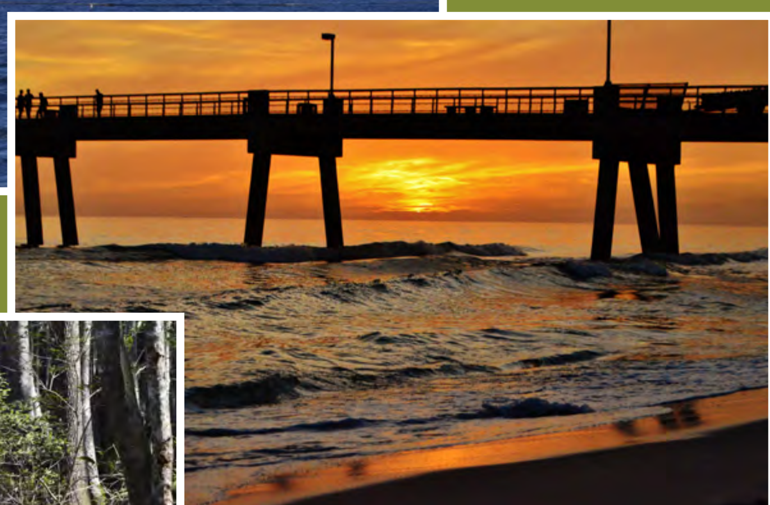
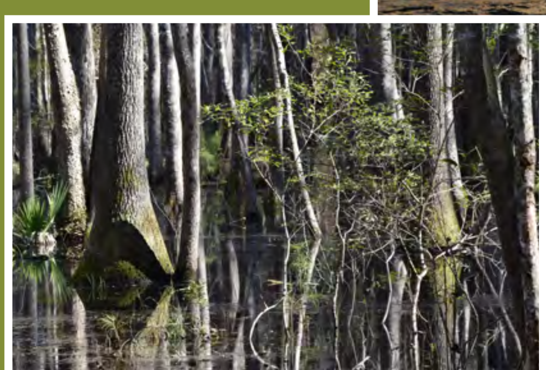
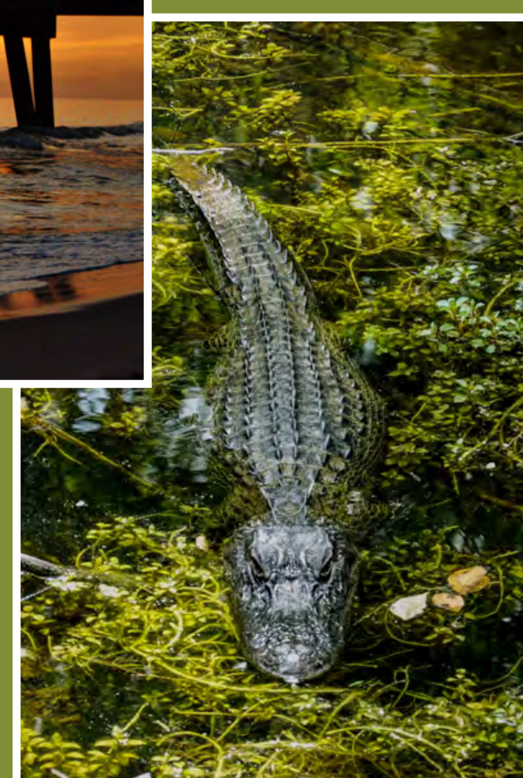
National Water-Quality Assessment (NAWQA) Program

Groundwater Age and Susceptibility of South Atlantic and Gulf Coast Principal Aquifers of the Contiguous United States



Scientific Investigations Report 2020–5050

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

Front cover:

Grey wood water mill, May 4, 2017.

Foggy offshore platform,
May 8, 2018.

Sunset dock, December 26, 2019.

Wetland mangrove, January 18, 2016.

Shallow focus photo of crocodile on body of
water, March 24, 2019.

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By John E. Solder

National Water-Quality Assessment (NAWQA) Program

Scientific Investigations Report 2020–5050

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: 2020

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic mile (mi^3)	4.168	cubic kilometer (km^3)
gallon (gal)	0.003785	cubic meter (m^3)
	Flow rate	
billion gallons per day (Bgal/d)	1.3815	billion cubic meters per year
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	1.547	cubic ft per second (ft^3/s)
million gallons per day (Mgal/d)	1.21	thousand acre-foot per year (acre-ft/yr)
million gallons per day (Mgal/day)	1.3815	million cubic meters per year
	Pressure	
atmosphere, standard (atm)	101.3	kilopascal (kPa)

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

°F = (1.8 × °C) + 32.

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

°C = (°F – 32) / 1.8.

Datum

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

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

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

Land surface altitudes were derived from 3DEP based on site coordinates (https://viewer.nationalmap.gov/apps/bulk_pqs/).

Supplemental Information

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

Concentrations of the noble gases, helium (He), neon (Ne), argon (Ar), krypton (Kr), and xenon (Xe), are reported in units of cubic centimeters (at standard temperature and pressure) per gram of water (cc(STP)/g). One cc(STP) of He, Ne, Ar, Kr, or Xe is equal to 2.6868×10^{19} atoms.

Tritium (^{3}H) concentrations are given in units of tritium units (TU). The conversion of TU to picocuries per liter, based on a tritium half-life of 12.32 years (Lucas and Unterweger, 2000), is 1 TU=3.22 picocuries per liter.

Sulfur hexafluoride (SF_6) concentrations are given in units of parts per trillion by volume (pptv).

Carbon-14 (^{14}C) concentrations are given in units of percent modern carbon (pmC). The conversion of percent modern carbon to picocuries per gram carbon is 1 pmC equals 0.061 pCi/g.

Helium isotopic ratios are reported as R/Ra values where R is the ratio of ^{3}He to ^{4}He in the sample, Ra is the ^{3}He to ^{4}He ratio of the reference standard air (1.384×10^{-6}).

Stable isotopes of carbon are reported as δ values computed from the formula equation

$$\delta = \left[\frac{R_x}{R_{std}} - \right] 1,000$$

where

R_x	is the ratio of ^{13}C to ^{12}C in the sample,
R_{std}	is the ^{13}C to ^{12}C ratio of the reference standard Vienna Pee Dee Belemnite, and
$\delta^{13}C$	is expressed in parts per thousand (‰).

Abbreviations

Ar	argon
BDL	below detection limit
BMM	binary mixture model
^{14}C	carbon-14
χ^2	chi-squared
CLOW	Coastal Lowlands
CDF	cumulative distribution fraction
$\delta^{13}C$	delta carbon-13
DM	dispersion model
DIC	dissolved inorganic carbon
EPM	exponential-piston flow model
ft bls	feet below land surface
He	helium
R	helium isotopic ratio of the sample
R_a	helium isotopic ratio of air
Kr	krypton
LPM	lumped parameter model
METX	Mississippi embayment and Texas coastal uplands
NAVD 88	North American Vertical Datum
NOSAMS	National Ocean Sciences Accelerator Mass Spectrometry Facility
Ne	neon
N_2	nitrogen gas
NGT	noble gas temperature
pmC	percent modern carbon
pptv	parts per trillion by volume
PFM	piston-flow model
$^4He_{rad}$	radiogenic helium-4
SECP	Southeastern Coastal Plain
SF_6	sulfur hexafluoride
SI	susceptibility index
$^4He_{terr}$	terrigenic helium-4
TU	tritium unit
$^3He_{trit}$	tritiogenic helium-3
^3H	tritium
Xe	xenon

Groundwater Age and Susceptibility of South Atlantic and Gulf Coast Principal Aquifers of the Contiguous United States

By John E. Solder

Abstract

Groundwater susceptibility to contamination was investigated by using environmental tracer-based groundwater age metrics in the south Atlantic and Gulf Coast principal aquifer systems of the Southeastern Coastal Plain, Mississippi embayment–Texas coastal uplands, and the Coastal Lowlands. Samples of dissolved gas, tritium, sulfur hexafluoride, tritiogenic helium, and carbon-14 were collected from 231 public supply wells in the 3 principal aquifer systems. Dissolved gas models were used to characterize recharge conditions and they identified recharge mechanisms that ranged from rapid, but short-lived, water table rises (possibly associated with large scale flooding), to slower diffuse recharge not associated with large water table fluctuations. Dissolved gas and geochemical correction models were used to calculate and (or) correct tracer concentrations before input to lumped parameter models of groundwater age. Lumped parameter models that were fit to tracer concentrations indicated groundwater was relatively old across the aquifer systems, with an estimated mean age of about 30,000 years. Estimates of groundwater age were related to hydrogeology, with increasing groundwater ages associated with greater depth, confinement, and distance from the recharge zone. Young groundwater with mean ages less than 2,000 years generally was in unconfined parts of the aquifer system, except for local areas of heavy groundwater extraction from unconfined aquifer units where estimated mean ages were up to 15,000 years. Lumped parameter model optimized age distributions describe the relative contribution of differing flow paths to the mean age, and a composite distribution of all samples from the three aquifer systems indicated that about 15 percent of the total sampled water had an age of less than 100 years. Various metrics of susceptibility, to land surface and geogenic contamination sources, derived from the age distributions, indicated geogenic sources as the primary threat to groundwater quality in the aquifer systems. Values of the susceptibility index (unitless) and fraction of recharge since 2,000 and 15,000 years before present are provided for assessment of individual well susceptibility. The data and interpretation methods presented here provide an additional means of investigating the susceptibility and sustainability of groundwater resources of the Southeastern Coastal Plain, Mississippi embayment–Texas coastal uplands, and the Coastal Lowlands aquifer systems.

Introduction

The three principal aquifer systems of the south Atlantic and Gulf Coasts of the continental United States—the Southeastern Coastal Plain (SECP), Mississippi embayment–Texas coastal uplands (METX), and the Coastal Lowlands (CLOW)—cover 12 states and encompass the major metropolitan centers of New Orleans, Memphis, Houston, and Corpus Christi. Combined, the SECP, METX, and CLOW provide 2.06 billion gallons per day (Bgal/day) for public supply and 1.7 Bgal/day for irrigation (Maupin and Barber, 2005), which accounts for approximately 32 percent and 9 percent, respectively, of the groundwater withdrawals for public supply and irrigation in the region (Dieter and others, 2018). Groundwater depletion, where groundwater withdrawals outpace recharge rates, and water quality are serious concerns. Total groundwater volumes in the CLOW and Mississippi embayment part of the METX were estimated to have declined approximately 20 and 44 cubic miles (mi^3), respectively, between 1900 and 2008 (Konikow, 2013). For reference, assuming a daily domestic water use of 100 gallons per person, the combined withdrawal of 64 mi^3 is enough to provide drinking, bathing, and cooking water for the U.S. population of 330 million people for more than 5 years. The long-term protection of the availability and quality of groundwater resources in the south Atlantic and Gulf Coast principal aquifer systems is of critical importance to the region and nation.

Groundwater age is defined as the time elapsed from recharge, once the groundwater is isolated from the atmosphere by moving below the water table, to the point that the groundwater is collected. Tracer-based estimates of groundwater age assume conservative tracer behavior, except for radioactive decay. The distribution of groundwater age describes the relative contribution of age from individual flow paths and provides additional information about the potential for contamination from the land surface and groundwater availability. Groundwater age and the age distribution are fundamental metrics integrating multiple physical processes (for example, recharge rates, porosity, mixing, and aquifer geometry) of a groundwater flow system. One method of estimating groundwater age distributions is by inverse modeling of environmental tracers with lumped parameter models (LPMs; Maloszewski and Zuber, 1982; Zuber, 1986; Maloszewski and Zuber, 1996). Lumped parameter models are fit to multiple tracer concentrations from a single groundwater sample to assess the validity of a piston-flow model or constrain more complex age distributions that account for mixing and dispersion processes. The selection of an appropriate LPM requires the evaluation of the hydrogeology and physical dimensions of the flow system.

Groundwater susceptibility is the likelihood of a contaminant reaching a specific position, such as a well, in the groundwater flow system. Groundwater in the south Atlantic and Gulf Coast aquifer systems is susceptible to contamination from land-surface sources but also geogenic sources such as high metals or total dissolved solids concentrations (see for example, Manheim and Paull, 1982; Szabo and others, 2012; Chakraborty and others, 2017). Although the presence of a contamination source and the subsurface processes that affect the concentration and transport determine whether groundwater quality is impaired, the intrinsic likelihood of contamination is related to the age distribution. Young groundwater (10s to a few 100s of years) will be more susceptible to land-surface contamination that infiltrates into the groundwater system. Old groundwater (1,000s to 10,000s of years), with longer residence times and subsequent contact time with the substrate, could be more susceptible to geogenic sources of contamination. In most cases, groundwater age alone is inadequate to fully evaluate the intrinsic susceptibility of groundwater. Often water-supply sources, such as large wells and springs, are a mixture of flow paths of differing ages. The mean age of all the flow paths does not capture the relative contribution of various flow paths that could be susceptible to contamination. The averaging of all the ages can possibly make a groundwater source appear more (or less) susceptible than it is, indicating the full distribution of ages is a better metric for evaluating intrinsic susceptibility.

A benefit and challenge associated with using age distributions in assessing groundwater susceptibility is that the age distribution is inherently data rich. Age distributions provide detailed information about the structure of groundwater age in a sample and allow for a robust characterization of the groundwater age and intrinsic susceptibility. The challenge of using age distributions to characterize groundwater age is reduction of the full distribution for quantitative comparison and assessment is difficult. For the case of young water where susceptibility is largely from land surface contamination, the susceptibility index (SI; Solder and others, 2020) provides a measure of the relative deviation of the estimated groundwater age distribution from a hypothetical highly susceptible age distribution (see the “Susceptibility Index” section). Formulation of the susceptibility index is in part possible because there is definable upper limit of susceptibility associated with a completely young groundwater age distribution. The deviation from a completely young groundwater age distribution then makes sense as a measure of susceptibility. For old water susceptible to geogenic sources, the age distribution can be used to derive the relative fraction of groundwater greater than a given age. For example, 75 percent of the sampled water had a mean age of greater than 1,000 years. If an appropriate age metric can be established, above which geogenic contamination is more possible or even likely, then susceptibility to geogenic sources can be extracted from the age distribution. Establishing an appropriate metric for geogenic contamination will depend on presence and reaction rates of a contaminant (dictating the dissolved contaminant flux to groundwater) and will be aquifer system specific.

Purpose and Scope

The purpose of this report is to present LPM interpretations of environmental tracer concentrations and various metrics to assess the susceptibility to contamination of three large regional aquifer systems. Estimates of mean groundwater age, groundwater age distribution, and susceptibility to land surface and geogenic contamination for 231 public supply groundwater wells are presented. A total of 253 samples were collected from 3 networks of wells from 2013 to 2015 as part of the U.S. Geological Survey National Water-Quality Assessment (NAWQA) Project (Arnold and others, 2016, 2017). These samples were used for this analysis. A combination of tracers for modern water recharged after 1950 (tritium, ^{3}H; sulfur hexafluoride, SF_6; tritiogenic helium-3, $^{3}He_{trit}$) and premodern water recharged 1,000 years before sample collection (carbon-14; ^{14}C) were used to determine age distributions. This report builds on previous investigations using environmental tracers for determination of age distributions and the susceptibility of groundwater (Kingsbury and others, 2017; Stackelberg and others, 2018; Solder and others, 2020) and expands the application of methods to the south Atlantic and Gulf Coast principal aquifer systems.

Study Area and Sample Network Description

The three principal aquifer systems described in this report are the SECP, CLOW, and METX. In total, the aquifer systems cover approximately 4.17x10^5 square miles (mi^2) in parts of 12 states (South Carolina, Georgia, Alabama, Florida, Mississippi, Louisiana, Texas, Arkansas, Tennessee, Kentucky, Missouri, and Illinois) along the south Atlantic and Gulf Coasts and extending northward along the Mississippi River (fig. 1). Long-term average precipitation across the region ranges from less than 20 inches per year in the southwestern parts of Texas to greater than 70 inches per year along the Louisiana, Mississippi, and Alabama Coasts (Wieczorek and LaMotte, 2010). The three principal aquifer study (PAS) well networks consist of 253 high-production public-supply wells, and the age interpretations for 231 wells (79 SECP; 92 METX; 60 CLOW) are presented here. Useful tracer concentrations were not available at all wells. Public-supply wells were selected for sampling on an equal-area grid basis (Belitz and others, 2010) to provide representative information about groundwater quality and identify water-quality issues. Most of the well dimensions are reported here as depth below land surface, providing context for the likelihood of land-surface and deeper natural contamination, and the altitude of the well bottom for comparison between wells and the hydrogeology. Well depths ranged from 80 to about 4,300 feet below land surface (ft bls) with a median depth of about 610 ft bls. Lengths of the screened interval ranged from 10 to 1,000 feet (ft) with a median interval length of 70 ft. The top of screened interval depth ranged from 60 to about 2,800 ft bls with a median top of screened interval depth of about 560 ft bls (fig. 2; table 1). Well-bottom altitudes ranged from about 420 ft above to about 4,010 ft below the North American Vertical Datum (NAVD 88) with a median well-bottom altitude of about 300 ft below the NAVD 88 (table 1). Of the total volume of groundwater extracted from the aquifer systems in 2000 (4.56 Bgal per day), the primary use was public supply (2.06 Bgal per day), followed by irrigation (1.7 Bgal per day; Maupin and Barber, 2005). Land use overlying the southeastern principal aquifer systems is dominantly rural—31 percent agricultural and 55 percent undeveloped—with the remaining 14 percent a mixture of urban, grasslands, and water or wetlands (Kingsbury and others, 2014; Barlow and Belitz, 2016; Barlow and others, 2016).

Southeast Coastal Plain (SECP)

The SECP principal aquifer system covers an approximate area of 1.2x10^5 mi^2 in eight states (South Carolina, Georgia, Alabama, Florida, Mississippi, Tennessee, Kentucky, and Illinois) extending from the southern North Carolina border to the Florida panhandle and from the Atlantic Coast to the eastern margin of the Mississippi embayment (fig. 1). Although the aquifer units extend offshore along the eastern seaboard, no groundwater wells are located beyond the shoreline. Total groundwater withdrawals from the SECP aquifer system in 2000 were 860 million gallons per day (Mgal/d) with approximately 340 Mgal/d used for public supply in that year (Maupin and Arnold, 2010). The primary land use overlying the Southeast Coastal Plains aquifer system is agriculture (19 percent) and urban (7 percent) with the remaining land classified as undeveloped (74 percent; Barlow and others, 2016). Groundwater samples in the SECP were collected from 79 spatially distributed pubic-supply wells (45 wells in the Chattahoochee River aquifer and 34 wells in the Black Warrior River aquifer; see respective "Hydrogeology" sections of this report). Well depths ranged from 140 to about 3,800 ft bls with a median depth of about 670 ft bls. Lengths of the screened interval ranged from 10 to 1,000 ft with a median interval length of about 90 ft. The top of screened interval depths ranged from 100 to about 2,800 ft bls with a median top of screened interval depth of about 490 ft bls. Well-bottom altitudes ranged from about 380 ft above to about 3,800 ft below the NAVD 88 with a median well-bottom altitude of about 320 ft below the NAVD 88.

Mississippi Embayment–Texas Coastal Uplands (METX)

The METX principal aquifer system covers an approximate area of 1.97x10^5 mi^2 in nine states (Alabama, Mississippi, Louisiana, Texas, Arkansas, Tennessee, Kentucky, Missouri, and Illinois) extending from the southern tip of Illinois in the north to southern Texas and east to Alabama (fig. 1). Previous regional aquifer analyses had defined the Mississippi embayment and Texas coastal uplands aquifer systems as separate (Ryder, 1996; Grubb, 1998; Renken, 1998). Equivalent aquifer units are easily mapped between the two aquifer systems; for the purpose of this study, the two aquifer systems are combined. Although the aquifer system extends offshore, no groundwater wells are located beyond the shoreline. Total groundwater withdrawals in 2000 were 1.33 Bgal per day from the Mississippi embayment–Texas coastal uplands aquifer systems (946 and 381 Mgal per day, respectively) with approximately 724 Mgal per day of the total being used for public supply in that year (Maupin and Arnold, 2010). Of significance to groundwater movement and water quality in the METX, groundwater withdrawals from the overlying Mississippi River Valley alluvial aquifer totaled about 9.3 Bgal per day in 2000 with most withdrawn groundwater being used for irrigation (9.15 Bgal per day; Maupin and Arnold, 2010). The primary land use overlying the METX aquifer system is agriculture (41 percent), followed by undeveloped forested lands (37 percent) with the remaining land classified as grasslands, urban, or water and wetlands (22 percent; Kingsbury and others, 2014).

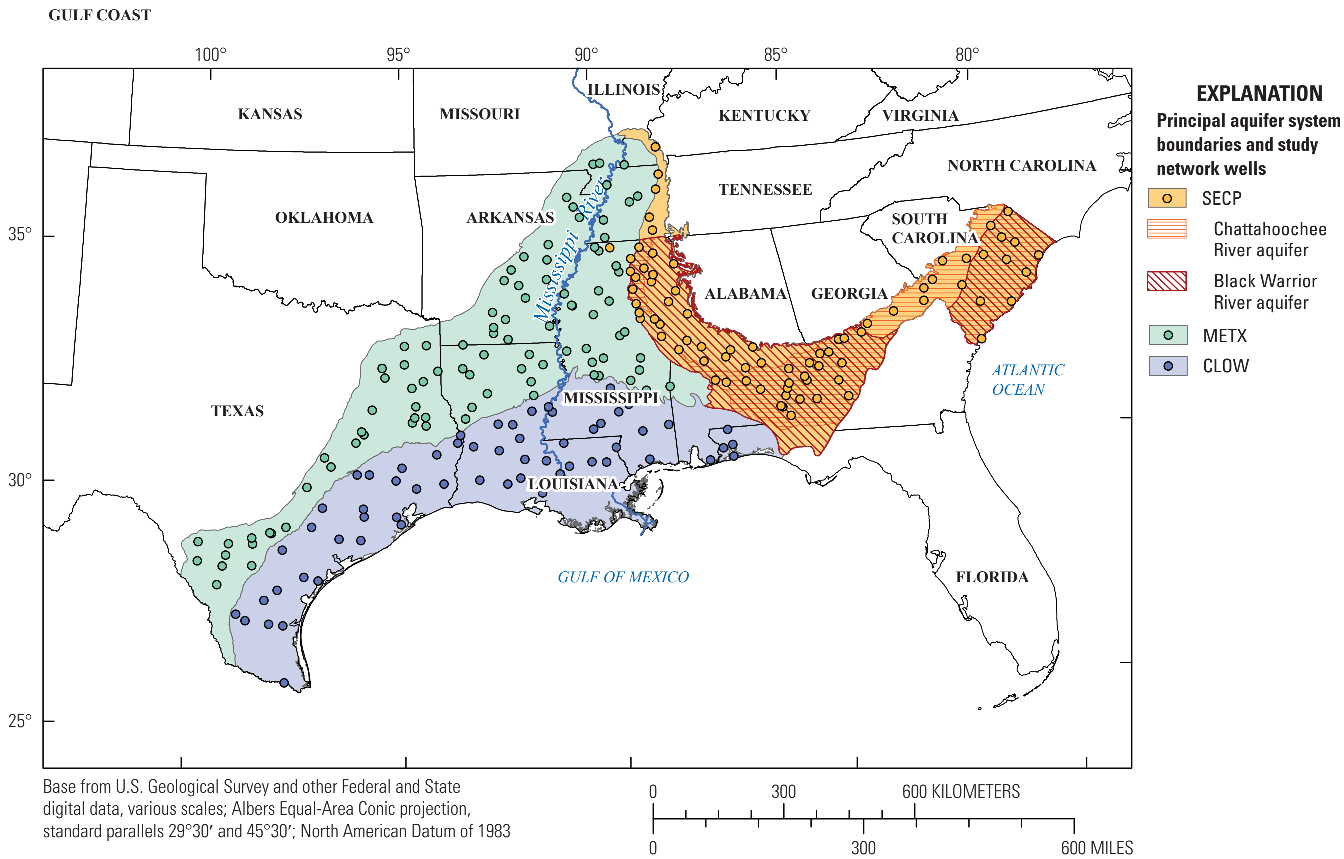

Figure 1. The Southeast Coastal Plain (SECP), Mississippi embayment–Texas coastal uplands (METX), and the Coastal Lowlands (CLOW) principal aquifer system boundaries and principal aquifer study network wells in the south Atlantic and Gulf Coast aquifer systems, USA.

Groundwater samples in the METX were collected from 92 spatially distributed pubic-supply wells with depths ranging from 80 to about 4,300 ft bls and a median depth of about 600 ft bls. Lengths of the screened interval ranged from 20 to about 120 ft with a median interval length of 60 ft. The top of screened interval depths ranged from 60 to 1300 ft bls with a median top of screened interval depth of about 400 ft. Well-bottom altitudes ranged from about 340 ft above to about 4,000 ft below the NAVD 88 with a median well-bottom altitude of about 280 ft below the NAVD 88.

Coastal Lowlands (CLOW)

The CLOW principal aquifer system covers an approximate area of 1x10^5 mi^2 in five states (Florida, Alabama, Mississippi, Louisiana, and Texas) extending from the Florida panhandle to south Texas along the Gulf Coast (fig. 1). The aquifer system extends some distance offshore, but no groundwater wells are located beyond the shoreline. Total groundwater withdrawals from the CLOW in 2000 were 2.37 Bgal per day with approximately 1 Bgal per day being used for public supply (Maupin and Arnold, 2010). The primary land use overlying the CLOW aquifer system is agriculture (24 percent) and urban (9 percent) with the remaining land classified as undeveloped (67 percent; Barlow and Belitz, 2016). Groundwater samples in the CLOW were collected from 60 spatially distributed pubic-supply wells with depths ranging from 115 to about 2,540 ft bls and a median depth of about 540 ft bls. Lengths of the screened interval ranged from about 20 to about 670 ft with a median interval length of 64 ft. The top of screened interval depths ranged from 115 to about 2,400 ft bls with a median top of screened interval depth of about 540 ft bls. Well-bottom altitudes ranged from about 410 ft above to about 2,500 ft below the NAVD 88 with a median well-bottom altitude of about 390 ft below the NAVD.

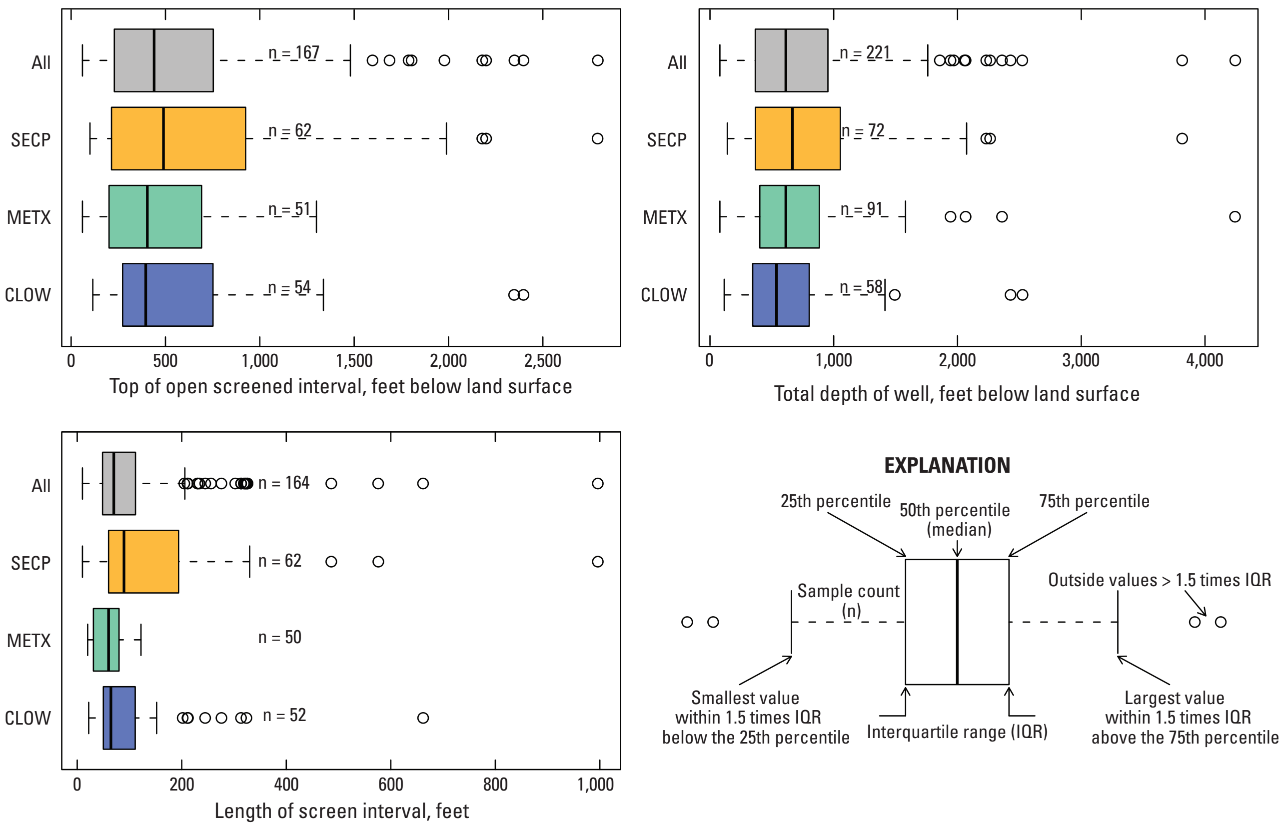

Figure 2. Well dimensions from principal aquifer study well networks in the south Atlantic and Gulf Coast aquifer systems, USA. Data from principal aquifer study well networks are indicated by color (Southeastern Coastal Plain; SECP, yellow; Coastal Lowlands; CLOW, purple; Mississippi embayment—Texas coastal uplands; METX, green). Data count (n) of principal aquifer study wells indicated.

Approach

The approaches for investigation in this study included the estimation of recharge conditions, calculation of tracer concentrations, optimization of lumped parameter models (LPMs) of groundwater age, and calculation of age-distribution metrics regarding aquifer susceptibility to contamination. Interpretation of dissolved noble gas and dissolved argon-nitrogen (Ar-N_2) gas concentrations were used to determine recharge conditions, such as recharge temperature and excess (or entrapped) air, and to calculate concentrations of excess nitrogen gas (N_2), $^3He_{trit}$, and SF_6. The ancillary gas tracers (not used quantitatively in age determinations) of radiogenic helium-4 ($^4He_{rad}$) and the helium isotopic ratio (R/R_a) also were determined from dissolved gas concentrations to help guide age interpretations. Final adjusted ^{14}C concentrations were calculated by geochemical and isotopic correction of measured ^{14}C accounting for non-atmospheric sources of dissolved inorganic carbon (DIC). Measured and calculated groundwater age tracer concentrations were input to LPMs of groundwater age. The LPM optimization of age distributions for each sample was guided by tracer concentrations, well dimensions, and conceptual hydrogeology. Modeled age distributions were used to calculate various summary metrics and composited to provide an overview of groundwater age and susceptibility across the three principal aquifer systems of the south Atlantic and Gulf Coasts.

Table 1. Summary of well dimensions and select noble gas model results, environmental tracer concentrations, and lumped parameter model results for principal aquifer study well networks in the south Atlantic and Gulf Coast aquifer systems, USA.

[USGS, U.S. Geological Survey; ID, identification; mm/dd/yyyy, month, day, year; ft, feet; bls, below land surface; NAVD 88, North American Vertical Datum of 1988; NGT, noble gas temperature; °C, degrees Celsius; R/Ra, isotopic ratio of helium-3 to helium-4 of the sample (R) relative to air (R_a); $^4He_{rad}$, radiogenic helium-4; ccSTP/g, cubic centimeters per gram at standard temperature and pressure (25 °C, 1 atmosphere); ^3H, tritium; TU, tritium units; $^3He_{trit}$, tritiogenic helium-3; SECP, Southeast Coastal Plain; —, not applicable; BDL, below detection limit; Not quant., not quantifiable; <, less than; METX, Mississippi embayment–Texas coastal uplands; CLOW, Coastal Lowlands; *, data in error; SF_6, sulfur hexafluoride; pptv, parts per trillion by volume; ^{14}C, carbon-14; pmC, percent modern carbon; $\delta^{13}C$, delta carbon-13; permil, parts per thousand; LPM, lumped parameter model; LPM χ^2, chi-square of LPM fit ; SI, susceptibility index; F post-2,000, fraction of recharge less than 2,000 years old; F post-15,000, fraction of recharge less than 15,000 years old; >, more than; DM, dispersion model; EPM, exponential-piston flow model; BMM, binary mixing model; PEM, partial exponential mixing model]

USGS station ID	Sample network	Sample date (mm/dd/yyyy)	Top of screen interval (ft bls)	Bottom of screen interval (ft bls)	Altitude of well bottom (ft above NAVD 88)	Well total depth (ft bls)	Screen length (ft)	NGT (°C)	R/R_a	$^4He_{rad}$ (ccSTP/g)	Reported ^3H (TU)	Reported $^3He_{trit}$ (TU)
310630085355601	SECP	07/18/2013	—	—	–522	810	—	12.6	—	—	—	—
311805085462401	SECP	07/17/2013	724	1,030	–715	1,045	306	7.8	0.15	8.47E-07	BDL	Not quant.
311928085494201	SECP	08/05/2013	565	753	–392	753	188	10.0	0.23	2.00E-07	BDL	Not quant.
312235084095301	SECP	09/23/2013	100	180	–803	973	80	11.5	0.04	1.97E-06	0.34	<1
312332084555101	SECP	09/25/2013	681	854	–544	854	173	12.4	0.04	1.60E-06	BDL	<1
312534085203401	SECP	07/16/2013	370	420	–31	420	50	13.0	0.58	1.68E-08	BDL	<1
313139085402101	SECP	07/15/2013	—	—	–338	830	—	8.2	0.10	5.20E-07	—	Not quant.
314038085365401	SECP	08/26/2013	538	650	–80	650	112	10.8	0.22	1.79E-07	BDL	Not quant.
314249086153501	SECP	07/25/2013	497	567	–225	567	70	8.3	0.08	1.32E-06	BDL	Not quant.
314315084205901	SECP	09/18/2013	475	620	–308	620	145	19.3	0.17	1.75E-07	BDL	<1
314647085333501	SECP	08/19/2013	—	—	258	299	—	13.8	0.88	1.36E-09	BDL	<1
314733085071401	SECP	09/25/2013	1,422	1,560	–1,340	1,560	138	14.0	0.01	9.40E-06	0.25	<1
315244085100401	SECP	08/28/2013	1,256	1,582	–1,391	1,602	326	10.0	0.02	5.21E-06	BDL	<1
315444086352901	SECP	09/05/2013	—	—	—	—	—	—	—	5.06E-07	—	—
315522087045901	SECP	08/20/2013	—	—	–307	682	—	8.4	0.18	4.80E-06	BDL	Not quant.
315820087202001	SECP	08/07/2013	—	—	–248	390	—	9.7	0.20	5.84E-06	BDL	Not quant.
320310084474201	SECP	09/19/2013	118	153	375	156	35	20.6	1.38	0	3.27	7.91
320348084132701	SECP	09/24/2013	260	590	–172	590	330	8.7	0.13	3.71E-07	0.21	Not quant.
320431085315301	SECP	07/22/2013	—	—	—	—	—	6.3	0.07	7.95E-07	—	Not quant.
320848080454301	SECP	07/10/2013	2,802	3,802	–3,824	3,832	1,000	20.1	—	—	BDL	—
320859085003701	SECP	09/18/2013	818	968	–713	1,025	150	11.9	0.02	5.96E-06	0.35	<1
321100086344501	SECP	07/24/2013	—	—	–820	1,061	—	13.5	0.12	6.14E-06	BDL	Not quant.
321505086104601	SECP	08/21/2013	—	—	—	—	—	12.6	0.28	1.20E-07	BDL	<1
321838084435101	SECP	09/19/2013	—	—	—	—	—	14.1	0.81	4.07E-10	BDL	<1
321914084304301	SECP	09/24/2013	250	361	285	366	111	16.6	—	—	1.05	—
322405087342601	SECP	08/12/2013	—	—	–1,331	1,550	—	10.6	0.04	1.85E-06	BDL	Not quant.

Table 1. Summary of well dimensions and select noble gas model results, environmental tracer concentrations, and lumped parameter model results for principal aquifer study well networks in the south Atlantic and Gulf Coast aquifer systems, USA.—Continued

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USGS station ID	Sample network	Sample date (mm/dd/yyyy)	Top of screen interval (ft bls)	Bottom of screen interval (ft bls)	Altitude of well bottom (ft above NAVD 88)	Well total depth (ft bls)	Screen length (ft)	NGT (°C)	R/R_a	$^4He_{rad}$ (ccSTP/g)	Reported ^3H (TU)	Reported $^3He_{trit}$ (TU)
322643087020001	SECP	07/30/2013	840	1,420	–1,235	1,420	580	7.5	0.02	4.75E-06	BDL	<1
323255084141801	SECP	09/17/2013	140	300	286	305	160	19.7	2.10	0	4.64	23.79
323316084140501	SECP	09/17/2013	195	260	376	260	65	17.4	1.36	0	4.30	8.41
323336084050601	SECP	09/17/2013	110	435	–4	435	325	19.3	0.85	8.94E-09	0.36	1.05
323500086542101	SECP	07/23/2013	—	—	—	—	—	15.5	0.80	7.53E-09	—	<1
323528086205801	SECP	07/08/2013	126	158	124	158	32	13.4	0.09	6.29E-07	BDL	Not quant.
323842083393201	SECP	09/16/2013	270	440	–24	464	170	18.6	1.99	0	3.42	21.69
324046088095101	SECP	08/13/2013	1,816	1,876	–1,685	1,876	60	7.7	0.06	9.85E-06	BDL	Not quant.
324159087362001	SECP	09/04/2013	—	—	—	—	—	14.4	0.84	4.32E-09	BDL	<1
324816083290901	SECP	09/16/2013	228	238	274	238	10	16.9	2.35	0	6.60	28.56
324829079533000	SECP	07/09/2013	1,800	1,986	–1,973	1,986	186	19.8	0.03	1.33E-05	BDL	Not quant.
325116087570601	SECP	07/10/2013	—	—	–492	645	—	9.4	0.05	4.57E-06	BDL	Not quant.
325447080383601	SECP	07/11/2013	1,698	1,760	–1,676	1,760	62	16.7	—	—	BDL	—
325846088340801	SECP	07/09/2013	1,480	1,540	–1,324	1,540	60	8.8	0.06	2.30E-05	BDL	Not quant.
325858082480101	SECP	09/12/2013	450	767	–327	772	317	17.6	0.26	9.04E-08	BDL	<1
330638082013601	SECP	08/14/2013	440	930	–641	940	490	—	—	—	BDL	—
331358088350001	SECP	07/10/2013	1,135	1,186	–914	1,186	51	9.4	0.04	5.04E-06	BDL	Not quant.
331822081020809	SECP	08/07/2013	762	1,000	–848	1,010	238	—	—	—	BDL	—
332036079244009	SECP	07/17/2013	560	795	–792	800	235	14.7	—	—	BDL	—
332056088420901	SECP	08/29/2013	1,302	1,368	–1,022	1,368	66	15.4	0.04	4.30E-06	BDL	Not quant.
332141081583601	SECP	08/27/2013	170	246	–120	254	76	—	—	—	7.21	—
332240089033401	SECP	08/28/2013	2,210	2,280	–1,816	2,280	70	13.7	0.06	3.06E-05	BDL	Not quant.
332357087524301	SECP	08/15/2013	160	190	314	190	30	15.6	1.24	0	1.87	5.89
332958089041701	SECP	08/28/2013	2,190	2,250	–1,648	2,250	60	9.4	0.06	2.34E-05	BDL	Not quant.
333036081442108	SECP	08/13/2013	214	423	22	485	209	—	—	—	15.24	—
333618089074301	SECP	07/11/2013	1,989	2,074	–1,546	2,074	85	9.2	0.06	1.84E-05	BDL	Not quant.

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USGS station ID	Sample network	Sample date (mm/dd/yyyy)	Top of screen interval (ft bls)	Bottom of screen interval (ft bls)	Altitude of well bottom (ft above NAVD 88)	Well total depth (ft bls)	Screen length (ft)	NGT (°C)	R/R_a	$^4He_{rad}$ (ccSTP/g)	Reported ^3H (TU)	Reported $^3He_{trit}$ (TU)
333850079014308	SECP	07/16/2013	387	710	–696	715	323	15.4	0.04	9.44E-06	BDL	Not quant.
334021079501308	SECP	08/15/2013	750	944	–897	953	194	14.8	—	—	BDL	—
334100088193001	SECP	08/29/2013	283	323	15	323	40	13.6	—	—	—	—
334947080492101	SECP	08/22/2013	118	140	–20	140	22	—	—	—	0.47	—
335103080230801	SECP	08/06/2013	489	723	–560	738	234	—	—	—	BDL	—
335128081250001	SECP	08/20/2013	129	169	334	179	40	—	—	—	16.42	—
335323088074301	SECP	08/14/2013	—	—	152	283	—	13.7	1.59	9.75E-10	3.32	15.88
335930089113701	SECP	07/22/2013	1,800	1,960	–1,462	1,960	160	9.5	0.08	1.61E-05	BDL	Not quant.
335934079332800	SECP	08/28/2013	210	300	–216	300	90	11.2	0.08	1.13E-06	BDL	Not quant.
340658088425101	SECP	07/23/2013	400	460	–197	460	60	8.6	0.06	6.14E-06	BDL	Not quant.
340823079514509	SECP	06/24/2013	380	710	–586	720	330	—	—	—	BDL	—
341359089062201	SECP	07/23/2013	1,303	1,383	–892	1,383	80	8.8	0.07	1.15E-05	BDL	Not quant.
341519088393901	SECP	07/23/2013	343	423	–116	423	80	7.0	0.07	4.85E-06	BDL	Not quant.
342111089124401	SECP	07/22/2013	545	625	–151	625	80	8.5	0.05	6.15E-06	BDL	Not quant.
342409088520901	SECP	07/24/2013	832	921	–465	921	89	5.5	0.06	1.00E-05	BDL	Not quant.
342455080045509	SECP	06/26/2013	195	312	–50	317	117	—	—	—	2.45	—
342640088065901	SECP	07/11/2013	—	—	—	—	—	—	—	—	2.34	—
343706089111601	SECP	07/24/2013	492	552	–135	552	60	5.8	—	—	—	—
343817079353709	SECP	06/25/2013	102	362	–165	367	260	14.3	—	—	2.66	—
345002088374401	SECP	07/25/2013	597	637	–119	637	40	6.8	0.07	4.10E-06	BDL	Not quant.
345021088572201	SECP	07/25/2013	925	1,025	–534	1,025	100	6.0	0.07	3.77E-06	BDL	Not quant.
345216089400201	SECP	07/24/2013	1,609	1,689	–1,292	1,689	80	13.3	0.06	4.09E-06	BDL	Not quant.
351004088351501	SECP	06/27/2013	490	560	–128	566	70	—	—	—	—	—
352613088381501	SECP	07/02/2013	175	275	143	275	100	—	—	—	BDL	—
360010088252901	SECP	06/26/2013	214	274	135	277	60	—	—	—	BDL	—
361802088194201	SECP	06/25/2013	375	425	74	425	50	—	—	—	BDL	—

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365200088210001	SECP	09/18/2013	—	—	174	202	—	—	—	—	BDL	—
280232099210601	METX	07/29/2015	—	—	–188	750	—	16.6	0.06	8.39E-07	BDL	<1
282605099141101	METX	07/27/2015	—	—	–1,925	2,376	—	19.8	0.08	1.25E-06	BDL	Not quant.
282733098325701	METX	07/29/2015	—	—	–4,009	4,261	—	—	—	—	—	—
283136099492501	METX	07/28/2015	—	—	50	530	—	—	—	2.28E-07	BDL	Not quant.
283942099101201	METX	08/10/2015	—	—	–1,544	2,082	—	15.6	0.10	5.81E-07	BDL	Not quant.
285358099063501	METX	08/12/2015	—	—	–950	1,572	—	18.0	0.38	8.24E-08	BDL	2.08
285435098324101	METX	08/11/2015	—	—	–1,499	1,960	—	14.7	0.45	5.36E-08	BDL	<1
285513099492801	METX	07/28/2015	—	—	37	695	—	20.8	0.63	3.90E-08	BDL	4.76
290205098335601	METX	08/11/2015	—	—	–610	1,064	—	21.6	0.64	2.13E-08	BDL	<1
290754098062601	METX	08/31/2015	—	—	–817	1,306	—	17.7	0.09	1.02E-06	BDL	Not quant.
290847098083801	METX	08/13/2015	—	—	–764	1,220	—	16.7	0.14	4.95E-07	BDL	Not quant.
291607097460201	METX	09/01/2015	—	—	–1,182	1,580	—	18.2	0.59	2.53E-08	BDL	<1
300603097170301	METX	09/03/2015	—	—	7	515	—	11.8	0.31	9.28E-08	BDL	<1
303137096425101	METX	09/02/2015	—	—	–883	1,314	—	14.8	0.10	3.80E-07	BDL	<1
304246096521201	METX	08/27/2015	—	—	–236	800	—	18.8	0.28	1.44E-07	BDL	Not quant.
310132096065501	METX	08/26/2015	—	—	–882	1,250	—	12.2	0.09	7.22E-07	BDL	Not quant.
311148095552001	METX	08/25/2015	—	—	–666	1,054	—	10.2	0.22	1.64E-07	BDL	<1
311512095584601	METX	08/24/2015	—	—	–713	1,033	—	13.3	0.07	6.44E-07	BDL	<1
312152094251001	METX	07/13/2015	—	—	–803	1,080	—	14.2	0.06	2.30E-05	BDL	Not quant.
312551094444901	METX	07/15/2015	—	—	–790	1,072	—	12.7	0.07	2.08E-06	BDL	Not quant.
312933093273601	METX	07/22/2014	115	145	221	145	30	17.8	—	—	1.32	—
313209094413801	METX	07/14/2015	—	—	–335	696	—	11.1	0.14	1.58E-07	BDL	<1
313221094253701	METX	07/14/2015	—	—	–208	630	—	11.1	—	—	BDL	—
314211095432701	METX	08/06/2015	—	—	–291	653	—	17.9	0.05	1.37E-06	—	Not quant.
314348094421401	METX	07/16/2015	—	—	—	—	—	15.6	0.94	3.68E-09	BDL	Not quant.

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314548094395401	METX	08/05/2015	—	—	–116	565	—	9.8	0.23	4.57E-07	BDL	Not quant.
315350089015601	METX	05/13/2014	495	541	–94	541	46	12.7	—	—	BDL	—
315540091470901	METX	06/18/2014	—	—	–15	80	—	20.8	—	—	0.52	—
315621088271901	METX	08/26/2014	322	382	–13	382	60	—	—	—	BDL	—
320009092543601	METX	07/29/2014	80	110	41	110	30	17.2	—	—	1.29	—
320736089235901	METX	07/15/2014	886	946	–544	946	60	13.0	—	—	BDL	—
320830094451201	METX	07/20/2015	—	—	–186	697	—	10.2	0.18	2.14E-07	BDL	<1
321245091495501	METX	07/21/2014	60	90	–41	110	30	16.9	—	—	1.56	—
321538090094201	METX	04/24/2014	749	829	–564	829	80	14.9	—	—	BDL	—
321648090170001	METX	06/30/2014	1,055	1,120	–745	1,120	65	10.3	0.30	1.71E-07	1.07	Not quant.
321648094281401	METX	08/03/2015	—	—	–292	560	—	14.8	0.02	7.37E-06	—	Not quant.
321908089095801	METX	05/15/2014	255	305	110	305	50	16.4	—	—	BDL	—
322137095243601	METX	08/04/2015	—	—	–291	825	—	13.0	0.12	3.78E-07	BDL	<1
322414093194001	METX	06/17/2014	240	270	–76	270	30	14.8	—	—	BDL	—
322918092031901	METX	06/19/2014	300	340	–274	340	40	13.3	—	—	BDL	—
322921094063901	METX	07/21/2015	—	—	84	156	—	12.2	0.22	2.96E-06	BDL	Not quant.
323133093293801	METX	07/30/2014	496	527	–285	527	31	7.4	—	—	BDL	—
323308090180901	METX	05/12/2014	1,245	1,325	–1,069	1,325	80	10.0	—	—	BDL	—
323308091310801	METX	07/23/2014	362	437	–355	443	75	14.8	—	—	BDL	—
323342095284201	METX	08/04/2015	—	—	–299	880	—	11.4	0.19	2.13E-07	BDL	Not quant.
323409089071601	METX	05/14/2014	160	252	222	252	92	11.5	—	—	BDL	—
323719090020201	METX	05/12/2014	935	995	–767	995	60	12.1	—	—	BDL	—
323750094554600	METX	07/22/2015	—	—	–140	510	—	14.3	0.06	5.88E-06	BDL	Not quant.
324627091505401	METX	07/24/2014	89	109	19	109	20	16.2	—	—	1.40	—
324806090553601	METX	07/02/2014	700	800	–697	800	100	—	—	—	0.28	—
324817092575701	METX	06/16/2014	525	555	–263	555	30	—	—	—	BDL	—

Table 1. Summary of well dimensions and select noble gas model results, environmental tracer concentrations, and lumped parameter model results for principal aquifer study well networks in the south Atlantic and Gulf Coast aquifer systems, USA.—Continued

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USGS station ID	Sample network	Sample date (mm/dd/yyyy)	Top of screen interval (ft bls)	Bottom of screen interval (ft bls)	Altitude of well bottom (ft above NAVD 88)	Well total depth (ft bls)	Screen length (ft)	NGT (°C)	R/R_a	$^4He_{rad}$ (ccSTP/g)	Reported ^3H (TU)	Reported $^3He_{trit}$ (TU)
324959090255901	METX	06/30/2014	910	990	–885	990	80	8.0	—	—	BDL	—
330024094551801	METX	07/23/2015	—	—	–55	423	—	11.8	0.11	5.32E-06	BDL	Not quant.
330107093283801	METX	07/28/2014	384	491	–189	491	107	8.7	—	—	—	—
330107094223201	METX	07/22/2015	—	—	–333	740	—	14.7	0.09	1.54E-05	BDL	Not quant.
330332089354101	METX	07/01/2014	345	450	–10	450	105	13.7	—	—	BDL	—
330607092212101	METX	08/12/2014	250	290	–156	290	40	12.7	—	—	—	—
330730089280001	METX	07/01/2014	174	204	234	204	30	13.4	—	—	1.28	—
331358092424301	METX	07/11/2014	493	615	–409	615	122	—	—	—	BDL	—
332030091185401	METX	07/28/2014	—	—	–204	330	—	11.7	—	—	—	—
332113092421001	METX	07/08/2014	430	470	–360	470	40	—	—	—	—	—
333040092240301	METX	07/08/2014	560	610	–407	613	50	—	—	—	—	—
333136090124801	METX	08/12/2014	710	780	–649	780	70	11.8	—	—	BDL	—
333944092430401	METX	07/08/2014	174	221	–87	221	47	—	—	—	BDL	—
334348090432401	METX	06/04/2014	683	744	–605	744	61	12.3	—	—	BDL	—
334420090444001	METX	06/04/2014	705	785	–649	785	80	10.5	—	—	—	—
334607089473801	METX	06/11/2014	135	175	21	175	40	11.2	—	—	BDL	—
335608091525601	METX	07/29/2014	—	—	–590	887	—	9.9	—	—	—	—
335853090543701	METX	06/04/2014	755	814	–661	814	59	11.0	—	—	3.19	—
340031090030201	METX	07/16/2014	489	529	–326	529	40	—	—	—	—	—
341147092022301	METX	07/22/2014	783	863	–626	863	80	9.6	—	—	—	—
341734091200601	METX	08/19/2014	—	—	–578	768	—	8.8	—	—	—	—
341845092235901	METX	08/07/2014	509	569	–310	569	60	13.1	—	—	0.94	—
342155089305401	METX	06/05/2014	71	96	340	96	25	16.1	—	—	2.38	—
342921089341201	METX	06/11/2014	317	337	17	337	20	8.9	—	—	BDL	—
343118092123701	METX	08/13/2014	215	—	–10	255	—	13.6	—	—	—	—
344145091175601	METX	08/21/2014	510	590	–418	590	80	10.0	—	—	BDL	—

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USGS station ID	Sample network	Sample date (mm/dd/yyyy)	Top of screen interval (ft bls)	Bottom of screen interval (ft bls)	Altitude of well bottom (ft above NAVD 88)	Well total depth (ft bls)	Screen length (ft)	NGT (°C)	R/R_a	$^4He_{rad}$ (ccSTP/g)	Reported ^3H (TU)	Reported $^3He_{trit}$ (TU)
344651091524301	METX	08/14/2014	—	—	–204	437	—	14.3	—	—	—	—
344927089583901	METX	06/03/2014	301	371	–13	371	70	14.0	—	—	1.28	—
345352090044301	METX	06/03/2014	404	424	–95	424	20	13.8	—	—	0.20	—
350026091145401	METX	08/20/2014	187	257	–65	257	70	13.8	—	—	0.21	—
350503089482201	METX	06/02/2014	516	616	–249	622	100	14.3	—	—	—	—
352658089483201	METX	06/17/2014	495	565	–136	565	70	15.5	—	—	—	—
353153090252201	METX	07/30/2014	1,205	1,285	–1,072	1,289	80	11.0	—	—	—	—
354437090335701	METX	08/04/2014	97	127	–258	485	30	—	—	—	—	—
354703089070701	METX	06/09/2014	168	213	140	213	45	—	—	—	—	—
355305088534801	METX	06/10/2014	355	445	1	450	90	12.5	—	—	—	—
355707090430401	METX	08/05/2014	97	127	229	129	30	11.9	—	—	—	—
360923089400601	METX	06/03/2014	1,300	1,390	–1,126	1,390	90	6.1	—	—	—	—
363300089110002	METX	06/04/2014	—	—	–283	672	—	12.3	—	—	—	—
363605089585501	METX	06/02/2014	—	—	–568	860	—	9.4	—	—	—	—
363642089485501	METX	06/02/2014	—	—	–179	460	—	10.9	—	—	—	—
260204097443701	CLOW	09/09/2013	—	—	—	—	—	26.3	0.96	1.45E-09	BDL	Not quant.
271315097473201	CLOW	09/10/2013	—	—	–767	802	—	26.4	0.08	7.92E-07	BDL	Not quant.
271505098073401	CLOW	09/19/2013	—	—	—	—	—	31.3	0.09	8.85E-07	BDL	Not quant.
271843098401101	CLOW	09/18/2013	784	1,450	–962	1,510	666	27.1	0.03	4.33E-06	BDL	Not quant.
272638098532301	CLOW	09/17/2013	320	380	417	395	60	7.8	0.28	1.42E-07	2.78	Not quant.
274439098144401	CLOW	09/16/2013	315	595	–286	610	280	16.5	0.09	7.67E-07	BDL	Not quant.
275725097562701	CLOW	09/11/2013	520	735	–542	745	215	19.2	—	—	BDL	—
280951096593801	CLOW	08/28/2013	210	350	–341	350	140	12.0	0.07	9.63E-07	BDL	Not quant.
281433097191300	CLOW	09/12/2013	180	270	–240	279	90	23.8	—	—	BDL	—
284749097503201	CLOW	08/27/2013	564	634	–209	650	70	17.2	—	—	BDL	—
290028095594700	CLOW	08/08/2013	—	—	–502	557	—	12.0	0.38	7.07E-08	BDL	<1

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USGS station ID	Sample network	Sample date (mm/dd/yyyy)	Top of screen interval (ft bls)	Bottom of screen interval (ft bls)	Altitude of well bottom (ft above NAVD 88)	Well total depth (ft bls)	Screen length (ft)	NGT (°C)	R/R_a	$^4He_{rad}$ (ccSTP/g)	Reported ^3H (TU)	Reported $^3He_{trit}$ (TU)
290209096302701	CLOW	08/29/2013	752	1,070	–1,024	1,090	318	—	—	—	BDL	—
291639097093901	CLOW	08/26/2013	262	590	–325	592	328	17.8	—	—	BDL	—
291949095024801	CLOW	09/24/2013	690	752	–736	756	62	23.6	0.03	4.38E-06	BDL	Not quant.
292923095091601	CLOW	09/24/2013	500	716	–702	730	216	15.4	0.04	1.85E-06	BDL	Not quant.
292944095550101	CLOW	08/07/2013	855	965	–867	975	110	13.5	0.14	3.59E-07	BDL	Not quant.
293938095561301	CLOW	08/06/2013	—	—	–406	518	—	16.6	0.34	9.62E-08	BDL	1.38
294040096542401	CLOW	08/14/2013	*1,069	*1,065	–775	1,104	—*	16.0	0.02	7.20E-06	BDL	<1
295446091403901	CLOW	08/14/2013	414	474	–465	476	60	19.3	0.28	3.30E-07	BDL	Not quant.
300413094402101	CLOW	08/22/2013	728	801	–730	801	73	11.4	0.19	3.83E-07	BDL	Not quant.
300719092294901	CLOW	08/13/2013	230	280	–268	280	50	17.4	0.23	1.55E-07	BDL	<1
300932094005301	CLOW	09/23/2013	284	490	–471	495	206	13.3	0.14	8.55E-07	BDL	Not quant.
301312093094101	CLOW	08/28/2013	416	516	–507	516	100	17.0	—	—	BDL	—
301407092104201	CLOW	07/31/2013	210	250	–222	250	40	17.4	0.23	1.86E-07	BDL	Not quant.
301420095093201	CLOW	08/21/2013	286	430	–314	440	144	16.8	0.82	8.11E-09	BDL	<1
301704091141201	CLOW	07/25/2013	179	250	–225	250	71	14.1	1.25	0	5.38	6.41
302120087374201	CLOW	06/12/2013	—	—	–230	248	—	18.6	1.08	0	BDL	2.31
302145095473901	CLOW	08/20/2013	703	748	–460	760	45	16.2	0.21	1.75E-07	BDL	<1
302207096050600	CLOW	08/19/2013	276	343	–153	358	67	21.2	0.02	7.27E-06	BDL	Not quant.
302329087040001	CLOW	12/11/2013	130	200	–178	200	70	20.2	—	—	BDL	—
302602091002505	CLOW	07/23/2013	822	1,071	–1,032	1,071	249	13.5	0.45	5.41E-08	BDL	<1
302825089042001	CLOW	06/12/2013	650	700	–645	700	50	14.2	—	—	BDL	—
302832090064101	CLOW	08/07/2013	2,408	—	–2,520	2,542	—	14.8	0.39	7.23E-08	BDL	<1
303000095002001	CLOW	08/21/2013	376	470	–317	490	94	13.4	—	—	BDL	—
303001090274201	CLOW	07/24/2013	2,360	2,445	–2,409	2,445	85	12.4	0.23	1.76E-07	BDL	Not quant.
303404091325402	CLOW	09/12/2013	1,117	1,178	–1,153	1,178	61	11.4	0.29	1.19E-07	0.28	Not quant.
303501087174801	CLOW	09/17/2013	195	331	–191	331	136	16.7	—	—	0.68	—

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303706092035101	CLOW	09/04/2013	375	436	–368	436	61	18.3	0.27	1.45E-07	BDL	Not quant.
303810087035701	CLOW	09/18/2013	226	338	–210	338	112	16.8	—	—	2.85	—
304603094101801	CLOW	09/03/2013	370	480	–273	475	110	11.4	0.44	5.89E-08	BDL	Not quant.
304612089512401	CLOW	08/06/2013	1,337	1,414	–1,319	1,414	77	13.8	0.37	7.41E-08	BDL	<1
304921092402202	CLOW	09/11/2013	840	910	–808	910	70	10.9	0.26	1.34E-07	BDL	Not quant.
305446093165601	CLOW	08/29/2013	115	175	37	175	60	18.9	1.61	0	1.60	14.59
305500091065201	CLOW	07/24/2013	535	585	–302	585	50	17.0	0.87	3.61E-09	BDL	<1
305708087091201	CLOW	09/18/2013	320	375	–116	375	55	13.2	—	—	BDL	—
305947093395001	CLOW	09/04/2013	990	1,050	–853	1,050	60	11.8	0.25	1.58E-07	BDL	Not quant.
310305092101202	CLOW	08/27/2013	358	399	–326	399	41	9.2	0.09	8.69E-07	BDL	Not quant.
310405089113701	CLOW	06/11/2013	800	840	–626	840	40	11.7	—	—	—	—
310929088334101	CLOW	06/12/2013	530	570	–460	570	40	13.9	—	—	BDL	—
310935093352701	CLOW	09/05/2013	115	—	97	115	—	20.4	1.26	0	1.68	5.6
311012090222901	CLOW	06/11/2013	282	322	98	322	40	16.8	—	—	—	—
311642090113601	CLOW	06/25/2013	315	345	74	345	30	17.0	—	—	BDL	—
312038092192601	CLOW	08/15/2013	769	803	–666	803	35	11.4	0.08	2.97E-06	BDL	Not quant.
312144092401801	CLOW	08/08/2013	635	670	–589	673	35	11.5	0.08	4.78E-06	BDL	Not quant.
312952089444201	CLOW	06/13/2013	377	412	50	412	35	18.0	—	—	2.44	—
313400091210001	CLOW	05/30/2013	139	161	28	161	22	18.0	—	—	—	—
313610091504501	CLOW	08/19/2013	709	763	–708	763	54	13.7	0.28	3.40E-06	BDL	Not quant.
313804089290501	CLOW	06/17/2013	926	986	–538	986	60	11.6	—	—	BDL	—
314050091260501	CLOW	08/22/2013	273	335	–272	335	62	12.1	0.13	2.79E-06	BDL	Not quant.
315920089541701	CLOW	06/19/2013	209	256	45	256	47	8.9	—	—	BDL	—

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USGS station ID	SF_6 (pptv)	Adjusted final ^{14}C (pmC)	Measured ^{14}C (pmC)	$\delta^{13}C$ (permil)	LPM	Age class	LPM χ^2	Fitted tracers	Reported mean age (years)	SI	Reported F post-2,000 years	Reported F post-15,000 years
310630085355601	0.31	0.6	0.14	–5	DM	Premodern	0	^{14}C	>50,000	0.022	<0.001	<0.001
311805085462401	0.33	0.4	0.09	–5.64	DM	Premodern	9.51E-30	^{14}C	>50,000	0.021	<0.001	<0.001
311928085494201	0.31	0.8	0.27	–7.99	DM	Premodern	1.24E-29	^{14}C	>50,000	0.023	<0.001	<0.001
312235084095301	0.31	3.1	0.28	–1.37	DM	Premodern	4.81E-30	^{14}C	44,000	0.028	<0.001	0.009
312332084555101	0.26	3.8	0.98	–5.78	DM	Premodern	3.46E-31	^{14}C	41,000	0.029	<0.001	0.01
312534085203401	0.20	0.6	0.36	–11.21	DM	Premodern	2.99E-30	^{14}C	>50,000	0.022	<0.001	<0.001
313139085402101	0.30	0.3	0.16	–10.35	DM	Premodern	0	^{14}C	>50,000	0.021	<0.001	<0.001
314038085365401	0.33	4.2	2.21	–12.49	DM	Premodern	2.80E-29	^{14}C	39,000	0.029	<0.001	0.02
314249086153501	0.18	0.5	0.25	–12.78	DM	Premodern	2.02E-29	^{14}C	>50,000	0.022	<0.001	<0.001
314315084205901	0.25	3.0	0.37	–2.15	DM	Premodern	2.25E-30	^{14}C	44,000	0.028	<0.001	0.008
314647085333501	0.43	75.8	44.93	–14.79	DM	Premodern	1.41E-29	^{14}C	2,300	0.048	0.45	1
314733085071401	0.39	0.6	0.3	–9.73	DM	Premodern	8.64E-29	^{14}C	>50,000	0.022	<0.001	<0.001
315244085100401	0.29	0.7	0.58	–14.49	DM	Premodern	1.47E-28	^{14}C	>50,000	0.023	<0.001	<0.001
315444086352901	0.22	0.9	0.29	–6.99	DM	Premodern	6.78E-29	^{14}C	>50,000	0.023	<0.001	<0.001
315522087045901	0.26	0.9	0.43	–9.69	DM	Premodern	3.77E-30	^{14}C	>50,000	0.023	<0.001	<0.001
315820087202001	0.23	0.7	0.21	–6.88	DM	Premodern	1.01E-29	^{14}C	>50,000	0.023	<0.001	<0.001
320310084474201	0.82	113.7	101.11	–22.26	DM	Modern	0.37	^3H, $^3He_{trit}$	22	0.304	1	1
320348084132701	0.22	1.3	1.3	–18.64	DM	Premodern	3.15E-30	^{14}C	>50,000	0.024	<0.001	<0.001
320431085315301	0.20	0.4	0.42	–16.37	DM	Premodern	4.75E-29	^{14}C	>50,000	0.021	<0.001	<0.001
320848080454301	—	0.3	0.1	–8.6	DM	Premodern	2.85E-28	^{14}C	>50,000	0.020	<0.001	<0.001
320859085003701	0.25	1.1	0.79	–17.41	DM	Premodern	2.06E-29	^{14}C	>50,000	0.024	<0.001	<0.001
321100086344501	0.33	0.5	0.43	–15.29	DM	Premodern	9.45E-29	^{14}C	>50,000	0.022	<0.001	<0.001
321505086104601	0.26	16.9	13.59	–14.97	DM	Premodern	1.80E-29	^{14}C	20,000	0.041	<0.001	0.34
321838084435101	0.17	69.7	54.45	–23.24	DM	Premodern	0	^{14}C	3,200	0.033	0.2	1
321914084304301	0.53	103.9	84.46	–22.21	EPM	Premodern	1.57E-27	^3H, SF_6	180	0.138	1	1
322405087342601	0.24	0.4	0.32	–19.95	DM	Premodern	3.01E-30	^{14}C	>50,000	0.021	<0.001	<0.001

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USGS station ID	SF_6 (pptv)	Adjusted final ^{14}C (pmC)	Measured ^{14}C (pmC)	$\delta^{13}C$ (permil)	LPM	Age class	LPM χ^2	Fitted tracers	Reported mean age (years)	SI	Reported F post-2,000 years	Reported F post-15,000 years
322643087020001	0.21	5.2	4.03	–19.57	DM	Premodern	9.02E-29	^{14}C	36,000	0.031	<0.001	0.03
323255084141801	0.75	114.1	96.53	–20.63	EPM	Modern	3.41E-22	^{3}H, $^{3}He_{trit}$	22	0.258	1	1
323316084140501	0.62	131.6	103.08	–19.85	DM	Modern	2.33	^{3}H, SF_6	36	0.227	1	1
323336084050601	0.34	95.9	63.67	–20.89	BMM-DM-DM	Mixed	7.94E-26	^{3}H, SF_6	650	0.093	0.99	1
323500086542101	0.41	92.7	67.47	–22.44	DM	Premodern	6.41E-28	^{14}C	630	0.173	1	1
323528086205801	0.34	68.5	59.26	–22.14	DM	Premodern	1.95E-27	^{14}C	3,300	0.032	0.17	1
323842083393201	0.43	121.7	105.28	–21.33	EPM	Modern	1.32	^{3}H, $^{3}He_{trit}$	29	0.229	1	1
324046088095101	0.28	0.4	0.29	–14.1	DM	Premodern	4.03E-31	^{14}C	>50,000	0.021	<0.001	<0.001
324159087362001	0.41	85.6	58.74	–22.34	DM	Premodern	4.41E-29	^{14}C	1,200	0.053	0.92	1
324816083290901	0.82	128.1	110.36	–22.32	EPM	Modern	0.09	^{3}H, SF_6	39	0.198	1	1
324829079533000	—	0.5	0.15	–6.73	DM	Premodern	4.52E-30	^{14}C	>50,000	0.022	<0.001	<0.001
325116087570601	0.38	0.9	0.66	–17.42	DM	Premodern	3.97E-29	^{14}C	>50,000	0.023	<0.001	<0.001
325447080383601	—	1.0	0.5	–12.46	DM	Premodern	7.72E-30	^{14}C	>50,000	0.024	<0.001	<0.001
325846088340801	0.59	0.6	0.33	–12.93	DM	Premodern	7.57E-30	^{14}C	>50,000	0.022	<0.001	<0.001
325858082480101	0.22	66.0	49.38	–19.33	DM	Premodern	1.17E-30	^{14}C	3,700	0.032	0.11	1
330638082013601	—	31.8	21.81	–17.69	DM	Premodern	5.06E-30	^{14}C	12,000	0.052	<0.001	0.78
331358088350001	0.32	0.3	0.22	–17.59	DM	Premodern	7.71E-28	^{14}C	>50,000	0.021	<0.001	<0.001
331822081020809	—	29.0	23.21	–20.69	DM	Premodern	6.07E-30	^{14}C	13,000	0.050	<0.001	0.71
332036079244009	—	1.0	0.24	–5.09	DM	Premodern	0	^{14}C	>50,000	0.024	<0.001	<0.001
332056088420901	0.41	0.8	0.65	–19.61	DM	Premodern	4.08E-30	^{14}C	>50,000	0.023	<0.001	<0.001
332141081583601	—	153.8	91.74	–22.05	DM	Modern	0.06	^{3}H, ^{14}C	44	0.211	1	1
332240089033401	0.20	0.2	0.12	–11.8	DM	Premodern	1.97E-27	^{14}C	>50,000	0.020	<0.001	<0.001
332357087524301	1.15	116.3	114.77	–21.5	DM	Modern	6.38	^{3}H, $^{3}He_{trit}$	25	0.261	1	1
332958089041701	0.23	0.2	0.12	–14.51	DM	Premodern	3.21E-29	^{14}C	>50,000	0.019	<0.001	<0.001
333036081442108	—	162.9	97.29	–21.7	DM	Modern	0.31	^{3}H, ^{14}C	47	0.182	1	1
333618089074301	0.29	0.5	0.38	–15.09	DM	Premodern	1.86E-29	^{14}C	>50,000	0.022	<0.001	<0.001

Table 1. Summary of well dimensions and select noble gas model results, environmental tracer concentrations, and lumped parameter model results for principal aquifer study well networks in the south Atlantic and Gulf Coast aquifer systems, USA.—Continued

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USGS station ID	SF_6 (pptv)	Adjusted final ^{14}C (pmC)	Measured ^{14}C (pmC)	$\delta^{13}C$ (permil)	LPM	Age class	LPM χ^2	Fitted tracers	Reported mean age (years)	SI	Reported F post-2,000 years	Reported F post-15,000 years
333850079014308	—	1.2	0.3	–5.85	DM	Premodern	1.50E-29	^{14}C	>50,000	0.024	<0.001	<0.001
334021079501308	—	1.1	0.55	–10.37	DM	Premodern	8.06E-28	^{14}C	>50,000	0.024	<0.001	<0.001
334100088193001	0.37	70.6	53.37	–19.97	DM	Premodern	4.98E-29	^{14}C	3,000	0.034	0.23	1
334947080492101	—	98.7	83.25	–21.25	EPM	Premodern	0.03	^3H, ^{14}C	170	0.178	1	1
335103080230801	—	45.6	34.35	–22.1	DM	Premodern	5.50E-30	^{14}C	7,700	0.026	<0.001	0.96
335128081250001	—	98.0	104.16	–20.29	DM	Modern	0.12	^3H, ^{14}C	47	0.177	1	1
335323088074301	0.56	113.1	110.41	–22.8	PEM	Modern	0	^3H, $^3He_{trit}$	21	0.019	1	1
335930089113701	0.32	0.3	0.25	–16.18	DM	Premodern	7.16E-28	^{14}C	>50,000	0.020	<0.001	<0.001
335934079332800	—	0.8	0.55	–17.65	DM	Premodern	5.36E-30	^{14}C	>50,000	0.023	<0.001	<0.001
340658088425101	0.34	0.2	0.19	–16.86	DM	Premodern	5.45E-31	^{14}C	>50,000	0.019	<0.001	<0.001
340823079514509	—	24.3	18.57	–19.7	DM	Premodern	2.16E-30	^{14}C	15,000	0.047	<0.001	0.58
341359089062201	0.33	0.2	0.17	–16.22	DM	Premodern	5.31E-31	^{14}C	>50,000	0.020	<0.001	<0.001
341519088393901	0.42	0.3	0.28	–16.44	DM	Premodern	2.38E-29	^{14}C	>50,000	0.020	<0.001	<0.001
342111089124401	0.67	0.5	0.12	–5.39	DM	Premodern	9.48E-29	^{14}C	>50,000	0.022	<0.001	<0.001
342409088520901	0.38	1.3	1.15	–15.92	DM	Premodern	6.52E-30	^{14}C	>50,000	0.024	<0.001	0.001
342455080045509	—	109.3	90.71	–21.56	EPM	Premodern	1.13E-28	^3H, ^{14}C	110	0.150	1	1
342640088065901	2.61	115.1	95.33	–19.06	DM	Modern	3.88E-11	^3H, SF_6	23	0.239	1	1
343706089111601	0.29	0.5	0.24	–10.55	DM	Premodern	1.28E-29	^{14}C	>50,000	0.021	<0.001	<0.001
343817079353709	—	107.1	86.6	–20.97	DM	Premodern	3.23E-10	^3H, ^{14}C	160	0.146	1	1
345002088374401	0.31	5.8	4.45	–15.21	DM	Premodern	5.93E-31	^{14}C	35,000	0.031	<0.001	0.04
345021088572201	0.31	0.2	0.18	–15.8	DM	Premodern	1.11E-29	^{14}C	>50,000	0.020	<0.001	<0.001
345216089400201	0.35	0.4	0.18	–9.66	DM	Premodern	1.02E-28	^{14}C	>50,000	0.021	<0.001	<0.001
351004088351501	—	2.7	2.03	–14.6	DM	Premodern	1.08E-29	^{14}C	46,000	0.028	<0.001	<0.001
352613088381501	—	83.7	71.4	–22.16	DM	Premodern	1.81E-29	^{14}C	1,400	0.052	0.85	1
360010088252901	—	70.0	56.64	–21.4	DM	Premodern	2.03E-28	^{14}C	3,100	0.033	0.21	1
361802088194201	—	34.6	23.74	–17.64	DM	Premodern	1.06E-30	^{14}C	11,000	0.055	<0.001	0.83

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USGS station ID	SF_6 (pptv)	Adjusted final ^{14}C (pmC)	Measured ^{14}C (pmC)	$\delta^{13}C$ (permil)	LPM	Age class	LPM χ^2	Fitted tracers	Reported mean age (years)	SI	Reported F post-2,000 years	Reported F post-15,000 years
365200088210001	0.49	90.0	72.37	–21.29	BMM-DM-DM	Mixed	1.84E-29	^3H, ^{14}C	840	0.072	0.98	1
280232099210601	0.24	3.7	1.93	–12.79	DM	Premodern	3.64E-29	^{14}C	41,000	0.029	<0.001	0.01
282605099141101	7.58	1.0	0.39	–9.09	DM	Premodern	1.35E-27	^{14}C	>50,000	0.024	<0.001	<0.001
282733098325701	—	1.0	0.48	–11.16	DM	Premodern	5.47E-30	^{14}C	>50,000	0.023	<0.001	<0.001
283136099492501	1.17	44.7	17.45	–9.37	DM	Premodern	2.55E-30	^{14}C	7,900	0.021	<0.001	0.96
283942099101201	0.26	18.7	6.75	–8.75	DM	Premodern	1.46E-29	^{14}C	18,000	0.042	<0.001	0.4
285358099063501	0.19	35.1	21.55	–10.18	DM	Premodern	6.62E-29	^{14}C	11,000	0.055	<0.001	0.84
285435098324101	0.20	40.1	13.97	–8.5	DM	Premodern	1.27E-29	^{14}C	9,100	0.020	<0.001	0.91
285513099492801	0.14	93.5	62.53	–11.2	DM	Premodern	3.88E-27	^{14}C	560	0.086	1	1
290205098335601	0.35	63.0	36.41	–14.81	DM	Premodern	3.27E-28	^{14}C	4,200	0.030	0.06	1
290754098062601	1.30	0.6	0.31	–11.87	DM	Premodern	0	^{14}C	>50,000	0.022	<0.001	<0.001
290847098083801	0.23	1.5	0.82	–10.25	DM	Premodern	8.43E-29	^{14}C	>50,000	0.025	<0.001	0.001
291607097460201	0.17	20.7	15.98	–16.02	DM	Premodern	1.20E-29	^{14}C	17,000	0.044	<0.001	0.47
300603097170301	0.25	5.2	3.22	–13.75	DM	Premodern	1.18E-29	^{14}C	36,000	0.031	<0.001	0.03
303137096425101	0.24	0.5	0.24	–13.26	DM	Premodern	5.42E-30	^{14}C	>50,000	0.022	<0.001	<0.001
304246096521201	0.26	44.8	32.43	–15.64	DM	Premodern	1.01E-29	^{14}C	7,900	0.021	<0.001	0.96
310132096065501	0.19	4.0	2.03	–12.52	DM	Premodern	1.24E-30	^{14}C	40,000	0.029	<0.001	0.02
311148095552001	0.06	10.4	6.94	–13.21	DM	Premodern	2.66E-29	^{14}C	26,000	0.036	<0.001	0.14
311512095584601	0.14	0.9	0.14	–3.06	DM	Premodern	1.16E-28	^{14}C	>50,000	0.023	<0.001	<0.001
312152094251001	0.38	0.3	0.16	–11.43	DM	Premodern	0	^{14}C	>50,000	0.021	<0.001	<0.001
312551094444901	0.42	1.5	1.51	–17.12	DM	Premodern	2.12E-30	^{14}C	>50,000	0.025	<0.001	0.002
312933093273601	0.71	101.3	102.74	–22.68	EPM	Premodern	1.39E-28	^3H, $^3He_{trit}$	140	0.203	1	1
313209094413801	0.38	11.9	7.86	–14.78	DM	Premodern	4.41E-28	^{14}C	24,000	0.037	<0.001	0.18
313221094253701	0.13	17.0	17.14	–19.2	DM	Premodern	4.41E-30	^{14}C	20,000	0.041	<0.001	0.34
314211095432701	0.21	2.4	0.33	–2.59	DM	Premodern	5.50E-29	^{14}C	48,000	0.027	<0.001	0.005
314348094421401	—	77.5	3.26	–21.04	DM	Premodern	3.50E-16	^{14}C	2,080	0.039	0.55	1

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USGS station ID	SF_6 (pptv)	Adjusted final ^{14}C (pmC)	Measured ^{14}C (pmC)	$\delta^{13}C$ (permil)	LPM	Age class	LPM χ^2	Fitted tracers	Reported mean age (years)	SI	Reported F post-2,000 years	Reported F post-15,000 years
314548094395401	0.04	3.7	1.86	–10.19	DM	Premodern	7.18E-29	^{14}C	41,000	0.029	<0.001	0.01
315350089015601	0.44	0.6	0.29	–10.74	DM	Premodern	0	^{14}C	>50,000	0.022	<0.001	<0.001
315540091470901	8.06	98.3	77.81	–14	DM	Modern	1.37E-03	^3H, $^3He_{trit}$	63	0.167	1	1
315621088271901	0.52	54.6	38.71	–17.37	DM	Premodern	2.72E-29	^{14}C	5,700	0.024	0.01	0.99
320009092543601	1.15	105.5	106.97	–22.39	EMM	Premodern	1.32	^3H, SF_6	140	0.141	1	1
320736089235901	1.27	39.5	17.82	–13.77	DM	Premodern	3.26E-30	^{14}C	9,300	0.020	<0.001	0.91
320830094451201	0.28	12.9	6.53	–12.04	DM	Premodern	7.69E-30	^{14}C	23,000	0.038	<0.001	0.21
321245091495501	8.63	106.8	88.78	–16.63	EMM	Premodern	8.10E-30	^3H	110	0.149	1	1
321538090094201	0.43	7.9	3.95	–11.88	DM	Premodern	2.06E-29	^{14}C	30,000	0.033	<0.001	0.08
321648090170001	1.98	4.3	2.17	–12.61	DM	Premodern	1.73E-29	^{14}C	39,000	0.030	<0.001	0.02
321648094281401	0.11	1.1	0.33	–6.78	DM	Premodern	4.03E-30	^{14}C	>50,000	0.024	<0.001	<0.001
321908089095801	0.52	97.1	58.2	–17.96	DM	Premodern	2.78E-27	^{14}C	260	0.169	1	1
322137095243601	5.21	2.8	2.68	–16.8	DM	Premodern	0	^{14}C	46,000	0.027	<0.001	0.007
322414093194001	0.44	77.5	60.86	–18.07	DM	Premodern	2.46E-27	^{14}C	2,100	0.041	0.54	1
322918092031901	0.26	1.1	0.37	–7.57	DM	Premodern	0	^{14}C	>50,000	0.024	<0.001	<0.001
322921094063901	0.47	14.9	14.98	–17.02	DM	Premodern	0	^{14}C	21,000	0.039	<0.001	0.27
323133093293801	0.28	4.5	3.46	–14.53	DM	Premodern	1.01E-28	^{14}C	38,000	0.030	<0.001	0.02
323308090180901	0.50	11.8	5.88	–12.63	DM	Premodern	2.32E-30	^{14}C	25,000	0.037	<0.001	0.17
323308091310801	0.41	48.9	26.08	–12.7	DM	Premodern	0	^{14}C	6,900	0.024	0.002	0.98
323342095284201	0.11	2.6	2.07	–15.48	DM	Premodern	4.68E-29	^{14}C	46,000	0.027	<0.001	0.006
323409089071601	0.69	73.8	51.41	–21.2	DM	Premodern	7.87E-27	^{14}C	2,600	0.031	0.36	1
323719090020201	0.51	45.6	28.28	–19.05	DM	Premodern	9.79E-30	^{14}C	7,700	0.022	<0.001	0.96
323750094554600	0.39	0.6	0.21	–8.75	DM	Premodern	3.90E-30	^{14}C	>50,000	0.022	<0.001	<0.001
324627091505401	5.38	103.4	86.44	–18.13	DM	Premodern	1.57E-15	^3H, $^3He_{trit}$	83	0.193	1	1
324806090553601	0.65	0.4	0.2	–9.68	DM	Premodern	7.78E-30	^{14}C	>50,000	0.021	<0.001	<0.001
324817092575701	0.00	17.2	16.69	–18.25	DM	Premodern	6.90E-29	^{14}C	19,000	0.041	<0.001	0.35

Table 1. Summary of well dimensions and select noble gas model results, environmental tracer concentrations, and lumped parameter model results for principal aquifer study well networks in the south Atlantic and Gulf Coast aquifer systems, USA.—Continued

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USGS station ID	SF_6 (pptv)	Adjusted final ^{14}C (pmC)	Measured ^{14}C (pmC)	$\delta^{13}C$ (permil)	LPM	Age class	LPM χ^2	Fitted tracers	Reported mean age (years)	SI	Reported F post-2,000 years	Reported F post-15,000 years
324959090255901	0.34	17.0	8.49	–13.5	DM	Premodern	0	^{14}C	20,000	0.041	<0.001	0.34
330024094551801	0.18	1.1	0.55	–11.09	DM	Premodern	1.04E-28	^{14}C	>50,000	0.024	<0.001	<0.001
330107093283801	—	3.4	2.41	–14.17	DM	Premodern	8.32E-29	^{14}C	42,000	0.028	<0.001	0.01
330107094223201	0.40	0.2	0.1	–10.02	DM	Premodern	3.63E-27	^{14}C	>50,000	0.020	<0.001	<0.001
330332089354101	0.54	54.7	44.66	–20.2	DM	Premodern	3.33E-28	^{14}C	5,700	0.026	0.01	0.99
330607092212101	—	0.2	0.2	–15.4	DM	Premodern	4.72E-28	^{14}C	>50,000	0.020	<0.001	<0.001
330730089280001	2.07	91.2	56.35	–21.05	BMM-DM-DM	Mixed	6.93E-29	^3H, SF_6, ^{14}C	1,500	0.095	0.62	1
331358092424301	0.39	0.5	0.34	–14.45	DM	Premodern	1.50E-30	^{14}C	>50,000	0.021	<0.001	<0.001
332030091185401	—	0.6	0.32	–10.68	DM	Premodern	1.33E-29	^{14}C	>50,000	0.022	<0.001	<0.001
332113092421001	—	0.3	0.28	–15.48	DM	Premodern	1.13E-28	^{14}C	>50,000	0.021	<0.001	<0.001
333040092240301	—	7.4	5.49	–14.44	DM	Premodern	5.30E-29	^{14}C	31,000	0.033	<0.001	0.07
333136090124801	0.35	0.7	0.38	–10.05	DM	Premodern	2.01E-29	^{14}C	>50,000	0.023	<0.001	<0.001
333944092430401	7.10	52.4	28.61	–18.62	DM	Premodern	1.85E-30	^{14}C	6,200	0.024	0.006	0.99
334348090432401	0.46	18.9	9.75	–11.6	DM	Premodern	3.59E-30	^{14}C	18,000	0.042	<0.001	0.4
334420090444001	—	21.7	11.23	–11.38	DM	Premodern	0	^{14}C	17,000	0.045	<0.001	0.5
334607089473801	0.51	25.6	16.06	–15.1	DM	Premodern	1.25E-28	^{14}C	14,000	0.048	<0.001	0.62
335608091525601	—	1.8	1.82	–17.81	DM	Premodern	1.64E-30	^{14}C	>50,000	0.025	<0.001	0.002
335853090543701	0.45	2.0	1.01	–10.73	DM	Premodern	4.61E-29	^{14}C	>50,000	0.026	<0.001	0.003
340031090030201	—	3.2	2.27	–11.43	DM	Premodern	7.22E-29	^{14}C	44,000	0.028	<0.001	0.01
341147092022301	—	22.9	19.4	–19.45	DM	Premodern	1.97E-28	^{14}C	16,000	0.046	<0.001	0.54
341734091200601	—	2.4	1.25	–13.65	DM	Premodern	1.37E-29	^{14}C	48,000	0.027	<0.001	0.005
341845092235901	1.01	106.9	74.33	–23.19	BMM-DM-DM	Mixed	0.14	^3H, SF_6, ^{14}C	120	0.194	1	1
342155089305401	1.76	109.7	112.75	–20.6	PEM	Modern	0.09	^3H, $^3He_{trit}$	17	0.019	1	1
342921089341201	1.17	11.9	7.96	–14.8	DM	Premodern	0	^{14}C	25,000	0.037	<0.001	0.18
343118092123701	—	93.0	80.6	–22.48	DM	Premodern	1.89E-28	^{14}C	600	0.074	1	1
344145091175601	0.28	1.4	0.87	–11.69	DM	Premodern	2.59E-30	^{14}C	>50,000	0.025	<0.001	0.001

Table 1. Summary of well dimensions and select noble gas model results, environmental tracer concentrations, and lumped parameter model results for principal aquifer study well networks in the south Atlantic and Gulf Coast aquifer systems, USA.—Continued

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USGS station ID	SF_6 (pptv)	Adjusted final ^{14}C (pmC)	Measured ^{14}C (pmC)	$\delta^{13}C$ (permil)	LPM	Age class	LPM χ^2	Fitted tracers	Reported mean age (years)	SI	Reported F post-2,000 years	Reported F post-15,000 years
344651091524301	—	87.2	47.98	–13.85	DM	Premodern	1.41E-27	^{14}C	1,100	0.063	0.95	1
344927089583901	0.57	91.4	83.74	–19.18	EPM	Premodern	2.10E-18	^3H, SF_6	200	0.136	1	1
341845092235901	0.51	83.3	77.47	–19.58	BMM-DM-DM	Mixed	3.82E-04	^3H, SF_6, ^{14}C	1,500	0.057	0.79	1
350026091145401	0.45	97.8	61.3	–15.8	EPM	Premodern	4.03E-03	^3H, $^3He_{trit}$	170	0.145	1	1
350503089482201	—	72.3	58.74	–21.01	DM	Premodern	3.88E-30	^{14}C	2,800	0.036	0.29	1
352658089483201	—	65.5	46.45	–19.13	DM	Premodern	7.57E-29	^{14}C	3,800	0.030	0.1	1
353153090252201	—	1.2	0.76	–13.7	DM	Premodern	3.05E-29	^{14}C	>50,000	0.024	<0.001	<0.001
354437090335701	—	0.52	0.28	–12.7	DM	Premodern	3.68E-28	^{14}C	>50,000	0.022	<0.001	<0.001
354703089070701	—	86.5	68.97	–20.63	DM	Premodern	4.31E-29	^{14}C	1,100	0.055	1	1
355305088534801	—	106.9	89.43	–21.69	DM	Modern	7.07E-30	^{14}C	64	0.156	1	1
355707090430401	—	117.4	82.04	–17.86	DM	Premodern	9.38E-29	^{14}C	64	0.164	1	1
360923089400601	—	19.3	6.22	–14.38	DM	Premodern	3.42E-30	^{14}C	18,000	0.043	<0.001	0.42
363300089110002	—	66.5	47.59	–20.1	DM	Premodern	1.49E-27	^{14}C	3,700	0.031	0.12	1
363605089585501	—	0.8	0.39	–12.81	DM	Premodern	7.63E-28	^{14}C	>50,000	0.023	<0.001	<0.001
363642089485501	—	83.8	47.61	–13.61	DM	Premodern	4.60E-29	^{14}C	1,300	0.045	1	1
260204097443701	8.58	115.2	81.63	–14.72	DM	Premodern	3.71E-29	^{14}C	1,600	0.069	0.76	1
271315097473201	3.64	1.4	0.42	–6.95	DM	Premodern	6.28E-31	^{14}C	>50,000	0.025	<0.001	0.001
271505098073401	3.19	5.3	1.68	–7.45	DM	Premodern	6.34E-30	^{14}C	36,000	0.031	<0.001	0.03
271843098401101	0.30	1.0	0.31	–7.72	DM	Premodern	1.67E-29	^{14}C	>50,000	0.023	<0.001	<0.001
272638098532301	12.47	1.5	0.51	–8.17	DM	Premodern	5.19E-30	^{14}C	>50,000	0.025	<0.001	0.001
274439098144401	7.12	1.9	0.56	–6.86	DM	Premodern	3.12E-30	^{14}C	>50,000	0.026	<0.001	0.003
275725097562701	4.44	5.0	1.59	–7.46	DM	Premodern	7.17E-30	^{14}C	37,000	0.030	<0.001	0.03
280951096593801	3.26	2.6	1.38	–10.36	DM	Premodern	2.95E-30	^{14}C	46,000	0.027	<0.001	0.006
281433097191300	1.14	0.7	0.36	–9.61	DM	Premodern	6.23E-31	^{14}C	>50,000	0.023	<0.001	<0.001
284749097503201	1.53	16.5	9.31	–11.49	DM	Premodern	1.88E-29	^{14}C	20,000	0.041	<0.001	0.33
290028095594700	0.74	1.2	0.63	–10.04	DM	Premodern	7.90E-30	^{14}C	>50,000	0.024	<0.001	<0.001

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USGS station ID	SF_6 (pptv)	Adjusted final ^{14}C (pmC)	Measured ^{14}C (pmC)	$\delta^{13}C$ (permil)	LPM	Age class	LPM χ^2	Fitted tracers	Reported mean age (years)	SI	Reported F post-2,000 years	Reported F post-15,000 years
290209096302701	—	0.7	0.37	–11.5	DM	Premodern	2.11E-29	^{14}C	>50,000	0.023	<0.001	<0.001
291639097093901	0.82	27.0	7.46	–6.39	DM	Premodern	1.76E-30	^{14}C	14,000	0.049	<0.001	0.66
291949095024801	0.36	0.2	0.12	–9.59	DM	Premodern	3.50E-31	^{14}C	>50,000	0.020	<0.001	<0.001
292923095091601	0.51	0.4	0.19	–10.67	DM	Premodern	1.43E-28	^{14}C	>50,000	0.021	<0.001	<0.001
292944095550101	—	0.7	0.34	–10.43	DM	Premodern	2.21E-27	^{14}C	>50,000	0.022	<0.001	<0.001
293938095561301	1.22	8.1	4.31	–12.67	DM	Premodern	1.95E-29	^{14}C	30,000	0.034	<0.001	0.08
294040096542401	1.08	1.0	0.57	–13.81	DM	Premodern	1.59E-27	^{14}C	>50,000	0.024	<0.001	<0.001
295446091403901	0.11	62.6	36.54	–11.78	DM	Premodern	1.16E-29	^{14}C	4,300	0.029	0.06	1
300413094402101	0.58	1.0	0.5	–12.58	DM	Premodern	5.18E-30	^{14}C	>50,000	0.024	<0.001	<0.001
300719092294901	0.05	31.4	17.6	–12.72	DM	Premodern	0	^{14}C	12,000	0.052	<0.001	0.77
300932094005301	0.26	10.1	5.62	–13.67	DM	Premodern	2.82E-29	^{14}C	27,000	0.035	<0.001	0.13
301312093094101	0.16	20.0	11.33	–13.38	DM	Premodern	1.28E-29	^{14}C	18,000	0.043	<0.001	0.44
301407092104201	0.10	92.4	36.67	–9.49	DM	Premodern	3.79E-29	^{14}C	650	0.102	1	1
301420095093201	2.39	63.8	43.12	–16.89	DM	Premodern	9.02E-29	^{14}C	4,100	0.032	0.07	1
301704091141201	574.27	112.3	97.35	–13.47	EPM	Modern	2.34	^3H, ^{14}C	62	0.023	1	1
302120087374201	0.83	97.7	78.55	–18.68	DM	Premodern	3.82	^3H, $^3He_{trit}$	86	0.161	1	1
302145095473901	—	13.7	7.85	–11.27	DM	Premodern	1.71E-30	^{14}C	23,000	0.038	<0.001	0.23
302207096050600	0.18	1.1	0.4	–8.34	DM	Premodern	8.71E-30	^{14}C	>50,000	0.024	<0.001	<0.001
302329087040001	0.19	98.0	61.32	–16.44	PEM	Premodern	1.58	^3H, SF_6	76	0.153	1	1
302602091002505	0.12	30.1	20.09	–16.57	DM	Premodern	5.63E-30	^{14}C	12,000	0.051	<0.001	0.74
302825089042001	0.20	12.2	8.99	–18.47	DM	Premodern	4.37E-29	^{14}C	24,000	0.037	<0.001	0.19
302832090064101	0.15	25.1	16.62	–16.28	DM	Premodern	2.03E-30	^{14}C	15,000	0.047	<0.001	0.61
303000095002001	1.36	0.4	0.22	–13.38	DM	Premodern	2.97E-28	^{14}C	>50,000	0.021	<0.001	<0.001
303001090274201	0.11	22.5	14.45	–15.81	DM	Premodern	2.54E-30	^{14}C	16,000	0.045	<0.001	0.52
303404091325402	0.13	16.9	10.9	–15.85	BMM-DM-DM	Mixed	2.47E-18	^3H, SF_6, ^{14}C	450	0.099	1	1
303501087174801	1.85	100.6	91.58	–20.16	PEM	Premodern	5.37	^3H, SF_6	78	0.166	1	1

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USGS station ID	SF_6 (pptv)	Adjusted final ^{14}C (pmC)	Measured ^{14}C (pmC)	$\delta^{13}C$ (permil)	LPM	Age class	LPM χ^2	Fitted tracers	Reported mean age (years)	SI	Reported F post-2,000 years	Reported F post-15,000 years
303706092035101	0.06	57.1	32.23	–10.39	DM	Premodern	7.63E-29	^{14}C	5,300	0.028	0.02	1
303810087035701	9.89	109.0	104.74	–20.76	EPM	Premodern	6.84E-26	^3H, ^{14}C	79	0.156	1	1
304603094101801	0.46	13.2	9.24	–17.45	DM	Premodern	1.83E-30	^{14}C	23,000	0.038	<0.001	0.22
304612089512401	0.14	23.5	16.13	–16.96	DM	Premodern	2.82E-29	^{14}C	15,000	0.046	<0.001	0.56
304921092402202	0.04	8.9	5.52	–15.37	DM	Premodern	1.01E-30	^{14}C	29,000	0.034	<0.001	0.1
305446093165601	0.67	110.4	100.81	–19.69	EPM	Premodern	2.84E-29	^3H, SF_6	91	0.181	1	1
305500091065201	0.45	97.0	70.28	–21.12	DM	Premodern	8.28E-18	^3H, ^{14}C	270	0.146	1	1
305708087091201	3.70	33.6	19.67	–14.6	DM	Premodern	1.80E-29	^{14}C	11,000	0.054	<0.001	0.82
305947093395001	0.33	18.3	14.36	–19.77	DM	Premodern	6.09E-29	^{14}C	19,000	0.042	<0.001	0.39
310305092101202	0.29	7.4	3.7	–12.91	DM	Premodern	3.26E-30	^{14}C	31,000	0.033	<0.001	0.07
310405089113701	0.26	13.6	8.14	–14.8	DM	Premodern	5.39E-30	^{14}C	23,000	0.038	<0.001	0.23
310929088334101	0.15	23.4	17.54	–19.13	DM	Premodern	6.00E-30	^{14}C	16,000	0.046	<0.001	0.55
310935093352701	2.07	117.0	112.05	–17.22	EPM	Modern	2.63E-03	^3H, $^3He_{trit}$, SF_6	25	0.230	1	1
311012090222901	0.62	133.7	96.02	–21.75	EPM	Modern	7.77E-30	SF_6	38	0.201	1	1
311642090113601	0.32	97.3	82.66	–21.99	PEM	Premodern	1.56E-24	^3H	67	0.164	1	1
312038092192601	0.11	4.9	4.18	–16.6	DM	Premodern	1.62E-29	^{14}C	37,000	0.030	<0.001	0.03
312144092401801	0.11	6.3	3.63	–18.46	DM	Premodern	9.53E-29	^{14}C	34,000	0.032	<0.001	0.05
312952089444201	0.18	113.1	98.77	–21.32	EPM	Premodern	2.04E-27	^3H, SF_6	87	0.144	1	1
313400091210001	0.81	130.5	92.65	–13.94	EPM	Modern	8.77E-30	SF_6	35	0.207	1	1
313610091504501	0.10	36.1	31.05	–21.93	DM	Premodern	3.12E-29	^{14}C	10,000	0.056	<0.001	0.86
313804089290501	0.23	3.8	1.87	–11.23	DM	Premodern	1.28E-29	^{14}C	41,000	0.029	<0.001	0.01
314050091260501	0.13	68.9	41.99	–15.04	DM	Premodern	6.49E-29	^{14}C	3,300	0.033	0.18	1
315920089541701	0.14	8.6	5.52	–16.13	DM	Premodern	2.13E-29	^{14}C	29,000	0.034	<0.001	0.09

Hydrogeology

The principal aquifer systems that were studied generally consisted of interbedded unconsolidated to semiconsolidated water-bearing and confining clastic units ranging in age from Pleistocene in the CLOW (Grubb, 1998) to Cretaceous in the SECP (Miller, 1990). Concurrent deposition of some units occurred across aquifer systems. The sedimentary units of the aquifer systems were deposited in fluvial, deltaic, and shallow-marine environments during periods of sea-level transgression and regression. The interbedded units, resulting from changes in depositional environment, displayed a high degree of spatial variability in lateral extent and thickness. The aquifer units generally dip toward the coast, or the synclinal axis of the Mississippi embayment, gradually thickening toward the down-dip direction. Water-bearing aquifer units are composed of fluvial and deltaic derived gravels to fine sands with a general trend from finer to coarser grained deposits moving from the coast toward the inland extent of the units. Confining units generally are composed of silt and clay, except for thick sequences of chalk in Alabama and Mississippi and shales in Arkansas, Louisiana, and Mississippi. Confining units in the aquifer systems generally are effective barriers to the vertical movement of water. The relative proportion of fine-grained sediments in the aquifer system increases toward the coastline, and although the sedimentary units overall thicken and extend past the coastline in many places, low transmissivity and high salinity (dissolved solids of 10,000 milligrams per liter [mg/L] or greater) makes groundwater from the down-dip extent unsuitable for public supply or agricultural applications (Miller, 1990; Lloyd and Lyke, 1995; Ryder, 1996; Renken, 1998). Although the three aquifer systems are next to each other, they are considered distinct flow systems, separated by laterally continuous confining units or complex geology, making correlation of units difficult. The METX overlies the SECP along the eastern margin of the Mississippi embayment and the aquifers are separated by massive clay beds of the Midway confining unit (Renken, 1998). The CLOW overlies the METX from south Texas to the eastern margin of the current day Mississippi delta and overlies the SECP at the eastern extent of the CLOW aquifer system. The CLOW is separated from the underlying aquifer systems by the Vicksburg–Jackson confining unit (Renken, 1998). Wells targeting the respective deep aquifer system can fall within the plan-view boundary of an overlying aquifer system. In general, groundwater recharges from precipitation that falls along the margins of the aquifer systems where water-bearing units crop out at the surface. Groundwater moves laterally to discharge at surface-water bodies or as evapotranspiration (ET) with the remainder moving down-dip toward the coast into confined parts of the aquifer (Miller, 1990).

Southeast Coastal Plain Aquifer System (SECP)

The SECP is composed of Cretaceous to late Tertiary clastic rocks deposited in fluvial, deltaic, and shallow marine environments. Water-bearing aquifer units of sand and gravel are interbedded with fine-grained silt and clay confining units that dip toward the Atlantic and Gulf Coasts to the east and south, and the Mississippi embayment to the west. The aquifer system ranges from a few 10s of ft thick at the upland extent to many 1,000s of ft thick near the coast. The aquifer sediments generally grade from coarser to finer grained deposits from up to down-dip with most of the water-bearing units composed of fine-grained sands. The lateral extent and thickness of individual units is spatially variable because of the variability in the depositional energy regime and environment. Four regional aquifer systems lie next to the SECP: (1) the North Atlantic Coastal Plain to the north; (2) the Floridan to the south; (3) the METX to the west; and (4) the CLOW to the southwest. Hydrogeologic units of the SECP grade into the adjacent aquifer system units and (or) are separated by well-defined confining units. Correlation of SECP units to the adjacent principle aquifer systems generally is difficult because of the high degree of spatial variability in individual unit character and lateral extent, except for the relatively shallow Pearl River aquifer of the SECP merging into the METX. The SECP is underlain by very low permeability bedrock ranging from Precambrian aged crystalline rock to Jurassic aged sedimentary rock (Miller, 1990). The SECP is bound at the top by land surface in the eastern and interior parts of the aquifer system and by the CLOW and Floridan aquifer systems along the southern coastal region. In the western part of the aquifer system, the SECP is separated from the overlying METX by the Midway confining unit (Renken, 1996). Although the SECP consists of four regional aquifer units, composed of sand and separated by regional silt and clay confining units (Miller, 1990), two laterally extensive lower aquifer units were selected to characterize groundwater quality used for public supply (Barlow and others, 2016). The Chattahoochee River aquifer and the Black Warrior River aquifer are the primary groundwater source for public supply in the region. The Chattahoochee aquifer overlies the Black Warrior River aquifer which are separated by the Black Warrior River confining unit (Miller, 1990). There is groundwater movement from the interior recharge zones where water-bearing units are exposed at land surface to the down-dip extent of the aquifer system toward the Atlantic Coast, Gulf Coast, and Mississippi embayment axis. Groundwater discharges to streams and as evapotranspiration in the updip recharge area and to the shallower aquifer units of the SECP and overlying aquifer systems (METX and Floridan) in deeper confined parts of the aquifer system (Renken, 1996).

The Chattahoochee River aquifer consists of two laterally continuous but disconnected units, extending from central Alabama to western South Carolina and the other extending northward from northern Mississippi along the eastern margin of the Mississippi embayment. The two sections of the Chattahoochee River aquifer are hydraulically disconnected. The Chattahoochee River aquifer is composed of late Cretaceous to late Paleocene aged sand, sandstone, gravel, and minor limestone beds that are locally interbedded with fine-grained sediments. The aquifer generally consists of fine- to coarse-grained quartz sand and appears as massive, thin, or lenticular beds. Aquifer thickness is greatest, approximately 1,000–1,500 ft, along a wide band extending from southern South Carolina to western Georgia. The aquifer ranges from 500 to 750 ft thick in the remainder of South Carolina and eastern Alabama, and from 100 to 200 ft thick in Mississippi, thinning toward the landward extent of the aquifer. The aquifer pinches out near the surface moving toward the interior margin of the aquifer system and at depth moving coastward. The aquifer crops out in central South Carolina, central Georgia and Alabama, and Mississippi along the northern and eastern aquifer margins (Renken, 1996).

The Black Warrior River confining unit is the thickest and most widespread confining unit of the SECP, nearly covering the entire extent of the principal aquifer. The confining unit is composed of thick sequences of low-permeability chalk, shale, clay, and mudstones of marine origin. The Black Warrior River confining unit is thickest (up to 3,000 ft) in Mississippi and western Alabama, where the Chattahoochee River aquifer is absent, but generally is less than 1,700 ft thick. To the east in South Carolina and eastern Georgia, the confining unit thins considerably with an average thickness of 250 ft. Lithology of the Black Warrior River confining unit is widely variable, but it is considered to be an effective barrier to groundwater flow between the overlying Chattahoochee River aquifer (or Pearl River aquifer where the Chattahoochee is absent) and the underlying Black Warrior River aquifer (Renken, 1996).

The Black Warrior River aquifer is the most extensive water-bearing unit in the SECP, extending from Tennessee to North Carolina with landward limit of the aquifer generally marking the interior margin of the SECP. The Black Warrior River aquifer has a complex stratigraphy (Renken, 1996) but generally is composed of Cretaceous-aged coarse- to fine-grained quartz sands that are cross bedded, laminated, or massive in nature. Sand units are interbedded with silt, clay, mudstone, shale, limestone, and chalk. The Black Warrior River aquifer crops out in a widening band from central Georgia to the west and north to Tennessee. Where the aquifer does not crop out in eastern Georgia and South Carolina, it is assumed to be under confined conditions. Aquifer thickness is greatest (up to 5,000 ft) at the down-dip extent near the Mississippi–Alabama border, but the maximum thickness of the freshwater (less than 10,000 mg/L dissolved solids) column generally is less than 2,500 ft. High-salinity water generally is more common near the base and the down-dip extent of the aquifer. Thickness of the freshwater column averages less than 750 ft in northern Mississippi and less than 500 ft in South Carolina and eastern Georgia (Renken, 1996).

Mississippi Embayment and Texas Coastal Uplands Aquifer System (METX)

The METX is composed of late Cretaceous to Eocene clastic rocks deposited in fluvial, deltaic, and shallow marine environments. Well defined, regionally extensive sand units are separated by thick continuous clay and shale confining units which dip toward the Mississippi embayment axis and the Gulf Coast. The aquifer units of the METX range in thickness from less than 10s of ft along the margins to more than 6,000 ft at the southern extent. The aquifer system also thickens from the margins of the aquifer system toward the Mississippi embayment axis with the deepest sediments in south-central Louisiana and southwestern Mississippi. The shallower water-bearing units become finer grained and pinch out to the south, and similar shallow clay confining units pinch out to the north as they become increasingly sandy. The deeper water-bearing and confining units are relatively homogeneous. Full detail of the METX hydrogeology is provided by Ryder (1996), Renken (1998), and Grubb (1998). Five regional principal aquifer systems are adjacent to the METX: (1) the SECP underlies and is adjacent to the east; (2) the CLOW overlies it to the south; (3) the Mississippi River Valley alluvial aquifer system overlies it through the central part; (4) part the Edwards-Trinity aquifer system lies to the west; and (5) the Ozarks Plateau aquifer system lies to the northwest. Aquifers of the METX merge eastward with the shallow Pearl River aquifer of the SECP (Renken, 1998). Most of the METX is underlain by the Midway confining unit which separates the METX from the SECP to the east. At the furthest down-dip limit, the aquifer system extent is defined by the geopressurized zone where abnormally high-fluid pressures occur due to formation water that is trapped by faulting and then pressurized during rapid sediment deposition and compaction (Grubb, 1998). The METX underlies the Vicksburg–Jackson confining unit, separating the METX from the CLOW and Mississippi River Valley alluvial aquifer system, and land surface. Groundwater generally flows from recharge zones at the up-dip extent of the aquifer system where water-bearing units crop out at land surface toward the Mississippi embayment axis and Gulf Coast. Groundwater is discharged to surface-water bodies (such as, streams, rivers, and wetlands), as evapotranspiration, and to the overlying CLOW and Mississippi River Valley aquifer systems (Renken, 1998).

Coastal Lowlands Aquifer System (CLOW)

The CLOW is composed of Oligocene to Holocene clastic rocks deposited in deltaic and shallow marine environments. The oldest sediments are exposed farther inland, with progressively younger units exposed toward the coast. The aquifer system ranges from few 10s of ft thick at the upland extent to more than 14,000 ft thick in southern Louisiana and the adjoining offshore areas. The aquifer system sediments grade from relatively permeable deltaic sands to less permeable silts and clays. Permeable aquifer zones of the CLOW are composed of interbedded sand and clay, rather than areally extensive massive beds, which thicken toward the Gulf Coast and the axis of the Mississippi embayment. Three regional aquifer systems lie adjacent to the CLOW: (1) the SECP to the north; (2) the Floridan to the east; (3) and the METX to the north and west. In the CLOW, five water-bearing permeable zones and two confining units have been identified and mapped locally. Variability in texture and thickness of the aquifer zones make extension of mapped units and correlation to other regional units difficult. The deltaic and shallow marine depositional environment make for numerous and complex changes in lithological facies. With the absence of areally extensive confining beds, the five permeable zones are defined based on changes in hydraulic head and aquifer permeability. The aquifer zones of the CLOW generally have a smaller percentage of sand than the water-bearing units of the SECP and METX. The CLOW is bound on the bottom by the regionally extensive Vicksburg–Jackson confining unit, except for the part of the aquifer system that includes the Continental Shelf and a narrow on-shore band along the Texas and Louisiana coast. The Vicksburg–Jackson confining unit separates the CLOW from the underlying METX. The top of the CLOW aquifer system is at land surface (Grubb, 1998; Renken, 1998). The down-dip extent of the aquifer system is demarcated by the geopressurized zone where abnormally high fluid pressures occur due to formation water that is trapped by faulting and pressurized during rapid sediment deposition and compaction. Groundwater movement in the geopressurized zone is very slow, and only a small part of the highly mineralized fluids moves into the shallower, active, meteoric groundwater flow system (Grubb, 1998). Groundwater in the shallow meteoritic system flows (moves) from recharge areas at the interior margin where aquifer units are exposed to down-dip parts of the aquifer system toward the coast. Groundwater discharge occurs as diffuse upward seepage to surface-water bodies (that is, major rivers, wetlands, and shallow nearshore marine environments) and as evapotranspiration (Renken, 1998).

Methods

In this section, groundwater tracer collection, laboratory analysis and systematics, geochemical correction of ^{14}C, and groundwater age tracer interpretation methods are described. Methods for calculating the susceptibility index and composite distributions of groundwater age and susceptibility from interpreted tracer-based LPMs of groundwater age are also described.

Data Collection, Laboratory Analysis, and Tracer Systematics

Water samples, from the three well networks described, were analyzed for a broad suite of inorganic and organic constituents and environmental tracers (Arnold and others, 2016, 2017). For this study, dissolved noble gas and dissolved argon-nitrogen (Ar-N_2) gas concentrations were used to determine recharge conditions and calculate concentrations of $^3He_{trit}$ and $^4He_{rad}$. Calculated $^3He_{trit}$, measured concentrations of tritium (^{3}H), corrected sulfur hexafluoride (SF_6), and carbon-14 (^{14}C) were used for estimating groundwater age. Delta carbon-13 (δ^{13}C) of DIC was used for geochemical correction of ^{14}C in DIC. Field parameters (water temperature, pH, and alkalinity), dissolved oxygen, and the inorganic and trace-element chemistry were used to parametrize ^{14}C correction models, assess redox conditions, and develop conceptual models that guided interpretation of tracer concentrations. Not all tracers were collected at every well.

Dissolved Gases

Nitrogen and noble gases naturally exist in the atmosphere. The gases of Ne, Ar, Kr, Xe, and N_2 dissolved in water were interpreted by using the closed-equilibrium (CE) model or the unfractionated air (UA) model (Aeschbach-Hertig and others, 2000; Stute and Schlosser, 2000) for determining noble gas temperature (NGT) of recharge (a proxy for altitude and timing of recharge), excess air or entrapped air (EA and A^e), and the fractionation factor (F) of the gases during recharge. The fractionation factor cannot be estimated for samples that only have Ar and N_2 analysis available. Nitrogen gas, in excess of atmospheric solubility, is primarily derived from denitrification. Presence of suboxic to anoxic conditions (see the "Redox Conditions" section) indicated possible denitrification. Excess N_2 was included as an additional dissolved gas model parameter at select sites with suboxic or anoxic redox conditions. Helium isotopes (^3He and ^4He) were used to determine the helium isotopic ratio of the sample to that of the atmosphere (R/R_a) and the amount of helium derived from radiogenic sources ($^4He_{rad}$) and the decay of tritium ($^3He_{trit}$; Solomon, 2000; Solomon and Cook, 2000). Calculations of $^4He_{rad}$ and $^3He_{trit}$ assumed a terrigenic $^3He/^4He$ ratio of $2.8x10^{-8}$, a value within the measured range of helium production from uranium- (U) and thorium- (Th) series decay (Andrews, 1985; Pearson and others, 1991). Following previous investigations of groundwater dissolved gas models (Aeschbach-Hertig and others, 2000; Manning and Solomon, 2003; Aeschbach-Hertig and Solomon, 2013), the calculated recharge parameters (EA, F) were evaluated by minimization of the noble gas chi-squared (χ^2), the misfit between measured and modeled dissolved gas concentrations. Derived tracer concentrations and dissolved gas results of noble gas temperatures, excess (or entrapped) air, and noble gas fractionation are reported in Solder (2019). Careful sampling of wells can ensure that no degassing takes place during sampling, and the gas concentrations can be assumed to be characteristic of recharge conditions. Noble gas samples were collected in copper tubes (Weiss, 1968). Sample preparation and analysis was done at the USGS Dissolved Noble Gas Laboratory in Denver, Colorado.

Tritium

Tritium is naturally produced as a cosmogenic isotope (half-life of 12.32 years; Lucas and Unterweger, 2000) and produced in nuclear fission. Tritium was released to the atmosphere in high concentrations during above-ground nuclear testing from 1953 to the early 1960s. Groundwater recharge had an elevated 'bomb-pulse' ^3H signal during that period. Water containing greater than 0.5 tritium units (TU) was interpreted here as having at least some fraction of recharge after 1953, and concentrations less than 0.2 TU were considered 'tritium-dead' in accordance with the analytical uncertainty. Tritium samples were collected in dry 1-liter (L) high-density polyethylene (HDPE) bottles and analyzed by electrolytic enrichment and liquid scintillation (Thatcher and others, 1977). Tritium sample preparation and analysis was done at the USGS-National Research Program Lab in Menlo Park, California, or at the University of Miami, Tritium Laboratory in Miami, Florida. Atmospheric ^3H concentration curves used for LPMs were based on interpolation of nationwide precipitation measurements (Michel, 1989; Michel and others, 2018) and varied by site location.

Sulfur Hexafluoride

Although SF_6 is present in some types of rocks, its presence in the environment generally is from industrial production and use. Sulfur hexafluoride is used to evaluate the age of younger (less than 60 years [yr]) groundwater or to identify a component of young water in a mixed signal. Atmospheric concentrations of SF_6 have steadily increased since 1970 (Busenberg and Plummer, 2000) and have a long atmospheric lifetime (about 3,200 yr; Land and Huff, 2010), making it a useful age tracer for young groundwater. Sulfur hexafluoride concentrations are subject to potential anthropogenic and natural contamination. For example, SF_6 is produced naturally in fluorite deposits and volcanic or hydrothermal terrains (Harnisch and Eisenhauer, 1998; Busenberg and Plummer, 2000). Sulfur hexafluoride concentrations were corrected for excess (or entrapped) air by using the calculated value (EA or A^e) from noble gas modeling, as described previously, and they have not been corrected for the potential unsaturated zone time-lag (Cook and Solomon, 1995). Samples were collected in duplicate in 1-L amber glass bottles with a polyseal cone-lined cap. Following the procedures outlined on the USGS Reston Groundwater Dating Laboratory website (https://water.usgs.gov/lab/), the bottles were bottom-filled, flushed for a minimum of three bottle volumes, and caps were secured with electrical tape. Sulfur hexafluoride was analyzed by using gas chromatography at the USGS Reston Groundwater Dating Laboratory in Reston, Virginia. Tracer input histories of SF_6 in recharge from the USGS Reston Groundwater Dating Laboratory (https://water.usgs.gov/lab/software/air_curve/) were used for LPMs. Sulfur hexafluoride input history in recharge was assumed to be constant throughout the study area.

Carbon-14

Carbon-14 is naturally produced as a cosmogenic isotope and is produced in nuclear fission with a half-life of 5,730 years (Kalin, 2000). Carbon-14 of DIC was used to evaluate the age of premodern groundwater between 2 and 50 thousand years (ka) and to identify the presence of old groundwater in mixtures of differing recharge sources. Carbon-14 samples were collected in 1-L clear-glass bottles with filtered water (0.45 micron [µm]). The bottles were bottom-filled, flushed for a minimum of three bottle volumes, and capped immediately sealing the bottle. Caps were secured with electrical tape. Samples were analyzed by the National Ocean Sciences Accelerator Mass Spectrometry Facility (NOSAMS) at Woods Hole Oceanographic Institution in Woods Hole, Massachusetts. Specifics of sample processing, analytical procedures, and information on reference standards can be found at https://www.whoi.edu/nosams/home. Carbon-14 input histories in recharge for lumped parameter modeling was constructed by combining the 2009 international radiocarbon calibration curve (IntCal13; Reimer and others, 2013) with modern historical tropospheric ^{14}C data for the northern hemisphere (northern hemisphere zone 2; Hua and others, 2013). Geochemical and isotopic exchange between DIC and various carbon reservoirs (such as, soil carbonates and aquifer carbonates) in groundwater systems makes ^{14}C more difficult to interpret, but available groundwater tracers for dating of 1,000s of year-old waters remain limited. Carbon-14 correction methods and model parameterization are discussed in the "Carbon-14 Geochemical Correction" section of this report.

Redox Conditions

The redox condition of each sample was categorized as 'oxic' if concentrations of dissolved oxygen (DO) were greater than or equal to 0.5 mg/L and iron (Fe) was less than or equal to 100 micrograms per liter (µg/L), or 'anoxic' if concentrations of DO were less than 0.5 mg/L and Fe was greater than 100 µg/L (McMahon and Chapelle, 2008; Jurgens and others, 2009). Samples that met the criteria for both oxic and anoxic conditions were categorized as 'mixed.' During dissolved gas analysis, anoxic or mixed conditions were used as indicators for the possibility of excess N_2 gas resulting from denitrification; anoxic or mixed conditions were also used as indicators during ^{14}C geochemical corrections for the possible influence of organic carbonate geochemistry.

Carbon-14 Geochemical Correction

A stable carbon isotope ($\delta^{13}C$) based analysis was used in preliminary determinations of whether mass exchange was occurring between soil gas derived DIC and other carbon sources. Assuming the simple case of carbon exchange, where the two carbon sources are soil gas and aquifer carbonate with commonly assumed $\delta^{13}C$ values of –25 parts per thousand (permil) and 0 permil, respectively, the fraction of soil gas carbon dioxide (CO_2) in total DIC (also known as, correction factor; Ingerson and Pearson, 1964) is calculated in the following equation:

$$correction\ factor = \frac{\delta^{13} C_{meas}}{-25} \tag{1}$$

where

$\delta^{13}C_{meas}$ is the measured $\delta^{13}C$ of DIC.

The larger the correction factor, the more dissolution of carbonate is required to account for the measured $\delta^{13}C$ of DIC. It is important to note that the correction factor does not account for additional sources of carbon or isotopic exchange between phases.

Analytical correction models (Han and Plummer, 2013), guided by the graphical interpretation of dominant geochemical reactions (Han and others, 2012), were used to correct measured ^{14}C concentrations for geochemical reactions other than radioactive-decay. Using the scheme of Han and Plummer (2013), the measured ^{14}C and $\delta^{13}C$ guided selection of the appropriate correction formulation. In this work, the Tamers, the revised Fontes and Garnier open system, and the revised Fontes and Garnier closed system formulations were considered. For some samples, the open-system assumptions resulted in grossly overcorrected final adjusted ^{14}C (that is, greater than 140 percent modern carbon [pmC]) in which case the closed-system model was used. For the unsaturated-zone gas, a ^{14}C of 100 pmC and $\delta^{13}C$ of –25 permil was assumed. Unsaturated-zone gas ^{14}C of 120 pmC was used at select sites (n=9) where a modern component of groundwater was indicated by carbon isotopes and measured ^{3}H, and models resulted in overcorrection of final adjusted ^{14}C. The unsaturated-zone gas $\delta^{13}C$ was likely in a range from –28 to –22 permil based on the dominance of C3 photosynthetic pathway plants in the study area (Cerling, 1984; Still and others, 2003), and the observation that the average measured $\delta^{13}C$ of DIC in all samples with ^{14}C greater than 100 pmC was –21 permil. For reference, the $\delta^{13}C$ of the dissolved CO_2 and bicarbonate (HCO_3) is –26 and –16.7 permil, respectively, when in equilibrium with an unsaturated zone gas $\delta^{13}C$ of –25 per mil. The solid phase carbonate (in other words, aquifer rock) was assumed to have a ^{14}C of 0 pmC and $\delta^{13}C$ ranging from +2 to –2 permil; a commonly assumed range for marine carbonates (Clark and Fritz, 1997). A narrower solid phase $\delta^{13}C$ range of +2 to 0 permil was used at select sites (n=11) where final adjusted ^{14}C was overcorrected. Reporting of geochemical model solutions were limited to final adjusted ^{14}C less than 120 pmC and initial ^{14}C (A_0) greater than 0 pmC.

Final adjusted ^{14}C was calculated for the range of assumed solid phase $\delta^{13}C$ values, which provided a preliminary estimate of uncertainty in ^{14}C correction. Model input and final adjusted ^{14}C values at individual sites, and corresponding LPM solutions, are provided in the USGS ScienceBase data release (Solder, 2019). Additional geochemical processes and carbon sources that affect the isotopic composition of DIC in the south Atlantic and Gulf Coast aquifer systems, and have been documented (for example, McMahon and others, 1990, 2017; McMahon and Chapelle, 1991; Haile and Fyar, 2017), were not accounted for in this study. Additional reaction-path and inverse geochemical modeling required to account for such processes and sources was outside the scope of this study.

Groundwater Age Estimates

Groundwater age is described in this study by the estimated mean age and the age distribution. In most cases, a groundwater sample is a mixture of flow paths with varying ages, and the age distribution represents the probability of a water parcel with a given estimated age occurring in the sample. Complete age distributions are presented as cumulative probabilities providing the fraction of sample younger than a given age (that is, proportion of sample recharged after a given year). Cumulative distributions provide a convenient and intuitive means for reporting the LPM optimized age distribution and a visual representation of the extent of mixing and (or) dispersion in a sample. Wider distributions indicated a larger range of groundwater parcel ages captured by a sample. Narrower distributions indicated a smaller range of groundwater parcel ages captured by a sample. The estimated mean age is the first moment of the groundwater age distribution. Mean ages are used to categorize the samples and evaluate spatial patterns, but they are an incomplete representation of groundwater age in a sample.

Mean ages, age distributions, and SI (described in the "Susceptibility Index" section) were determined by calibrating LPMs to the measured or calculated tracer concentrations. Tracers used for age determination are assumed to be conservative or have a predictable decay or accumulation rate. A modified version of the USGS program TracerLPM (Jurgens and others, 2012) was used for calibration of LPMs. Measured tracer concentrations were compared with each other and compared to respective atmospheric histories to identify tracer concentrations outside of the expected range; they were excluded from subsequent analyses. Plausible distribution types are selected based on hydrogeology and well characteristics such as depth to and length of screened interval. Simulated tracer concentrations, for each tracer selected for fitting, were matched to corresponding measured (or calculated) tracer concentrations simultaneously by varying the LPM parameters (that is, simulated mean age, distribution type, and distribution parameters). Lumped parameter model parameters are varied to minimize the misfit (that is, chi-squared [χ^2]) between measured and simulated concentrations of the select modeled tracers. Age interpretation was not possible at all sites due to sample-loss or contamination-affected tracer concentrations.

The approach for LPM selection and interpretation of mean age was dictated by the measured tracer concentrations. Modern groundwater is dominated by post-1950 recharge and characterized by quantifiable concentration of one or more of the modern age tracers (^3H, $^3He_{trit}$, and SF_6), and ancillary tracers indicated no substantial amounts of pre-1950 recharge (such as R/R_a about equal to 1 and terrigenic helium-4 [$^4He_{terr}$] less than 10^{-8} cubic centimeters at standard temperature and pressure per gram of water [ccSTP/g]). For modern samples, age-distribution parameters were constrained based on well characteristics and lithology where available, and age distributions were fit to the modern tracers. In the limited cases where either no modern tracer was available or the available tracer(s) was deemed unreliable, ^{14}C was used to fit the age distribution of modern samples. For modern samples fit to ^{14}C the confidence in estimate age generally is low. Premodern samples are largely composed of pre-1950 recharge and are identified by low-measured modern tracer concentrations, and ancillary tracers indicated residence times greater than few 100s of years (such as, R/R_a less than 0.7 and fraction $^4He_{terr}$ greater than 0.5). For the south Atlantic and Gulf Coast aquifer systems, ^3H concentrations indicated that most sites were premodern (^3H less than 0.5 TU), meaning ^{14}C was the primary tracer useful for age dating samples from the three principal aquifer study networks. In this study, mixtures of separate and distinct modern and premodern recharge sources in a single sample (binary mixtures) were rarely considered in LPMs. The general aquifer system characteristics of dipping aquifer units bounded by well-defined and relatively impermeable confining units limits possible pathways for mixing two distinct water sources. Although numerical modeling results (Campbell and Coes, 2010) indicated that interlayer flow (vertical flow between hydrogeologic units) is a large part of the water budget in select areas, there was little indication of mixtures of modern and premodern water in the tracer data. Such mixtures generally are easily identified by measurable ^3H and (or) SF_6, low ^{14}C (less than 70 pmC), and significant accumulations of $^4He_{terr}$ (more than 10^{-8} ccSTP/g). The limited number of available tracers, nearly ubiquitous SF_6 of about 0.3 parts per trillion by volume (pptv), and ^3H detection limit of 0.2 TU, made determination of a unique binary mixture distribution difficult and introduced a high level of uncertainty. As such, binary mixtures were evaluated cautiously and only applied to select cases where tracer data were sufficient (n=8).

Radiogenic helium-4 was used as a qualitative indicator of groundwater age with values greater than about $5x10^{-8}$ ccSTP/g, which indicated a substantial component of groundwater more than a few 1,000 years old. Additional analysis of radiogenic helium source and crustal helium accumulation rates are needed to calculate $^4He_{rad}$ based mean ages, which is outside the scope of the study.

Not all tracers were collected at every site. Ten samples from south Atlantic and Gulf Coast aquifer systems had SF_6 only and no other tracers to verify the concentration; thus, no age could be assigned (table 2 in Solder, 2019). Eight sites had ^{14}C greater than 80 pmC and no modern tracers were available for those sites (table 1). In these cases, an estimated mean age was assigned, but the uncertainty in mean age is high.

Conceptual hydrogeology of relatively coarse-grained water-bearing units interbedded and overlain by finer grained units indicate that most of the groundwater flow is under confined conditions. Confined aquifers might be reasonably represented by the exponential-piston flow model (EPM; Jurgens and others, 2012) that represents a flow system with spatially uniform recharge becoming confined before discharge or capture. To define a unique solution of the EPM for a given sample, the mean age and EPM ratio (unitless ratio of horizontal length of recharge area to confined area along the assumed flow path; Jurgens and others, 2012) must be constrained by fitting the LPM to multiple tracer concentrations, or on the basis of aquifer geometry. For many sites where ^{14}C is the only useful tracer, the EPM is poorly constrained and a different LPM was selected. The piston flow model (PFM) can be a reasonable conceptual model if the recharge area is small compared to the length of the flow paths under confined conditions, although the implicit assumption of conservative tracer behavior (no mixing) of the PFM is perhaps not valid in the south Atlantic and Gulf Coast aquifer systems. Tracer dispersion and diffusion in heterogeneous systems of interbedded water-bearing and fine-grained confining units can strongly affect tracer concentrations (Sudicky and Frind, 1981). Accordingly, the dispersion model (DM) was used in this study to represent the physical processes of tracer dispersion along the length of the flow paths and tracer diffusion between the active flow paths and stagnant low-flow velocity parts of the aquifer system (such as, fine-grained confining units). A dispersion parameter (inverse of the peclet number; Jurgens and others, 2012) of 0.1 was used to represent the mixing as a conservative underestimate of the likely true field-scale mixing based on the range of published field-scale dispersion parameter estimates (0.004–1.5 for sedimentary bedrock, 0.002–1.25 for unconsolidated sand, gravel, and cobbles; Gelhar and others, 1992). Underestimation of dispersion and diffusion processes results in an underestimation of mean age.

With most of the sites limited to ^{14}C for estimation of mean groundwater ages, the optimized mean age will be sensitive to uncertainty in the ^{14}C correction methods and measured ^{14}C values. Uncertainty in the measured values of ^{14}C is of secondary influence compared to geochemical correction on final corrected ^{14}C values. Uncertainty in the geochemical correction method parameters was estimated by allowing the solid phase $\delta^{13}C$ to vary (see "Carbon-14" in the "Data Collection, Laboratory Analysis, and Tracer Systematics" section of this report). Two LPM solutions are reported in the ScienceBase data release (Solder, 2019) for groundwater ages estimated using ^{14}C to provide an estimate of the uncertainty in mean age. Although the analytical uncertainty is not explicitly accounted for in the reported estimated mean ages, ^{14}C detection limits guide the maximum reported mean age. According to the NOSAMS website (https://www.whoi.edu/nosams/home), the average process blank for DIC has a ^{14}C of about 0.15 pmC. A concentration of 0.15 pmC corresponds to a conventional radiocarbon apparent age of approximately 50,000 years or a DM (parameter of 0.1) estimated age of greater than 90,000 years. An upper reporting limit of 50,000 years is adopted for the results in this report and the uncensored ages are provided in the ScienceBase data release (Solder, 2019).

Susceptibility Index

The susceptibility index (SI) provides a quantitative estimate of susceptibility of a well to land surface contamination. More specifically, it is a relative measure of how soon a contaminant in the recharge area would arrive at the well by groundwater, accounting for the age distribution. The SI assumes conservative tracer behavior, measuring the travel time from the water table to the well, and does not account for transport properties and reactivity of potential contaminants, or unsaturated zone travel time. The SI is calculated as the normalized difference between the cumulative distribution function (CDF) of age for the well of interest and a reference CDF described by Solder and others (2020) in the following equations:

$$SI = \frac{1}{1 + D_H} \qquad (2)$$

where

D_H is the Hellinger distance calculated as

$$D_H = \frac{\sqrt{\sum_{i=1}^{k} \left(\sqrt{P(i)} - \sqrt{Q(i)}\right)^2}}{\sqrt{2}} \qquad (3)$$

where

- $P(i)$ is the cumulative probability of the age distribution of interest for a given time-step,
- $Q(i)$ is the cumulative probability of the reference age distribution for a given time-step,
- i is the time-step of the cumulative distribution function, and
- k is the age corresponding to the last time-step.

For this metric, the more rapidly a land-surface contaminant arrives at the well, the more susceptible the given well. As such, the reference CDF is defined as a piston-flow model with a mean age of 1 year. The susceptibility index is unitless and ranges between 1 (indicating young ages and a narrow age distribution) and approaching 0 (indicating older ages and a broad age distribution).

It is worth emphasizing that SI is a measure of relative susceptibility to land surface contaminants behaving conservatively and originating near the water table. In the south Atlantic and Gulf Coast aquifer systems, naturally existing contaminants such as salinity and fluoride are of concern. Under appropriate geochemical conditions, the concentration of such contaminants is inversely related to the age of a given parcel of water. It is tempting then, to use the SI inversely; 1 indicating lower and 0 indicating higher relative susceptibility to natural contamination. Although in theory, the SI is potentially useful in this manner, the metric does not account for factors other than the age distribution. Any differences in geochemical conditions between sites can render the comparison of SI meaningless. Cautious use of the SI as a measure of susceptibility to natural or non-conservative contamination is required.

Composite Age and Susceptibility Index Distributions

The composite distributions provide a means of summary and characterization of age at the scale of the aquifer system and for future comparison to other groundwater systems. Composite age distributions are constructed by averaging the cumulative age distributions of all samples from each of the three principle aquifer study networks and for all samples from the combined networks. Calculation of composite age distributions for the three networks assumed equal weighting of the individual samples. Similar composite distributions of the SI values were constructed by ordering the values of SI for samples from each of the networks and normalizing the number of samples to 1. The composite SI distributions were plotted in reverse order of SI (from 1 to 0) to correlate with the respective composite age distributions (young and highly susceptible wells on the left to old and low susceptibility wells on the right).

To summarize and describe the composite age distributions, the estimated mean composite age, the composite SI, and the composite fraction of recharge that occurred over a given number of years before the sample date can be calculated from the composite age distributions. For this study, the fraction of recharge that occurred 2,000 years before present and 15,000 years before present was calculated to summarize data on the older components of the composite age distributions.

Results

A summary of well dimensions, noble gas temperature results, measured and calculated tracer concentrations, and estimated mean ages and LPM results are provided in table 1 and described in the respective sections, tables, and figures. Complete details regarding the data are provided in the ScienceBase data release (Solder, 2019).

Dissolved Gas Analysis

Dissolved gas samples were analyzed for 229 sites, with final models based on Ar and N_2 at 56 sites and noble gases at 173 sites. For the remaining 24 sites, reliable dissolved gas concentrations were not available. Overall, measured gas concentrations were well fit by models with a mean noble gas χ^2 of 0.37 and most frequently best fit by the unfractionated air model (n=172; Solder, 2019). Noble gas temperatures ranged from about 5 to about 31 degrees Celsius (°C; table 1) with cooler temperatures generally in the SECP and Mississippi embayment (fig. 3). Additional noble gas model-fitting parameters are reported in the ScienceBase data release (Solder, 2019). The measured helium isotopic ratio of the sample relative to air (R/Ra) ranged from about 0.01 to about 2.3 (unitless) with a median value of 0.14. Helium budget calculations at the 127 sites showed that $^4He_{rad}$ ranged from about 0 to about 3.06×10^{-5} ccSTP/g (table 1), which accounted for between 0 and nearly 100 percent of the total helium for a given sample (Solder, 2019).

Tracers

Tritium was measured at 194 wells and generally was very low across the three networks. Most of the samples ranged from below detection limit (BDL; 0.2 TU) to about 6.6 TU (table 1). The vast majority of samples (162) were premodern with ^3H less than 0.5 TU. Three samples in the SECP (335128081250001, 333036081442108, 332141081583601) had elevated ^3H above expected atmospheric levels (about 7 TU) and were observed in south central Georgia, near the Savanah River National Lab where ^3H is produced, and in central Louisiana where several nuclear power generation plants were nearby. Capture of ‘bomb-pulse’ ^3H from above ground nuclear testing is tentatively ruled out because measured ^{14}C in the samples were about 100 pmC, which is consistent with expected concentrations for young water unaffected by elevated bomb-pulse ^3H and ^{14}C atmospheric concentrations.

Tritiogenic helium was calculated at 15 sites with values ranging from about 1 to about 28.6 TU (table 1). Tritiogenic helium was used in LPM mean age estimates at 11 sites where mean age ranged between 17 and 144 years. Reported $^3He_{trit}$ was less than 1 TU at 34 sites and not quantifiable at 77 sites (Solder, 2019). Calculated values of $^3He_{trit}$ were considered not quantifiable, and thus not useful as a fitting tracer for LPM, due to high amounts of radiogenic helium in the sample and sensitivity of the helium budget to assumed isotopic ratios of helium sources.

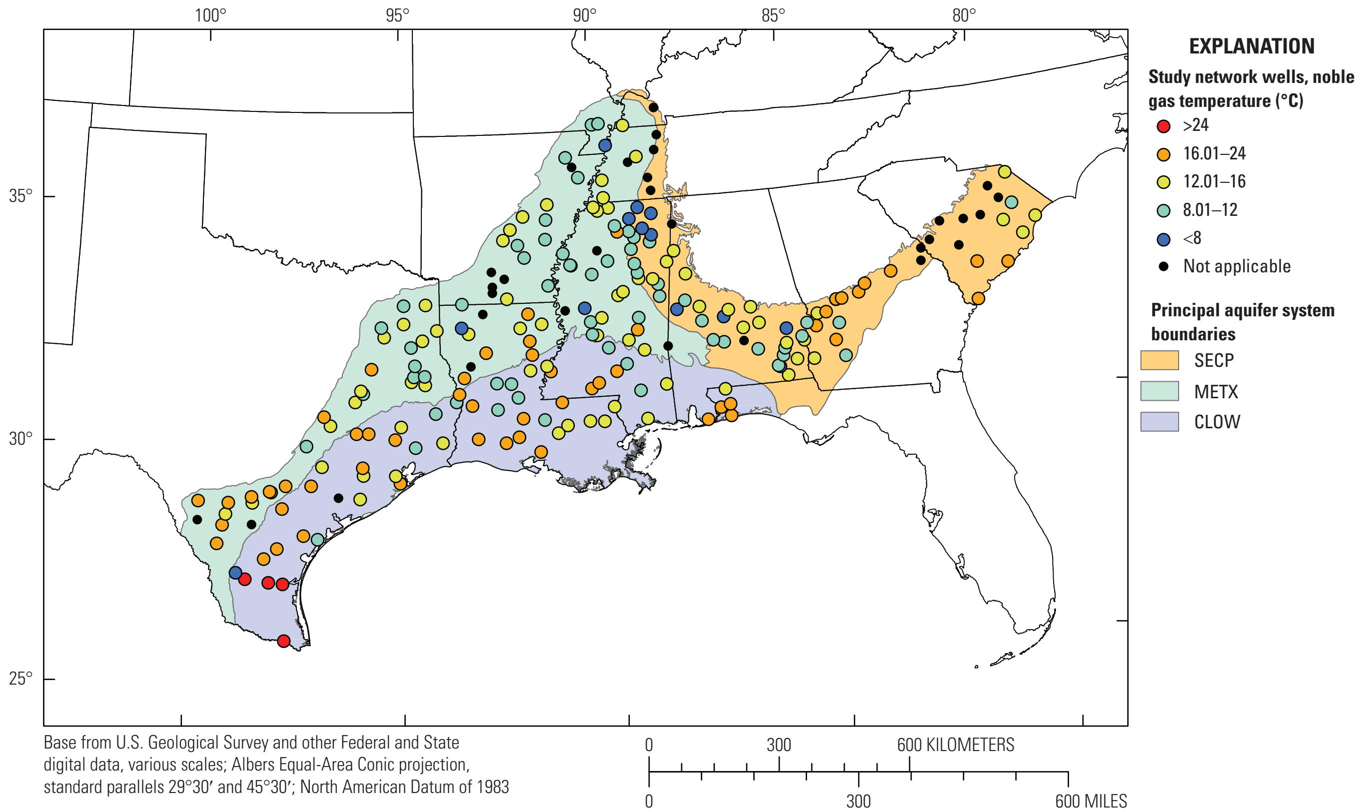

Figure 3. Noble gas temperatures from principal aquifer study well networks in the south Atlantic and Gulf Coast aquifer systems, USA. The extent of principal aquifer study networks is indicated by color (Southeastern Coastal Plain; SECP, yellow; Coastal Lowlands; CLOW, purple; Mississippi embayment–Texas coastal uplands; METX, green).

Sulfur hexafluoride was measured at 182 wells where air-equilibrated concentrations ranged from about 0 to about 12.5 pptv (one grossly contaminated sample measured 574 pptv, table 1) and median value of 0.35 pptv. Comparison of ^{3}H and SF_6 with expected concentrations of the tracers indicated a pervasive secondary source of SF_6 in addition to excepted atmospheric concentrations for the Northern Hemisphere, with "background" SF_6 ranging from about 0.2 to 0.5 pptv in ^{3}H-dead samples. Potential SF_6 contamination sources included area geology (for example, evaporite or volcanic deposits; Land and Huff, 2010), local release of gaseous SF_6 to the atmosphere, or local anthropogenic contamination (for example, landfills). The near ubiquity of SF_6 above expected concentrations in ^{3}H-dead samples across the study area indicated a geologic source and made the use of the tracer for age determinations problematic, particularly for mixtures. Sulfur hexafluoride was used as a fitted tracer when no other tracer data were available (two sites), resulting in high uncertainty in the estimated age, or when additional modern tracers (such as ^{3}H, $^{3}He_{trit}$) could be used to verify the reasonability of the SF_6 concentration (16 sites; table 1).

Carbon 14 and $\delta^{13}C$ were measured at 231 wells with uncorrected ^{14}C activities ranging from about 0.1 to 115 pmC and $\delta^{13}C$ values ranging from –23.2 to –1.4 permil (table 1). Maps of uncorrected ^{14}C showed that ^{14}C generally is related to hydrologic position, with higher ^{14}C values associated with younger groundwater near the recharge areas and lower ^{14}C values down-dip toward the coast in deeper parts of the aquifer systems (fig. 4). The spatial pattern of ^{14}C and hydrologic position is most clearly illustrated in the SECP where water-bearing aquifer units outcrop (in other words, recharge areas) more consistently on the margins of the aquifer system and where confining layers are more laterally continuous. In contrast, the multiple unconfined recharge areas and steeply dipping confining layers of the CLOW lead to a more irregular spatial pattern of ^{14}C (fig. 4).

Geochemical and isotopic exchange is occurring after recharge between DIC, soil, and aquifer carbon in the aquifer systems. The dissolution of solid carbonate is evidenced by ^{14}C correction factors less than 1, which are negatively correlated with ^{14}C (Kendall's tau =0.44, p value << 0.01), implying there is increasing amounts of carbon in DIC from sources other than soil gas (fig. 5). Before LPM estimation of mean age could be calculated, a geochemical and isotopic correction of ^{14}C was necessary, as detailed in the "Carbon-14 Geochemical Correction" section of this report. Final adjusted ^{14}C ranged from 0.17 to greater than 100 pmC with a median value of 12 pmC (table 1; Solder, 2019).

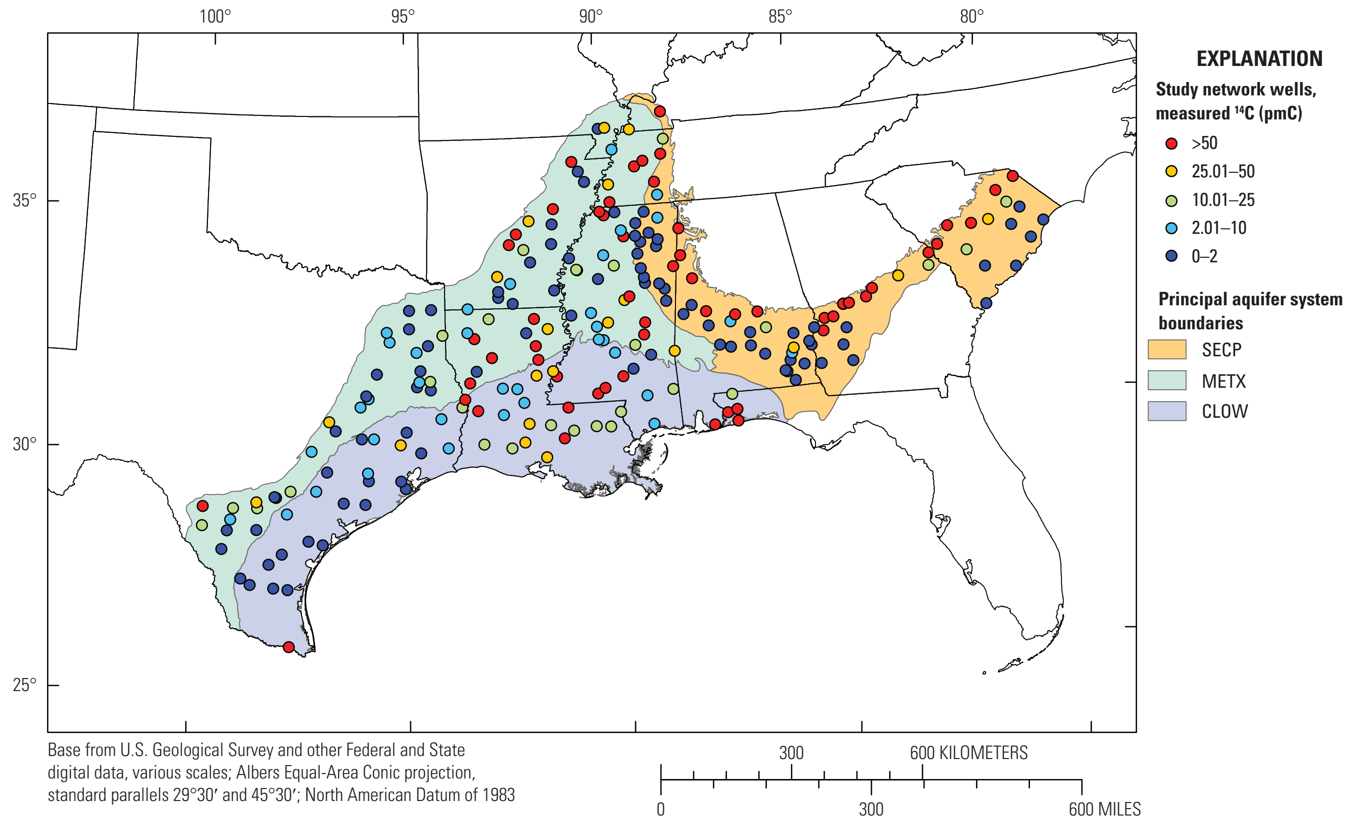

Figure 4. Measured (uncorrected) carbon-14 (^{14}C) from principal aquifer study well networks in the south Atlantic and Gulf Coast aquifer systems, USA. The extent of principal aquifer systems is indicated by color (Southeastern Coastal Plain; SECP, yellow; Coastal Lowlands; CLOW, purple; Mississippi embayment– Texas coastal uplands; METX, green).

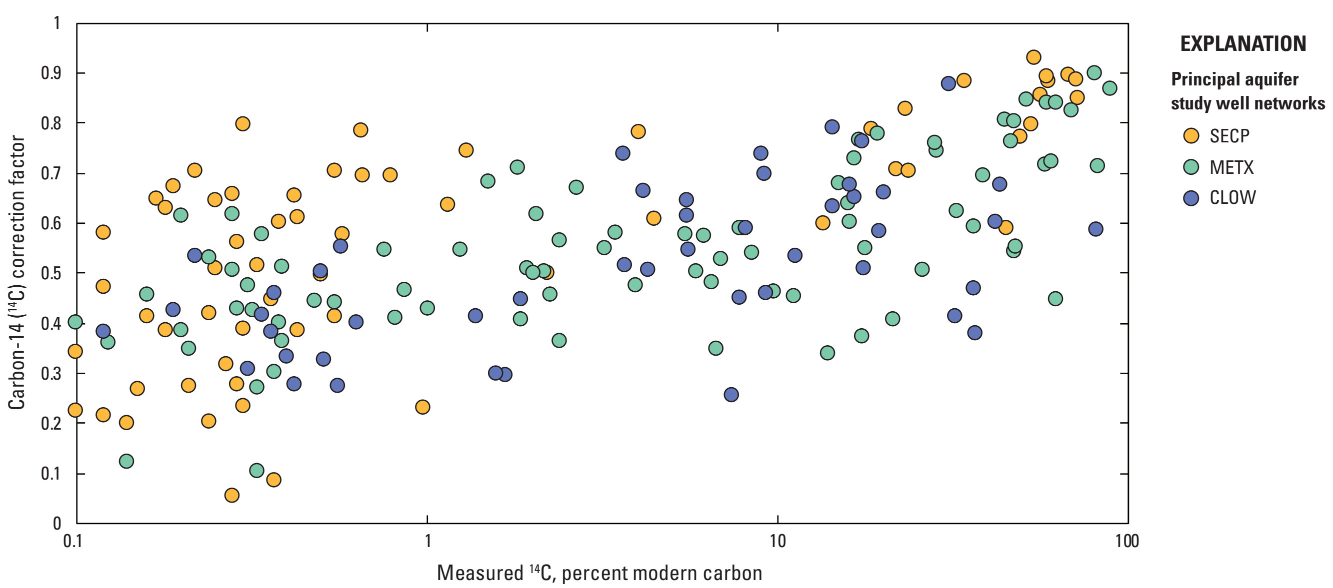

Figure 5. Measured (uncorrected) carbon-14 versus carbon-14 correction factor from principal aquifer study well networks in the south Atlantic and Gulf Coast aquifer systems, USA. Data from principal aquifer systems are indicated by color (Southeastern Coastal Plain; SECP, yellow; Coastal Lowlands; CLOW, purple; Mississippi embayment–Texas coastal uplands; METX, green).

Mean Age and Susceptibility Index

Estimated mean ages in all aquifer systems ranged from 17 years to greater than 50,000 years with a median age of about 24,000 years (tables 1, 2; fig. 6*A*). Estimated mean ages were youngest near the inland extent of each aquifer system and increased in age moving down-dip toward the coast (fig. 7*A*). Groundwater ages generally were oldest in the SECP with a mean age of 42,000 years, followed by the METX (30,000 years) and the CLOW (26,000 years, table 2). Of the 231 total samples, 207 samples classified as premodern with estimated mean recharge year (sample year minus estimated mean age) before 1950; 18 samples classified as modern with estimated mean recharge year after 1950; and 6 samples classified as mixed with the best-fit LPM of a binary mixture model of two age distributions (table 2). The DM was the most frequently fit LPM, and ^{14}C was the most commonly fitted tracer (table 1). The LPM misfits between measured and modeled tracer concentrations were acceptable with LPM χ^2 values generally less than 0.4 (223 sites) with a mean LPM χ^2 of 0.1 for all sites. There were LPM χ^2 values greater than 1 at eight sites where estimated mean age was less than about 140 years (table 1). Calculated values of SI for individual samples in all aquifer systems ranged from about 0.02 to about 0.3 (unitless) with a median value of 0.03 (tables 1, 2; fig. 6*B*). Inverse to estimated mean age, SI generally was largest near the inland extent of the aquifer system and decreased down-dip toward the coast (fig. 7*B*). The fraction of recharge for individual samples in all aquifer systems that were less than 2,000 years old and less than 15,000 years old had an average value of 0.25 and 0.43, respectively (table 2; fig. 6*C*). The age-distribution metrics of SI and fraction of recharge post-2,000 years showed a larger overall proportion of young water in the SECP than the CLOW and METX (larger mean SI and smaller mean fraction of recharge post-2,000 years), but the CLOW and METX were more skewed to younger groundwater than the SECP (smaller median SI and larger median fraction of recharge post-2,000 years, table 2).

Table 2. Count of age class and summary statistics for estimated mean ages, susceptibility index, and fraction of recharge less than 2,000 and 15,000 years old for principal aquifer study well networks in the south Atlantic and Gulf Coast aquifer systems, USA.

[Ages are in years. **Abbreviations**: SECP, Southeast Coastal Plain; METX, Mississippi embayment–Texas coastal uplands; CLOW, Coastal Lowlands; >, greater than; min., minimum; max., maximum; SI, susceptibility index; F post-2,000, fraction of recharge less than 2,000 years old; F post-15,000, fraction of recharge less than 15,000 years old]

	All	SECP	METX	CLOW
Premodern (count)	207	66	86	55
Modern (count)	18	11	3	4
Mixed (count)	6	2	3	1
Mean age	33,000	42,000	30,000	26,000
Median age	24,000	>50,000	20,000	19,000
Max age	>50,000	>50,000	>50,000	>50,000
Min. age	17	21	17	25
Mean SI	0.057	0.062	0.049	0.062
Median SI	0.03	0.024	0.029	0.036
Max. SI	0.303	0.303	0.203	0.229
Min SI	0.0187	0.0193	0.0187	0.0199
Mean F post-2,000	0.25	0.28	0.22	0.25
Mean F post-15,000	0.43	0.40	0.44	0.46
Composite SI	0.0198	0.0179	0.0201	0.0217

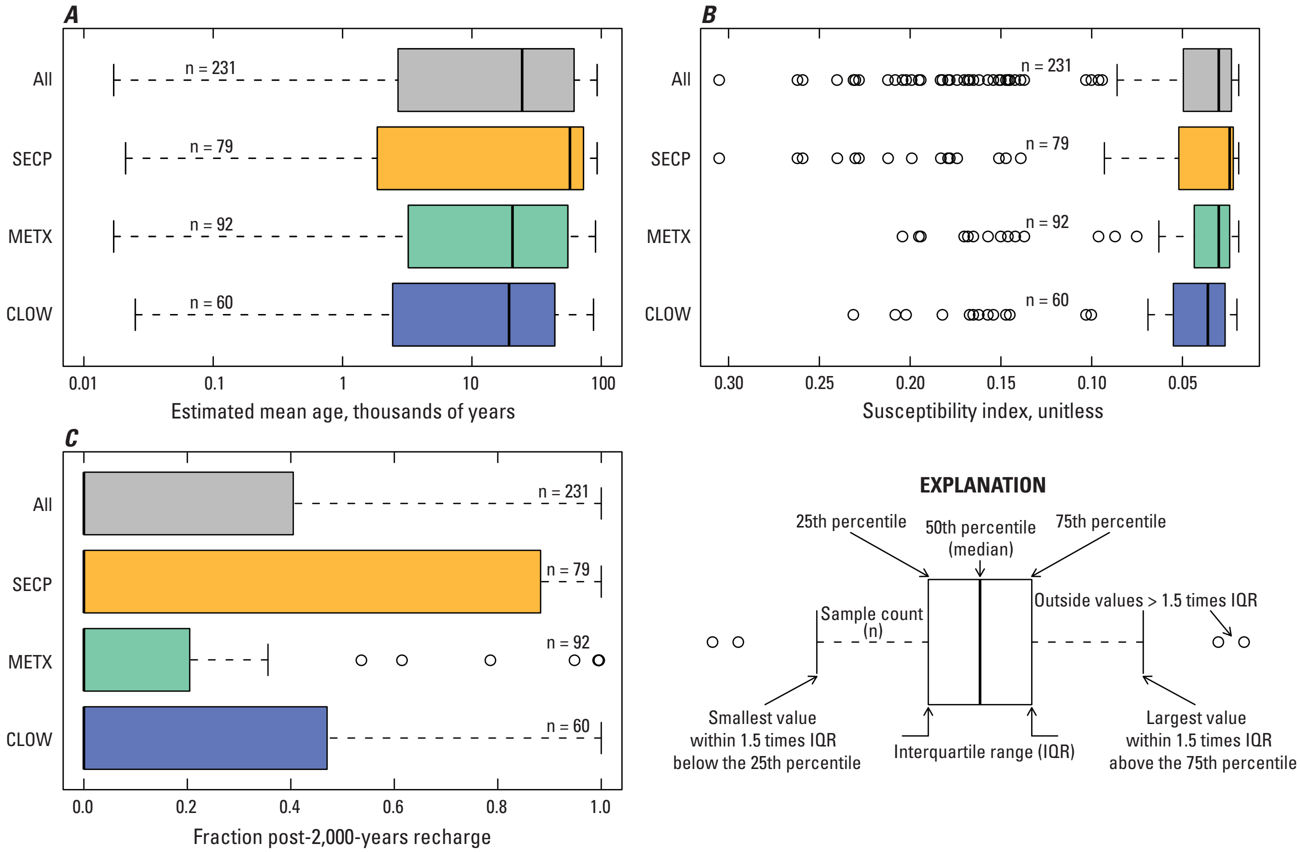

Figure 6. *A*, Estimated mean ages; *B*, Susceptibility index; and *C*, Fraction of recharge less than 2,000 years old from principal aquifer study well networks in the south Atlantic and Gulf Coast aquifer systems, USA. Data from principal aquifer systems are indicated by color (Southeastern Coastal Plain; SECP, yellow; Coastal Lowlands; CLOW, purple; Mississippi embayment–Texas Coastal Uplands; METX, green).

Composite Age and Susceptibility Index Distributions

Composite age and SI distributions were calculated for all the samples and for each of the three sample networks (fig. 8). Age-distribution metrics for the composite age distributions, such as the estimated mean age and the fraction of recharge post-2,000 years, do not meaningfully differ from the average values of individual samples reported in table 2. Calculated SI for the composite age distributions was meaningfully less than the average SI of individual values (table 2). The difference between mean SI and the composite SI illustrated that the composite-age distribution was less sensitive to outlier data than calculated averages of the SI.

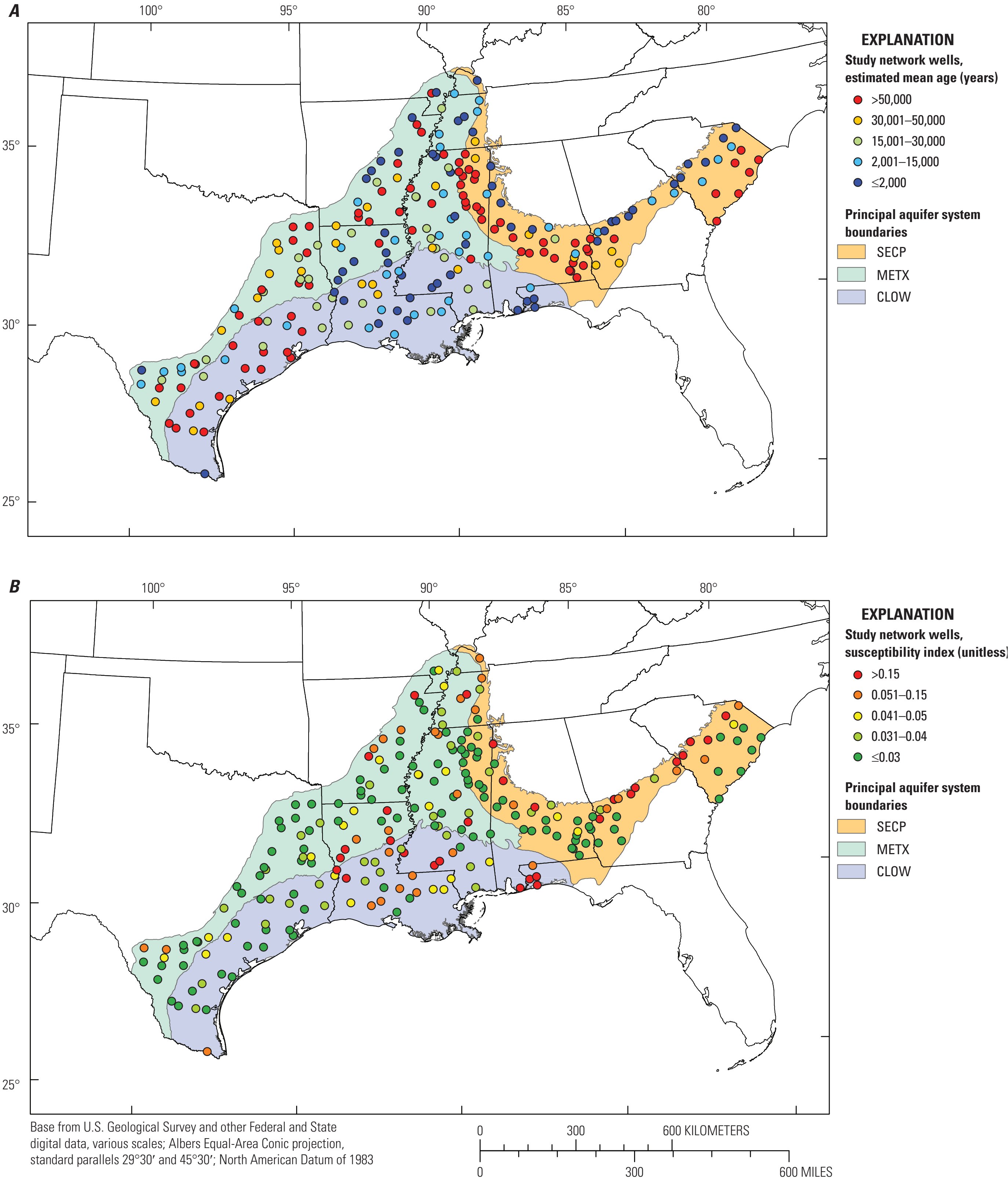

Figure 7. *A*, Estimated mean ages; and *B*, Susceptibility index from principal aquifer study well networks in the south Atlantic and Gulf Coast aquifer systems, USA. The extent of principal aquifer systems is indicated by color (Southeastern Coastal Plain; SECP, yellow; Coastal Lowlands; CLOW, purple; Mississippi embayment–Texas coastal uplands; METX, green).

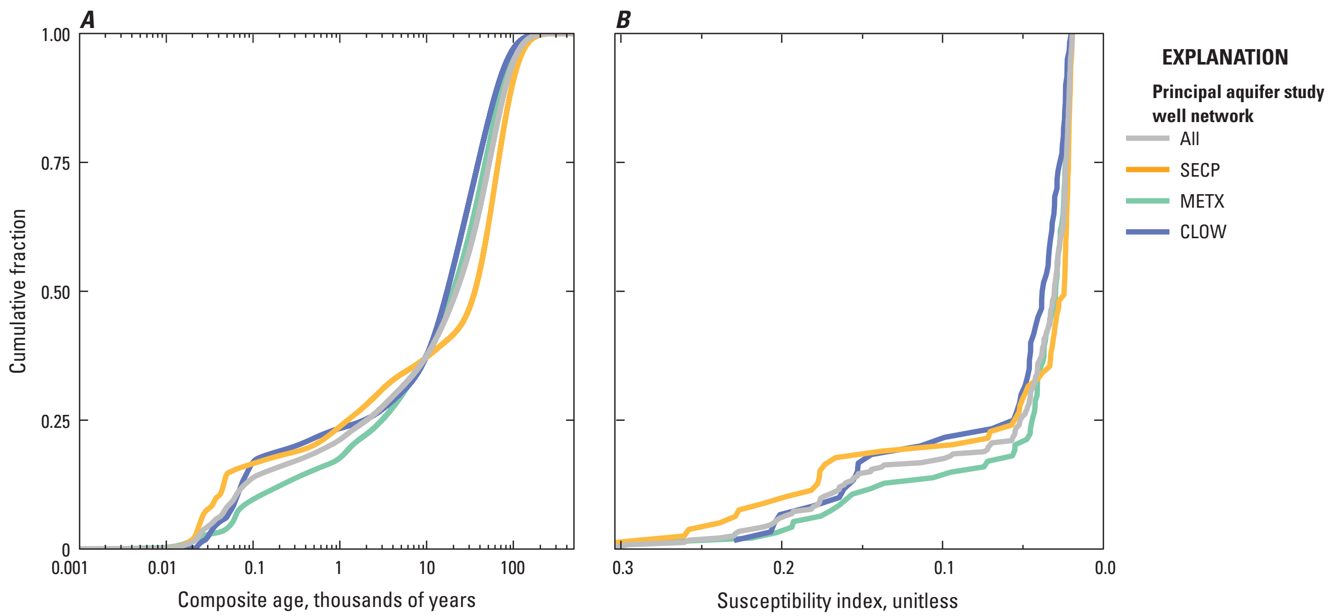

Figure 8. Cumulative distributions of *A*, estimated age; and *B*, susceptibility index from principal aquifer study networks in the south Atlantic and Gulf Coast aquifer systems, USA. Data from principal aquifer systems are indicated by color (all samples; All, grey; Southeastern Coastal Plain; SECP, yellow; Coastal Lowlands; CLOW, purple; Mississippi embayment–Texas Coastal Uplands; METX, green).

Discussion and Summary of Important Findings

The primary objectives of this study were to estimate groundwater age and evaluate the intrinsic susceptibility to contamination of the south Atlantic and Gulf Coast principal aquifer systems through lumped parameter model (LPM) interpretations of environmental tracer concentrations. Dissolved gas modeling, environmental tracer interpretations, geochemical modeling of carbon-14 (^{14}C), and evaluation of various metrics of susceptibility were used to meet the objective. Results presented in this report are a summary of select data from the ScienceBase data release associated with this report (Solder, 2019).

Dissolved gas concentrations were useful for the determination of groundwater recharge conditions and calculated tracer concentrations as indicated by (1) good model fits with noble gas chi-squared (χ^2) values indicating 95 percent confidence (following the criteria of Aeschbach-Hertig and Solomon, 2013) in model results for 215 of 217 total samples and (2) fractionation factors less than 1 (table 2 in Solder, 2019), suggesting that the gas-stripping process did not strongly affect the dissolved gas concentrations (Aeschbach-Hertig and others, 1999, 2000). Recharge conditions across all three aquifer systems estimated by dissolved gas analysis indicated that 72 samples had high amounts of excess air (or entrapped air), greater than 5 cubic centimeters at standard temperature and pressure per kilogram of water (ccSTP/kg; table 1 in Solder, 2019), which is indicative of large and rapid changes in water-table altitudes. Such dramatic changes in water altitudes is conceptually consistent with wide-spread flooding driving large recharge pulses into the groundwater system. There were 28 samples with very high values of entrapped air (greater than 20 ccSTP/kg; table 1 in Solder, 2019) that had fractionation factors greater than 0.6 (table 2 in Solder, 2019). Large amounts of fractionation of dissolved gas indicated that the excess air (or entrapped air) was not completely dissolved into the water and could be a result of water-table rises that were relatively short lived (on the order of weeks or less), preventing the complete dissolution of trapped soil gas before falling water tables exposed the previously trapped gases back to the atmosphere. The remaining 191 samples with excess air (or entrapped air) values less than 5 ccSTP/kg were consistently best fit by models with no fractionation (table 2 in Solder, 2019) and conceptually consistent with relatively small and more persistent changes in water-table elevation. Excess air (or entrapped air) values less than 5 ccSTP/kg is indicative of steady recharge processes such as seasonal precipitation patterns or widespread application of irrigation. The fact that low excess air (or entrapped air) values correspond with no fractionation is partly due to limited gas availability for those samples. Models including fractionation would have been under-parametrized and non-unique, but the goodness of model fit suggests that there is validity to less fractionation in samples with lower amounts of excess air (or entrapped air).

Recently recharged groundwater (with estimated mean age less than 1,000 years) generally has a narrow and uniformly distributed range of noble gas temperatures (NGT) between about 11 and 21 degrees Celsius (°C), with a median of 17 °C (table 1). In contrast, samples with estimated mean ages greater than 10,000 years span the full range of NGTs and are heavily skewed toward cooler temperatures with a median of 12 °C (table 1). This result is consistent with previous investigations conducted at a smaller scale (Stute and others, 1992; Castro and others, 2007) indicating robust records of climatic shifts have been preserved in the south Atlantic and Gulf Coast principal aquifer systems. Although previous investigations of groundwater NGTs across the region is limited, a direct comparison between results of this study at a local scale (between about 14.7 and 18.2 °C; table 1) are consistent with previous investigations (15.4–21.2 °C from Stute and others, 1992; 12.6 to 21.5 °C from Castro and others, 2007) in south Texas parts of the Mississippi embayment–Texas coastal uplands (METX).

Measured concentrations of tritium (^3H) and sulfur hexafluoride (SF_6) and calculated concentrations of tritiogenic helium-3 ($^3He_{trit}$) generally are good indicators of modern water in the three aquifer systems; although as noted, additional factors should be considered in the case of SF_6 and $^3He_{trit}$. Tritium is the most reliable of the modern tracers because it is much less susceptible to contamination and the measured concentration of ^3H does not require any correction. Based on ^3H alone, modern water makes up a small part of the groundwater in the south Atlantic and Gulf Coast principal aquifer systems with ^3H below detection limit (BDL) for 152 of the 231 samples (table 1). Human and geologic sources of SF_6 (Harnisch and Eisenhauer, 1998; Busenberg and Plummer, 2000) and $^3He_{trit}$ uncertainty resulting from error in helium mass balance calculations (Solomon and Cook, 2000) makes use of these tracers suspect for fitting LPMs. In the case of SF_6, measured concentrations (after correction for excess air) generally are much higher than expected when compared to ^3H (table 1). The observation is relatively consistent throughout the three aquifer systems with a median SF_6 of 0.32 parts per trillion by volume (pptv) for samples with ^3H BDL where no SF_6 is expected. Such widespread contamination is likely a result of geogenic sources of SF_6. The presence of SF_6 was not a reliable indicator of modern groundwater and was used in LPMs of groundwater age only when the concentration could be verified by comparison to other tracers. In the case of $^3He_{trit}$, substantial accumulations of terrigenic helium (greater than 70 percent of the total dissolved helium) greatly increases the uncertainty because the calculated values of $^3He_{trit}$ become increasingly sensitive to the assumed isotopic ratio of terrigenic helium. With high amounts of terrigenic helium across the three aquifer systems, the utility of $^3He_{trit}$ was limited. Although samples containing modern water could be identified, parameterization of LPM age distributions with a component of modern water generally was limited, particularly for samples with a mixture of modern and premodern groundwater. As previously discussed in the "Groundwater Age Estimates" section of this report, the age distribution cannot be uniquely defined with one tracer. Ultimately, the lack of modern tracers likely had a minor effect on final interpreted ages in general because most samples did not contain large fractions of modern groundwater.

Carbon-14 was the primary tracer used in this study to optimize LPMs of groundwater age (table 1). Geochemical correction of ^{14}C was done by using analytical correction models (assuming that carbonate dissolution was the primary process affecting the isotopes of dissolved inorganic carbon). Open- and closed-system formulations of the analytical correction model (Han and Plummer, 2013) were selected as appropriate for individual samples (table 4 in Solder, 2019). On average, final adjusted ^{14}C values were about 10 percent modern carbon (pmC; or an order of magnitude on a percentage basis) greater than measured ^{14}C (table 1), which translates to an average of about 4,000 years difference in conventional radiocarbon ages, with uncorrected ^{14}C providing older ages. Previous investigations of geochemistry in portions of the Southeastern Coastal Plain (SECP) and METX (McMahon and others, 1990, 2017; McMahon and Chapelle, 1991; Haile and Fyar, 2017) suggest additional processes could affect ^{14}C; for example, organic carbon reduction and cation exchange can be important processes to consider when using ^{14}C in the south Atlantic and Gulf Coast aquifer systems. Of note, in regard to groundwater age, is the need for explicit accounting for diffusive chemical exchange among aquifer units and confining beds which McMahon and Chapelle (1991) indicated as critical for explaining the geochemistry of the SECP. Kennedy and Genereux (2007) illustrated the importance of accounting for such exchanges in a similar aquifer system, but with thinner water-bearing units, indicating ^{14}C age-dating adjustments as large as multiple 1,000s of years. In this study, it was determined that the influence of exchanges between aquifer and confining units on ^{14}C were likely not significant following the criteria of Sanford (1997) because the confining units generally were quite thick. Diffusive loss of ^{14}C could be an important process affecting groundwater chemistry in regions of the aquifer system with thin confining units and young groundwater ages, both of which typically exist in the shallow up-dip regions of the aquifer system. However, for young water on the order of a few 1000s years old, a significant loss of ^{14}C (10s of pmC) is required before mean ages are significantly altered. Further refinement of mean ages that are a few 1000s of years old does not significantly alter the primary findings presented in this report.

Calculation of groundwater ages using tracers is fundamentally limited by the tracer analytical detection limit. In the case of ^{14}C, the reported analytical limit of about 0.15 pmC limits interpretation of groundwater ages to less than 50,000 years. Previous investigations in similar aquifers in the north Atlantic coastal plain (Plummer and others, 2012) and southern Texas (Castro and others, 2000) have indicated groundwater ages well outside the ^{14}C age-dating range. The likely tracer candidate for such dating, helium-4 (^{4}He), is produced by uranium and thorium nuclide decay (Andrews and Lee, 1979) and accumulates in groundwater with increasing residence time (Mazor and Bosch, 1992). Radiogenic ^{4}He sources to groundwater, excluding deep mantle sources separable by noble gas isotopes, include in situ production from aquifer sediments; diffusion from mineral grains; and flux from adjacent hydrogeologic units (Solomon, 2000). Determination of the aquifer-specific ^{4}He accumulation rate is needed for calculation of ^{4}He based groundwater age. Previous investigations in the region or similar hydrogeologic settings, such as, Castro and others (2000), Carey and others (2004), and Plummer and others (2012), have used ^{14}C ages to estimate the ^{4}He accumulation rate. Such a method would possibly improve estimated groundwater ages in the south Atlantic and Gulf Coast aquifer systems, but the required additional investigation of the noble gas isotopes and detailed ^{14}C geochemical correction modeling is outside the scope of this study.

The distribution of estimated mean ages across the three aquifer systems generally was consistent with the hydrogeology and well sample network design. Groundwater generally increases in age moving toward the down-dip extent of the aquifer systems; most clearly illustrated in the SECP (fig. 7*A*). This pattern of increasing groundwater ages moving down-dip also was apparent in the METX to some extent. Groundwater ages generally increase moving toward the embayment axis and, in the far western portions of the aquifer system, moving toward the coast. Estimated mean ages were oldest in the SECP, followed by the METX and Coastal Lowlands (CLOW; tables 1, 2; fig. 6*A*), which was consistent with the well dimensions (deepest wells and longest screen intervals in the SECP, fig. 2) and general hydrogeology of the three aquifer systems. The SECP has the most spatially extensive confining units resulting in longer groundwater flow paths, thus, older groundwater ages were captured at the wells. Conversely, the hydrogeology of the CLOW is more complex, particularly in the eastern half of the aquifer system, with discontinuous confining units resulting in more regions of unconfined aquifer units. The larger regions of unconfined aquifer units relative to the respective confined flow-path length result in the capture of more short flow paths and young groundwater ages at the wells. The hydrogeology of the METX is somewhere along the spectrum between the extensive confining units more characteristic of the SECP and the exposure of aquifer units at the surface of the CLOW, as represented in the intermediate mean ages. The respective age distributions of the three aquifer systems (fig. 8*A*) show the SECP has the largest range of estimated groundwater ages as indicated by the width of the distribution. In fact, the SECP contains both the youngest and the oldest groundwater of the region. Interestingly, the METX and CLOW have very similar distributions of the old component of groundwater (fig. 8*A*), but the CLOW contains around 10 percent more groundwater that is less than 100 years old than the METX does.

Estimated mean ages from this study are in relatively good agreement with previous investigations that were conducted on smaller parts of the three aquifer systems. In Texas, groundwater ages in the METX were previously estimated to range between modern and greater than 42,000 years (Pearson and White, 1967; Castro and others, 2000; Oden and Truini, 2007). Also, in Texas, groundwater ages in the CLOW ranged between modern and 5,000 years in the up-gradient portion of the aquifer system (Oden and Truini, 2007). In southern Alabama, groundwater age in shallow portions of the CLOW was estimated to range from 400 to 7,000 years (Carey and others, 2004) and in North Carolina, just north of the SECP in similar aquifer units, groundwater ages were estimated to range from 5,500 to 34,000 years (Kennedy and Genereux, 2007). The previously estimated mean ages are in good agreement with the results of this study: For example, the Texas parts of the METX (140 to greater than 50,000 years); the central Texas parts of the CLOW (25 to 23,000 years); the southern Alabama parts of the CLOW (67 to 24,000 years); and the northern SECP (110 to greater than 50,000 years; table 1; fig. 7*A*; table 3 in Solder, 2019).

Regional variations in modern climate and groundwater use also influence the distribution of ages across the three aquifer systems. Long-term average rainfall generally decreases across the study area from east to west (Wieczorek and LaMotte, 2010), with the highest annual precipitation falling along the Louisiana, Mississippi, and Alabama coast north into the Mississippi embayment and the lowest annual precipitation falling in the southwestern portions of Texas. Increased recharge rates in response to higher annual precipitation generally would result in younger groundwater ages, and vice-versa. Combined with the expectation that young groundwater generally is constrained to up-dip and unconfined portions of the aquifer, groundwater ages less than 2,000 years old occur more frequently in the regions receiving more annual rainfall (fig. 7*A*). A notable exception to the relationship between young water and high precipitation is the up-dip portions of the METX and CLOW in eastern Texas. The hydrogeology and annual precipitation in east Texas are comparable to the inland portions of the SECP in South Carolina and Georgia, but estimated mean ages are much older, generally by more than an order of magnitude.

Well depths that are approximately 60 percent deeper in east Texas are unlikely to account for the differences in age alone. A dominant control could be that the CLOW and METX of east Texas are heavily pumped (Huang and others, 2012; Konikow, 2013) for municipal and irrigation uses. In general, groundwater withdrawals result in the capture of older groundwater over time as increasingly more water from storage in deeper portions of the aquifer is required to match pumping demand, with the possible exceptions of shallow screen intervals or substantial drawdown resulting in the capture of a larger proportion of shallow, young groundwater over time. Discordant groundwater ages in respect to hydrogeology and climate, or large changes in groundwater age over time, could provide some indication of unsustainable groundwater development. In addition to water budget calculations and numerical groundwater modeling, groundwater ages can provide additional value in investigations of groundwater sustainability in the three aquifer systems.

Quantitative assessment of groundwater susceptibility to contamination requires differing metrics for young groundwater more susceptible to land-surface contamination versus groundwater with long residence times more susceptible to geogenic contamination sources. Metrics such as the susceptibility index (SI; see “Susceptibility Index” section) are good candidates for quantifying groundwater susceptible to land-surface contaminants. Conversely, the estimated mean age and fraction of recharge after a set number of years before present (see “Composite Age and Susceptibility Index Distributions” section) could be used to quantify intrinsic susceptibility to geogenic contamination. More complete understanding of contamination requires identifying source, such as, land-surface contaminants or sediment mineral composition, and specific characterization of water-rock-solute geochemistry, which is outside of the scope for this report. Age metrics for intrinsic susceptibility provide some guidance on what type of groundwater is likely more susceptible. Mixtures of groundwater containing young and old groundwater are susceptible to land-surface and geogenic contaminants which suggests that a combination of metrics (or a differing set of metrics) are potentially more useful for identifying groundwater well susceptibility. Depending on the conceptual hydrology and age distributions of individual samples, alternative age and age distribution metrics might be more appropriate. An exhaustive investigation of relation between observed concentrations for contaminants of concern and various age metrics is outside the scope of this work. A limited set of tracer-based metrics for identifying the presence of young and old groundwater are provided in this report, with the requisite data for calculation of additional metrics provided in the associated ScienceBase data release (Solder, 2019).

Conclusion

Tracer-based estimates of mean age, age distributions, and susceptibility metrics for 231 wells in the south Atlantic and Gulf Coast principal aquifer systems (Southeastern Coastal Plain, SECP; Mississippi embayment–Texas coastal uplands, METX; and Coastal Lowlands, CLOW) are presented in this report. As might be expected for a large study area that covered approximately 4.17×10^5 square miles in parts of 12 states, a wide range of groundwater age and susceptibility was observed. Estimates of mean groundwater ages ranged from 17 years to greater than 50,000 years. In general, groundwater across the three aquifer systems is dominated by premodern water (207 of the 231 total samples) with an overall mean age of about 33,000 years. Estimated groundwater ages are youngest at the up-dip extent of the aquifer systems where the aquifer units crop out and increase in age with increasing depth, confinement, and distance from the outcrop. In the SECP, with relatively continuous confining units, groundwater age has a coherent spatial structure with younger groundwater along the in-land extent of the aquifer system and the oldest groundwater located in the furthest down-dip portions of the aquifer system. In the CLOW and METX, with a more complex hydrogeology of discontinuous confining units and steeply dipping aquifer units, groundwater ages are more spatially variable with young groundwater ages (less than 2,000 years) interspersed with groundwater greater than 10,000 years old. Estimated groundwater age also is related in the regional climate and groundwater extraction rates. The relation between age and climate is best illustrated by the less frequent occurrence of groundwater less than 2,000 years old in the more arid western portions of the METX and CLOW; this is indicative of lower recharge rates compared to aquifer-recharge areas in the three aquifer systems that receive more precipitation. The impact of heavy pumping on groundwater age might be apparent in the eastern portions of Texas near the Houston metropolitan area. This region of east Texas generally has a similar climate to that of South Carolina and eastern Georgia but with markedly older groundwater in the unconfined up-dip portions of the respective aquifers. The increased groundwater ages can be related to groundwater extraction rates in excess of recharge rates resulting in capture of older groundwater from storage to meet pumping demands. The intrinsic susceptibility across the aquifer system was estimated based on metrics which summarize the groundwater age distributions. Separate metrics, such as the susceptibility index (SI) for assessing susceptibility to land-surface contamination and the fraction of recharge less than 15,000 years old for assessing susceptibility to geogenic contamination, were calculated for individual and composite age distributions for each of the three aquifer systems. Individual SI generally was low with a median value of about 0.03 indicating that groundwater susceptibility to land surface contamination generally was not a concern across the three aquifer systems except at specific sites. Conversely, the fraction of recharge less than 15,000 years old also was relatively low with an average value of 0.43, meaning 57 percent of the total groundwater sampled was greater in age than 15,000 years and implies that contamination of groundwater from geogenic sources is likely a greater concern than anthropogenic contamination. A third group of samples, containing a mixture of young water susceptible to land-surface contamination and old groundwater susceptible to geogenic contamination sources, were difficult to identify in this study because of modern tracer contamination (sulfur hexafluoride) and calculation uncertainty (tritiogenic helium-3). Wells that were sampled in this study that showed measurable tritium greater than 0.2 tritium units and carbon-14 less than 75 percent modern carbon, indicative of a mixture of young and old groundwater, likely would benefit from additional investigation to determine the relative susceptibility to contamination.

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Back cover:

Leafed trees, June 11, 2005.

Red building with clock tower, April 9, 2010.

Man riding red tractor on field, May 22, 2009.

Paddle wheel, July 28, 2018.

Ornate tap, September 5, 2019.

Aerial view photography of green leaf trees surrounded by body of water at daytime, March 7, 2018.

Water tower sunset, July 30, 2016.

Group of pink pigs on cage, April 2, 2015.

White sheet metal tower blue sky, January 22, 2018.

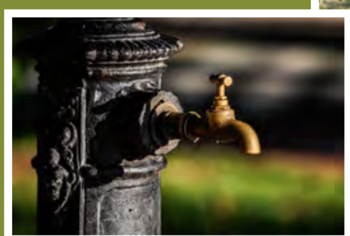
Texas house, white painted structure with green palm trees in the front, October 15, 2012.

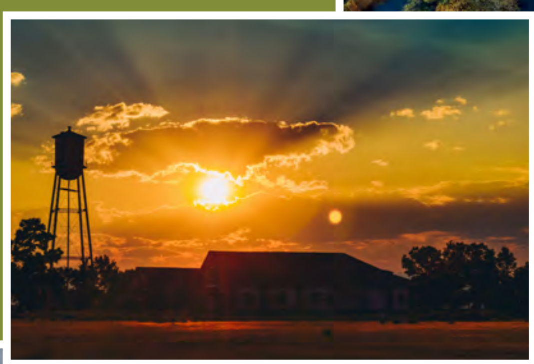
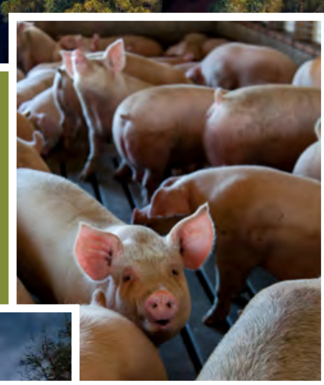
Dead tree swamp, September 24, 2017.

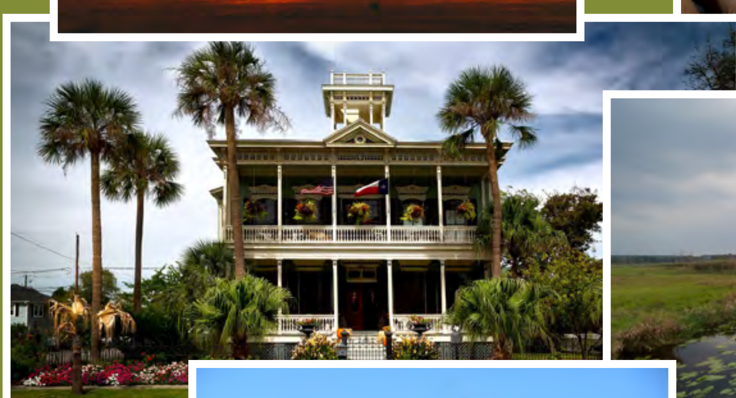
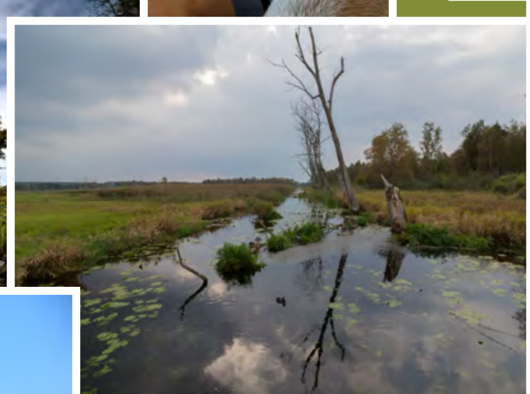
Hand under water pouring from pipe, April 11, 2018.

Red pumpjack blue sky, June 12, 2018.



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