b>
Strontium (µg/L)	0	4	445	501	482	491	0	14	283	618	424	379
Thallium (µg/L)	52	4	<0.05	0.2	0.1	0.1	86	14	<0.05	0	--	--
Vanadium (µg/L)	100	4	<5	<5	--	--	100	14	<5	<5	--	--
Zinc (µg/L)	25	4	<5	6.0	5.1	6.0	29	14	<5	11.0	5.7	5.0
Arsenate (µg/L) as arsenic	100	4	<0.3	<1.6	--	--	0	14	0.6	2.1	1.3	1.2
Arsenic (µg/L)	0	6	0.7	1.3	1.0	<b>0.9</b>	0	14	0.8	3.5	1.7	<b>1.7</b>
Boron (µg/L)	0	4	33	41	38	38	0	14	22	69	50	51
Selenium (µg/L)	0	4	6.7	13	10	<b>11</b>	0	14	0.7	3.5	1.9	<b>1.9</b>
Deep groundwater												
Aluminum (µg/L)	75	4	<20	32	16	10	100	8	<20	<20	--	--
Barium (µg/L)	0	4	26	56	41	41	0	8	24	57	40	41
Cadmium (µg/L)	100	4	<0.05	<0.05	--	--	100	8	<0.05	<0.05	--	--
Lead (µg/L)	50	4	<0.1	0.2	0.2	0.1	100	8	<0.1	<0.1	--	--
Manganese (µg/L)	0	4	43	198	112	<b>88</b>	0	8	171	311	224	<b>216</b>
Nickel (µg/L)	0	4	0.2	1.4	0.9	<b>0.9</b>	0	8	1.4	2.1	1.7	<b>1.7</b>
Strontium (µg/L)	0	4	761	800	781	781	0	8	735	851	782	775
Thallium (µg/L)	50	4	<0.05	0.1	0.1	0.1	100	8	<0.05	<0.05	--	--
Vanadium (µg/L)	25	4	<5	9.0	6.6	7.5	38	8	<5	10.0	6.4	7.5
Zinc (µg/L)	50	4	<5	6.0	4.3	4.3	38	8	<5	8.0	4.9	5.0
Arsenate (µg/L) as arsenic	0	4	2.2	3.1	2.7	2.7	0	8	2.4	4.3	3.3	3.2
Arsenic (µg/L)	0	6	2.5	5.5	4.1	4.2	0	8	3.1	5.1	4.0	4.0
Boron (µg/L)	0	4	37	41	39	39	0	8	31	39	36	36
Selenium (µg/L)	0	4	1.3	5.9	3.3	2.9	0	8	1.4	10	5.7	6.5

**Table 22.** Discretely collected pesticides summary statistics for groundwater samples at sites near the recharge basin near Sedgwick, Kansas, before (January 2011 to April 2013) and after (May 2013 to December 2014) artificial recharge.

[Censoring levels are for all samples. The before and after groundwater samples were not statistically compared when greater than 50 percent of data were left-censored. Means and medians were not computed when greater than 80 percent of data were left-censored. *n*, number of measurements; CIAT, 2-Chloro-4-isopropylamino-6-amino-s-triazine; µg/L, microgram per liter; CEAT, 2-Chloro-6-ethylamino-4-amino-s-triazine; <, less than; --, not applicable; OIET, 2-Hydroxy-4-isopropylamino-6-ethylamino-s-triazine]

Water-quality constituent (unit of measure)	Before recharge					After recharge						
	Left-censored data (percent)	<i>n</i>	Minimum	Maximum	Mean	Median	Left-censored data (percent)	<i>n</i>	Minimum	Maximum	Mean	Median
Shallow groundwater												
CIAT (µg/L)	0	4	0.024	0.148	0.071	0.056	0	14	0.027	1.79	0.361	0.056
CEAT (µg/L)	100	4	<0.02	<0.02	--	--	0	1	0.86	0.86	--	--
OIET (µg/L)	100	4	<0.02	<0.02	--	--	0	1	0.03	0.03	--	--
Acetochlor (µg/L)	100	4	<0.01	<0.01	--	--	79	14	<0.01	0.049	0.017	0.003
Atrazine (µg/L)	25	4	<0.02	0.02	0.008	0.008	0	14	0.015	1.39	0.344	0.035
Metolachlor (µg/L)	100	4	<0.02	<0.02	--	--	29	14	<0.02	0.138	0.047	0.029
Metribuzin (µg/L)	100	4	<0.012	<0.012	--	--	93	14	<0.012	0.017	--	--
Simazine (µg/L)	100	4	<0.006	<0.006	--	--	79	14	<0.006	0.02	0.413	0.036
Triazines (µg/L as atrazine)	100	6	<0.1	<0.1	--	--	57	14	<0.1	1.8	0.5	0.1
Deep groundwater												
CIAT (µg/L)	50	4	<0.006	0.016	0.013	0.010	50	8	<0.006	0.040	0.015	0.011
CEAT (µg/L)	100	4	<0.06	<0.06	--	--	100	1	<0.02	<0.02	--	--
OIET (µg/L)	100	4	<0.06	<0.06	--	--	100	1	<0.02	<0.02	--	--
Acetochlor (µg/L)	100	4	<0.01	<0.01	--	--	100	8	<0.01	<0.01	--	--
Atrazine (µg/L)	100	4	<0.008	<0.008	--	--	100	8	<0.008	<0.008	--	--
Metolachlor (µg/L)	100	4	<0.02	<0.02	--	--	100	8	<0.02	<0.02	--	--
Metribuzin (µg/L)	100	4	<0.012	<0.012	--	--	100	8	<0.012	<0.012	--	--
Simazine (µg/L)	100	4	<0.006	<0.006	--	--	100	8	<0.006	<0.006	--	--
Triazines (µg/L as atrazine)	100	6	<0.1	<0.1	--	--	100	8	<0.1	<0.1	--	--

**Table 23.** Discretely collected brominated and chlorinated organic compounds and radioactivity summary statistics for groundwater samples at sites near the recharge basin near Sedgwick, Kansas, before (January 2011 to April 2013) and after (May 2013 to December 2014) artificial recharge.

[Medians in **bold** indicate significant differences (*p*-value less than 0.05) between before and after recharge. Censoring levels are for all samples. The before and after groundwater samples were not statistically compared when greater than 50 percent of data were left-censored. Means and medians were not computed when greater than 80 percent of data were left-censored. *n*, number of measurements; µg/L, microgram per liter; <, less than; --, not applicable; α, alpha; pCi/L, picocurie per liter; β, beta]

Water-quality constituent (unit of measure)	Before recharge					After recharge						
	Left-censored data (percent)	<i>n</i>	Minimum	Maximum	Mean	Median	Left-censored data (percent)	<i>n</i>	Minimum	Maximum	Mean	Median
Shallow groundwater												
Bromodichloromethane (µg/L)	100	4	<0.1	<0.1	--	--	21	14	<0.1	0.5	0.2	0.2
Dibromochloromethane (µg/L)	100	4	<0.2	<0.2	--	--	100	14	<0.2	<0.2	--	--
Tribromomethane (µg/L)	100	4	<0.2	<0.2	--	--	100	14	<0.2	<0.2	--	--
Trichloromethane (µg/L)	75	4	<0.1	4.7	4.7	0.0	0	14	1.3	5.2	2.3	1.8
Trihalomethanes, maximum summation (µg/L)	100	4	<0.6	<0.6	--	--	100	14	<1.9	<1.9	--	--
Trihalomethanes, minimum summation (µg/L)	0	1	4.7	--	--	--	0	14	1.4	5.5	2.5	2.05
α radioactivity (pCi/L)	0	4	0.6	1.1	0.9	1.0	0	14	0.1	5.7	2.4	2.0
Gross β radioactivity (pCi/L)	0	4	2.5	4.4	3.3	<b>3.1</b>	0	14	5.3	18.0	12.7	<b>13.2</b>
Deep groundwater												
Bromodichloromethane (µg/L)	50	4	<0.1	0.8	0.4	0.2	100	8	<0.1	<0.1	--	--
Dibromochloromethane (µg/L)	50	4	<0.2	0.8	0.5	0.3	100	8	<0.2	<0.2	--	--
Tribromomethane (µg/L)	50	4	<0.2	0.3	0.3	0.2	100	8	<0.2	<0.2	--	--
Trichloromethane (µg/L)	25	4	<0.1	3.2	1.5	1.4	100	8	<0.1	<0.1	--	--
Trihalomethanes, maximum summation (µg/L)	50	4	<0.6	5.0	3.5	2.2	100	8	<0.6	<0.6	--	--
Trihalomethanes, minimum summation (µg/L)	0	3	0.3	5.0	3.0	3.8	--	0	--	--	--	--
α radioactivity (pCi/L)	0	4	1.6	3.0	2.3	2.2	0	8	1.0	5.4	2.9	2.3
Gross β radioactivity (pCi/L)	0	4	2.9	3.8	3.2	<b>3.1</b>	0	8	3.6	9.4	5.9	<b>5.8</b>

overall equilibrium status with regard to those specific minerals. Undersaturation (negative SI) of metal-bearing minerals, either consistent across the study period or as a result of changes in the aquifer, can indicate potential for release of metals such as manganese and arsenic, which are harmful in drinking water. Similar to previous analyses describing artificial recharge in another location in the *Equus* Beds aquifer (fig. 1) (Schmidt and others, 2007; Ziegler and others, 2010; Garinger and others, 2011), for this study near the recharge basin near Sedgwick, Kans., SI values for manganite (manganese bearing) and scorodite (arsenic bearing) were consistently negative throughout the study (table 24). The absence or very low concentrations of manganese or arsenic in groundwater samples near the Sedgwick recharge basin, however, suggests that these minerals are either not present in this part of the aquifer or that kinetic factors were not conducive to dissolution. Additional select minerals near or ranging across equilibrium for discrete groundwater samples are summarized in table 24.

Several carbonate minerals varied near or across equilibrium state, such as calcite (table 24, fig. 15A). Stream sample  $\text{CaCO}_3$  SI (median=0.5), ranged more broadly (-1.8 to 1.2) than groundwater. Before recharge periods,  $\text{CaCO}_3$  was slightly under-saturated in shallow groundwater wells (MW-7 site 375327097285401 and MW-8 site 375332097284801), with little change after the onset of recharge. Before recharge, median SI with respect to  $\text{CaCO}_3$  in shallow groundwater well samples was -0.8; after recharge the median SI with respect to  $\text{CaCO}_3$  was -0.6. Median deep groundwater well (MW-7 site 375327097285402 and MW-8 site 375332097284802)  $\text{CaCO}_3$  SI values were similar before (median=-0.1) and after (median=-0.1) recharge. The near-equilibrium of  $\text{CaCO}_3$  in shallow groundwater and the broad range of stream-water saturation states indicate a vulnerability to a shift toward over-saturation of  $\text{CaCO}_3$ , potentially resulting in formation of  $\text{CaCO}_3$  mineral deposits.

Phosphate minerals, such as hydroxyapatite, before recharge periods were under-saturated in groundwater, but samples after recharge began were closer to equilibrium for shallow groundwater well samples (table 24, fig. 15B). Stream water was generally oversaturated with respect to hydroxyapatite, with a median SI of 3.8. Shallow groundwater median hydroxyapatite before recharge was -5.7 and was -1.7 after recharge began. Deep groundwater was similar before and after recharge.

Similar to carbonates, oxyhydroxides, such as the iron bearing mineral iron (II) hydroxide, were under-saturated in

shallow groundwater well samples before recharge with a shift toward equilibrium (table 24, fig. 15C). Median SI for iron (II) hydroxide in streams was 2.0 and ranged from -1.3 to 6.6 with seasonal minima in summer and peaks in winter. Median SI for shallow groundwater well samples was -3.8 before and -1.3 after recharge. Deep groundwater was consistently near equilibrium with respect to iron (II) hydroxide and had a median of 0.5 before and 0.2 after recharge.

Shifts in saturation indices of the minerals calcite, iron hydroxide, hydroxyapatite, and similar carbonates, oxyhydroxides, and phosphate minerals were generally from under-saturation toward equilibrium and, in some cases, toward over-saturation. Saturation indices for these minerals are closely related to pH, and the recharge source water tended to have higher pH values and positive (oversaturated) SI values, relative to groundwater (fig. 16). The shift toward neutral SI may indicate decreased weathering of the minerals present in the aquifer. Even at equilibrium, however, these minerals may react and move in and out of solution, with the reaction rates governed by kinetic factors such as accessible reaction sites on particle surfaces and temperature.

Because of positive shifts in SI closely related to pH, conditions are more favorable to precipitate iron during and after recharge periods. Though dissolved iron was not detected in the groundwater wells studied near the recharge basin, iron is present in other wells in the well field and was measured in stream samples. Ongoing continuous monitoring of shallow groundwater for changes in pH, specifically an increase above 7.0, may highlight periods when the conditions are favorable to precipitate iron. Additionally, recharge source water samples can be used to determine if dissolved iron may have been introduced into the aquifer system through the recharge basin.

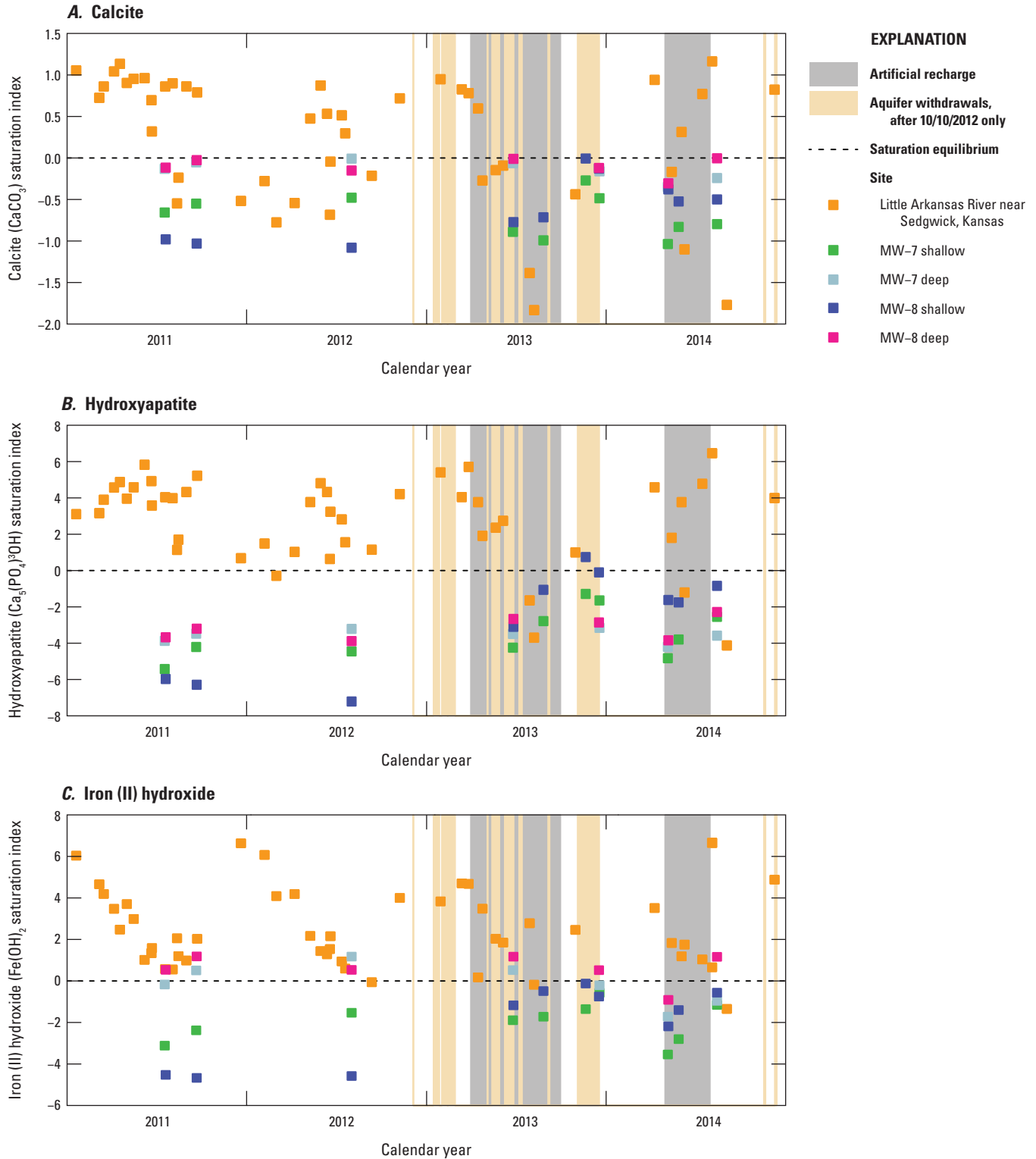
Precipitation and dilution reaction rates increase with water temperature at disequilibrium, with SI as an indication of the net direction of the reaction. Even for SI near zero, however, a mineral still will dissolve and precipitate to maintain local equilibrium at a faster rate with increased water temperature. This exchange includes the potential release of key ions, such as arsenic, iron, and manganese. Observed water temperatures in shallow groundwater wells after recharge have remained about 4 to 11 °C warmer than median temperatures before the first recharge period. Thus, chemical weathering in the shallow parts of the aquifer will be accelerated because of the increased water temperatures, and the system is more vulnerable to clogged pores and mineral dissolution as the equilibrium state is affected by recharge and withdrawal.



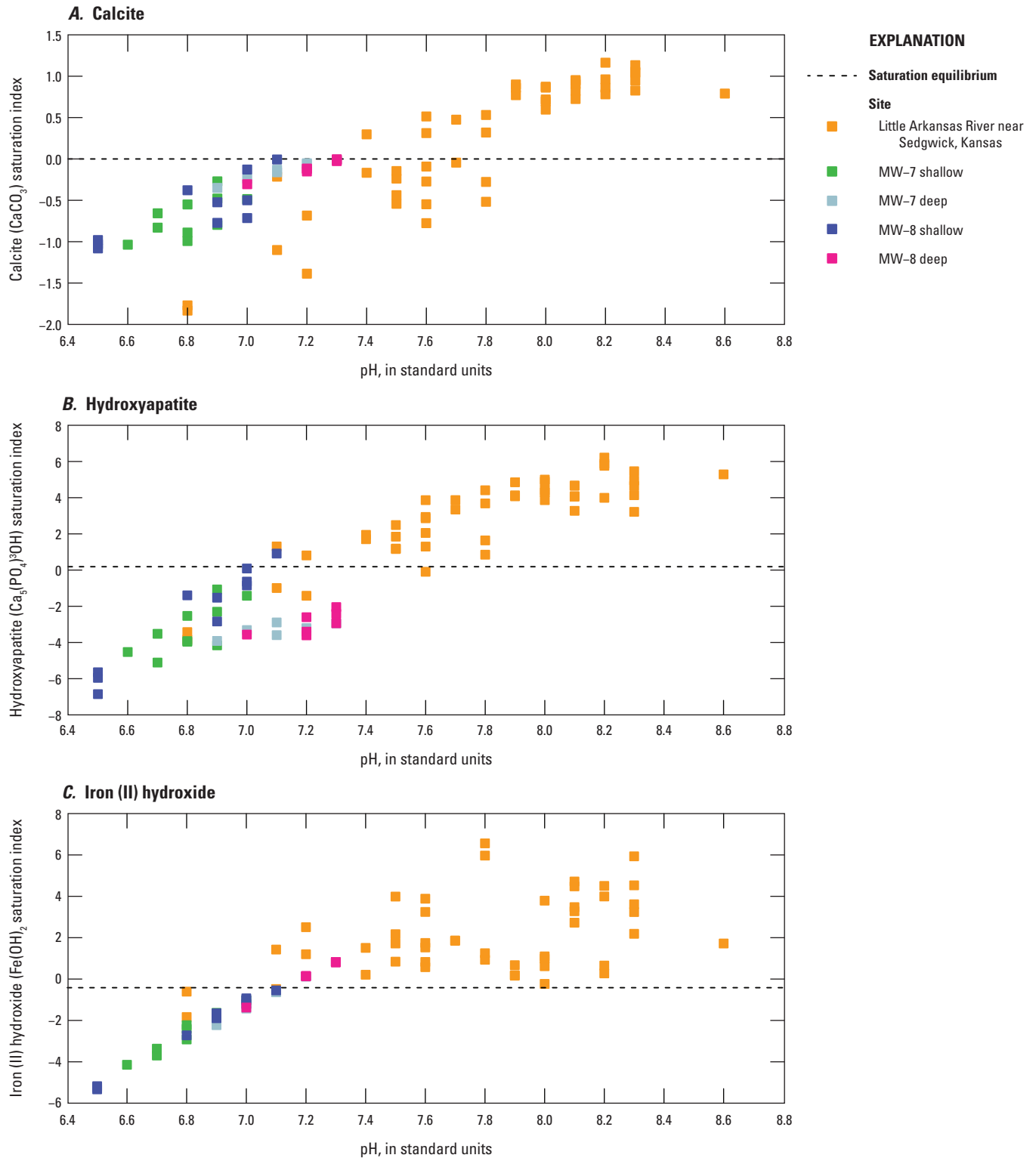
**Table 24.** Saturation indices for select minerals for groundwater samples collected at sites near the recharge basin near Sedgwick, Kansas, before (January 2011 to April 2013) and after (May 2013 to December 2014) artificial recharge.

[n, number of measurements]

Mineral (unitless)	Stream (n=47)			Shallow groundwater						Deep groundwater						
	Minimum	Median	Maximum	Before recharge (n=6)			After recharge (n=14)			Before recharge (n=6)			After recharge (n=8)			
				Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum	
Aragonite	-2.0	0.4	1.0	-1.2	-1.0	-0.6	-1.2	-0.8	-0.2	-0.3	-0.2	-0.2	-0.2	-0.5	-0.3	-0.2
Calcite	-1.8	0.5	1.2	-1.1	-0.8	-0.5	-1.0	-0.6	-0.0	-0.2	-0.1	-0.0	-0.4	-0.1	-0.0	-0.0
Chalcedony	-0.3	-0.0	0.3	0.1	0.1	0.2	-0.0	0.0	0.1	0.2	0.3	0.3	0.2	0.3	0.3	0.3
Cristobalite	-2.9	0.0	0.3	0.1	0.2	0.2	-0.0	0.1	0.1	0.3	0.3	0.4	0.3	0.3	0.3	0.4
Dolomite	-4.0	0.6	1.9	-2.7	-2.2	-1.5	-2.5	-1.7	-0.4	-0.8	-0.6	-0.5	-1.2	-0.8	-0.5	-0.5
Iron (III) hydroxide (Fe(OH) <sub>3</sub> )	0.6	2.1	3.5	-0.6	-0.3	0.6	-0.2	0.7	1.2	1.1	1.4	1.6	0.5	1.2	1.6	1.6
Iron (II) hydroxide (Fe <sub>3</sub> (OH) <sub>2</sub> )	-1.3	2.0	6.6	-4.7	-3.8	-1.5	-3.5	-1.3	-0.1	-0.2	0.5	1.2	-1.7	0.2	1.2	1.2
Fluorapatite	-1.3	5.4	7.4	-4.0	-2.6	-1.1	-1.7	1.0	3.2	-1.3	-1.0	-0.6	-1.2	-0.3	0.5	0.5
Gypsum	-3.5	-1.9	-1.2	-1.9	-1.8	-1.7	-2.5	-2.0	-1.7	-1.9	-1.8	-1.8	-1.9	-1.9	-1.8	-1.8
Hydroxy- apatite	-4.1	3.8	6.2	-7.2	-5.7	-4.2	-4.8	-1.7	0.7	-3.9	-3.6	-3.2	-4.2	-3.3	-2.3	-2.3
Manganite	-8.1	-4.0	-2.1	-9.1	-8.8	-8.0	-8.8	-7.9	-7.4	-6.2	-5.9	-5.2	-6.3	-5.6	-5.3	-5.3
Rhodochrosite	-2.7	-0.0	1.0	-2.7	-2.5	-2.2	-2.5	-2.1	-1.9	-0.8	-0.6	-0.1	-0.5	-0.2	-0.0	-0.0
Scorodite	-8.8	-7.3	-6.5	-9.0	-8.8	-8.1	-8.6	-7.8	-7.3	-7.6	-7.3	-7.1	-7.8	-7.4	-7.1	-7.1
Strenite	-1.5	0.1	1.5	-1.6	-1.4	-1.0	-0.7	-0.1	0.4	-1.0	-0.9	-0.9	-1.0	-0.8	-0.5	-0.5
Quartz	0.1	0.4	0.7	0.5	0.6	0.6	0.4	0.5	0.5	0.7	0.7	0.8	0.7	0.7	0.8	0.8



**Figure 15.** Saturation indices of minerals calculated for stream water and groundwater samples collected from monitoring wells near the infiltration basin, 2011 through 2014. *A*, calcite; *B*, hydroxyapatite; and *C*, iron (II) hydroxide.



**Figure 16.** pH of minerals calculated for groundwater samples collected from monitoring wells near the infiltration basin, 2011 through 2014. *A*, calcite; *B*, hydroxyapatite; and *C*, iron (II) hydroxide.

## Summary and Conclusions

The city of Wichita, Kansas, uses the *Equus* Beds aquifer as a primary municipal water supply source. The *Equus* Beds aquifer storage and recovery (ASR) project was developed to help the city of Wichita meet increasing future water demands. The *Equus* Beds ASR project pumps water out of the Little Arkansas River during above-base flow conditions, treats it using drinking-water quality standards as a guideline, and recharges it into the *Equus* Beds aquifer for later use. Phase II of the *Equus* Beds ASR project includes a river intake facility currently (2016) equipped to divert 30 million gallons per day (Mgal/d) and a 30 Mgal/d surface-water treatment facility. Water diverted from the Little Arkansas River is delivered to an adjacent presedimentation basin for solids removal. Waste from the surface-water treatment facility and the presedimentation basin is returned directly to the Little Arkansas River through a residuals return line. The U.S. Geological Survey, in cooperation with the city of Wichita, developed and implemented a hydrobiological monitoring program (HBMP) as part of the ASR project to characterize and quantify the effects of aquifer storage and recovery activities on the Little Arkansas River and *Equus* Beds aquifer water quality.

For this study, data were collected from two surface-water sites, one upstream and one downstream from the residuals return line; one residuals return line site; and two groundwater well sites (each having a shallow and deep part) to characterize and quantify the effects of aquifer storage and recovery activities on Little Arkansas River and *Equus* Beds aquifer water quality: the Little Arkansas River stream from the ASR facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), about 0.03 miles (mi) upstream from the residuals return line site; the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), about 1.68 mi downstream from the residuals return line site; discharge from the Little Arkansas River ASR facility near Sedgwick, Kansas (residuals return line site 375348097262800); 25S 01 W 07BCC01 SMW-S11 near CW36 (MW-7 shallow groundwater well site 375327097285401); 25S01 W 07BCCC02 DMW-S10 near CW36 (MW-7 deep groundwater well site 375327097285402); 25S 01W 07BCCA01 SMW-S13 near CW36 (MW-8 shallow groundwater well site 375332097284801); and 25S 01W 07BCCA02 DMW-S14 near CW36 (MW-8 deep groundwater well site 375332097284802). The U.S. Geological Survey, in cooperation with the city of Wichita, assessed the effects of the ASR Phase II facility residuals return line discharges on stream quality of the Little Arkansas River by measuring or computing continuous physicochemical properties and collecting discrete water-quality and sediment samples for about 2 years pre- (January 2011 through April 2013) and post-ASR (May 2013 through December 2014) Phase II facility operation upstream and downstream from the ASR Phase II facility discharges as well as in the residuals return line. Additionally, habitat variables were quantified and macroinvertebrate and fish communities were sampled upstream and downstream from the ASR

Phase II facility during the study period. To assess the effects of aquifer recharge on *Equus* Beds groundwater quality, continuous physicochemical properties were measured and discrete water-quality samples were collected before and during the onset of Phase II aquifer recharge in four groundwater wells (two well clusters having a shallow and deep well).

The city of Wichita's HBMP presented the opportunity to quantify and characterize Little Arkansas River stream quality upstream and downstream from the ASR facility as well as *Equus* Beds aquifer groundwater quality in response to ASR activities. Continuous measurement and computation of physicochemical properties in real time allowed characterization during conditions and time scales that would not have been possible otherwise and served as a complement to discrete water-quality sampling as well as biological monitoring. Similar future data collection efforts will provide data under different conditions, identify new and changing trends, and allow more powerful statistical analyses.

Little Arkansas River post-ASR streamflow was about 10 times larger than pre-ASR streamflow because of larger post-ASR precipitation. Residuals return line release volumes included a very minimal proportion (0.06 percent) of downstream streamflow volume during the months the ASR facility was operating during 2013 and 2014. Specific conductance was similar upstream and downstream from the ASR facility during the study period. Residuals return line specific conductance was about 68 percent smaller than the specific conductance downstream from the facility. Upstream and downstream water temperature differences were smaller post-ASR than pre-ASR; however, median water temperature upstream and downstream from the facility was within 3 degrees Celsius (°C) or less before and after facility operation onset and did not exceed the Kansas Department of Health and Environment (KDHE) criterion of 32 °C during the study. Median residuals return line temperature was about 23 percent larger than the downstream site and never exceeded the KDHE temperature criterion during the study. Median pH upstream and downstream from the facility varied by less than 2 percent before and after the facility began operating. Upstream and downstream pH exceeded the Kansas aquatic life-support criterion of 8.5 about 8 and 4 percent of the time before facility operation onset and 3 and 4 percent of the time after facility operation onset, respectively. Residuals return line pH never exceeded Kansas aquatic life-support criteria or the ASR Phase II National Pollutant Discharge Elimination System (NPDES) permit limits (6.0 to 9.0) during the study period. Dissolved oxygen was somewhat larger at the downstream site compared to the upstream site during the study and decreased slightly at both sites after the ASR Phase II facility began operating. Upstream and downstream dissolved oxygen differences were smaller post-ASR than pre-ASR. Dissolved oxygen exceeded the Kansas aquatic life-support criterion about 6 percent and 3 percent of the time before facility operation at the upstream and downstream sites, respectively, and about 7 percent of the time after facility operation began at both sites. Residuals return line dissolved oxygen was about 17 percent smaller than the downstream site.

Turbidity generally was smaller at the downstream site compared to the upstream site throughout the study period and decreased at both sites after the ASR Phase II facility began discharging despite a median residuals return line turbidity that was about an order of magnitude larger than the downstream site. Upstream and downstream continuously measured turbidity median differences were larger post-ASR than pre-ASR. Turbidity exceeded the U.S. Environmental Protection Agency (EPA) level III ecoregion 27 guideline of 22.13 formazin turbidity units about 72 percent of the time at the upstream site and 62 percent of the time at the downstream site before facility operation onset, and about 52 percent of the time at the upstream site and 46 percent of the time at the downstream site after facility operation onset. Regression-computed total suspended solids and suspended-sediment concentrations at the downstream site were generally smaller after the onset of facility operation, likely because of larger post-ASR streamflow and dilution. Because the ASR facility operates only during high-flow conditions, physicochemical properties and water-quality concentrations of stream water and residual return line releases are more indicative of higher flow event conditions than the distribution of all continuously collected water-quality data. During events, stream specific conductance, pH, and dissolved oxygen are smaller than during base-flow conditions, and turbidity is larger. The small delay (as much as 5 hours) between water withdrawal and residual releases could prolong event conditions for pH, specific conductance, and turbidity; however, effects would likely be localized near the residuals return line outflow.

None of the discretely measured water-quality constituents (dissolved and suspended solids, primary ions, suspended sediment, nutrients, carbon, trace element, viral and bacterial indicator, and pesticides) in surface water were significantly different between the upstream and downstream sites after the ASR Phase II facility began discharging; however, pre-ASR calcium, sodium, hardness, manganese, and arsenate concentrations were substantially larger at the upstream site, indicating that some water-quality conditions at the upstream and downstream sites were more similar post-ASR. Dissolved solids at both surface-water sites upstream and downstream from the ASR Phase II facility were about 18 percent to 27 percent smaller after the facility began operating. Median dissolved solids concentrations at all sites during the study period did not exceed the Federal Secondary Maximum Contaminant Level (SMCL) although occasionally individual samples from all sites did. Most of the primary dissolved solids constituents decreased at both sites after the facility began operation; however, dilution during higher post-ASR streamflow conditions compared to pre-ASR streamflow conditions complicate comparisons. Median primary dissolved solids constituent concentrations in the residuals return line, with the exception of potassium, were always at least about 10 percent smaller than median primary dissolved solids constituent concentrations at the upstream and downstream sites after the facility began discharging. Discretely collected total suspended solids concentrations were similar among the upstream and downstream sites

before the facility began operating but were about 27 percent smaller at the downstream site after the facility began operating, despite the residuals return line total suspended solids concentration being 15 times larger than the downstream site. Discretely collected post-ASR suspended-sediment concentration medians were larger than pre-ASR concentrations at both sites, which is contradictory to the continuously computed suspended-sediment concentration medians at the downstream site that decreased post-ASR. These differences in suspended-sediment concentration medians highlight the utility of continuous monitoring by capturing temporal variability and the need to continue continuous monitoring as a complement to discrete water-quality sampling.

Nitrate concentrations were smaller at the upstream site during the entire study period and decreased about 38 and 18 percent at the upstream and downstream sites, respectively, after the facility began operating despite the residuals return line nitrate being about 100 percent larger than the downstream site. Median total nitrogen was similar upstream and downstream from the facility before operation and about 26 percent larger downstream from the facility after operation began. Residuals return line total nitrogen was about 250 percent larger than the downstream site. All upstream, downstream, and residuals return line total nitrogen samples collected during the study period exceeded the EPA guideline of 0.71 milligrams per liter (mg/L) for level III ecoregion streams. Phosphorus species generally were smaller downstream from the ASR facility and were larger upstream and downstream from the facility after the facility began operating. Total phosphorus was similar upstream and downstream from the ASR facility despite the residuals return line total phosphorus being about 200 percent larger than the downstream site. All upstream, downstream, and residuals return line total phosphorus samples collected during the study period exceeded the EPA guideline of 0.09 mg/L for level III ecoregion streams.

Median arsenic concentrations in surface water were 7 to 19 percent larger before the ASR Phase II facility began operating and were similar upstream and downstream from the facility after operation onset, likely because of larger post-ASR streamflow and dilution. Median residuals return line arsenic concentration was about 38 percent smaller than downstream from the facility. Surface water arsenic concentrations exceeded the EPA Maximum Contaminant Level (MCL) of 10 micrograms per liter ( $\mu\text{g/L}$ ) in about 30 to 55 percent of samples before the facility began operating and about 43 percent of samples after the facility began operating. Arsenic concentrations never exceeded the MCL in the residuals return line during the study period.

All indicator bacterial and viral densities upstream and downstream from the ASR Phase II facility generally were larger after the facility began operating, likely because of runoff during larger streamflows during this period. The upstream site's *Escherichia coli* (*E. coli*) densities exceeded the State of Kansas' primary contact criterion of 262 colonies per 100 milliliters (col/100 mL) in about 33 percent of samples before the facility began operating and 75 percent of samples after the

facility began operating; the downstream site's *E. coli* densities exceeded 262 col/100 mL in about 28 percent of samples before facility operation onset and about 63 percent of samples after facility operation onset. All residuals return line *E. coli* samples exceeded 262 col/100 mL. The upstream site's fecal coliform densities exceeded the State of Kansas' primary contact criterion of 200 col/100 mL in about 61 percent of samples before the facility began operating and 88 percent of samples after the facility began operating; the downstream site's fecal coliform densities exceeded 200 col/100 mL in about 44 percent of samples before facility operation onset and about 63 percent of samples after facility operation onset. All residuals return line fecal coliform sample densities exceeded 200 col/100 mL.

Pesticide concentrations generally were similar upstream and downstream from the ASR Phase II facility and larger after facility operation onset. Residuals return line pesticide concentrations generally were similar to surface-water concentrations. Atrazine concentrations were larger at the site upstream from the ASR Phase II facility and at both sites after the facility began operating, likely because of runoff during larger streamflows during this period. Atrazine concentrations at the site upstream from the facility exceeded the EPA MCL of 3.0 µg/L in about 20 percent of samples before the facility began operating and 50 percent of samples after the facility began operating. Atrazine concentrations downstream from the facility exceeded the MCL in about 25 and 38 percent of samples before and after facility operation onset, respectively. Residuals return line atrazine concentrations exceeded the MCL in about 43 percent of samples.

Nutrients (nitrogen and phosphorus species) and carbon (total and organic) in streambed sediment generally were larger downstream from the ASR Phase II facility during the study period and smaller at both surface-water sites after the facility began operating. Residuals return line total nitrogen, total phosphorus, and total and organic carbon was 50 percent larger, 13 percent smaller, and 27 percent larger than the downstream site, respectively. Streambed-sediment trace element concentrations at the surface-water sites generally were similar among sites before and after the facility began operating. Residuals return line sediment trace element concentrations were larger than those downstream from the facility with the exception of barium, calcium, manganese, selenium, silver, sodium, and strontium. No trace element samples from any site exceeded their respective probable effect concentration (PEC). Pesticides were the most frequently detected organic wastewater compound (OWC) at all sites during the study period and there were no clear patterns in OWC concentrations before and after the ASR Phase II facility began operating.

Overall habitat scores were indicative of suboptimal conditions upstream and downstream from the ASR Phase II facility throughout the study period. Channel conditions and characteristics scores were indicative of marginal conditions at the upstream site before and after the ASR Phase II facility began operating and the downstream site before facility operation onset. Channel conditions and characteristics at

the downstream site after the facility began discharging were indicative of suboptimal conditions. Bank and riparian conditions were suboptimal at the upstream site and optimal at the downstream site during the entire study period. Aquatic habitat availability was marginal at the upstream and downstream sites during the study period. Substrate fouling and sediment deposition mean scores indicated marginal conditions at the upstream and downstream sites during the study period, demonstrating that sediment deposition was evident pre- and post-ASR and no substantial changes in these habitat characteristics were noted after the ASR facility began discharging.

Macroinvertebrate community composition, including functional feeding, behavioral, and tolerance groups, generally was similar among sites during the study period. Predators and collector-gatherers were the two most common macroinvertebrate functional feeding groups throughout the study. Among macroinvertebrate behavioral groups, most organisms were swimmers and sprawlers during the study period. Intolerant macroinvertebrates had the lowest abundance among tolerance groups at both sites for the duration of the study. Several indicator metrics were significantly different between the upstream and downstream sites. These included 14 metrics before the ASR Phase II facility began operating and 6 metrics after the facility began operating, indicating that the upstream and downstream sites were more similar post-ASR; however, higher post-ASR streamflow conditions compared to pre-ASR streamflow conditions complicate comparisons. Upstream-downstream comparisons in macroinvertebrate aquatic-life-support metrics did not reveal any significant differences for post-ASR time periods and neither site was fully-supporting for any of the four metrics. Overall, using macroinvertebrate aquatic life-support criteria from the Kansas Department of Health and Environment, both upstream and downstream sites were classified as partially-supporting both before and after the onset of ASR facility operations.

Shiners were the most dominant fish group at the upstream and downstream sites during the study period. Fish community trophic status generally was similar among sites during the study period. Omnivores increased and insectivores and piscivores decreased at both the upstream and downstream sites after the ASR Phase II facility began operating. Fish community tolerance groups generally were similar among sites during the study period. Tolerant species increased and intermediately tolerant and intolerant species decreased at both sites after the ASR Phase II facility began operating. Fish community Little Arkansas River Basin Index of Biotic Integrity scores at the upstream and downstream sites were indicative of fair-to-good conditions before the facility began operating and decreased to fair conditions after the facility began operating at both sites.

Groundwater physicochemical changes concurrent with the beginning of recharge operations at the Sedgwick basin were more pronounced in shallow groundwater. No constituent concentrations in the pre-recharge period in comparison to the post-recharge period increased to concentrations exceeding drinking-water regulations; however, nitrate concentrations

decreased significantly by 90 percent from a 3 percent pre-recharge EPA MCL (10 mg/L) exceedance to nonexceedance after recharge onset. Shallow groundwater chemical concentrations or rates of detection increased after artificial recharge began for the ions potassium, chloride, and fluoride; phosphorus and organic carbon species; trace elements barium, manganese, nickel, arsenate, arsenic, and boron; agricultural pesticides atrazine, metolachlor, metribuzin, and simazine; organic disinfection byproducts bromodichloromethane and trichloromethane; and gross beta levels. Additionally, water temperature and pH were larger after recharge began; and total solids and slime-forming bacteria concentrations and densities were smaller. Total solids, nitrate, slime-forming bacteria, and selenium significantly decreased; and potassium, chloride, nickel, arsenic, fluoride, phosphorus, carbon species, and gross beta levels significantly increased in shallow groundwater after artificial recharge. These significant changes in shallow groundwater concentrations were likely caused by the artificially recharged treated surface water and natural infiltration of precipitation.

Changes in deep groundwater chemistry were less pronounced than changes in shallow wells before and after recharge activities. Although increased concentrations were statistically significant for dissolved organic carbon, absolute changes in the mean and median concentrations were minimal. Bacteria detection frequencies increased for iron-related bacteria and sulfate-reducing bacteria. Results of biological activity reaction tests indicated that water quality microbiology was different before and after artificial recharge began; at times, these differences may lead to changes in dominant bacterial populations that, in turn, may lead to formation and expansion in populations that may cause bioplugging and other unwanted effects. Manganese and nickel concentrations were significantly larger after recharge and frequency of detections increased for arsenate. Frequency of detections increased for several brominated and chlorinated organic compounds. Similar to shallow groundwater, gross beta levels were significantly larger in deep groundwater after recharge began.

Changes in groundwater chemistry can affect mineral saturation, resulting in precipitation and dissolution of the minerals. Calcite, iron (II) hydroxide, hydroxyapatite, and similar minerals, had shifts in saturation indices (SI) that generally were from under-saturation toward equilibrium and, in some cases, toward over-saturation. These shifts toward neutral SI might suggest reduced weathering of these minerals, if present in the aquifer. Even for minerals at equilibrium, these minerals may react to move in and out of solution with reaction rates governed by kinetic factors such as accessible reaction sites on particle surfaces and temperature, which was notably warmer after recharge. Chemical weathering in the shallow parts of the aquifer may be accelerated because of the increased water temperatures, and the system is more vulnerable to clogged pores and mineral dissolution as the equilibrium state is affected by recharge and withdrawal. When oversaturation is indicated for iron minerals, plugging of the aquifer materials may happen.

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# Appendixes

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## Appendix 1. Water-Quality Data of the Little Arkansas River and *Equus* Beds Aquifer, Aquifer Storage and Recovery Project, South-Central Kansas, 2011–14

Appendix tables 1–1 through 1–10 are available for download at <http://dx.doi.org/10.3133/sir20165042>. See the Abbreviations list in the front of this report for definitions of variables in the appendixes.

**Table 1–1.** Discretely collected constituents from the residual basin aquifer storage and recovery treatment plant near Sedgwick, Kansas (site 375330097290200), diverted water at the Sedgwick recharge site, Kansas (site 375331097285301), and treated source water at the high service pump station (site 375338097290800; part of Aquifer Storage and Recovery treatment facility), July 2012 through September 2014.

**Table 1–2.** Sample collection dates and streamflow conditions for discrete water-quality samples collected at surface-water sites (upstream and downstream sites 375350097262800 and 0714100, respectively), the residuals return line site (375348097262800), and groundwater well sites (MW–7 shallow, 375327097285401; MW–7 deep, 375327097285402; MW–8 shallow, 375332097284801; and MW–8 deep, 375332097284802), March 2011 through September 2014.

**Table 1–3.** High flow summary statistics for continuously (hourly) measured physicochemical properties and computed water-quality constituents of interest for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), discharge from the Little Arkansas River aquifer storage and recovery facility (residuals return line site 375348097262800) near Sedgwick, Kansas, January 2011 through December 2014.

**Table 1–4.** Regression models and summary statistics for continuous dissolved and total organic carbon concentration computations for the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), March 2012 through September 2014.

**Table 1–5.** Dissolved and total organic carbon datasets using chromophoric (colored) dissolved organic matter and turbidity as explanatory variables for the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), 2012 through 2014.

**Table 1–6.** Discretely collected during high flow condition water-quality constituent summary statistics for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), and discharge from the Little Arkansas River aquifer storage and recovery facility (residuals return line site 375348097262800) near Sedgwick, Kansas, March 2011 through September 2014.

**Table 1–7.** Discrete organic material characterization data for samples collected at the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), and discharge from the Little Arkansas River aquifer storage and recovery facility (residuals return line site 375348097262800) near Sedgwick, Kansas, March 2011 through September 2014.

**Table 1–8.** Macroinvertebrate taxa abundances identified for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), and the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), April 2011 through August 2014.

**Table 1–9.** Seasonal and annual mean selected macroinvertebrate metric values and Kansas Department of Health and Environment aquatic life-support status for the Little Arkansas River upstream from the aquifer storage and recovery facility near Sedgwick, Kansas (upstream surface-water site 375350097262800), and the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), April 2011 through August 2014.

**Table 1–10.** Constituents analyzed but not detected in groundwater samples for sites near the recharge basin near Sedgwick, Kansas, January 2011 to December 2014.

## Appendix 2. S+® Output of Regression Model Development and Graphs from Simple Linear Regression Analysis

```

*** Linear Model ***

Call: lm(formula = LOG10DOC ~ LOG10CDOM, data = SEDG.DOC.ALL.PTS.REM, na.action =
na.exclude)
Residuals:
    Min       1Q   Median       3Q      Max
-0.1558 -0.06308 -0.002884  0.06727  0.1295

Coefficients:
            Value Std. Error  t value Pr(>|t|)
(Intercept) -0.7888   0.1284   -6.1420  0.0000
LOG10CDOM    0.7973   0.0636   12.5298  0.0000

Residual standard error: 0.08401 on 37 degrees of freedom
Multiple R-Squared:  0.8093    Adjusted R-squared:  0.8041
F-statistic: 157 on 1 and 37 degrees of freedom, the p-value is 6.994e-015
58 observations deleted due to missing values

Correlation of Coefficients:
      (Intercept)
LOG10CDOM -0.9945

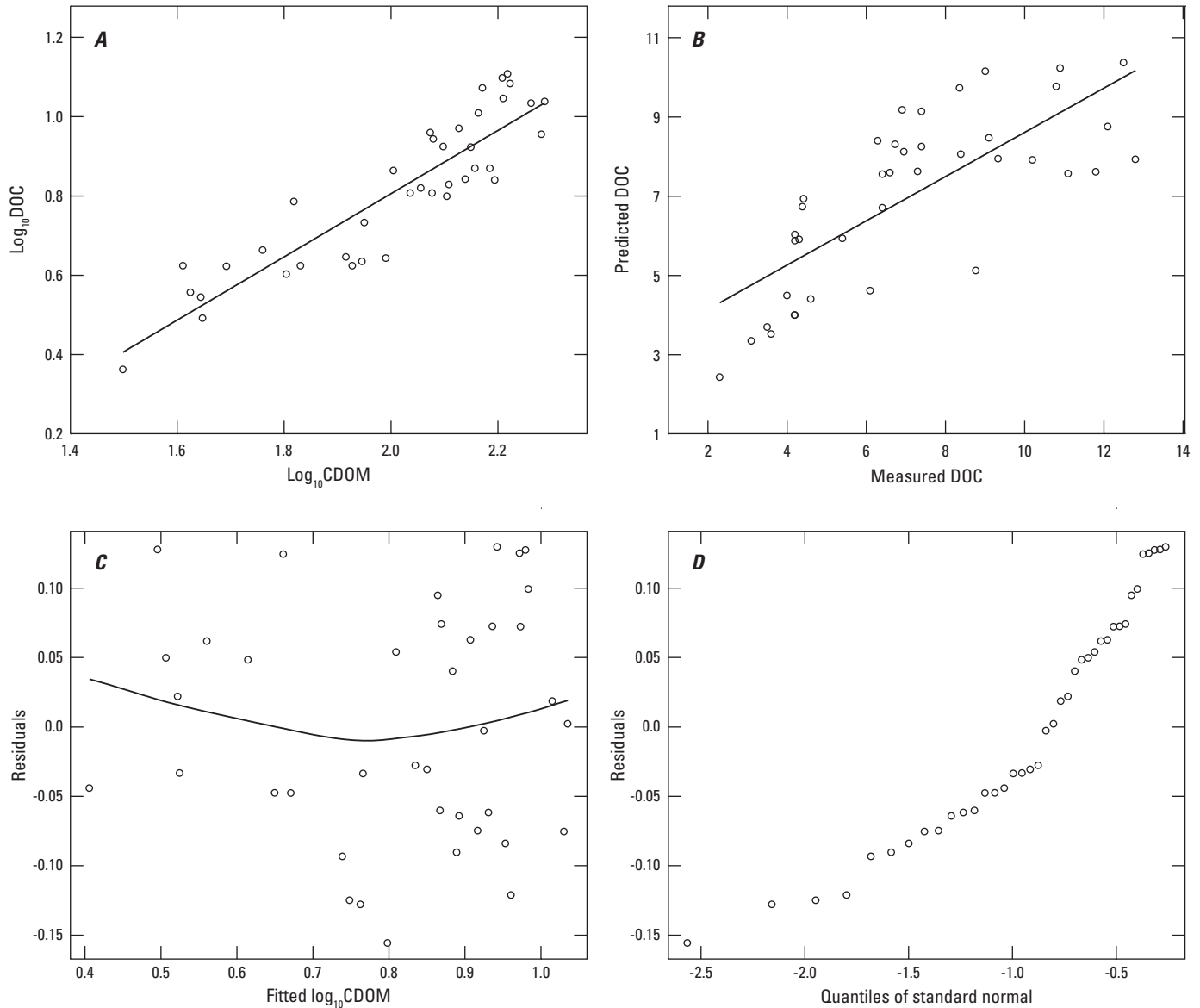
Analysis of Variance Table

Response: LOG10DOC

Terms added sequentially (first to last)
      Df Sum of Sq  Mean Sq  F Value    Pr(F)
LOG10CDOM  1  1.108087  1.108087  156.9954  6.994405e-015
Residuals 37  0.261149  0.007058

```

**Figure 2-1.** S+® output of regression model development using chromophoric (colored) dissolved organic matter (CDOM) as the explanatory variable for dissolved organic carbon (DOC) from the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), 2009 through 2012.



**EXPLANATION**

- Line of best fit
- DOC Dissolved organic carbon, in milligrams per liter
- CDOM Chromophoric (colored) dissolved organic material

**Figure 2-2.** S+® output graphs from simple linear regression analysis from the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), 2012 through 2014. *A*, log-transformed chromophoric (colored) dissolved organic matter (CDOM) versus log-transformed dissolved organic carbon (DOC) concentrations; *B*, measured versus predicted DOC concentrations; *C*, computed log-transformed DOC concentrations versus regression residuals; and, *D*, standard normal quantiles versus regression residuals.

```

*** Linear Model ***

Call: lm(formula = TOC ~ TBY + LOG10CDOM, data = SEDG.TOC.ALL.PTS.REM, na.action =
na.exclude)
Residuals:
    Min       1Q   Median       3Q      Max
-1.684 -0.6288 -0.3303  0.4346  2.525

Coefficients:
                Value Std. Error  t value Pr(>|t|)
(Intercept) -12.3672    2.8405   -4.3538  0.0007
          TBY   0.0630    0.0081    7.8043  0.0000
    LOG10CDOM  8.8422    1.5540    5.6899  0.0001

Residual standard error: 1.26 on 14 degrees of freedom
Multiple R-Squared:  0.9382    Adjusted R-squared:  0.9294
F-statistic: 106.3 on 2 and 14 degrees of freedom, the p-value is 3.431e-009
112 observations deleted due to missing values

Correlation of Coefficients:
      (Intercept)      TBY
TBY      0.4269
LOG10CDOM -0.9813      -0.5690

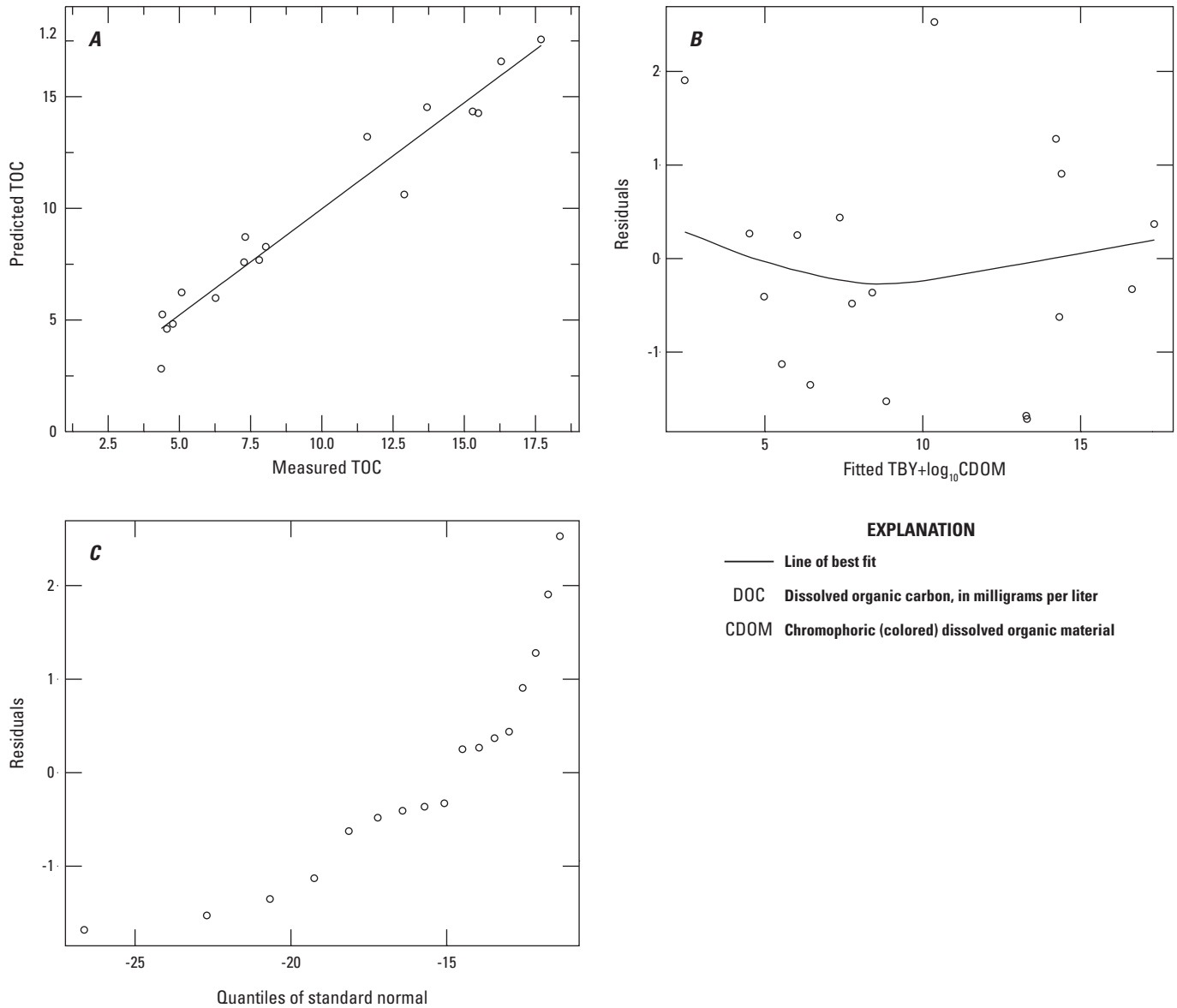
Analysis of Variance Table

Response: TOC

Terms added sequentially (first to last)
      Df Sum of Sq Mean Sq F Value    Pr(F)
TBY    1  286.2619 286.2619 180.2776 0.00000000218
LOG10CDOM 1   51.4072  51.4072  32.3744 0.00005584709
Residuals 14   22.2305   1.5879

```

**Figure 2–3.** S+® output of regression model development using chromophoric (colored) dissolved organic matter (CDOM) and turbidity (TBY) as explanatory variables for total organic carbon (TOC) from the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), 2009 through 2012.



**Figure 2-4.** S+® output graphs from simple linear regression analysis using turbidity (TBY) and log-transformed chromophoric (colored) dissolved organic matter (CDOM) as explanatory variables for total organic carbon (TOC) concentrations from the Little Arkansas River near Sedgwick, Kansas (downstream surface-water site 07144100), 2012 through 2014. *A*, measured versus predicted TOC concentrations; *B*, computed TOC concentrations versus regression residuals; and, *C*, standard normal quantiles versus regression residuals.

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