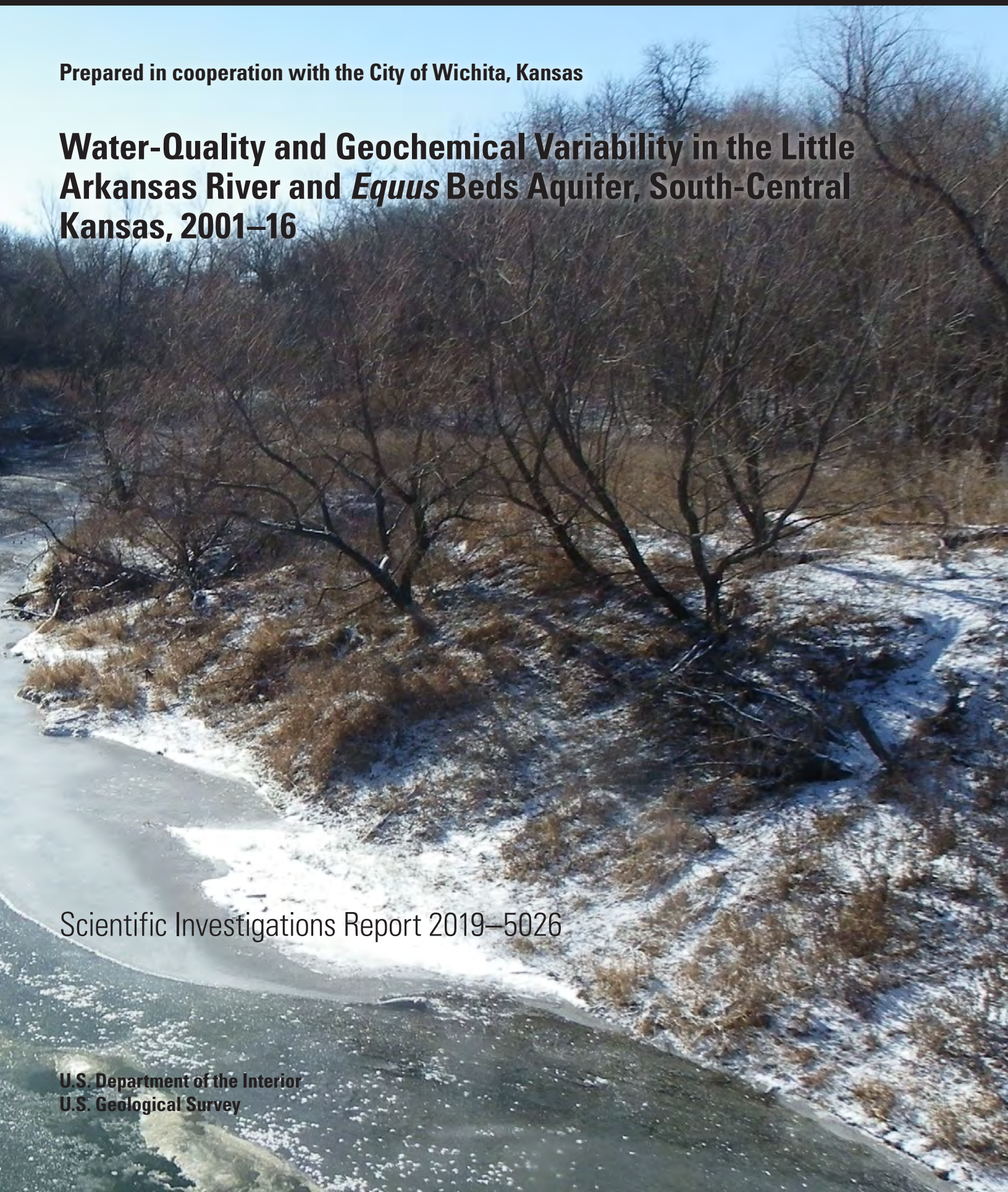


Prepared in cooperation with the City of Wichita, Kansas

Water-Quality and Geochemical Variability in the Little Arkansas River and *Equus* Beds Aquifer, South-Central Kansas, 2001–16

Scientific Investigations Report 2019–5026

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

Cover. The Little Arkansas River near Sedgwick, Kansas, January 2018. Photograph by Trudy Bennett, U.S. Geological Survey.

Water-Quality and Geochemical Variability in the Little Arkansas River and *Equus* Beds Aquifer, South-Central Kansas, 2001–16

By Mandy L. Stone, Brian J. Klager, and Andrew C. Ziegler

Prepared in cooperation with the City of Wichita, Kansas

Scientific Investigations Report 2019–5026

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

U.S. Department of the Interior
DAVID BERNHARDT, Secretary

U.S. Geological Survey
James F. Reilly II, Director

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

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment—visit https://www.usgs.gov or call 1–888–ASK–USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit https://store.usgs.gov.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Although this information product, for the most part, is in the public domain, it also may contain copyrighted materials as noted in the text. Permission to reproduce copyrighted items must be secured from the copyright owner.

Suggested citation:
Stone, M.L., Klager, B.J., and Ziegler, A.C., 2019, Water-quality and geochemical variability in the Little Arkansas River and *Equus* Beds aquifer, south-central Kansas, 2001–16: U.S. Geological Survey Scientific Investigations Report 2019–5026, 79 p., https://doi.org/10.3133/sir20195026.

ISSN 2328-0328 (online)

Contents

Acknowledgments viii
Abstract 1
Introduction 2
Equus Beds Aquifer Storage and Recovery Project 4
Purpose and Scope 4
Description of Study Area and Background Information 5
Recent Investigations 6
Methods 6
Sampling Sites 6
Data Collection 7
Continuous Water-Quality Monitoring 7
Discrete Water-Quality Sampling 8
Data Analysis 8
Water-Chemistry Data 8
Geochemical Modeling 8
Quality Assurance and Quality Control 9
Water Quality of the Little Arkansas River 14
Little Arkansas River Streamflow 14
Discrete Little Arkansas River Water Quality 15
Water Quality and Geochemistry of the *Equus* Beds Aquifer 15
Equus Beds Aquifer Physicochemical Properties 15
Solids and Primary Ions 39
Nutrients and Carbon 45
Coliform Bacteria and Viral Indicators 55
Iron-Related, Slime-Forming, and Sulfate-Reducing Bacteria 55
Trace Elements and Associated Compounds 56
Trace Element Detections and Exceedances 56
Iron 56
Manganese 56
Arsenic Species 57
Organic Compounds 65
Radioactivity 65
Geochemistry 65
Summary and Conclusions 70
References Cited 72
Appendix 1 79

Figures

1. Maps showing location of the study area near Wichita, south-central Kansas 3
2. Graph showing relation between the Yellow Springs Incorporated 6136 optical turbidity and EXO Turbidity Smart sensor measurements at the Little Arkansas River near Sedgwick, Kansas, September 2014 through March 2015 10

3–8. Maps showing:
   3. Mean specific conductance in the *Equus* Beds aquifer, 2001–16, south-central Kansas 40
   4. Mean oxidation-reduction potential in the *Equus* Beds aquifer, 2001–16, south-central Kansas 42
   5. Mean bromide concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas 46
   6. Mean chloride concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas 48
   7. Mean sulfate concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas 50
   8. Mean nitrate plus nitrite concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas 52

9. Graphs showing relation between shallow index well mean constituents ranges in the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16 54

10–12. Maps showing:
   10. Mean dissolved iron concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas 58
   11. Mean dissolved manganese concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas 60
   12. Mean dissolved arsenic concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas 62

13. Graphs showing relations between shallow index well oxidation reduction potential ranges and mean depth to water level and mean dissolved arsenic concentration in the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16 64
14. Maps showing mean α radioactivity concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas 66
15. Boxplots showing select mineral saturation indices in the *Equus* Beds aquifer, south-central Kansas, 2001–16 69

Tables

1. Annual total and mean annual precipitation during 2001 through 2016 and mean annual precipitation during 1900 through 2016 at the “MT HOPE” station 5
2. Continuously measured physicochemical property summary statistics for *Equus* Beds aquifer groundwater sites, 2001–16 11
3. Physicochemical summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16 16
4. Solids and primary ions summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16 17
5. Nutrient and carbon species summary statistics of discrete groundwater samples for the *Equus* aquifer index wells near Sedgwick, Kansas, 2001–16 19

6. Bacterial and viral indicator summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16 20
7. Trace element summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16 21
8. Dissolved arsenic species summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16 23
9. Organic compound summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16 24
10. Radioactivity summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16 32
11. Mineral saturation indices for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16 33

Appendix Tables

[The appendix tables are available for download at https://doi.org/10.3133/sir20195026]

1.1. Data collection sites for the *Equus* Beds ASR project 79
1.2. Summary statistics for continuously measured physicochemical properties for the Little Arkansas River at Highway 50 near Halstead, Kansas, and near Sedgwick, Kansas, during 2001 through 2016 79
1.3. Summary statistics for continuously measured turbidity data measured with different sensors at the Little Arkansas River near Sedgwick, Kansas, September 2014 through March 2015 79
1.4. Relative percentage differences for replicate, and detection percentages for blank discrete water-quality samples for the Little Arkansas River and *Equus* Beds aquifer sites near Sedgwick, Kansas, 2001–16 79
1.5. Discrete sample water-quality constituent summary statistics for the Little Arkansas River sites near Sedgwick, Kansas, 2001–16 79
1.6. Discrete sample physicochemical groundwater-quality constituent summary statistics for the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16 79
1.7. Solids and primary ions summary statistics of discrete groundwater samples for the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16 79
1.8. Nutrient and carbon species summary statistics of discrete groundwater samples for the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16 79
1.9. Bacterial and viral indicator summary statistics of discrete groundwater samples for the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16 79
1.10. Trace element summary statistics of discrete groundwater samples for the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16 79
1.11. Dissolved arsenic species summary statistics of discrete groundwater samples for the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16 79
1.12. Organic compound summary statistics of discrete groundwater samples for the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16 79
1.13. Radioactivity summary statistics of discrete groundwater samples for the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16 79
1.14. Mineral saturation indices for the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16 79

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
million gallons (Mgal)	3,785	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Radioactivity	
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)

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

$$°F = (1.8 \times °C) + 32.$$

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88) or the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Supplemental Information

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

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

Densities of bacterial and viral indicators are in colony forming units per milliliter (cfu/mL) or per 100 milliliters (cfu/100 mL), most probable number per 100 milliliters (mpn/100 mL), or plaque forming units per 100 milliliters (pfu/100 mL).

Aquifer storage volume is in billion gallons (Bgal).

Turbidity is in formazin nephelometric units (FNU) or nephelometric turbidity units (NTU).

Oxidation-reduction potential is in millivolts (mV).

Abbreviations

>	greater than
<	less than
≤	less than or equal to
ASR	aquifer storage and recovery
E. coli	*Escherichia coli*
EPA	U.S. Environmental Protection Agency
fDOM	fluorescent dissolved organic matter
GRDP	Groundwater Recharge Demonstration Project
HBMP	hydrobiological monitoring program
ILWS	Integrated Local Water Supply
IW	index well
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MRDL	maximum residual disinfectant level
NWQL	National Water Quality Laboratory
ORP	oxidation-reduction potential
QA/QC	quality assurance and quality control
RPD	relative percentage difference
SI	saturation index
SMCL	secondary maximum contaminant level
TT	treatment technique
USGS	U.S. Geological Survey
YSI	Yellow Springs Incorporated

Acknowledgments

The authors thank Mike Jacobs, Scott Macey, and Shawn Maloney of the City of Wichita 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 also thank Groundwater Management District No. 2 personnel, including manager Tim Boese.

The authors thank the U.S. Geological Survey staff that assisted with data collection, analysis, and interpretation, including Trudy Bennett, Barb Dague, Carlen Collins, John Rosendale, David Eason, Courtney Huston, Patrick Eslick, and Diana Restrepo-Osorio.

Water-Quality and Geochemical Variability in the Little Arkansas River and *Equus* Beds Aquifer, South-Central Kansas, 2001–16

By Mandy L. Stone, Brian J. Klager, and Andrew C. Ziegler

Abstract

The city of Wichita's water supply currently (2019) comes from two primary sources: Cheney Reservoir and the *Equus* Beds aquifer. The *Equus* Beds aquifer storage and recovery project was developed to help the city of Wichita meet increasing future water demands. Source water for artificial recharge comes from the Little Arkansas River during above-base-flow conditions, is treated using National Primary Drinking Water Regulations as a guideline, and is injected into the *Equus* Beds aquifer through recharge wells or surface spreading basins for later use. The *Equus* Beds aquifer storage and recovery project currently (2019) consists of two coexisting phases. Phase I began in 2007 and captures Little Arkansas River water and indirect streambank diversion well water for aquifer recharge using 4 wells and 2 recharge basins. Phase II began in 2013 and currently (2019) includes a surface-water treatment facility, a river intake facility, eight recharge injection wells, and a third recharge basin. The U.S. Geological Survey, in cooperation with the City of Wichita, completed this study to summarize water-quality and geochemical variability of the *Equus* Beds aquifer. Data in this report can be used to establish baseline conditions before implementing artificial aquifer recharge further, document groundwater quality, evaluate changing conditions, identify environmental factors affecting groundwater, provide science-based information for decision making, and help meet regulatory monitoring requirements.

Physicochemical properties were measured and water-quality data were collected from 2 Little Arkansas River surface-water sites and 63 *Equus* Beds aquifer groundwater sites, including 38 areal assessment index wells (IWs) during 2001 through 2016. Data collection included discrete samples and additional continuous measurements at selected sites. Discretely collected samples were analyzed for physicochemical properties, dissolved solids, primary ions, nutrients (nitrogen and phosphorus species), organic carbon, indicator bacteria, trace elements, arsenic species, organic compounds, and radioactivity. This report focuses discussion on aquifer water quality. Federal drinking-water criteria were used to evaluate aquifer water quality. Primary drinking-water criteria are those that are enforceable for public drinking water. Secondary criteria are those that can cause aesthetics or tastes that are unpleasant.

Continuously collected data at a subset of sites included streamflow, groundwater levels, water temperature, specific conductance, pH, oxidation-reduction potential (ORP), dissolved oxygen, turbidity, nitrate plus nitrite, and fluorescent dissolved organic matter. Continuous measurement of physicochemical properties in near-real time allowed characterization of Little Arkansas River surface water and *Equus* Beds aquifer groundwater during conditions and time scales that would not have been possible otherwise and served as a complement to discrete water-quality sampling. During 2001 through 2016, less than 1 percent of chloride and nitrate plus nitrite, 7 percent of dissolved iron, 48 percent of dissolved manganese, 12 percent of dissolved arsenic, and 39 percent of atrazine detections in surface-water samples exceeded their respective Federal primary or secondary drinking-water criteria. None of the surface-water samples collected exceeded the Federal sulfate criterion, and every sample had detections of total coliform bacteria during the study.

Constituents of concern in the *Equus* Beds aquifer exceeded their respective Federal criteria throughout the study period and included chloride, sulfate, nitrate plus nitrite, *Escherichia coli* (*E. coli*), total coliforms, and dissolved iron and arsenic species. About 5 percent of shallow (less than 80 feet) and 7 percent of deep (greater than 80 feet) IW chloride sample concentrations exceeded the secondary Federal criterion of 250 milligrams per liter (mg/L). Chloride tended to exceed its criterion in shallow and deep wells along the Arkansas River and near Burrton, Kansas, an area with past oil and gas activities. Chloride concentrations near Burrton were larger in the deep parts of the aquifer. About 18 percent of shallow and 13 percent of deep IW sulfate sample concentrations exceeded the secondary Federal criterion of 250 mg/L. Mean sulfate concentrations tended to exceed the criterion in the central part of the study area. Shallow IW mean nitrate plus nitrite (hereafter referred to as "nitrate") was substantially larger than mean deep IW nitrate. Geochemical conditions in the deeper aquifer reduced forms of nitrogen to species such as ammonia. About 15 percent of shallow and less than 1 percent of deep IW nitrate sample concentrations exceeded the Federal

criterion of 10 mg/L. Mean shallow IW nitrate concentrations exceeded the criterion in the northeastern and southeastern parts of the study area; on average, deep IW nitrate concentrations did not exceed the criterion. *E. coli* and fecal coliform bacteria detections were usually at or near the detection limit. *E. coli* was detected in 3 percent of shallow and deep IWs, and fecal coliform bacteria were detected in 8 percent of shallow and 6 percent of deep IWs. Total coliforms were detected in 24 percent of shallow and 12 percent of deep IWs. *E. coli* coliphage was detected in two shallow IW samples (1 percent of samples) at the detection limit and was not detected in deep IW samples.

Dissolved iron was detected in 51 percent of shallow and 62 percent of deep IW samples. Dissolved iron concentrations exceeded the secondary Federal criterion of 0.3 mg/L in 38 percent of shallow and 46 percent of deep IW samples. Mean dissolved iron concentrations were largest mostly in the central and northwest part of the study area corresponding to an area of the aquifer where aquifer material is more clay-rich. The distribution of large dissolved iron concentrations was similar to that of large sulfate concentrations. About 55 percent of shallow and 92 percent of deep IW dissolved manganese samples exceeded the secondary Federal criterion of 0.05 mg/L. Almost all samples from the central and northern parts of the study area had mean dissolved manganese concentrations that exceeded the Federal criterion in the shallow part of the aquifer. Mean dissolved manganese concentrations in the shallow part of the aquifer were substantially large (greater than 1,000 micrograms per liter [µg/L]) in wells near the Little Arkansas River and in the central part of the study area because of chemically reducing conditions in the aquifer that likely related to larger percentages of clay in the aquifer material.

Concentrations of dissolved arsenic species generally were larger in the deep parts of the aquifer. Arsenite was the dominant form of arsenic on average in shallow (52 percent) and deep (55 percent) IWs. About 12 percent of shallow and 34 percent of deep IW dissolved arsenic sample concentrations exceeded the Federal primary drinking criterion of 10 µg/L. Shallow IW dissolved arsenic concentrations were larger near the Little Arkansas River and the center of the study area; large shallow IW dissolved arsenic concentrations (10–50 µg/L) in the center of the study area correspond to areas that have had the most water-level recovery since the historical low in 1993. Mean ORP in shallow IWs generally decreased with increasing water-level depths and were inversely related to mean dissolved arsenic concentrations because of more reducing conditions (smaller ORP) at larger depths below the land surface. Larger dissolved arsenic concentrations in the shallow parts of the aquifer were associated with decreases in water levels and a subsequent decrease in ORP and thus more reducing conditions.

Atrazine was detected in about 58 percent of shallow and 28 percent of deep IWs and did not exceed the primary Federal criterion of 3 µg/L in any groundwater samples. Atrazine concentrations in shallow IWs generally were largest in the northwest part of the study area near the North Branch Kisiwa Creek, and atrazine concentrations in deep IWs generally were largest most often in the southern part of the study area. Gross α radioactivity concentrations exceeded the primary Federal criterion of 15 picocuries per liter in 4 percent of shallow IW samples. Gross α and gross β radioactivity concentrations generally were larger in the southern third of the aquifer.

Most groundwater-sample-simulated minerals saturation indices (SIs) were consistently negative (undersaturated). Minerals that had SI values that were consistently or typically positive (oversaturated) included iron oxide, hydroxide, and quartz-group minerals. Several SI values for arsenic- and manganese-bearing minerals were consistently negative. Some manganese-bearing mineral SI values ranged from undersaturated to oversaturated in shallow and deep IWs during the study. Several carbonate minerals in shallow and deep IWs varied across their equilibrium state. Calcite SI values were larger more often in the deep parts of the aquifer and did not show a clear distributional pattern. Mean and median calcite SI values for shallow and deep IWs were negative (undersaturated) indicating the potential for calcite dissolution if calcite is present for a substantial part of the study period. However, some individual calcite SI values in this study indicated saturation and subsequent calcite precipitation may occur in the study area, potentially resulting in formation of calcite mineral deposits that may reduce efficiency of injection wells. SI values with respect to iron hydroxide varied across their equilibrium states. Mean and median SI values with respect to iron hydroxide were undersaturated in shallow and deep IWs; however, some samples had positive SI values indicating there is potential for iron hydroxide precipitation, possibly caused by leaching and oxidation of iron-containing minerals, like pyrite, in the aquifer material.

Introduction

The city of Wichita's water supply currently (2019) comes from two primary sources: Cheney Reservoir, which was completed between 1962 and 1965, and the *Equus* Beds aquifer (fig. 1) Wichita well field, which was completed in the 1950s. An Integrated Local Water Supply (ILWS) Plan was developed by the City of Wichita's Water Utilities Department (Warren and others, 1995) because future water demands were expected to exceed supply. A major component of the ILWS Plan was to increase the city of Wichita's available water supply for 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 (fig. 1) during above-base-flow conditions, treats it using the National Primary Drinking Water Regulations (U.S. Environmental Protection Agency, 2009) as a guideline, and either injects it or recharges it through spreading basins into the *Equus* Beds aquifer for later use.

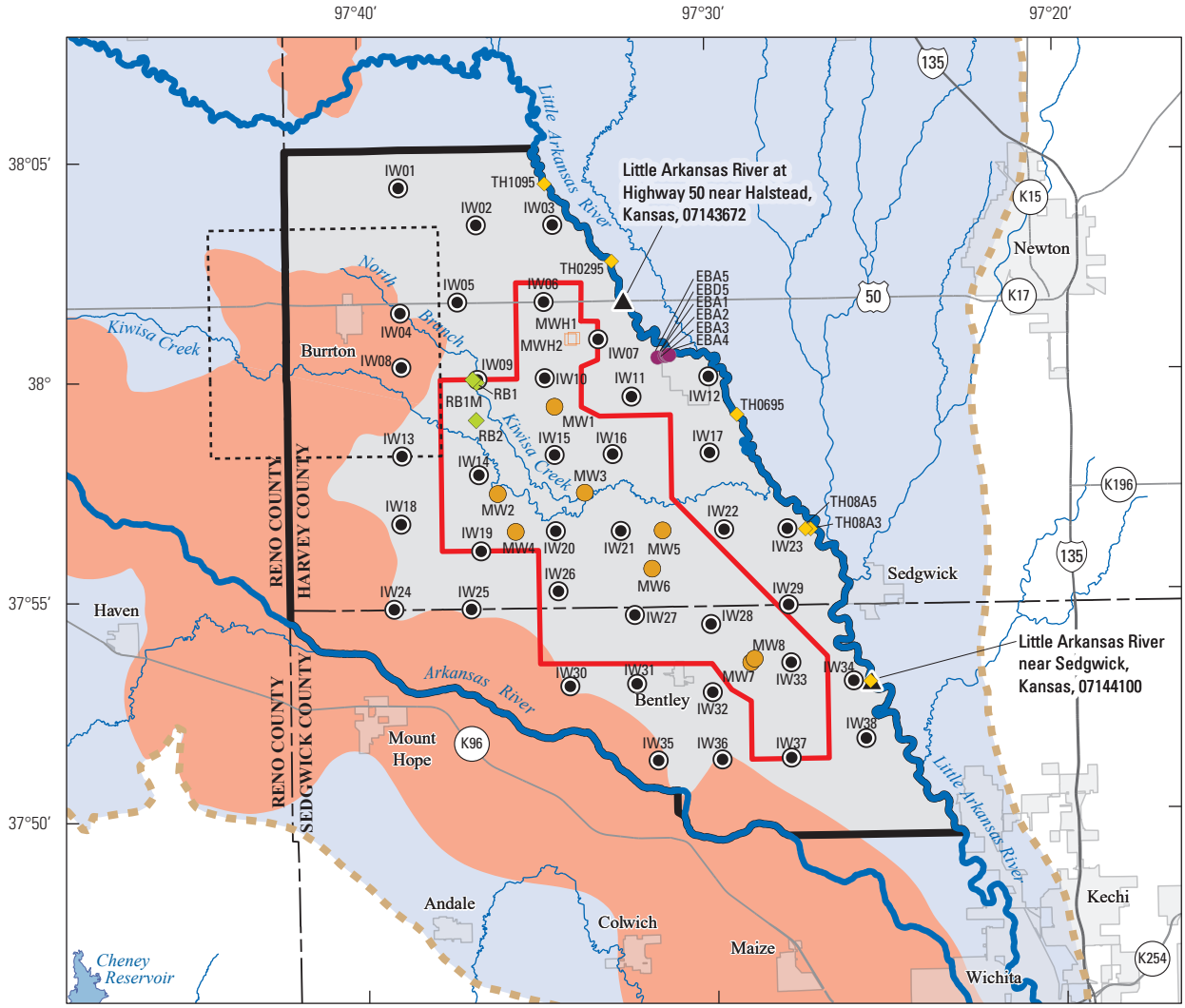


Figure 1. Location of the study area near Wichita, south-central Kansas (modified from Hansen and others, 2014; Tappa and others, 2015; and Whisnant and others, 2015).

The U.S. Geological Survey (USGS), in cooperation with the City of Wichita, completed this study to summarize water-quality and geochemical variability in the *Equus* Beds aquifer (fig. 1). To complete this objective, physicochemical and biological data were collected for the *Equus* Beds aquifer and the Little Arkansas River during 2001 through 2016. Numerous studies summarizing *Equus* Beds aquifer water quality and its relation to the city of Wichita's ASR efforts have been completed, including Schmidt and others (2007), Ziegler and others (2010), Garinger and others (2011), Tappa and others (2015), and Stone and others (2016).

Equus Beds Aquifer Storage and Recovery Project

The city of Wichita, Kansas, uses the *Equus* Beds aquifer as a primary municipal water-supply source. Historically, the volume of water that has been pumped out of parts of the *Equus* beds aquifer by irrigators, industries, and municipalities has exceeded its natural recharge rate; thus, aquifer water levels have decreased substantially (Hansen and others, 2014; Whisnant and others, 2015; Klager, 2016). The lowest water levels were recorded in 1993 and were as much as 50 feet (ft) lower than predevelopment (1940) water levels in some parts of the aquifer (Hansen and Aucott, 2001, 2003; Hansen, 2007). The easternmost area of the aquifer is susceptible to saltwater contamination from the Arkansas River and saltwater intrusion from existing upgradient contamination plumes near Burrton, Kans., caused by oil field evaporation pits remaining from the 1930s (fig. 1; Whittemore, 2007; Klager and others, 2014). The *Equus* Beds ASR project was created to help the city of Wichita meet increasing future water demands. As an added benefit, the ASR project also can help inhibit saltwater encroachment into the easternmost part of the aquifer (Ziegler and others, 2010; Klager and others, 2014).

The City of Wichita implemented the *Equus* Beds Groundwater Recharge Demonstration Project (GRDP) in 1995 to investigate the feasibility of using Little Arkansas River water to artificially recharge the aquifer. Ziegler and others (1999) indicated that the Little Arkansas River and *Equus* Beds aquifer had compatible water quality, and Ziegler and others (2001) documented minimal changes in aquifer water quality after 3 years of artificial recharge associated with the GRDP. Primary constituents of concern were arsenic, atrazine, chloride, iron, manganese, nitrate, sodium, and total coliform bacteria (Ziegler and others; 1999, 2001). Ziegler and others (1999), Ziegler and others (2010), and Garinger and others (2011) provided detailed descriptions of GRDP site locations and permit regulations for recharge operations associated with the *Equus* Beds GRDP.

The City of Wichita proceeded with the *Equus* Beds ASR project after successfully implementing artificial recharge of the aquifer during the GRDP. The *Equus* Beds ASR project currently (2019) consists of two coexisting phases. Phase I began in 2007 and has a capacity to capture 10 million gallons per day (Mgal/d) of Little Arkansas River (fig. 1) water and indirect streambank-diversion well (diversion well sites; fig. 1) water for recharge activity with water injection in 4 wells (phase I well sites, two shown; fig. 1) and 2 recharge basins (not shown). Directly diverted stream water is treated using membrane filtration and advanced oxidation 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 and others, 2011). Phase II began in 2013 and provides, in addition to phase I, a 30 Mgal/d surface-water treatment facility (not shown), a 60 Mgal/d river intake facility (not shown) currently (2019) equipped to divert 30 Mgal/d and treat 15 Mgal/d, eight recharge-injection wells (phase II well sites; fig. 1), and a third recharge basin (not shown). The city of Wichita has a National Pollutant Discharge Elimination System 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, 2017). The phase II ASR facility diversion permit requires that 30 cubic feet per second (ft^3/s) or greater is maintained downstream in the Little Arkansas River at the USGS streamgage at Valley Center, Kans. (site 07144200; not shown). The current phase II ASR facility capacity of 30 Mgal/d (46.4 ft^3/s) requires a streamflow of about 100 ft^3/s or greater at the USGS streamgage near Sedgwick, Kans. (site 07144100; Sedgwick surface-water site on fig. 1), to operate. Phase II water is directly diverted from the Little Arkansas River at the intake structure when streamflow exceeds about 100 ft^3/s at this site. The ASR facilities have an operational period of April 15 through October 15 because of climatological restrictions related to the potential for freezing conditions. Total phase I and II recharged water was about 3.2 billion gallons during 2007 through 2016 (Stone, 2017). Phase I and II recharge water volumes are available online at https://www.usgs.gov/centers/kswsc/science/equus-beds-recharge-project?qt-science_center_objects=7#qt-science_center_objects.

Purpose and Scope

The purpose of this report is to document water-quality and geochemical variability in the *Equus* Beds aquifer during 2001 through 2016. The data in this report can be used to establish baseline conditions before further implementation of artificial aquifer recharge. In addition, data from this report can be used to document surface- and groundwater quality, evaluate changing conditions, identify environmental factors affecting groundwater, provide science-based information for decision making, and help meet regulatory monitoring requirements. Physicochemical conditions during January 2001 through December 2016 were quantified using sample data collected from 63 groundwater and 2 surface-water sites, combined with groundwater geochemical modeling. Nationally,

results presented in this report contribute to understanding the potential effects related to ASR activities on surface- and groundwater resources.

Description of Study Area and Background Information

The study area includes about 117 square miles in south-central Kansas northwest of Wichita in Harvey and Sedgwick counties (fig. 1). The study area is bounded by the Arkansas River to the southwest and the Little Arkansas River to the northeast (fig. 1). The Little Arkansas River drainage basin is about 1,200 square miles of primarily agricultural (corn, sorghum, soybeans, and wheat) land. Fertilizers containing nitrogen, phosphorus, and herbicides (such as alachlor and atrazine) are commonly applied in the drainage basin (Kansas Department of Agriculture, 2016). Cattle and hogs are the primary livestock raised in the area (Kansas Department of Agriculture, 2016). Long-term mean annual precipitation (1900 through 2016) in the study area, based on data recorded near Mount Hope, Kans. (fig. 1; National Oceanic and Atmospheric Administration, 2017), was 30.1 inches (table 1). During the study period (2001 through 2016) mean annual precipitation was 33.3 inches (table 1).

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) in Kansas. The *Equus* Beds aquifer is named for Pleistocene horse fossils in its sediments. Up to about 300 ft in thickness, the aquifer consists of alluvial deposits of sand and gravel interbedded with clay or silt that lay on top of the shale in the Wellington Formation (Ziegler and others, 2010). The aquifer 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-northeast except where the hydraulic gradient (not shown) is altered by pumping wells and near a low-head dam on the Little Arkansas River at Halstead, Kans. (fig. 1; Klager, 2016). The primary surface-water drainage for the *Equus* Beds aquifer is the Little Arkansas River (fig. 1). The *Equus* Beds aquifer is one of the primary sources of water for the city of Wichita and surrounding area, and numerous irrigation wells also withdraw aquifer water within the boundaries (not shown) of *Equus* Beds Groundwater Management District Number 2 (*Equus* Beds Groundwater Management District No. 2, 1990), which contain the study area boundary. Historically, 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 from oil production activities in the 1930s, the Arkansas River, or both (Hansen and Aucott, 2003, 2010; Hansen, 2007; Klager and others, 2014). Water quality in the study area is controlled by the geology of the underlying bedrock and aquifer materials, hydraulic permeability (porosity), geochemical (oxidation and reduction) properties, effects related to past oil and gas activities, and effects related to agricultural activities.

Table 1. Annual total and mean annual precipitation during 2001 through 2016 and mean annual precipitation during 1900 through 2016 at the "MT HOPE" (Global Historical Climatology Network–Daily: USC00145539) station.

[Data are from the National Centers for Environmental Information's Global Historical Climatology Network available at https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/global-historical-climatology-network-ghcn]

Year or period	Precipitation, in inches
Total precipitation	
2001	28.2
2002	33.6
2003	30.6
2004	39.8
2005	36.8
2006	25.9
2007	36.7
2008	38.5
2009	31.4
2010	34.5
2011	20.3
2012	23.6
2013	45.1
2014	25.0
2015	42.0
2016	41.5
Mean annual precipitation	
2001–16	33.3
1900–2016	30.1

The Kansas Department of Health and Environment has listed several streams in the Little Arkansas River drainage basin as impaired waterways under section 303(d) of the 1972 Clean Water Act (Kansas Department of Health and Environment, 2016). 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 sediment for aquatic life; and *Escherichia coli* (*E. coli*) bacteria for recreation (Kansas Department of Health and Environment, 2014, 2016). Main pollutants of concern listed in the Little Arkansas River Watershed Restoration and Protection Strategy were atrazine, sediment, nutrients, and fecal coliform bacteria (Kansas State University Research and Extension and others, 2011). The Little Arkansas River has total maximum daily loads 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, 2000a, 2000b, 2000c, 2006a, 2006b, 2008, 2014).

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 to quantify artificial and natural recharge, well pumping, and streamflow change effects on groundwater; and simulate changes in water withdrawals, water levels caused by drought or pumping, and natural and artificial aquifer recharge. 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., which originated from previous oil and gas activities, will continue moving eastward toward the well field regardless of pumping in that area at an average rate of about 1 foot per day. Increased recharge across the study area or decreased pumping along the Arkansas River will slow chloride movement to the east and northeast.

Hansen and others (2014), Whisnant and others (2015), and Klager (2016) documented water levels and storage volumes in the *Equus* Beds aquifer. Water levels in the aquifer during 1993 through 2016 increased in the central part of the *Equus* Beds aquifer study area because the city of Wichita decreased water use from the aquifer by about 40 percent and increased precipitation and infiltration after an all-time low in water levels was measured 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; Klager, 2016). About 62 percent of the storage volume lost between predevelopment and 1993 has been recovered (Klager, 2016).

Tappa and others (2015) summarized *Equus* Beds aquifer (fig. 1) water quality before (1995 through 2006) and concurrent with (2007 through 2012) ASR phase I recharge. Groundwater chloride concentrations exceeded the U.S. Environmental Protection Agency (EPA) secondary maximum contaminant level (SMCL) in 6 and 7 percent of shallow and deep samples, respectively, primarily near Burrton, Kans., and along the Arkansas River. Groundwater nitrate concentrations exceeded the EPA maximum contaminant level (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 in shallow and deep aquifer samples. 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 was small (1 billion gallons) compared to aquifer storage volume (greater than [>] 990 billion gallons [3,038,200 acre-feet] in winter 2012; Tappa and others, 2015). Artificial recharge at phase I recharge locations likely slowed eastward movement of the Burrton chloride plume. Concentrations and densities of 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 (µg/L), particularly in the deeper aquifer.

Stone and others (2016) quantified ASR phase II activity effects on Little Arkansas River and *Equus* Beds aquifer water quality using data collected before (2011–13) and after (2013–14) the phase II facility began operating. Phase II recharge activities did not result in substantial changes in Little Arkansas River or *Equus* Beds aquifer water quality. Most Little Arkansas River water-quality constituent changes after phase II activities began were attributable to hydrology and effects of higher streamflows, dilution, and runoff. Groundwater physicochemical changes concurrent with the beginning of phase II recharge operations were more pronounced in shallow groundwater. Constituent concentrations in the postrecharge period compared to the prerecharge period did not increase to concentrations exceeding drinking-water regulations; however, nitrate concentrations decreased significantly postrecharge. Total solids, nitrate, slime-forming bacteria, and selenium significantly decreased, and potassium, chloride, nickel, arsenic, fluoride, phosphorus, carbon species, and gross β levels significantly increased after phase II operation began. These substantial changes in shallow groundwater concentrations were likely caused by the artificial recharge of treated surface water and natural infiltration of precipitation.

Methods

Data collection efforts followed protocols (Ziegler and Combs, 1997; Stone and others, 2012) developed for the *Equus* Beds ASR project. In addition to Ziegler and Combs (1997) and Stone and others (2012), numerous studies detailing *Equus* Beds aquifer water-quality sampling, processing, and analysis have been completed, including Ziegler and others (2010), Garinger and others (2011), Tappa and others (2015), and Stone and others (2016).

Sampling Sites

Data were collected from 114 groundwater wells (including 50 pairs of wells consisting of 1 shallow well and 1 deep well clustered together; appendix table 1.1) during 2001 through 2016 to quantify and characterize geochemical variability in the aquifer. The USGS has collected data from numerous (>300) wells throughout the lifetime (since the 1920s) of the *Equus* Beds study. An exhaustive list of groundwater and surface-water sites associated with the *Equus* Beds aquifer ASR project is available at https://www.usgs.

gov/media/files/equus-beds-site-table. For this study, wells were selected that were sampled for at least 50 percent of the years during 2001 through 2016. These included 38 pairs of areal assessment index wells (herein referred to as index wells [IWs]; each with a shallow and deep well), 6 background wells, 6 diversion wells, 1 pair of 2 recharge wells (each with a shallow and deep well), 3 pairs of phase I wells (each with a shallow and deep well), and 8 pairs of phase II wells (each with a shallow and deep well; appendix table 1.1). Data also were collected from two surface-water sites along the Little Arkansas River (appendix table 1.1).

Groundwater wells were divided into two groups by depth: shallow wells were at depths below land surface equal to or less than 80 ft and deep wells were at depths below land surface greater than 80 ft. Detailed descriptions of background, recharge, phase I, and phase II well types are provided by Ziegler and others (1999), Schmidt and others (2007), Ziegler and others (2010), Tappa and others (2015), and Stone and others (2016). The 38 pairs of IWs were established by the city of Wichita throughout the study area in 2001. Statistical summaries of groundwater chemistry presented and discussed in detail in this report are restricted to samples collected in the IW network. All IWs were constructed of polyvinyl chloride pipe, and the screened interval was typically in the lowermost 10 to 20 ft of the borehole.

Data Collection

Continuous streamflow and water-quality data were collected at two Little Arkansas River surface-water sites that bracketed a substantial part of the easternmost part of the *Equus* Beds aquifer (fig. 1). Continuous water levels were measured at 11 wells, and continuous water-quality data were collected at 3 wells (appendix table 1.1). Discrete water-quality data also were collected from the 2 Little Arkansas River surface-water sites and 114 groundwater wells. About 4,700 surface and groundwater samples were collected and analyzed for more than 300 water-quality constituents. Data collected by the USGS are stored in the USGS National Water Information System database (U.S. Geological Survey, 2017).

Continuous Water-Quality Monitoring

Detailed method descriptions for continuous water-quality monitoring by the USGS Kansas Water Science Center are presented in Bennett and others (2014) and Putnam and Hansen (2014). Continuous streamflow was measured at two Little Arkansas River sites (fig. 1): Little Arkansas River at Highway 50 near Halstead, Kans. (upstream surface-water site, 07143672, hereafter “Hwy 50 site”), and Little Arkansas River near Sedgwick, Kans. (downstream surface-water site, 07144100, hereafter “Sedgwick site;” appendix table 1.1). Continuous groundwater levels were measured at the shallow and deep wells of 2 IW pairs (375814097324701, IW16S; 375814097324702, IW16D; and 375642097385304, IW18S; 375642097385305, IW18D), 1 background well (375259097252901, Sedg), the shallow and deep wells of 1 phase I well pair (375954097363801, RB1S; and 375954097363802, RB1D), and the shallow and deep wells of 2 phase II well pairs (375327097285401, S11; 375332097284801, S13; and 375327097285402, S10; 375332097284802, S14; appendix table 1.1).

Streamflow was measured using standard USGS methods (Sauer and Turnipseed, 2010; Turnipseed and Sauer, 2010). Streamgages were installed on the Little Arkansas River at the Hwy 50 site in May 1995 and the Sedgwick site in November 1993. Each surface-water site also was equipped with a Yellow Springs Incorporated (YSI) 6600 Extended Deployment System water-quality monitor to continuously measure specific conductance, pH, water temperature, dissolved oxygen (YSI optical dissolved oxygen sensor), and turbidity (YSI 6136 optical turbidity sensor). Specific conductance, pH, water temperature, and dissolved oxygen were measured beginning in June 1998, and turbidity was measured beginning in July 2004 at the surface-water sites. A nitrate sensor (HACH® Nitratax plus sc) was installed at the Sedgwick 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. 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).

Continuous water levels were measured with submersible pressure transducers that were operated according to standard USGS methods (Cunningham and Schalk, 2011). YSI 600OMS water-quality monitors equipped with water temperature, specific conductance, pH/oxidation-reduction potential (ORP), and dissolved oxygen (YSI optical dissolved oxygen) sensors were installed at the phase II groundwater sites S10 and S11 (abbreviated well cluster MW7, fig. 1) and S13 and S14 (abbreviated well cluster MW8, fig. 1). Groundwater monitors were installed in the well screen and were maintained in accordance with standard USGS procedures (Wagner and others, 2006; Bennett and others, 2014).

Some equipment was upgraded throughout the life of the project. A YSI EXO2 water-quality monitor equipped with water temperature, specific conductance, pH, dissolved oxygen, turbidity, and YSI EXO fluorescent dissolved organic matter (fDOM) sensors was installed at the Sedgwick site in September 2014. Xylem EXO1 water-quality monitors that were equipped with water temperature, specific conductance, pH/ORP, dissolved oxygen, and fDOM sensors were installed at the S11 and S13 groundwater sites in June 2014. Continuous streamflow, water-level, and water-quality data were recorded at hourly intervals. Continuous data for Kansas are available at https://waterdata.usgs.gov/ks/nwis.

Discrete Water-Quality Sampling

About eight discrete surface-water water-quality samples were collected annually (at minimum six times annually) at each site across a range of Little Arkansas River (fig. 1) streamflows during 2001 through 2016 using USGS equal-width increment methods (U.S. Geological Survey, 2006; Stone and others, 2012; Rasmussen and others, 2014). Groundwater samples typically were collected biannually (at minimum annually) at each site during 2001 through 2016 using standard USGS methods (U.S. Geological Survey, 2006). Surface-water and groundwater samples were analyzed for physicochemical properties, dissolved solids, primary ions, nutrients (nitrogen and phosphorus species), organic carbon, indicator bacteria, trace elements, arsenic species, organic compounds, and radioactivity.

Analyses for physicochemical properties and concentrations of dissolved solids, primary ions, nutrients, organic carbon, trace elements, coliform bacteria, and pesticides followed methods described by Ziegler and Combs (1997), Ziegler and others (1999, 2010), Tappa and others (2015), and Stone and others (2016). 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, 2001a, 2006a, and 2006b). Methods used to analyze biological activity reaction tests were described by Droycon Bioconcepts, Inc. (2004). The biological activity reaction test for iron-related and sulfate-reducing bacteria were used to evaluate aquifer-material plugging and well-fouling potential.

Dissolved solids, primary ion, nutrients and carbon species, and trace element samples were analyzed by the City of Wichita Municipal Water and Wastewater Laboratory (Wichita, Kans.). Bacteria and viral-indicator samples were analyzed by the USGS Kansas Water Science Center (Lawrence, Kans.). Arsenic species and organic compound samples were analyzed by the USGS National Water Quality Laboratory (Denver, Colorado). Triazine and glyphosate samples were analyzed by the USGS Organic Geochemistry Research Laboratory (Lawrence, Kans.). Samples were analyzed by ALS Environmental Laboratories in Fort Collins, Colo., for gross α and gross β 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 https://waterdata.usgs.gov/ks/nwis.

Data Analysis

Water-chemistry data were summarized for the Little Arkansas River and the shallow and deep parts of the *Equus* Beds aquifer during 2001 through 2016. Federal drinking-water criteria were used to evaluate aquifer water quality. Interpolated water-quality maps were generated. Water-quality constituents of interest also were quantified and compared with water-level data. Groundwater data were geochemically modeled to describe the potential for precipitation and dissolution of minerals.

Water-Chemistry Data

Water-quality conditions in the Little Arkansas River and the *Equus* Beds aquifer were measured during 2001 through 2016, and summary statistics were computed for water-quality data. Some water-quality constituents had censored values. Summary statistics (means and medians) for constituents that had censored values were calculated using regression on order statistics (Helsel and Cohn, 1988) for datasets with sample sizes less than (<) 50 and having as much as 80 percent censored data and datasets with sample sizes greater than or equal to 50 and having as much as 50 percent censored data (Helsel, 2005; Bolks and others, 2014). Summary statistics for constituents that had censored values were calculated using maximum likelihood estimation (Helsel and Cohn, 1988) for datasets that had sample sizes greater than or equal to 50 and having between 50 and 80 percent censored data (Helsel, 2005; Bolks and others, 2014). Summary statistics were not computed when >80 percent of data were censored. Statistical summaries of groundwater samples were computed using R 3.4.1 (R Core Team, 2017). Select shallow and deep IW water-quality constituent concentrations were interpolated for mapping using the ArcGIS tool “Topo to Raster” (Esri, 2017) in a geographic information system. Where applicable, water-quality data were compared to EPA national drinking-water regulations (U.S. Environmental Protection Agency, 2009), which include the following types: MCL, SMCL, maximum contaminant level goal (MCLG), treatment technique (TT) and maximum residual disinfectant level (MRDL). An MCL is the highest permissible level of a contaminant in water that is delivered to any user of a public water system. The SMCLs were established as guidelines to assist public water-supply systems in managing their drinking water for aesthetic considerations such as taste, color, and odor. An MCLG is the level of a contaminant in drinking water below which there is no known or expected risk to human health. A TT is a required process intended to reduce the level of a contaminant in drinking water. An MRDL is the highest level of a disinfectant allowed in drinking water.

Geochemical Modeling

Changes in groundwater chemistry because of artificial recharge and water withdrawals may result in precipitation or dissolution of minerals causing physical plugging or changes in the aquifer and its properties. Mineral precipitation could adversely affect water yield by clogging aquifer pores, and dissolution of certain minerals may mobilize 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 using R (R Core Team, 2017; 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 (SIs) for discrete groundwater and surface-water samples. About 1,300 groundwater chemistry samples were geochemically modeled. 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. ORP values were used to approximate electron potential following Kalin (1995):

$$pE = \frac{E_h F}{2.30RT} \tag{1}$$

where

pE is the electron potential;
E_h is the ORP;
F is the Faraday constant;
R is the gas constant; and
T is the absolute temperature.

PHREEQC was run once per sample. Out of 1,972 samples, only 8 (<1 percent) samples had cation-anion balances that exceeded 20 percent. All samples were retained in the dataset regardless of cation-anion balances and presence of left-censored data. Left-censored data values were arbitrarily replaced with one-half of the censoring level.

The SI is a dimensionless measure of the departure from equilibrium of the water with respect to various mineral phases. A solution near equilibrium has an SI value of zero. 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, determined by the SI, other factors that affect precipitation and dissolution reactions include kinetics and the presence of the mineral at available reaction sites. A SI is calculated as the logarithm of the ion-activity product of a solution (water sample), divided by the solubility product for the mineral, such as for calcite:

$$SI = \log \frac{\left[Ca^{2+}\right]\left[CO_3^{\,2-}\right]}{K_{sp(calcite)}} \tag{2}$$

where

$[Ca^{2+}]$ is the activity of the calcium ion,
$[CO_3^{\,2-}]$ is the activity of the carbonate ion, and
$K_{sp(calcite)}$ 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 samples. Relative percentage difference (RPD) was used to evaluate differences in analyte concentrations detected in replicate water 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). RPDs were not calculated for replicate pairs that had consistent nondetections (both values in the replicate pair were censored) or inconsistent detections (one value in the replicate pair was a detected value and the other value was censored; Mueller and others, 2015).

The water temperature, pH, specific conductance, and dissolved-oxygen sensors have wide ranges of operation (for example, pH sensors measure from 0 to 14 units; Wagner and others, 2006) that were not exceeded in this study. Groundwater fDOM sensors frequently (51 and 38 percent at the S11 and S13 sites, respectively) measured less than zero. Data that exceeded the minimum operation value were retained in datasets and classified as poor. The upper bound of individual turbidity sensor concentration ranges differ: the manufacturer specifications for the YSI 6136 optical turbidity sensor indicate the maximum turbidity concentration is 1,000 formazin nephelomeric units (FNU) and the specifications for the EXO Turbidity Smart Sensor indicate the maximum turbidity concentration is 4,000 FNU, which was never exceeded during the study. Individual turbidity sensors differ in actual maximum readings. The maximum turbidity reading recorded at the surface-water sites was 1,640 FNU at the Hwy 50 site and 1,250 FNU at the Sedgwick site (appendix table 1.2; fig. 1). Less than 0.01 percent of continuously measured turbidity data exceeded 1,000 FNU. Data that exceeded the maximum operation value were retained in datasets and classified as poor. Monitors equipped with YSI 6136 optical turbidity and EXO Turbidity Smart Sensors were deployed concurrently at the Sedgwick site during September 2014 through March 2015 to measure differences in sensor readings. Ordinary least squares regression analyses were performed on the concurrent turbidity measurements to compare sensor measurements. The ordinary least squares regression shows the relation between the YSI 6136 optical turbidity and EXO Turbidity Smart sensors and explains 99 percent of the variance in turbidity readings (fig. 2). EXO turbidity sensor measurements were, on average, 6 percent smaller than YSI turbidity sensor measurements (appendix table 1.3).

Comparison of field cross-sectional measurements collected during high- and low-flow conditions at the surface-water sites provided verification that bias in continuous data because of monitor location within the stream cross section

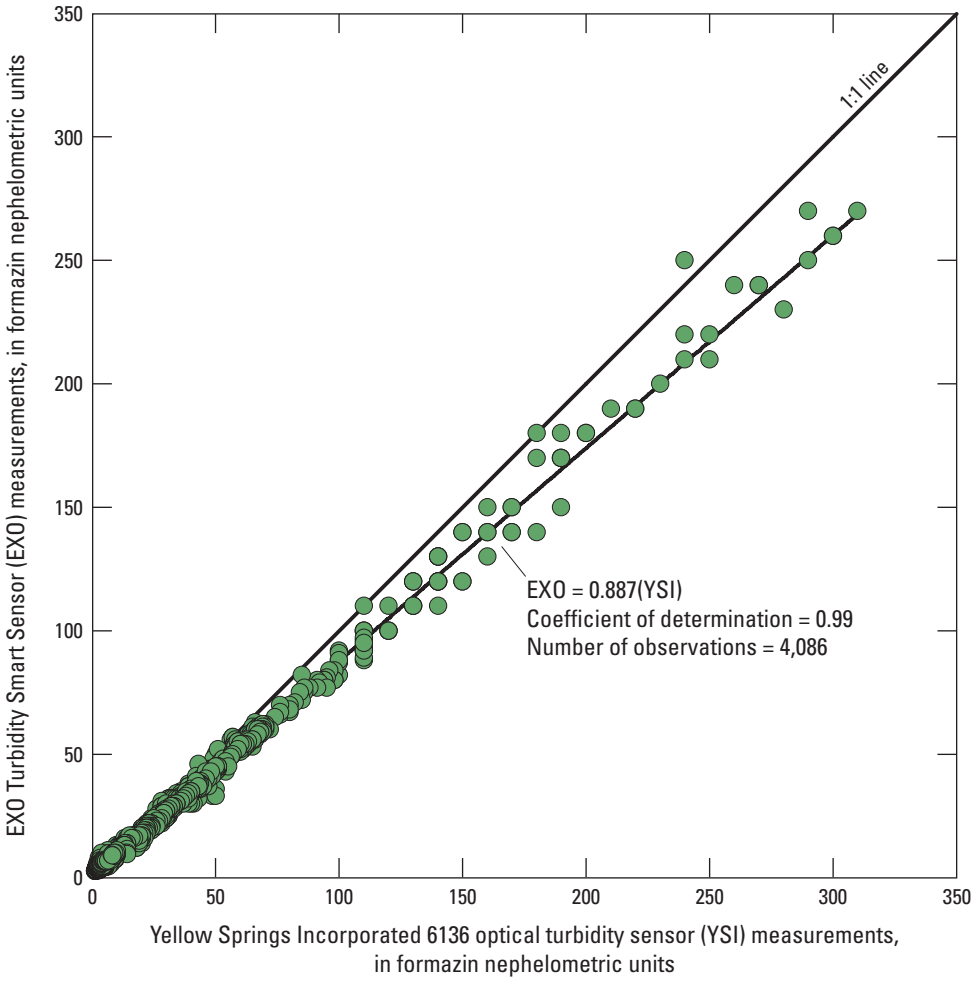


Figure 2. Relation between the Yellow Springs Incorporated 6136 optical turbidity and EXO Turbidity Smart sensor measurements at the Little Arkansas River near Sedgwick, Kansas (Sedgwick site; station 07144100), September 2014 through March 2015.

was minimal. The RPDs between continuous and field monitors were <4 percent except for turbidity, which had median RPDs of <7 percent at both sites compared to field cross-sectional data. Larger differences between continuous and field-monitor values commonly happened when conditions were changing rapidly.

Continuous data during the study period generally required corrections (such as computations to account for instrument fouling or calibration drift) of <10 percent. Continuous water-quality data were missing or deleted because of equipment malfunction, excessive sensor fouling, and, for the surface-water sites, low-flow conditions. During the study period, <1 percent of the streamflow records and less than or equal to (≤) 10 percent of the specific conductance, water temperature, dissolved oxygen, nitrate plus nitrite, and fDOM records were missing or deleted from the surface-water sites (appendix table 1.2). Turbidity data were missing from 31 to 37 percent of the surface-water sites (appendix table 1.2). Groundwater levels were missing ≤3 percent of the study period and ≤33 percent of groundwater water temperature, specific conductance, pH, ORP, dissolved-oxygen, and fDOM records were missing or deleted (table 2). The fDOM data for the surface-water sites 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 and over a range of streamflow conditions for surface-water sites. Replicate comparisons included 3,985 dissolved-solids and primary-ion pairs, 2,358 nutrient- and carbon-species pairs, 907 indicator-bacteria pairs, 3,067 trace-element pairs, 536 arsenic-species pairs, 3,022 organic-compound pairs, and 76 radioactivity pairs (appendix table 1.4). Replicate pairs with an RPD within 10 percent were considered acceptable for inorganic constituents (Ziegler and Combs, 1997). Replicate pairs with an RPD within 20 percent were considered acceptable for nutrient and organic constituents, and RPDs within 50 percent were considered acceptable for bacterial analysis. Replicate pair RPDs were not calculated for pairs that had censored data for one or both data values. Primary ions had 115 replicate pairs with values that were both left-censored and 12 replicate pairs that had 1 value that was left-censored. Nutrient and carbon species had 703 replicate pairs with values that were both left-censored and 252 replicate pairs that had 1 value that was left-censored. Bacteria had 417 replicate pairs with values that were both censored and 74 replicate pairs that had 1 value that was censored. Trace elements had 1,152 replicate pairs with

Table 2. Continuously measured physicochemical property summary statistics for *Equus* Beds aquifer groundwater sites, 2001–16.

[Continuous real-time water-quality data for Kansas are available on the U.S. Geological Survey (USGS) National Water Information System website at https://waterdata.usgs.gov/ks/nwis; *n*, number of measurements; pcode, parameter code; <, less than; SHE, standard hydrogen electrode; fDOM, colored dissolved organic matter fluorescence]

Station name (report identifier; USGS station identifier)	Data collection period	*n*	Minimum	Maximum	Mean	Median	Missing or deleted data, in percent
Groundwater level, in feet above the National Geodetic Vertical Datum of 1929 (USGS pcode 62610)							
25S 01W 15BBBA01 SEDGWICK WELL (Sedgwick; 375259097252901)	January 2001–December 2016	130,202	1,045	1,358	1,337	1,345	<1
Groundwater level, in feet above the North American Vertical Datum of 1988 (USGS pcode 62611)							
25S 01W 07BCCC01 SMW–S11 NR CW36 (S11; 375327097285401)	June 2014–December 2016	20,424	1,357	1,377	1,364	1,364	<1
25S 01W 07BCC02 DMW–S10 NR CW36 (S10; 375327097285402)	October 2012–May 2015	35,064	1,343	1,360	1,354	1,356	3
25S 01W 07BCCA01 S,W–S13 NR CW36 (S13; 375332097284801)	June 2014–May 2015	8,217	1,357	1,364	1,358	1,358	<1
25S 01W 07BCCA02 DMW–S14 NR CW36 (S14; 375332097284802)	October 2012–May 2015	22,600	1,344	1,360	1,355	1,356	2
24S 03W 02AADA01 RB1–MS SHALLOW (RB1S; 375954097363801)	September 2008–December 2016	71,735	1,410	1,421	1,415	1,415	<1
24S 03W 02AADA02 RB1–MS DEEP (RB1D; 375954097363802)	September 2008–December 2016	71,532	1,396	1,414	1,406	1,406	<1
24S 02W 16BAAA01 IW–16A SHALLOW (IW16S; 375814097324701)	March 2014–December 2016	24,611	1,381	1,392	1,386	1,386	<1
24S 02W 16BAAA02 IW–16C DEEP (IW16D; 375814097324702)	January 2006–December 2016	96,349	1,372	1,392	1,382	1,382	<1
24S 03W 21DDAA04 IW–18A SHALLOW (IW18S; 375642097385304)	March 2014–December 2016	24,512	1,422	1,429	1,425	1,424	<1
24S 03W 21DDAA05 IW–18C DEEP (IW18D; 375642097385305)	January 2006–December 2016	95,309	1,419	1,429	1,424	1,424	<1
Water temperature, in degrees Celsius (USGS pcode 00010)							
25S 01W 07BCCC01 SMW–S11 NR CW36 (S11; 375327097285401)	July 2011–December 2016	47,013	14.2	29.0	20.7	21.6	2
25S 01W 07BCC02 DMW–S10 NR CW36 (S10; 375327097285402)	October 2012–May 2015	17,350	15.2	15.3	15.3	15.3	25
25S 01W 07BCCA01 S,W–S13 NR CW36 (S13; 375332097284801)	July 2011–May 2015	26,598	14.3	27.6	20.0	22.0	21
25S 01W 07BCCA02 DMW–S14 NR CW36 (S14; 375332097284802)	October 2012–May 2015	16,473	15.6	15.8	15.7	15.7	28

Table 2. Continuously measured physicochemical property summary statistics for *Equus* Beds aquifer groundwater sites, 2001–16.—Continued

[Continuous real-time water-quality data for Kansas are available on the U.S. Geological Survey (USGS) National Water Information System website at https://waterdata.usgs.gov/ks/nwis; *n*, number of measurements; pcode, parameter code; <, less than; SHE, standard hydrogen electrode; fDOM, colored dissolved organic matter fluorescence]

Station name (report identifier; USGS station identifier)	Data collection period	*n*	Minimum	Maximum	Mean	Median	Missing or deleted data, in percent
Water temperature, in degrees Celsius (USGS pcode 00010)—Continued							
24S 03W 02AADA01 RB1–MS SHALLOW (RB1S; 375954097363801)	June 2008–December 2016	73,593	14.9	15.8	15.4	15.4	<1
24S 03W 02AADA02 RB1–MS DEEP (RB1D; 375954097363802)	June 2008–December 2016	73,279	14.8	15.3	15.0	15.0	1
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius (USGS pcode 00095)							
25S 01W 07BCCC01 SMW–S11 NR CW36 (S11; 375327097285401)	July 2011–December 2016	47,015	146	922	532	500	2
25S 01W 07BCC02 DMW–S10 NR CW36 (S10; 375327097285402)	October 2012–May 2015	17,032	578	807	766	760	26
25S 01W 07BCCA01 S,W–S13 NR CW36 (S13; 375332097284801)	July 2011–May 2015	26,562	129	928	570	512	21
25S 01W 07BCCA02 DMW–S14 NR CW36 (S14; 375332097284802)	October 2012–May 2015	16,473	684	752	728	728	28
24S 03W 02AADA01 RB1–MS SHALLOW (RB1S; 375954097363801)	June 2008–December 2016	73,264	476	581	497	494	1
24S 03W 02AADA02 RB1–MS DEEP (RB1D; 375954097363802)	June 2008–December 2016	72,160	498	1,050	703	725	3
pH, in standard units (USGS pcode 00400)							
25S 01W 07BCCC01 SMW–S11 NR CW36 (S11; 375327097285401)	July 2011–December 2016	47,015	6.6	7.5	6.8	6.8	2
25S 01W 07BCC02 DMW–S10 NR CW36 (S10; 375327097285402)	February 2011–June 2014	14,256	7.0	7.5	7.3	7.3	30
25S 01W 07BCCA01 S,W–S13 NR CW36 (S13; 375332097284801)	July 2011–June 2014	18,804	5.9	7.7	6.7	6.6	25
25S 01W 07BCCA02 DMW–S14 NR CW36 (S14; 375332097284802)	March 2013–May 2015	12,587	7.1	7.4	7.3	7.2	33
24S 03W 02AADA01 RB1–MS SHALLOW (RB1S; 375954097363801)	June 2008–December 2016	72,870	6.8	7.9	7.1	7.1	2
24S 03W 02AADA02 RB1–MS DEEP (RB1D; 375954097363802)	June 2008–December 2016	73,026	6.8	8.8	7.4	7.3	1

Table 2. Continuously measured physicochemical property summary statistics for *Equus* Beds aquifer groundwater sites, 2001–16.—Continued

[Continuous real-time water-quality data for Kansas are available on the U.S. Geological Survey (USGS) National Water Information System website at https://waterdata.usgs.gov/ks/nwis; *n*, number of measurements; pcode, parameter code; <, less than; SHE, standard hydrogen electrode; fDOM, colored dissolved organic matter fluorescence]

Station name (report identifier; USGS station identifier)	Data collection period	*n*	Minimum	Maximum	Mean	Median	Missing or deleted data, in percent
Oxidation reduction potential, relative to the SHE, in millivolts (USGS pcode 63002)							
25S 01W 07BCCC01 SMW–S11 NR CW36 (S11; 375327097285401)	July 2011–December 2016	46,202	−391	563	229	233	3
25S 01W 07BCC02 DMW–S10 NR CW36 (S10; 375327097285402)	February 2011–June 2014	14,219	−444	170	−24	28	29
25S 01W 07BCCA01 S,W–S13 NR CW36 (S13; 375332097284801)	July 2011–May 2015	26,853	−84	502	212	190	21
25S 01W 07BCCA02 DMW–S14 NR CW36 (S14; 375332097284802)	March 2013–May 2015	12,581	−256	174	20	12	33
24S 03W 02AADA01 RB1–MS SHALLOW (RB1S; 375954097363801)	September 2008–December 2016	71,969	−474	59	−323	−348	3
24S 03W 02AADA02 RB1–MS DEEP (RB1D; 375954097363802)	September 2008–December 2016	72,558	−568	130	−356	−374	2
Dissolved oxygen, in milligrams per liter (USGS pcode 00300)							
25S 01W 07BCCC01 SMW–S11 NR CW36 (S11; 375327097285401)	July 2011–December 2016	46,977	0.1	10.4	2.9	3.3	2
25S 01W 07BCC02 DMW–S10 NR CW36 (S10; 375327097285402)	March 2013–June 2014	10,069	0.0	0.2	0.1	0.1	2
25S 01W 07BCCA01 S,W–S13 NR CW36 (S13; 375332097284801)	July 2011–May 2015	25,840	0.0	8.9	3.2	3.5	24
25S 01W 07BCCA02 DMW–S14 NR CW36 (S14; 375332097284802)	March 2013–June 2014	10,521	0.0	0.5	0.1	0	<1
fDOM (uncorrected), in micrograms per liter as quinine sulfate equivalents (USGS pcode 32295)							
25S 01W 07BCCC01 SMW–S11 NR CW36 (S11; 375327097285401)	June 2014–December 2016	21,666	−7.6	40.2	4.7	−0.4	2
25S 01W 07BCCA01 S,W–S13 NR CW36 (S13; 375332097284801)	June 2014–May 2015	6,491	−5.5	24.0	1.9	0.6	21

values that were both left-censored and 330 replicate pairs that had 1 value that was left-censored. Arsenic species had 149 replicate pairs with values that were both left-censored and 23 replicate pairs that had 1 value that was left-censored. Organic compounds had 2,627 replicate pairs with values that were both left-censored and 35 replicate pairs that had 1 value that was left-censored. Radioactivity values had 3 replicate pairs with values that were both censored and 9 replicate pairs that had 1 value that was censored.

Nearly all inorganic constituent replicate pairs had median RPDs that were <10 percent (appendix table 1.4). Primary-ion constituent RPD medians were all <3 percent except for fluoride (7 percent) (appendix table 1.4). All nutrient- and carbon-species replicate pairs had median RPDs that were ≤14 percent (appendix table 1.4). Four bacteria constituent RPD medians were 0 percent, and the remaining bacteria constituents had RPD medians that were ≤35 percent (appendix table 1.4). Bacteria RPDs were often larger when densities were at or near the censoring level. Trace-element constituent median RPDs were <10 percent except for aluminum (11 percent), zinc (12 percent), and selenium (15 percent); arsenic-species median RPDs were <7 percent; organic-compound median RPDs were ≤10 percent except for 3,4-Dichloroaniline (13 percent) and Simazine (67 percent); and radioactivity median RPDs were ≤22 percent (appendix table 1.4). Primary sources of larger RPDs in the study area recorded during 1999 through 2004 and 2005 through 2012 are discussed in Ziegler and others (2010) and Tappa and others (2015), respectively.

Blank samples were collected to measure the magnitude of contaminant concentration that might have been introduced into samples because 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 2001 through 2016, 187 blank samples were collected. Overall, primary ions were detected in 6 percent of samples, and detections were generally at or near the detection limit except for five dissolved-solids detections that ranged from 29 to 61 mg/L. Individual primary ions that had more than 10 percent detections in blank samples included dissolved solids and fluoride (12 detections each; appendix table 1.4). Overall, nutrients were detected in 6 percent of blank samples, and detections were at or near the detection limit. Individual nutrient constituent detections did not exceed 10 percent (appendix table 1.4). Dissolved and total organic carbon were detected in 48 and 43 percent of blank samples, respectively (appendix table 1.4); however, nearly all organic carbon detections were at or near the detection limit. Some organic carbon detections were traced to potentially contaminated blank water used for the samples. Overall, indicator bacteria were detected in 8 percent of blank samples, and most bacteria detections were at or near the detection limit. *E. coli* coliphage was detected in 13 percent and total coliforms were detected in 17 percent of blank samples (appendix table 1.4). Overall, trace elements were detected in <1 percent of blank samples, and detections were at or near the detection limit. Individually, one trace element, nickel, was detected in more than 10 percent of blanks (four detections; appendix table 1.4). Overall, organic compounds were detected in 2 percent of blank samples, and detections were generally at or near the detection limit. Individual organic compounds that were detected in more than 10 percent of blanks included atrazine (2 detections), metolachlor (2 detections), and toluene (3 detections; appendix table 1.4).

Standard reference samples were analyzed by the Wichita Municipal Water and Wastewater laboratory and analytical results submitted to the USGS Branch of Quality Systems at least annually and oftentimes biannually for laboratory-performance evaluation. Standard reference sample data are available at https://bqs.usgs.gov/srs/. Reported values usually were within 10 percent of the most probable value during 2001 through 2016. Median RPDs between laboratory results and most probable values indicated that laboratory data generally were consistent and unbiased.

Water Quality of the Little Arkansas River

Continuous measurement of physicochemical properties in near-real time allowed characterization of Little Arkansas River surface water during conditions and time scales that would not have been possible otherwise and served as a complement to discrete water-quality sampling. Similar future data-collection efforts will provide data during different conditions and may identify new and changing trends. Surface-water physicochemical properties and water-quality constituents that frequently exceeded EPA Federal drinking water-quality criteria and those that are of potential interest or concern for artificial recharge operations are briefly discussed in this report to characterize the quality of potential aquifer recharge water. These data include streamflow, chloride, sulfate, nitrate plus nitrite, total coliform bacteria, iron, manganese, arsenic, and atrazine. Statistical summaries for these data are presented for the two surface-water monitoring sites on the Little Arkansas River (Hwy 50 and Sedgwick sites; fig. 1) in appendix tables 1.2 and 1.5. Ziegler and others (2010) and Tappa and others (2015) provided detailed descriptions of Little Arkansas River surface-water physicochemical properties and water-quality constituents for the Hwy 50 and Sedgwick sites.

Little Arkansas River 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. The *Equus* Beds ASR project operations are limited to above-base-flow conditions. Streamflow at the Hwy 50

and Sedgwick sites ranged from <1 to 11,023 ft^3/s and <1 to 16,735 ft^3/s, respectively, during 2001 through 2016 (appendix table 1.2). Mean and median streamflow at the Hwy 50 site was 183 and 19 ft^3/s, respectively, and mean and median streamflow at the Sedgwick site was 325 and 47 ft^3/s, respectively, during the study period. Little Arkansas River streamflow values during the study were within the ranges reported during 1995 through 2012 by Tappa and others (2015).

Discrete Little Arkansas River Water Quality

The Little Arkansas River has highly variable chloride concentrations that can exceed drinking-water standards (Ziegler and others, 1999). The EPA SMCL for chloride is 250 milligrams per liter (mg/L; U.S. Environmental Protection Agency, 2009) for aesthetics, including taste and odor, and was exceeded in <1 percent of samples from the two Little Arkansas River surface-water sites. Chloride concentrations ranged from <5 to 530 mg/L (appendix table 1.5) and did not exceed the range of values previously reported during 1995 through 2012 by Tappa and others (2015). Sulfate concentrations ranged from <5 to 170 mg/L (appendix table 1.5) and did not exceed the range of values previously reported during 1995 through 2012 by Tappa and others (2015).

Little Arkansas nitrate concentrations can exceed the EPA MCL of 10 mg/L (U.S. Environmental Protection Agency, 2009; Ziegler and others, 2010; Tappa and others, 2015; Stone and others, 2016). Surface-water nitrate plus nitrite concentrations ranged from <0.02 to 11.7 mg/L during 2001 through 2016 (appendix table 1.5), exceeded the MCL in <1 percent of samples, and did not exceed the range of values previously reported during 1995 through 2012 (Tappa and others, 2015). The EPA has a MCLG for total coliforms of 0 colony forming units per 100 milliliters (cfu/100 mL; U.S. Environmental Protection Agency, 2013). Total coliforms are commonly detected in the Little Arkansas River (Tappa and others, 2015; Stone and others, 2016). Little Arkansas River surface-water total coliform densities ranged from 30 to 36,000 most probably number per 100 milliliters (mpn/100 mL), and every water sample collected had total coliform detections (appendix table 1.5). The range of surface-water total coliform densities during this study did not exceed the ranges previously reported during 1995 through 2012 by Tappa and others (2015).

The SMCL for iron (300 µg/L; U.S. Environmental Protection Agency, 2009) is often exceeded in the Little Arkansas River (Ziegler and others, 2010; Tappa and others, 2015; Stone and others, 2016). Surface-water iron concentrations ranged from <4 to 620 µg/L during the study (appendix table 1.5) and exceeded the SMCL in 7 percent of samples. Surface-water iron concentrations did not exceed the range of values previously reported during 1995 through 2012 by Tappa and others (2015). The SMCL for manganese (50 µg/L; U.S. Environmental Protection Agency, 2009) is often exceeded in the Little Arkansas River (Ziegler and others, 2010; Tappa and others, 2015; Stone and others, 2016). Surface-water manganese concentrations ranged from <1 to 826 µg/L during the study (appendix table 1.5), exceeded the SMCL 48 percent of the time, and did not exceed the range of values previously reported during 1995 through 2012 (Tappa and others, 2015). The MCL for arsenic (10 µg/L; U.S. Environmental Protection Agency, 2009) is frequently exceeded in the Little Arkansas River (Ziegler and others, 2010; Tappa and others, 2015; Stone and others, 2016). Little Arkansas River surface-water arsenic concentrations ranged from <1 to 16.2 µg/L during 2001 through 2016 (appendix table 1.5) and exceeded the MCL in about 12 percent of samples. Surface-water arsenic concentrations did not exceed the range of values previously reported for these sites during 1995 through 2012 (Tappa and others, 2015).

The MCL for atrazine (3.0 µg/L; U.S. Environmental Protection Agency, 2009) is often exceeded in Little Arkansas River surface-water samples (Ziegler and others, 2010; Tappa and others, 2015; Stone and others, 2016). Surface-water atrazine concentrations ranged from <0.025 to 48.0 µg/L (appendix table 1.5) and 39 percent of samples exceeded the MCL during 2001 through 2016. The range of surface-water atrazine concentrations measured in this study did not exceed that previously reported during 1995 through 2012 (Tappa and others, 2015).

Water Quality and Geochemistry of the *Equus* Beds Aquifer

Groundwater physicochemical properties and water-quality constituents that frequently exceeded EPA drinking water-quality criteria and those that are of potential interest or concern for artificial recharge operations are discussed in this report to characterize *Equus* Beds aquifer water quality. These data include groundwater levels, specific conductance, ORP, dissolved solids, bromide, chloride, sulfate, select nutrients, bacterial (fecal coliform, *E. coli,* and total coliforms) and viral (*E. coli* coliphage) indicators, iron, manganese, arsenic speciation, atrazine, and radioactivity. Statistical summaries for these data are presented for the shallow and deep IW *Equus* Beds aquifer sites in tables 3–10. *Equus* Beds aquifer IW geochemical equilibria are discussed to characterize groundwater geochemistry and are presented in table 11. Statistical summaries for additional groundwater sites (background, diversion, recharge, phase I, and phase II wells) are presented in appendix tables 1.7 through 1.14 and are not discussed further in this report.

Equus Beds Aquifer Physicochemical Properties

Historically, groundwater levels in the *Equus* Beds aquifer have substantially declined because of city and irrigation withdrawals; these declines are likely to cause increased movement of brine from past oil and gas production near

Table 3. Physicochemical summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.

[USGS; U.S. Geological Survey; *n*, number of measurements; NAVD 88, North American Vertical Datum of 1988; <, less than; SHE, standard hydrogen electrode]

Water-quality constituent	USGS parameter code	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Shallow index wells											
Depth to water level, in feet below land surface	72019	719	1.42	60.3	17.7	15.4	10.1	0.38	0.57	10.5	22.7
Groundwater level, in feet above NAVD 88	62611	720	1,342	1,473	1,390	1,386	28.6	1.07	0.02	1,367	1,411
pH, in standard units	00400	719	5.4	7.6	6.7	6.8	0.4	0.01	0.06	6.5	7.0
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	00095	719	89	2,310	897	838	468	17.5	0.5	544	1,205
Water temperature, in degrees Celsius	00010	718	10.9	21.5	15.9	15.9	0.94	0.04	0.06	15.4	16.4
Dissolved oxygen, in milligrams per liter	00300	704	<0.1	9.7	1.7	0.7	2.0	0.08	1.2	0.2	2.6
Turbidity, in nephelometric turbidity units	63676	707	<1	42.0	2.24	1.20	3.57	0.13	1.59	0.50	2.50
Oxidation-reduction potential, relative to the SHE, in millivolts	63002	708	−70	730	324	330	159	5.97	0.49	178	443
Deep index wells											
Depth to water level, in feet below land surface	72019	723	4.12	68.3	22.7	20.6	11.4	0.42	0.50	14.0	29.0
Groundwater level, in feet above NAVD 88	62611	723	1,342	1,433	1,386	1,384	24.2	0.90	0.02	1,365	1,408
pH, in standard units	00400	721	6.2	8.6	7.1	7.1	0.2	0.01	0.03	7.0	7.2
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	00095	723	32	4,520	966	858	645	24.0	0.7	643	1,135
Water temperature, in degrees Celsius	00010	723	14.4	18.4	16.1	16.2	0.51	0.02	0.03	15.8	16.5
Dissolved oxygen, in milligrams per liter	00300	682	<0.01	7.2	0.3	0.1	0.5	0.01	1.8	0.1	0.2
Turbidity, in nephelometric turbidity units	63676	712	<1	120.0	2.58	1.20	8.60	0.32	3.33	0.60	2.43
Oxidation-reduction potential, relative to the SHE, in millivolts	63002	711	−160	640	234	180	133	4.97	0.57	140	330

Table 4. Solids and primary ions summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.

[Summary statistics were not computed when more than 80 percent of data were censored; USGS, U.S. Geological Survey; *n*, number of measurements; $CaCO_3$, calcium carbonate; <, less than; --, not applicable; SiO_2, silicon dioxide]

Water-quality constituent	USGS parameter code	Censored data, in percent	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Shallow index wells												
Carbonate, in milligrams per liter	29809	0	707	0	4.0	0	0	0.2	0	17.0	0	0
Carbonate hardness, in milligrams per liter as $CaCO_3$	00901	0	707	23	760	305	300	152	5.72	0.5	190	390
Alkalinity, in milligrams per liter as $CaCO_3$	39087	0	706	27	420	207	208	87	3.3	0.42	155	271
Bicarbonate, in milligrams per liter	29806	0	707	33	510	252	250	106	4.0	0.42	190	330
Dissolved solids, in milligrams per liter	70300	0	707	74	2,700	587	531	333	12.5	0.57	338	769
Suspended solids, in milligrams per liter	00530	96	706	<4	46	--	--	--	--	--	--	--
Total solids, in milligrams per liter	00500	0	214	2.0	1,550	601	551	335	22.9	0.6	359	754
Calcium, in milligrams per liter	00915	0	707	6.6	244	93.6	93.3	46.3	1.74	0.49	58.9	119
Magnesium, in milligrams per liter	00925	0	707	1.6	41.4	17.3	16.2	9.4	0.35	0.54	10.6	22.9
Potassium, in milligrams per liter	00935	0	702	1.0	13.0	3.7	3.3	1.7	0.06	0.47	2.6	4.6
Sodium, in milligrams per liter	00930	0	707	9.5	336	82.5	60.4	66.9	2.5	0.81	38.8	98.4
Bromide, in milligrams per liter	71870	18	628	<0.02	1.40	0.14	0.10	0.13	--	--	0.10	0.20
Chloride, in milligrams per liter	00940	5	705	<5	773	67.0	36	85.3	--	--	13.0	88.0
Chlorine, total residual, in milligrams per liter	50060	94	189	<0.05	0.1	--	--	--	--	--	--	--
Fluoride, in milligrams per liter	00950	<1	702	<0.02	1.50	0.44	0.40	0.23	--	--	0.29	0.60
Silica, in milligrams per liter as SiO_2	00955	0	707	8.2	36.6	20.4	19.7	4.8	0.2	0.2	17.2	23.6
Sulfate, in milligrams per liter	00945	<1	699	<5	770	152	100	156	--	--	43	197

Table 4. Solids and primary ions summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.—Continued

[Summary statistics were not computed when more than 80 percent of data were censored; USGS, U.S. Geological Survey; *n*, number of measurements; $CaCO_3$, calcium carbonate; <, less than; --, not applicable; SiO_2, silicon dioxide]

Water-quality constituent	USGS parameter code	Censored data, in percent	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Deep index wells												
Carbonate, in milligrams per liter	29809	0	713	0	2.0	0	0	0.1	0	13.3	0	0
Carbonate hardness, in milligrams per liter as $CaCO_3$	00901	0	713	84	1,300	313	260	200	7.5	0.64	200	360
Alkalinity, in milligrams per liter as $CaCO_3$	39087	0	711	113	395	226	240	55.7	2.1	0.25	172	268
Bicarbonate, in milligrams per liter	29806	0	712	21	480	275	290	68.8	2.6	0.25	210	330
Dissolved solids, in milligrams per liter	70300	0	713	5	3,230	615	534	450	16.9	0.73	361	688
Suspended solids, in milligrams per liter	00530	50	712	<4	514	4.7	2.0	20.3	--	--	2.0	4.0
Total solids, in milligrams per liter	00500	0	213	62.0	3,340	626	540	479	32.9	0.8	348	698
Calcium, in milligrams per liter	00915	0	713	27.3	392	96.8	80.7	60.1	2.26	0.62	62.2	108
Magnesium, in milligrams per liter	00925	0	713	3.4	81.7	17.5	15.0	12.5	0.47	0.72	10.7	20.4
Potassium, in milligrams per liter	00935	0	713	1.0	10.9	3.4	3.0	1.4	0.05	0.41	2.63	4.0
Sodium, in milligrams per liter	00930	0	713	16.9	409	92.3	81.1	64.8	2.4	0.70	46.6	110
Bromide, in milligrams per liter	71870	16	612	<0.02	5.30	0.22	0.10	0.59	--	--	0.10	0.10
Chloride, in milligrams per liter	00940	5	708	<5	1,460	110	65	191	--	--	21.0	120
Chlorine, total residual, in milligrams per liter	50060	100	194	<0.05	<0.1	--	--	--	--	--	--	--
Fluoride, in milligrams per liter	00950	1	708	<0.02	1.10	0.42	0.40	0.17	--	--	0.30	0.50
Silica, in milligrams per liter as SiO_2	00955	0	713	15.8	30.1	22.8	22.5	2.7	0.1	0.1	20.9	24.5
Sulfate, in milligrams per liter	00945	2	705	<5	720	111	69	128	--	--	28	114

Table 5. Nutrient and carbon species summary statistics of discrete groundwater samples for the *Equus* aquifer index wells near Sedgwick, Kansas, 2001–16.

[Summary statistics were not computed when more than 80 percent of data were censored; USGS, U.S. Geological Survey; *n*, number of measurements; <, less than; --, not applicable]

Water-quality constituent	USGS parameter code	Censored data, in percent	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Shallow index wells												
Ammonia, in milligrams per liter as nitrogen	00608	36	702	<0.03	3.22	0.98	0.04	0.22	--	--	0.02	0.12
Nitrate plus nitrite, in milligrams per liter as nitrogen	00631	30	705	<0.02	42.6	3.79	0.70	5.81	--	--	0.05	5.31
Nitrate, in milligrams per liter as nitrogen	00618	31	702	<0.001	42.6	3.79	0.65	5.82	--	--	0.04	5.33
Nitrite, in milligrams per liter as nitrogen	00613	93	702	<0.02	3.52	--	--	--	--	--	--	--
Orthophosphate, in milligrams per liter as phosphorus	00671	36	702	<0.01	10.8	0.10	0.04	0.46	--	--	0.01	0.09
Dissolved phosphorus, in milligrams per liter as phosphorus	00666	5	707	<0.03	4.9	0.17	0.1	0.38	--	--	0.05	0.18
Dissolved organic carbon, in milligrams per liter	00681	0	153	0.40	10.8	1.15	0.9	1.22	0.10	1.06	0.80	1.1
Total organic carbon, in milligrams per liter	00680	0	332	0.30	10.8	1.10	0.91	1.06	0.06	0.96	0.70	1.19
Deep index wells												
Ammonia, in milligrams per liter as nitrogen	00608	15	709	<0.03	1.01	0.12	0.12	0.09	--	--	0.05	0.18
Nitrate plus nitrite, in milligrams per liter as nitrogen	00631	56	713	<0.02	11.3	0.48	0.01	1.54	--	--	0.01	0.16
Nitrate, in milligrams per liter as nitrogen	00618	57	708	<0.01	11.3	0.48	0.01	1.54	--	--	0.01	0.16
Nitrite, in milligrams per liter as nitrogen	00613	93	708	<0.01	0.48	--	--	--	--	--	--	--
Orthophosphate, in milligrams per liter as phosphorus	00671	9	708	<0.01	0.38	0.06	0.03	0.07	--	--	0.02	0.07
Dissolved phosphorus, in milligrams per liter as phosphorus	00666	4	713	<0.03	0.491	0.14	0.14	0.09	--	--	0.05	0.2
Dissolved organic carbon, in milligrams per liter	00681	<1	157	<0.3	1.7	0.75	0.7	0.28	--	--	0.50	0.9
Total organic carbon, in milligrams per liter	00680	<1	339	<0.2	4.3	0.72	0.65	0.40	--	--	0.48	0.9

Table 6. Bacterial and viral indicator summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.

[Summary statistics were not computed when more than 80 percent of data were censored; USGS, U.S. Geological Survey; *n*, number of measurements; *E. coli*, *Escherichia coli*; <, less than; --, not applicable]

Water-quality constituent	USGS parameter code	Censored data, in percent	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Shallow index wells												
E. coli, in colony forming units per 100 milliliters	90902	97	268	<1	37	--	--	--	--	--	--	--
Fecal coliforms, in colony forming units per 100 milliliters	31625	92	701	<1	360	--	--	--	--	--	--	--
Total coliforms, in the most probable number per 100 milliliters	31504	76	441	<1	370	7	1	32	--	--	0.5	1
E. coli coliphage, Famp host, in plaque forming units per 100 milliliters	90904	99	188	<1	1	--	--	--	--	--	--	--
Iron-related bacteria, in colony forming units per milliliter	31695	7	197	<1	35,000	8,910	2,300	12,070	--	--	500	9,000
Slime-forming bacteria, in colony forming units per milliliter	31700	4	151	<1	1,800,000	286,700	66,500	488,360	--	--	12,500	350,000
Sulfate-reducing bacteria, in colony forming units per milliliter	31697	60	197	<1	700,000	17,910	100	99,520	--	--	0.5	1,200
Deep index wells												
E. coli, in colony forming units per 100 milliliters	90902	97	270	<1	130	--	--	--	--	--	--	--
Fecal coliforms, in colony forming units per 100 milliliters	31625	94	708	<1	81	--	--	--	--	--	--	--
Total coliforms, in the most probable number per 100 milliliters	31504	88	442	<1	84	--	--	--	--	--	--	--
E. coli coliphage, Famp host, in plaque forming units per 100 milliliters	90904	100	152	<1	<1	--	--	--	--	--	--	--
Iron-related bacteria, in colony forming units per milliliter	31695	15	200	<1	35,000	4,760	500	8,700	--	--	150	9,000
Slime-forming bacteria, in colony forming units per milliliter	31700	8	155	<1	1,800,000	174,880	12,500	380,090	--	--	2,500	350,000
Sulfate-reducing bacteria, in colony forming units per milliliter	31697	72	200	<1	100,000	1,760	1	7,970	--	--	0.5	200

Table 7. Trace element summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.

[Summary statistics were not computed when more than 80 percent of data were censored; USGS, U.S. Geological Survey; *n*, number of measurements; <, less than; --, not applicable]

Water-quality constituent	USGS parameter code	Censored data, in percent	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Shallow index wells												
Aluminum, in micrograms per liter	01106	95	327	<10	250	--	--	--	--	--	--	--
Barium, in micrograms per liter	01005	0	327	0.1	600	152	120	104	5.8	0.7	84	170
Beryllium, in micrograms per liter	01010	98	327	<0.6	9	--	--	--	--	--	--	--
Cadmium, in micrograms per liter	01025	80	323	<0.05	1	--	--	--	--	--	--	--
Chromium, in micrograms per liter	01030	99	289	<1	5	--	--	--	--	--	--	--
Copper, in micrograms per liter	01040	95	326	<5	11	--	--	--	--	--	--	--
Iron, in micrograms per liter	01046	49	695	<5	40,700	2,437	107	6,447	--	--	17	1,830
Lead, in micrograms per liter	01049	93	323	<0.05	50	--	--	--	--	--	--	--
Manganese, in micrograms per liter	01056	34	692	<1	1,660	279	90	372	--	--	14	400
Mercury, in micrograms per liter	71890	99	204	<0.1	0.05	--	--	--	--	--	--	--
Nickel, in micrograms per liter	01065	35	273	<1	200	3.25	1.3	13.6	--	--	0.50	3.1
Silver, in micrograms per liter	01075	98	327	<0.1	10	--	--	--	--	--	--	--
Strontium, in micrograms per liter	01080	0	320	50	2,140	727	692	397	22.2	0.55	430	973
Thallium, in micrograms per liter	01057	89	320	<0.05	3	--	--	--	--	--	--	--
Vanadium, in micrograms per liter	01085	92	320	<2	13	--	--	--	--	--	--	--
Zinc, in micrograms per liter	01090	55	269	<5	90	12.50	6	17.3	--	--	2.50	10
Antimony, in micrograms per liter	01095	98	236	<0.05	1	--	--	--	--	--	--	--
Boron, in micrograms per liter	01020	35	327	<10	279	46	39	36	--	--	25	58
Cyanide, in milligrams per liter	00723	100	194	<0.01	<0.02	--	--	--	--	--	--	--
Selenium, in micrograms per liter	01145	45	321	<0.2	76	5.3	1.0	11.3	--	--	1.0	4.0

Table 7. Trace element summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.—Continued

[Summary statistics were not computed when more than 80 percent of data were censored; USGS, U.S. Geological Survey; *n*, number of measurements; <, less than; --, not applicable]

Water-quality constituent	USGS parameter code	Censored data, in percent	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Deep index wells												
Aluminum, in micrograms per liter	01106	94	333	<10	56	--	--	--	--	--	--	--
Barium, in micrograms per liter	01005	0	333	25	1,150	133	89	172	9.5	1.3	61	130
Beryllium, in micrograms per liter	01010	98	333	<0.12	9	--	--	--	--	--	--	--
Cadmium, in micrograms per liter	01025	96	333	<0.05	1	--	--	--	--	--	--	--
Chromium, in micrograms per liter	01030	99	298	<1	5	--	--	--	--	--	--	--
Copper, in micrograms per liter	01040	95	333	<5	11	--	--	--	--	--	--	--
Iron, in micrograms per liter	01046	38	702	<5	17,900	1,441	150	3,196	--	--	50	1,080
Lead, in micrograms per liter	01049	92	324	<0.05	1	--	--	--	--	--	--	--
Manganese, in micrograms per liter	01056	2	707	<1	1,640	440	310	368	--	--	178.0	549
Mercury, in micrograms per liter	71890	100	205	<0.1	<0.1	--	--	--	--	--	--	--
Nickel, in micrograms per liter	01065	45	312	<1	1,190	8.08	0.5	82.5	--	--	0.50	2.1
Silver, in micrograms per liter	01075	98	333	<0.2	<5	--	--	--	--	--	--	--
Strontium, in micrograms per liter	01080	0	323	2	4,760	855	778	608	34.0	0.71	489	1055
Thallium, in micrograms per liter	01057	89	323	<0.01	2	--	--	--	--	--	--	--
Vanadium, in micrograms per liter	01085	94	323	<2	10	--	--	--	--	--	--	--
Zinc, in micrograms per liter	01090	64	284	<5	50	10.60	2.5	15.8	--	--	2.50	8
Antimony, in micrograms per liter	01095	99	226	<0.1	1	--	--	--	--	--	--	--
Boron, in micrograms per liter	01020	30	333	<0.02	110	37	35	19	--	--	25	50
Cyanide, in milligrams per liter	00723	99	196	<0.01	0.01	--	--	--	--	--	--	--
Selenium, in micrograms per liter	01145	66	323	<0.2	20	1.7	1.0	2.9	--	--	0.6	1.0

Table 8. Dissolved arsenic species summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.

[Summary statistics were not computed when more than 80 percent of data were censored; USGS, U.S. Geological Survey; *n*, number of measurements; <, less than; --, not applicable]

Water-quality constituent	USGS parameter code	Censored data, in percent	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Shallow index wells												
Arsenic, in micrograms per liter	01000	1	703	<1.0	55.0	3.83	1.50	4.94	--	--	0.73	5.10
Arsenate, in micrograms per liter	62453	4	360	<0.2	8.50	1.31	0.70	1.52	--	--	0.40	1.50
Arsenite, in micrograms per liter	62452	80	361	<0.1	17.3	1.88	0.48	2.75	--	--	0.16	2.80
Dimethylarsinate, in micrograms per liter as arsenic	62455	89	361	<0.3	1.00	--	--	--	--	--	--	--
Monomethylarsonate, in micrograms per liter as arsenic	62454	90	361	<0.1	1.60	--	--	--	--	--	--	--
Deep index wells												
Arsenic, in micrograms per liter	01000	12	705	<1.0	23.9	7.43	6.00	6.43	--	--	1.60	13.20
Arsenate, in micrograms per liter	62453	9	364	<0.2	9.20	1.89	1.30	1.53	--	--	0.70	2.70
Arsenite, in micrograms per liter	62452	31	359	<0.1	18.4	4.87	2.90	4.98	--	--	0.30	9.15
Dimethylarsinate, in micrograms per liter as arsenic	62455	80	364	<0.3	1.90	0.3	0.3	0.2	--	--	0.2	0.3
Monomethylarsonate, in micrograms per liter as arsenic	62454	85	364	<0.1	1.60	--	--	--	--	--	--	--

Table 9. Organic compound summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.

[Summary statistics were not computed when more than 80 percent of data were censored; USGS, U.S. Geological Survey; *n*, number of measurements; <, less than; --, not applicable]

Water-quality constituent	USGS parameter code	Censored data, in percent	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Shallow index wells												
1,2-Dichloroethane, in micrograms per liter	32103	97	206	<0.2	0.800	--	--	--	--	--	--	--
2,4-D, in micrograms per liter	39732	99	135	<0.04	0.180	--	--	--	--	--	--	--
2,4-Dichlorophenol, in micrograms per liter	34601	99	139	<0.36	<2.5	--	--	--	--	--	--	--
2,6-Diethylaniline, in micrograms per liter	82660	93	200	<0.006	0.002	--	--	--	--	--	--	--
2-Chloro-4-isopropylamino-6-amino-*s*-triazine, in micrograms per liter	04040	72	244	<0.006	1.080	0.080	0.017	0.144	--	--	0.005	0.074
2-Chloro-6-ethylamino-4-amino-*s*-triazine, in micrograms per liter	04038	78	147	<0.01	0.280	0.040	0.030	0.033	--	--	0.025	0.040
2-Hydroxy-4-isopropylamino-6-ethylamino-*s*-triazine, in micrograms per liter	50355	71	113	<0.006	0.159	0.021	0.019	0.018	--	--	0.013	0.030
3,4-Dichloroaniline, in micrograms per liter	61625	97	151	<0.004	0.060	--	--	--	--	--	--	--
4-Chloro-2-methylphenol, in micrograms per liter	61633	99	151	<0.003	0.002	--	--	--	--	--	--	--
Acetochlor, in micrograms per liter	49260	98	246	<0.006	0.040	--	--	--	--	--	--	--
Alachlor, in micrograms per liter	46342	98	246	<0.005	<0.05	--	--	--	--	--	--	--
Aminomethylphosphonic acid, in micrograms per liter	62649	94	67	<0.02	0.300	--	--	--	--	--	--	--
Atrazine, in micrograms per liter	39632	42	246	<0.006	2.280	0.062	0.009	0.204	--	--	0.004	0.038
Bentazon, in micrograms per liter	38711	99	134	<0.02	0.800	--	--	--	--	--	--	--
Chlorodiamino-*s*-triazine, in micrograms per liter	04039	88	56	<0.01	0.470	--	--	--	--	--	--	--
Desulfinylfipronil amide, in micrograms per liter	62169	99	162	<0.03	<0.09	--	--	--	--	--	--	--

Table 9. Organic compound summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.—Continued

[Summary statistics were not computed when more than 80 percent of data were censored; USGS, U.S. Geological Survey; *n*, number of measurements; <, less than; --, not applicable]

Water-quality constituent	USGS parameter code	Censored data, in percent	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Shallow index wells—Continued												
Desulfinylfipronil, in micrograms per liter	62170	99	162	<0.004	0.007	--	--	--	--	--	--	--
Dieldrin, in micrograms per liter	39381	99	200	<0.004	<0.012	--	--	--	--	--	--	--
Dimethenamid, in micrograms per liter	61588	97	69	<0.02	<0.2	--	--	--	--	--	--	--
Fipronil sulfide, in micrograms per liter	62167	98	162	<0.005	0.008	--	--	--	--	--	--	--
Flumetsulam, in micrograms per liter	61694	99	98	<0.01	<0.08	--	--	--	--	--	--	--
Glyphosate, in micrograms per liter	62722	96	67	<0.02	0.130	--	--	--	--	--	--	--
Hexazinone, in micrograms per liter	04025	94	151	<0.008	0.020	--	--	--	--	--	--	--
Metolachlor, in micrograms per liter	39415	78	246	<0.006	2.610	0.075	0.010	0.291	--	--	0.007	0.025
Metsulfuron-methyl, in micrograms per liter	61697	99	97	<0.03	<0.14	--	--	--	--	--	--	--
Molinate, in micrograms per liter	82671	98	49	<0.002	<0.01	--	--	--	--	--	--	--
Nicosulfuron, in micrograms per liter	50364	99	98	<0.01	<0.32	--	--	--	--	--	--	--
Picloram, in micrograms per liter	49291	98	132	<0.02	0.200	--	--	--	--	--	--	--
Prometon, in micrograms per liter	04037	86	846	<0.005	0.380	--	--	--	--	--	--	--
Simazine, in micrograms per liter	04035	96	246	<0.005	0.025	--	--	--	--	--	--	--
Tebuthiuron, in micrograms per liter	82670	97	200	<0.012	0.024	--	--	--	--	--	--	--
Triazines, in micrograms per liter as atrazine	34756	88	704	<0.1	5.000	--	--	--	--	--	--	--
2-Nitrophenol, in micrograms per liter	34591	99	138	<0.2	0.700	--	--	--	--	--	--	--

Table 9. Organic compound summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.—Continued

[Summary statistics were not computed when more than 80 percent of data were censored; USGS, U.S. Geological Survey; *n*, number of measurements; <, less than; --, not applicable]

Water-quality constituent	USGS parameter code	Censored data, in percent	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Shallow index wells—Continued												
9*H*-Fluorene, in micrograms per liter	34381	99	139	<0.02	<2	--	--	--	--	--	--	--
Acenaphthylene, in micrograms per liter	34200	99	139	<0.02	<2	--	--	--	--	--	--	--
Anthracene, in micrograms per liter	34220	99	138	<0.02	<2	--	--	--	--	--	--	--
Benzo[*a*]anthracene, in micrograms per liter	34526	99	139	<0.04	1.200	--	--	--	--	--	--	--
Benzo[*b*]fluoranthene, in micrograms per liter	34230	99	139	<0.02	<2	--	--	--	--	--	--	--
Benzo[*ghi*]perylene, in micrograms per liter	34521	98	139	<0.02	<3	--	--	--	--	--	--	--
Benzo[*k*]fluoranthene, in micrograms per liter	34242	99	138	<0.02	<2	--	--	--	--	--	--	--
Benzyl *n*-butyl phthalate, in micrograms per liter	34292	96	139	<0.4	4.000	--	--	--	--	--	--	--
Bis(2-ethylhexyl) phthalate, in micrograms per liter	39100	92	139	<1.1	45.000	--	--	--	--	--	--	--
Caffeine, in micrograms per liter	50305	99	92	<0.01	<0.08	--	--	--	--	--	--	--
Chrysene, in micrograms per liter	34320	97	139	<0.02	<3	--	--	--	--	--	--	--
Diethyl phthalate, in micrograms per liter	34336	97	139	<0.12	<2.4	--	--	--	--	--	--	--
Di-*n*-butyl phthalate, in micrograms per liter	39110	96	139	<0.4	3.170	--	--	--	--	--	--	--
Fluoranthene, in micrograms per liter	34376	98	139	<0.06	<2.4	--	--	--	--	--	--	--
Indeno[1,2,3-*cd*]pyrene, in micrograms per liter	34403	99	139	<0.02	<3	--	--	--	--	--	--	--
Isophorone, in micrograms per liter	34408	98	139	<0.12	<2.2	--	--	--	--	--	--	--
Phenanthrene, in micrograms per liter	34461	98	139	<0.04	<2.3	--	--	--	--	--	--	--

Table 9. Organic compound summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.—Continued

[Summary statistics were not computed when more than 80 percent of data were censored; USGS, U.S. Geological Survey; *n*, number of measurements; <, less than; --, not applicable]

Water-quality constituent	USGS parameter code	Censored data, in percent	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Shallow index wells—Continued												
Phenol, in micrograms per liter	34694	91	139	<0.12	<3.4	--	--	--	--	--	--	--
Pyrene, in micrograms per liter	34469	99	139	<0.02	<2.2	--	--	--	--	--	--	--
Trichloroethene, in micrograms per liter	39180	99	206	<0.1	0.700	--	--	--	--	--	--	--
Trichloromethane, in micrograms per liter	32106	97	206	<0.1	1.000	--	--	--	--	--	--	--
Deep index wells												
1,2-Dichloroethane, in micrograms per liter	32103	95	207	<0.2	1.700	--	--	--	--	--	--	--
1-Naphthol, in micrograms per liter	49295	99	155	<0.007	<0.088							
2,4,6-Trichlorophenol, in micrograms per liter	34621	98	122	<0.04	<2.8	--	--	--	--	--	--	--
2,4-D, in micrograms per liter	39732	99	97	<0.02	<0.06	--	--	--	--	--	--	--
2,4-Dichlorophenol, in micrograms per liter	34601	99	122	<0.04	<2.5	--	--	--	--	--	--	--
2,6-Diethylaniline, in micrograms per liter	82660	98	165	<0.002	0.008	--	--	--	--	--	--	--
2-Chloro-2',6'-diethylacetanilide, in micrograms per liter	61618	99	154	<0.005	<0.016	--	--	--	--	--	--	--
2-Chloro-4-isopropylamino-6-amino-*s*-triazine, in micrograms per liter	04040	68	183	<0.006	0.390	0.018	0.006	0.054	--	--	0.003	0.008
2-Chloro-6-ethylamino-4-amino-*s*-triazine, water, in micrograms per liter	04038	96	114	<0.01	0.070	--	--	--	--	--	--	--
2-Ethyl-6-methylaniline, in micrograms per liter	61620	99	154	<0.005	0.010	--	--	--	--	--	--	--
2-Hydroxy-4-isopropylamino-6-ethylamino-*s*-triazine, in micrograms per liter	50355	94	108	<0.004	<0.04	--	--	--	--	--	--	--
3,4-Dichloroaniline, in micrograms per liter	61625	99	154	<0.004	0.006	--	--	--	--	--	--	--

Table 9. Organic compound summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.—Continued

[Summary statistics were not computed when more than 80 percent of data were censored; USGS, U.S. Geological Survey; *n*, number of measurements; <, less than; --, not applicable]

Water-quality constituent	USGS parameter code	Censored data, in percent	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Deep index wells—Continued												
4-Chloro-2-methylphenol, in micrograms per liter	61633	99	154	<0.002	0.006	--	--	--	--	--	--	--
Acetochlor, in micrograms per liter	49260	99	183	<0.006	0.025	--	--	--	--	--	--	--
Alachlor, in nanograms per liter	65064	99	183	<0.005	<0.025	--	--	--	--	--	--	--
Aminomethylphosphonic acid, in micrograms per liter	62649	99	69	<0.02	<10	--	--	--	--	--	--	--
Atrazine, in micrograms per liter	39632	72	183	<0.007	0.090	0.009	0.004	0.012	--	--	0.004	0.007
Benfluralin, in micrograms per liter	82673	99	165	<0.01	<0.014	--	--	--	--	--	--	--
Bentazon, in micrograms per liter	38711	98	98	<0.01	<0.06	--	--	--	--	--	--	--
Carbaryl, in micrograms per liter	82680	99	165	<0.02	<0.2	--	--	--	--	--	--	--
Carbofuran, in micrograms per liter	49309	99	98	<0.006	<0.06	--	--	--	--	--	--	--
Chlorpyrifos, in micrograms per liter	38933	99	165	<0.004	<0.016	--	--	--	--	--	--	--
cis-Permethrin, in micrograms per liter	82687	99	165	<0.006	<0.014	--	--	--	--	--	--	--
DCPA, in micrograms per liter	82682	99	165	<0.003	<0.008	--	--	--	--	--	--	--
Desulfinylfipronil, in micrograms per liter	62170	99	165	<0.01	<0.03	--	--	--	--	--	--	--
Diazinon, in micrograms per liter	39572	99	165	<0.006	<0.014	--	--	--	--	--	--	--
Dieldrin, in micrograms per liter	39381	99	165	<0.006	<0.014	--	--	--	--	--	--	--
Fipronil sulfide, in micrograms per liter	62167	99	165	<0.006	0.008	--	--	--	--	--	--	--
Fipronil sulfone, in micrograms per liter	62168	99	165	<0.005	<0.024	--	--	--	--	--	--	--

Table 9. Organic compound summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.—Continued

[Summary statistics were not computed when more than 80 percent of data were censored; USGS, U.S. Geological Survey; *n*, number of measurements; <, less than; --, not applicable]

Water-quality constituent	USGS parameter code	Censored data, in percent	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Deep index wells—Continued												
Fipronil, in micrograms per liter	62166	99	165	<0.008	<0.04	--	--	--	--	--	--	--
Fonofos, in micrograms per liter	04095	99	165	<0.002	0.007	--	--	--	--	--	--	--
Hexachlorobenzene, in micrograms per liter	39700	99	122	<0.08	<2.2	--	--	--	--	--	--	--
Hexazinone, in micrograms per liter	04025	99	154	<0.008	<0.026	--	--	--	--	--	--	--
Imazaquin, in micrograms per liter	50356	96	95	<0.02	<0.1	--	--	--	--	--	--	--
Imazethapyr, in micrograms per liter	50407	99	97	<0.02	<0.08	--	--	--	--	--	--	--
Isofenphos, in micrograms per liter	61594	99	154	<0.004	0.010	--	--	--	--	--	--	--
Malaoxon, in micrograms per liter	61652	99	154	<0.008	<0.08	--	--	--	--	--	--	--
Malathion, in micrograms per liter	39532	99	165	<0.016	<0.028	--	--	--	--	--	--	--
Metalaxyl, in micrograms per liter	61596	99	154	<0.005	0.008	--	--	--	--	--	--	--
Methidathion, in micrograms per liter	61598	99	154	<0.004	<0.012	--	--	--	--	--	--	--
Metolachlor, in micrograms per liter	39415	92	183	<0.004	<0.05	--	--	--	--	--	--	--
Metribuzin, in micrograms per liter	82630	99	183	<0.005	<0.05	--	--	--	--	--	--	--
Myclobutanil, in micrograms per liter	61599	99	154	<0.008	<0.033	--	--	--	--	--	--	--
Phorate, in micrograms per liter	82664	99	165	<0.012	<0.056	--	--	--	--	--	--	--
Prometon, in micrograms per liter	04037	99	183	<0.005	<0.05	--	--	--	--	--	--	--
Prometryn, in micrograms per liter	04036	99	172	<0.005	<0.1	--	--	--	--	--	--	--

Table 9. Organic compound summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.—Continued

[Summary statistics were not computed when more than 80 percent of data were censored; USGS, U.S. Geological Survey; *n*, number of measurements; <, less than; --, not applicable]

Water-quality constituent	USGS parameter code	Censored data, in percent	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Deep index wells—Continued												
Propyzamide, in micrograms per liter	82676	99	165	<0.004	<0.015	--	--	--	--	--	--	--
Simazine, in micrograms per liter	04035	99	183	<0.005	<0.05	--	--	--	--	--	--	--
Terbufos, in micrograms per liter	82675	99	157	<0.012	<0.018	--	--	--	--	--	--	--
Terbuthylazine, in micrograms per liter	04022	99	155	<0.006	<0.014	--	--	--	--	--	--	--
Triazines, in micrograms per liter as atrazine	34756	98	711	<0.1	0.500	--	--	--	--	--	--	--
Trifluralin, in micrograms per liter	82661	99	165	<0.006	<0.018	--	--	--	--	--	--	--
2-Chloronaphthalene, in micrograms per liter	34581	99	122	<0.06	<1.9	--	--	--	--	--	--	--
4-Bromophenyl phenyl ether, in micrograms per liter	34636	99	122	<0.1	<2.1	--	--	--	--	--	--	--
9*H*-Fluorene, in micrograms per liter	34381	96	122	<0.02	<2	--	--	--	--	--	--	--
Acenaphthene, in micrograms per liter	34205	99	122	<0.05	<1.9	--	--	--	--	--	--	--
Acenaphthylene, in micrograms per liter	34200	99	122	<0.03	<1.8	--	--	--	--	--	--	--
Anthracene, in micrograms per liter	34220	98	122	<0.02	<2	--	--	--	--	--	--	--
Benzo[*a*]anthracene, in micrograms per liter	34526	99	122	<0.18	<2.4	--	--	--	--	--	--	--
Benzo[*a*]pyrene, in micrograms per liter	34247	98	121	<0.04	<1.3	--	--	--	--	--	--	--
Benzo[*b*]fluoranthene, in micrograms per liter	34230	99	122	<0.24	<1.9	--	--	--	--	--	--	--
Benzo[*ghi*]perylene, in micrograms per liter	34521	98	122	<0.04	<1.6	--	--	--	--	--	--	--
Benzo[*k*]fluoranthene, in micrograms per liter	34242	99	122	<0.12	<1.4	--	--	--	--	--	--	--

Table 9. Organic compound summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.—Continued

[Summary statistics were not computed when more than 80 percent of data were censored; USGS, U.S. Geological Survey; *n*, number of measurements; <, less than; --, not applicable]

Water-quality constituent	USGS parameter code	Censored data, in percent	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Deep index wells—Continued												
Benzyl *n*-butyl phthalate, in micrograms per liter	34292	97	122	<0.4	<2	--	--	--	--	--	--	--
Bis(2-chloroethoxy)methane, in micrograms per liter	34278	99	122	<0.08	<2.6	--	--	--	--	--	--	--
Bis(2-ethylhexyl) phthalate, in micrograms per liter	39100	99	123	<1.1	5.300	--	--	--	--	--	--	--
Caffeine, in micrograms per liter	50305	97	92	<0.006	<0.08	--	--	--	--	--	--	--
Chrysene, in micrograms per liter	34320	97	122	<0.1	<2.7	--	--	--	--	--	--	--
Dibenzo[*a,h*]anthracene, in micrograms per liter	34556	99	122	<0.12	<2.2	--	--	--	--	--	--	--
Dimethyl phthalate, in micrograms per liter	34341	98	122	<0.04	<1	--	--	--	--	--	--	--
Di-*n*-octyl phthalate, in micrograms per liter	34596	99	122	<0.4	<2.3	--	--	--	--	--	--	--
Fluoranthene, in micrograms per liter	34376	92	122	<0.02	<2.4	--	--	--	--	--	--	--
Indeno[1,2,3-*cd*]pyrene, in micrograms per liter	34403	98	122	<0.04	<3	--	--	--	--	--	--	--
Isophorone, in micrograms per liter	34408	99	122	<0.12	<2.2	--	--	--	--	--	--	--
Methyl *tert*-butyl ether, in micrograms per liter	78032	96	207	<0.2	9.000	--	--	--	--	--	--	--
Naphthalene, in micrograms per liter	34696	99	238	<0.04	<1.6	--	--	--	--	--	--	--
N-Nitrosodimethylamine, in micrograms per liter	34438	99	122	<0.08	<1.9	--	--	--	--	--	--	--
Phenanthrene, in micrograms per liter	34461	93	122	<0.02	<2.3	--	--	--	--	--	--	--
Phenol, in micrograms per liter	34694	87	122	<0.26	<3.4	--	--	--	--	--	--	--
Pyrene, in micrograms per liter	34469	91	121	<0.02	<2.2	--	--	--	--	--	--	--
Trichloromethane, in micrograms per liter	32106	99	207	<0.1	0.200	--	--	--	--	--	--	--

Table 10. Radioactivity summary statistics of discrete groundwater samples for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.

[USGS, U.S. Geological Survey; *n*, number of measurements; α, alpha; <, less than; --, not applicable; β, beta]

Water-quality constituent	USGS parameter code	Censored data, in percent	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Shallow index wells												
α radioactivity, in picocuries per liter	04126	8	195	<0.1	84	4.5	2.4	7.8	--	--	1.1	5.0
Gross β radioactivity, in picocuries per liter	03515	<1	195	0.50	44	6.3	5.4	5.0	--	--	3.4	7.8
Deep index wells												
α radioactivity, in picocuries per liter	04126	11	195	<0.1	15	2.6	2.0	2.5	--	--	0.8	3.8
Gross β radioactivity, in picocuries per liter	03515	2	195	1.20	17	5.0	4.2	2.7	--	--	3.1	6.5

Table 11. Mineral saturation indices for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.

[Statistical measures are unitless and saturation indices were computed using PHREEQC geochemical modeling software (Parkhurst and Appelo, 2013); saturation indices in **bold** indicate those whose range includes negative and positive values; *n*, number of measurements; (d), disordered; F, fluorine; C, carbon; O, oxygen; Fe, iron; H, hydrogen; Cl, chlorine; (ss), solid solution; K, potassium; Na, sodium; Mn, manganese; As, arsenic]

Mineral	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
				Shallow index wells						
Anhydrite	679	−4.11	−0.80	−1.90	−1.81	0.61	0.02	−0.32	−2.21	−1.49
Aragonite	679	**−3.75**	**0.12**	−0.86	−0.66	0.75	0.03	−0.87	−1.05	−0.35
Arsenolite	679	−60.92	−10.78	−32.54	−32.66	11.57	0.44	−0.36	−41.46	−21.36
Artinite	679	−15.93	−7.42	−9.99	−9.58	1.60	0.06	−0.16	−10.55	−8.88
Arsenic pentoxide	679	−39.92	−23.82	−33.08	−32.87	1.39	0.05	−0.04	−34.10	−32.10
Arsenic (native)	679	−75.17	−10.78	−40.98	−41.27	14.03	0.54	−0.34	−51.76	−27.68
Birnessite	679	**−24.69**	**2.19**	−11.93	−12.77	4.93	0.19	−0.41	−16.11	−8.35
Bixbyite	679	**−26.45**	**2.43**	−13.33	−14.32	4.68	0.18	−0.35	−16.71	−10.20
Brucite	679	−10.73	−5.92	−7.53	−7.29	0.88	0.03	−0.12	−7.89	−6.91
Calcium arsenate	679	−25.53	−10.01	−16.78	−16.49	2.36	0.09	−0.14	−17.62	−15.20
Calcite	679	**−3.60**	**0.27**	−0.71	−0.51	0.75	0.03	−1.05	−0.90	−0.19
Chalcedony	679	**−0.19**	**0.46**	0.18	0.18	0.10	<0.01	0.58	0.11	0.25
Chrysotile	679	−19.71	−5.78	−10.51	−9.87	2.54	0.10	−0.24	−11.50	−8.76
Claudetite	679	−60.96	−10.82	−32.58	−32.71	11.57	0.44	−0.36	−41.51	−21.51
Clinoenstatite	679	−8.36	−3.77	−5.35	−5.13	0.83	0.03	−0.16	−5.67	−4.78
Carbon dioxide	679	−2.16	−0.45	−1.42	−1.43	0.25	0.01	−0.18	−1.56	−1.26
Cristobalite	679	**−0.13**	**0.51**	0.23	0.23	0.10	<0.01	0.45	0.17	0.31
Diopside	679	−13.37	−3.93	−7.21	−6.76	1.69	0.06	−0.23	−7.86	−6.06
Dolomite	679	−7.57	−0.10	−1.94	−1.61	1.48	0.06	−0.76	−2.32	−0.90
Dolomite(d)	679	−8.16	−0.68	−2.53	−2.20	1.48	0.06	−0.58	−2.90	−1.49
Epsomite	679	−6.61	−3.44	−4.55	−4.48	0.63	0.02	−0.14	−4.89	−4.09
FCO_3Apatite	679	**−12.84**	**21.25**	7.14	8.22	5.35	0.21	0.75	4.70	10.64
$Fe(OH)_{2.7}Cl_{0.3}$	679	0.48	9.49	5.72	5.60	1.08	0.04	0.19	5.15	6.49
Iron (III) hydroxide	679	**−4.75**	**4.34**	0.72	0.60	1.08	0.04	1.50	0.16	1.47
Iron hydroxide	679	**−13.69**	**6.88**	−2.52	−1.92	3.04	0.12	−1.20	−4.24	−0.59
Fluorapatite	679	**−12.55**	**5.98**	−2.58	−2.17	2.78	0.11	−1.08	−3.99	−0.77
Fluorite	679	−4.98	−0.47	−1.77	−1.60	0.70	0.03	−0.40	−2.04	−1.29
Forsterite	679	−19.25	−9.84	−13.03	−12.58	1.71	0.07	−0.13	−13.70	−11.84
Goethite	679	0.69	9.89	6.28	6.16	1.08	0.04	0.17	5.73	7.04

Table 11. Mineral saturation indices for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.—Continued

[Statistical measures are unitless and saturation indices were computed using PHREEQC geochemical modeling software (Parkhurst and Appelo, 2013); saturation indices in **bold** indicate those whose range includes negative and positive values; *n*, number of measurements; (d), disordered; F, fluorine; C, carbon; O, oxygen; Fe, iron; H, hydrogen; Cl, chlorine; (ss), solid solution; K, potassium; Na, sodium; Mn, manganese; As, arsenic]

Mineral	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Shallow index wells—Continued										
Greenalite	679	**−28.85**	**2.02**	−8.33	−7.32	7.25	0.28	−0.87	−13.32	−1.52
Gypsum	679	−3.86	−0.55	−1.65	−1.56	0.61	0.02	−0.37	−1.96	−1.24
H_2	679	−38.35	−11.36	−24.74	−24.90	5.51	0.21	−0.22	−28.88	−19.58
H_2O	679	−1.89	−1.60	−1.75	−1.75	0.03	<0.01	−0.01	−1.77	−1.74
Halite	679	−9.13	−5.22	−7.24	−7.27	0.78	0.03	−0.11	−7.78	−6.72
Hausmannite	679	−33.31	−0.21	−17.79	−18.45	4.80	0.18	−0.27	−20.90	−15.34
Hematite	679	3.34	21.76	14.52	14.29	2.16	0.08	0.15	13.43	16.04
Huntite	679	−19.90	−4.89	−8.78	−8.19	2.94	0.11	−0.33	−9.54	−6.72
Hydromagnesite	679	−35.35	−15.54	−21.18	−20.36	3.79	0.15	−0.18	−22.37	−18.52
Hydroxyapatite	679	**−16.63**	**2.79**	−5.66	−5.17	2.98	0.11	−0.53	−7.03	−3.71
Jarosite(ss)	679	**−21.25**	**6.11**	−4.62	−4.58	3.18	0.12	−0.69	−6.29	−2.55
Jarosite-K	679	**−22.27**	**5.25**	−5.48	−5.47	3.19	0.12	−0.58	−7.15	−3.40
Jarosite-Na	679	**−24.43**	**2.70**	−8.02	−8.04	3.19	0.12	−0.40	−9.78	−5.98
JarositeH	679	−30.01	−1.84	−12.43	−12.44	3.21	0.12	−0.26	−14.19	−10.38
Magadiite	679	−8.62	−4.38	−5.99	−5.93	0.63	0.02	−0.11	−6.33	−5.60
Maghemite	679	**−6.09**	**12.08**	4.83	4.59	2.16	0.08	0.45	3.71	6.33
Magnesite	679	−4.52	−0.77	−1.78	−1.64	0.73	0.03	−0.41	−1.98	−1.27
Magnetite	679	1.25	22.39	12.81	13.47	3.05	0.12	0.24	11.12	14.74
Manganite	679	**−12.61**	**2.02**	−6.04	−6.55	2.34	0.09	−0.39	−7.76	−4.49
Melanterite	679	−15.17	−3.75	−7.88	−7.64	2.50	0.10	−0.32	−9.48	−5.88
Mirabilite	679	−9.66	−4.86	−6.98	−6.97	0.95	0.04	−0.14	−7.66	−6.25
Manganese	679	−70.95	−45.52	−58.85	−59.44	4.57	0.18	−0.08	−61.95	−55.81
$Mn_3(AsO_4)2{\cdot}8H_2O$	679	−26.80	−10.26	−17.54	−17.68	4.03	0.16	−0.24	−21.34	−13.79
Manganese (II) phosphate	679	−29.78	−12.66	−20.53	−20.25	3.63	0.14	−0.18	−23.70	−17.71
Manganese (II) chloride tetrahydrate	679	−18.99	−11.16	−14.90	−14.89	1.40	0.05	−0.09	−15.76	−13.81
Manganese (II) hydrogen phosphate	679	**−3.27**	**2.80**	−0.29	−0.20	1.24	0.05	−4.21	−1.34	0.54
Manganese sulfate	679	−14.96	−10.57	−12.78	−12.79	1.22	0.05	−0.10	−13.95	−11.68
Nahocolite	679	−5.99	−3.50	−4.47	−4.42	0.49	0.02	−0.11	−4.77	−4.13
Natron	679	−13.23	−7.64	−9.77	−9.63	1.03	0.04	−0.10	−10.30	−9.04

Table 11. Mineral saturation indices for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.—Continued

[Statistical measures are unitless and saturation indices were computed using PHREEQC geochemical modeling software (Parkhurst and Appelo, 2013); saturation indices in **bold** indicate those whose range includes negative and positive values; *n*, number of measurements; (d), disordered; F, fluorine; C, carbon; O, oxygen; Fe, iron; H, hydrogen; Cl, chlorine; (ss), solid solution; K, potassium; Na, sodium; Mn, manganese; As, arsenic]

Mineral	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Shallow index wells—Continued										
Nesquehonite	679	−6.92	−3.17	−4.18	−4.04	−0.73	0.03	−0.18	−4.38	−3.67
Nsutite	679	**−23.65**	**3.23**	−10.89	−11.74	4.93	0.19	−0.45	−15.07	−7.31
O_2	679	−2.16	−0.45	−1.42	−1.43	0.25	0.01	−0.18	−1.56	−1.26
Portlandite	679	−16.42	−11.30	−13.05	−12.79	0.90	0.03	−0.07	−13.43	−12.43
Pyrochroite	679	−11.87	−5.60	−8.26	−8.33	1.33	0.05	−0.16	−9.26	−7.16
Pyrolusite	679	**−23.89**	**2.58**	−11.20	−12.02	4.94	0.19	−0.44	−15.45	−7.61
Quartz	679	0.28	0.92	0.64	0.63	0.10	<0.01	0.16	0.57	0.71
Rhodochrosite	679	**−4.56**	**0.62**	−1.57	−1.54	1.24	0.05	−0.79	−2.59	−0.48
Rhodochrosite(d)	679	−5.26	−0.09	−2.28	−2.25	1.24	0.05	−0.55	−3.30	−1.19
Scorodite	679	−15.43	−3.60	−7.67	−7.55	1.18	0.05	−0.15	−8.24	−7.11
Sepiolite	679	−12.37	−3.50	−6.58	−6.17	1.63	0.06	−0.25	−7.17	−5.47
Sepiolite(d)	679	−15.00	−6.17	−9.24	−8.84	1.63	0.06	−0.18	−9.83	−8.11
Siderite	679	**−9.30**	**0.88**	−2.29	−1.88	2.42	0.09	−1.06	−3.85	0.04
Siderite(d)(3)	679	**−9.67**	**0.49**	−2.67	−2.28	2.42	0.09	−0.91	−4.23	−0.35
Silicagel	679	−0.73	−0.08	−0.36	−0.36	0.10	<0.01	−0.28	−0.43	−0.29
Silicon dioxide	679	−1.06	−0.42	−0.69	−0.70	0.10	<0.01	−0.15	−0.76	−0.62
Strengite	679	**−7.44**	**4.24**	−0.64	−0.63	1.28	0.05	−2.00	−1.40	0.18
Talc	679	−15.41	−1.90	−6.58	−5.94	2.46	0.09	−0.37	−7.49	−4.91
Thenardite	679	−11.08	−6.19	−8.36	−8.35	0.94	0.04	−0.11	−9.03	−7.66
Thermonatrite	679	−15.13	−9.63	−11.63	−11.48	1.02	0.04	−0.09	−12.16	−10.91
Tremolite	679	−37.19	−4.83	−16.06	−14.51	5.83	0.22	−0.36	−18.26	−12.10
Trona	679	−21.22	−13.31	−16.16	−15.95	1.50	0.06	−0.09	−16.97	−15.14
Vivianite	679	**−31.34**	**2.66**	−9.76	−8.48	7.08	0.27	−0.73	−14.22	−3.68
Deep index wells										
Anhydrite	655	−3.59	−0.77	−2.02	−2.01	0.56	0.02	−0.28	−2.35	−1.71
Aragonite	655	**−1.48**	**0.69**	−0.36	−0.31	0.27	0.01	−0.74	−0.46	−0.19
Arsenolite	655	−58.23	−11.54	−28.15	−24.10	10.31	0.40	−0.37	−36.50	−19.88
Artinite	655	−11.76	−5.32	−8.72	−8.61	0.74	0.03	−0.08	−9.07	−8.28
Arsenic pentoxide	655	−43.85	−28.91	−33.45	−33.32	1.44	0.06	−0.04	−34.38	−32.24

Table 11. Mineral saturation indices for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.—Continued

[Statistical measures are unitless and saturation indices were computed using PHREEQC geochemical modeling software (Parkhurst and Appelo, 2013); saturation indices in **bold** indicate those whose range includes negative and positive values; *n*, number of measurements; (d), disordered; F, fluorine; C, carbon; O, oxygen; Fe, iron; H, hydrogen; Cl, chlorine; (ss), solid solution; K, potassium; Na, sodium; Mn, manganese; As, arsenic]

Mineral	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Deep index wells—Continued										
Arsenic (native)	655	−71.49	−7.61	−35.21	−30.50	12.32	0.48	−0.35	−44.55	−25.68
Birnessite	655	**−25.17**	**0.74**	−12.75	−14.30	4.62	0.18	−0.36	−16.11	−9.25
Bixbyite	655	**−24.96**	**0.27**	−12.54	−13.81	4.57	0.18	−0.36	−15.80	−9.28
Brucite	655	−8.47	−4.15	−6.73	−6.68	0.46	0.02	−0.07	−6.96	−6.46
Calcium arsenate	655	−23.75	−10.26	−14.69	−14.60	1.48	0.06	−0.10	−15.51	−13.57
Calcite	655	**−1.33**	**0.84**	−0.21	−0.16	0.27	0.01	−1.27	−0.30	−0.04
Chalcedony	655	0.08	0.36	0.23	0.23	0.05	<0.01	0.21	0.20	0.27
Chrysotile	655	−13.10	−0.43	−8.01	−7.86	1.34	0.05	−0.17	−8.73	−7.24
Claudetite	655	−58.28	−11.59	−28.20	−24.15	10.31	0.40	−0.37	−36.54	−19.93
Clinoenstatite	655	−6.15	−1.98	−4.49	−4.44	0.45	0.02	−0.10	−4.73	−4.23
Carbon dioxide	655	−3.45	−0.87	−1.74	−1.74	0.26	0.01	−0.15	−1.88	−1.57
Cristobalite	655	0.14	0.42	0.29	0.28	0.05	<0.01	0.17	0.25	0.32
Diopside	655	−8.63	−0.22	−5.47	−5.38	0.87	0.03	−0.16	−5.92	−4.95
Dolomite	655	**−3.37**	**0.93**	−0.97	−0.83	0.58	0.02	−0.60	−1.19	−0.59
Dolomite(d)	655	**−3.96**	**0.34**	−1.56	−1.42	0.58	0.02	−0.37	−1.78	−1.18
Epsomite	655	−6.50	−3.43	−4.71	−4.63	0.64	0.02	−0.14	−5.06	−4.32
FCO_3Apatite	655	**−0.69**	**21.66**	10.78	11.01	2.99	0.12	0.28	8.77	12.74
$Fe(OH)_{2.7}Cl_{0.3}$	655	**−0.05**	**9.62**	5.65	5.56	1.10	0.04	0.19	5.15	6.35
Iron (III) hydroxide	655	**−4.69**	**4.63**	0.71	0.63	1.09	0.04	1.52	0.22	1.43
Iron hydroxide	655	**−13.49**	**7.89**	−1.35	−0.90	2.57	0.10	−1.91	−2.09	0.10
Fluorapatite	655	**−6.80**	**5.69**	−0.69	−0.61	1.78	0.07	−2.58	−1.87	0.43
Fluorite	655	−5.08	−0.75	−1.73	−1.66	0.57	0.02	−0.33	−1.90	−1.42
Forsterite	655	−14.78	−6.28	−11.37	−11.28	0.90	0.04	−0.08	−11.85	−10.86
Goethite	655	0.87	10.21	6.28	6.19	1.09	0.04	0.17	5.78	7.01
Greenalite	655	**−26.18**	**4.58**	−4.65	−2.72	5.76	0.23	−1.24	−7.55	−0.22
Gypsum	655	−3.35	−0.52	−1.77	−1.76	0.56	0.02	−0.32	−2.10	−1.46
H_2	655	−36.52	−9.22	−22.34	−20.53	4.79	0.19	−0.21	−25.93	−18.69
H_2O	655	−1.79	−1.68	−1.75	−1.74	0.01	<0.01	−0.01	−1.75	−1.74
Halite	655	−8.91	−4.90	−6.99	−6.85	0.81	0.03	−0.12	−7.49	−6.50

Table 11. Mineral saturation indices for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.—Continued

[Statistical measures are unitless and saturation indices were computed using PHREEQC geochemical modeling software (Parkhurst and Appelo, 2013); saturation indices in **bold** indicate those whose range includes negative and positive values; *n*, number of measurements; (d), disordered; F, fluorine; C, carbon; O, oxygen; Fe, iron; H, hydrogen; Cl, chlorine; (ss), solid solution; K, potassium; Na, sodium; Mn, manganese; As, arsenic]

Mineral	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Deep index wells—Continued										
Hausmannite	655	−29.58	−3.22	−15.40	−16.43	4.61	0.18	−0.30	−18.59	−12.20
Hematite	655	3.70	22.39	14.52	14.35	2.18	0.09	0.15	13.53	15.98
Huntite	655	−11.83	−3.28	−6.86	−6.56	1.22	0.05	−0.18	−7.32	−6.07
Hydromagnesite	655	−25.37	−12.56	−18.49	−18.13	1.68	0.07	−0.09	−19.18	−17.45
Hydroxyapatite	655	**−9.29**	**4.76**	−3.37	−3.36	1.90	0.07	−0.56	−4.66	−2.23
Jarosite(ss)	655	**−24.90**	**5.69**	−6.22	−6.28	3.34	0.13	−0.54	−7.69	−4.07
Jarosite-K	655	**−25.65**	**4.89**	−7.00	−7.06	3.35	0.13	−0.48	−8.53	−4.85
Jarosite-Na	655	**−28.31**	**2.48**	−9.43	−9.50	3.41	0.13	−0.36	−10.97	−7.28
JarositeH	655	−33.08	−2.25	−14.30	−14.38	3.33	0.13	−0.23	−15.82	−12.20
Magadiite	655	−6.64	−3.92	−5.11	−5.16	0.44	0.02	−0.09	−5.41	−4.82
Maghemite	655	**−5.99**	**12.66**	4.82	4.66	2.17	0.08	0.45	3.85	6.26
Magnesite	655	−2.59	−0.47	−1.31	−1.23	0.32	0.01	−0.25	−1.44	−1.10
Magnetite	655	1.84	23.30	14.01	14.45	2.58	0.10	0.18	13.27	15.47
Manganite	655	**−11.92**	**0.80**	−5.66	−6.30	2.27	0.09	−0.40	−7.29	−4.05
Melanterite	655	−15.00	−4.19	−7.64	−7.36	2.07	0.08	−0.27	−8.73	−6.21
Mirabilite	655	−9.59	−5.38	−6.99	−6.79	0.92	0.04	−0.13	−7.75	−6.36
Manganese (III) sulfate	655	−76.73	−48.61	−60.87	−61.42	4.60	0.18	−0.08	−64.10	−57.92
$Mn_3(AsO_4)_2 \cdot 8H_2O$	655	−23.18	−8.56	−13.18	−12.38	2.60	0.10	−0.20	−14.45	−11.21
Manganese (II) phosphate	655	−26.57	−12.78	−17.01	−16.82	2.16	0.08	−0.13	−17.95	−15.55
Manganese (II) chloride tetrahydrate	655	−17.21	−10.27	−13.77	−13.67	1.18	0.05	−0.09	−14.42	−13.02
Manganese (II) hydrogen phosphate	655	**−2.53**	**2.04**	0.67	0.72	0.80	0.03	1.19	0.24	1.25
Manganese sulfate	655	−15.64	−10.61	−12.14	−12.14	0.75	0.03	−0.06	−12.60	−11.74
Nahocolite	655	−5.12	−3.73	−4.32	−4.20	0.35	0.01	−0.08	−4.59	−4.08
Natron	655	−11.15	−7.94	−9.15	−8.99	0.62	0.02	−0.07	−9.47	−8.72
Nesquehonite	655	−4.99	−2.87	−3.71	−3.63	0.32	0.01	−0.09	−3.84	−3.50
Nsutite	655	**−24.14**	**1.78**	−11.71	−13.26	4.62	0.18	−0.39	−15.07	−8.21
O_2	655	−3.45	−0.87	−1.74	−1.74	0.26	0.01	−0.15	−1.88	−1.57
Portlandite	655	−13.79	−9.42	−12.22	−12.18	0.44	0.02	−0.04	−12.44	−11.98
Pyrochroite	655	−10.51	−4.19	−6.69	−6.56	0.70	0.03	−0.10	−6.91	−6.31

Table 11. Mineral saturation indices for the *Equus* Beds aquifer index wells near Sedgwick, Kansas, 2001–16.—Continued

[Statistical measures are unitless and saturation indices were computed using PHREEQC geochemical modeling software (Parkhurst and Appelo, 2013); saturation indices in **bold** indicate those whose range includes negative and positive values; *n*, number of measurements; (d), disordered; F, fluorine; C, carbon; O, oxygen; Fe, iron; H, hydrogen; Cl, chlorine; (ss), solid solution; K, potassium; Na, sodium; Mn, manganese; As, arsenic]

Mineral	*n*	Minimum	Maximum	Mean	Median	Standard deviation	Standard error	Coefficient of variation	First quartile	Third quartile
Deep index wells—Continued										
Pyrolusite	655	**−24.42**	**1.39**	−11.98	−13.53	4.64	0.18	−0.39	−15.38	−8.45
Quartz	655	0.54	0.82	0.69	0.69	0.05	<0.01	0.07	0.66	0.72
Rhodochrosite	655	**−3.48**	**0.53**	−0.31	−0.17	0.60	0.02	−1.92	−0.40	0.02
Rhodochrosite(d)	655	−4.18	−0.18	−1.02	−0.87	0.60	0.02	−0.59	−1.10	−0.69
Scorodite	655	−18.40	−4.25	−7.86	−7.73	1.23	0.05	−0.16	−8.21	−7.25
Sepiolite	655	**−8.09**	**0.12**	−4.83	−4.75	0.88	0.03	−0.18	−5.28	−4.30
Sepiolite(d)	655	−10.76	−2.56	−7.49	−7.41	0.88	0.03	−0.12	−7.93	−6.97
Siderite	655	**−8.68**	**1.54**	−1.42	−0.78	1.93	0.08	−1.36	−2.51	0.08
Siderite(d)(3)	655	**−9.06**	**1.15**	−1.80	−1.17	1.93	0.08	−1.07	−2.90	−0.31
Silicagel	655	−0.46	−0.18	−0.31	−0.31	0.05	<0.01	−0.16	−0.34	−0.27
Silicon dioxide	655	−0.79	−0.51	−0.64	−0.64	0.05	<0.01	−0.08	−0.67	−0.60
Strengite	655	**−7.29**	**2.86**	−1.25	−1.19	1.13	0.04	−0.90	−1.84	−0.55
Talc	655	**−8.86**	**3.52**	−3.96	−3.84	1.34	0.05	−0.34	−4.66	−3.17
Thenardite	655	−10.91	−6.76	−8.36	−8.16	0.92	0.04	−0.11	−9.08	−7.75
Thermonatrite	655	−12.97	−9.77	−11.00	−10.84	0.62	0.02	−0.06	−11.33	−10.58
Tremolite	655	**−21.21**	**7.98**	−9.97	−9.69	3.07	0.12	−0.31	−11.57	−8.16
Trona	655	−18.07	−13.70	−15.37	−15.11	0.96	0.04	−0.06	−15.98	−14.72
Vivianite	655	**−30.73**	**0.71**	−7.42	−4.83	6.03	0.24	−0.81	−10.87	−3.00

Burrton, Kans., and natural saline water from the Arkansas River (fig. 1; Whisnant and others, 2015). Groundwater-level rises in the aquifer are likely because of the city of Wichita withdrawal reductions, less pumping by irrigators, more recharge because of increased precipitation, and introduction of artificial recharge (Whisnant and others, 2015; Klager, 2016). Groundwater levels in the two continuously monitored IWs (sites IW16S and IW16D; and IW18S and IW18D) ranged from 1,372 to 1,392 ft above the North American Vertical Datum of 1988 (NAVD 88) and 1,419 to 1,429 ft above the NAVD 88 during 2001 through 2016, respectively (table 2). Discretely measured groundwater levels ranged from 1,342 to 1,473 ft above the NAVD 88 in shallow IWs and 1,342 to 1,433 ft above the NAVD 88 in deep IWs (table 3). During 2001 through 2016, the median shallow IW altitude relative to the NAVD 88 was 1,386 ft and the median deep IW altitude was 1,384 ft (table 3).

Specific conductance is an indirect measure of dissolved solids in water (Hem, 1992). Previous studies in the Little Arkansas River developed simple linear regression relations between specific conductance and water-quality constituents of interest, including sulfate and chloride, to continuously compute water-quality constituents of interest at the two surface-water sites (Christensen and others, 2000, 2003; Rasmussen and others, 2016). Ziegler and others (2010) developed regression relations for the *Equus* Beds aquifer IWs between specific conductance and the water-quality constituents of interest, sulfate and chloride.

Specific conductance measurements in water samples collected from shallow IWs ranged from 89 to 2,310 microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C; mean equals 897 µS/cm) and measurements from deep IWs ranged from 32 to 4,520 µS/cm (mean equals 966 µS/cm; table 3). Large specific conductance (>1,000 µS/cm) was measured along Kisiwa Creek and near the Arkansas River in the shallow and deep parts of the *Equus* Beds aquifer (figs. 3*A*, *B*). Large specific conductance measurements are associated with past oil and gas activities (Williams and Lohman, 1949; Whittemore, 2007) and were in the shallow and deep parts of the aquifer near Burrton, Kans. (fig. 1), primarily at IW08D in the deep part of the aquifer (fig. 3*B*). Specific conductance means were smallest in the northeast part of the study area in the shallow and deep parts of the aquifer (figs. 3*A*, *B*). Hathaway and others (1981), Ziegler and others (2010), and Tappa and others (2015) reported similar specific conductance distribution in the aquifer during 1979 through 1980, 1995 through 2005, and 2006 through 2012, respectively.

ORP is a measurement of a solution's tendency to gain or lose electrons and indicates a water-quality constituent's ability to undergo oxidation or reduction reactions. ORP measurements are useful for monitoring basic oxidation-reduction changes: larger ORP values indicate an increased oxidation potential (tendency to gain electrons), and smaller ORP values indicate increased reducing potential (tendency to lose electrons). Groundwater with an increased oxidation potential (ORP >250 millivolts [mV]) indicates ferric iron as the dominant iron species in groundwater, which may lead to chemical precipitation of ferric iron oxides or hydroxides in aquifer material and decrease effective porosity (Schmidt and others, 2007). Groundwater with an increased reducing potential (ORP values <250 mV) may result in dissolution of iron, manganese, and arsenic in aquifer materials. Greater reducing conditions that involve geochemical and biological processes that convert dissolved sulfate to hydrogen sulfide gas are associated with smaller ORP values than those that result in dissolution of iron, manganese, and arsenic. Communities of iron-related and sulfate-reducing bacteria thrive under different ORP conditions (Cullimore, 2007), and large densities of these bacteria may potentially plug or foul groundwater wells.

Measurements of ORP averaged 324 mV (ranged from −70 to 730 mV) in shallow IWs and 234 mV (ranged from −160 to 640 mV) in deep IWs (table 3). Mean shallow IW ORP indicated more oxidizing conditions (>250 mV) in the northern and southern parts (near the Arkansas River) of the study area and more reducing conditions (<250 mV) along the Little Arkansas River and the downstream part of Kisiwa Creek (fig. 4*A*). Mean deep IW ORP were indicative of more oxidizing conditions in the southern one-third of the study area and more reducing conditions in the northern part of the aquifer (fig. 4*B*). Larger deep IW ORP means tended to correspond to parts of the aquifer that contained sandy aquifer materials (had larger effective porosity; Ziegler and others, 2010; Tappa and others, 2015). Ziegler and others (2010) and Tappa and others (2015) reported similar ORP distribution in the aquifer during 1995 through 2005 and 2006 through 2012, respectively.

Solids and Primary Ions

The primary constituents of dissolved ions come from decomposing rocks and soils and generally include calcium, magnesium, sodium, potassium, bicarbonate, carbonate, chloride, and sulfate ions (Hem, 1992). However, primary sources of chloride in the study area are from past oil and gas activities near Burrton, Kans., the Arkansas River, and municipal wastewater and industrial discharges (Whittemore, 2007). *Equus* Beds aquifer groundwater is predominantly a calcium bicarbonate type that changes to a sodium chloride type near the Arkansas River (Leonard and Kleinschmidt, 1976).

Constituents of concern in drinking water include major ions because large concentrations of ions may cause physiological effects, unpalatable mineral tastes, and greater costs because of corrosion or additional treatment needs (U.S. Environmental Protection Agency, 2009). Sodium, chloride, and sulfate frequently exceed water-quality criteria in the study area (Ziegler and others, 2010; Tappa and others, 2015; Stone and others, 2016); of these, sulfate and chloride are of particular concern because of the potential for saltwater migration from the Burrton oil field and the Arkansas River into the Wichita well field.

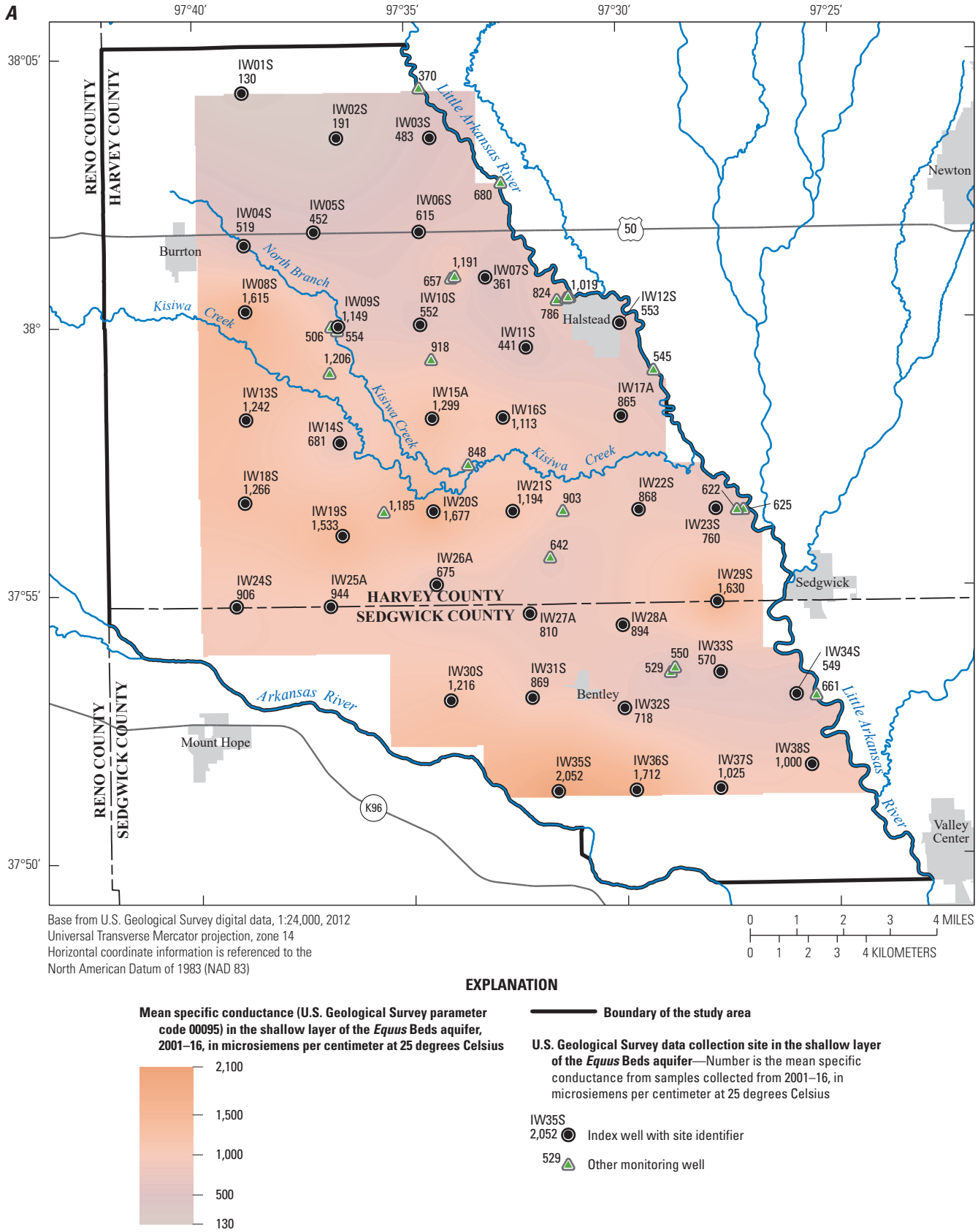


Figure 3. Mean specific conductance in the *Equus* Beds aquifer, 2001–16, south-central Kansas. *A*, shallow (depths below land surface equal to or less than 80 feet) wells. *B*, deep (depths below land surface greater than 80 feet) wells.

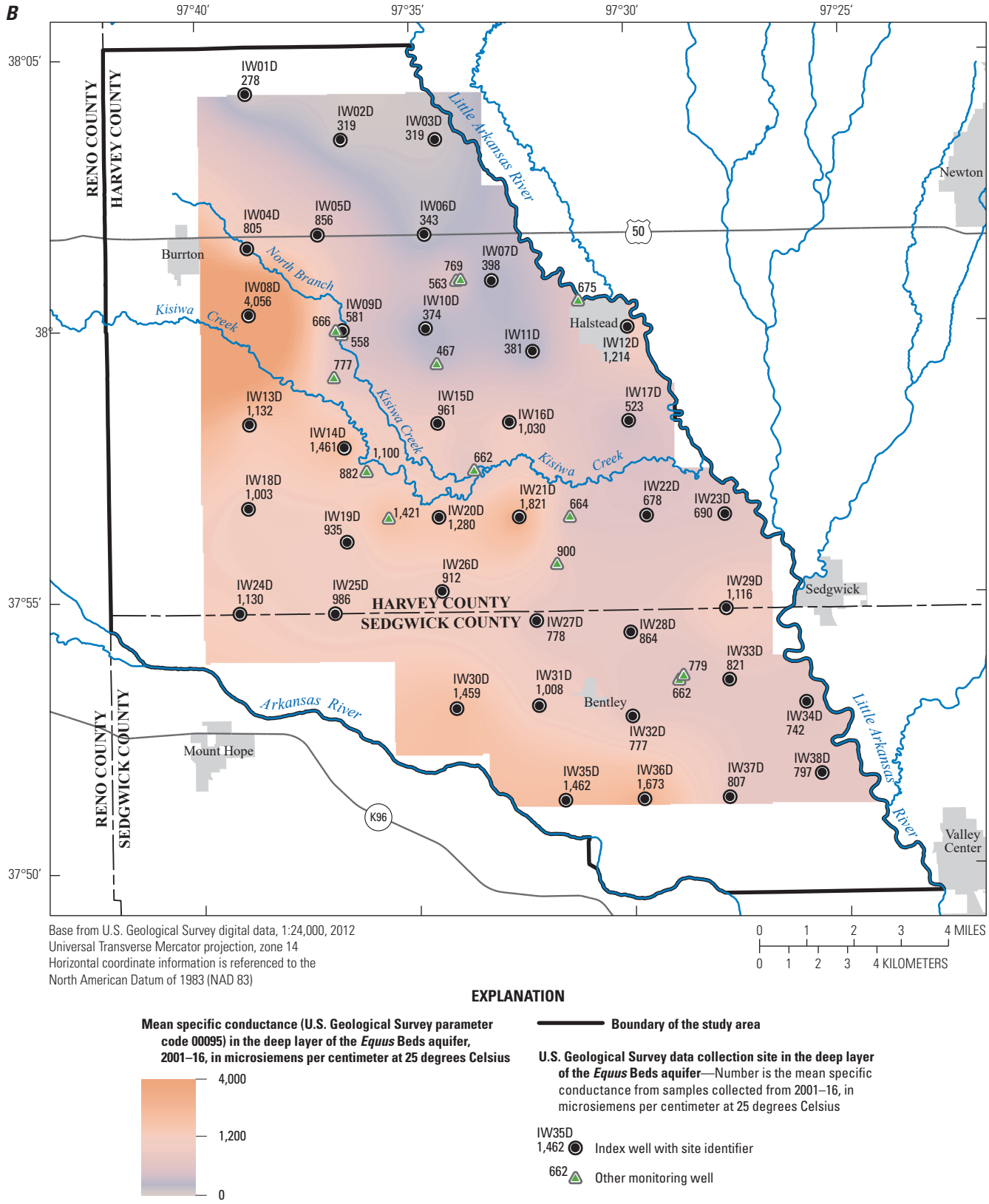


Figure 3. Mean specific conductance in the *Equus* Beds aquifer, 2001–16, south-central Kansas. *A*, shallow (depths below land surface equal to or less than 80 feet) wells. *B*, deep (depths below land surface greater than 80 feet) wells.—Continued

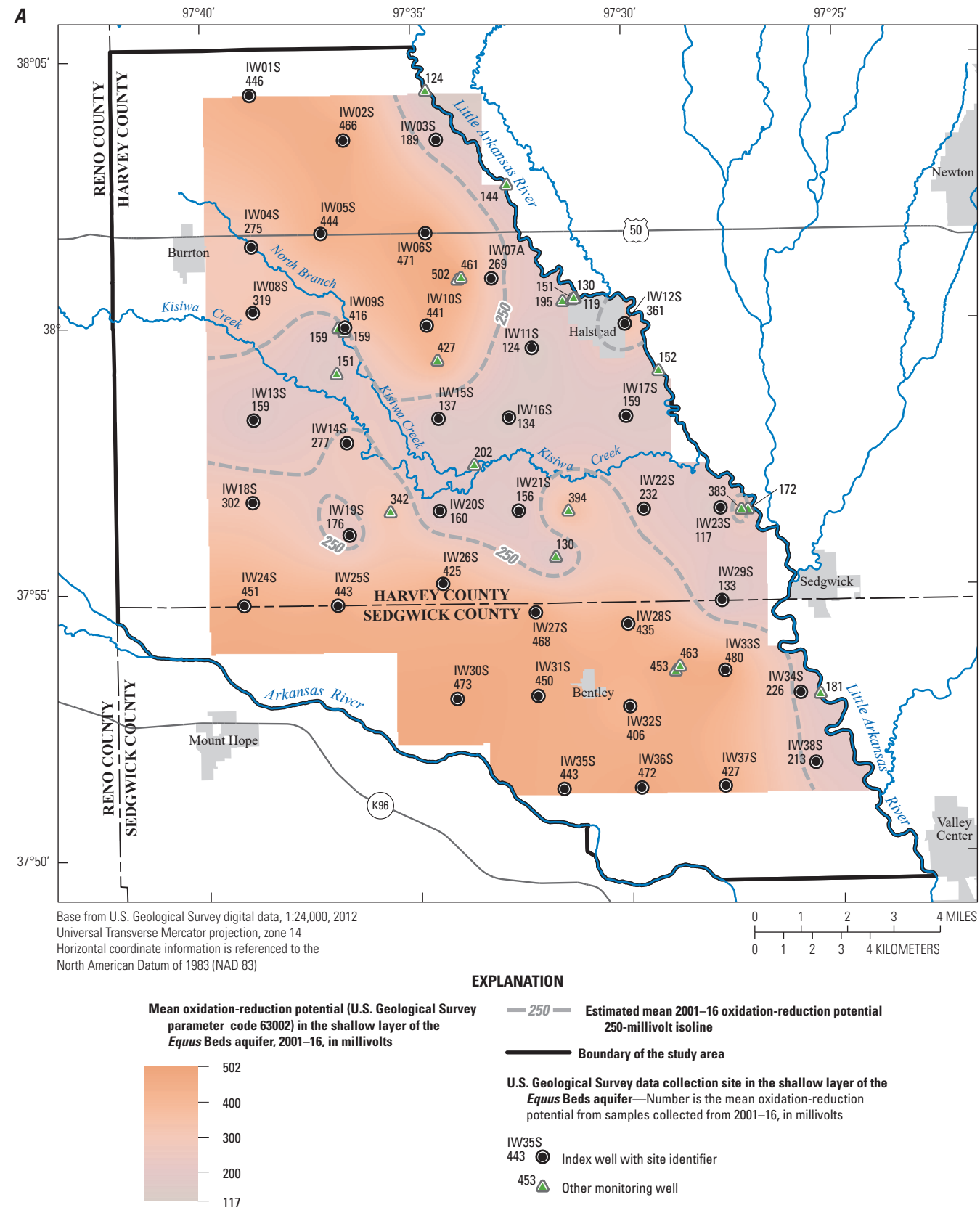


Figure 4. Mean oxidation-reduction potential in the *Equus* Beds aquifer, 2001–16, south-central Kansas. *A*, shallow (depths below land surface less than or equal to 80 feet) wells. *B*, deep (depths below land surface greater than 80 feet) wells.

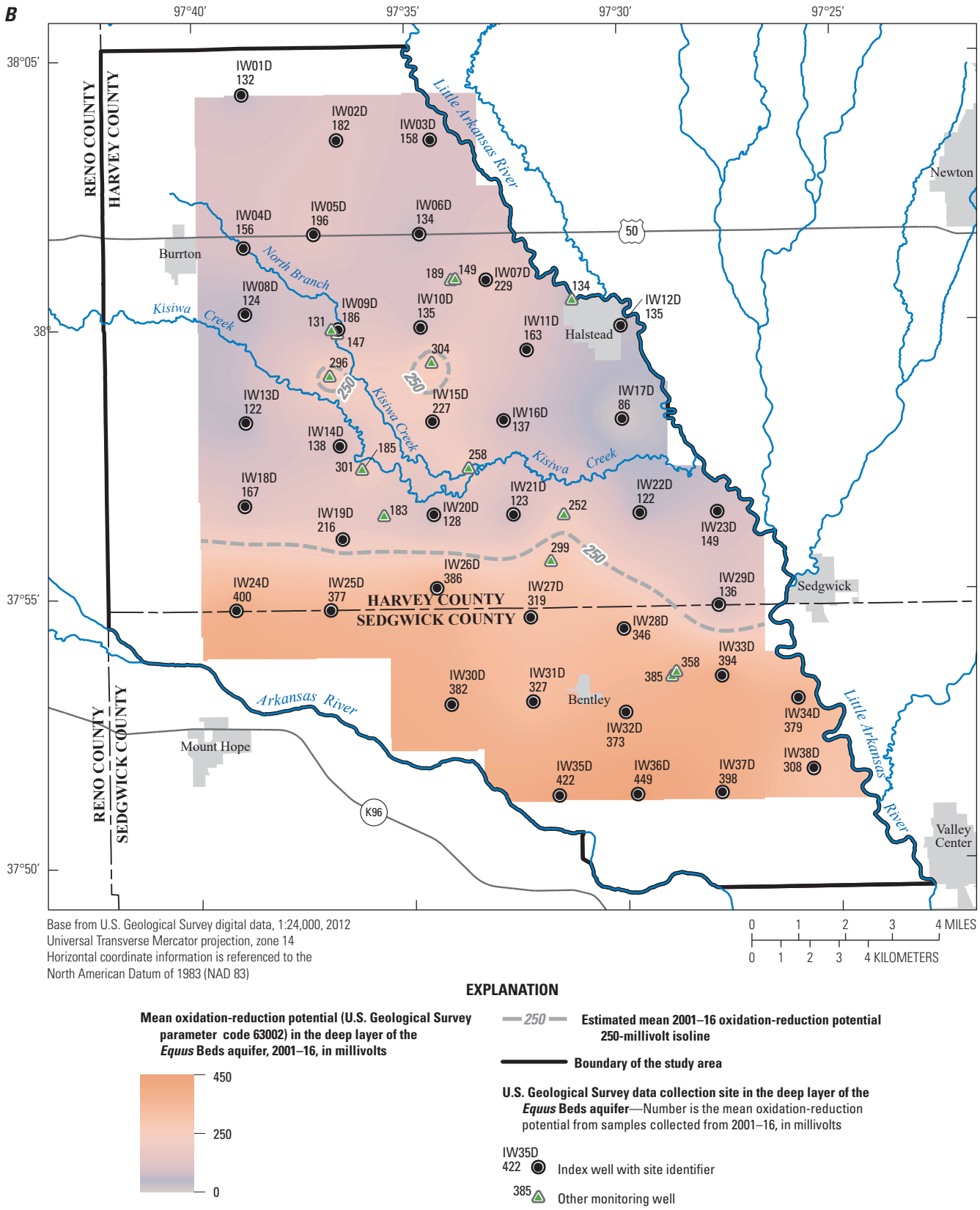


Figure 4. Mean oxidation-reduction potential in the *Equus* Beds aquifer, 2001–16, south-central Kansas. *A*, shallow (depths below land surface less than or equal to 80 feet) wells. *B*, deep (depths below land surface greater than 80 feet) wells.—Continued

Dissolved solids often are used as a general indicator of salinity as pertaining to water quality. The EPA has established a drinking water dissolved-solids SMCL of 500 mg/L (U.S. Environmental Protection Agency, 2009). Shallow IW dissolved solids ranged from 74 to 2,700 mg/L (mean equals 587 mg/L), and deep IW dissolved solids ranged from 5 to 3,230 mg/L (mean equals 615 mg/L; table 4). IW dissolved-solids means for shallow (587 mg/L) and deep (615 mg/L) wells exceeded the SMCL (table 4). About 54 percent of shallow IW and 56 percent of deep IW dissolved-solids sample concentrations exceeded the SMCL during 2001 through 2016. Index well dissolved-solids concentrations during this study did not exceed the ranges previously reported (Ziegler and others, 2010).

Bromide is a constituent of interest in the *Equus* Beds aquifer because of its potential for conversion to brominated organics of concern through drinking-water treatment processes. Bromate, a known carcinogen, can form during disinfection processes that oxidize drinking water to kill pathogens when the water contains bromide (Xie, 2003; U.S. Environmental Protection Agency, 2009). Shallow IW bromide ranged from <0.02 to 1.40 mg/L (mean equals 0.14 mg/L), and deep IW bromide ranged from <0.02 to 5.30 mg/L (mean equals 0.22 mg/L; table 4). Bromide concentrations were largest near Burrton, particularly in the deep parts of the *Equus* Beds aquifer (figs. 5*A*, *B*).

Equus Beds aquifer chloride sources include underlying rocks and past disposal of oil-field brines. Natural, unconsolidated aquifer water usually has chloride concentrations less than 100 mg/L; however, large concentrations (100 to 500 mg/L) are common in the western part of the study area and along the Arkansas River (fig. 1; Ziegler and others, 2010; Klager and others, 2014; Tappa and others, 2015). Mean Arkansas River chloride concentration was about 600 mg/L during 1988 through 1991 (Myers and others, 1996) and about 500 mg/L during 1997 through 2006 between Hutchinson and Maize, Kans. (Kansas Department of Health and Environment, 2006a). Underlying Permian salt-bed brine upwells and enters tributaries upstream from Hutchinson, Kans., that flow into the Arkansas River (Kansas Department of Health and Environment, 2006a; Whittemore, 2007). Western Colorado irrigation practices increase and prolong the exposure of water to the surface, thereby increasing evaporation, which increases the dissolved-ion concentration in water reentering the Arkansas River (Whittemore, 2007). Little Arkansas River chloride sources include contamination from past oil and gas activity near McPherson, Kans., and industrial and municipal wastewater discharges (Leonard and Kleinschmidt, 1976; Kansas Department of Health and Environment, 2006b; Schmidt and others, 2007; Whittemore, 2007).

The SMCL for chloride is 250 mg/L (U.S. Environmental Protection Agency, 2009). Drinking-water consumers detect a salty taste and bleach-like odor when chloride concentrations exceed 250 mg/L. Large chloride concentrations can contribute to corrosion and staining of plumbing and fixtures. Irrigation water with chloride exceeding 350 mg/L is likely to have adverse effects on crops (Bauder and others, 2007). Chloride is of particular concern in the *Equus* Beds aquifer because of the chloride plume estimated to be moving toward the city of Wichita's well field at a rate of as much as 1,150 feet per year and is expected to continue moving toward the well field regardless of pumping in the area (Klager and others, 2014). Chloride concentrations, which significantly doubled in shallow parts of two phase II recharge wells after the onset of artificial recharge, were likely caused by treated and artificially recharged treated surface water (Stone and others, 2016).

Shallow IW chloride ranged from <5 to 773 mg/L (mean equals 67.0 mg/L), deep IW chloride ranged from <5 to 1,460 mg/L (mean equals 110 mg/L; table 4), and about 5 percent of shallow and 7 percent of deep IW chloride sample concentrations exceeded the SMCL during 2001 through 2016. Shallow and deep wells near the downstream part of the Arkansas River and near Burrton, Kans., had mean chloride concentrations that exceeded the SMCL (figs. 6*A*, *B*). Myers and others (1996), Ziegler and others (2010), and Tappa and others (2015) reported similar chloride distribution in the aquifer during 1989 through 1990, 1995 through 2005, and 2006 through 2012, respectively. Chloride concentrations near Burrton were larger in the deep parts of the aquifer (figs. 6*A*, *B*) likely because of saltwater migration downward from disposal brines in surface pits during 1910 through the 1940s (Whittemore, 2007). Larger chloride concentrations in deep parts of the aquifer also could be caused by upward movement of saltwater in wells or natural fractures in bedrock or the result of rainfall infiltration (Leonard and Kleinschmidt, 1976). Deep saltwater flushing from the aquifer may take many centuries (Whittemore, 2007). IW chloride concentrations during this study did not exceed the ranges previously reported (Ziegler and others, 2010; Tappa and others, 2015).

Natural sources of sulfate in surface water and groundwater are rock weathering, oxidation of sulfide minerals, and biological processes (Hem, 1992). Anthropogenic sources of sulfate in water include atmospheric deposition from coal and petroleum combustion products (Hem, 1992) and irrigation-return flows (Ziegler and others, 2010). The EPA SMCL for sulfate is 250 mg/L (U.S. Environmental Protection Agency, 2009). Sulfate is a constituent of concern for artificial recharge and often exceeds the SMCL of 250 mg/L in the *Equus* Beds aquifer (Ziegler and others, 2010; Tappa and others, 2015). Wells with mean sulfate concentrations exceeding the SMCL generally were in the central part of the study area (figs. 7*A*, *B*).

Average sulfate concentrations exceeding the SMCL were mostly in the central part of the study area (figs. 7*A*, *B*). Index well sulfate concentrations in this study did not exceed the ranges previously reported and exhibited similar distribution in the aquifer to those that were reported during 1995 through 2005 (Ziegler and others, 2010) and 2006 through 2012 (Tappa and others, 2015). Shallow IW sulfate concentrations ranged from <5 to 770 mg/L (mean equals 152 mg/L), and deep IW sulfate ranged from <5 to 720 mg/L (mean equals 111 mg/L; table 4). About 18 percent of shallow and 13 percent of deep IW sulfate-sample concentrations exceeded the SMCL during 2001 through 2016. Areas of largest sulfate concentrations

are where the aquifer is the thickest and generally associated with areas that were substantially dewatered between about 1940 through 1993 and have subsequently recovered (Ziegler and others, 2010; Tappa and others, 2015). *Equus* Beds aquifer sulfate concentrations increased from 1980 to 2012 (Hathaway and others, 1981; Ziegler and others, 2010; Tappa and others, 2015) likely because of dewatering and subsequent oxidation of aquifer material during water-level minima during the early 1990s (Ziegler and others, 2010). However, the mean overall sulfate average during 2013 through 2016 for this study was not substantially larger (137 mg/L) as compared to 141 mg/L during 2001 through 2012 (Tappa and others, 2015) and 129 mg/L during 1995 through 2005 (Ziegler and others, 2010).

Additional primary ions and constituents of concern for the *Equus* Beds aquifer are fluoride and chlorine, both of which were detected in IW samples during 2001 through 2016. The EPA fluoride SMCL of 2.0 mg/L (U.S. Environmental Protection Agency, 2009) was not exceeded during this study, although fluoride was detected in nearly all (about 99 percent) IW samples (table 4). Stone and others (2016) reported a substantial fluoride increase in shallow parts of two phase II recharge wells after the onset of artificial recharge that was likely caused by the artificially recharged, treated surface water (Stone and others, 2016). Several IW fluoride concentrations during this study (18 shallow and 23 deep during 2009 through 2014) throughout the aquifer exceeded the maximum reported by Ziegler and others (2010) during 1995 through 2005: shallow IW fluoride concentrations exceeded the maximum by about 8 to 48 percent (1.0 to 1.5 mg/L), and deep IW fluoride concentrations exceeded the maximum by about 3 to 40 percent (0.75 to 1.1 mg/L). The MRDL for chlorine is 4.0 mg/L (U.S. Environmental Protection Agency, 2009), and chlorine was detected in about 6 percent of shallow IWs but did not exceed the MRDL during the study.

Nutrients and Carbon

Nutrients, particularly nitrogen and phosphorus, have been identified as a primary cause of water-quality degradation in Kansas and the Nation (U.S. Environmental Protection Agency, 2000b, 2006c; Kansas Department of Health and Environment, 2004; Dubrovsky and others, 2010). Nutrients are associated with agricultural activities because they are present in fertilizers and animal waste and can percolate into groundwater. Other sources of nutrients in water include wastewater treatment plants, sewage lagoons, domestic septic tanks, and organic-matter decomposition. Ammonia and dissolved phosphorus are not persistent or mobile enough to affect groundwater concentrations substantially under most conditions (Dubrovsky and others, 2010) and are not discussed in this report.

Nitrogen is present as ammonia, nitrate, nitrite, and as part of organic compounds. Most algae use dissolved forms of inorganic nitrogen (Hem, 1992); of those, 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 more unstable than nitrate and is easily oxidized to nitrate. 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). Nitrate contamination of groundwater used for drinking water, particularly shallow wells in agricultural areas with large amounts of fertilizer and manure applications, is a human-health concern (Dubrovsky and others, 2010). Large (>10 mg/L) nitrate concentrations in drinking water can cause adverse health effects for 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; Camargo and Alonso, 2006; U.S. Environmental Protection Agency, 2009). Consumption of nitrate and nitrite in drinking water also has been implicated in other human-health problems, including specific cancers and reproductive problems; however, more research is needed to confirm associations (Ward and others, 2005; Dubrovsky and others, 2010). Nitrate is the primary nutrient of most concern for the *Equus* Beds aquifer (Ziegler and others, 1999) and often exceeds the EPA MCL of 10 mg/L (U.S. Environmental Protection Agency, 2009; Ziegler and others, 2010; Tappa and others, 2015; Stone and others, 2016). Nitrate in two phase II recharge wells in the study area decreased substantially from a prerecharge exceedance of the MCL to a postrecharge nonexceedance (Stone and others, 2016).

Mean shallow IW nitrate plus nitrite (hereafter referred to as “nitrate” for consistency with previous studies) was substantially larger (3.79 mg/L) than mean deep IW nitrate (0.48 mg/L; table 5), which is common in the *Equus* Beds aquifer and the central High Plains aquifer (Spruill, 1982; Townsend and Young, 2000; Pope and others, 2001, 2002; Ziegler and others, 2010; Tappa and others, 2015; Stone and others, 2016). Shallow IW nitrate ranged from <0.02 to 42.6 mg/L and deep IW nitrate ranged from <0.02 to 11.3 mg/L (table 5). About 15 percent of shallow and <1 percent of deep IW nitrate-sample concentrations exceeded the MCL during 2001 through 2016. Mean shallow IW nitrate concentrations exceeding the MCL were in the northeastern and southeastern parts of the study area (fig. 8*A*); mean deep IW nitrate concentrations did not exceed the MCL during 2001 through 2016 (fig. 8*B*). Shallow IW nitrate distribution in the *Equus* Beds aquifer was similar to that reported in Ziegler and others (2010) and Tappa and others (2015) during 1995 through 2005 and 2006 through 2012, respectively. Larger mean nitrate concentrations that were in the southeastern part of the study area are in the area having larger effective porosity (Ziegler and others, 2010; Tappa and others, 2015) and were likely the result of more rapid percolation from agricultural land uses and geochemical controls. Nitrate from fertilizer runoff, feedlots, and sewage lagoons is more likely to increase concentrations in the shallow parts of the aquifer. Reducing conditions for microbial denitrification (conversion of nitrate to nitrogen gas; ORP <50 mV) are rare in the shallow parts of the aquifer on average (fig. 4*A*; Tappa and others, 2015). Smaller nitrate concentrations in the deeper parts of the aquifer may be a result of more

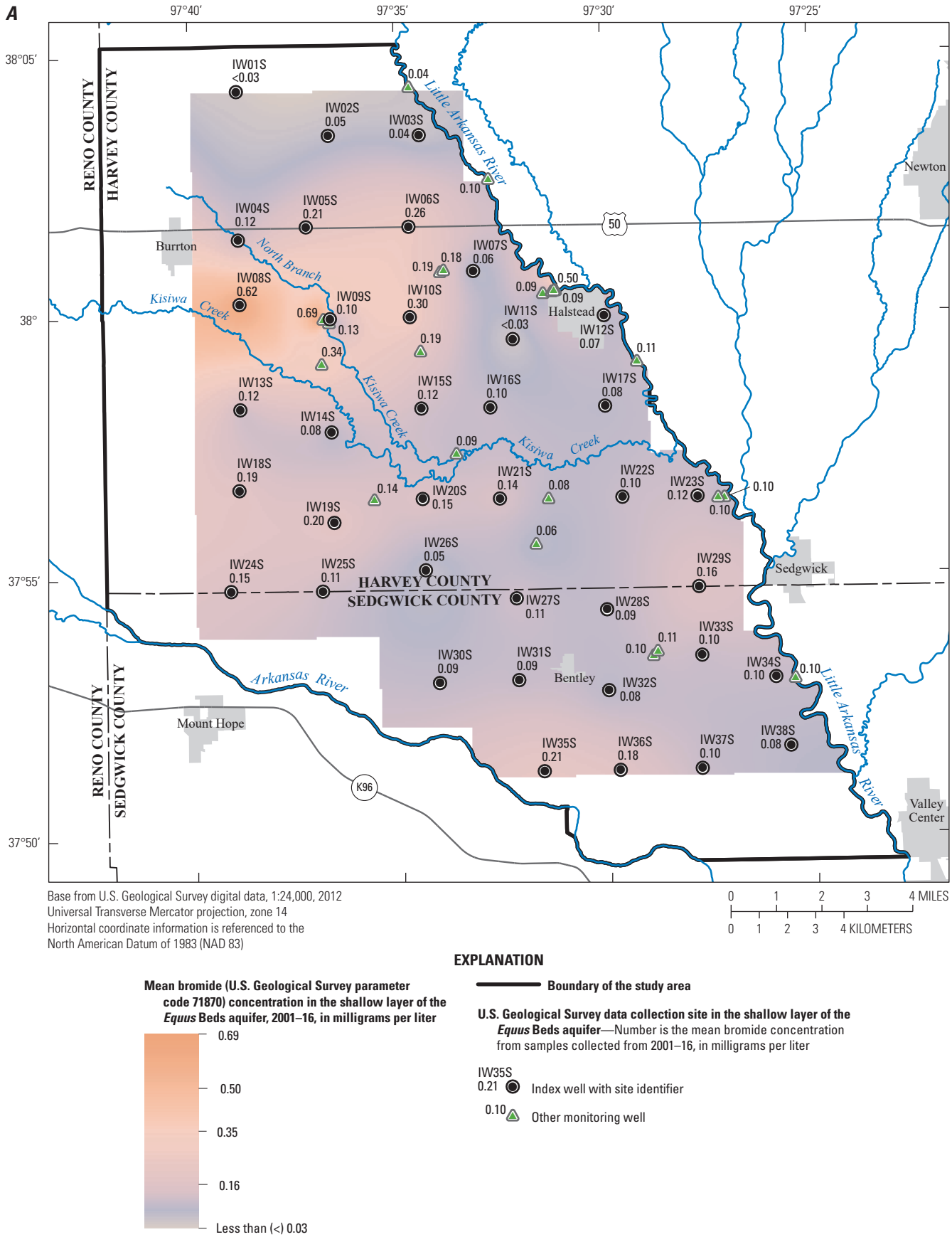


Figure 5. Mean bromide concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas. *A*, shallow (depths below land surface less than or equal to 80 feet) wells. *B*, deep (depths below land surface greater than 80 feet) wells.

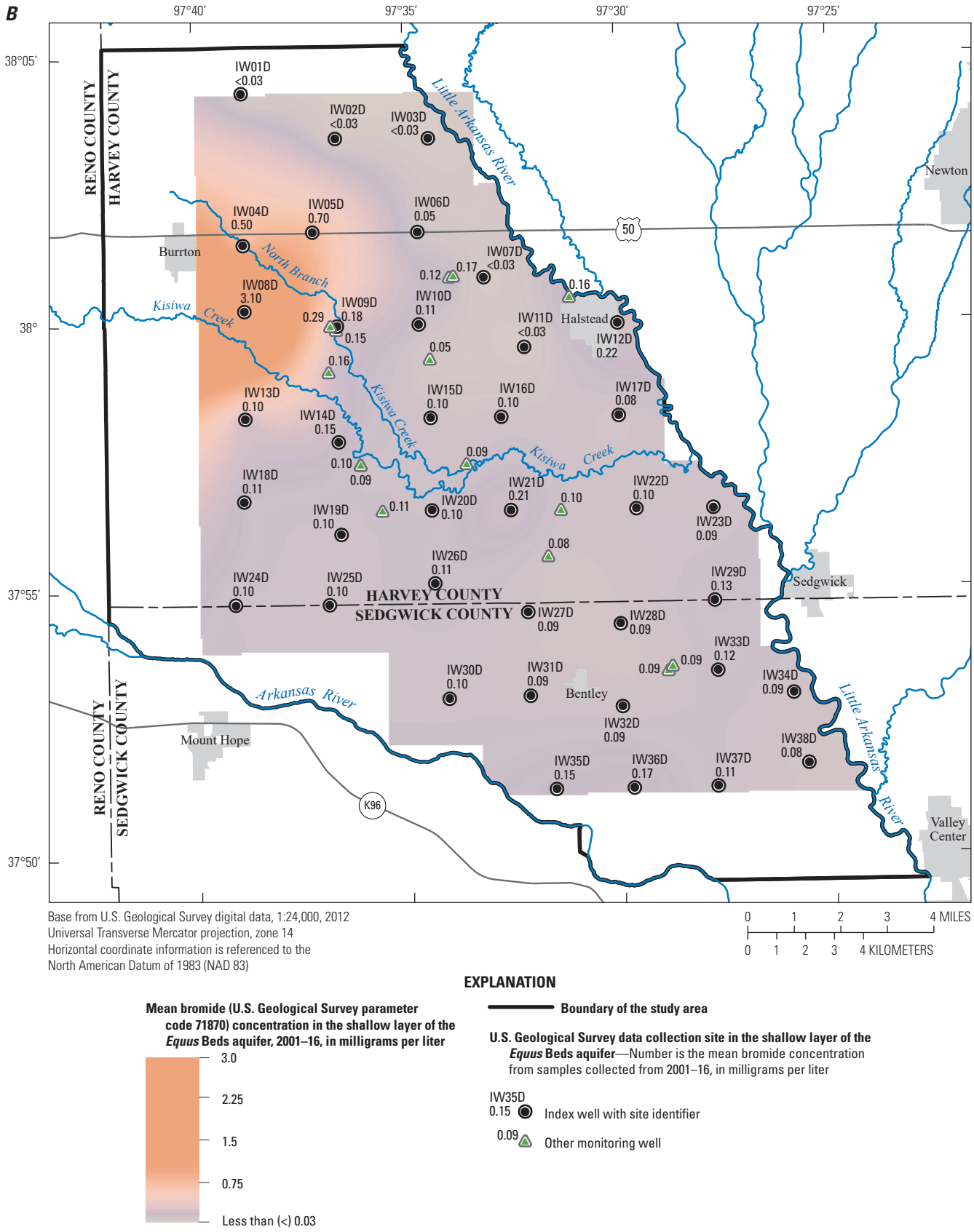


Figure 5. Mean bromide concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas. *A*, shallow (depths below land surface less than or equal to 80 feet) wells. *B*, deep (depths below land surface greater than 80 feet) wells.—Continued

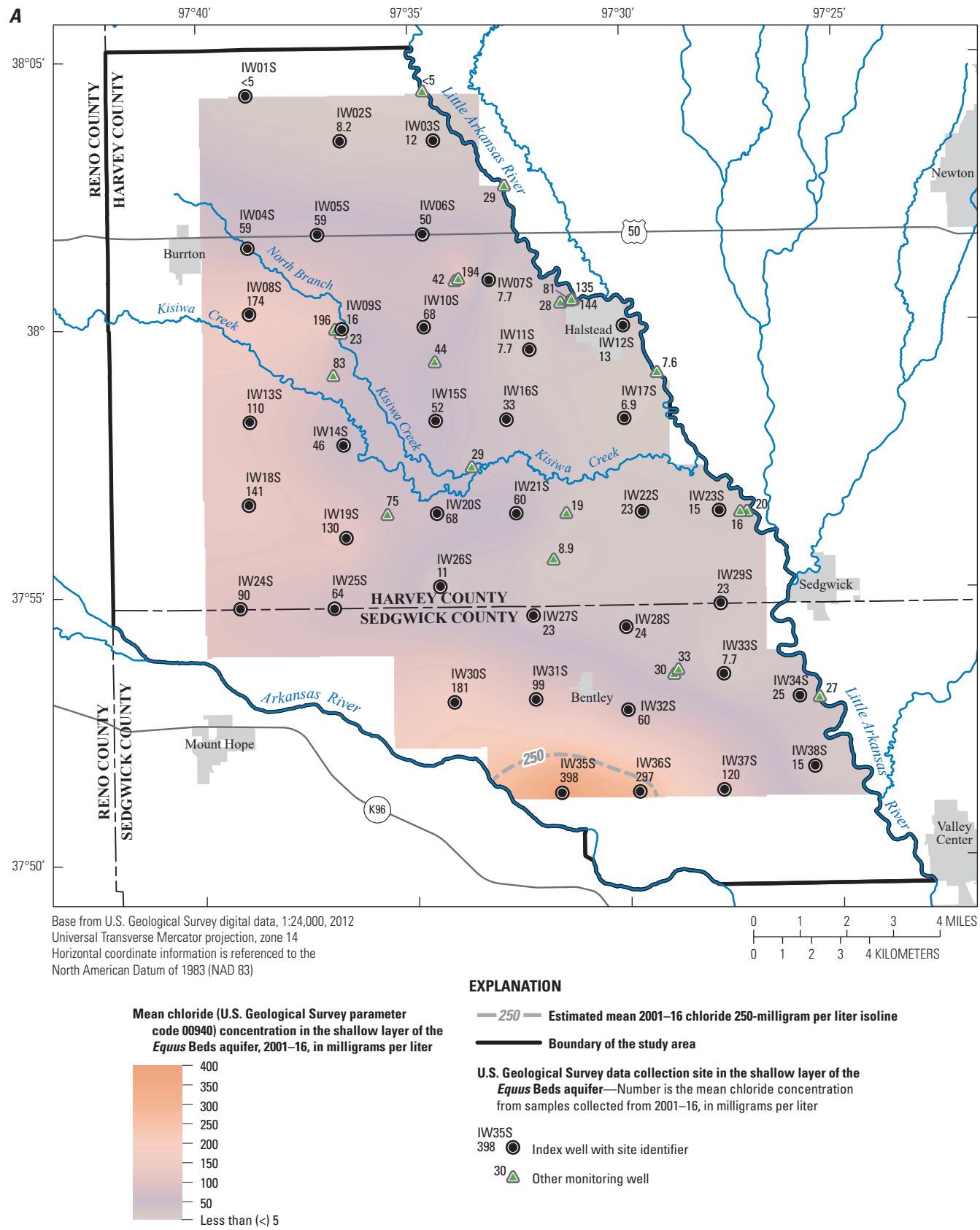


Figure 6. Mean chloride concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas. *A*, shallow (depths below land surface less than or equal to 80 feet) wells. *B*, deep (depths below land surface greater than 80 feet) wells.

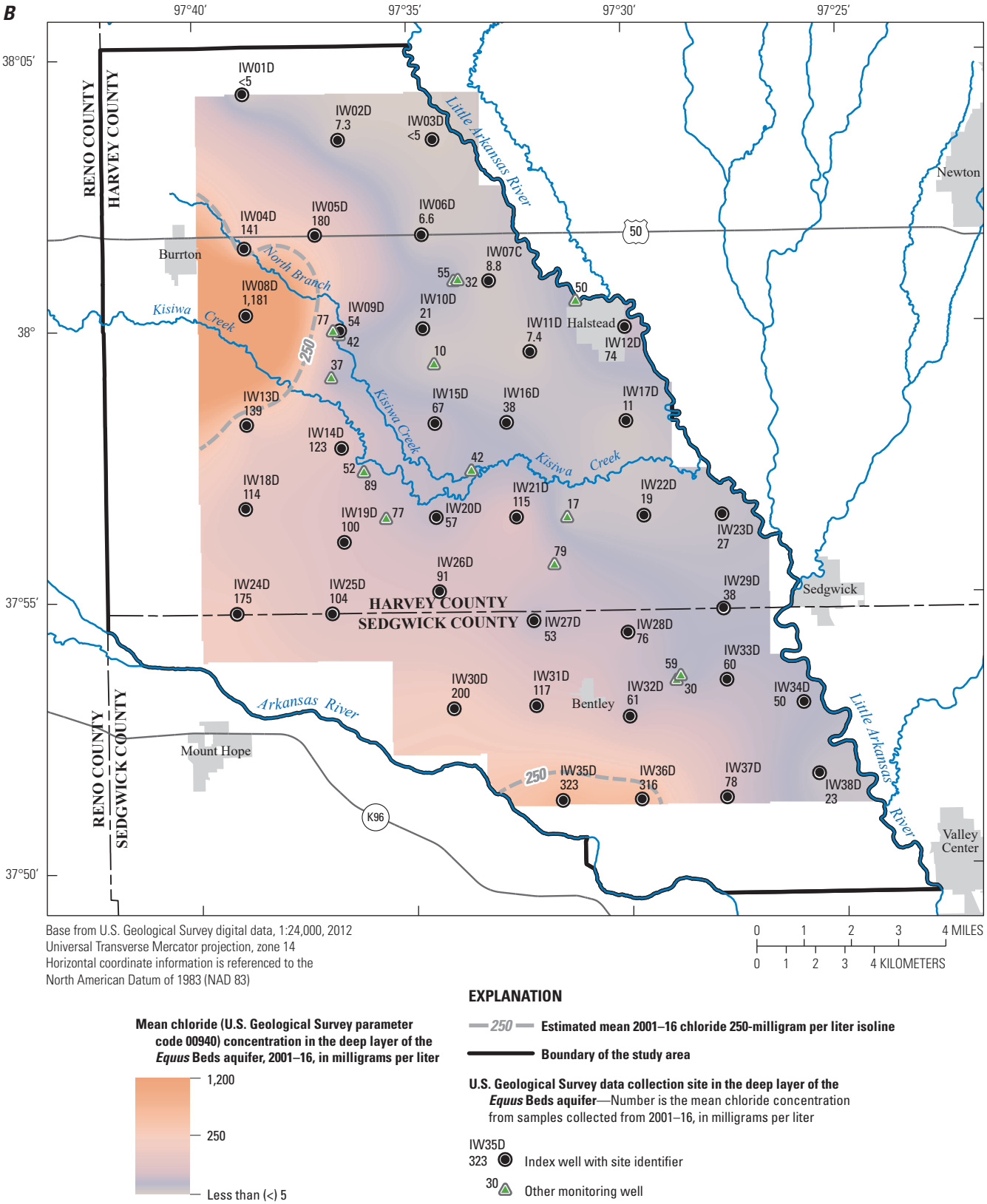
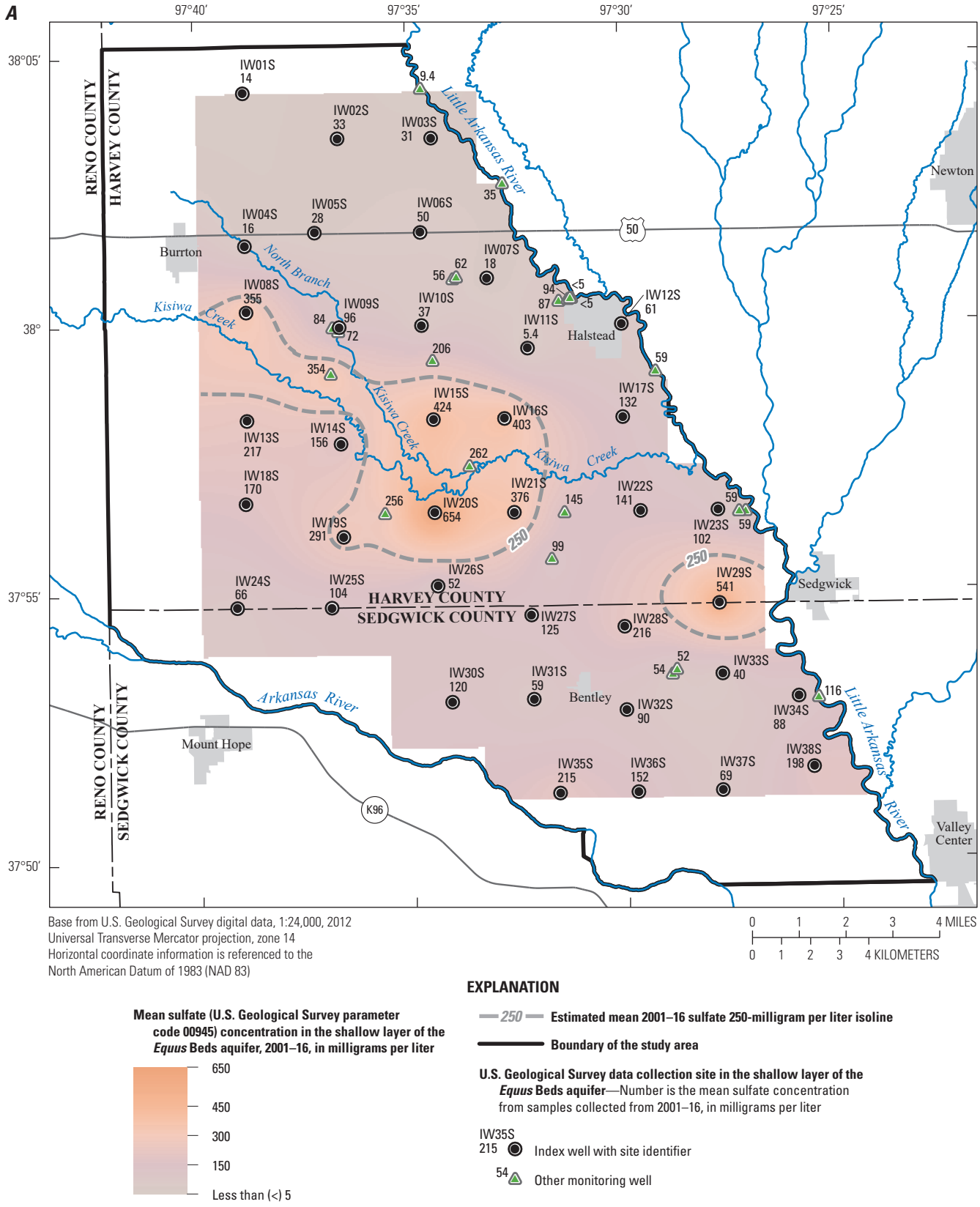


Figure 6. Mean chloride concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas. *A*, shallow (depths below land surface less than or equal to 80 feet) wells. *B*, deep (depths below land surface greater than 80 feet) wells.—Continued



Base from U.S. Geological Survey digital data, 1:24,000, 2012
Universal Transverse Mercator projection, zone 14
Horizontal coordinate information is referenced to the
North American Datum of 1983 (NAD 83)

0 1 2 3 4 MILES
0 1 2 3 4 KILOMETERS

Mean sulfate (U.S. Geological Survey parameter code 00945) concentration in the shallow layer of the *Equus* Beds aquifer, 2001–16, in milligrams per liter

650
450
300
150
Less than (<) 5

EXPLANATION

250 **Estimated mean 2001–16 sulfate 250-milligram per liter isoline**

Boundary of the study area

U.S. Geological Survey data collection site in the shallow layer of the *Equus* Beds aquifer—Number is the mean sulfate concentration from samples collected from 2001–16, in milligrams per liter

IW35S 215 **Index well with site identifier**

54 **Other monitoring well**

Figure 7. Mean sulfate concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas. *A*, shallow (depths below land surface less than or equal to 80 feet) wells. *B*, deep (depths below land surface greater than 80 feet) wells.

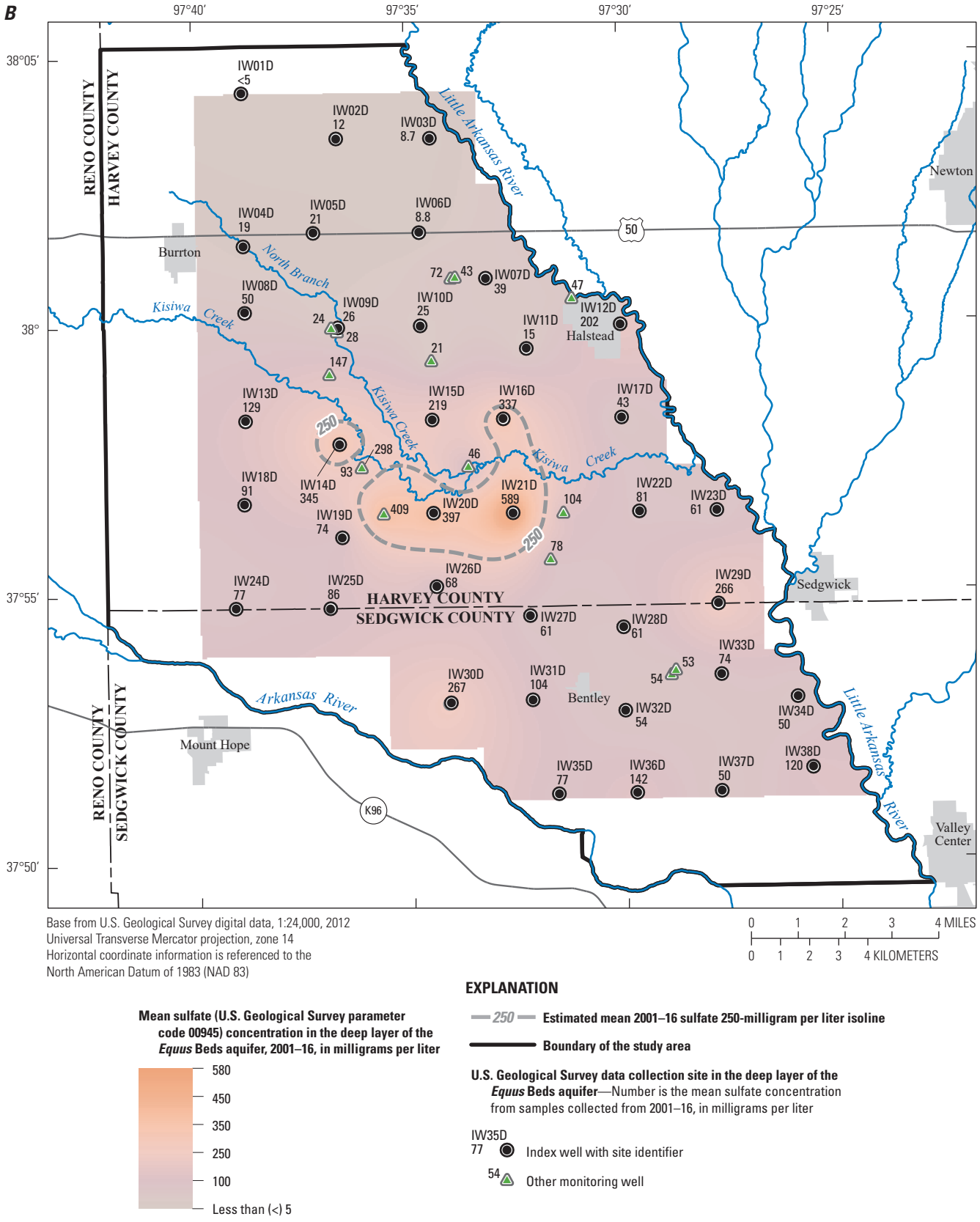


Figure 7. Mean sulfate concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas. *A*, shallow (depths below land surface less than or equal to 80 feet) wells. *B*, deep (depths below land surface greater than 80 feet) wells.—Continued

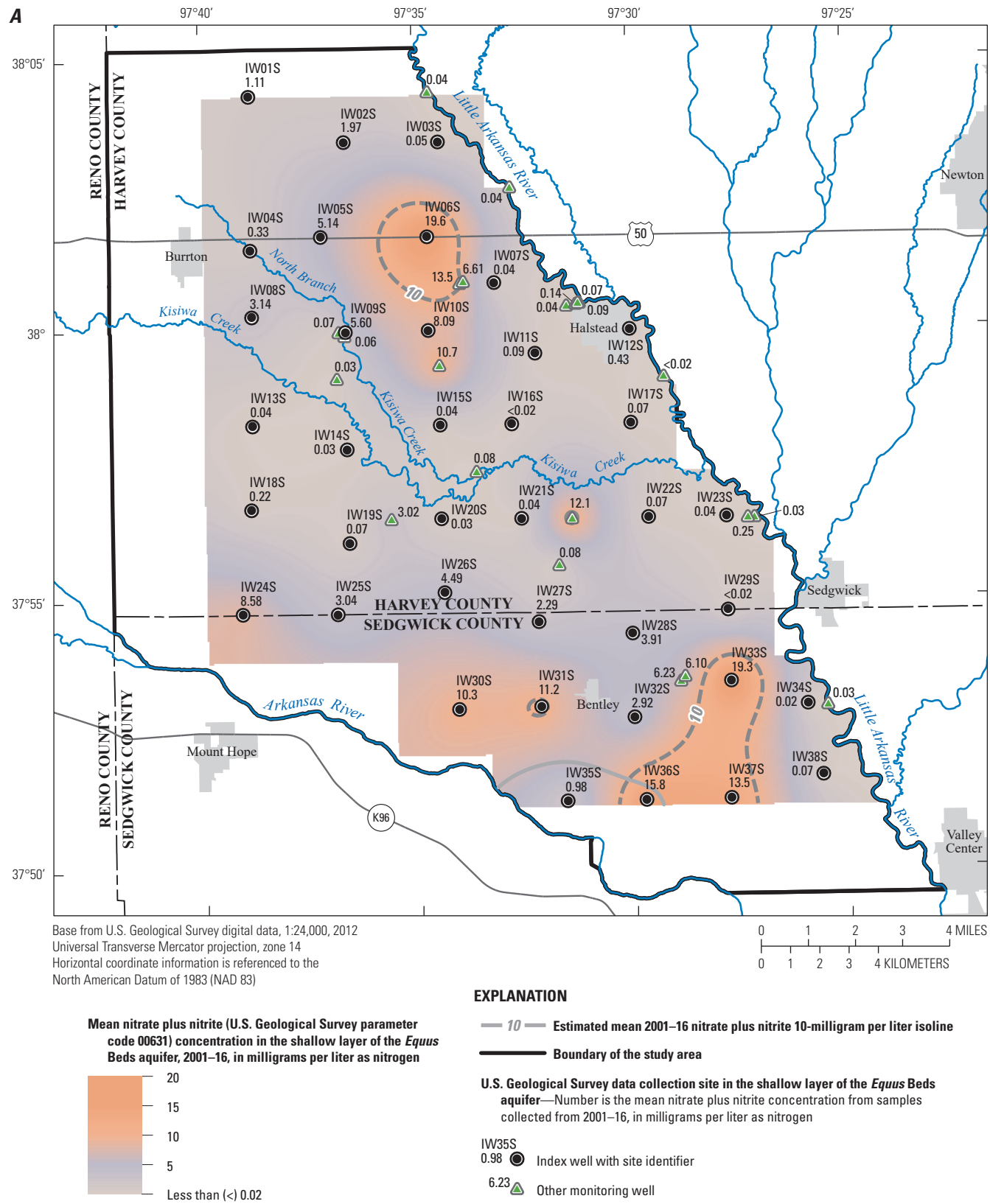
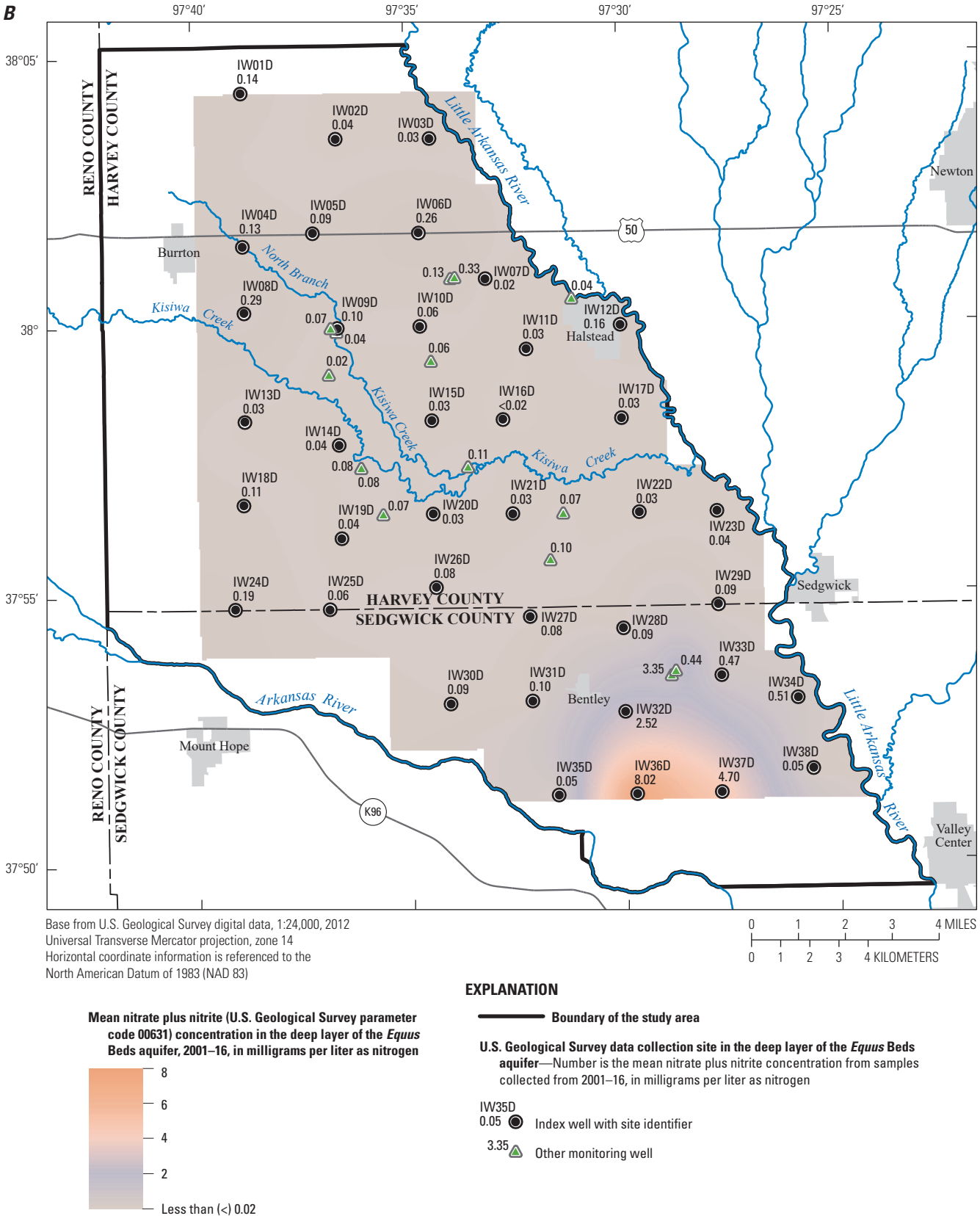


Figure 8. Mean nitrate plus nitrite concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas. *A*, shallow (depths below land surface less than or equal to 80 feet) wells. *B*, deep (depths below land surface greater than 80 feet) wells.



Base from U.S. Geological Survey digital data, 1:24,000, 2012
Universal Transverse Mercator projection, zone 14
Horizontal coordinate information is referenced to the
North American Datum of 1983 (NAD 83)

0 1 2 3 4 MILES
0 1 2 3 4 KILOMETERS

EXPLANATION

Mean nitrate plus nitrite (U.S. Geological Survey parameter code 00631) concentration in the deep layer of the *Equus* Beds aquifer, 2001–16, in milligrams per liter as nitrogen

8
6
4
2
Less than (<) 0.02

Boundary of the study area

U.S. Geological Survey data collection site in the deep layer of the *Equus* Beds aquifer—Number is the mean nitrate plus nitrite concentration from samples collected from 2001–16, in milligrams per liter as nitrogen

IW35D 0.05 Index well with site identifier

3.35 Other monitoring well

Figure 8. Mean nitrate plus nitrite concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas. *A*, shallow (depths below land surface less than or equal to 80 feet) wells. *B*, deep (depths below land surface greater than 80 feet) wells.—Continued

reducing conditions (smaller ORP values); however, the mean ORPs in the study area were still above 50 mV in all IWs (figs. 4*B* and 9*A*, *B*). One shallow IW nitrate concentration (42.6 mg/L) in well IW33S (fig. 8*A*; table 5) in 2016 exceeded the range reported by Ziegler and others (2010) during 1995 through 2005 by 56 percent. Five deep IW nitrate concentrations (9.98 to 11.3 mg/L) during this study exceeded the range reported by Ziegler and others (2010) by about 4 to 16 percent and all in IW36D (fig. 8*B*).

Nitrite is unstable in oxygenated water and generally constitutes a small fraction of the dissolved nitrogen species. Nitrite has an EPA MCL of 1 mg/L and also is associated with potential health effects including "blue baby syndrome" (U.S. Environmental Protection Agency, 2009; ingested nitrate is reduced to nitrite, which binds to hemoglobin to form methemoglobin and interferes with the oxygen-carrying capacity of blood). Nitrite was detected in 7 percent of shallow and deep IWs during the study period (table 5). Shallow IW nitrite ranged from <0.02 to 3.52 mg/L (table 5) and exceeded the MCL in two samples from 2002 (<1 percent of samples). Deep IW nitrite ranged from <0.01 to 0.48 mg/L and never exceeded the MCL (table 5). Two deep IW nitrite concentrations during 2001 through 2016 exceeded the range reported by Ziegler and others (2010) during 1995 through 2005 by 64 and 82 percent in IW29D and IW33D (fig. 1), respectively, in 2012.

Organic material in natural water 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 operations because of its role in trihalomethanes formation during the water-treatment process. Trihalomethanes are disinfection byproducts that are formed when naturally existing inorganic and organic materials in water react with the disinfectants chlorine and chloramine. Trihalomethanes 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 concentration is the potential for decreased oxygen because of higher respiration rates that subsequently lead to increased arsenic concentrations in groundwater. Dissolved and total organic carbon significantly increased in two *Equus* Beds aquifer phase II wells after the onset of recharge activity (Stone and others, 2016), but the increased concentrations were within the range of concentrations for organic carbon reported for the aquifer (Tappa and others, 2015). Mean organic carbon concentrations were larger in the shallow parts of the aquifer. Mean shallow IW dissolved and total organic-carbon concentrations were 53 percent larger than deep IW concentrations (table 5). Shallow and deep

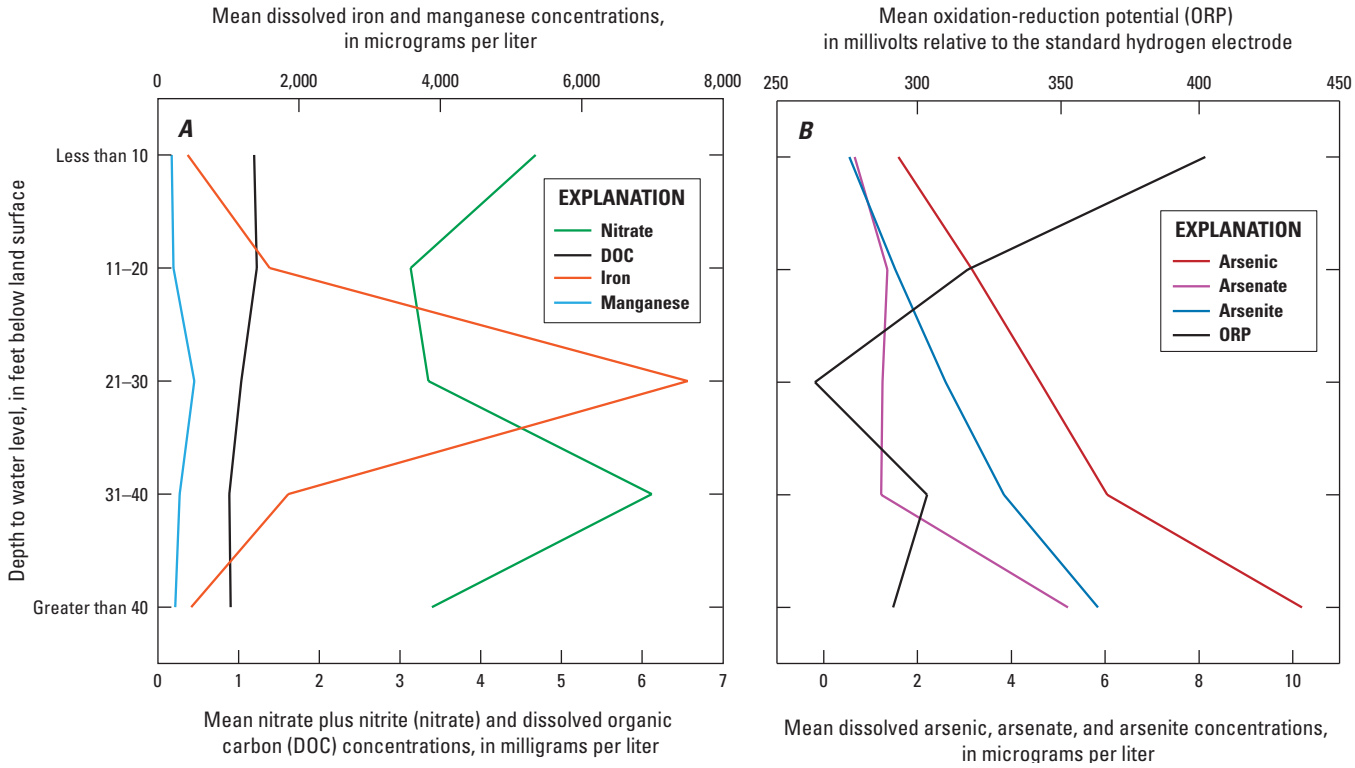


Figure 9. Relation between shallow (depths below land surface less than or equal to 80 feet) index well mean constituents ranges in the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16. *A*, nitrate plus nitrite [U.S. Geological Survey (USGS) parameter code (pcode) 00631], dissolved organic carbon (USGS pcode 00681), iron (USGS pcode 01046), and manganese (USGS pcode 01056) concentrations. *B*, dissolved concentrations of arsenic (USGS pcode 01000), arsenate (USGS pcode 62453), arsenite (USGS pcode 62452), and oxidation-reduction potential (USGS pcode 63002) with depth to water level (USGS pcode 72019).

IW dissolved organic carbon ranged from 0.40 to 10.8 mg/L (mean equals 1.15 mg/L) and <0.3 to 1.7 mg/L (mean equals 0.75 mg/L; table 5), respectively. Shallow and deep IW dissolved total organic carbon ranged from 0.30 to 10.8 mg/L (mean equals 1.10 mg/L) and <0.2 to 4.3 mg/L (mean equals 0.72 mg/L; table 5), respectively. Two shallow IW total organic-carbon concentrations from IW04S (fig. 1) in 2014 and 2016 exceeded the range previously reported by Ziegler and others (2010) during 1995 through 2005 by 23 and 17 percent in 2014 and 2016, respectively.

Coliform Bacteria and Viral Indicators

E. coli and fecal coliform bacteria are types of coliform bacteria that are generally specific to fecal material from homeotherms and are common types of bacteria used as pathogen indicators. The presence of *E. coli*, fecal coliform bacteria, or both indicates 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) and are often called indicator bacteria. The presence of these indicator bacteria implies the 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). Indicator bacteria are transported into water from a variety of sources including farms, yards, septic systems, sewer pipes, and wastewater treatment plants.

The EPA MCL for *E. coli* and fecal coliform bacteria in drinking water requires repeated samples if a sample contains *E. coli* or fecal coliform bacteria; an acute MCL violation occurs if any repeat sample contains total coliform bacteria (U.S. Environmental Protection Agency, 2009). The EPA MCL for total coliform bacteria requires 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). The EPA also has an MCLG for total coliforms of 0 cfu/100 mL (U.S. Environmental Protection Agency, 2013). *E. coli* was detected in 3 percent of shallow and deep IWs and had maxima of 37 and 130 cfu/100 mL, respectively (table 6). Most *E. coli* detections were at or near the detection limit. Fecal coliforms were detected in 8 percent of shallow IWs and 6 percent of deep IWs and had maxima of 360 and 81 cfu/100 mL, respectively (table 6). Most fecal coliform detections were at or near the detection limit. Total coliforms were detected in 24 percent of shallow IWs and 12 percent of deep IWs and had maxima of 370 and 84 cfu/100 mL, respectively (table 6). Bacteria detections in the first samples collected from the wells after they were developed may be related to drilling and bacteria may be detected more commonly in water from wells associated with recharge sites. Some *E. coli* and fecal coliform bacteria detections exceeded the ranges reported by Ziegler and others (2010); however, bacteria reaching groundwater are expected to die off because of lower concentrations of dissolved oxygen in groundwater.

E. coli coliphage is a viral indicator because it is a virus that infects coliform bacteria and, therefore, is an indicator of possible fecal contamination. Large densities of *E. coli* coliphage have been detected in treated surface water used for ASR project recharge (Garinger and others, 2011). *E. coli* coliphage was detected in two shallow IW samples (1 percent of samples) at the detection limit and was not detected in deep IW samples during 2001 through 2016.

Iron-Related, Slime-Forming, and Sulfate-Reducing Bacteria

Iron-related, slime-forming, and sulfate-reducing bacteria (Cullimore, 2007) are a natural part of the environment and multiply under suitable growth conditions. These bacteria are of interest because they may enter an aquifer through wells or other surface interactions. 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 nitrate for oxygen during metabolism. Slime-forming bacteria can produce extracellular polysaccharide polymers that act as a foundation for biofilm (slime) formation. The biofilm supports iron-related and sulfate-reducing bacterial growth. Sulfate-reducing bacteria reduce sulfate for energy primarily in anaerobic and reducing conditions. Hydrogen sulfide is a byproduct of sulfate-reducing bacteria metabolism (Cullimore, 2007). Iron-related bacteria and sulfate-reducing bacteria were commonly detected in *Equus* Beds aquifer phase I and II wells, and slime-forming bacteria substantially increased in two phase II recharge wells after the onset of ASR activity (Garinger and others, 2011; Stone and others, 2016). Differences in water-quality microbiology may lead to changes in dominant bacterial populations that may subsequently lead to formation and expansion in populations that cause bioplugging and other unwanted effects.

Bacteria detections commonly were larger in the shallow part of the *Equus* Beds aquifer (Garinger and others, 2011; Stone and others, 2016). Mean iron-related, slime-forming, and sulfate-reducing bacteria densities in shallow IWs were 87, 64, and 919 percent larger, respectively, than mean densities in deep IWs during the study. Iron-related bacteria were detected in 93 percent of shallow IWs and 85 percent of deep IW samples and ranged from <1 to 35,000 colony forming units per milliliter (cfu/mL) for shallow (mean equals 8,910 cfu/mL) and deep (mean equals 4,760 cfu/mL) IWs (table 6). Slime-forming bacteria were detected in 96 percent of shallow and 92 percent of deep IW samples and ranged from <1 to 1,800,000 cfu/mL for shallow (mean equals 286,700 cfu/mL) and deep (mean equals174,880 cfu/mL) IWs (table 6). Sulfate-reducing bacteria were detected in 40 percent of shallow and 28 percent of deep IW samples and ranged from <1 to 700,000 cfu/mL in shallow (mean equals

17,910 cfu/mL) and <1 to 100,000 cfu/mL in deep (mean equals 1,760 cfu/mL) IWs (table 6).

Trace Elements and Associated Compounds

Iron, manganese, and arsenic are trace elements of particular concern in the *Equus* Beds aquifer (Ziegler and others, 2010; Tappa and others, 2015; Stone and others, 2016). Concentrations of iron, manganese, and arsenic frequently exceeded Federal criteria in the study area (Ziegler and others, 2010; Tappa and others, 2015; Stone and others, 2016). Iron and manganese precipitates can plug wells and give water an undesirable taste and color, and arsenic is a carcinogen. Infiltration of stream or treated water into the *Equus* Beds aquifer by artificial recharge operations could cause precipitation of iron and manganese minerals from groundwater and affect the mobility of dissolved arsenic. Nickel significantly increased and selenium significantly decreased in two *Equus* Beds aquifer phase II wells after the onset of ASR activity (Stone and others, 2016).

Trace Element Detections and Exceedances

Trace elements that were detected in 20 percent or more of the groundwater samples included barium, cadmium, iron, manganese, nickel, strontium, zinc, boron, and selenium (table 7). Several trace elements with EPA MCLs, SMCLs, or TTs were detected during the study. Those that were detected but did not exceed their respective criteria were barium, cadmium, chromium, copper, lead, mercury, silver, thallium, zinc, antimony, and selenium (table 7). The MCL for beryllium is 4 µg/L; potential health effects include intestinal lesions (U.S. Environmental Protection Agency, 2009). Beryllium was detected in 2 percent of samples, ranged from <0.6 to 9 µg/L in shallow IWs (table 7), and exceeded the MCL in 6 samples in shallow and deep IWs in the southern part of the study area.

Iron

Iron in water is derived from rocks and soils (Hem, 1992). Water with excessive concentrations of iron is unpalatable because of odor, a metallic taste, and rusty color. The EPA SMCL for iron is 300 µg/L (U.S. Environmental Protection Agency, 2009). Iron forms red oxyhydroxide precipitates in water that can stain laundry and plumbing fixtures and causes corrosion at concentrations exceeding the SMCL. Iron becomes more soluble in water at low pH and ORP values. Bacterial activity may also affect iron concentrations (Hem, 1992) and can be a concern for artificial-recharge activities. Adding oxygenated water could favor bacterial activity that could produce biofilms, clog well screens, and decrease injection-well efficiency (Schmidt and others, 2007).

Dissolved iron concentrations are commonly larger in the shallow part of the *Equus* Beds aquifer than in the deep part (Ziegler and others, 2010; Tappa and others, 2015). Iron was detected in 51 percent of shallow IW samples and 62 percent of deep IW samples during 2001 through 2016 (table 7). Dissolved iron concentrations ranged from <5 to 40,700 µg/L (mean equals 2,437 µg/L) in shallow IWs and <5 to 17,900 µg/L (mean equals 1,441 µg/L) in deep IWs during 2001 through 2016 (table 7) and were within the ranges reported by Ziegler and others (2010) and Tappa and others (2015). Dissolved iron concentrations exceeded the SMCL in 38 percent of shallow IWs and 46 percent of deep IWs. Dissolved-iron concentrations were largest mostly in the central and northwest part of the study area (figs. 10*A*, *B*). Hathaway and others (1981), Ziegler and others (2010), and Tappa and others (2015) reported similar iron distribution in the aquifer during 1979 through 1980, 1995 through 2005, and 2006 through 2012, respectively.

Dissolved iron in the *Equus* Beds aquifer most likely is present naturally from pyrite oxidation in aquifer clay (Ziegler and others, 2010). Substantially large (>3,000 µg/L) iron concentrations in the shallow parts of the aquifer are associated with areas of larger water-level declines and subsequent recovery (Tappa and others, 2015) and have been attributed to oxidation of the aquifer material during the drawdown period. Ferric oxyhydroxides formed during dewatering are likely reduced after an increase in water levels, thereby increasing dissolved-iron concentrations (Tappa and others, 2015). The distribution of large iron concentrations (fig. 10*A*) was similar to that of large sulfate concentrations (fig. 6*A*), indicating likely pyrite oxidation during dewatering.

Manganese

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 may have a bitter metallic taste, a black-to-brown color, and cause black staining on plumbing fixtures at manganese concentrations larger than the SMCL (U.S. Environmental Protection Agency, 2009). Dissolved manganese concentrations in the *Equus* Beds aquifer concentrations often exceed the SMCL (Ziegler and others, 2010; Tappa and others, 2015) and increased substantially in two phase II deep wells after the onset of phase II recharge activities in the study area (Stone and others, 2016).

Shallow IW dissolved manganese concentrations ranged from <1 to 1,660 µg/L (mean equals 279 µg/L), and deep IW dissolved manganese concentrations ranged from <1 to 1,640 µg/L (mean equals 440 µg/L) during 2001 through 2016 (table 7). About 55 percent of shallow IW samples and 92 percent of deep IW samples exceeded the SMCL during the study period. Shallow and deep IWs had dissolved manganese concentrations that exceeded those recorded in Ziegler and others (2010) and Tappa and others (2015): shallow IW dissolved-manganese concentrations (1,630 to 1,660 µg/L) exceeded previously reported maxima by about 9 to 11 percent, and deep IW dissolved-manganese concentrations (1,580 to 1,640 µg/L) exceeded previously reported maxima by about 7 to 11 percent (Ziegler and others, 2010; Tappa and others, 2015). Almost all the central and northern parts

of the study area had mean dissolved-manganese concentrations that exceeded the SMCL in the shallow parts of the aquifer (fig. 11*A*). Mean dissolved-manganese concentrations in the shallow part of the aquifer were substantially large (>1,000 µg/L) in wells near the Little Arkansas River and in the central part of the study area (fig. 11*A*). Most of the study area had mean dissolved manganese concentrations that exceeded the SMCL in the deep part of the aquifer (fig. 11*B*). Mean dissolved manganese concentrations in the deep part of the aquifer were substantially large (>1,000 µg/L) in wells along the Little Arkansas River, in the central part of the study area, and near Burrton, Kans. (fig. 11*B*). Manganese-concentration distributions in the shallow and deep parts of the *Equus* Beds aquifer are similar to those reported in Ziegler and others (2010) and Tappa and others (2015).

Arsenic Species

Arsenic is present naturally in clay layers associated with iron sulfide minerals (Hem, 1992) and is also a health concern in drinking water because it causes skin damage, affects the circulatory system, increases cancer risk, and is linked with diabetes and H1N1 viral susceptibility (Kozul and others, 2009; U.S. Environmental Protection Agency, 2009). The EPA MCL for arsenic is 10 µg/L (U.S. Environmental Protection Agency, 2009). Concentrations of arsenic in groundwater are widespread and large (>10 µg/L) in aquifers in the western United States, the Great Lakes region, and New England (Ryker, 2003). Nationally, arsenic in groundwater exceeded the MCL in 10 percent of samples, and these exceedances were more frequent in the western United States (Welch and others, 2000). Arsenic mobility is generally controlled by adsorption and desorption reactions and solid-phase precipitation and dissolution reactions (Hem, 1992; Hinkle and Polette, 1999; Smedley and Kinniburgh, 2002; McMahon and Chapelle, 2008). These processes are affected by pH, oxidation/reduction reactions, and competing anion presence, all of which could be altered because of artificial recharge activities. Groundwater pH often naturally increases with time because of free hydrogen ion consumption during water-bedrock interactions, particularly in systems with long residence times.

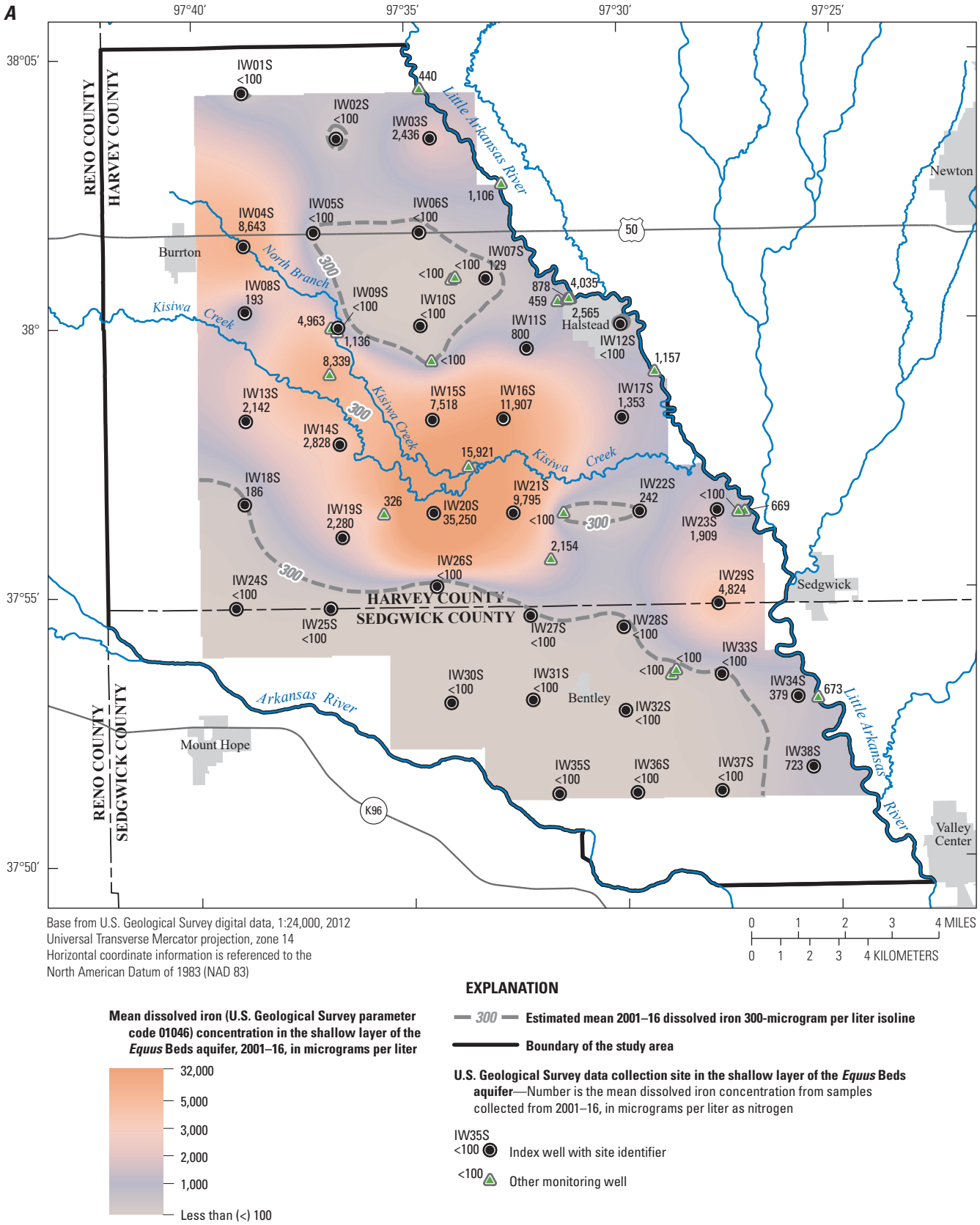
The oxidation state in which arsenic occurs has an important effect on its mobility and toxicity. Arsenic is generally present in most groundwaters as arsenate or arsenite (Stollenwerk, 2003). Arsenate (pentavalent arsenic oxidative state; As^{5+}; $H_2AsO_4^-$) is dominant under oxidizing conditions and pH values between 3 and 7. Arsenite (trivalent arsenic oxidative state; As^{3+}; $HAsO_2$) is dominant under more moderately reducing conditions. Arsenite is considered more toxic and more difficult to remove from water than arsenate (U.S. Environmental Protection Agency, 2001b). If conditions are favorable, biomethylation can form a variety of methylated species of arsenate and arsenite, including the most toxic species of arsenic dimethylarsinate and monomethylarsonate.

Arsenic is a constituent of concern in the *Equus* Beds aquifer and commonly is present at concentrations that exceed the MCL in the shallow and deep parts of the aquifer (Ziegler and others, 2010; Tappa and others, 2015). Ziegler and others (2010) developed linear regression relations between IW arsenic and ORP in the study area; ORP was useful in estimating dissolved arsenic concentrations and explained about 60 percent of the variability in dissolved arsenic concentrations in groundwater. Dissolved arsenic concentrations did not seem to be affected by phase I recharge activities (Garinger and others, 2011); however, dissolved arsenic concentrations in two shallow phase II wells increased significantly after the onset of phase II ASR activity (Stone and others, 2016).

Arsenic-species concentrations generally were larger in the deep parts of the aquifer during the study (table 8). Shallow IW dissolved arsenic concentrations ranged from <1.0 to 55.0 µg/L (mean equals 3.83 µg/L), and deep IW dissolved arsenic concentrations ranged from <1.0 to 23.9 µg/L (mean equals 7.43 µg/L) during 2001 through 2016 (table 8). Dissolved arsenic concentrations did not exceed the ranges reported by Ziegler and others (2010) and Tappa and others (2015). About 12 percent of shallow IW dissolved arsenic concentrations and 34 percent of deep IW dissolved arsenic concentrations exceeded the MCL. Shallow IW dissolved arsenic concentrations were larger near the Little Arkansas River and the center of the study area (fig. 12*A*). Large shallow IW dissolved arsenic concentrations in the central part of the study area correspond to areas that have had the most water-level recovery since the historical low in 1993 (Hansen and others, 2014; Whisnant and others, 2015; Klager, 2016). Deep IW dissolved arsenic concentrations were larger near the central western part of the study area and near the eastern side of the study area along the Little Arkansas River (fig. 12*B*).

Behavior of stable forms of arsenic (arsenate and arsenite oxyanions) is related to pH and ORP (Hem, 1992). Arsenite tends to be the dominant form in the Midwest (Korte, 1991; Kim and others, 2003; Sorg and others, 2014) and was the dominant form on average in shallow (52 percent) and deep (55 percent) IWs in this study. Mean arsenate percent dominance was 40 percent in shallow IWs and 39 percent in deep IWs. Dissolved arsenite concentrations increased with increasing depths to water levels in shallow IWs (fig. 9*B*). Mean dissolved arsenic concentration exceeded the MCL at water-level depths greater than 40 ft (fig. 9*B*). Dissolved arsenate concentrations remained relatively small (<1.5 µg/L) at water-level depths less than 40 ft and increased to greater than 5.0 µg/L at water-level depths greater than 40 ft (fig. 9*B*). Dimethylarsinate was detected in 11 percent of shallow IW samples and 20 percent of deep IW samples, and monomethylarsonate was detected in 10 percent of shallow IW samples and 15 percent of deep IW samples (table 8), suggesting some small amount of arsenic methylation in the *Equus* Beds aquifer.

Larger dissolved-arsenic concentrations in the shallow parts of the aquifer are associated with increased water-level depth and a subsequent decrease in ORP (more reducing conditions; figs. 9*B* and 13*A*, *B*). Groundwater with an increased reducing potential (ORP values <250 mV) can result in the release of arsenic from aquifer materials, such as



Base from U.S. Geological Survey digital data, 1:24,000, 2012
Universal Transverse Mercator projection, zone 14
Horizontal coordinate information is referenced to the
North American Datum of 1983 (NAD 83)

0 1 2 3 4 MILES
0 1 2 3 4 KILOMETERS

EXPLANATION

Mean dissolved iron (U.S. Geological Survey parameter code 01046) concentration in the shallow layer of the *Equus* Beds aquifer, 2001–16, in micrograms per liter

- 32,000
- 5,000
- 3,000
- 2,000
- 1,000
- Less than (<) 100

300 — **Estimated mean 2001–16 dissolved iron 300-microgram per liter isoline**

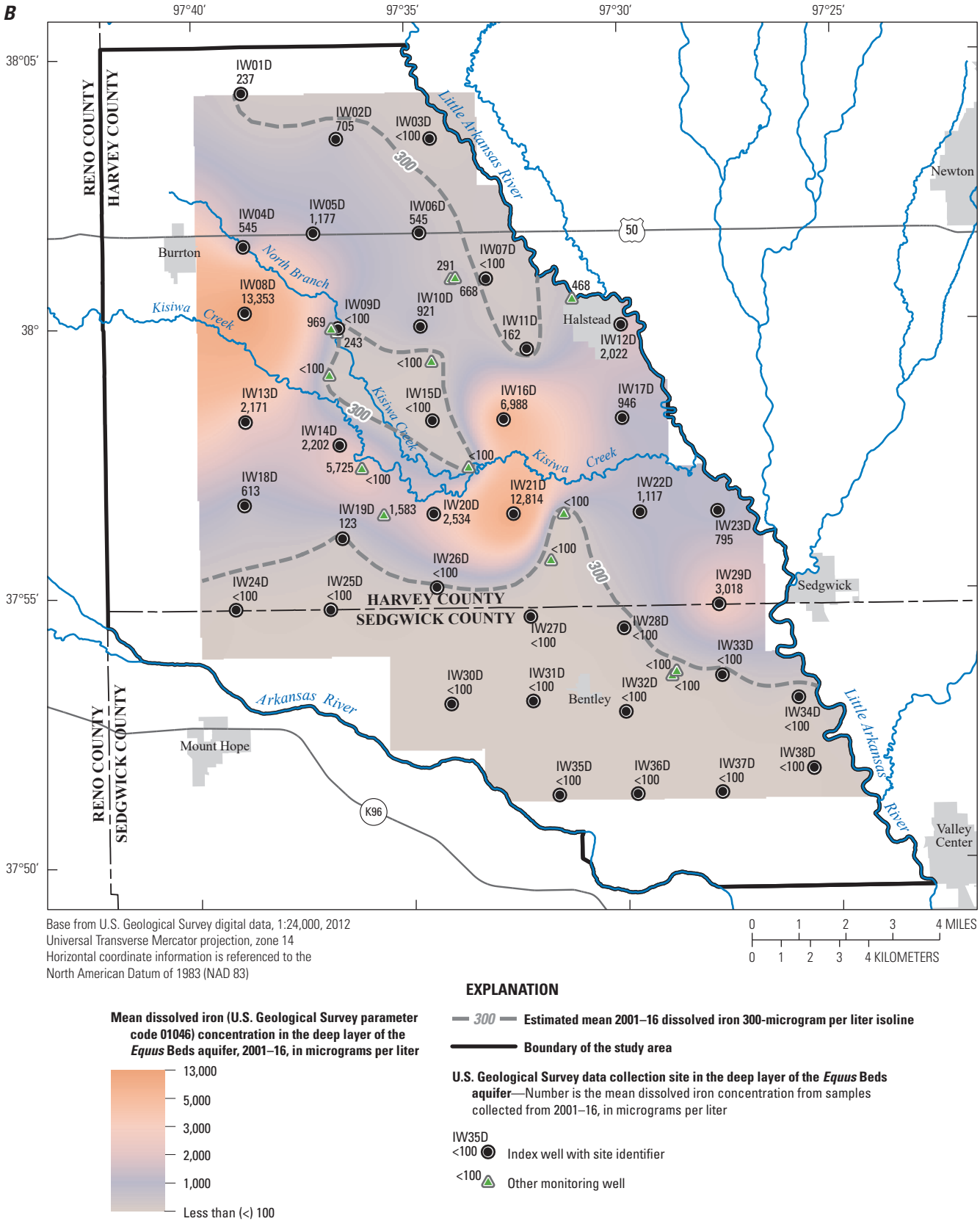
Boundary of the study area

U.S. Geological Survey data collection site in the shallow layer of the *Equus* Beds aquifer—Number is the mean dissolved iron concentration from samples collected from 2001–16, in micrograms per liter as nitrogen

IW35S <100 — Index well with site identifier

<100 — Other monitoring well

Figure 10. Mean dissolved iron concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas. *A*, shallow (depths below land surface equal to or less than 80 feet) wells. *B*, deep (depths below land surface greater than 80 feet) wells.



Base from U.S. Geological Survey digital data, 1:24,000, 2012
Universal Transverse Mercator projection, zone 14
Horizontal coordinate information is referenced to the
North American Datum of 1983 (NAD 83)

Mean dissolved iron (U.S. Geological Survey parameter code 01046) concentration in the deep layer of the *Equus* Beds aquifer, 2001–16, in micrograms per liter

- 13,000
- 5,000
- 3,000
- 2,000
- 1,000
- Less than (<) 100

EXPLANATION

300 — **Estimated mean 2001–16 dissolved iron 300-microgram per liter isoline**

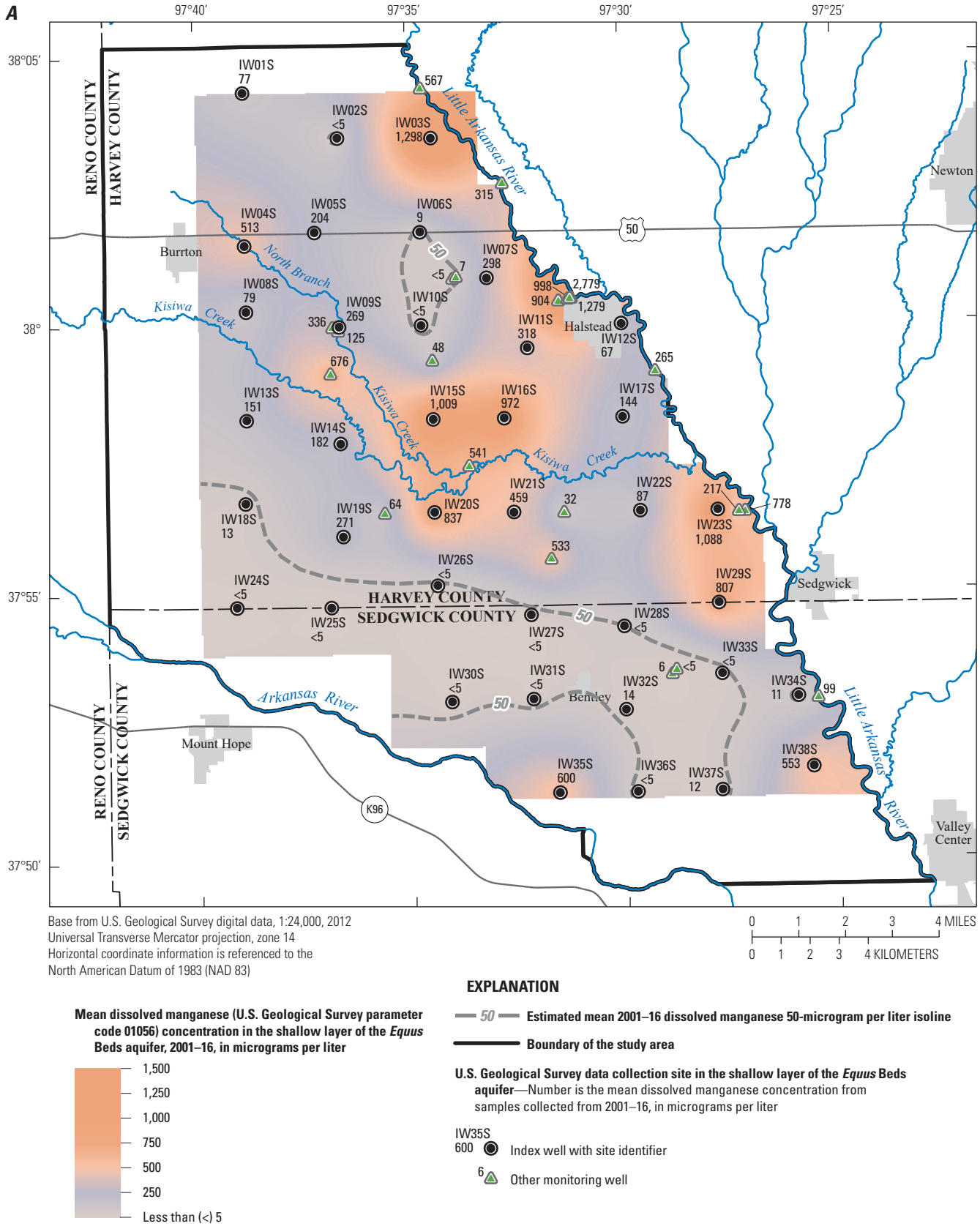
Boundary of the study area

U.S. Geological Survey data collection site in the deep layer of the *Equus* Beds aquifer—Number is the mean dissolved iron concentration from samples collected from 2001–16, in micrograms per liter

IW35D <100 — Index well with site identifier

<100 — Other monitoring well

Figure 10. Mean dissolved iron concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas. *A*, shallow (depths below land surface equal to or less than 80 feet) wells. *B*, deep (depths below land surface greater than 80 feet) wells.—Continued



Base from U.S. Geological Survey digital data, 1:24,000, 2012
Universal Transverse Mercator projection, zone 14
Horizontal coordinate information is referenced to the
North American Datum of 1983 (NAD 83)

0 1 2 3 4 MILES
0 1 2 3 4 KILOMETERS

Mean dissolved manganese (U.S. Geological Survey parameter code 01056) concentration in the shallow layer of the *Equus* Beds aquifer, 2001–16, in micrograms per liter

1,500
1,250
1,000
750
500
250
Less than (<) 5

EXPLANATION

50 **Estimated mean 2001–16 dissolved manganese 50-microgram per liter isoline**

Boundary of the study area

U.S. Geological Survey data collection site in the shallow layer of the *Equus* Beds aquifer—Number is the mean dissolved manganese concentration from samples collected from 2001–16, in micrograms per liter

IW35S 600 **Index well with site identifier**

6 **Other monitoring well**

Figure 11. Mean dissolved manganese concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas. *A*, shallow (depths below land surface equal to or less than 80 feet) wells. *B*, deep (depths below land surface greater than 80 feet) wells.

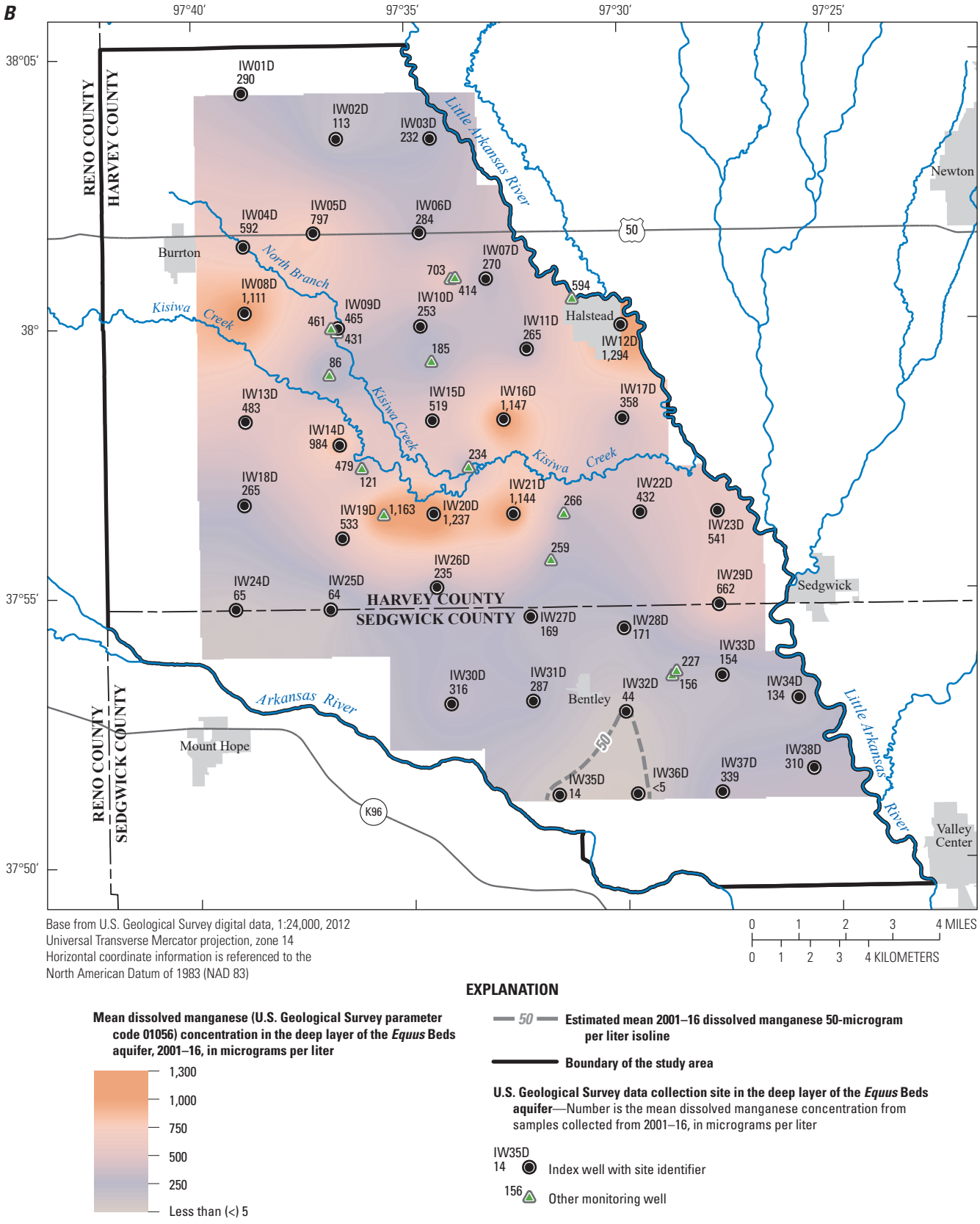


Figure 11. Mean dissolved manganese concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas. *A*, shallow (depths below land surface equal to or less than 80 feet) wells. *B*, deep (depths below land surface greater than 80 feet) wells.—Continued

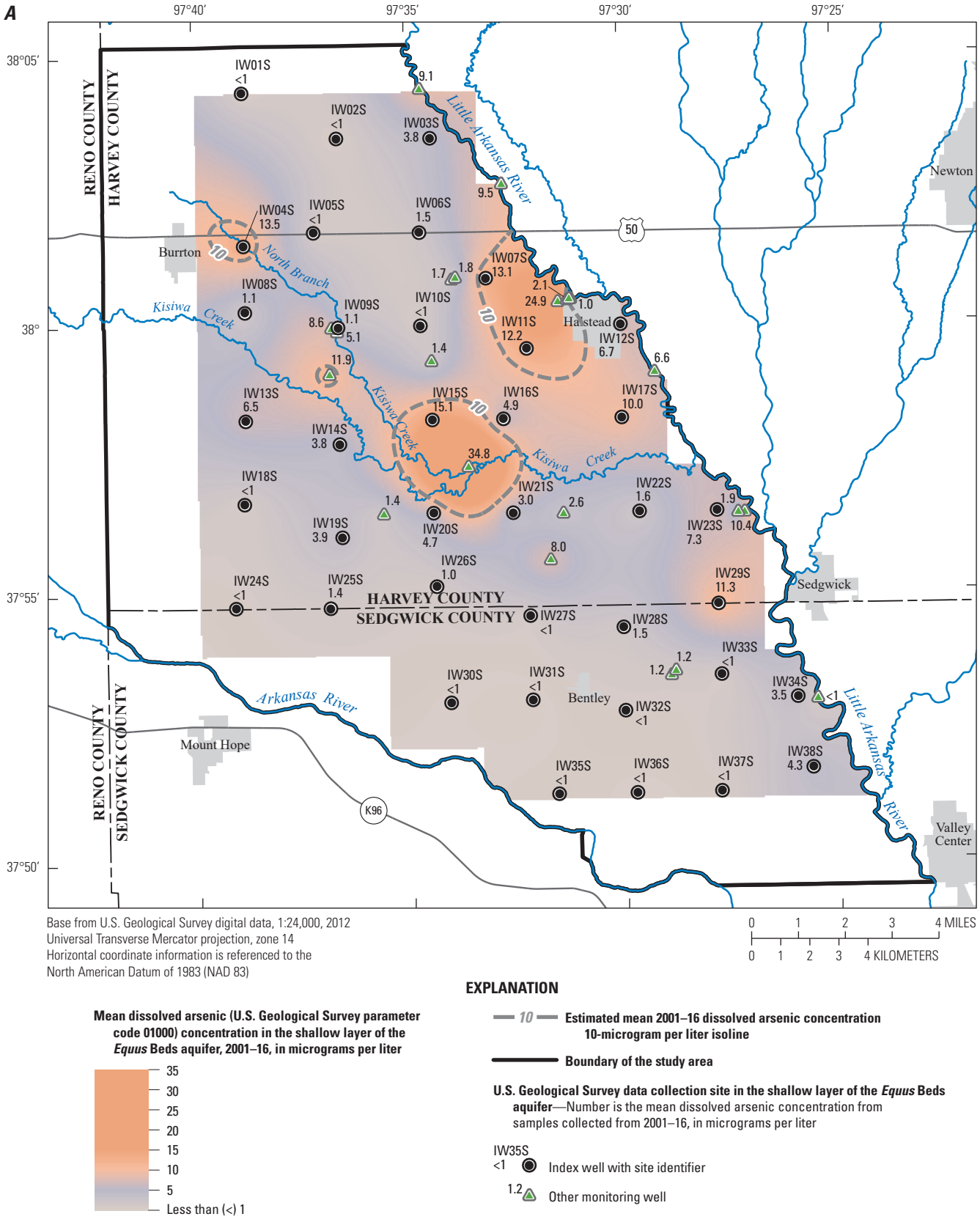
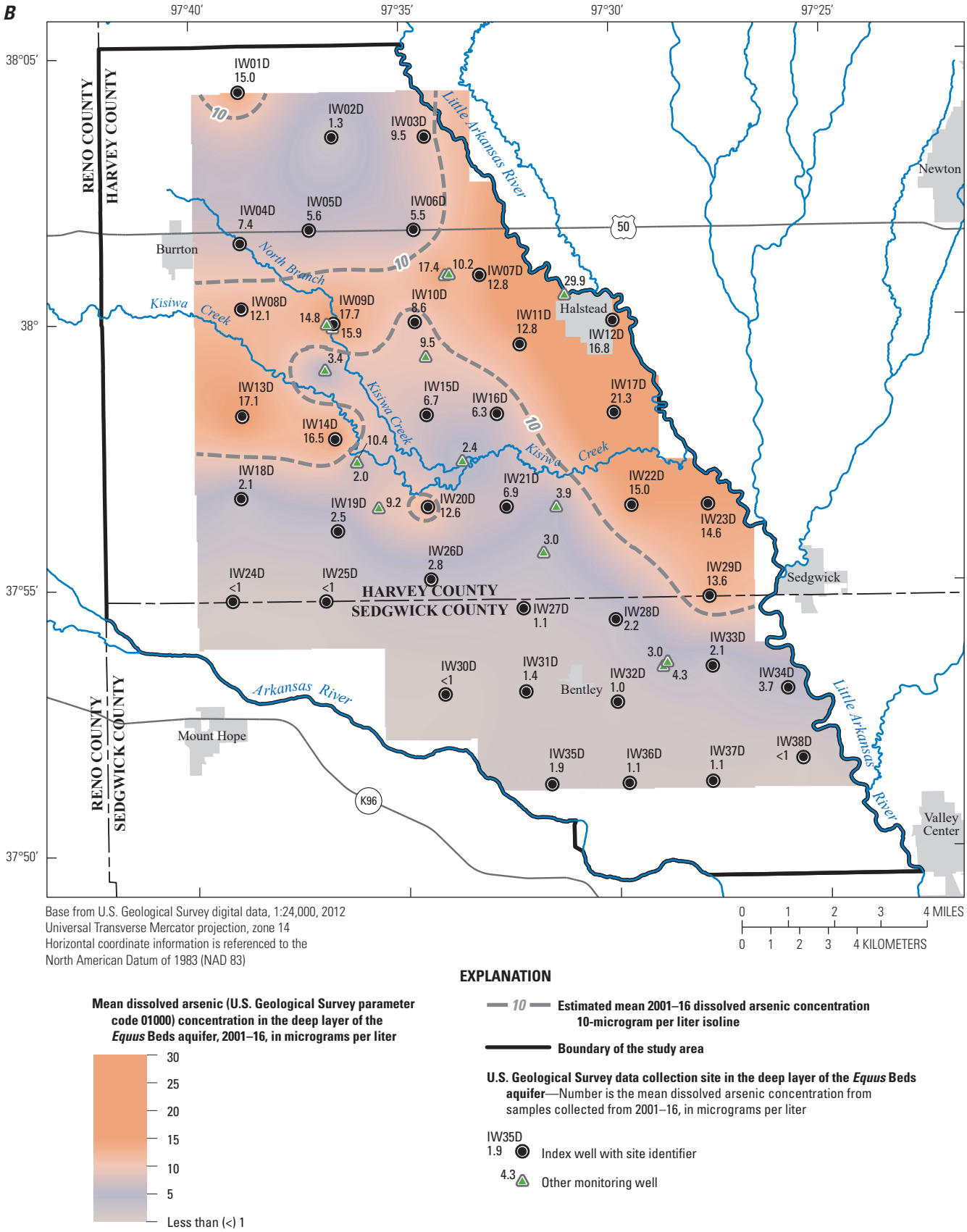


Figure 12. Mean dissolved arsenic concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas. *A*, shallow (depth below land surface equal to or less than 80 feet) wells. *B*, deep (depth below land surface greater than 80 feet) wells.



Base from U.S. Geological Survey digital data, 1:24,000, 2012
Universal Transverse Mercator projection, zone 14
Horizontal coordinate information is referenced to the
North American Datum of 1983 (NAD 83)

0 1 2 3 4 MILES
0 1 2 3 4 KILOMETERS

EXPLANATION

Mean dissolved arsenic (U.S. Geological Survey parameter code 01000) concentration in the deep layer of the *Equus* Beds aquifer, 2001–16, in micrograms per liter

30
25
20
15
10
5
Less than (<) 1

10 **Estimated mean 2001–16 dissolved arsenic concentration 10-microgram per liter isoline**

Boundary of the study area

U.S. Geological Survey data collection site in the deep layer of the *Equus* Beds aquifer—Number is the mean dissolved arsenic concentration from samples collected from 2001–16, in micrograms per liter

IW35D 1.9 **Index well with site identifier**

4.3 **Other monitoring well**

Figure 12. Mean dissolved arsenic concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas. *A*, shallow (depth below land surface equal to or less than 80 feet) wells. *B*, deep (depth below land surface greater than 80 feet) wells.—Continued

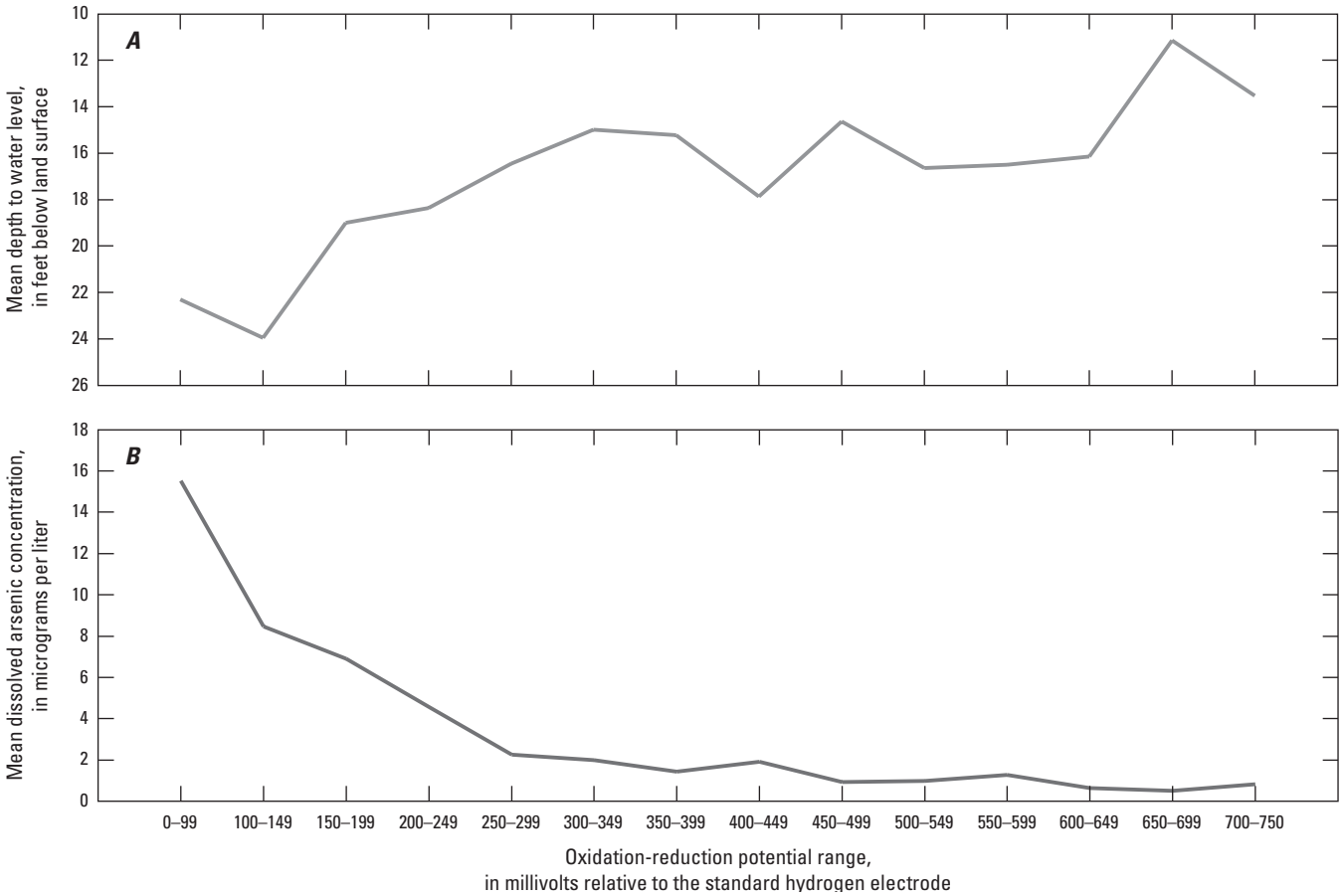


Figure 13. Relations between shallow (depths below land surface equal to or less than 80 feet) index well oxidation reduction potential (U.S. Geological Survey [USGS] parameter code [pcode] 63002) ranges and *A*, mean depth to water level (USGS pcode 72019) and *B*, mean dissolved arsenic (USGS pcode 01000) concentration in the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16.

arsenic sorbed onto ferric oxyhydroxides that become unstable under reducing conditions. As previously mentioned, shallow parts of the aquifer were subjected to substantial dewatering between about 1940 to the early 1990s and likely resulted in oxidation of pyrite and formation of ferric oxyhydroxides (Tappa and others, 2015) that in subsequent years are being chemically reduced and dissolved as water levels have risen since 1993. The mean dissolved-arsenic concentrations above the 10 µg/L MCL in the central part of the study area near wells IW15S and IW20S (fig. 12*A*) generally coincide with the area of increased mean sulfate and dissolved-iron concentrations (figs. 7*A*, 10*A*) and could be related to this same mechanism. However, larger mean dissolved-arsenic concentrations in areas such as well IW07S and IW11S (fig. 12*A*) that are slightly smaller than the MCL are not associated with larger dissolved iron or sulfate concentrations; however, these well are near recharge well sites (fig. 1) and the increased dissolved arsenic could be related to artificial recharge.

Redox conditions in groundwater wells can change rapidly in response to groundwater withdrawals (Gotkowitz and others, 2004) and water-level decreases caused by large or variable pumping can cause increases in arsenic concentrations (Ayotte and others, 2011, 2015). Groundwater withdrawal for irrigation or municipal use in the *Equus* Beds aquifer that decrease water levels likely result in larger arsenic concentrations in the shallow part of the aquifer because of subsequent ORP changes. Increased arsenic concentrations resulting from its mobilization because of artificial recharge have been observed in the United States in California, Florida, Idaho, Montana, and Wisconsin, as well as in Australia, China, Germany, and The Netherlands (Neil and others, 2012). Artificial recharge can cause arsenic mobilization if oxygenated water is recharged (Neil and others, 2012). Stone and others (2016) reported increased dissolved oxygen in two shallow wells in the study area caused by artificial recharge of Little Arkansas River water containing larger dissolved-oxygen concentrations; however, elevated dissolved-oxygen concentrations recovered to concentrations similar to or smaller than those before recharge began. Effects of artificial recharge on arsenic concentrations in the *Equus* Beds aquifer can be minimized by maintaining the ORPs near pre-ASR activity values (Schmidt and others, 2007). Artificial recharge may help ameliorate large arsenic concentrations by creating a less reducing geochemical environment in the deep parts of the *Equus* Beds aquifer (Ziegler and others, 2010).

Organic Compounds

Many of the organic compounds detected in the *Equus* Beds aquifer are pesticides (Tappa and others, 2015; Stone and others, 2016) that infiltrate into the aquifer from field application. 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, crops commonly grown in the study area. Atrazine can cause cardiovascular system or reproductive problems (U.S. Environmental Protection Agency, 2009). The EPA MCL for atrazine is 3.0 µg/L (U.S. Environmental Protection Agency, 2009). Concentrations of atrazine in water from some *Equus* Beds aquifer shallow groundwater wells increased minimally after artificial recharge but did not exceed the MCL (Ziegler and others, 1999; Stone and others, 2016).

Organic compounds that were detected in less than 20 percent of samples and did not exceed their MCL included alachlor (herbicide from chloroacetanilide family; detected in 2 percent of shallow and 1 percent of deep IW samples; MCL=2 µg/L), benzo[*a*]pyrene (a polycyclic aromatic hydrocarbon detected in 2 percent of deep IW samples; MCL=0.2 µg/L), carbofuran (a carbamate pesticide; detected in 1 percent of deep IW samples; MCL=40 µg/L), 2,4-D (an herbicide; detected in 1 percent of shallow and deep IW samples; MCL=70 µg/L), 1,2-dichloroethane (a chlorinated hydrocarbon; detected in 3 percent of shallow and 5 percent of deep IW samples; MCL=5 µg/L), glyphosate (an herbicide; detected in 4 percent of shallow IW samples; MCL=700 µg/L), picloram (an herbicide; detected in 2 percent of shallow IW samples; MCL=500 µg/L), and simazine (a triazine herbicide parent compound; detected in 4 percent of shallow and 1 percent of deep IW samples; MCL=4 µg/L; table 9; U.S. Environmental Protection Agency, 2009). Shallow IW organic compounds that were detected in greater than 20 percent of samples were herbicides and included atrazine (a triazine herbicide parent compound), three triazine degradation products (2-chloro-4-isopropylamino-6-amino-*s*-triazine [also known as deethylatrazine or CIAT], 2-chloro-6-ethylamino-4-amino-*s*-triazine [also known as deisopropylatrazine or CEAT], and 2-hydroxy-4-isopropylamino-6-ethylamino-*s*-triazine [also known as hydroxyatrazine or OIET]), and metolachlor (a member of the chloroacetanilide family of herbicides, table 9). Deep IW pesticides that were detected in greater than 20 percent of samples were atrazine and 2-chloro-4-isopropylamino-6-amino-*s*-triazine (table 9).

Atrazine was detected in about 58 percent of shallow IWs and about 28 percent of deep IWs during 2001 through 2016 (table 9). Atrazine ranged from <0.006 to 2.280 µg/L (mean equals 0.062 µg/L) in shallow IWs and from <0.007 to 0.090 µg/L (mean equals 0.009 µg/L) in deep IWs (table 9). The MCL for atrazine was not exceeded in groundwater IWs during the study (table 9). One shallow IW sample from 2016 had an atrazine concentration of 2.280 µg/L that exceeded the maximum reported in Ziegler and others (2010) and Tappa and others (2015) during 1995 through 2012 by about 66 percent. Atrazine concentrations in shallow IWs generally were largest in the northwest part of the study area near the North Branch Kisiwa Creek (fig. 1), and atrazine concentrations in deep IWs generally were largest most often in the southern part of the study area. Atrazine distributions in the shallow parts of the *Equus* Beds aquifer are similar to those reported in Ziegler and others (2010) and Tappa and others (2015).

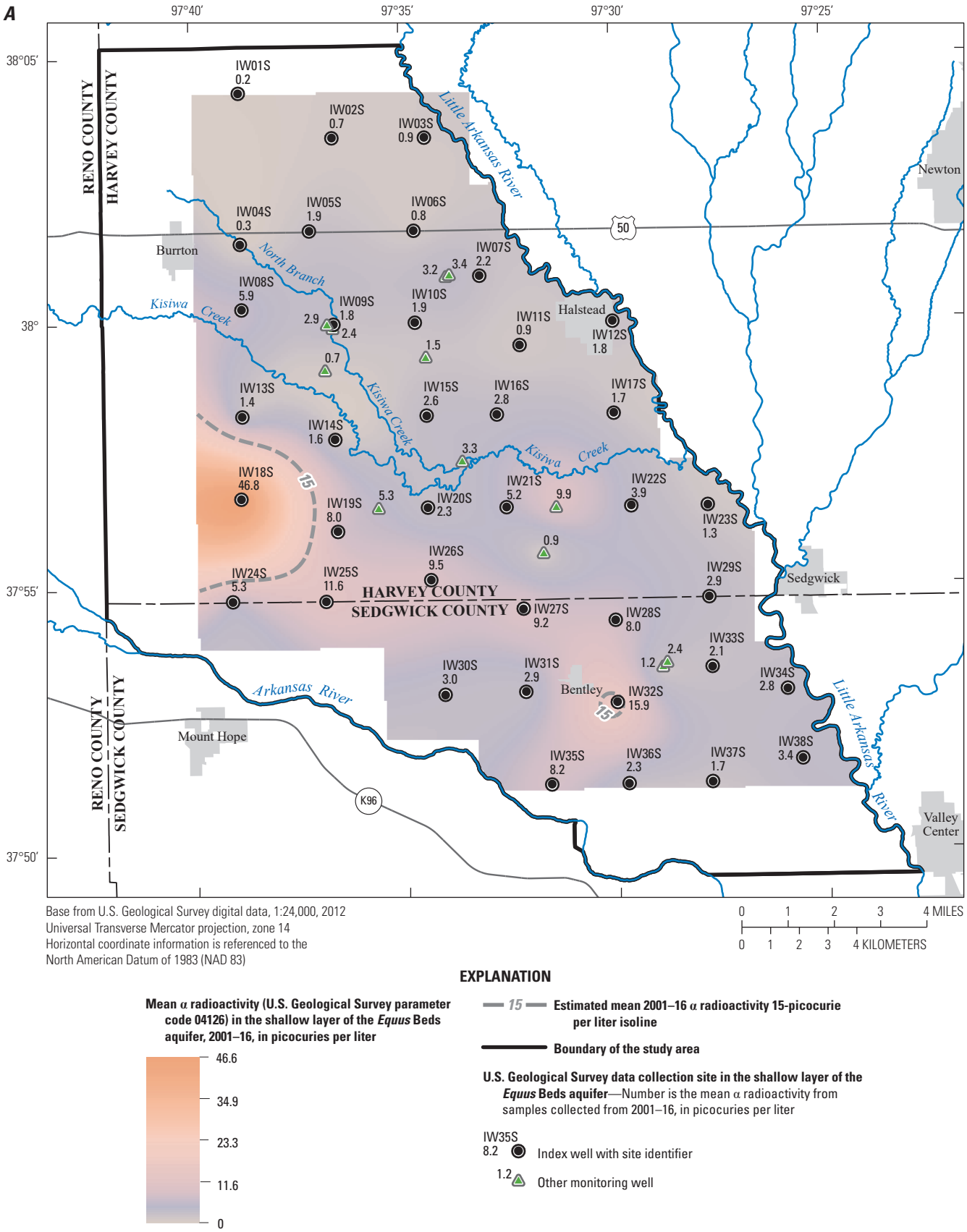
Radioactivity

The α and gross-β activity measurements are used in drinking-water regulations as a general screening tool to indicate the need for additional analysis of specific radionuclides. The EPA MCL for α radioactivity is 15 picocuries per liter (pCi/L; U.S. Environmental Protection Agency, 2009). Gross-β radioactivity significantly increased after phase II recharge-activity onset in 2 shallow and 2 deep groundwater wells in the study area (Stone and others, 2016).

Radioactivity measurements generally were larger in the shallow part of the *Equus* Beds aquifer (table 10; figs. 14*A*, *B*). The α radioactivity (Th-230 curve) ranged from <0.1 to 84 pCi/L (mean equals 4.5 pCi/L) in shallow IWs and <0.1 to 15 pCi/L (mean equals 2.6 pCi/L) in deep IWs during 2001 through 2016 (table 10). The α radioactivity measurements exceeded the MCL in 4 percent of shallow IW samples, whereas no deep IW measurements exceed the MCL during the study. Exceedances in α radioactivity shallow IWs were in the southern one-third of the study area, particularly near IW18S (fig. 14*A*). Gross-β radioactivity (Cs-137 curve) ranged from 0.50 to 44 pCi/L (mean equals 6.3 pCi/L) in shallow IWs and 1.20 to 17 pCi/L (mean equals 5.0 pCi/L) in deep IWs during the study (table 10). Gross-β radioactivity in shallow IWs generally were larger in the southern one-third of the study area. One shallow IW and two deep IW α radioactivity measurements (collected during 2008 and during 2007 and 2009, respectively) exceeded the IW range reported by Ziegler and others (2010) during 1995 through 2005. Gross-β radioactivity measurements did not exceed the ranges reported for IWs during 1995 through 2005 by Ziegler and others (2010).

Geochemistry

Groundwater 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 for the mineral and indicates the extent of disequilibrium with respect to the mineral (Parkhurst and Appelo, 2013). The equilibrium state only describes the potential for dissolution (negative SI) and precipitation (positive SI), but reaction kinetics and interaction among other constituents also affect whether minerals precipitate or dissolve. As such, a mineral is of interest if it has relatively short reaction times (fast kinetics) and if the SI changes across equilibrium during the study period (for example, minerals for which the SI range includes



Base from U.S. Geological Survey digital data, 1:24,000, 2012
Universal Transverse Mercator projection, zone 14
Horizontal coordinate information is referenced to the
North American Datum of 1983 (NAD 83)

EXPLANATION

Mean α radioactivity (U.S. Geological Survey parameter code 04126) in the shallow layer of the *Equus* Beds aquifer, 2001–16, in picocuries per liter

46.6
34.9
23.3
11.6
0

15 **Estimated mean 2001–16 α radioactivity 15-picocurie per liter isoline**

Boundary of the study area

U.S. Geological Survey data collection site in the shallow layer of the *Equus* Beds aquifer—Number is the mean α radioactivity from samples collected from 2001–16, in picocuries per liter

IW35S 8.2 **Index well with site identifier**

1.2 **Other monitoring well**

Figure 14. Mean α radioactivity concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas. *A*, shallow (depths below land surface equal to or less than 80 feet) wells. *B*, deep (depths below land surface greater than 80 feet) wells.

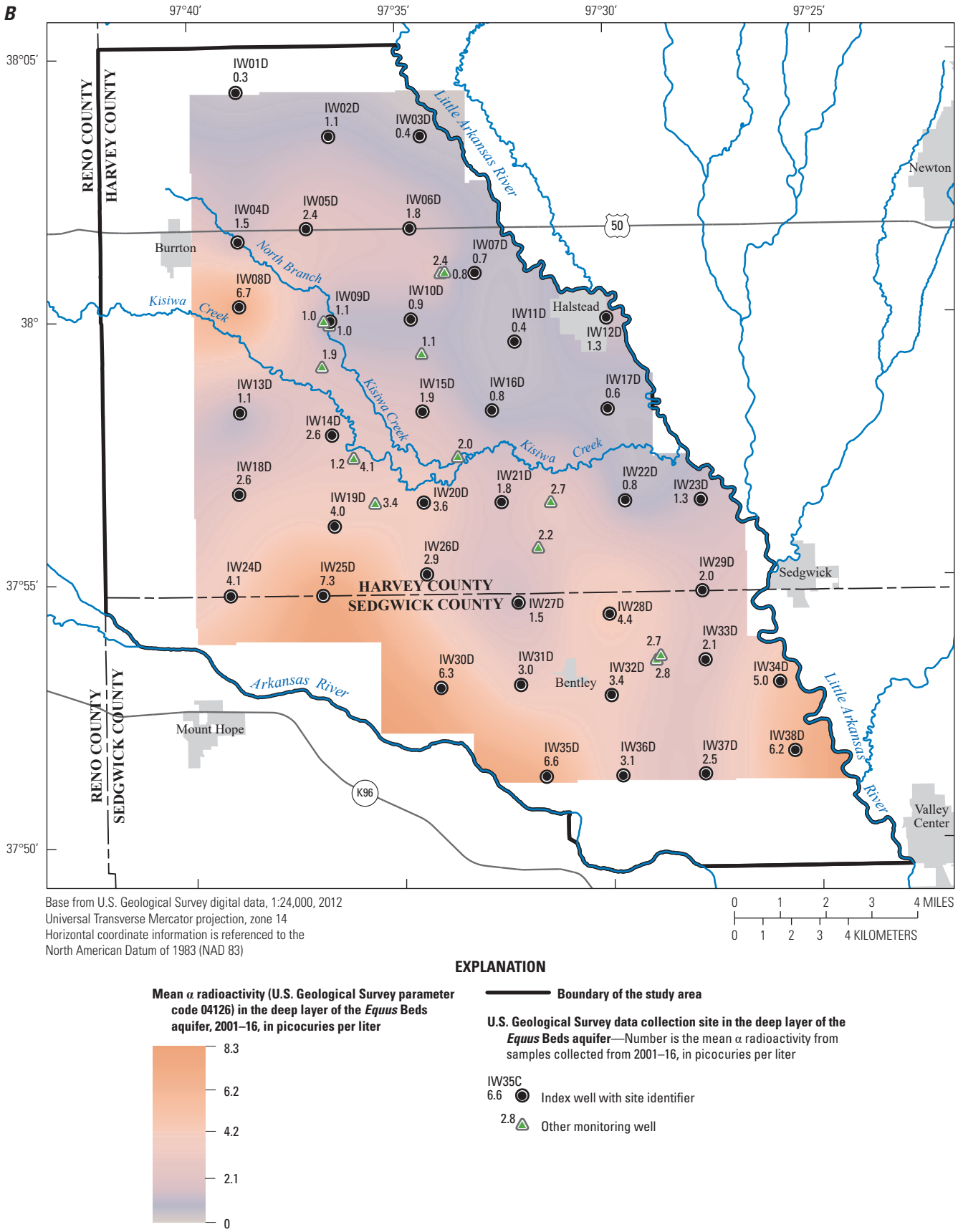


Figure 14. Mean α radioactivity concentrations in the *Equus* Beds aquifer, 2001–16, south-central Kansas. *A*, shallow (depths below land surface equal to or less than 80 feet) wells. *B*, deep (depths below land surface greater than 80 feet) wells.—Continued

negative and positive numbers). Saturation equilibrium for many minerals is closely and positively related to pH across the range of sample conditions. Minerals of most importance determined by predominant water types for the *Equus* Beds aquifer include the carbonate minerals calcite and dolomite and iron hydroxides (Schmidt and others, 2007). Schmidt and others (2007) and Garinger and others (2011) reported chemical precipitation of calcite and iron oxyhydroxide as likely to occur during recharge activity in the study area and the potential increase of iron bacteria may combine to cause reduced efficiency of recharge wells. SI values for calcite, iron (III) hydroxide, iron (II) hydroxide, hydroxyapatite, and manganite increased during phase I and II recharge activities (Garinger and others, 2011; Stone and others, 2016). Chemical weathering in the shallow parts of two phase II wells in the study area may be accelerated because of increased water temperatures and because the aquifer is more vulnerable to clogged pores and mineral dissolution as the equilibrium state is affected by recharge and withdrawal (Stone and others, 2016).

SI values that were strongly and consistently negative or positive for groundwater samples indicate no change in overall equilibrium status regarding those specific minerals during the study. Most minerals had SI values that were consistently negative, whereas some minerals had SI values that were consistently or typically positive such as iron oxide and hydroxide minerals [$Fe(OH)_{2.7}Cl_{0.3}$, goethite, hematite, and magnetite] and quartz group minerals (chalcedony and quartz; table 11). Undersaturation (negative SI) of metal-bearing minerals can indicate potential for release of metals such as arsenic and manganese, which are harmful in drinking water. Several SI values for arsenic- (arsenolite, arsenic pentoxide, calcium arsenate, claudetite, and scorodite) and manganese-bearing [hausmannite, manganese (III) sulfate, $Mn_3(AsO_4)_2 \cdot 8H_2O$, manganese (II) phosphate, manganese (II) chloride tetrahydrate, manganese sulfate, pyrochroite, and rhodochrosite(d)] minerals were consistently negative in all the shallow and deep IWs during 2001 through 2016 (table 11).

Several carbonate minerals in shallow and deep IWs varied across their equilibrium state during 2001 through 2016 and included aragonite, calcite, dolomite, dolomite (d), siderite, and siderite(d) (table 11; figs. 15*A*, *B*). Shallow IW calcite SI values ranged from −3.60 to 0.27 (mean equals −0.71), and deep IW calcite SI values ranged from −1.33 to 0.84 (mean equals −0.21; table 11, figs. 15*A*, *B*). Calcite SI values were larger more often in the deep parts of the aquifer and did not show a clear distributional pattern. Mean and median calcite SI values for shallow and deep IWs were negative (undersaturated) during the study period (table 11; figs. 15*A*, *B*), indicating the potential for calcite dissolution if calcite is present for a substantial part of the study period. However, some individual samples had positive calcite SI values (table 11; figs. 15*A*, *B*), indicating that calcite precipitation may occur in the study area; and artificial recharge activity has been shown to cause aquifer geochemistry to shift toward more oversaturated calcite SI values (Schmidt and others, 2007; Garinger and others, 2011; Stone and others, 2016) potentially resulting in formation of calcite mineral deposits that may reduce efficiency of injection wells.

Some manganese-bearing mineral SI values ranged from undersaturation to oversaturation in shallow and deep IWs during the study; these included birnessite, bixbyite, manganite, manganese (II) hydrogen phosphate, nsutite, pyrolusite, and rhodochrosite (table 11; figs. 15*A*, *B*). Mean and median manganite SI values in the shallow and deep IWs were negative (undersaturated) during 2001 through 2016 (table 11; figs. 15*A*, *B*). Positive manganite SI values were not reported previously in phase I and II recharge wells (Garinger and others, 2011; Stone and others, 2016), but, in this study, tended to occur in the southeast part of the study area, and manganite SI values tended to be strongly negative in the northeast and southern part of the study area. Manganite SI values increased in phase I recharge wells during artificial recharge in the study area likely because of the introduction of recharge water (Garinger and others, 2011). Should manganite SI values continue to increase, manganite might begin to precipitate and contribute to clogging of aquifer pores.

Several phosphate minerals in shallow and deep IWs varied across their equilibrium state during the study and included FCO_3apatite, fluorapatite, hydroxyapatite, and vivianite (table 11; figs. 15*A*, *B*). Phosphate mineral SI values indicated undersaturation most of the time in shallow and deep IWs during the study period, except for FCO_3apatite, whose SI values usually indicated oversaturation (table 11, figs. 15*A*, *B*). Stone and others (2016) reported a shift from undersaturation toward equilibrium of phosphate minerals in two shallow phase II wells in the study area. Shallow IW dolomite SI values were negative and ranged from negative to positive in the deep IWs during the study (table 11, figs. 15*A*, *B*). Schmidt and others (2007) and Stone and others (2016) reported groundwater dolomite values that were consistently negative in shallow and deep diversion and phase II wells in the study area.

SI values with respect to iron hydroxide varied across equilibria during the study and exceeded the minima and maxima previously recorded (table 11, figs. 15*A*, *B*; Schmidt and others, 2007; Garinger and others, 2011). Mean and median SI values with respect to iron hydroxide were undersaturated in shallow and deep IWs (table 11, figs. 15*A*, *B*). Positive SI indices indicated that, at times, groundwater in shallow and deep IWs was oversaturated with respect to iron hydroxide and there was potential for iron hydroxide precipitation. Schmidt and others (2007) determined that iron hydroxide is likely to chemically precipitate in the study area and that the potential for biofouling by iron-related bacteria exists when fully oxygenated treated stream water is injected into the aquifer.

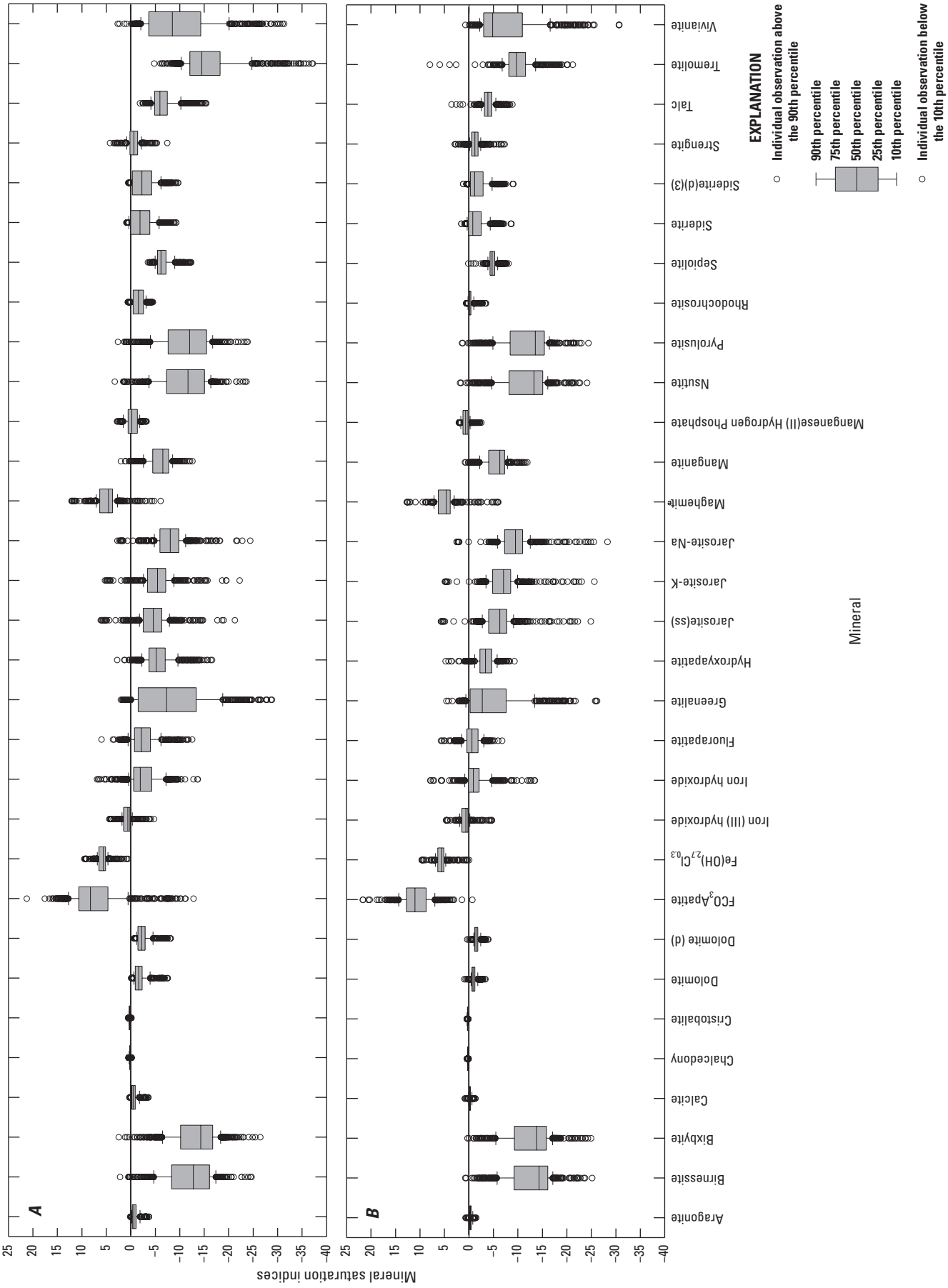


Figure 15. Select mineral saturation indices in the *Equus* Beds aquifer, south-central Kansas, 2001–16. *A*, shallow (depths below land surface equal to or less than 80 feet) index wells and *B*, deep (depths below land surface greater than 80 feet) index wells.

Summary and Conclusions

The city of Wichita's water supply currently (2019) comes from two primary sources: Cheney Reservoir and the *Equus* Beds aquifer. The *Equus* Beds aquifer storage and recovery (ASR) project was developed to help the city of Wichita meet increasing future water demands. The ASR project pumps water out of the Little Arkansas River during above-base-flow conditions, treats it using National Primary Drinking Water Regulations as a guideline, and injects it into the *Equus* Beds aquifer for later use. The City of Wichita implemented the *Equus* Beds Groundwater Recharge Demonstration Project (GRDP) in 1995 to investigate the feasibility of using Little Arkansas River water to artificially recharge the aquifer. The City of Wichita proceeded with the *Equus* Beds ASR project after successfully implementing artificial recharge of the aquifer during the GRDP. The *Equus* Beds ASR project currently (2019) consists of two coexisting phases. Phase I began in 2007 and captures Little Arkansas River water and indirect streambank diversion well water for recharge activity with water injection in 4 wells and 2 recharge basins. Phase II began in 2013 and currently (2019) includes a surface-water treatment facility, a river intake facility, seven recharge injection wells, and a third recharge basin. The U.S. Geological Survey, in cooperation with the City of Wichita, completed this study to summarize water-quality and geochemical variability of the *Equus* Beds aquifer. Data in this report can be used to establish baseline conditions before further implementation of artificial aquifer recharge, document groundwater quality, evaluate changing conditions, identify environmental factors affecting groundwater, provide science-based information for decision making, and help meet regulatory monitoring requirements.

Physicochemical properties were measured and water-quality data were collected from 2 Little Arkansas River surface-water sites that bracketed a substantial part of the easternmost part of the *Equus* Beds aquifer and 63 *Equus* Beds aquifer groundwater sites during 2001 through 2016. Continuous streamflow was measured at the 2 surface-water sites and continuous water levels were measured at the shallow and deep parts of 2 index wells (IWs), 1 background well, the shallow and deep parts of 1 Phase I well, and the shallow and deep parts of 2 Phase II wells. Continuous surface-water water-quality monitors measured water temperature, specific conductance, pH, dissolved oxygen, and turbidity at both surface-water sites, and the monitor at the downstream surface-water site measured nitrate plus nitrite and fluorescent dissolved organic matter (fDOM). Continuous groundwater-quality monitors in the two shallow and two deep Phase II wells measured water temperature, specific conductance, pH/oxidation-reduction potential (ORP), and dissolved oxygen, and the monitors in the shallow wells also measured fDOM. Discrete water-quality samples were collected from the 2 surface-water sites, 76 areal assessment IWs (38 pairs each with a shallow and deep well), 6 background wells, 4 recharge wells (2 pairs each with a shallow and deep well), 6 Phase I wells (3 pairs each with a shallow and deep well), and 16 Phase II wells (8 pairs each with a shallow and deep well). Discretely collected samples were analyzed for physicochemical properties including dissolved solids, primary ions, nutrients (nitrogen and phosphorus species), organic carbon, indicator bacteria, trace elements, arsenic species, organic compounds, and radioactivity. Water chemistry data summary statistics were computed for the Little Arkansas River and the shallow and deep parts of the *Equus* Beds aquifer. Federal drinking-water criteria were used to evaluate aquifer water quality. Water-quality constituents of interest also were quantified and compared with water-level data. Groundwater data were geochemically modeled to describe the potential for precipitation and dissolution of minerals.

Continuous measurement of physicochemical properties in near-real time allowed characterization of Little Arkansas River surface water during conditions and time scales that would not have been possible otherwise and served as a complement to discrete water-quality sampling. Surface-water physicochemical properties and water-quality constituents that may exceed Federal (U.S. Environmental Protection Agency [EPA]) drinking-water quality criteria and those that are of potential interest or concern for artificial recharge operations included streamflow, chloride, sulfate, nitrate plus nitrite, total coliform bacteria, iron, manganese, arsenic, and atrazine. Ranges for surface-water physicochemical properties and water-quality constituents of interest did not exceed historical (1995 through 2012) ranges in the study area during the study. During 2001 through 2016, less than (<) 1 percent of chloride and nitrate plus nitrite, 7 percent of iron, 48 percent of manganese, 12 percent of arsenic, and 39 percent of atrazine detections in surface-water samples exceeded their respective Federal criteria. None of the surface-water samples collected exceeded the sulfate Federal criterion and every sample had detections of total coliform bacteria during the study.

Continuous measurement of physicochemical properties in near-real time allowed characterization of *Equus* Beds aquifer groundwater during conditions and time scales that would not have been possible otherwise and served as a complement to discrete water-quality sampling. Groundwater physicochemical properties and water-quality constituents that exceeded Federal drinking-water quality criteria and those that are of potential interest or concern for artificial recharge operations included groundwater levels, specific conductance, ORP, dissolved solids, chloride, sulfate, nitrate plus nitrite, arsenic species, iron, manganese, atrazine, and bacterial (fecal coliform, *Escherichia coli* [*E. coli*], and total coliforms) and viral (*E. coli* coliphage) indicators.

Large groundwater specific conductance was measured along Kisiwa Creek and near the Arkansas River in the shallow and deep parts of the *Equus* Beds aquifer. Largest specific conductances were associated with past oil and gas activities in the shallow and deep parts of the aquifer near Burrton, Kansas, and smaller specific conductances were in the northeast part of the study area in the shallow and deep parts of the aquifer. Shallow IW ORP mean values indicated more oxidizing

conditions in the northern and southern (near the Arkansas River) parts of the study area and more reducing conditions along part of the Little Arkansas River. Deep IW ORP mean values were indicative of more oxidizing conditions in the southern one-third of the study area and more reducing conditions in the northern part. Larger ORP values in the deep part of the aquifer tended to correspond to parts of the aquifer that had larger effective porosity.

About 54 percent of shallow and 56 percent of deep IW dissolved-solids samples exceeded the EPA secondary maximum contaminant level (SMCL) of 500 mg/L but did not exceed the historical ranges reported for the study area. The EPA SMCL for chloride is 250 mg/L, and chloride is of particular concern in the *Equus* Beds aquifer because of the chloride plume moving toward the city of Wichita's well field regardless of pumping in the area. About 5 percent of shallow and 7 percent of deep IW chloride-sample concentrations exceeded the Federal criterion. Chloride exceedances tended to occur in shallow and deep wells along the Arkansas River and near Burrton, Kans. Chloride concentrations near Burrton were larger in the deep parts of the aquifer. About 18 percent of shallow and 13 percent of deep IW sulfate-sample concentrations exceeded the EPA sulfate SMCL of 250 mg/L. Wells with mean sulfate concentrations exceeding the Federal criterion tended to be in the central part of the study area.

Fluoride never exceeded the EPA SMCL of 2.0 mg/L during the study but was detected in nearly all (about 99 percent) groundwater IW samples. Several fluoride concentrations in groundwater were larger than the historical range reported for 1995 through 2005 by about 8 to 48 percent. Chlorine was detected in about 6 percent of shallow IWs but did not exceed the EPA maximum residual disinfectant level (MRDL) of 4.0 mg/L during the study.

Mean shallow IW nitrate plus nitrite (hereafter referred to as nitrate) was substantially larger than mean deep IW nitrate. About 15 percent of shallow and <1 percent of deep IW nitrate sample concentrations exceeded the EPA maximum contaminant level (MCL) of 10 mg/L. Shallow IW mean nitrate concentrations that exceeded the MCL were in the northeastern and southeastern parts of the study area; on average, deep IW nitrate concentrations did not exceed the MCL. Larger mean nitrate concentrations that were in the southeastern part of the study area are in the area that has larger effective porosity and were likely the result of more rapid percolation from agricultural land uses and geochemical controls. Nitrite was detected in 7 percent of shallow and deep IWs and exceeded the EPA MCL of 1 mg/L in two shallow IW samples. Two deep IW nitrite concentrations from 2012 exceeded the historical range reported during 1995 through 2005 by 64 and 82 percent. Two shallow IW total organic carbon concentrations from 2014 and 2016 exceeded the historical range reported during 1995 through 2005 by 23 and 17 percent, respectively.

E. coli and fecal coliform bacteria detections were usually at or near the detection limit. *E. coli* was detected in 3 percent of shallow and deep IWs and had maxima of 37 and 130 colony forming units per 100 milliliters (cfu/100 mL), respectively. Fecal coliform bacteria were detected in 8 percent of shallow IWs and 6 percent of deep IWs and had maxima of 360 and 81 cfu/100 mL, respectively. Total coliforms were detected in 24 percent of shallow and 12 percent of deep IWs and had maxima of 370 and 84 most probable number per 100 milliliters (mpn/100 mL), respectively. Bacteria detections that occurred in the first samples collected from the wells after they were developed may be related to drilling. Some *E. coli* and fecal coliform bacteria detections exceeded the historical ranges reported during 1995 to 2005. *E. coli* coliphage was detected in two shallow IW samples (1 percent of samples) at the detection limit and was not detected in deep IW samples. Iron-related, slime-forming, and sulfate-reducing bacteria densities in shallow IWs were 87, 64, and 919 percent larger, respectively, than densities in deep IWs during the study. Iron-related bacteria were detected in 93 percent of shallow IWs and 85 percent of deep IW samples. Slime-forming bacteria were detected in 96 percent of shallow and 92 percent of deep IWs. Sulfate-reducing bacteria were detected in 40 percent of shallow and 28 percent of deep IW samples.

Trace elements that were detected in 20 percent or more of the groundwater samples included barium, iron, manganese, nickel, strontium, zinc, boron, and selenium. Several trace elements with EPA MCLs, SMCLs, or treatment techniques (TT) were detected. The EPA MCL for beryllium is 4 µg/L and was exceeded in 6 samples in the shallow and deep IWs in the southern part of the study area. Dissolved iron was detected in 51 percent of shallow and 62 percent of deep IW samples. Dissolved-iron concentrations exceeded the EPA SMCL of 300 µg/L in 38 percent of shallow and 46 percent of deep IW samples. Mean dissolved-iron concentrations were largest mostly in the central and northwest part of the study area. The distribution of large dissolved-iron concentrations was similar to that of large sulfate concentrations, indicating pyrite oxidation during dewatering. About 55 percent of shallow and 92 percent of deep IW dissolved-manganese samples exceeded the EPA SMCL of 50 µg/L. Almost all the central and northern parts of the study area had mean dissolved-manganese concentrations that exceeded the SMCL in the shallow part of the aquifer. Mean dissolved-manganese concentrations in the shallow part of the aquifer were substantially large (>1,000 µg/L) in wells near the Little Arkansas River and in the central part of the study area; most of the deep part of the aquifer in the study area had dissolved-manganese concentrations that exceeded the SMCL.

Arsenic species concentrations generally were larger in the deep parts of the aquifer. Arsenite was the dominant form on average in shallow (52 percent) and deep (55 percent) IWs. About 12 percent of shallow and 34 percent of deep IW dissolved-arsenic sample concentrations exceeded the EPA MCL of 10 µg/L. Shallow IW dissolved-arsenic concentrations were larger near the Little Arkansas River and the center of the study area; large shallow IW dissolved-arsenic concentrations in the center of the study area correspond to areas that have had the most water-level recovery since the historical low in 1993. Mean ORP in shallow IWs generally decreased with

increasing water-level depths and were inversely related to mean dissolved-arsenic concentrations because of more reducing conditions at larger depths below the land surface. Larger dissolved arsenic concentrations in the shallow parts of the aquifer are associated with decreases in water levels and a subsequent decrease in ORP and thus more reducing conditions.

Shallow IW organic compounds that were detected in greater than 20 percent of samples were herbicides and included atrazine (a triazine herbicide parent compound), three triazine degradation products (2-chloro-4-isopropylamino-6-amino-*s*-triazine [also known as deethylatrazine or CIAT], 2-chloro-6-ethylamino-4-amino-*s*-triazine [also known as deisopropylatrazine or CEAT], and 2-hydroxy-4-isopropylamino-6-ethylamino-*s*-triazine [also known as hydroxyatrazine or OIET]), and metolachlor (a member of the chloroacetanilide family of herbicides). Deep IW pesticides that were detected in greater than 20 percent of samples were atrazine and 2-chloro-4-isopropylamino-6-amino-*s*-triazine. Atrazine was detected in about 58 percent of shallow and 28 percent of deep IWs and did not exceed the EPA MCL of 3.0 µg/L. Atrazine concentrations in shallow IWs generally were largest in the northwest part of the study area near the North Branch Kisiwa Creek, and the atrazine concentrations in deep IWs generally were largest most often in the southern part of the study area. Alpha (α) radioactivity measurements exceeded the EPA MCL of 15 picocuries per liter (pCi/L) in 4 percent of shallow IW samples, and deep IW measurements did not exceed the EPA MCL. α and gross beta (β) radioactivity measurements generally were larger in the southern one-third of the aquifer. One shallow and two deep IW α radioactivity measurements exceeded the reported historical range during 1995 through 2005.

Changes in groundwater chemistry can affect mineral saturation, resulting in precipitation and dissolution of the minerals. Most groundwater minerals had saturation indices (SIs) that were consistently negative. Minerals that had SI values that were consistently or typically positive included iron oxide and hydroxide minerals and quartz-group minerals. Several SI values for arsenic- (arsenolite, arsenic pentoxide, calcium arsenate, claudetite, and scorodite) and manganese-bearing [hausmannite, manganese (III) sulfate, $Mn_3(AsO_4)_2 \cdot 8H_2O$, manganese (II) phosphate, manganese (II) chloride tetrahydrate, manganese sulfate, pyrochroite, rhodochrosite(d)] minerals were consistently negative. Several carbonate minerals in shallow and deep IWs varied across their equilibrium state and included aragonite, calcite, siderite, and siderite(d). Calcite SI values were larger more often in the deep parts of the aquifer but did not show a clear distributional pattern. Mean and median calcite SI values for shallow and deep IWs were negative (undersaturated) indicating the potential for calcite dissolution if calcite is present for a substantial part of the study period. However, calcite SI values in this study indicated saturation and subsequent calcite precipitation may occur in the study area, potentially resulting in formation of calcite mineral deposits that may reduce efficiency of injection wells. Some manganese-bearing mineral SI values ranged from undersaturation to oversaturation in shallow and deep IWs during the study; these included birnessite, bixbyite, manganite, manganese (II) hydrogen phosphate, nsutite, pyrolusite, and rhodochrosite. SI values with respect to iron hydroxide varied across equilibria. Mean and median SI values with respect to iron hydroxide were undersaturated in shallow and deep IWs. Positive SIs indicate that, at times, groundwater in shallow and deep IWs was oversaturated with respect to iron hydroxide and there is potential for iron hydroxide precipitation.

References Cited

Aiken, G.R., 2002, Organic matter in ground water [abs.], *in* Aiken, G.R., and Kuniansky, E.L., eds., U.S. Geological Survey artificial recharge workshop proceedings, April 2–4, 2002, Sacramento, California: U.S. Geological Survey Open-File Report 02–89, p. 21–23. [Also available at https://water.usgs.gov/ogw/pubs/ofr0289/ga_organic.htm.]

Allan, J.D., and Castillo, M.M., 2007, Stream ecology—Structure and function of running waters (2d ed.): Dordrecht, The Netherlands, Springer Science and Business Media, 436 p.

Ayotte, J.D., Belaval, M., Olson, S.A., Burow, K.R., Flanagan, S.M., Hinkle, S.R., and Lindsey, B.D., 2015, Factors affecting temporal variability of arsenic in groundwater used for drinking water supply in the United States: Science of the Total Environment, v. 505, p. 1,370–1,379. [Also available at https://doi.org/10.1016/j.scitotenv.2014.02.057.]

Ayotte, J.D., Szabo, Z., Focazio, M.J., and Eberts, S.M., 2011, Effects of human-induced alteration of groundwater flow on concentrations of naturally-occurring trace elements at water-supply wells: Applied Geochemistry, v. 26, no. 5, p. 747–762. [Also available at https://doi.org/10.1016/j.apgeochem.2011.01.033.]

Ball, J.W., and Nordstrom, D.K., 1991, User's manual for WATEQ4F, with revised thermodynamic data base and test cases for calculating speciation of major, trace, and redox elements in natural waters: U.S. Geological Survey Open-File Report 91–183, 193 p. [Also available at https://pubs.er.usgs.gov/publication/ofr91183.]

Bauder, T.A., Waskom, R.M., Sutherland, P.L., and Davis, J.G., 2007, Irrigation water quality criteria: Colorado State University Extension, Fact Sheet no. 0.506, 4 p. [Also available at http://extension.colostate.edu/topic-areas/agriculture/irrigation-water-quality-criteria-0-506/.]

Bennett, T.J., Graham, J.L., Foster, G.M., Stone, M.L., Juracek, K.E., Rasmussen, T.J., and Putnam, J.E., 2014, U.S. Geological Survey quality-assurance plan for continuous water-quality monitoring in Kansas, 2014: U.S. Geological Survey Open-File Report 2014–1151, 34 p. plus appendixes. [Also available at https://doi.org/10.3133/ofr20141151.]

Bolks, A., DeWire, A., and Harcum, J.B., 2014, Baseline assessment of left-censored environmental data using R: National Nonpoint Source Monitoring Program Tech Notes 10, Developed for U.S. Environmental Protection Agency by Tetra Tech, Inc., Fairfax, Va., 28 p. [Also available at https://www.epa.gov/sites/production/files/2016-05/documents/tech_notes_10_jun2014_r.pdf].

Bushon, R.N., 2003, Fecal indicator viruses: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A7, sec. 7.2, 24 p. [Also available at https://water.usgs.gov/owq/FieldManual/Chapter7/7.2.html.]

Camargo, J.A., and Alonso, Á., 2006, Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems—A global assessment: Environment International, v. 32, no. 6, p. 831–849. [Also available at https://doi.org/10.1016/j.envint.2006.05.002.]

Charlton, S.R., and Parkhurst, D.L., 2011, Modules based on the geochemical model PHREEQC for use in scripting and programming languages: Computers & Geosciences, v. 37, no. 10, p. 1653–1663. [Also available at https://doi.org/10.1016/j.cageo.2011.02.005.]

City of Wichita, 1993, Integrated Local Water Supply Plan: Wichita, Kans., City of Wichita.

Christensen, V.G., Jian, X., and Ziegler, A.C., 2000, Regression analysis and real-time water-quality monitoring to estimate constituent concentrations, loads, and yields in the Little Arkansas River, south-central Kansas, 1995–99: U.S. Geological Survey Water-Resources Investigations Report 00–4126, 36 p. [Also available at https://pubs.er.usgs.gov/publication/wri004126.]

Christensen, V.G., Ziegler, A.C., Rasmussen, P.P., and Jian, X., 2003, Continuous real-time water-quality monitoring of Kansas streams, *in* Proceedings of 2003 Spring Specialty Conference on Agricultural Hydrology and Water Quality, Kansas City, Mo., May 12–14, 2003: Middleburg, Va., American Water Resources Association Technical Publication Series No. TPS–03–1, compact disc. [Also available at https://nrtwq.usgs.gov/ks/methods/christensen2003.]

Cullimore, D.R., 2007, Practical manual of groundwater microbiology (2d ed.): Boca Raton, Fla., CRC Press, Taylor & Francis Group, 376 p.

Cunningham, W.L., and Schalk, C.W., comps., 2011, Groundwater technical procedures of the U.S. Geological Survey: U.S. Geological Survey Techniques and Methods, book 1, chap. A1, 151 p. [Also available at https://pubs.usgs.gov/tm/1a1/pdf/tm1-a1.pdf.]

Downing, B.D., Pellerin, B.A., Bergamaschi, B.A., Saraceno, J.F., and Kraus, T.E.C., 2012, Seeing the light—The effects of particles, dissolved materials, and temperature on in situ measurements of DOM fluorescence in rivers and streams: Limnology and Oceanography—Methods, v. 10, no. 10, p. 767–775. [Also available at https://doi.org/10.4319/lom.2012.10.767.]

Droycon Bioconcepts, Inc., 2004, Biological activity reaction test BART™—User manual: Regina, Saskatchewan, Canada, Droycon Bioconcepts, Inc., 54 p. [Also available at http://www.dbi.ca/BARTs/Docs/Manual.pdf.]

Dubrovsky, N.M., Burrow, K.R., Clark, G.M., Gronberg, J.M., Hamilton, P.A., Hitt, K.J., Mueller, D.K., Munn, M.D., Nolan, B.T., Puckett, L.J., Rupert, M.G., Short, T.M., Spahr, N.E., Sprague, L.A., and Wilber, W.G., 2010, The quality of our Nation's waters—Nutrients in the Nation's streams and groundwater, 1992–2004: U.S. Geological Survey Circular 1350, 174 p. [Also available at https://pubs.usgs.gov/circ/1350/.]

Dufour, A.P., 1984, Bacterial indicators of recreational water quality: Canadian Journal of Public Health, v. 75, no. 1, p. 49–56. [Also available at https://www.jstor.org/stable/41990233.]

Dufour, A.P., Strickland, E.R., and Cabelli, V.J., 1981, Membrane filter method for enumerating *Escherichia coli*: Applied and Environmental Microbiology, v. 41, no. 5, p. 1152–1158. [Also available at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC243882/pdf/aem00198-0082.pdf.]

Esri, 2017, How topo to raster works: Esri, ArcMap website, accessed August 2017 at https://desktop.arcgis.com/en/arcmap/10.5/tools/3d-analyst-toolbox/how-topo-to-raster-works.htm.

Garbarino, J.R., Bednar, A.J., and Burkhardt, M.R., 2002, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Arsenic speciation in natural-water samples using laboratory and field methods: U.S. Geological Survey Water-Resources Investigations Report 02–4144, 40 p. [Also available at https://nwql.usgs.gov/rpt.shtml?WRIR-02-4144.]

Garinger, L.P., King, A.S., and Ziegler, A.C., 2011, Effects of experimental passive artificial recharge of treated surface water on water quality in the *Equus* Beds Aquifer, 2009–2010: U.S. Geological Survey Scientific Investigations Report 2011–5070, 106 p. [Also available at https://pubs.usgs.gov/sir/2011/5070/.]

Gotkowitz, M.B., Schreiber, M.E., and Simo, J.A., 2004, Effects of water use on arsenic release to well water in a confined aquifer: Groundwater, v. 42, no. 4, p. 568–575. [Also available at https://doi.org/10.1111/j.1745-6584.2004.tb02625.x.]

Hansen, C.V., 2007, Status of ground-water levels and storage volume in the *Equus* Beds aquifer near Wichita, Kansas, January 2003–January 2006: U.S. Geological Survey Scientific Investigations Report 2006–5321, 34 p. [Also available at https://pubs.usgs.gov/sir/2006/5321/.]

Hansen, C.V., and Aucott, W.R., 2001, Status of groundwater levels and storage volume in the Wichita well field area, south-central Kansas, 1998–2000: U.S. Geological Survey Water-Resources Investigations Report 00–4267, 27 p. [Also available at https://pubs.er.usgs.gov/publication/wri004267.]

Hansen, C.V., and Aucott, W.R., 2003, Status of ground-water levels and storage volume in the *Equus* Beds aquifer near Wichita, Kansas, January 2000–January 2003: U.S. Geological Survey Water Resources Investigations Report 03–4298, 36 p. [Also available at https://pubs.usgs.gov/wri/wrir034298/.]

Hansen, C.V., and Aucott, W.R., 2010, Status of groundwater levels and storage volume in the *Equus* Beds aquifer near Wichita, Kansas, January 2006 to January 2010: U.S. Geological Survey Scientific Investigations Report 2010–5231, 47 p. [Also available at https://pubs.usgs.gov/sir/2010/5231/.]

Hansen, C.V., Whisnant, J.A., and Lanning-Rush, J.L., 2014, Status of groundwater levels and storage volume in the *Equus* Beds aquifer near Wichita, Kansas, 2012 to 2014: U.S. Geological Survey Scientific Investigations Report 2014–5185, 39 p. [Also available at https://doi.org/10.3133/sir20145185.]

Hathaway, L.R., Waugh, T.C., Gaile, O.K., and Dickey, H.P., 1981, Chemical quality of irrigation water in the *Equus* Beds area, south-central Kansas: Kansas Geological Survey, Chemical Quality Series 10, 45 p. [Also available at http://www.kgs.ku.edu/Publications/Bulletins/CQS10/index.html.]

Helsel, D.R., 2005, Nondetects and data analysis—Statistics for censored environmental data: Hoboken, N.J., Wiley-Interscience, 268 p.

Helsel, D.R., and Cohn, T.A., 1988, Estimation of descriptive statistics for multiply censored water quality data: Water Resources Research, v. 24, no. 12, p. 1997–2004. [Also available at https://doi.org/10.1029/WR024i012p01997.]

Hem, J.D., 1992, Study and interpretation of chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p. [Also available at https://pubs.usgs.gov/wsp/wsp2254/.]

Hinkle, S.R., and Polette, D.J., 1999, Arsenic in groundwater of the Willamette Basin, Oregon: U.S. Geological Survey Water-Resources Investigations Report 98–4205, 28 p. [Also available at https://pubs.er.usgs.gov/publication/wri984205.]

Kalin, R.M., 1995, Basic concepts and formulations for isotope geochemical modelling of groundwater systems: Belfast, Northern Ireland, United Kingdom, The Queen's University, 155 p. [Also available at https://inis.iaea.org/collection/NCLCollectionStore/_Public/28/020/28020907.pdf].

Kansas Department of Agriculture, 2016, Kansas farm facts: Topeka, Kans., Kansas Department of Agriculture, 63 p. [Also available at https://agriculture.ks.gov/docs/default-source/ag-marketing/kansas-farm-facts-10052016.pdf?sfvrsn=4.]

Kansas Department of Agriculture and Kansas Geological Survey, 2017, Water Information Management and Analysis System (WIMAS) for the web: Kansas Department of Agriculture, Division of Water Resources database, http://hercules.kgs.ku.edu/geohydro/wimas/index.cfm.

Kansas Department of Health and Environment, 2000a, Lower Arkansas River Basin total maximum daily load—Water body—Little Arkansas River subbasin, water quality impairment—Sediment impact on aquatic life: Kansas Department of Health and Environment, 11 p. [Also available at http://www.kdheks.gov/tmdl/la/LittleArkSed.pdf.]

Kansas Department of Health and Environment, 2000b, Lower Arkansas River Basin total maximum daily load—Water body—Little Arkansas River subbasin, water quality impairment—Nutrients and oxygen demand impact on aquatic life: Kansas Department of Health and Environment, 14 p. [Also available at http://www.kdheks.gov/tmdl/la/LittleArkBOD.pdf.]

Kansas Department of Health and Environment, 2000c, Lower Arkansas River Basin total maximum daily load—Waterbody—Little Arkansas River subbasin, water quality impairment—Fecal coliform bacteria: Kansas Department of Health and Environment, 14 p. [Also available at http://www.kdheks.gov/tmdl/la/LittleArkFCB.pdf.]

Kansas Department of Health and Environment, 2004, Surface water nutrient reduction plan: Topeka, Kans., Kansas Department of Health and Environment, Bureau of Water, 47 p. [Also available at http://cdm16884.contentdm.oclc.org/cdm/ref/collection/p16884coll4/id/88.]

Kansas Department of Health and Environment, 2006a, Lower Arkansas River Basin total maximum daily load—Waterbody/assessment unit (AU)—Lower Arkansas River—Hutchinson to Maize water quality impairment—Chloride: Topeka, Kans., Bureau of Water, 27 p. [Also available at http://www.kdheks.gov/tmdl/la/2006_Ark_Hutch_to_MaizeCl.pdf.]

Kansas Department of Health and Environment, 2006b, Lower Arkansas River Basin total maximum daily load—Water body/assessment unit—Upper Little Arkansas River, water quality impairment—Chloride: Bureau of Water, 25 p. [Also available at http://www.kdheks.gov/tmdl/la/UpperLittleArkClTMDLFinal.pdf.]

Kansas Department of Health and Environment, 2008, Lower Arkansas River Basin category 4B alternative—Water body/assessment unit—Little Arkansas River, water quality impairment—Atrazine: Bureau of Water, 35 p. [Also available at http://www.kdheks.gov/tmdl/la/Lit_Ark_CAT4B_10-12-06.pdf.]

Kansas Department of Health and Environment, 2014, Lower Arkansas Basin total maximum daily load—Waterbody/assessment unit—Little Arkansas River watershed, water quality impairment—Total suspended solids (TSS): Bureau of Water, 53 p. [Also available at http://www.kdheks.gov/tmdl/2013/LitArk_TSS.pdf.]

Kansas Department of Health and Environment, 2016, 2016 303(d) list of all impaired/potentially impaired waters: Bureau of Water, 90 p. [Also available at http://www.kdheks.gov/tmdl/2016/Proposed_Public_List_2016_All_Impaired_Waters.pdf.]

Kansas State University Research and Extension, Kansas Center for Agricultural Resources and the Environment, and Kansas Department of Health & Environment, 2011, Little Arkansas River watershed—Watershed restoration and protection strategy: Kansas State University Research and Extension, Kansas Center for Agricultural Resources and the Environment, Kansas Department of Health & Environment, 365 p. [Also available at http://www.kswraps.org/files/attachments/littlearkansas_plansummary.pdf.]

Kelly, B.P., Pickett, L.L, Hansen, C.V., and Ziegler, A.C., 2013, Simulation of groundwater flow, effects of artificial recharge, and storage volume changes in the *Equus* Beds aquifer near the city of Wichita, Kansas well field, 1935–2008: U.S. Geological Survey Scientific Investigations Report 2013–5042, 90 p. [Also available at https://pubs.usgs.gov/sir/2013/5042/.]

Kim, M., Nriagu, J., and Haack, S., 2003, Arsenic behavior in newly drilled wells: Chemosphere, v. 52, no. 3, p. 623–633. [Also available at https://doi.org/10.1016/S0045-6535(03)00244-3.]

Klager, B.J., 2016, Status of groundwater levels and storage volume in the *Equus* Beds aquifer near Wichita, Kansas, January 2016: U.S. Geological Survey Scientific Investigations Report 2016–5165, 15 p. [Also available at https://doi.org/10.3133/sir20165165.]

Klager, B.J., Kelly, B.P., and Ziegler, A.C., 2014, Preliminary simulation of chloride transport in the *Equus* Beds aquifer and simulated effects of well pumping and artificial recharge on groundwater flow and chloride transport near the city of Wichita, Kansas, 1990 through 2008: U.S. Geological Survey Open-File Report 2014–1162, 76 p. [Also available at https://doi.org/10.3133/ofr20141162.]

Korte, N., 1991, Naturally occurring arsenic in groundwaters of the midwestern United States: Environmental Geology and Water Sciences, v. 18, no. 2, p. 137–141. [Also available at https://doi.org/10.1007/BF01704667.]

Kozul, C.D., Ely, K.H., Enelow, R.I., and Hamilton, J.W., 2009, Low-dose arsenic compromises the immune response to influenza A infection *in vivo*: Environmental Health Perspectives, v. 117, no. 9, p. 1441–1447. [Also available at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2737023/.]

Leonard, R.B., and Kleinschmidt, M.K., 1976, Saline water in the Little Arkansas River basin area, south-central Kansas: Kansas Geological Survey, Chemical Quality Series 3, 24 p. [Also available at http://www.kgs.ku.edu/Publications/Bulletins/CQS3/index.html.]

McMahon, P.B., and Chapelle, F.H., 2008, Redox processes and water quality of selected principal aquifer systems: Groundwater, v. 46, no. 2, p. 259–271. [Also available at https://doi.org/10.1111/j.1745-6584.2007.00385.x.]

Mueller, D.K., Schertz, T.L., Martin, J.D., and Sandstrom, M.W., 2015, Design, analysis, and interpretation of field quality-control data for water-sampling projects: U.S. Geological Survey Techniques and Methods, book 4, chap. C4, 54 p. [Also available at https://pubs.usgs.gov/tm/04/c04].

Myers, D.N., Stoeckel, D.M., Bushon, R.N., Francy, D.S., and Brady, A.M.G., 2014, Fecal indicator bacteria (ver. 2.1): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A7, sec. 7.1, 73 p. [Also available at https://water.usgs.gov/owq/FieldManual/Chapter7/7.1.html.]

Myers, N.C., Hargadine, G.D., and Gillespie, J.B., 1996, Hydrologic and chemical interaction of the Arkansas River and the *Equus* Beds aquifer between Hutchinson and Wichita, south-central Kansas: U.S. Geological Survey Water-Resources Investigations Report 95–4191, 100 p. [Also available at https://doi.org/10.3133/wri954191.]

National Oceanic and Atmospheric Administration, 2017, Daily summaries station details, accessed August 2017, at https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USC00145539/detail.

Neil, C.W., Yang, Y.J., and Jun, Y., 2012, Arsenic mobilization and attenuation by mineral-water interactions—Implications for managed aquifer recharge: Journal of Environmental Monitoring, v. 114, p. 1772–1788. [Also available at https://pubs.rsc.org/en/content/articlehtml/2012/em/c2em30323j.]

Parkhurst, D.L., and Appelo, C.A.J., 2013, Description of input and examples for PHREEQC version 3—A computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations: U.S. Geological Survey Techniques and Methods, book 6, chap. A43, 497 p. [Also available at https://pubs.usgs.gov/tm/06/a43/.]

Pellerin, B.A., Bergamaschi, B.A., Downing, B.D., Saraceno, J.F., Garrett, J.D., and Olsen, L.D., 2013, Optical techniques for the determination of nitrate in environmental waters—Guidelines for instrument selection, operation, deployment, maintenance, quality assurance, and data reporting: U.S. Geological Survey Techniques and Methods, book 1, chap. D5, 37 p. [Also available at https://pubs.usgs.gov/tm/01/d5/.]

Pope, L.M., Bruce, B.W., and Hansen, C.V., 2001, Groundwater quality in quaternary deposits of the Central High Plains aquifer, south-central Kansas, 1999: U.S. Geological Survey Water-Resources Investigations Report 2000–4259, 44 p. [Also available at https://doi.org/10.3133/wri004259.]

Pope, L.M., Bruce, B.W., Rasmussen, P.P., and Milligan, C.R., 2002, Quality of shallow ground water in areas of recent residential and commercial development, Wichita, Kansas, 2000: U.S. Geological Survey Water-Resources Investigations Report 02–4228, 67 p. [Also available at https://doi.org/10.3133/wri024228.]

Pyne, R.D.G., Singer, P.C., and Miller, C.T., 1996, Aquifer storage recovery of treated drinking water: Denver, Colo., AWWA Research Foundation and American Water Works Association, 176 p.

Putnam, J.E., and Hansen, C.V., 2014, Quality-assurance and data management plan for groundwater activities by the U.S. Geological Survey in Kansas, 2014: U.S. Geological Survey Open-File Report 2014–1060, 37 p. [Also available at https://doi.org/10.3133/ofr20141060.]

R Core Team, 2017, R—A language and environment for statistical computing: Vienna, Austria, R Foundation for Statistical Computing. [Also available at https://www.R-project.org.]

Rasmussen, P.P., Eslick, P.J., and Ziegler, A.C., 2016, Relations between continuous real-time physical properties and discrete water-quality constituents in the Little Arkansas River, south-central Kansas, 1998–2014: U.S. Geological Survey Open-File Report 2016–1057, 16 p. [Also available at https://doi.org/10.3133/ofr20161057.]

Rasmussen, T.J., Bennett, T.J., Stone, M.L., Foster, G.M., Graham, J.L., and Putnam, J.E., 2014, Quality-assurance and data-management plan for water-quality activities in the Kansas Water Science Center, 2014: U.S. Geological Survey Open-File Report 2014–1233, 41 p. [Also available at https://doi.org/10.3133/ofr20141233.]

Rasmussen, T.J., Lee, C.J., and Ziegler, A.C., 2008, Estimation of constituent concentrations, loads, and yields in streams of Johnson County, northeast Kansas, using continuous water-quality monitoring and regression models, October 2002 through December 2006: U.S. Geological Survey Scientific Investigations Report 2008–5014, 103 p. [Also available at https://pubs.usgs.gov/sir/2008/5014/.]

Ryker, S.J., 2003, Arsenic in ground water used for drinking water in the United States, *in* Welch, A.H., and Stollenwerk, K.G., eds., Arsenic in Groundwater—Geochemistry and Occurrence: Norwell, Mass., Kluwer Academic Publishers, p. 165–178. [Also available at https://doi.org/10.1007/0-306-47956-7_6.]

Sauer, V.B., and Turnipseed, D.P., 2010, Stage measurement at gaging stations: U.S. Geological Survey Techniques and Methods, book 3, chap. A7, 45 p. [Also available at https://pubs.usgs.gov/tm/tm3-a7/.]

Schmidt, H.C.R., Ziegler, A.C., and Parkhurst, D.L., 2007, Geochemical effects of induced stream-water and artificial recharge on the *Equus* Beds aquifer, south-central Kansas, 1995–2004: U.S. Geological Survey Scientific Investigations Report 2007–5025, 58 p. [Also available at https://pubs.usgs.gov/sir/2007/5025/.]

Smedley, P.L., and Kinniburgh, D.G., 2002, A review of the source, behavior and distribution of arsenic in natural waters: Applied Geochemistry, v. 17, no. 5, p. 517–568. [Also available at https://doi.org/10.1016/S0883-2927(02)00018-5.]

Sorg, T.J., Chen, A.S.C., and Wang, L., 2014, Arsenic species in drinking water wells in the USA with high arsenic concentrations: Water Research, v. 48, p. 156–169. [Also available at https://doi.org/10.1016/j.watres.2013.09.016.]

Spruill, T.B., 1982, Nitrate-nitrogen concentrations in groundwater from three selected areas in Kanas: U.S. Geological Survey Water-Resources Investigations Report 82–11, 32 p. [Also available at https://pubs.usgs.gov/wri/1982/0011/report.pdf.]

Stollenwerk, K.G., 2003, Geochemical processes controlling transport of arsenic in groundwater—A review of adsorption, *in* Welch, A.H., and Stollenwerk, K.G., eds., Arsenic in ground water—Geochemistry and occurrence: Norwell, Mass., Kluwer Academic Publishers, p. 67–100. [Also available at https://link.springer.com/book/10.1007/b101867#page=75.]

Stone, M.L., 2017, Eighty years of cooperative water science: U.S. Geological Survey General Information Product 174, 2 p. [Also available at https://doi.org/10.3133/gip174.]

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 Scientific Investigations Report 2016–5042, 88 p. [Also available at https://doi.org/10.3133/sir20165042.]

Stone, M.L., Rasmussen, T.J., Bennett, T.J., Poulton, B.C., and Ziegler, A.C., 2012, Protocols for collection of streamflow, water-quality, streambed-sediment, periphyton, macroinvertebrate, fish, and habitat data to describe stream quality for the Hydrobiological Monitoring Program, *Equus* Beds Aquifer Storage and Recovery Program, city of Wichita, Kansas: U.S. Geological Survey Open-File Report 2012–1055, 55 p. [Also available at https://pubs.usgs.gov/ofr/2012/1055/.]

Tappa, D.J., Lanning-Rush, J.L., Klager, B.J., Hansen, C.V., and Ziegler, A.C., 2015, Water quality of the Little Arkansas River and *Equus* Beds Aquifer before and concurrent with large-scale artificial recharge, south-central Kansas, 1995–2012 (ver. 1.1, May 6, 2015): U.S. Geological Survey Scientific Investigations Report 2015–5023, 67 p. [Also available at https://doi.org/10.3133/sir20155023.]

Townsend, M.A., and Young, D.P., 2000, Assessment of nitrate-nitrogen distribution in Kansas groundwater, 1990–1998: Natural Resources Research, v. 9, no. 2, p. 125–134. [Also available at https://doi.org/10.1023/A:1010143426576].

Turnipseed, D.P., and Sauer, V.B., 2010, Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods, book 3, chap. A8, 87 p. [Also available at https://pubs.usgs.gov/tm/tm3-a8/.]

U.S. Environmental Protection Agency, 2000a, Improved enumeration methods for the recreational water quality indicators—Enterococci and *Escherichia coli*: Washington, D.C., U.S. Environmental Protection Agency, Office of Science and Technology, EPA/821/R–97/004, 40 p. [Also available at https://nepis.epa.gov/Exe/ZyPDF.cgi/200036RZ.PDF?Dockey=200036RZ.PDF.]

U.S. Environmental Protection Agency, 2000b, Nutrient criteria technical guidance manual—Rivers and streams: Washington, D.C., U.S. Environmental Protection Agency, Office of Water, EPA–822–B–00–002, [variously paged]. [Also available at https://nepis.epa.gov/Exe/ZyPDF.cgi/20003CVP.PDF?Dockey=20003CVP.PDF.]

U.S. Environmental Protection Agency, 2001a, Method 1602—Male-specific (F^+) and somatic coliphage in water by single agar layer (SAL) procedure: Washington, D.C., U.S. Environmental Protection Agency, Office of Water, EPA 821–R–01–029, 30 p. [Also available at https://nepis.epa.gov/Exe/ZyPDF.cgi/P1002D21.PDF?Dockey=P1002D21.PDF.]

U.S. Environmental Protection Agency, 2001b, National primary drinking water regulations; arsenic and clarifications to compliance and new source contaminants monitoring; final rule: Federal Register, v. 66, no. 14, p. 6976–7066. [Also available at https://www.gpo.gov/fdsys/pkg/FR-2001-01-22/pdf/01-1668.pdf].

U.S. Environmental Protection Agency, 2005, Occurrence assessment for the final stage 2 disinfectants and disinfection byproducts rule: Washington, D.C., U.S. Environmental Protection Agency, Office of Water, EPA 815–R–05–011, [variously paged]. [Also available at https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1005ED2.txt.]

U.S. Environmental Protection Agency, 2006a, Method 1103.1—*Escherichia coli* (*E. coli*) in water by membrane filtration using membrane-thermotolerant *Escherichia coli* agar (mTEC): Washington, D.C., U.S. Environmental Protection Agency, Office of Water, EPA–821–R–06–010, 45 p. [Also available at https://nepis.epa.gov/Exe/ZyPDF.cgi/P1002D92.PDF?Dockey=P1002D92.PDF.]

U.S. Environmental Protection Agency, 2006b, Method 1603—*Escherichia coli* (*E. coli*) in water by membrane filtration using modified membrane-thermotolerant *Escherichia coli* agar (modified mTEC): Washington, D.C., U.S. Environmental Protection Agency, Office of Water, EPA–821–R–06–011, 42 p. [Also available at https://nepis.epa.gov/Exe/ZyPDF.cgi/P1002DAB.PDF?Dockey=P1002DAB.PDF.]

U.S. Environmental Protection Agency, 2006c, Wadeable streams assessment—A collaborative survey of the Nation's streams: Washington, D.C., U.S. Environmental Protection Agency, EPA–841–B–06–002, [variously paged]. [Also available at https://www.epa.gov/sites/production/files/2014-10/documents/2007_5_16_streamsurvey_wsa_assessment_may2007.pdf.]

U.S. Environmental Protection Agency, 2009, National primary drinking water regulations: U.S. Environmental Protection Agency, EPA 816–F–09–004, 7 p. [Also available at https://epa.gov/sites/production/files/2016-06/documents/npwdr_complete_table.pdf.]

U.S. Environmental Protection Agency, 2013, National primary drinking water regulations—Revisions to the total coliform rule; final rule: Federal Register, v. 78, no. 30, p. 10270–10365. [Also available at https://www.gpo.gov/fdsys/pkg/FR-2013-02-13/pdf/2012-31205.pdf.]

U.S. Environmental Protection Agency and Environmental Monitoring and Support Laboratory, 1980, Prescribed procedures for measurement of radioactivity in drinking water: U.S. Environmental Protection Agency, EPA–600/4–80–032, 133 p. [Also available at https://nepis.epa.gov/Exe/ZyPDF.cgi/30000QHM.PDF?Dockey=30000QHM.PDF.]

U.S. Geological Survey, 2006, Collection of water samples (ver. 2.0): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A4, 231 p. [Also available at https://pubs.water.usgs.gov/twri9A4/.]

U.S. Geological Survey, 2017, USGS water data for the Nation: U.S. Geological Survey National Water Information System database, accessed August 2017, at https://doi.org/10.5066/F7P55KJN.

Wagner, R.J., Boulger, R.W., Jr., Oblinger, C.J., and Smith, B.A., 2006, Guidelines and standard procedures for continuous water-quality monitors—Station operation, record computation, and data reporting: U.S. Geological Survey Techniques and Methods, book 1, chap. D3, 96 p. [Also available at https://pubs.usgs.gov/tm/2006/tm1D3/.]

Walton, G., 1951, Survey of literature relating to infant methemoglobinemia due to nitrate-contaminated water: American Journal of Public Health and the Nation's Health, v. 41, no. 8, pt. 1, p. 986–996. [Also available at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1525621/.]

Ward, M.H., deKok, T.M., Levallois, P., Brender, J., Gulis, G., Nolan, B.T., and VanDerslice, J., 2005, Workgroup report—Drinking-water nitrate and health—Recent findings and research needs: Environmental Health Perspectives, v. 113, no. 11, p. 1607–1614. [Also available at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1310926/.]

Warren, D.R., Blain, G.T., Shoney, F.L., and Klein, L.J., 1995, IRP—A case study from Kansas: Journal of the American Water Works Association, v. 87, no. 6, p. 57–71. [Also available at https://doi.org/10.1002/j.1551-8833.1995.tb06379.x.]

Welch, A.H., Westjohn, D.B., Helsel, D.R., and Wanty, R.B., 2000, Arsenic in ground water of the United States—Occurrence and geochemistry: Groundwater, v. 38, no. 4, p. 568–604. [Also available at https://doi.org/10.1111/j.1745-6584.2000.tb00251.x.]

Whisnant, J.A., Hansen, C.V., and Eslick, P.J., 2015, Groundwater-level and storage-volume changes in the *Equus* Beds aquifer near Wichita, Kansas, predevelopment through January 2015: U.S. Geological Survey Scientific Investigations Report 2015–5121, 27 p. [Also available at https://doi.org/10.3133/sir20155121.]

Whittemore, D.O., 2007, Fate and identification of oil-brine contamination in different hydrogeologic settings: Applied Geochemistry, v. 22, no. 10, p. 2099–2114. [Also available at https://doi.org/10.1016/j.apgeochem.2007.04.002.]

Williams, C.C., and Lohman, S.W., 1949, Geology and ground-water resources of a part of south-central Kansas, with special reference to the Wichita municipal water supply: Kansas Geological Survey, Bulletin No. 79, 455 p.

Xie, Y., 2003, Disinfection byproducts in drinking water: formation, analysis, and control: Florida, CRC Press., 176 p.

Zar, J.H., 1999, Biostatistical analysis (4th ed.): New Jersey, Prentice-Hall Inc., 663 p.

Ziegler, A.C., Christensen, V.G., and Ross, H.C., 1999, Baseline water-quality and preliminary effects of artificial recharge on groundwater, south-central Kansas, 1995–98: U.S. Geological Survey Water-Resources Investigations Report 99–4250, 74 p.

Ziegler, A.C., and Combs, L.J., 1997, Baseline data-collection and quality control protocols and procedures for the *Equus* Beds groundwater recharge demonstration project near Wichita, Kansas, 1995–96: U.S. Geological Survey Open-File Report 97–235, 57 p. [Also available at https://doi.org/10.3133/ofr97235.]

Ziegler, A.C., Hansen, C.V., and Finn, D.A., 2010, Water quality in the *Equus* Beds aquifer and the Little Arkansas River before implementation of large-scale artificial recharge, south-central Kansas, 1995–2005: U.S. Geological Survey Scientific Investigations Report 2010–5023, 143 p. [Also available at https://pubs.usgs.gov/sir/2010/5023/.]

Ziegler, A.C., Ross, H.C., Trombley, T.J., and Christensen, V.G., 2001, Effects of artificial recharge on water quality in the *Equus* Beds aquifer, south-central, Kansas, 1995–2000: U.S. Geological Survey Fact Sheet 096–01, 4 p. [Also available at https://pubs.er.usgs.gov/publication/fs09601.]

Appendix 1

Appendix 1 tables are available for download as a Microsoft Excel® file at https://doi.org/10.3133/sir20195026.

Table 1.1. Data collection sites for the *Equus* Beds ASR project.

Table 1.2. Summary statistics for continuously (hourly) measured physicochemical properties for the Little Arkansas River at Highway 50 near Halstead, Kansas (Hwy 50 site; station identifier 07143672), and near Sedgwick, Kansas (Sedgwick site; station identifier 07144100), during 2001 through 2016.

Table 1.3. Summary statistics for continuously (hourly) measured turbidity data measured with different sensors at the Little Arkansas River near Sedgwick, Kansas (Sedgwick; station identifier 01744100), September 2014 through March 2015.

Table 1.4. Relative percentage differences for replicate, and detection percentages for blank discrete water-quality samples for the Little Arkansas River and *Equus* Beds aquifer sites near Sedgwick, Kansas, 2001–16.

Table 1.5. Discrete sample water-quality constituent summary statistics for the Little Arkansas River sites near Sedgwick, Kansas, 2001–16.

Table 1.6. Discrete sample physicochemical groundwater-quality constituent summary statistics for the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16.

Table 1.7. Solids and primary ions summary statistics of discrete groundwater samples for the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16.

Table 1.8. Nutrient and carbon species summary statistics of discrete groundwater samples for the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16.

Table 1.9. Bacterial and viral indicator summary statistics of discrete groundwater samples for the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16.

Table 1.10. Trace element summary statistics of discrete groundwater samples for the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16.

Table 1.11. Dissolved arsenic species summary statistics of discrete groundwater samples for the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16.

Table 1.12. Organic compound summary statistics of discrete groundwater samples for the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16.

Table 1.13. Radioactivity summary statistics of discrete groundwater samples for the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16.

Table 1.14. Mineral saturation indices for the *Equus* Beds aquifer near Sedgwick, Kansas, 2001–16.

For more information about this publication, contact:
Director, USGS Kansas Water Science Center
1217 Biltmore Drive
Lawrence, KS 66049
785–842–9909

For additional information, visit: https://www.usgs.gov/centers/kswsc

Publishing support provided by the
Rolla Publishing Service Center

ISSN 2328-0328 (online)
https://doi.org/10.3133/sir20195026