(one-size fits all) for recharge determination, many methods have been developed for estimating recharge rates. Selection of the appropriate method for a given study is important and can be challenging. A detailed description of all recharge-estimation methods and their limitations is beyond the scope of this fact sheet (see Healy, 2010, for a thorough review of recharge estimation methods and their associated limitations). The section of this fact sheet entitled "Estimated Recharge Rates in Montgomery and Adjacent Counties" provides a general description of the groundwater age-dating method that was used effectively for estimating groundwater recharge rates in Montgomery County.

Hydrogeology of Montgomery County

The Gulf Coast aquifer system in Montgomery County, Texas, consists of the Chicot, Evangeline, and Jasper aquifers, Burkeville confining unit, and the underlying Catahoula confining system (fig. 1). The sediments composing the Gulf Coast aquifer system were deposited by rivers and deltas and subsequently eroded and redeposited (reworked) by large episodic changes in sea level, resulting in stacked, wedge-shaped sequences of coarser and finer-grained sediments that dip and thicken towards the Gulf of Mexico (Ryder, 1996).

This type of coastal depositional environment created a complex, heterogeneous aquifer of multiple confined and unconfined aquifers where sand and clay lens thicknesses and horizontal extents can change rapidly over short distances. The Evangeline and Jasper aquifers are for the most part confined aquifers in the study area. The Chicot aquifer is designated as "unconfined" in the study area, as are the up-dip regions of the Evangeline and Jasper where each aquifer is exposed at land surface. Figure 1 shows the relative position of the each of the aquifers; a detailed hydrogeologic section is available in the USGS Scientific Investigations Report referenced by this fact sheet (Oden and Truini, 2013, p. 7).

Estimated Recharge Rates in Montgomery and Adjacent Counties

Recharge rates to the Gulf Coast aquifer system in Montgomery County and the surrounding region have been estimated in previous studies by using many methods (table 1). The method used for this study is briefly described here, with further details available in Oden and Truini (2013).

Groundwater Age-Dating Method

Groundwater ages are a measure of the time since the water entered the saturated zone and was isolated (as a result of additional recharge) from the atmosphere, which sets the "age" of the water. The actual groundwater is not dated, but the apparent age of groundwater can be estimated from concentrations of dissolved chemicals or isotopes used as environmental tracers and from a comparison of the equivalent atmospheric concentration of each tracer to the atmospheric input signal for that tracer. Factors affecting the time since isolation from the atmosphere can include the sorption or degradation of the tracer, porosity of the unsaturated zone, recharge rate, thickness of the unsaturated zone, and magnitude of water level fluctuations (Plummer and Busenberg, 2000).

Table 1. Comparison of recharge rates determined in Montgomery and adjacent counties in Texas during March–September 2008 and April–May 2011 by using environmental age tracers with recharge rates from previous studies using various methods in the Gulf Coast aquifer system.

[in./yr, inches per year; <, less than; $^3H/^3He$, tritium/helium-3; CFC-12, dichlorodifluoromethane; SF_6, sulfur hexafluoride; ^4He, helium-4; ^{14}C, carbon-14; ^3H, tritium; Cl, chloride]

Sample collection dates	Counties	Aquifer	Recharge rate (in./yr)	Method
March–September 2008 April–May 2011	Montgomery	Chicot aquifer	0.2–7.2	Environmental age tracers ($^3H/^3He$, CFC-12, SF_6, ^4He and ^{14}C)
March–September 2008 April–May 2011	Montgomery	Evangeline aquifer	<0.1–2.8	Environmental age tracers ($^3H/^3He$, CFC-12, SF_6, ^4He and ^{14}C)
March–September 2008 April–May 2011	Montgomery, Walker, and Waller	Jasper aquifer	<0.1–0.5	Environmental age tracers ($^3H/^3He$, CFC-12, SF_6, ^4He and ^{14}C)
Previous studies	**Counties**	**Aquifer**	**Recharge rate (in./yr)**	**Method**
Popkin (1971)	Montgomery	Gulf Coast aquifer system	1.7	Transmission capacity
Ryder (1988)	Montgomery	Gulf Coast aquifer system	0–2	Groundwater model
Williamson and others (1990)	Montgomery	Gulf Coast aquifer system	0.00–0.66	Groundwater model, predevelopment conditions
Williamson and others (1990)	Montgomery	Gulf Coast aquifer system	0.66–3.00	Groundwater model, 90 percent 1980 pumpage
Noble and others (1996)	Harris, Montgomery, and Walker	Chicot and Evangeline aquifers	0.0–6.0	^3H interface method
Nolan and others (2007)	Harris and Montgomery	Chicot and Evangeline aquifers	0.03–4.13	Cl tracer in saturated zone
Scanlon and others (2011)	Montgomery	Chicot aquifer	0.8–4.8	Hydrograph analysis and chloride mass balance.

The environmental tracers used in this study were chlorofluorocarbons (CFC-12), sulfur hexafluoride (SF_6), and tritium/helium-3 ($^3H/^3He$) (table 2). These tracers were used to estimate the apparent age of groundwater recharged after the 1940s. Helium-4 (^4He) and carbon-14 (^{14}C) were also used in this study to estimate the apparent age of groundwater recharged from about 100 to about 40,000 years before present (Healy, 2010) (table 2, fig. 3). Estimated recharge rates from this study ranged from 0.2 to 7.2 inches per year for the Chicot aquifer, less than 0.1 to 2.8 inches per year for the Evangeline aquifer, and less than 0.1 to 0.5 inches per year for the Jasper aquifer (table 2, figs. 2 and 3).

Limitations of Estimating Recharge Rates

Estimation of groundwater ages and recharge rates requires some assumptions about the hydrogeologic properties of the aquifer system which creates some uncertainty in these estimates. Despite the complexity of the aquifer system in Montgomery County, the estimates of groundwater ages and recharge rates are considered to be appropriate for use as a general guide in hydrologic investigations. For example, these estimates can be used for further investigation into the availability of the groundwater resources in the county and can be used as input parameters in groundwater-flow models. Results of this study—that is, recharge rates in Montgomery County are less than 0.1 to 7.2 inches per year—are within the range of expected values in and near the study area (table 1). The following limitations of these results should be considered:

1. The hydrogeology is highly variable on a regional scale, so estimated recharge rates in the study area may reflect (or represent) localized groundwater flow paths contrary to the regional flow pattern.

2. For the conceptual model of this system, piston flow in the aquifer is assumed, and the constituent concentration is assumed to be unaltered by mixing or dispersion from the point of recharge to the sampling point in the aquifer. This assumption is most likely an oversimplification for the specific aquifers in the study area.

3. The calculation of recharge rates for confined and unconfined aquifers requires an estimation of aquifer porosity; the porosity values used were based on previous scientific investigations of the aquifers in and adjacent to the study area. A decrease in porosity will lower the estimated recharge rate, whereas an increase in porosity will raise the estimated recharge rate.

4. The possibility exists for the mixing of waters of different composition and age through vertical connection between aquifers such as a well with multiple screens or along preferential flow paths of the aquifers.

5. The estimated recharge rates are specific to each well location and should not be extrapolated or inferred as a countywide average.

6. The interpretation of environmental tracer data can be complicated along individual flow paths by additional independent variables that affect the tracer concentrations such as degassing, contamination, dispersion, sorption, chemical reactions, transport through thick unsaturated zones, and aquifer/water interactions, such as input of excess ^4He.

Table 2. Apparent groundwater ages and recharge estimates derived by using samples collected during March–September 2008 and April–May 2011 from wells completed in the Chicot, Evangeline and Jasper aquifers in Montgomery and adjacent counties, Texas.

[in./yr, inches per year; $^3H/^3He$, tritium/helium-3; CFC-12, dichlorofluoromethane; ^4He, helium-4; SF_6, sulfur hexafluoride; <, less than; >, greater than; ^{14}C, carbon-14]

Map identifier (fig. 2)	Sample date	Recharge (in./yr)	Apparent age (years)	Tracer	Aquifer
1	3/12/2008	3.7	73	$^3H/^3He$	Chicot
2	3/13/2008	4.8	27	CFC-12	Chicot
4	3/19/2008	3.8	62	^4He	Chicot
5	3/19/2008	2.3	23	$^3H/^3He$	Chicot
7	3/24/2008	2.7	71	$^3H/^3He$	Chicot
10	3/26/2008	2.1	32	SF_6	Chicot
12	3/27/2008	1.0	48	CFC-12	Chicot
14	4/21/2008	0.5	62	CFC-12	Jasper
16	4/22/2008	0.1	52	CFC-12	Evangeline
17	4/27/2011	<0.1	>42,000	^{14}C	Jasper
18	4/20/2011	1.0	900	^{14}C	Evangeline
19	4/24/2008	2.4	50	CFC-12	Chicot
20	4/28/2008	1.9	44	^4He	Chicot
21	4/30/2008	3.4	32	$^3H/^3He$	Chicot
22	7/10/2008	1.5	825	^4He	Evangeline
23	5/3/2011	2.8	2,700	^{14}C	Evangeline
24	5/9/2011	<0.1	13,000	^{14}C	Jasper
25	7/18/2008	7.2	35	$^3H/^3He$	Chicot
27	4/20/2011	0.1	27,000	^{14}C	Jasper
28	4/26/2011	0.1	26,000	^{14}C	Evangeline
30	8/18/2008	2.4	2,092	^4He	Evangeline
31	4/15/2011	0.1	18,000	^{14}C	Jasper
32	4/28/2011	<0.1	33,000	^{14}C	Jasper
34	4/25/2011	0.2	8,000	^{14}C	Evangeline
36	4/18/2011	0.9	650	^{14}C	Chicot
37	4/18/2011	0.4	900	^{14}C	Chicot
38	4/18/2011	0.2	5000	^{14}C	Chicot
39	4/21/2011	<0.1	42,000	^{14}C	Evangeline
40	4/21/2011	0.1	32,000	^{14}C	Evangeline
41	5/11/2011	0.1	42,000	^{14}C	Jasper
42	5/12/2011	0.1	19,000	^{14}C	Jasper
43	5/12/2011	0.1	16,000	^{14}C	Jasper
44	5/13/2011	0.1	37,000	^{14}C	Jasper.

This fact sheet is based on the following USGS report:

Oden, T.D. and Truini, M., 2013, Estimated rates of groundwater recharge to the Chicot, Evangeline, and Jasper aquifers by using environmental tracers in Montgomery and adjacent counties, Texas, 2008 and 2011: U.S. Geological Survey Scientific Investigations Report 2013-5024, 50 p., http://pubs.usgs.gov/sir/2013/5024.

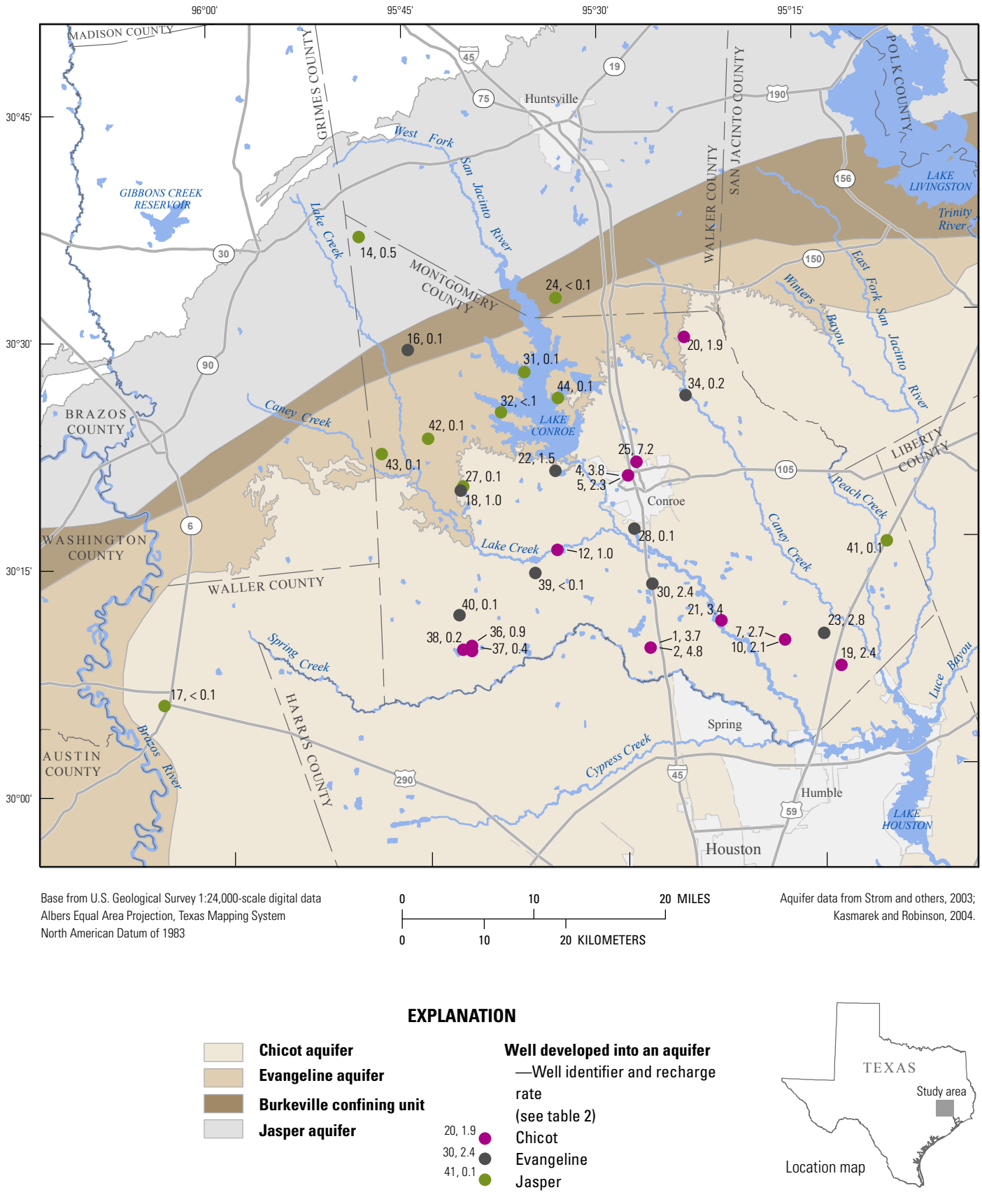

Figure 2. Location of wells completed in the Chicot, Evangeline, and Jasper aquifers where recharge estimates were determined on the basis of measured environmental tracer concentrations in Montgomery, Walker, and Waller Counties, Texas 2008–11.

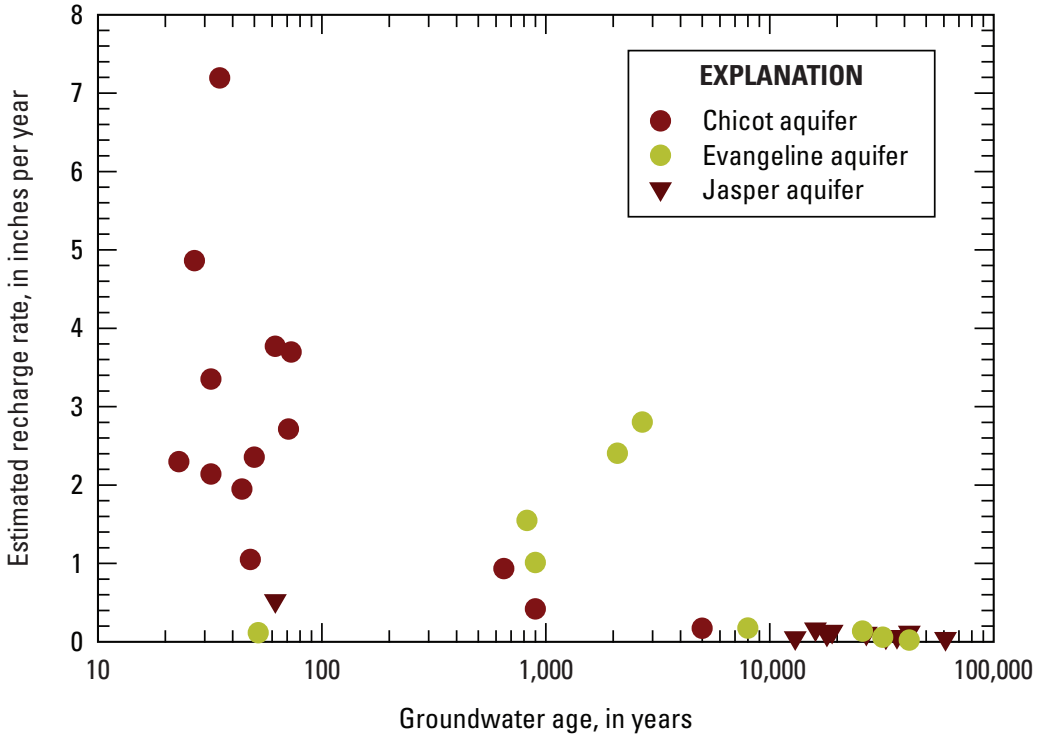

Figure 3. Groundwater age and estimated recharge rate by aquifer from wells sampled in Montgomery, Walker, and Waller Counties, Texas 2008–11.

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By Timothy D. Oden and Geoffrey N. Delin

For additional information contact:

Director, Texas Water Science Center
U.S. Geological Survey
1505 Ferguson Lane
Austin, Texas 78754–4501
http://tx.usgs.gov/