In cooperation with the San Antonio Water System

Water-Level, Borehole Geophysical Log, and Water-Quality Data from Wells Transecting the Freshwater/Saline-Water Interface of the San Antonio Segment of the Edwards Aquifer, South-Central Texas, 1999–2007

Data Series 403

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

Front cover:

Left, San Antonio Water System drilling equipment used to drill Pitluk wells, Bexar County.

Right, Tri-County 2 well shelter and water-level monitoring equipment, Guadalupe County.

Back cover:

Left, East Uvalde 3 well shelter, Uvalde County.

Right, San Antonio Water System drilling equipment used to drill Pitluk wells, Bexar County.

All photographs by David Mahula, San Antonio Water System.

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Conversion Factors, Datums, Water-Quality Units, and Isotope Units

Inch/Pound to SI

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)
	Pressure	
bar	100	kilopascal (kPa)
	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 follows:

$$°F=(1.8\times°C)+32$$

Datums

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

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Altitude, as used in this report, refers to distance above the vertical datum.

Water-Quality Units

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

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

Isotope Units

Per mil: A unit expressing the ratio of stable-isotope abundances of an element in a sample to those of a standard material. Per mil units are equivalent to parts per thousand. Stable-isotope ratios, also known as delta values, are computed as follows (Kendall and McDonnell, 1998):

$$\delta X = \{(R_{sample} - R_{standard})/ R_{standard}\} \times 1{,}000,$$

where

δ= delta,

X = heavier stable isotope, and

R = ratio of rare (heavier) isotope to common (lighter) isotope in sample or standard.

The δ values for stable-isotope ratios discussed in this report are referenced to the following standard materials:

Element	R	Standard identity and reference
Hydrogen	Hydrogen-2/hydrogen-1	Vienna Standard Mean Ocean Water (Craig, 1961; Gonfiantini, 1984)
Oxygen	Oxygen-18/oxygen-16	Vienna Standard Mean Ocean Water (Craig, 1961; Gonfiantini, 1984)
Carbon	Carbon-13/carbon-12	Vienna Pee Dee Belemnite (Hut, 1987)

Water-Level, Borehole Geophysical Log, and Water-Quality Data from Wells Transecting the Freshwater/Saline-Water Interface of the San Antonio Segment of the Edwards Aquifer, South-Central Texas, 1999–2007

By Rebecca B. Lambert, Andrew G. Hunt, Gregory P. Stanton, and Michael B. Nyman

Abstract

As a part of a 9-year (1999–2007) study done by the U.S. Geological Survey in cooperation with the San Antonio Water System to improve understanding of the San Antonio segment of the Edwards aquifer, south-central Texas, in and near the freshwater/saline-water transition zone of the aquifer, the U.S. Geological Survey collected water-level, borehole geophysical, and water-quality data during 1999–2007 from 37 wells arranged in nine transects (except for two wells) across the freshwater/saline-water interface of the aquifer. This report presents the data collected and also describes the data-collection, analytical, and quality-assurance methods used. The wells, constructed with casing from land surface into the upper part of the aquifer and completed as open hole in the aquifer, are in Uvalde County (East Uvalde transect), in Medina County (South Medina and Devine wells), in Bexar County (Pitluk, Mission, and San Antonio transects), in Comal and Guadalupe Counties (Tri-County transect), in Comal County (New Braunfels transect), and in Hays County (Fish Hatchery, San Marcos, and Kyle transects). Data collected included continuous water level at 18 wells; fluid electrical conductivity and temperature with depth (fluid profiles) obtained by borehole geophysical logging of 15 wells; discrete (periodic) samples for major ions and trace elements at 36 wells; stable isotopes or stable isotopes and tritium at 27 wells; dissolved gases obtained by pumping (or collecting flow) of 19 wells; and continuous specific conductance and temperature at three of the wells equipped with continuous water-level sensors.

Introduction

The San Antonio segment of the Edwards aquifer (hereinafter, Edwards aquifer), is the primary source of water supply in south-central Texas and one of the most permeable and productive carbonate aquifers in the United States. The Edwards aquifer is about 180 miles long from west to east and ranges from 5 to 40 miles wide from north to south (Maclay, 1995). The Edwards aquifer consists of regionally extensive carbonate rocks of the Georgetown Formation and the Edwards Group, or their stratigraphic equivalents, that are strongly influenced by faults in the Balcones fault zone. The freshwater zone of the aquifer extends north to the northern limit of the formations, which is coincident with the northern limit of the recharge zone (outcrop) of the aquifer. To the west and east, the aquifer is bounded by ground-water divides and to the south by a zone of transition from freshwater to saline water (fig. 1). The transition zone of the aquifer is defined as the region with dissolved solids concentrations ranging from 1,000 to 10,000 milligrams per liter (Schultz, 1994). Freshwater is defined as water with dissolved solids concentrations of 1,000 milligrams per liter or less; thus the freshwater/saline-water interface is the 1,000-milligrams per liter dissolved solids concentration threshold. Slightly saline water is defined as water with dissolved solids concentrations ranging from 1,000 to 3,000 milligrams per liter; moderately saline is defined as water with dissolved solids concentrations ranging from 3,000 to 10,000 milligrams per liter; and very saline is defined as water with dissolved solids concentrations ranging from 10,000 to 35,000 milligrams per liter. On the basis of these definitions (Winslow and Kister, 1956), the transition zone primarily contains water that is slightly or moderately saline, with very saline water in a few isolated locations.

As population increases throughout the region, withdrawals from the aquifer increase, which in turn increases the potential for encroachment of saline water into the freshwater zone of the aquifer. The potential for saline-water encroachment likely is greater during periods of drought when water levels in the freshwater zone are relatively low.

In 1985, the U.S. Geological Survey (USGS), the San Antonio Water System (SAWS), and other Federal, State, and local agencies began a series of studies to learn more about the interaction between the freshwater and saline-water zones of the Edwards aquifer. The ultimate goal of the studies is to better understand the potential for movement of saline water into the freshwater zone of the aquifer. The objective of the most recent study, a 9-year (1999–2007) study done by the USGS in cooperation with SAWS, was to analyze the hydraulics of flow

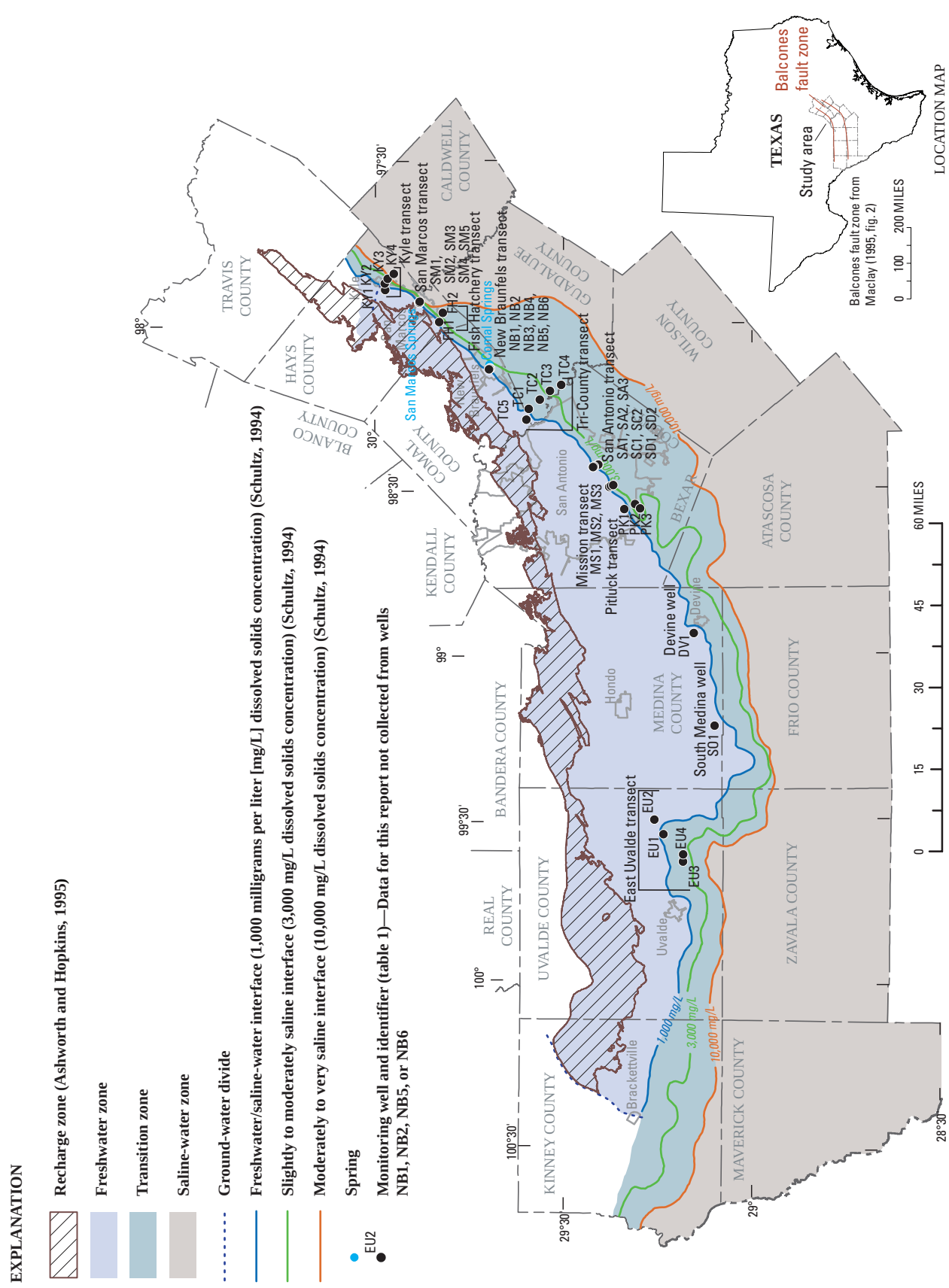

Figure 1. Location of monitoring wells and spatial extent of freshwater/saline-water transition zone of the San Antonio segment of the Edwards aquifer, south-central Texas.

in and near the transition zone using water-level and borehole geophysical log data collected during 1999–2007 and, on the basis of findings, to assess the potential for movement of saline water into the freshwater zone of the aquifer. The study included drilling of additional monitoring wells by SAWS in transects across the freshwater/saline-water interface. Monitoring wells were drilled or re-completed near the interface in Uvalde County (East Uvalde transect), in Medina County (South Medina and Devine wells), in Bexar County (Pitluk, Mission, and San Antonio transects), in Comal and Guadalupe Counties (Tri-County transect), in Comal County (New Braunfels transect), and in Hays County (Fish Hatchery, San Marcos, and Kyle transects) (fig. 1).

Purpose and Scope

This report presents the water-level, borehole geophysical log, and water-quality data collected by the USGS during 1999–2007 as a part of its most recent study of the interaction between the freshwater and saline-water zones of the Edwards aquifer. The report also describes the water-level and borehole geophysical data-collection techniques, and water-quality sampling, analytical, and quality-assurance methods. Data were collected from 37 wells arranged in nine transects (with two exceptions) across the freshwater/saline-water interface of the aquifer. Data collected included continuous water levels (hydraulic head) at 18 wells; fluid conductivity and fluid temperature with depth obtained by borehole geophysical logging the boreholes of 15 wells; discrete (periodic) samples for major ions and trace elements at 36 wells; either stable isotopes only or stable isotopes and tritium at 27 wells; dissolved gases obtained by pumping (or collecting flow) of 19 wells; and continuous specific conductance and temperature at three wells equipped with continuous water-level sensors.

Description of Monitoring Wells and Transects

The monitoring wells (table 1) were drilled during 1972–2005 by various Federal, State, and local agencies. Most of the monitoring wells were constructed with the casing extending from land surface about 20 feet into the upper part of the Edwards aquifer. The remaining vertical extent of the borehole was completed as open hole in the aquifer. Where possible, the open-hole section of each well was drilled through the entire aquifer thickness, but some wells do not penetrate the entire thickness because of depth limitations of the drilling rig.

All wells except two (South Medina and Devine wells) are arranged in nine transects across the freshwater/saline-water interface; the transects are distributed spatially from Uvalde County to Hays County (fig. 1). The East Uvalde transect comprises four wells; the Pitluk transect three wells; the Mission transect three wells; the San Antonio transect seven wells; the Tri-County transect five wells; the New Braunfels transect six wells (data collected at only two wells for this report); the Fish Hatchery transect two wells; the San Marcos transect five wells; and the Kyle transect four wells. The monitoring wells in the transects were installed by either the USGS, SAWS, Texas Water Development Board, or Edwards Aquifer Authority.

Water-Level, Borehole Geophysical, and Water-Quality Data

Water-Level Data

Continuous water-level data from 18 monitoring wells (table 1; continuous water-level data) were collected by the USGS and SAWS on various dates during February 1999–December 2007 to obtain head distribution over time along each transect and variation in head between transects. Each monitoring well was equipped with a vented submersible pressure transducer programmed to record the water level and compute the depth of water below land-surface datum (LSD) in feet. Data in most wells were recorded at 1-hour intervals. The transducers were set in the wells at depths below the lowest historical water levels so that the transducers would remain submerged under all water-level conditions. Instrument recordings at USGS-monitored sites were verified by periodic manual measurement of water levels during periodic field visits by USGS personnel. The USGS instrument-recorded values and field measurements were reviewed for accuracy, and corrections were applied if necessary. Water-level data from SAWS-monitored sites were provided to the USGS after internal review by SAWS personnel (David Mahula, San Antonio Water System, written commun., 2007). Daily mean water levels were computed as depth below LSD for each of the wells (tables 2–5). The data also are available from the USGS National Water Information System Web (NWISWeb) interface (U.S. Geological Survey, 2008a).

Borehole Geophysical Data

Measurements of vertical changes in fluid conductivity and fluid temperature were obtained by borehole geophysical logging the boreholes of 15 monitoring wells (table 1) that were accessible with the logging equipment. The wells were logged multiple times during November 2002–November 2007 over a range in hydraulic head. Two methods of fluid profile logging were used to collect the data on fluid conductivity and temperature. For the first method, a portable fluid-profile logging system from the USGS Geologic Discipline, consisting of a winch equipped with about 2,600 feet of single-conductor wireline cable coupled with a single-processor digital logging system, downhole sonde, and digital depth encoder, was used to obtain fluid profiles during 2002–03. The downhole sonde included a conductivity probe, a temperature sensor, and a self-contained pressure transducer. Conductivity and temperature of the borehole fluid were logged at about 0.15-foot

Table 1. Descriptive information for monitoring wells transecting the freshwater/saline-water interface, San Antonio segment of the Edwards aquifer, south-central Texas, from which data were collected during 1999–2007.

[LSD, land-surface datum. Well descriptor: Fresh, water with dissolved solids concentration less than 1,000 milligrams per liter; Saline, water with dissolved solids concentration greater than 1,000 milligrams per liter; Transitional, freshwater and saline water in stratified lenses. Data collected: WLc, continuous water level; FP, fluid profile; QW, periodic field properties, major ions, and trace elements; IS, periodic stable isotopes and tritium; DG, periodic dissolved gases; QWc, continuous conductivity and temperature]

U.S. Geological Survey site number	State well number	Well name	Well identifier (fig. 1)	Year drilled	Well depth (feet)	Altitude of LSD (feet above NAVD 88)	Open interval (feet below LSD)	Well descriptor based on water type	Data collected
291443099325801	YP–69–52–202	East Uvalde 1	EU1	1998	1,500	874.02	985 to 1,500	Fresh	WLc, FP, QW, IS, DG
291612099302001	YP–69–44–902	East Uvalde 2	EU2	1999	1,560	899.91	1,072 to 1,560	Fresh	WLc, FP, QW, IS, DG
291136099375801	YP–69–51–606	East Uvalde 3	EU3	1999	1,400	877.55	768 to 1,400	Saline	WLc, FP, QW, IS, QWc
291133099363801	YP–69–52–404	East Uvalde 4	EU4	1999	1,463	867.02	950 to 1,463	Saline	WLc, FP, QW, IS, DG
290639099131201	TD–69–63–103	South Medina	SO1	1993	3,406	661.18	2,626 to 3,406	Fresh	QW
290955098562101	TD–68–49–813	Devine	DV1	1972	3,200	663.20	2,570 to 3,194	Fresh	WLc, QW, IS, DG
292059098335201	AY–68–44–2	Pitluk 1	PK1	2005	1,735	645.31	1,145 to 1,735	Fresh	QW, IS
291916098330001	AY–68–44–506	Pitluk 2	PK2	2005	2,155	622.20	1,530 to 2,155	Saline	QW, IS
291830098334701	AY–68–44–505	Pitluk 3	PK3	2004	2,205	581.42	1,589 to 2,205	Saline	QW, IS
292323098294501	AY–68–37–722	Mission 1	MS1	2002	2,110	602.71	1,516 to 2,110	Saline	QW, IS
292306098293301	AY–68–37–723	Mission 2	MS2	2002	1,900	592.88	1,316 to 1,900	Fresh	QW
292244098292501	AY–68–37–724	Mission 3	MS3	2002	1,900	593.03	1,328 to 1,900	Saline	QW, IS
292505098254001	AY–68–37–521	San Antonio A1	SA1	1985	1,275	621.53	1,211 to 1,275	Saline	QW, IS, DG
292505098254002	AY–68–37–522	San Antonio A2	SA2	1985	1,075	621.53	1,014 to 1,075	Saline	WLc, QW, IS, DG
292505098254003	AY–68–37–523	San Antonio A3	SA3	1985	1,175	621.53	1,113 to 1,175	Saline	QW, IS, DG
292546098260001	AY–68–37–524	San Antonio C1	SC1	1985	881	626.21	842 to 881	Fresh	QW, IS, DG
292546098260002	AY–68–37–525	San Antonio C2	SC2	1986	1,150	625.19	1,087 to 1,150	Saline	QW, IS, DG
292556098260701	AY–68–37–526	San Antonio D1	SD1	1986	1,223	643.60	1,220 to 1,223	Fresh	WLc, QW, IS, DG
292556098260702	AY–68–37–527	San Antonio D2	SD2	1986	926	642.97	873 to 926	Fresh	QW, IS
293610098152701	KX–68–30–314	Tri-County 1	TC1	1999	920	871.01	385 to 920	Fresh	WLc, FP, QW, IS, DG, QWc

Table 1. Descriptive information for monitoring wells transecting the freshwater/saline-water interface, San Antonio segment of the Edwards aquifer, south-central Texas, from which data were collected during 1999–2007—Continued.

U.S. Geological Survey site number	State well number	Well name	Well identifier (fig. 1)	Year drilled	Well depth (feet)	Altitude of LSD (feet above NAVD 88)	Open interval (feet below LSD)	Well descriptor based on water type	Data collected
293424098134701	KX–68–31–403	Tri-County 2	TC2	1999	1,050	709.08	486 to 1,050	Transitional	WLc, FP, QW, IS, DG
293245098121001	KX–68–31–511	Tri-County 3	TC3	1999	1,222	674.00	656 to 1,222	Saline	WLc, FP, QW, IS, DG
293058098110501	KX–68–31–808	Tri-County 4	TC4	2000	1,562	648.92	1,000 to 1,562	Saline	WLc, FP, QW, IS, DG
293632098172401	DX–68–30–315	Tri-County 5	TC5	2000	975	782.22	553 to 975	Fresh	WLc, FP, QW , IS
294219098080401	DX–68–23–617	New Braunfels 617	NB3	1989	743	633.46	742 to 743	Saline	QW
294219098080402	DX–68–23–618	New Braunfels 618	NB4	1990	594	633.62	550 to 594	Saline	QW
295019097592701	LR–67–09–113	Fish Hatchery 1	FH1	2000	280	714.73	216 to 280	Fresh	WLc, FP
294946097574501	LR–67–09–401	Fish Hatchery 2	FH2	2001	1,030	642.51	510 to 1,030	Saline	WLc, FP, QW, IS, DG
295324097554101	LR–67–01–812	San Marcos 812	SM1	1990	554	581.35	493 to 554	Saline	QW
295327097555401	LR–67–01–813A	San Marcos 813A	SM2	1990	564	581.52	503 to564	Saline	QW
295327097555402	LR–67–01–814B	San Marcos 813B	SM3	1990	699	581.52	639 to 699	Saline	QW
295330097555001	LR–67–01–814A	San Marcos 814A	SM4	1992	582	577	506 to 582	Saline	QW
295330097555002	LR–67–01–814B	San Marcos 814B	SM5	1992	742	577	676 to 742	Saline	QW
295853097532901	LR–67–01–311	Kyle 1	KY1	1997	810	770.52	307 to 810	Fresh	WLc, FP, QW, IS, DG
295858097521801	LR–67–02–104	Kyle 2	KY2	1998	975	674.32	427 to 975	Transitional	WLc, FP, QW, IS, DG, QWc
295829097512601	LR–67–02–106	Kyle 3	KY3	1998	1,100	678.28	600 to 1,100	Saline	WLc, FP, QW, IS, DG
295730097503201	LR–67–02–105	Kyle 4	KY4	1998	970	646.70	562 to 970	Saline	WLc, FP, QW, IS, DG

intervals at a rate of about 10 feet per minute over the length of open hole of each monitoring well. For the second method, conventional borehole geophysical logging techniques using USGS Water Resources Discipline equipment were used to measure the fluid resistivity and the temperature with depth at 0.2-foot intervals to obtain fluid profiles during 2005–07 (Stanton and others, 2007, appendix 1). The fluid resistivity logs then were converted to fluid conductivity logs for comparison to other conductivity datasets (Keys, 1997, p. 59). The fluid conductivity and fluid temperature datasets collected using the two methods were resampled to a consistent 0.1-foot interval for comparison purposes. Fluid conductivity and fluid temperature with depth for each of the 15 wells are listed in tables 6–20. The fluid conductivity data are listed in microsiemens per centimeter at the temperature encountered in the borehole, and the fluid temperature data are listed in degrees Celsius. This conversion allows comparison of the borehole data to other datasets including water-quality monitoring data and discrete water-chemistry data, but does not imply that these measurements are high precision specific conductance measurements.

Water-Quality Data

Water-quality samples and water-quality monitoring data were collected from monitoring wells in the transition zone to characterize the chemical properties of the water and changes in the chemical properties over time. The monitoring wells were identified as fresh, transitional, or saline (table 1) on the basis of dissolved solids concentrations in samples from the wells or from borehole geophysical logging.

Water-Quality Sampling Methods and Analyses

Field properties (pH, specific conductance, water temperature) and samples for analysis of major ions and trace elements were collected from 36 wells (non-flowing and flowing) (table 1). Samples from 27 wells were analyzed for either stable isotopes or stable isotopes and tritium; samples from 19 wells were analyzed for dissolved gases. For non-flowing wells in which the casing was accessible, samples were collected at discrete depths in the uncased borehole using a 6-liter, stainless steel Kemmerer sampling flask attached to a portable cable winch fitted with a digital depth counter. The lengths of the depth intervals between points in a borehole where discrete samples were collected were based on changes with depth in conductivity obtained from the fluid profiling. Fewer samples were collected in intervals of relatively stable conductivity than in intervals in which conductivity changed appreciably. After being lowered to the selected sampling depth, the Kemmerer flask was closed by a sender weight and retrieved. For flowing wells in which the casing was accessible, a single composite sample was collected from a sampling spigot at the top of the casing after the well was purged and the field properties (pH, specific conductance, water temperature) had stabilized.

Field properties and samples were collected following procedures documented in the USGS “National Field Manual for the Collection of Water-Quality Data” (U.S. Geological Survey, variously dated). Samples for major ions; trace elements; stable isotopes (hydrogen [H], oxygen [O], carbon [C]); tritium (^3H); and dissolved gases (helium [He], neon [Ne], argon [Ar], nitrogen [N_2], methane [CH_4]) were collected by gravity feed from a drain valve in the Kemmerer sampler (or directly from the spigot for flowing wells) through 0.25-inch-diameter Tygon tubing. Dissolved gas samples were collected first to minimize atmospheric contamination; then the other samples were collected. Dissolved gas samples were collected by connecting a length of 0.375-inch-diameter copper tubing to the Tygon tubing and allowing the water sample to flow from the Kemmerer sampler through the copper tubing. Once the air bubbles were purged from the copper tubing, the copper tubing was crimped on both ends and sealed with refrigeration clamps. Care was taken to ensure that the samples were bubble-free and did not come into contact with the atmosphere. Tritium samples were collected following collection of the gas samples. Tritium samples were collected from the Tygon tubing into 500-milliliter glass bottles and sealed free of bubbles with a polyethylene cap. Samples for the remaining constituents were collected from the Tygon tubing into specified sample bottles and then shipped to the appropriate lab for analysis.

Samples for major ions and trace elements were analyzed by the USGS National Water Quality Laboratory in Denver, Colo., using analytical methods documented in Wershaw and others (1987), Fishman and Friedman (1989), Faires (1993), Fishman (1993), McLain (1993), American Public Health Association (1998), and Garbarino (1999). Results of analyses for major ions and trace elements are listed in table 21.

Samples for the stable isotopes hydrogen and oxygen were analyzed by the USGS Reston Stable Isotope Laboratory in Reston, Va.; carbon isotope samples were analyzed by the National Water Quality Laboratory; and tritium samples were analyzed by the USGS Noble Gas Laboratory in Denver, Colo. For stable isotopes, the ratio of the rare (heavier) isotope to the common (lighter) isotope is determined—for hydrogen isotopes, the ratio is $^2H/^1H$ (^2H is called deuterium [D], thus the ratio is $D/^1H$); for oxygen, the ratio is $^{18}O/^{16}O$; and for carbon, the ratio is $^{13}C/^{12}C$. The isotopic ratios are reported relative to a standard as delta values (delta deuterium [δD], delta oxygen-18 [$\delta^{18}O$], and delta carbon-13 [$\delta^{13}C$]). Delta values represent the relative difference in parts per thousand (per mil) between the sample isotope ratio and a known standard isotope ratio. The known standard ratio for hydrogen and oxygen isotopes is the Vienna Standard Mean Ocean Water (VSMOW) (Craig, 1961; Gonfiantini, 1984). For carbon isotopes, the known standard ratio is the Vienna Pee Dee Belemnite (VPDB) (Hut, 1987). Hydrogen isotope ratios were determined using the gaseous hydrogen equilibration procedure of Coplen and others (1991) and following guidance in Coplen (1988; 1994). Oxygen isotope ratios were determined using

the carbon dioxide-water equilibration procedure of Epstein and Mayeda (1953), also following guidance in Coplen (1988; 1994). Carbon isotope ratios were determined using continuous flow isotope ratio mass spectrometry after conversion of the sample into gaseous nitrogen in an elemental analyzer using the method described in Qi and others (2003).

Tritium was analyzed either by electrolytic enrichment and gas counting or by the tritium "in-growth" technique (Clark and others, 1976; Bayer and others, 1989). Tritium activities analyzed using the electrolytic enrichment and gas counting technique are expressed in picocuries per liter. Tritium activities analyzed using the in-growth technique are expressed in tritium units where 1 tritium unit equals 1 tritium atom in 10^{18} hydrogen atoms. One tritium unit is about 3.19 picocuries per liter (U.S. Geological Survey, 2006a). Results of analyses for stable isotopes and tritium are listed in table 22.

Dissolved gas samples were analyzed by the USGS Noble Gas Laboratory. Isotopic ratios of helium-3 to helium-4 ($^{3}He/^{4}He$), neon-20 to neon-22 ($^{20}Ne/^{22}Ne$), argon-40 to argon-36 ($^{40}Ar/^{36}Ar$), and nitrogen to argon (N_2/Ar) also were determined. The ratio of helium-3 to helium-4 in a sample (R) is expressed as the ratio of helium-3 to helium-4 of the sample normalized to the ratio of helium-3 to helium-4 in the atmosphere (R_A); thus the value reported is R/R_A. The dissolved gas samples were analyzed using procedures documented in Bayer and others (1989) and Solomon and others (1995). The results of the dissolved gas analyses are shown in table 23.

Quality-Assurance Samples

Quality-assurance samples included one major ion and trace element equipment blank; one major ion and trace element field blank; eight major ion and trace element replicate samples (table 21); and four stable isotope replicate samples (table 22). No tritium or dissolved gas replicate samples were analyzed. The equipment blank was collected at the San Antonio A2 well from the Kemmerer sampler to determine if, and in what concentration, the sampler contributed to the constituent concentrations. The equipment blank was analyzed for calcium, magnesium, sodium, and silica. Results of the analysis indicate detectable concentrations of all of these constituents in the equipment blank. However, the concentrations were extremely low (0.01 to 0.2 milligram per liter) relative to constituent concentrations in the environmental samples. The equipment blank also was analyzed for 20 trace elements. The analytical results showed detectable concentrations of iron, manganese, nickel, strontium, and zinc. Most of the concentrations were extremely low and close to the laboratory reporting level. However, the zinc concentration was 32.3 micrograms per liter, which is within the range of values measured in the environmental samples. The result from the equipment blank indicates that, except for zinc, the sampler did not contribute to the analytical results.

The field blank was collected from San Marcos 814B, a flowing well in Hays County, to determine if the equipment setup (tubing and clamps) used to sample flowing wells contributed to constituent concentrations. The field blank was analyzed for calcium, magnesium, potassium, sodium, bromide, chloride, fluoride, silica, sulfate, and dissolved solids (residue on evaporation). Results of the analysis indicate that only calcium was detected (estimated 0.02 milligram per liter concentration), and that the detected concentration was less than the laboratory reporting level. The field blank also was analyzed for 22 trace elements. The analytical results indicate that only nickel was detected at an extremely low concentration of 0.09 microgram per liter (table 21). The results of the field blank indicate that the tubing and clamps used to collect samples from flowing wells did not contribute to the analytical results.

For the major ion and trace element replicate samples, no concentrations of any constituents were other than negligibly different from concentrations in corresponding environmental samples. For the stable isotope replicate samples, the relative percentage difference (RPD) between the replicate and environmental sample concentrations was computed to measure the variability in concentrations associated with the analytical method. Two of the four isotope replicate samples collected were analyzed for δD, $\delta^{18}O$, and $\delta^{13}C$ (table 22). The RPDs for the two δD sample pairs were 3.1 and 13 percent; the RPDs for the two $\delta^{18}O$ sample pairs were 1.4 and 2.1 percent; and the RPDs for the two $\delta^{13}C$ sample pairs were 0.40 and 4.6 percent.

Quality-assurance information regarding analytical methods of the National Water Quality Laboratory and the Reston Stable Isotope Laboratory are available online (U.S. Geological Survey, 2008b and 2006b, respectively). For the Noble Gas Laboratory, in-house standards were used to determine percentage deviation from known values and compute laboratory error for tritium and dissolved gas analyses. The in-house standards for tritium and dissolved gas analyses were cross-calibrated with air samples collected from Loveland Pass, Colo., and compared to known dissolved gas and bulk gas compositions of U.S. Standard Atmosphere 1976 (Weast, 1983). Tritium values were calibrated using an inter-laboratory comparison between the Noble Gas Laboratory and the USGS Reston Chlorofluorocarbon Laboratory (L.N. Plummer, U.S. Geological Survey, written commun., 2004).

Continuous Water-Quality Data

Water-quality monitors were installed with water-level sensors in the East Uvalde 3, Tri-County 1, and Kyle 2 wells (table 1) to record continuous specific conductance and temperature over time at or near the freshwater/saline-water interface. These wells were chosen because fluid-profile data showed a change in conductivity with depth in the borehole of each. The monitors were installed at depths of 700 to 800 feet below land surface, within the vertical range of where the freshwater/saline-water interface generally occurs in the

boreholes. The purpose of installing the monitors at those depths was to determine whether changes in specific conductance over time occurred; and if they did, could those changes be related to changes in water level over time. Fluid profiles in the boreholes of these wells have shown that the transition from freshwater to saline water in a well can be gradational, as in the East Uvalde 3 and Tri-County 1 wells, or sharp, as in the Kyle 2 well. Each monitor recorded hourly measurements of specific conductance and temperature coincident with hourly measurements of the water level in each well. The daily mean specific conductance and temperature recorded in each of the three wells are shown in table 24.

The water-quality monitors were operated and the data were analyzed and reviewed for accuracy using a modification of the procedures described in Wagner and others (2006). The procedures in Wagner and others (2006) were developed for continuous water-quality monitors installed at shallow depths in streams and lakes. Because the water-quality monitors were installed at well depths of 700 to 800 feet and because of continuous fouling of the conductance probes (caused by hydrogen sulfide precipitating onto the probe) in the boreholes, the procedures were modified to include a cleaning correction and an instrument-drift correction applied to the raw data as described below.

In-situ measurements by the water-quality monitors were obtained and recorded on field sheets before removing the specific conductance probe from the borehole. Once out of the borehole, the probe was submerged in a potassium chloride specific conductance standard solution of 1,000 microsiemens per centimeter at 25 degrees Celsius. The specific conductance value measured while the probe was in the standard solution was recorded; then the specific conductance cell block was cleaned, the probe again submerged in the standard solution, and the specific conductance value recorded. The difference between the pre-cleaning measurement and the post-cleaning measurement was the cleaning correction applied to the data.

After the probe was cleaned, it was submerged in a fresh potassium chloride specific conductance standard solution and the value recorded. Then the probe was calibrated according to the manufacturer's instructions. A final calibrated reading was obtained. The difference between the pre-calibration measurement and the post-calibration measurement was the instrument-drift correction applied to the data.

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