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Groundwater Recharge to the Gulf Coast Aquifer System in Montgomery and Adjacent Counties, Texas

Simply stated, groundwater recharge is the addition of water to the groundwater system. Most of the water that is potentially available for recharging the groundwater system in Montgomery and adjacent counties in southeast Texas moves relatively rapidly from land surface to surface-water bodies and sustains streamflow, lake levels, and wetlands. Recharge in southeast Texas is generally balanced by evapotranspiration, discharge to surface waters, and the downward movement of water into deeper parts of the groundwater system; however, this balance can be altered locally by groundwater withdrawals, impervious surfaces, land use, precipitation variability, or climate, resulting in increased or decreased rates of recharge. Recharge rates were compared to the 1971–2000 normal annual precipitation measured Cooperative Weather Station (COOP) 411956, Conroe, Tex. (National Climatic Data Center, 2013).

- Recharge rates to the Chicot aquifer in Montgomery County ranged from 0.2 to 7.2 inches per year or 0.4 to 14.6 percent of normal annual precipitation.
- Recharge rates to the Evangeline aquifer in Montgomery County ranged from less than 0.1 to 2.8 inches per year or 0.2 to 5.67 percent of normal annual precipitation.
- Recharge rates to the Jasper aquifer in Montgomery, Walker and Waller Counties ranged from less than 0.1 to 0.5 inches per year or 0.2 to 1.01 percent of normal annual precipitation.

What is Groundwater Recharge?

The term "groundwater recharge" generally describes the replenishment of water to a groundwater flow system (Healy, 2010). Recharge, an integral part of the hydrologic cycle, is the process by which water that first fell as precipitation moves to the water table and then away from that area through saturated materials, adding to groundwater storage. Figure 1 depicts the hydrologic processes of precipitation recharging the Gulf Coast aquifer system. Runoff from precipitation first infiltrates the sediments exposed at the land surface and then moves downward through layers of sediments until it reaches the water table and becomes part of the groundwater flow of the Gulf Coast aquifer system. Once water is part of the groundwater flow system, it begins to move toward rivers or other surface water bodies and eventually discharges into the Gulf of Mexico. Recharge in southeast Texas is generally balanced by evapotranspiration, discharge to surface waters, and the downward movement of water into deeper parts of the groundwater system; however, this balance can be altered locally by groundwater withdrawals, impervious surfaces, land use, precipitation variability, or climate, resulting in increased or decreased rates of recharge.

Where Does Recharge Occur?

Recharge to the groundwater system occurs mostly in unconfined outcrop areas where aquifer sediments are exposed at land surface (an aquifer is designated as "confined" when the top of the aquifer is bounded by another aquifer or confining unit). Precipitation infiltrates the groundwater system at various rates in the unconfined outcrop areas, and moves downward into the more confined parts of the system. Given an equal amount of precipitation, recharge rates are higher in outcrop areas composed of a larger percentage of sand and smaller percentage of clay and silt (such as the relatively sandy sediments present in the northern parts of outcrop areas of the Gulf Coast aquifer system) compared to outcrop areas composed of a smaller percentage of sand and a larger percentage of clay and silt (such as the relatively clayey sediments present in the southern part of outcrop or confined parts of the Gulf Coast aquifer system). Additionally, surface runoff from precipitation flowing into low topographic areas or depressions (lowlands) contributes recharge to the aquifer system (fig. 1). The recharge becomes part of the groundwater flow system, moves down gradient in a coastward direction through the multiple interbedded sands and clay layers, and discharges into streams (as base flow) and to larger bodies of water such as bays and estuaries and to the Gulf of Mexico.

Additional water recharges the Evangeline aquifer by leakage of water from the overlying Chicot aquifer. Leakage is a process similar to but not the same as recharge. Rates of leakage to confined aquifers are generally less than rates of recharge to unconfined aquifers. Upward leakage also occurs from a confined aquifer in areas where hydraulic head in the confined aquifer is greater than that in the overlying formation, that is, water moves from areas of greater to lower hydraulic head.

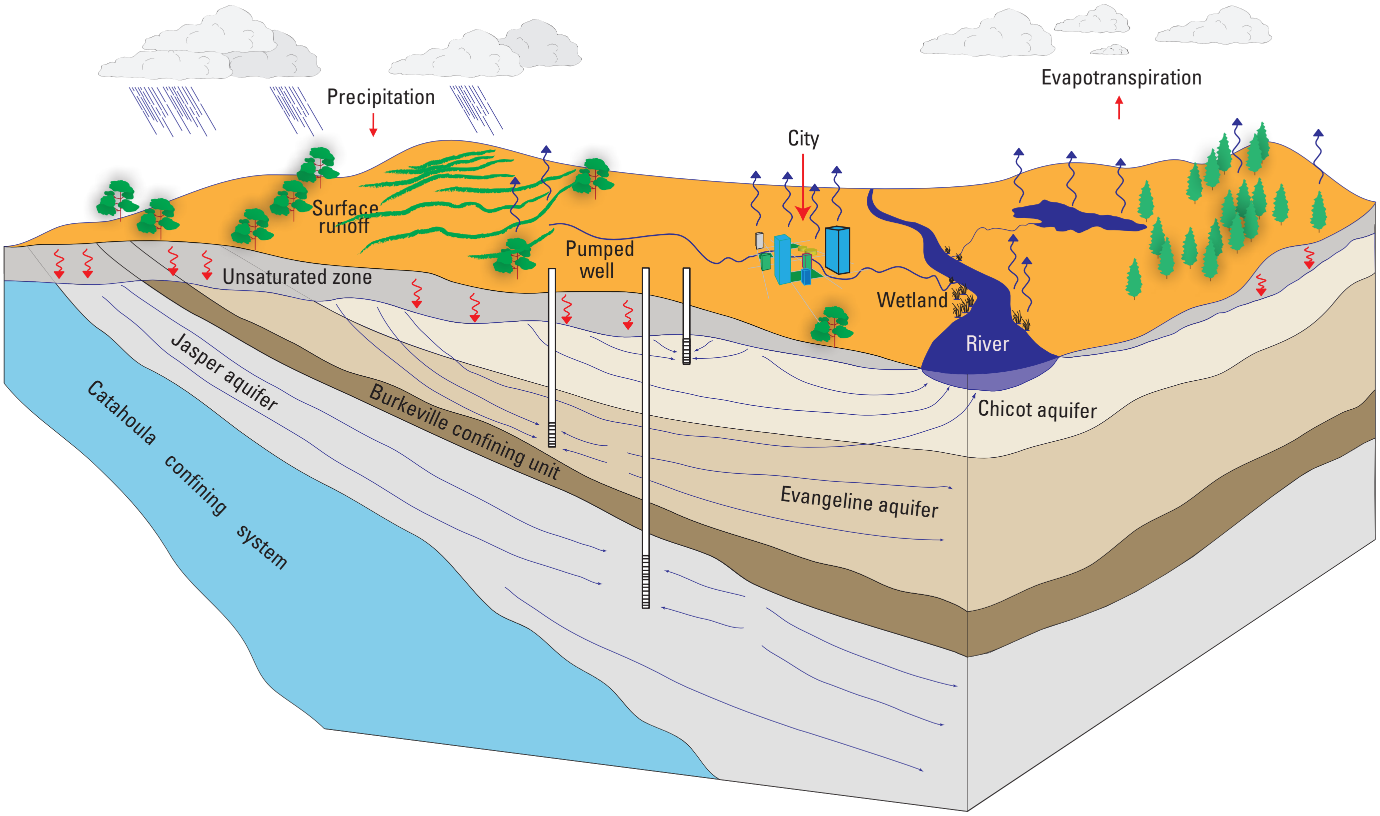

Figure 1. Groundwater recharge is an important part of the hydrologic cycle (modified from Delin and Falteisek, 2007).

Why Do Recharge Rates Vary?

Numerous factors—including physical characteristics of the soil, vegetation cover, land use, topography, water content of surface materials, and the presence and depth of the fine-grain clay layers—influence the spatial variability of recharge rates. Weather patterns, including the timing and intensity of precipitation and evapotranspiration during the summer growing season, play an important role in controlling spatial and temporal variability in recharge rates.

When Does Recharge Occur?

The amount of groundwater recharge varies seasonally in response to precipitation. During fall and winter, water levels generally increase because precipitation rates are higher, withdrawal is lower, and evapotranspiration is lower. During the spring and summer seasons, withdrawals generally increase, precipitation rates are lower, and evapotranspiration is higher.

Why Is Information on Groundwater Recharge Rates Important?

Knowledge of groundwater recharge rates is important to studies of water availability, sustainability, wellhead protection, contaminant transport, groundwater and surface-water interactions, effects of urbanization, and aquifer vulnerability to contamination (Scanlon and others, 2002). Estimates of recharge rates are necessary to quantify the volume of water flowing through near-surface groundwater systems and are important to understand the water balance of an aquifer or aquifer system and the human impact on that balance. For example, by estimating the spatial distribution of recharge rates, one can estimate the total volume of water entering a system. The recharge rate is one of the more sensitive and important parameters of groundwater flow models and is the parameter least understood (Delin and Falteisek, 2007).

Groundwater recharge is not

- equivalent to "infiltration" of water at the land surface. Most water that infiltrates at the land surface is returned to the atmosphere by plant transpiration and evaporation from soil and water surfaces (fig. 1). Recharge is typically only a small percentage of infiltration;
- equated to the process of "percolation"; instead, percolation refers to the movement of water through unsaturated sediments; however, percolating water can be viewed as potential recharge; if it reaches the water table it will become recharge;
- to be confused with the term "aquifer yield." This term refers to the amount of water that an aquifer can yield to pumping;
- the same as "sustainable yield." Recharge can be less than sustainable yield. For example, if all recharge water were utilized, stream, lake, and wetland levels could decrease over time. Furthermore, it cannot be assumed that pumping at less than the recharge rate will not cause water-level declines and groundwater storage depletions (Delin and Falteisek, 2007).

How Are Recharge Rates Estimated?

Groundwater recharge rates cannot be measured with an instrument; thus, recharge rates must be estimated by using indirect methods. Although there is no single method (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.

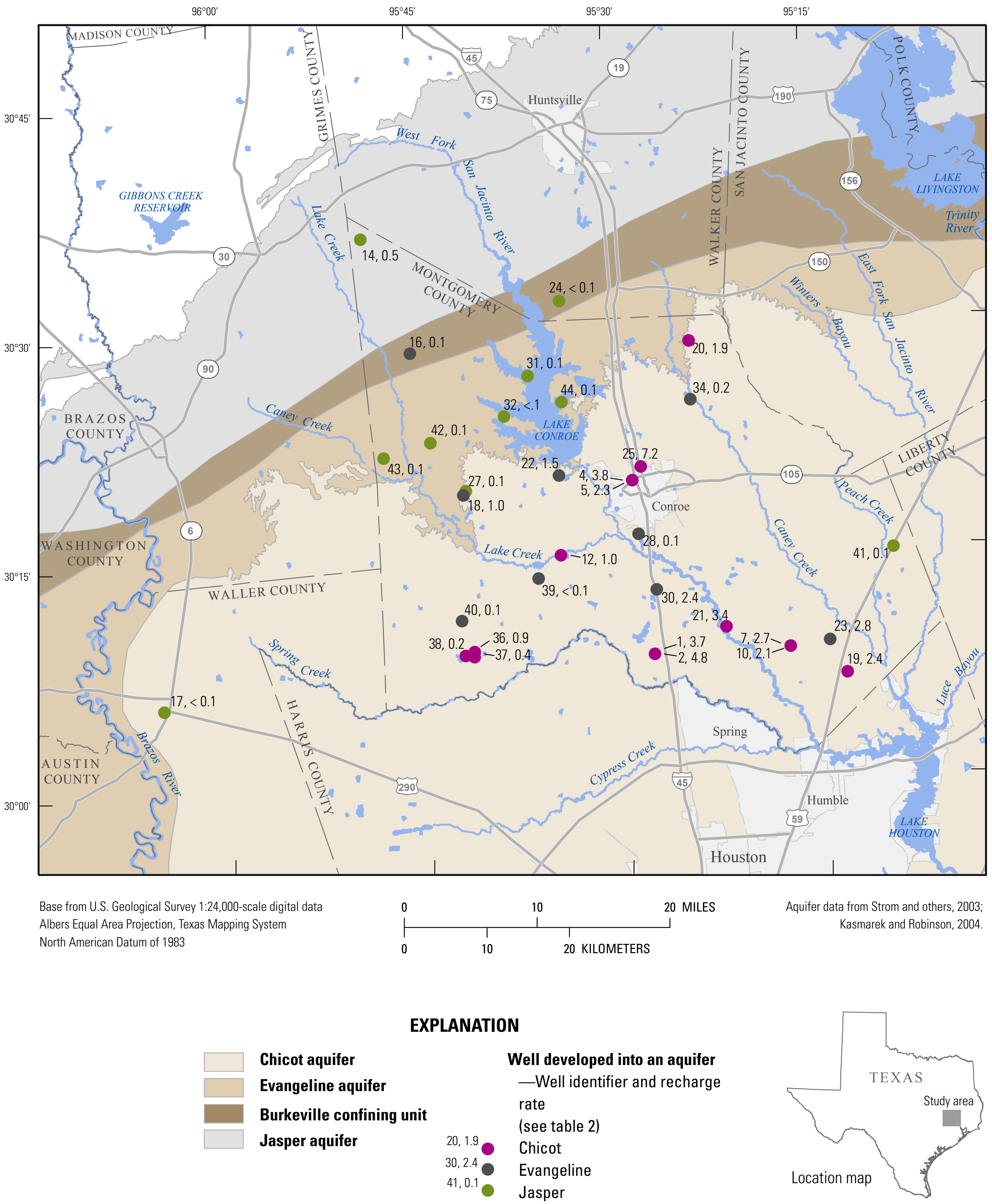

Figure 2. Location of wells completed in the Chicot, Evangeline, and Jasper aquifers where recharge estimates were determined on the basis of measured environmental tracer concentrations in Montgomery, Walker, and Waller Counties, Texas 2008–11.

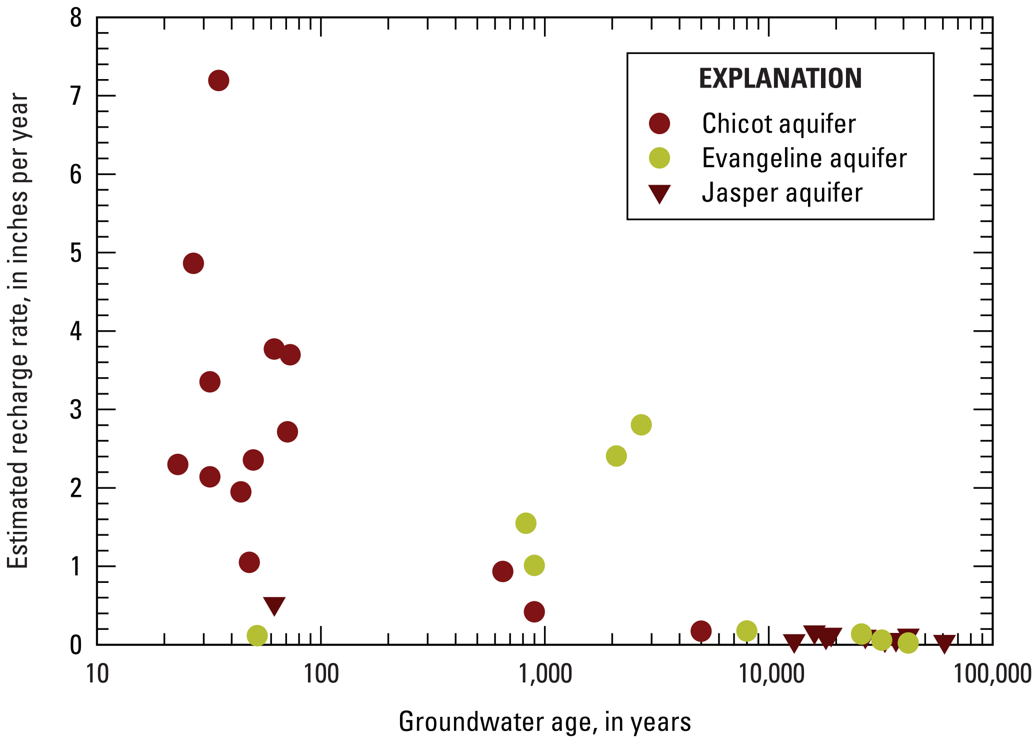

Figure 3. Groundwater age and estimated recharge rate by aquifer from wells sampled in Montgomery, Walker, and Waller Counties, Texas 2008–11.

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