In cooperation with the Goliad County Groundwater Conservation District, the Victoria County Groundwater Conservation District, the Pecan Valley Groundwater Conservation District, the Guadalupe-Blanco River Authority, and the San Antonio River Authority

Streamflow, Groundwater Hydrology, and Water Quality in the Upper Coleto Creek Watershed in Southeast Texas, 2009–10

Scientific Investigations Report 2011–5157

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

Cover. Coleto Creek near Schroeder, Texas. Photograph by U.S. Geological Survey personnel.

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

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
liter (L)	0.2642	gallon (gal)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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

°F=(1.8×°C)+32

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

°C=(°F-32)/1.8

Datums

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

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

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

Water-Quality Units

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

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

Isotope Units

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

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

where

δ = delta,

X = heavier stable isotope, and

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

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

Element	R	Standard identity and reference
Hydrogen	Hydrogen-2/hydrogen-1	Vienna Standard Mean Ocean Water (Craig, 1961; Gonfiantini, 1984)
Oxygen	Oxygen-18/oxygen-16	Vienna Standard Mean Ocean Water (Craig, 1961; Gonfiantini, 1984)

Streamflow, Groundwater Hydrology, and Water Quality in the Upper Coleto Creek Watershed in Southeast Texas, 2009–10

By Christopher L. Braun and Rebecca B. Lambert

Abstract

The U.S. Geological Survey (USGS), in cooperation with the Goliad County Groundwater Conservation District, Victoria County Groundwater Conservation District, Pecan Valley Groundwater Conservation District, Guadalupe-Blanco River Authority, and San Antonio River Authority, did a study to examine the hydrology and stream-aquifer interactions in the upper Coleto Creek watershed. Findings of the study will enhance the scientific understanding of the study-area hydrology and be used to support water-management decisions to help ensure protection of the Evangeline aquifer and surface-water resources in the study area. This report describes the results of streamflow measurements, groundwater-level measurements, and water quality (from both surface-water and groundwater sites) collected from three sampling events (July–August 2009, January 2010, and June 2010) designed to characterize groundwater (from the Evangeline aquifer) and surface water, and the interaction between them, in the upper Coleto Creek watershed upstream from Coleto Creek Reservoir in southeast Texas. This report also provides a baseline level of water quality for the upper Coleto Creek watershed.

Three surface-water gain-loss surveys—July 29–30, 2009, January 11–13, 2010, and June 21–22, 2010—were done under differing hydrologic conditions to determine the locations and amounts of streamflow recharging or discharging from the Evangeline aquifer. During periods when flow in the reaches of the upper Coleto Creek watershed was common (such as June 2010, when 12 of 25 reaches were flowing) or probable (such as January 2010, when 22 of 25 reaches were flowing), most of the reaches appeared to be gaining (86 percent in January 2010 and 92 percent in June 2010); however, during drought conditions (July 2009), streamflow was negligible in the entire upper Coleto Creek watershed; streamflow was observed in only two reaches during this period, one that receives inflow directly from Audilet Spring and another reach immediately downstream from Audilet Spring. Water levels in the aquifer at this time declined to the point that the aquifer could no longer provide sufficient water to the streams to sustain flow.

Groundwater-level altitudes were measured at as many as 33 different wells in the upper Coleto Creek watershed during three different survey events: August 4–7 and 12, 2009; January 12–14 and 22, 2010; and June 21–24, 2010. These data were used in conjunction with groundwater-level altitudes from three continuously monitored wells to generate potentiometric surface maps for each of the three sampling events to help characterize the groundwater hydrology of the Evangeline aquifer. The altitudes of potentiometric surface contours from all three sampling events are highest in the northeast part of the study area and lowest in the southwest part of the study area. Groundwater flow direction shifts from southeast to east across the watershed, roughly coinciding with the general flow direction of the main stem of Coleto Creek. Groundwater-level altitudes increased an average of 2.35 inches between the first and third sampling events as drought conditions in summer 2009 were followed by consistent rains the subsequent fall and winter, an indication that the aquifer responds relatively quickly to both the absence and relative abundance of precipitation.

A total of 44 water-quality samples were collected at 21 different sites over the course of the three sampling events (August 4–7, 2009, January 12–14, 2010, and June 21–24, 2010). In most cases, samples from each site were analyzed for the following constituents: dissolved solids, major ions, alkalinity, nutrients, trace elements, and stable isotopes (hydrogen, oxygen, and strontium). Major-ion compositions were relatively consistent among most of the samples from the upper Coleto Creek watershed (generally calcium bicarbonate waters, with chloride often making a major contribution). Of the 23 trace elements that were analyzed in water samples as part of this study, only arsenic (in two samples) and manganese (in seven samples) had concentrations that exceeded public drinking-water standards or guidelines. At 3 of the 19 sites sampled—State wells 79-06-411, 79-14-204, and Audilet Spring—nitrate concentrations exceeded the threshold (2.0 milligrams per liter) associated with anthropogenic contributions. The majority of the water samples (36 out of 44) that were analyzed for stable isotopes of hydrogen and oxygen during the three sampling events plotted in a relatively tight cluster centered near the global meteoric water line. The

eight remaining samples, which include the four surface-water samples collected in June 2010, the sample collected from Coleto Creek Reservoir in January 2010, and all three samples collected at State well 79-15-904, deviate from the global meteoric water line in a way that indicates evaporative losses. The isotopic signatures of the three samples collected at State well 79-15-904, when taken in conjunction with its proximity to Coleto Creek Reservoir, indicate that there is likely a hydraulic connection between the two. When all of the sites are examined as a whole, there is a general pattern in strontium concentrations across the entire watershed that indicates that both the surface-water and groundwater samples derive from a single source (the Evangeline aquifer) with relatively uniform water-rock interactions.

Introduction

The U.S. Geological Survey (USGS), in cooperation with the Goliad County Groundwater Conservation District (GCGCD), Victoria County Groundwater Conservation District (VCGCD), Pecan Valley Groundwater Conservation District (PVGCD), Guadalupe-Blanco River Authority (GBRA), and San Antonio River Authority (SARA), did a study to examine the hydrology and stream-aquifer interactions in the upper Coleto Creek watershed (fig. 1). Findings of the study will enhance the scientific understanding of the study-area hydrology and be used to support water-management decisions for the Evangeline aquifer and surface-water resources in the study area.

The data documented in this report will provide baseline information to address different hydrologic and water-quality issues in a coastal study area undergoing changes in land use, such as possible streambank erosion, loss of wetlands, subsidence, saltwater intrusion, problems associated with excessive nutrients, disease-causing microorganisms, and toxic chemicals originating from industrial activities or mining practices.

Purpose and Scope

The purpose of this report is to describe streamflow, groundwater-level altitudes, and water quality (from both surface-water and groundwater sites) from three sampling events (July–August 2009, January 2010, and June 2010) in order to characterize surface water, groundwater from the Evangeline aquifer, and the interaction between them, in the upper Coleto Creek watershed upstream from Coleto Creek Reservoir in southeast Texas.

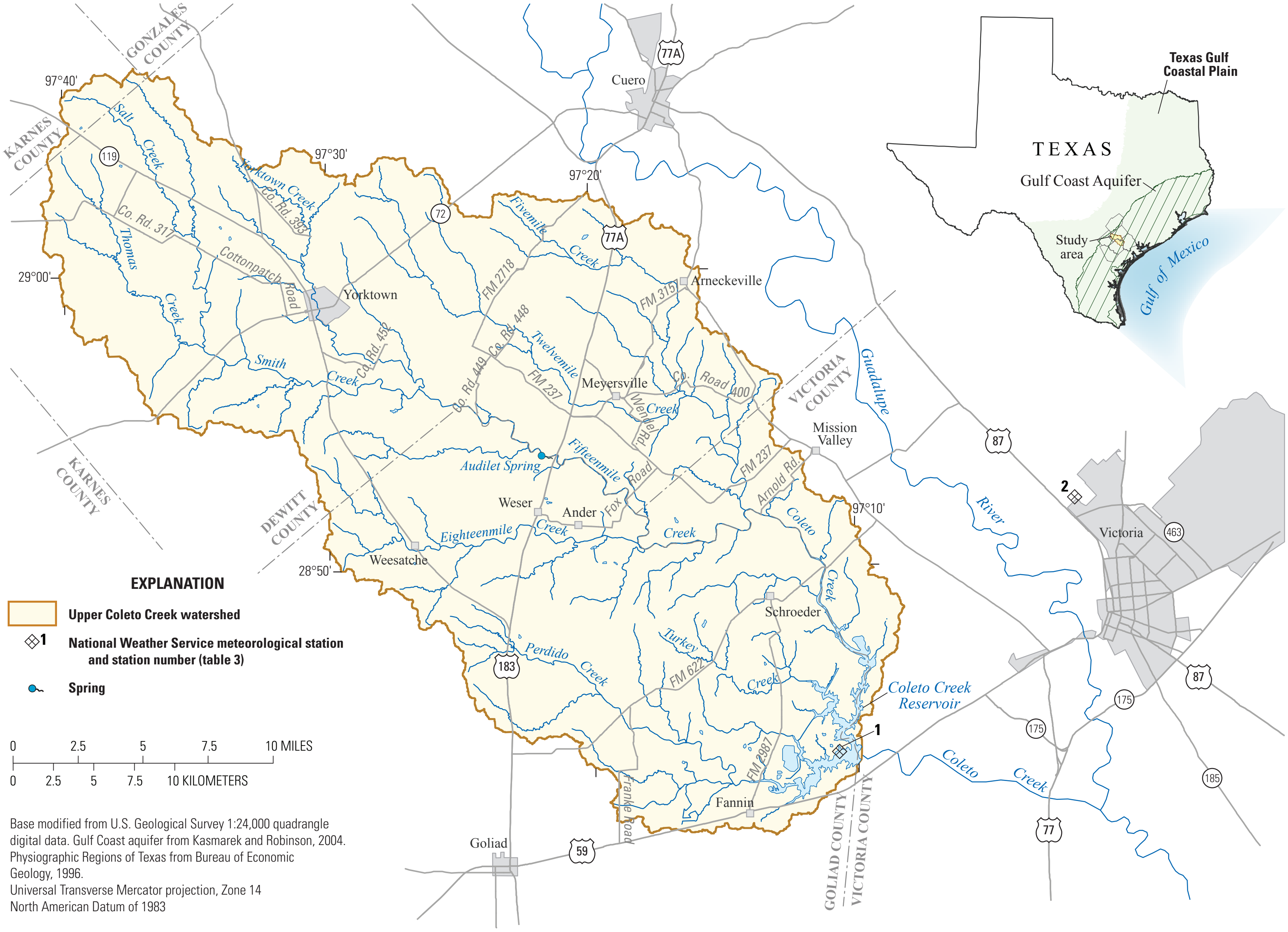
Description of Study Area

The upper Coleto Creek watershed (fig. 1) is mostly rural and, like other areas of Texas, is experiencing population growth (U.S. Census Bureau, 2011); as a whole, the three counties that make up the study area (De Witt, Goliad, and Victoria) experienced slightly less than a 3 percent population increase between 2000 and 2009. The upper Coleto Creek watershed starts about 12 miles (mi) northwest of Yorktown and ends at Coleto Creek Reservoir. Coleto Creek Reservoir, which is used primarily to provide cooling water for electric power generation, is about 12 mi southwest of Victoria on Coleto and Perdido Creeks and impounds runoff from 507 square miles (mi^2) of drainage area (Guadalupe-Blanco River Authority, 2007). Conservation storage for the reservoir is 31,040 acre-feet (Texas Water Development Board, 2011).

The upper Coleto Creek watershed overlies the Texas coastal lowlands aquifer system (Chicot, Evangeline, and Jasper aquifers). The Texas coastal lowlands aquifer system is equivalent to the Gulf Coast aquifer system (Ashworth and Hopkins 1995; Kasmarek and Robinson, 2004). The Texas coastal lowlands aquifer system is composed of formations from Oligocene through Holocene age (fig. 2) that dip and thicken toward the Gulf of Mexico. The sediments composing the Texas coastal lowlands aquifer system consist of overlapping mixtures of sand, silt, and clay deposited and reworked by numerous oscillations of ancient shorelines (Ryder, 1996; Lizárraga and Ockerman, 2010). The Jasper aquifer crops out (that is, becomes exposed at land surface) in the northwest corner of the study area; the following hydrogeologic units crop out successively towards the southeast corner of the study area: Burkeville confining unit, Evangeline aquifer, and Chicot aquifer (fig. 3). Geologic units corresponding with each hydrogeologic unit are shown in figure 2.

The Evangeline aquifer, which is the principal aquifer of interest in this study, is typically wedge shaped (because it dips and thickens toward the coast) and has a high sand-clay ratio; it contains individual sand beds that are characteristically tens of feet thick (Baker, 1979). The aquifer ranges in thickness from 400 to 1,000 feet (ft) where it crops out (the surface expression is shown in fig. 3). Near the coastline, where the top of the aquifer is about 1,000 ft deep, its thickness averages about 2,000 ft (Baker, 1979). The Evangeline is considered one of the most prolific producing aquifers in the Texas Coastal Plain and is known for its abundance of good-quality groundwater (Baker, 1979).

The climate of the study area is described as subtropical humid and is characterized by warm summers and mild winters (Larkin and Bomar, 1983). Heaviest precipitation tends to occur in late spring to early summer and in the fall (Texas Water Development Board, 2007); droughts and floods are common.



Base modified from U.S. Geological Survey 1:24,000 quadrangle digital data. Gulf Coast aquifer from Kasmarek and Robinson, 2004.
Physiographic Regions of Texas from Bureau of Economic Geology, 1996.
Universal Transverse Mercator projection, Zone 14
North American Datum of 1983

Figure 1. Location of study area.

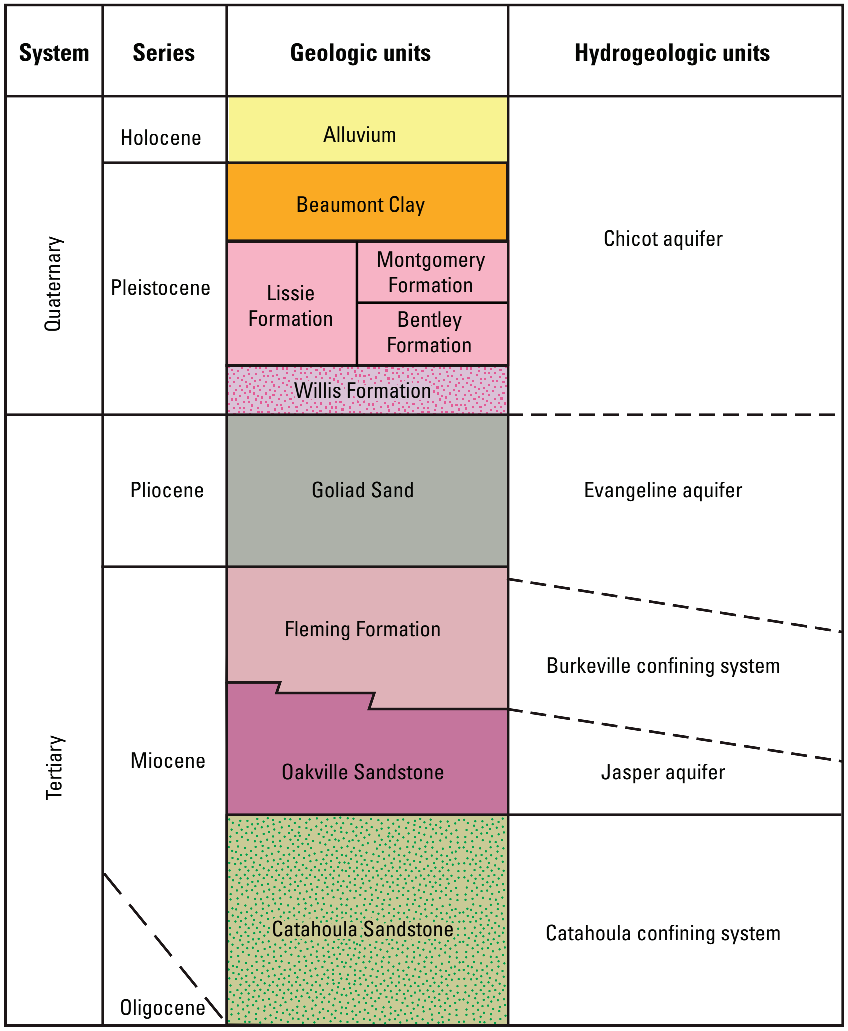


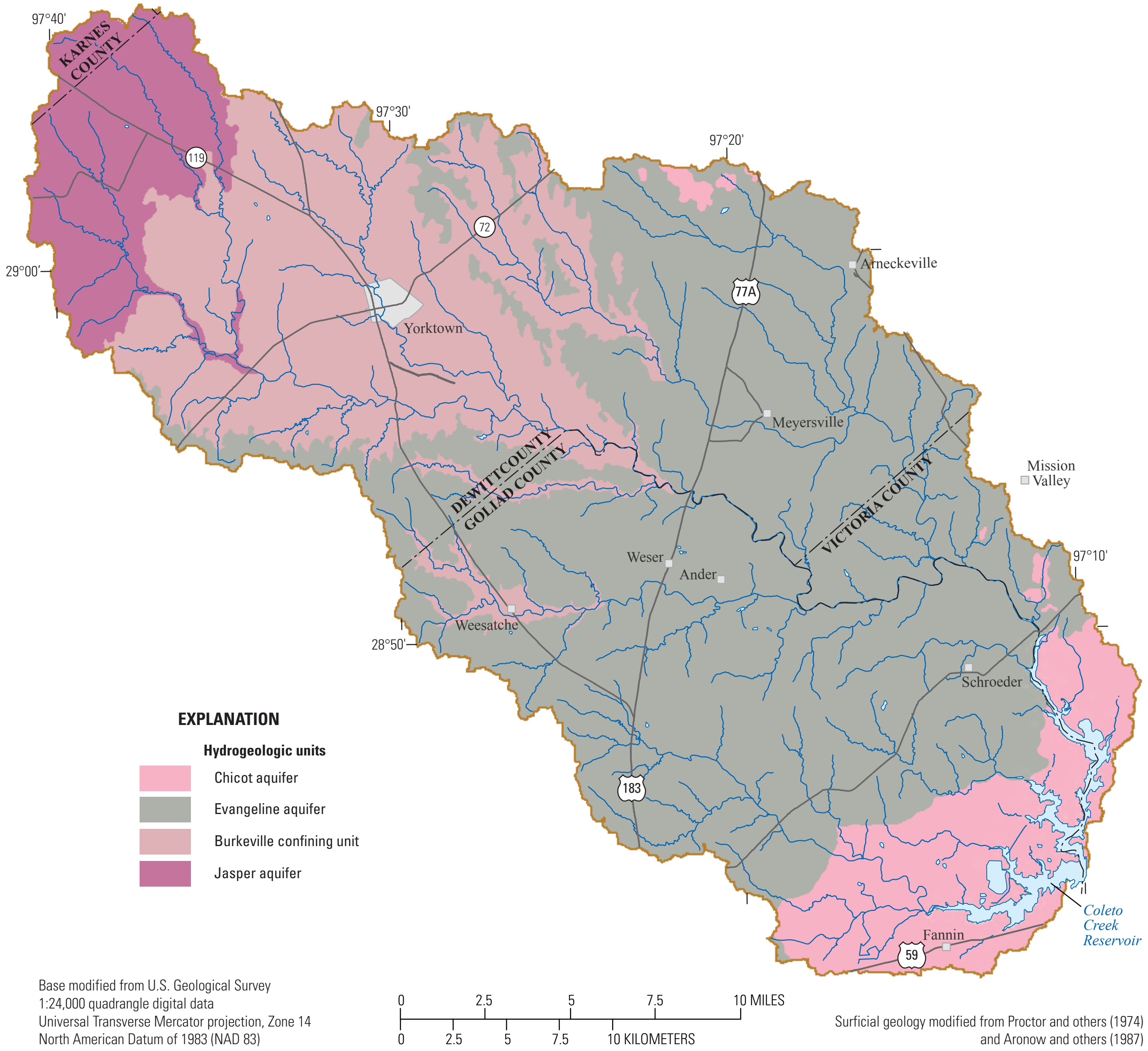
Figure 2. Geologic and hydrogeologic units of the Texas coastal lowlands aquifer system in the upper Coleto Creek watershed in southeast Texas (modified from Baker, 1979, table 1, and Mace and others, 2006, fig. 2–12).

Methods of Study

Site Selection

Surface-water sites were selected as part of the initial, broad-based inventory (table 1, fig. 4) on the basis of their accessibility (typically adjacent to public roads, thereby eliminating the need for permission to access private land), position relative to where the Evangeline aquifer crops out, potential contribution to streamflow of the upper Coleto Creek watershed (larger, perennial streams were given priority over smaller, intermittent ones), and location within the study area relative to existing USGS streamflow-gaging stations and to the other surface-water sites identified during the inventory. A subset of the surface-water sites from the broad-based inventory was selected for the gain-loss survey. Sites were selected that provided the greatest potential for streamflow during variable (wet and dry) hydrologic conditions, as well as the most information regarding streamflow gains from or losses to the Evangeline aquifer. Sites at or just below the confluence of two streams, which were considered to be major contributors to streamflow in the study area, also were selected whenever possible. Surface-water sites were selected for water-quality analyses on the basis of potential for perennial flow and proximity to groundwater sites selected for water-quality analyses in order to allow for comparison of water quality between the two.

Available monitoring wells completed in the Evangeline aquifer in the study area were inventoried with assistance from the cooperating agencies (GCGCD, VCGCD, PVGCD, GBRA, SARA) to identify suitable wells for monitoring and water-quality sampling. Approximately 75 percent of the selected wells were within a 1-mi buffer zone around Coleto Creek and its major tributaries; a few additional wells along Perdido Creek were also identified. Information from the



Base modified from U.S. Geological Survey
1:24,000 quadrangle digital data
Universal Transverse Mercator projection, Zone 14
North American Datum of 1983 (NAD 83)

Surficial geology modified from Proctor and others (1974)
and Aronow and others (1987)

Figure 3. Hydrogeologic units in the upper Coleto Creek watershed, southeast Texas.

initial broad-based well inventory culminated in the selection of 37 existing State wells (fig. 4). Of the selected wells, four were chosen because of their proximity to each of the four surface-water sites selected for water-quality analyses, whereas some wells were selected because they were farther from streams and represented aquifer conditions that were less likely to be influenced by streamflow. Wells were also selected to provide a good spatial distribution across the study area. Both shallow and deep Evangeline aquifer wells were selected for the study. No wells were selected where the Jasper aquifer crops out in the northwest corner of the upper Coleto Creek watershed (fig. 3), because the Evangeline aquifer is absent in this area. Depth to water, well depth, discharge, general construction information, aquifer(s) penetrated, and location were determined for each of the wells inventoried whenever possible. This information was compiled, reviewed, and entered into the USGS National Water Information System (NWIS) database (U.S. Geological Survey, 2011).

Table 1. Description of surface-water sites in the upper Coleto Creek watershed, southeast Texas, July 2009–June 2010.

[USGS, U.S. Geological Survey; x, measurement made; M, miscellaneous streamflow measurement site; C, continuous streamflow measurement site; R, reservoir-stage gaging station]

Site identifier (figs. 4, 6, 12–15)	USGS station number	USGS station name	Site type	Data type	County	Gain-loss survey			Water-quality sampling		
						July 2009	January 2010	June 2010	August 2009	January 2010	June 2010
1	08176523	Salt Creek at County Road 317 near Yorktown, Tex.	M	Streamflow	De Witt	x	x	x			
11	08176526	Thomas Creek at Cottonpatch Road near Yorktown, Tex.	M	Streamflow	De Witt	x	x	x			
13	08176529	Smith Creek at Highway 72 near Yorktown, Tex.	M	Streamflow	De Witt	x	x	x			
14	08176532	Smith Creek at Highway 119 near Yorktown, Tex.	M	Streamflow	De Witt	x	x	x			
2	08176535	Yorktown Creek at County Road 393 near Yorktown, Tex.	M	Streamflow	De Witt	x	x	x			
12	08176538	Yorktown Creek at Highway 72 at Yorktown, Tex.	M	Streamflow	De WItt	x	x	x			
23	08176540	Yorktown Creek at County Road 452 near Yorktown, Tex.	M	Streamflow	De Witt	x	x	x		x	x
26	08176544	Fifteenmile Creek at County Road 449 Road near Ander, Tex.	M	Streamflow	Goliad	x	x	x			
44	08176548	Fifteenmile Creek at Audilet Crossing near Ander, Tex.	M	Streamflow	DeWitt		x				
46	08176550	Fifteenmile Creek near Weser, Tex.	M	Streamflow	DeWitt	x	x	x			
76	08176555	Fifteenmile Creek at Fox Road near Ander, Tex.	M	Streamflow	Goliad	x	x	x			
62	08176565	Eighteenmile Creek at Highway 119 at Weesatche, Tex.	M	Streamflow	Goliad	x	x	x			
70	08176580	Eighteenmile Creek at Highway 77A/183 near Ander, Tex.	M	Streamflow	Goliad	x	x	x			
80	08176590	Fifteenmile Creek below Eighteenmile Creek near Ander, Tex.	M	Streamflow	Goliad		x	x		x	x
79	08176592	Fifteenmile Creek near Ander, Tex.	M	Streamflow	Goliad	x	x				
20	08176594	Twelvemile Creek at Farm Road 2718 near Yorktown, Tex.	M	Streamflow	De Witt	x	x	x			
34	08176596	Twelvemile Creek at Highway 77A/183 near Meyersville, Tex.	M	Streamflow	De Witt	x	x	x			
51	08176598	Twelvemile Creek at Wendel Road near Meyersville, Tex.	M	Streamflow	De Witt	x	x	x			
9	08176599	Fivemile Creek at Highway 77A/183 near Arneckville, Tex.	M	Streamflow	De Witt	x	x	x			
32	08176675	Fivemile Creek at Farm Road 3157 near Arneckville, Tex.	M	Streamflow	De Witt	x	x	x			
37	08176750	Fivemile Creek at County Road 400 near Meyersville, Tex.	M	Streamflow	De Witt	x	x	x			
55	08176825	Twelvemile Creek at Farm Road 237 near Mission Valley, Tex.	M	Streamflow	Victoria	x	x	x			
90	08176900	Coleto Creek at Arnold Road Crossing near Schroeder, Tex.	C	Streamflow	Goliad	x	x	x		x	x
97	08177000	Coleto Creek near Schroeder, Tex.	M	Streamflow	Victoria	x	x	x			
99	08177270	Turkey Creek at Farm Road 2987 near Fannin, Tex.	M	Streamflow	Goliad	x	x	x			
87	08177300	Perdido Creek at Farm Road 622 near Fannin, Tex.	C	Streamflow	Goliad	x	x	x		x	x
101	08177310	Perdido Creek at Franke Road near Fannin, Tex.	M	Streamflow	Goliad	x					
104	08177350	Perdido Creek at Farm Road 2987 near Fannin, Tex.	M	Streamflow	Goliad	x	x	x			
106	08177400	Coleto Creek Reservoir near Victoria, Tex.	R	Reservoir stage	Victoria	x	x	x		x	

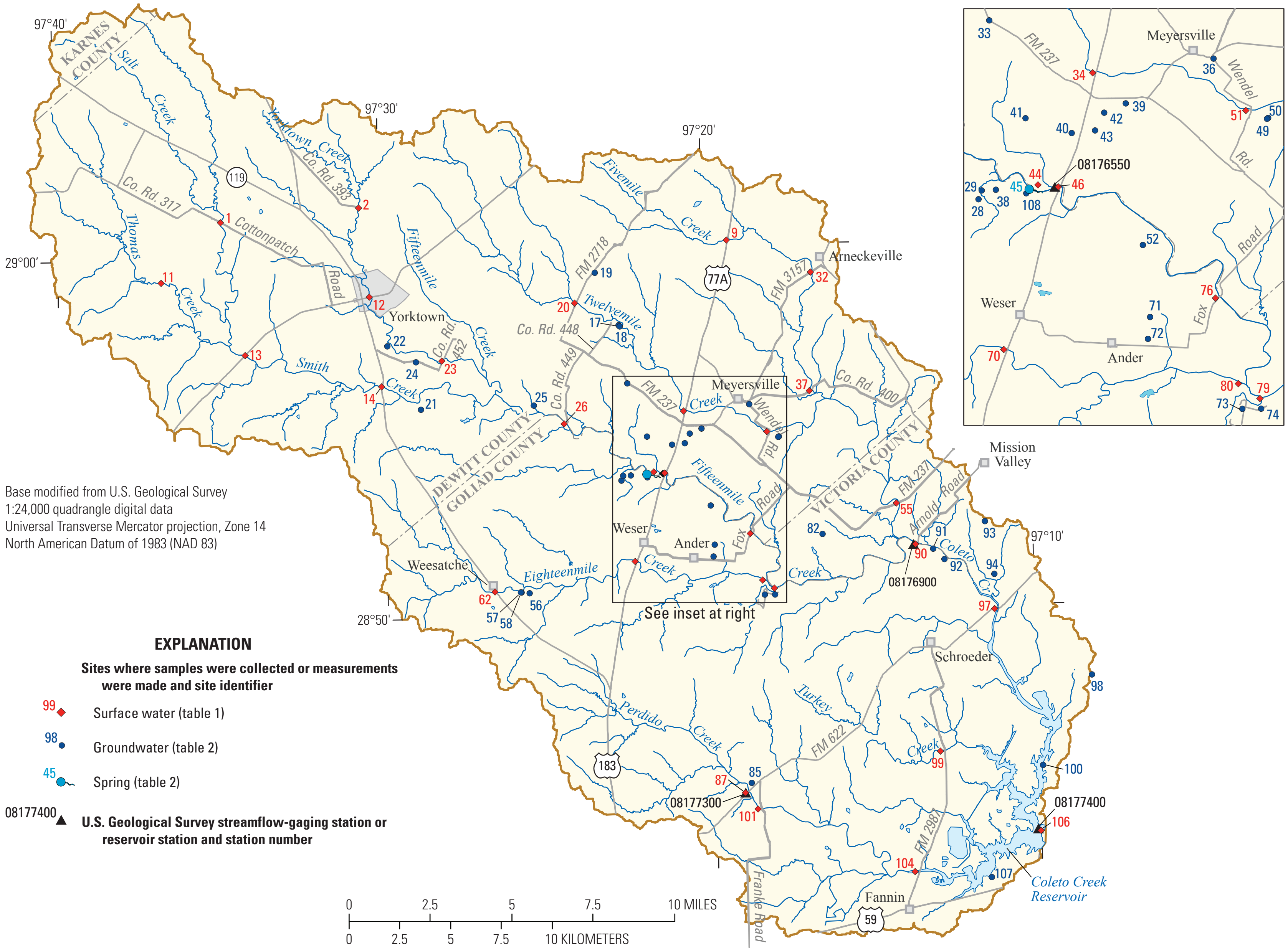


Figure 4. Locations of all sites where samples were collected or measurements were made in the upper Coleto Creek watershed, southeast Texas.

Streamflow: Synoptic Gain-Loss Surveys and Gaged Data

Three surface-water gain-loss surveys were done in different seasons with differing hydrologic conditions—summer 2009 (July 29–30), winter 2010 (January 11–13), and again in summer 2010 (June 21–22)—to more accurately determine the seasonal variation, locations, and magnitude of stream-aquifer interaction. Methods used to measure streamflow (discharge) amounts during each gain-loss survey are described in detail by Rantz and others (1982). The results of the gain-loss assessments in this study are intended to provide initial information to improve the understanding of the study-area hydrology, but these results will not be adequate for broad characterization of gaining and losing streamflow over all hydrologic regimes, nor can they be extrapolated over time. Synoptic streamflow measurements were made at 25 surface-water measurement sites during each of the three gain-loss surveys (table 1, fig. 4). Streamflow measurements were made in one or two of the three gain-loss surveys at three alternate measurement sites (USGS stations 08176548 Fifteenmile Creek at Audilet Crossing near Ander, Tex., 08176590 Fifteenmile Creek below Eighteenmile Creek near Ander, Tex., and 08177310 Perdido Creek at Franke Road near Fannin, Tex.). These alternate sites were used to verify results collected at the primary sites or as a check for flow in a site upstream from a primary site that had no flow. Streamflow measurements were made in two of the three gain-loss surveys at one site (USGS station 08176592 Fifteenmile Creek near Ander, Tex.).

Streamflow data collected during June 1, 2009–June 30, 2010, from two USGS streamflow-gaging stations in the upper Coleto Creek watershed (08176900 Coleto Creek at Arnold Road Crossing near Schroeder, Tex. [hereinafter station 08176900 on Coleto Creek] and 08177300 Perdido Creek at Farm Road 622 near Fannin, Tex. [hereinafter station 08177300 on Perdido Creek]) provided additional data points (for the time periods between gain-loss surveys) for the assessment of gaining and losing reaches. Streamflow measurements were made about every 2 months during the study at the two streamflow-gaging stations, and continuous streamflow records are computed from the stage, or gage height, which is measured every 60 minutes by using a pressure transducer or radar equipment. An analysis of potential measurement error for the rated streamflow values has been included in the gain-loss calculations that include rated streamflow from existing streamflow-gaging stations (discussed in the “Gain-Loss Streamflow Measurements” section).

Water-Level-Altitude Measurements

Using methods described by Cunningham and Schalk (2011), depth to groundwater was measured at as many as 33 different State wells in the upper Coleto Creek watershed with either a steel tape or an electronic water-level contact tape (e-line) three separate times: (1) August 4–7 and 12, 2009; (2) January 12–14 and 22, 2010; and (3) June 21–24, 2010. At some sites, water levels might not have been measured for one of the following reasons: the well was being pumped at the time of the site visit, the field technician was unable to obtain permission to access the well, or the well was not incorporated into the network until after the first round of sampling. The depth to groundwater data were used to generate potentiometric surface maps for each of the three rounds of data collection. Water-level altitudes (WLAs) were subsequently computed by subtracting depth to water at each sampling location from ground-surface elevation at that location; ground-surface elevations were obtained by intersecting well locations with land-surface altitudes derived from the USGS National Digital Elevation dataset (Gesch, 2007). These data were used in conjunction with WLAs (when available) from three wells, which are continuously monitored for WLAs by the Texas Commission on Environmental Quality (TCEQ). Data from the three TCEQ wells used for this report were entered into the NWIS database (U.S. Geological Survey, 2011). Of the three monitoring wells operated by TCEQ, two were deactivated by TCEQ after the first sampling event (State wells 79-05-505 and 79-15-604 were deactivated on October 18, 2009, and November 4, 2009, respectively), but the third (State well 79-13-224) was active throughout the course of the study. USGS station numbers corresponding to all State well numbers used in this report are listed in table 2.

Water-Quality Sample Collection

A total of 44 water-quality samples were collected at 21 sites over the course of the three sampling events (August 4–7, 2009, January 12–14, 2010, and June 21–24, 2010). However, all sites were not sampled for all chemical constituents during all three sampling events. Stable isotope samples for hydrogen and oxygen were collected at all 21 sites. Physical properties (dissolved oxygen, pH, specific conductance, temperature, and turbidity) were measured onsite using a YSI handheld multiparameter meter at all sites except USGS station 08177400 Coleto Creek Reservoir near Victoria, Tex., (hereinafter the Coleto Creek Reservoir site). Water-quality samples collected from all surface-water sites (table 1), and from Audilet Spring and the groundwater sampling sites (with the exception of those collected from State well 79-23-205 and the Coleto Creek Reservoir site; table 2) were analyzed for dissolved solids, major ions, alkalinity, nutrients, trace elements, and the stable isotope of strontium. Samples collected from State well 79-23-205 and the Coleto Creek Reservoir site were analyzed for hydrogen and oxygen stable isotope analyses exclusively. Of the 19 sites analyzed for a full suite of constituents, 4 were surface-water sites (streams) and the remaining 15 were groundwater sites (wells).

The four stream sites selected for water-quality analyses (USGS stations 08176540 Yorktown Creek at County Road 452 near Yorktown, Tex., 08176590 Fifteenmile Creek below Eighteenmile Creek near Ander, Tex., 08176900 on Coleto

Table 2. Description of groundwater and spring sites in the upper Coleto Creek watershed, southeast Texas, August 2009–June 2010.

[USGS, U.S. Geological Survey; x, measurement made]

Site identifier (figs. 4, 6, 12–15)	USGS station number	State well number	Site type	County	Water-level measurement			Water-quality sampling		
					August 2009	January 2010	June 2010	August 2009	January 2010	June 2010
17	285750097224001	79-05-303	Groundwater	DeWitt	x	x	x	x		
18	285752097224201	79-05-304	Groundwater	DeWitt		x	x			
19	285919097232301	79-05-305	Groundwater	DeWitt		x	x			
21	285541097285301	79-05-407	Groundwater	DeWitt	x	x	x			
22	285726097295301	79-05-406	Groundwater	DeWitt	x	x	x			
24	285658097290101	79-05-408	Groundwater	De Witt	x	x	x	x	x	x
25	285543097252301	79-05-505	Groundwater	De Witt	x					
28	285337097224301	79-05-903	Groundwater	Goliad	x	x	x			
29	285344097224001	79-05-904	Groundwater	Goliad	x	x	x			
33	285616097222801	79-06-411	Groundwater	DeWitt	x	x	x	x	x	x
36	285537097184201	79-06-506	Groundwater	De Witt	x	x	x			
38	285345097222501	79-06-712	Groundwater	Goliad	x	x	x			
39	285459097201101	79-06-703	Groundwater	DeWitt	x	x	x			
40	285434097191901	79-06-807	Groundwater	DeWitt	x	x	x			
41	285445097215301	79-06-709	Groundwater	DeWitt	x	x	x	x		
42	285451097203401	79-06-710	Groundwater	DeWitt	x	x	x			
43	285435097204301	79-06-707	Groundwater	DeWitt	x	x				
49	285443097174801	79-06-808	Groundwater	DeWitt	x	x	x	x	x	x
50	285443097174802	79-06-809	Groundwater	DeWitt	x	x				
52	285254097195801	79-06-810	Groundwater	Goliad	x	x	x	x		
56	285037097253901	79-13-231	Groundwater	Goliad		x	x			
57	285038097255402	79-13-224	Groundwater	Goliad	x		x			
58	285038097255401	79-13-225	Groundwater	Goliad	x	x	x			
71	285149097195201	79-14-204	Groundwater	Goliad	x	x	x	x	x	x
72	285129097195401	79-14-202	Groundwater	Goliad	x	x	x			
73	285025097182101	79-14-205	Groundwater	Goliad	x	x	x	x	x	x
74	285025097180201	79-14-203	Groundwater	Goliad	x		x			
82	285203097163001	79-14-303	Groundwater	Victoria	x	x	x			
85	284518097185401	79-14-804	Groundwater	Goliad	x	x	x	x	x	x
91	285134097130601	79-15-101	Groundwater	Goliad	x	x	x	x	x	x
92	285116097124501	79-15-102	Groundwater	Goliad	x	x	x			
93	285216097112801	79-15-205	Groundwater	Victoria	x	x	x	x		
94	285049097111201	79-15-206	Groundwater	Victoria	x	x	x	x		
98	284801097081601	79-15-604	Groundwater	Victoria	x					
100	284535097095101	79-15-904	Groundwater	Victoria	x	x	x	x	x	x
107	284240097112201	79-23-205	Groundwater	Victoria					x	
108	285345097215201	79-06-713	Groundwater	DeWitt		x	x		x	x
45	285354097215401	79-06-711 (Audilet Spring)	Spring	Goliad				x	x	x

Creek, and 08177300 on Perdido Creek [table 1, fig. 4]) were not flowing when the sites were visited during August 2009, so five alternate sites (wells) were sampled in their place (State wells 79-15-206, 79-15-205, 79-06-810, 79-06-709, and 79-05-303, respectively). Because the streams were flowing past the four streamflow-gaging stations during the two subsequent sampling events, the five alternate sites were sampled only once (August 2009), and the four stream sites were sampled two times each (January 2010 and June 2010). Samples were collected only once (during January 2010) from the Coleto Creek Reservoir site and from State well 79-23-205, whereas State well 79-06-713 was sampled twice, in January 2010 and June 2010. The nine remaining sites (all wells) were each sampled during all three sampling events.

Water-quality samples were collected, processed, and preserved in accordance with standard USGS methods documented in the "National Field Manual for the Collection of Water-Quality Data" (U.S. Geological Survey, variously dated). In preparation for the collection of groundwater samples, all wells were pumped until the physical properties stabilized prior to sample collection and processing. Surface-water sampling was also predicated on field-measurement stabilization prior to sample collection and processing. Physical properties were considered stable when the variation between five or more sequential field-measurement readings was less than 0.3 milligram per liter (mg/L) for dissolved oxygen, 5 percent for specific conductance, 0.05 unit for pH, and 0.2 degrees Celsius for temperature. Groundwater and surface-water samples were collected at each site in a 2-liter Teflon bottle, which was then subsampled into the appropriate bottles for the desired analyses at the site in question.

Analytical Methods

Using the inflection point method, alkalinity was determined at the time of sample collection by titration of 50 mL of filtered sample with 1.6-normal sulfuric acid to a pH of less than 4.0 (Rounds, 2006). All samples had negligible hydroxide and carbonate concentrations, so these ions were not considered in this report. The water-quality samples were analyzed for major ions, nutrients, trace elements, and selected stable isotopes. Water samples were analyzed in accordance with approved methods by the USGS National Water Quality Laboratory (NWQL) in Denver, Colo., for major ions (Fishman and Friedman, 1989; Fishman, 1993), nutrients (Fishman, 1993; Patton and Truitt, 2000), and trace elements (Fishman and Friedman, 1989; Garbarino, 1999; and Garbarino and others, 2006).

Samples for stable isotopes of hydrogen and oxygen were analyzed by the USGS Stable Isotope Laboratory in Reston, Va. (Epstein and Mayeda, 1953; Coplen and others, 1991). Stable isotopes are reported as the ratio of the two most abundant isotopes of a given element. The most abundant isotopes of hydrogen are hydrogen-2 (^{2}H), which is also referred to as deuterium (D), and hydrogen-1 (^{1}H), which is also referred to as protium. The most abundant isotopes of oxygen are oxygen-18 (^{18}O) and oxygen-16 (^{16}O) (Clark and Fritz, 1997). Water molecules with a larger percentage of the lighter hydrogen and oxygen isotopes (^{1}H and ^{16}O, respectively) evaporate preferentially compared to water molecules with a larger percentage of the heavier hydrogen and oxygen isotopes (^{2}H and ^{18}O, respectively) (Bruckner, 2009). Stable isotope analysis results for $^{2/1}H$ and $^{18/16}O$ are reported as δD and $\delta^{18}O$, respectively, each of which represents the relative difference in parts per thousand (per mil) between the sample isotope ratio and the isotope ratio of a known standard (Kendall and McDonnell, 1998). The ratios of naturally occurring, stable isotopes of strontium (strontium-87/strontium-86, also notated $\delta^{87}Sr/\ \delta^{86}Sr$) were determined by the USGS National Research Program Laboratory in Menlo Park, Calif., in accordance with approved methods (Bayless and others, 2004).

Quality Assurance

Quality control (QC) samples were collected to ensure the quality, precision, accuracy, and completeness of the water-quality dataset. Water-quality samples were collected and processed by following the procedures documented in the USGS National Field Manual (U.S. Geological Survey, variously dated). One equipment blank was collected on August 10, 2009, and sequential-replicate samples were collected on August 5, 2009 (State well 79-06-411), and on January 11, 2010 (State well 79-14-804); these results are listed in appendix 1. The equipment blank was analyzed for major ions, nutrients, and trace elements; replicate samples were analyzed for major ions, nutrients, trace elements, and stable isotopes (δD, $\delta^{18}O$, and $\delta^{87}Sr/\ \delta^{86}Sr$).

As noted by Fleming and others (2011, p. 18), "the accuracy of major dissolved-constituent values in a reasonably complete chemical analysis of a water sample can be checked by calculating the cation-anion balance (Hem, 1985). If the analytical work has been performed accurately, and if all major ions were analyzed, the difference between the two sums will generally not exceed approximately plus or minus 5 percent." Additional quality-control checks of ionic balances revealed the analyses for some constituents were suspect for samples collected at two of the wells. The cation-anion balance of samples collected August 6, 2009, at State well 79-15-101 exceeded the plus or minus 5 percent criterion (the cation concentrations were all markedly smaller compared to the anion concentrations, possibly because the deionized water used to rinse the filter had not been completely evacuated prior to filling the sample bottle) and the cation concentrations were judged erroneous by the authors. In addition, alkalinity for the sample collected at State well 79-15-904 on June 21, 2010, was judged erroneously low; there were no corroborating data (such relatively low concentrations of other anions or cations) to substantiate the validity of this alkalinity value. The cation data collected August 6, 2009, from State well 79-15-101 and alkalinity measured June 21, 2010, from

State well 79-15-904 were not included in the report and will not be discussed further.

Total nitrogen (calculated as the sum of nitrate, nitrite, ammonia, and organic nitrogen) and two trace-metal constituents (cobalt and iron) were detected in the equipment blank collected on August 10, 2009. Cobalt was detected in the blank at a concentration of 0.08 microgram per liter (µg/L), which is relatively small compared to the cobalt concentrations in most environmental samples (less than 26 percent of the median concentration of 0.32 µg/L for all 31 groundwater environmental samples [excluding Audilet Spring]) collected during the study. Iron was detected in the blank at an estimated concentration of 2 µg/L, which was less than iron concentrations in each of the 12 groundwater environmental samples in which iron was detected; iron was not detected (had a concentration less than the laboratory reporting level) in the remaining 19 groundwater environmental samples. The estimated concentration of total nitrogen in the blank was 0.07 mg/L, which was less than 7 percent of the median total nitrogen concentration of 1.02 µg/L measured in the 26 groundwater samples with detected amounts of total nitrogen; total nitrogen was not detected in the four remaining groundwater environmental samples. Dissolved solids also were detected at a concentration of 10 mg/L, which was less than 2 percent of the median dissolved solids concentration of 585 mg/L in the 31 groundwater environmental samples.

The two replicate samples were compared to their associated environmental samples by calculating the relative percent difference (RPD) for each pair of detected constituents (appendix 1). If one or both of the concentrations in a constituent pair were less than the long-term method detection level (LT-MDL) or were reported as estimated, the RPD was not calculated for that pair. Estimated concentrations fall between the laboratory reporting limit (LRL), which is twice the LT-MDL, and the LT-MDL. Concentrations less than the LT-MDL are reported as less than the LRL (Childress and others, 1999). RPDs also were not calculated for physical properties measured in the field or laboratory analysis of specific conductance and pH. Of the 103 constituent pairs (52 from State well 79-06-411 on August 5, 2009, and 51 from State well 79-14-804 on January 11, 2010), the RPD was computed for 74 sequential-replicate pairs of data (37 from State well 79-14-804 and 37 from State well 79-06-411) using the equation

$$\mathrm{RPD} = |C_1 - C_2| / ((C_1 + C_2)/2) \times 100 \qquad (1)$$

where

C_1 is the concentration from environmental sample and

C_2 is the concentration from sequential-replicate sample.

RPDs less than 15 percent indicate good agreement between analytical results, assuming the concentrations are sufficiently large compared to the LRL. Using samples collected from State well 79-14-804, the RPD was computed for 37 pairs of analyses of physical properties or constituents (hereinafter data pairs). Of these 37 data pairs, the RPD was within 15 percent for 35 data pairs; the 2 data pairs that exceeded 15 percent were for cobalt (62 percent), and lead (35 percent). Of the 37 data pairs for which RPD was computed using samples collected from State well 79-06-411, the RPD was within 15 percent for 35 data pairs; the 2 data pairs that exceeded 15 percent were for noncarbonate hardness (36 percent) and cobalt (86 percent).

Water-level measurements were made in accordance with standard USGS procedures (U.S. Geological Survey, 1980). All water-level data were entered into the National Water Information System (NWIS) database and reviewed by USGS personnel following standard USGS procedures. A minimum of two measurements were made at each well. If the two initial measurements were within 0.01 ft of each other, then no additional measurements were required. If the two measurements did not agree within a precision of about 0.02 ft, owing to recent pumpage, damp casing, or general difficulty in obtaining a good reading, measurements were repeated until the reason for the lack of agreement was determined or until the results were shown to be reliable. WLA measurements were made when the pumps in wells were idle; however, antecedent pumping conditions and the pumping status of adjacent wells were not always known.

Field logs were used to document proper equipment operation and maintenance, as well as representative sample-collection and measurement conditions. Site visits to streamflow-gaging stations were made routinely (about every 6 weeks) by USGS personnel to ensure that equipment was functioning properly; sites were also visited in the event of equipment malfunctions.

Streamflow

Continuous Streamflow Data

Streamflow hydrographs for June 1, 2009–June 30, 2010, were prepared for stations 08176900 on Coleto Creek and 08177300 on Perdido Creek in the study area (figs. 5*A* and 5*B*). Rainfall data recorded at the National Weather Service (NWS) meteorological station 411880 Coleto Creek Reservoir (fig. 1, table 3) are shown (fig. 5*C*). Data from NWS 419361 Victoria Fire Department Station 5 (approximately 18 mi northeast of NWS station 411880) were used to fill in missing record on April 25, 2010, and June 10, 2010. There appears to be a relation between the observed rainfall at NWS station 411880 and the measured streamflow at stations 08176900 on Coleto Creek and 08177300 on Perdido Creek (fig. 5). Exceptional drought conditions (U.S. Drought Monitor, 2011) persisted in the study area during summer 2009; from June 1 through August 12, 2009, only 0.89 inch (in.) of precipitation was recorded at NWS station 411880 (National Climatic Data Center, 2011). As a result, there was no flow past the USGS streamflow-gaging stations on Coleto or Perdido Creek

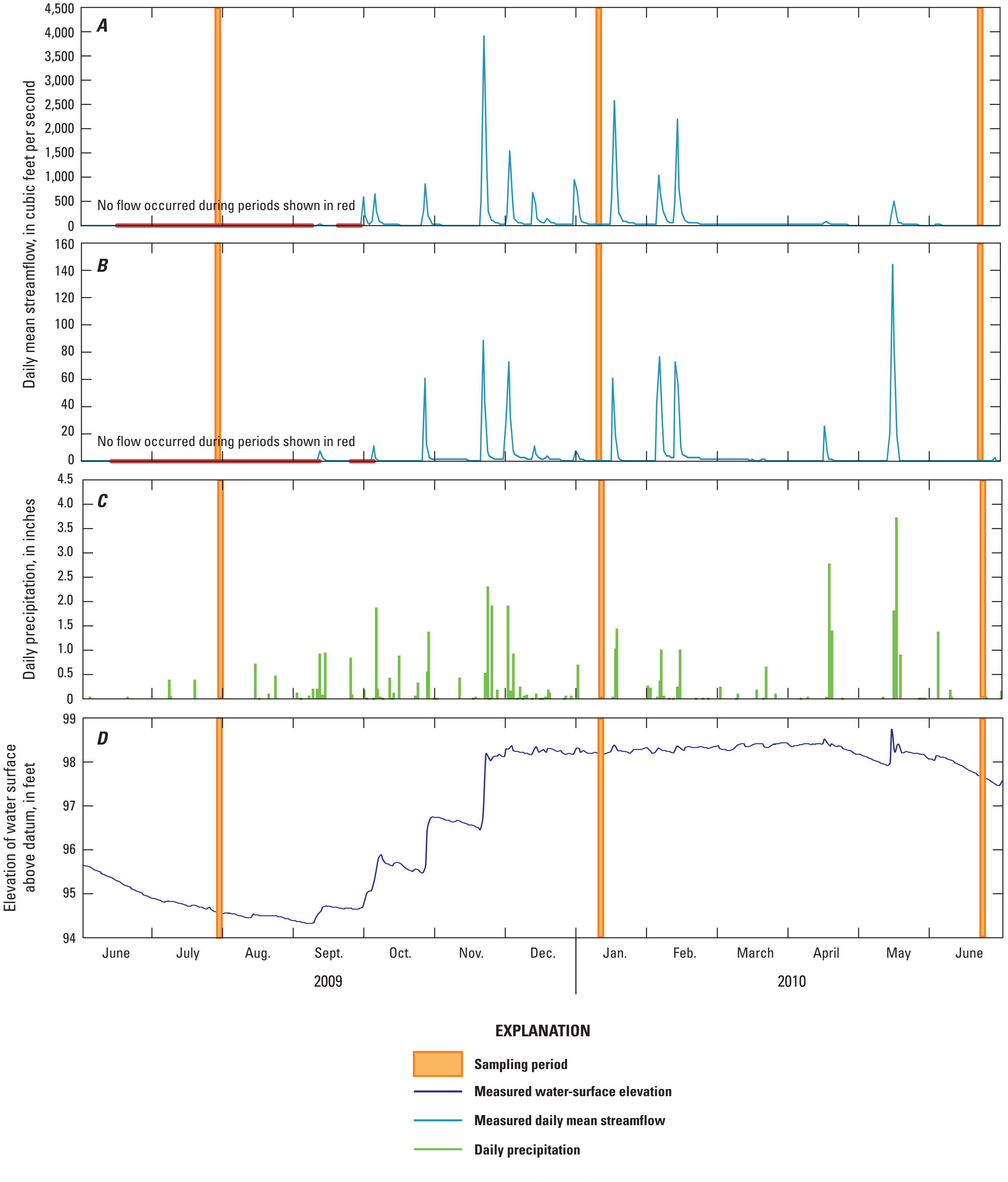


Figure 5. Measured daily mean streamflow at U.S. Geological Survey (USGS) streamflow-gaging stations *A*, 08176900 Coleto Creek at Arnold Road Crossing near Schroeder, Texas, and *B*, 08177300 Perdido Creek at Farm Road 622 near Fannin, Texas; *C*, Precipitation data measured at National Weather Service meteorological station 411880 Coleto Creek Reservoir (National Climatic Data Center, 2011); and *D*, Measured water-surface elevations at USGS station 08177400 Coleto Creek Reservoir near Victoria, Texas, June 1, 2009–June 30, 2010.

Table 3. Rainfall data obtained from National Weather Service meteorological stations in and near the upper Coleto Creek watershed, southeast Texas, during June 1, 2009–August 12, 2009.

[NWS, National Weather Service; DMS, degrees, minutes, seconds; --, not available]

NWS site identifier (fig. 2)	Station number and name	Latitude (DMS)	Longitude (DMS)	Type of data	Period of record used	Amount of rainfall, in inches
1	NWS 411880 Coleto Creek Reservoir	28°43′--″	97°10′--″	Rainfall	June 1, 2009, through August 12, 2009	0.89
2	NWS 419361 Victoria Fire Department Station 5[1]	28°52′--″	97°01′--″	Rainfall	April 25, 2010, and June 19, 2010	0.00 (both days)

[1] Used to fill in missing record at NWS 411880.

(stations 08176900 on Coleto Creek and 08177300 on Perdido Creek) during most of the summer of 2009 (figs. 5*A* and 5*B*); there also was no flow past the streamflow-gaging stations on Coleto or Perdido Creek during parts of September and October 2009. Rainfall events and resulting increases in streamflow were more frequent from early October 2009 through February 2010. Figure 5 also shows when streamflow measurement surveys were made (“Sampling periods”). During the three measurement surveys (July 29, 2009, January 11, 2010, and June 21, 2010), instantaneous streamflows at the station 08176900 on Coleto Creek were zero, 24.6, and 5.85 cubic feet per second (ft^3/s), respectively; daily mean streamflows measured at the adjacent gaging station on those same three days were zero, 27, and 5.4 ft^3/s, respectively. Instantaneous streamflows at station 08177300 on Perdido Creek were zero, 0.23, and 0.04 ft^3/s, respectively; daily mean streamflows measured at the adjacent gaging station on those same three days were zero, 0.23, and 0.04 ft^3/s, respectively.

Water-surface elevation data measured at the Coleto Creek Reservoir site from June 1, 2009, through June 30, 2010, are plotted on figure 5*D*, along with daily precipitation data measured at the NWS meteorological weather 411880 on figure 5*C*. The stage of Coleto Creek Reservoir is regulated by GBRA and is 98 ft when the reservoir is at normal capacity. The general expression of reservoir stage depicts a gradual decrease in stage from 95.65 ft on June 1, 2009, to 94.33 ft on September 6, 2009, after several months of below-average precipitation in the region; minimal inflows from contributing streams were likely received by Coleto Creek Reservoir during this period based on continuously monitored streamflow data collected at stations 08176900 and 08177300 on Coleto and Perdido Creeks, respectively, as well as data collected during the gain-loss survey during July 29–30, 2009. Evaporative effects associated with the summer months also contributed to the reduction in stage during this period. After precipitation events on September 6–9, 2009 (3.86 in.), October 3–4, 2009 (2.28 in.), October 26, 2009 (1.84 in.), and November 20, 2009 (2.85 in.), abrupt increases, in stairstep fashion, raised the overall reservoir stage to the 98.0- to 98.5-ft range, where it remained from late November until mid-April; releases from the reservoir were made by GBRA during this period to maintain normal reservoir capacity. From mid-April to the end of June 2010, gradual decreases in reservoir stage, likely associated with evaporative effects, were observed. A large precipitation event on May 14–15, 2010 (5.08 in.), resulted in the peak stage of 98.75 ft for the period shown. Precipitation from large storms tends to be variable, with the largest amounts falling in localized areas. This likely explains why certain precipitation events (1.76 in. on September 22, 2009) did not elicit comparable responses in reservoir stage relative to other events of similar magnitude (1.84 in. on October 26, 2009). Virtually no change in reservoir stage was observed after the precipitation event on September 22, whereas an increase in reservoir stage of 0.8 ft was observed after the October 26 event. Additionally, no change in flow was observed at station 08176900 on Coleto Creek after the precipitation event on September 22 (fig. 5*A*), which indicates that this event likely occurred downstream from station 08176900. Peaks in daily mean streamflow at station 08176900 on Coleto Creek from December 2009 through February 2010 did correspond to peaks in reservoir stage measured at the Coleto Creek Reservoir site, indicating releases likely were being made from Coleto Creek Reservoir to control reservoir stage during this period. Abrupt increases in reservoir stage from June to November 2009 were also observed in measured daily mean streamflow at station 08176900 on Coleto Creek. Changes in reservoir stage caused by releases from Coleto Creek Reservoir are unknown and were not considered in the evaluation of Coleto Creek Reservoir stage.

Gain-Loss Streamflow Measurements

Groundwater inflow to streams and stream outflow to groundwater are typically not measured directly because these processes usually cannot be observed; even visible inflow from springs cannot always be measured accurately (Ockerman, 2002). As a result, inflow from or outflow to groundwater in stream reaches within the study area were estimated by measuring the difference in streamflow at the upstream and downstream ends of the reaches (fig. 6). Groundwater inflow and outflow are not exclusive sources of gain or loss to the streams; other sources might include tributary inflow, stream diversions and return flows, spring inflow, and evaporative losses. Groundwater flux, G, is estimated as

$$G = Q_D - Q_U - I + D - R - S + E \qquad (2)$$

where

Q_D is measured streamflow at the downstream boundary of the reach,

Q_U is measured streamflow at the upstream boundary of the reach,

I is measured or estimated inflows from tributaries,

D is diversions from the reach,

R is return flows to the reach,

S is spring contributions, and

E is estimated evaporation losses.

A positive value for G is indicative of a gaining stream reach, whereas a negative value for G is indicative of a losing stream reach. Tributary inflows (I) do exist within the study area, but the way in which the affected reaches (C4, C6, C11, C15, and C19; fig. 6) were established incorporates these contributions automatically into the measured streamflow at the upstream boundary of the reach. Tributaries other than those that contribute to reaches C4, C6, C11, C15, and C19 were ignored because they were assumed to be dry during the three gain-loss surveys. As a result, tributary inflow provides no additional contribution to streamflow. No diversions (D) from reaches in the upper Coleto Creek watershed are known, nor are there any known return flows (R) to the reaches in the upper Coleto Creek watershed, so these contributions were excluded from groundwater flux calculations.

Spring contributions (S) to streamflow were not measured at any of the known springs in the study area. As a result, spring contributions could not be included as a separate source in the groundwater flux calculations. Rather, spring contributions were part of the measured streamflow at the downstream boundaries of each reach that a spring (or springs) contributed to. Discharge from Audilet Spring was observed during all three sampling events but was never measured directly. However, the streamflow contribution associated with Audilet Spring is likely substantial relative to the magnitude of flows observed in individual stream reaches over the upper Coleto Creek watershed as a whole. The greatest difference in measured streamflow in January 2010 within a single reach (10.37 ft^3/s) occurred in reach C9, which receives contributions from Audilet Spring; this value is more than 2.5 times the second highest difference in measured streamflow within a reach from that same time period (4.02 ft^3/s at reach C15). In addition, the only reaches in the study area with measurable streamflow in July 2009 were reaches C9 and C10 (the reach immediately downstream from reach C9). By eliminating these four terms (I, D, R, and S) from the equation above, equation 2 for G reduces to

$$G = Q_D - Q_U + E$$

Evaporation within each reach was estimated by using pan evaporation data from the Texas Water Development Board Center for Research in Water Resources (2010) for a station in Cheapside, Tex. (about 16 mi northwest of Cuero, Tex.). Monthly evaporation data from a 52-month period (starting on August 1, 2003, and ending on December 1, 2007) were used to calculate average daily pan evaporation rates for each of the three sampling periods. These rates were then applied to the surface area of each reach to estimate evaporative losses. Using the stream widths measured prior to the collection of discharge data, the surface area of each reach was calculated by multiplying the average of the widths at the upstream and downstream ends of the reach by reach length.

Five of the stream reaches in the study area (C4, C6, C11, C15, and C19) include a confluence of two streams, which means there are two upstream ends to each of these five reaches. In these five cases, the average stream width used in the reach surface-area component of the evaporative loss calculation was calculated as a weighted proportion of upstream and downstream widths and stream-segment lengths. Data used in the calculation of evaporative loss estimates are given in appendix 2.

During periods when flow was common (such as June 2010, with 12 of 25 reaches flowing) or likely (such as January 2010, with 22 of 25 reaches flowing) the majority of the reaches were gaining, which means that the aquifer was discharging water to the stream reaches. During January 2010, 19 of the 22 reaches with streamflow were gaining (about 86 percent), and during June 2010, 11 of the 12 reaches with streamflow were gaining (about 92 percent). However, during drought-like conditions (July 2009), there was virtually no streamflow in the entire upper Coleto Creek watershed. The only streamflow observed was in reach C9 (fig. 6), which receives inflow from Audilet Spring, and reach C10 (fig. 6), which is the next downstream reach from C9. Water levels in the aquifer at this time seemed to have been reduced to the point that quantities of water discharged to the streams were insufficient to sustain flow.

In two cases, reaches had to be grouped together for gain-loss calculations because a streamflow measurement was not made at the site that acts as the dividing point between the two reaches in question. This occurred in July 2009, when reaches C11 and C14 had to be combined because streamflow was not measured at USGS station 08176590 Fifteenmile Creek below Eighteenmile Creek site (site 80 in figs. 4 and 6). There was no way to calculate gains or losses in the two stream reaches individually because this site acts as the downstream boundary of reach C11 and the upstream boundary of reach C14. The same is true of reaches C14 and C15 in June 2010, when streamflow was not measured at station 08176592 Fifteenmile Creek near Ander, Tex. (site 79; figs. 4 and 6).

For this report, a stream reach is classified as verifiably gaining or losing only if the difference in streamflow between the upstream and downstream measuring sites exceeds the potential error associated with the flow measurements made at those locations. Measurement error is a function of the streamflow measurement rating (excellent, good, fair, or poor) as determined by the hydrographer (streamgager) (Sauer and Meyer, 1992). The rating is based on streambed conditions, velocity homogeneity, cross-section uniformity, and any additional factors that affect the measurement accuracy. Measurements rated as excellent are believed to be within 2 percent of the actual flow, good are believed to be within 5 percent of flow, fair are believed to be within 8 percent of flow, and poor are believed to differ from actual flow by greater than 8 percent (set at 10 percent for the purposes of error calculations in this report). In the event that a measurement rating was unspecified, a measurement rating of "poor" was applied. The potential errors associated with the one to three streamflow measurements used to calculate gain-loss measurements for each reach were summed to obtain the potential composite error for comparison with the computed gain or loss. Most of the reported streamflows in this study (table 4) were an average of two measurements, each made by a different hydrographer. For three cases (at USGS station 08176580 Eighteenmile Creek at Highway 77A/183 near Ander, Tex., on June 22, 2010, station 08177300 on Perdido Creek on June 21, 2010, and at USGS station 08177270 Turkey Creek at Farm

Figure 6. Location of stream reaches, U.S. Geological Survey streamflow-measurement sites, streamflow-gaging stations, reservoir-stage gaging station, inflows, and spring in the upper Coleto Creek watershed, southeast Texas.

Road 2987 near Fannin, Tex., on January 11, 2010), only one measurement could be made, so the value shown has been qualified as an estimate. In one case (USGS station 08176550 Fifteenmile Creek near Weser, Tex., on July 29, 2009), the reported streamflow was an average of four measurements. In some cases, the measurement rating differed between the two consecutively collected measurements at a site. In these instances, an average of the potential errors associated with each of the streamflow measurements was applied to the average of the two streamflow measurements for that location in the potential composite error calculations. None of the streamflow measurements from this study were classified as good or excellent. A summary of gain-loss determinations for reaches along Coleto Creek and contributing streams during each of the three streamflow-measurement surveys is given in table 5.

Groundwater Hydrology

Potentiometric-surface maps (maps of water-level-altitude contours) were generated for each of three sampling periods (August 2009, fig. 7; January 2010, fig. 8; and June 2010, fig. 9) to help characterize the groundwater hydrology of the Evangeline aquifer in the study area. For each of the potentiometric-surface maps, there were one or two water-level-altitude measurements that were not used because they differed markedly from surrounding water-level altitudes and groundwater-level-altitude contours, possibly because the well had been recently pumped; these values are designated on figs. 7–9. In general, the groundwater flow direction is toward the southeast in the upper part of the study area (west of U.S. Highway 77A) and toward the east in the lower part of the study area (east of U.S. Highway 77A), roughly coinciding with the general flow direction of the main stem of Coleto Creek (figs. 7–9). Surface-water elevations from the streams in the study area were not included in the contouring process. The number of sites with continuous streamflow data (USGS streamflow-gaging station 08176550 Fifteenmile Creek near Weser, Tex., station 08176900 on Coleto Creek, and station 08177300 on Perdido Creek) is insufficient to provide an accurate graphical representation of the expected potentiometric-surface response with respect to the streams in the study area, particularly at the scale that these maps are presented.

The potentiometric-surface contours exhibit relatively consistent spacing patterns temporally from one sampling interval to the next (figs. 7–9), but some shifting of the potentiometric-surface between contours (to the southeast) did occur between each sampling event. This shift is especially apparent in figure 10, where potentiometric-surface contours from all three sampling events are overlain; in generating this figure, every other contour was removed from figures 7–9 to enhance interpretability. The most substantial shift occurred between August 2009 and January 2010, coincident with consistent precipitation from September 2009 through December 2009 (fig. 5*C*) after drought conditions during summer 2009 (fig. 10). The magnitude of the shift between January 2010 and June 2010 was much smaller after inconsistent precipitation between January 2010 and May 2010 (fig. 5*C*). On the basis of data collected during these three sampling events, it appears that the Evangeline aquifer in the study area might be responding relatively quickly (within 3 months or less) to both the absence of precipitation (August 2009) and relative abundance of precipitation (January 2010). However, a network of wells continuously monitored for water levels on a long-term basis across the study area would be necessary to confirm this relation between changes in groundwater altitudes and rainfall.

Only 0.89 in. of precipitation was recorded at the NWS weather station at Coleto Creek Reservoir (fig. 5*C;* table 3) between June 1, 2009, and August 12, 2009, when the measurement of groundwater-level altitudes (WLAs) was completed. As a result, WLAs increased across the study area between the first (August 2009) and third (June 2010) sampling events (table 6); in wells where WLAs were measured during all three sampling events, WLAs increased 2.35 ft on average during this period, and only one of the wells exhibited a decrease in WLA (State well 79-15-206). Most of the rebound in WLAs (1.71 ft, on average) was observed between the first and second (January 2010) sampling events. Only a 0.64-in. increase in WLAs was observed, on average, between the second and third sampling events.

Each of the three potentiometric-surface maps (figs. 7, 8, and 9) shows mounding of groundwater around one or more wells. Mounding occurs around State well 79-06-703 in all three of the figures and around State well 79-15-206 in both August 2009 and June 2010. A small groundwater mound also occurs around State well 79-05-904 in August 2009. One possible reason for these patterns would be perched zones within the aquifer.

A perched aquifer zone might also be responsible for the highly elevated WLAs at State wells 79-13-231 (January 2010 and June 2010) and 79-13-224 (August 2009 and June 2010) relative to the WLAs measured at State well 79-13-225 during the same sampling events (table 6). The WLA at State well 79-13-224 was 28.86 ft higher than the WLA at State well 79-13-225 in August 2009; the WLA at State well 79-13-231 was 39.95 ft higher than the WLA at State well 79-13-225 in January 2010; and the WLAs at State wells 79-13-231 and 79-13-224 were 40.53 and 40.16 ft higher than the WLA at State well 79-13-225 in June 2010, respectively. This is despite the fact that State wells 79-13-224 and 79-13-225 are only about 20 ft from one another and State well 79-13-231 is about 0.25 mi away from State well 79-13-225 over relatively flat terrain. WLAs from State wells 79-13-231 and 79-13-224 were not used during the potentiometric surface contouring process because of the large disparities between these two wells and State well 79-13-225. WLAs measured at State well 79-13-225 seemed to be more compatible with WLAs measured across the remainder of the study area, so this is the only one of the three wells used in the potentiometric-surface contouring process. An alternative explanation for the elevated WLAs measured at State wells 79-13-231 and 79-13-224 might be that these wells are partially or completely screened across an alluvial aquifer above the Evangeline aquifer. This scenario seems particularly plausible at State well 79-13-231, which is a hand-dug well.

Water Quality

During the three synoptic sampling events, a total of 44 water-quality samples (9 surface-water samples, 32 groundwater samples, and 3 spring samples) were collected and analyzed in most cases for selected physical properties (specific conductance, pH, water temperature, dissolved oxygen, and alkalinity) and constituents (dissolved solids, major ions, nutrients, trace elements, and stable isotopes of hydrogen and oxygen, and strontium). Physical properties were not collected at the Coleto Creek Reservoir site, and the only constituents analyzed in samples collected from the Coleto Creek Reservoir site and State well 79-23-205 were stable isotopes of hydrogen and oxygen. Analytical results for all of the water-quality samples are listed in table 7.

Dissolved Solids and Major-Ion Chemistry

Dissolved solids concentrations were greater than the (U.S. Environmental Protection Agency (USEPA) Secondary Maximum Contaminant Level (SMCL) for drinking water of 500 mg/L in 74 percent of the samples that were analyzed for dissolved solids (U.S. Environmental Protection Agency, 2000). Water samples were relatively consistent in major-ion composition and largely reflect the mineral composition of the rock and sediment that make up the aquifer. Trilinear diagrams (fig. 11) show that the predominant cation is calcium, and bicarbonate constitutes the major anion. Chloride tends to be present in higher equivalent concentrations in spring and surface-water samples than in groundwater samples.

Dissolved solids concentrations are an important indicator of the suitability of water for human consumption, agriculture, and industrial use. Drinking water containing dissolved solids in excess of the USEPA SMCL is aesthetically undesirable but might be an adequate option in areas where less mineralized water is unavailable. Measured dissolved solids concentrations from the wells ranged from 435 to 871 mg/L (table 7); the median dissolved solids concentration among 31 well samples was 585 mg/L, and 22 had concentrations greater than 500 mg/L.

Chloride concentrations in excess of 250 mg/L (the USEPA SMCL) can impart an objectionable, salty taste in drinking water and accelerate the corrosion of metal pipes (U.S. Environmental Protection Agency, 2000). Chloride concentrations ranged from 34.1 to 271 mg/L among the samples collected at wells, and the median concentration among these 31 samples was 123 mg/L. All three samples that exceeded 250 mg/L were collected at State well 79-05-408. The source or sources of elevated chloride concentrations at this location are unknown; however, possible anthropogenic sources might include inorganic fertilizers, septic-tank effluent, animal feed, or irrigation drainage (World Health Organization, 2011). Chloride might also be leaching from soil or rock into the groundwater in this area.

Stiff diagrams (Stiff, 1951) were constructed by using major-ion data to depict temporal changes in water composition at a given site (fig. 12). At all four surface-water sampling locations, calcium, magnesium, and chloride concentrations were higher in January 2010 than in June 2010. Bicarbonate concentrations also were higher at three of the four surface-water sites (samples collected at station 08177300 on Perdido Creek were the exception) in January 2010 compared to June 2010. Calcium concentrations in groundwater samples tended to be slightly lower in January 2010 than they were in the August 2009 and June 2010 sampling events. However, these variations are likely too small to be within the range of reproducibility for the laboratory analyses. The fact that all of the calcium concentrations were lower without a corresponding decrease in anion concentrations indicates this pattern might be a result of laboratory bias.

Stiff diagrams were also used as an alternative method for comparing water compositions spatially between different sites. Calcium, bicarbonate, and in some cases chloride were the predominant major ions (fig. 12, table 7). Major-ion compositions were relatively consistent among most of the samples, which can be characterized as generally calcium bicarbonate waters, with chloride often making a major contribution. The principal differences between diagrams from different sites were the magnitude of the calcium and bicarbonate contributions and the contribution of chloride relative to the other major-ion contributions. Chloride contributions to water composition seemed to be most prevalent in the samples collected either from streams or from wells close to the main stem of Coleto Creek. All State wells farther from the main stem of Coleto Creek, such as 79-05-303, 79-06-808, 79-14-204, 79-14-804, and 79-15-904, tended to have a smaller relative contribution of chloride to the major-ion composition. The Stiff diagrams for Audilet Spring and State well 79-06-713 have similar shapes, but the Audilet Spring diagram appears different relative to the State well 79-06-713 diagram. This means that the major ionic constituents that are used to construct Stiff diagrams were present in roughly the same proportions but at higher concentrations in Audilet Spring. This finding indicates that water from both sites might be derived from the same source but that the groundwater at State well 79-06-713 is likely (at least in part) from a different source. The other source is most likely recharge from precipitation, which tends to have relatively low concentrations of major ions compared to surface water or groundwater and would therefore serve to dilute the overall major-ion concentrations.

Table 4. Summary of streamflow-measurement results, measurement error ratings, and potential measurement errors for reaches along Coleto Creek and contributing streams during streamflow-measurement surveys in July 2009, January 2010, and June 2010, upper Coleto Creek watershed, southeast Texas.

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second. Error ratings: F, fair; P, poor; U, unspecified; --, no data]

Site identifier (figs. 4, 6, 12–15)	USGS station number	Site name	1st gain-loss survey, July 29–30, 2009 (ft^3/s)	1st gain-loss survey measurement error rating	1st gain-loss survey potential measurement error (ft^3/s)	2nd gain-loss survey, January 11–13, 2010 (ft^3/s)	2nd gain-loss survey measurement error rating	2nd gain-loss survey potential measurement error (ft^3/s)	3rd gain-loss survey, June 21–22, 2010 (ft^3/s)	3rd gain-loss survey measurement error rating	3rd gain-loss survey potential measurement error (ft^3/s)
1	08176523	Salt Creek at County Road 317 near Yorktown, Tex.	No flow	--	--	0.14[a]	P/P	0.014	No flow	--	--
2	08176535	Yorktown Creek at County Road 393 near Yorktown, Tex.	No flow	--	--	No flow	--	--	No flow	--	--
9	08176599	Fivemile Creek at Highway 77A/183 near Arneckville, Tex.	No flow	--	--	No flow	--	--	No flow	--	--
11	08176526	Thomas Creek at Cottonpatch Road near Yorktown, Tex.	No flow	--	--	.07[a]	P/P	.007	No flow	--	--
12	08176538	Yorktown Creek at Highway 72 at Yorktown, Tex.	No flow	--	--	.72[a]	P/P	.072	0.30[a]	P/P	0.03
13	08176529	Smith Creek at Highway 72 near Yorktown, Tex.	No flow	--	--	.46[a]	F/P	.041	No flow	--	--
14	08176532	Smith Creek at Highway 119 near Yorktown, Tex.	No flow	--	--	2.21[a]	F/F	.177	1.28[a]	P/P	.0128
20	08176594	Twelvemile Creek at Farm Road 2718 near Yorktown, Tex.	No flow	--	--	.27[a]	F/P	.024	No flow	--	--
23	08176540	Yorktown Creek at County Road 452 near Yorktown, Tex.	No flow	--	--	2.16[a]	P/F	.194	.83[a]	P/P	.083
26	08176544	Fifteenmile Creek at County Road 449 Road near Ander, Tex.	No flow	--	--	.23[a]	P/P	.023	2.89[a]	P/P	.289
32	08176675	Fivemile Creek at Farm Road 3157 near Arneckville, Tex.	No flow	--	--	No flow	--	--	No flow	--	--
34	08176596	Twelvemile Creek at Highway 77A/183 near Meyersville, Tex.	No flow	--	--	No flow	--	--	No flow	--	--
37	08176750	Fivemile Creek at County Road 400 near Meyersville, Tex.	No flow	--	--	.27[a]	P/P	.027	No flow	--	--
46	08176550	Fifteenmile Creek near Weser, Tex.	0.026[a]	P/P/P/P	0.0026	10.6[a]	F/F	.848	3.94[a]	P/P	.394
44	08176548	Fifteenmile Creek at Audilet Crossing near Ander, Tex.	--	--	--	9.49*	U/U	.949	--	--	--

Table 4. Summary of streamflow-measurement results, measurement error ratings, and potential measurement errors for reaches along Coleto Creek and contributing streams during streamflow-measurement surveys in July 2009, January 2010, and June 2010, upper Coleto Creek watershed, southeast Texas.—Continued

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second. Error ratings: F, fair; P, poor; U, unspecified; --, no data]

Site identifier (figs. 4, 6, 12–15)	USGS station number	Site name	1st gain-loss survey, July 29–30, 2009 (ft^3/s)	1st gain-loss survey measurement error rating	1st gain-loss survey potential measurement error (ft^3/s)	2nd gain-loss survey, January 11–13, 2010 (ft^3/s)	2nd gain-loss survey measurement error rating	2nd gain-loss survey potential measurement error (ft^3/s)	3rd gain-loss survey, June 21–22, 2010 (ft^3/s)	3rd gain-loss survey measurement error rating	3rd gain-loss survey potential measurement error (ft^3/s)
51	08176598	Twelvemile Creek at Wendel Road near Meyersville, Tex.	No flow	--	--	1.51[a]	P/P	0.151	No flow	--	--
55	08176825	Twelvemile Creek at Farm Road 237 near Mission Valley, Tex.	No flow	--	--	3.40[a]	U/U	.34	No flow	--	--
62	08176565	Eighteenmile Creek at Highway 119 at Weesatche, Tex.	No flow	--	--	.26[a]	U/U	.026	0.05[a]	P/P	0.005
70	08176580	Eighteenmile Creek at Highway 77A/183 near Ander, Tex.	No flow	--	--	1.46[a]	U/U	.146	.07[e]	P	.007
76	08176555	Fifteenmile Creek at Fox Road near Ander, Tex.	No flow	--	--	12.13[a]	U/U	1.213	4.54[a]	F/F	.363
80	08176590	Fifteenmile Creek below Eighteenmile Creek near Ander, Tex.	--	--	--	15.88[a]	U/U	1.588	5.85[a]	P/P	.585
79	08176592	Fifteenmile Creek near Ander, Tex.	No flow	--	--	17.21[a]	U/U	1.721	--	--	--
87	08177300	Perdido Creek at Farm Road 622 near Fannin, Tex.	No flow	--	--	.23[a]	P/P	.023	.04[e]	P	.004
101	08177310	Perdido Creek at Franke Road near Fannin, Tex.	No flow	--	--	--	--	--	--	--	--
90	08176900	Coleto Creek at Arnold Road Crossing near Schroeder, Tex.	No flow	--	--	24.63[a]	F/F	1.97	5.85[a]	F/F	.468
97	08177000	Coleto Creek near Schroeder, Tex.	No flow	--	--	Backwater	--	--	Backwater	--	--
99	08177270	Turkey Creek at Farm Road 2987 near Fannin, Tex.	No flow	--	--	.017[e]	U	.0017	No flow	--	--
104	08177350	Perdido Creek at Farm Road 2987 near Fannin, Tex.	No flow	--	--	No flow	--	--	No flow	--	--

[a] Average of measurements.

*Data not used in gain-loss calculations.

[e] Estimated.

Table 5. Gain-loss determinations for reaches along Coleto Creek and contributing streams during three streamflow-measurement surveys in July 2009, January 2010, and June 2010, upper Coleto Creek watershed, southeast Texas.

[ft, feet; ft^3/s, cubic feet per second; **bold font** indicates gain or loss that is less than potential measurement error for that particular reach]

Reach (fig. 6)	Reach length (ft)	Mean streamflow in reach (ft^3/s)	Measured difference in streamflow within reach (ft^3/s)	Estimated evaporation loss within reach (ft^3/s)	Estimated ground-water inflow within reach (ft^3/s)	Potential measurement error between downstream and upstream sites (ft^3/s)
July 2009						
C1	19,121	0	0	0	0	0
C2	18,681	0	0	0	0	0
C3	23,038	0	0	0	0	0
C4	56,004	0	0	0	0	0
C5	46,129	0	0	0	0	0
C6	54885	0	0	0	0	0
C7	56,480	0	0	0	0	0
C8	28,743	0	0	0	0	0
C9	25,138	.01	.03	.00	.03	.003
C10	25,991	.01	-.03	.00	-.02	.003
C11 and C14	39,816	0	0	0	0	0
C12	34,268	0	0	0	0	0
C13	29,177	0	0	0	0	0
C15	40,322	0	0	0	0	0
C16	53,698	0	0	0	0	0
C17	32,320	0	0	0	0	0
C18	15,873	0	0	0	0	0
C19	48,366	0	0	0	0	0
C20	30,230	0	0	0	0	0
C21	19,770	0	0	0	0	0
C22	24,544	0	0	0	0	0
T1	38,035	0	0	0	0	0
P1	48,681	0	0	0	0	0
P2	42,940	0	0	0	0	0
January 2010						
C1	19,121	0	0	0	0	0
C2	18,681	.36	.72	.003	.72	.07
C3	23,038	1.44	1.44	.008	1.45	.27
C4	56,004	2.3	-4.14	.024	-4.12	.39
C5	46,129	.035	.07	.005	.07	.01
C6	54,885	.335	.25	.010	.26	.06
C7	56,480	.07	.14	.003	.14	.01
C8	28,743	1.335	1.75	.014	1.76	.22
C9	25,138	5.415	10.37	.018	10.39	.87
C10	25,991	11.365	1.53	.034	**1.56**	2.06
C11	37,930	14.735	2.29	.030	**2.32**	2.95
C12	34,268	.13	.26	.004	.26	.03
C13	29,177	.86	1.2	.012	1.21	.17

Table 5. Gain-loss determinations for reaches along Coleto Creek and contributing streams during three streamflow-measurement surveys in July 2009, January 2010, and June 2010, upper Coleto Creek watershed, southeast Texas.—Continued

[ft^3/s, cubic feet per second; bold font indicates gain or loss that is less than potential measurement error for that particular reach]

Reach (fig. 6)	Reach length (ft)	Mean streamflow in reach (ft^3/s)	Measured difference in streamflow within reach (ft^3/s)	Estimated evaporation loss within reach (ft^3/s)	Estimated ground-water inflow within reach (ft^3/s)	Potential measurement error between downstream and upstream sites (ft^3/s)
January 2010—Continued						
C14	1,886	16.545	1.33	0.002	**1.33**	3.31
C15	40,322	22.62	4.02	.057	4.08	4.03
C16	53,698	.135	.27	.007	.28	.02
C17	32,320	.135	-.27	.004	-.27	.02
C18	15,873	.755	1.51	.003	1.51	.15
C19	48,366	2.59	1.62	.029	1.65	.52
C20	30,230	0	0	0	0	0
C21	19,770	0	0	0	0	0
C22	24,544	.135	.27	.004	.27	.03
T1	38,035	.0085	.017	.001	.02	.002
P1	48,681	.115	.23	.013	.24	.02
P2	42,940	.115	-.23	.012	-.22	.02
June 2010						
C1	19,121	0	0	0	0	0
C2	18,681	.15	.3	.007	.31	.03
C3	23,038	.565	.53	.023	.55	.11
C4	56,004	2.5	.78	.080	.86	.38
C5	46,129	0	0	0	0	0
C6	54,885	0	0	0	0	0
C7	56,480	0	0	0	0	0
C8	28,743	.64	1.28	.021	1.30	.013
C9	25,138	3.415	1.05	.042	1.09	.68
C10	25,991	4.24	.6	.057	**.66**	.76
C11	37,930	5.23	1.24	.039	1.28	.96
C12	34,268	.025	.05	.012	.06	.005
C13	29,177	.06	.02	.015	.04	.01
C14 and C15	42,208	5.85	0	.093	**.09**	1.05
C16	53,698	0	0	0	0	0
C17	32,320	0	0	0	0	0
C18	15,873	0	0	0	0	0
C19	48,366	0	0	0	0	0
C20	30,230	0	0	0	0	0
C21	19,770	0	0	0	0	0
C22	24,544	0	0	0	0	0
T1	38,035	0	0	0	0	0
P1	48,681	.02	.04	.005	.04	.004
P2	42,940	.02	-.04	.004	-.04	.004

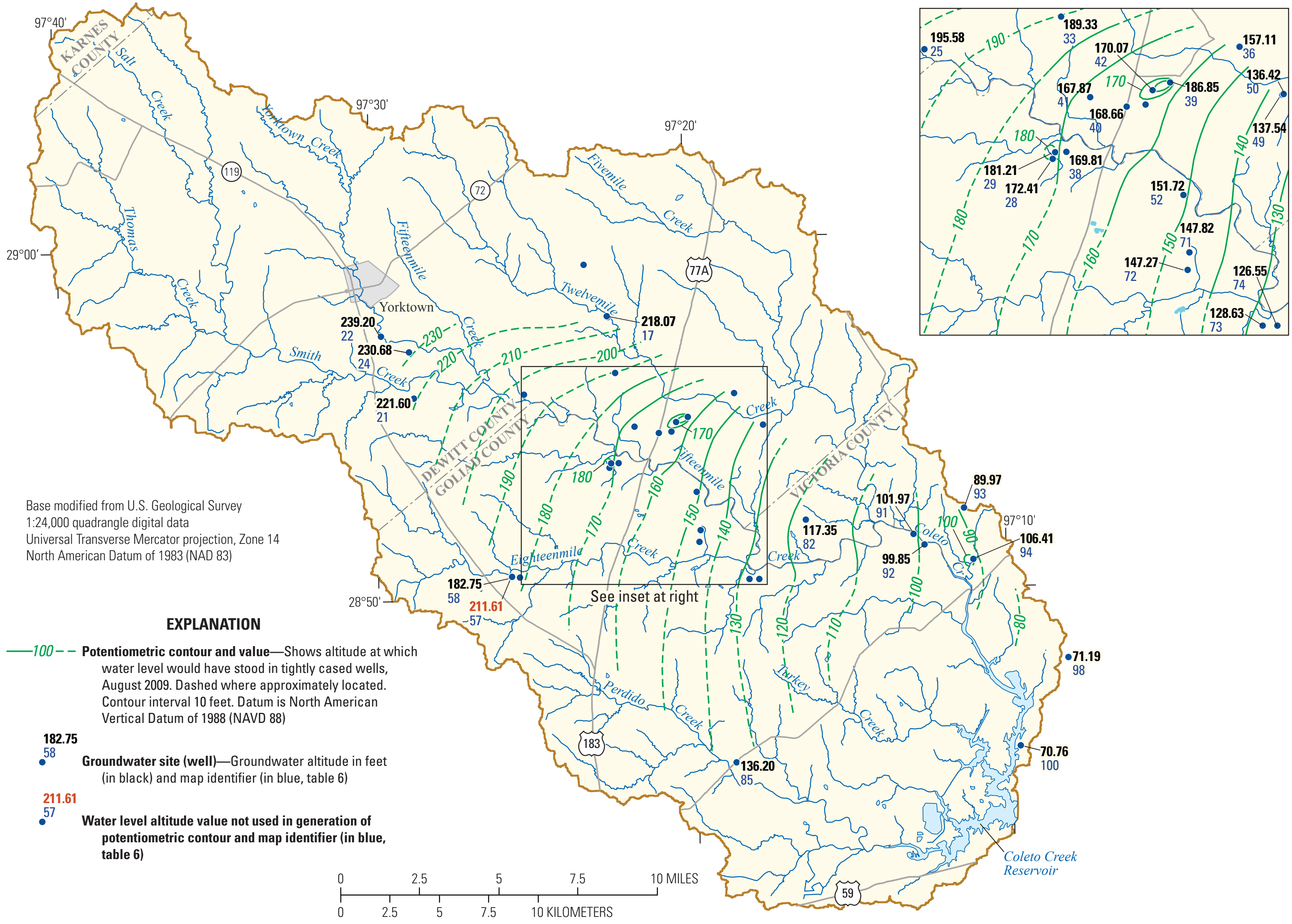
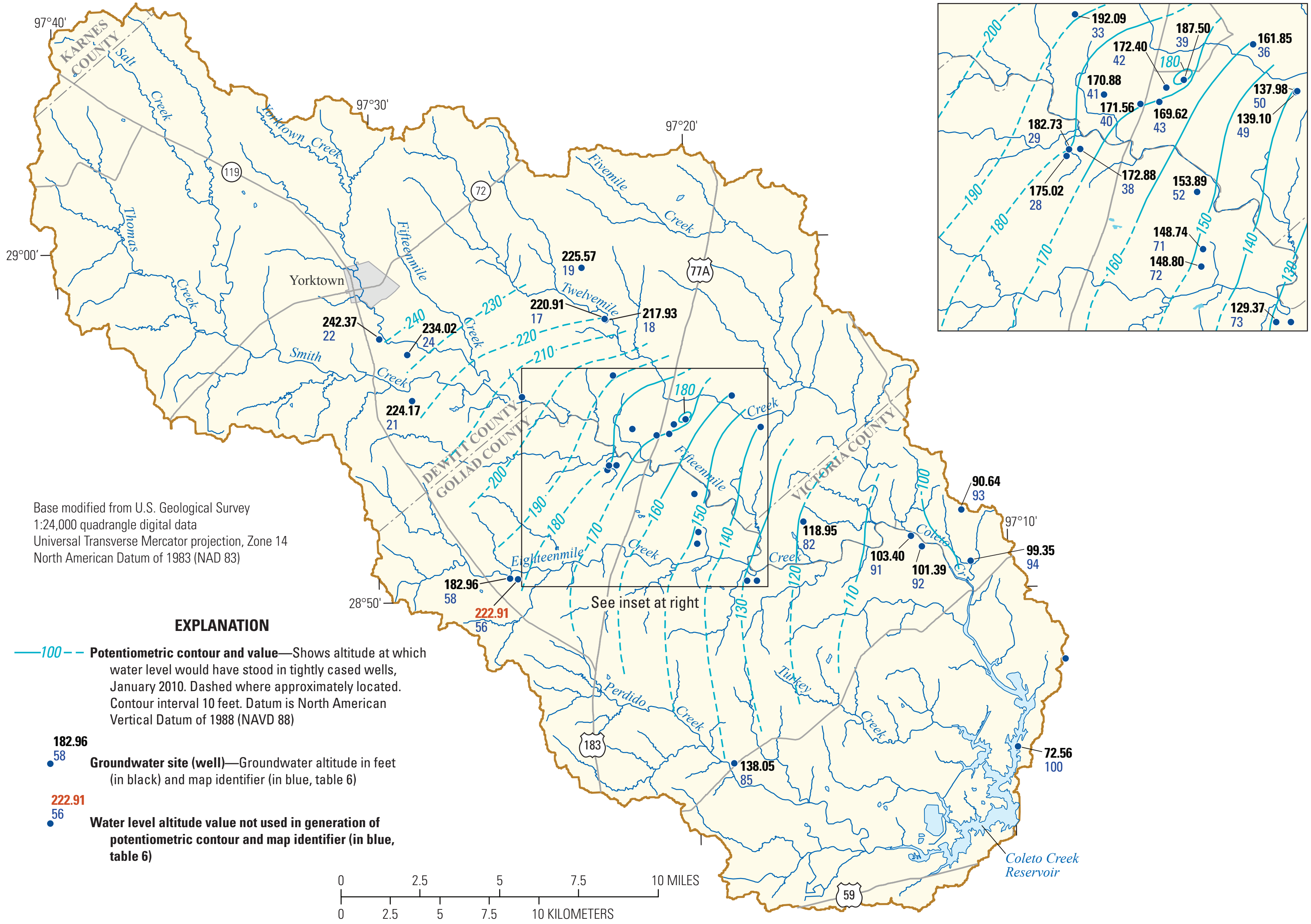


Figure 7. Potentiometric surface of the Evangeline aquifer in the upper Coleto Creek watershed, southeast Texas, August 2009.



Base modified from U.S. Geological Survey
1:24,000 quadrangle digital data
Universal Transverse Mercator projection, Zone 14
North American Datum of 1983 (NAD 83)

EXPLANATION

100 — — **Potentiometric contour and value**—Shows altitude at which water level would have stood in tightly cased wells, January 2010. Dashed where approximately located. Contour interval 10 feet. Datum is North American Vertical Datum of 1988 (NAVD 88)

● 182.96 58 **Groundwater site (well)**—Groundwater altitude in feet (in black) and map identifier (in blue, table 6)

● 222.91 56 **Water level altitude value not used in generation of potentiometric contour and map identifier (in blue, table 6)**

Figure 8. Potentiometric surface of the Evangeline aquifer in the upper Coleto Creek watershed, southeast Texas, January 2010.

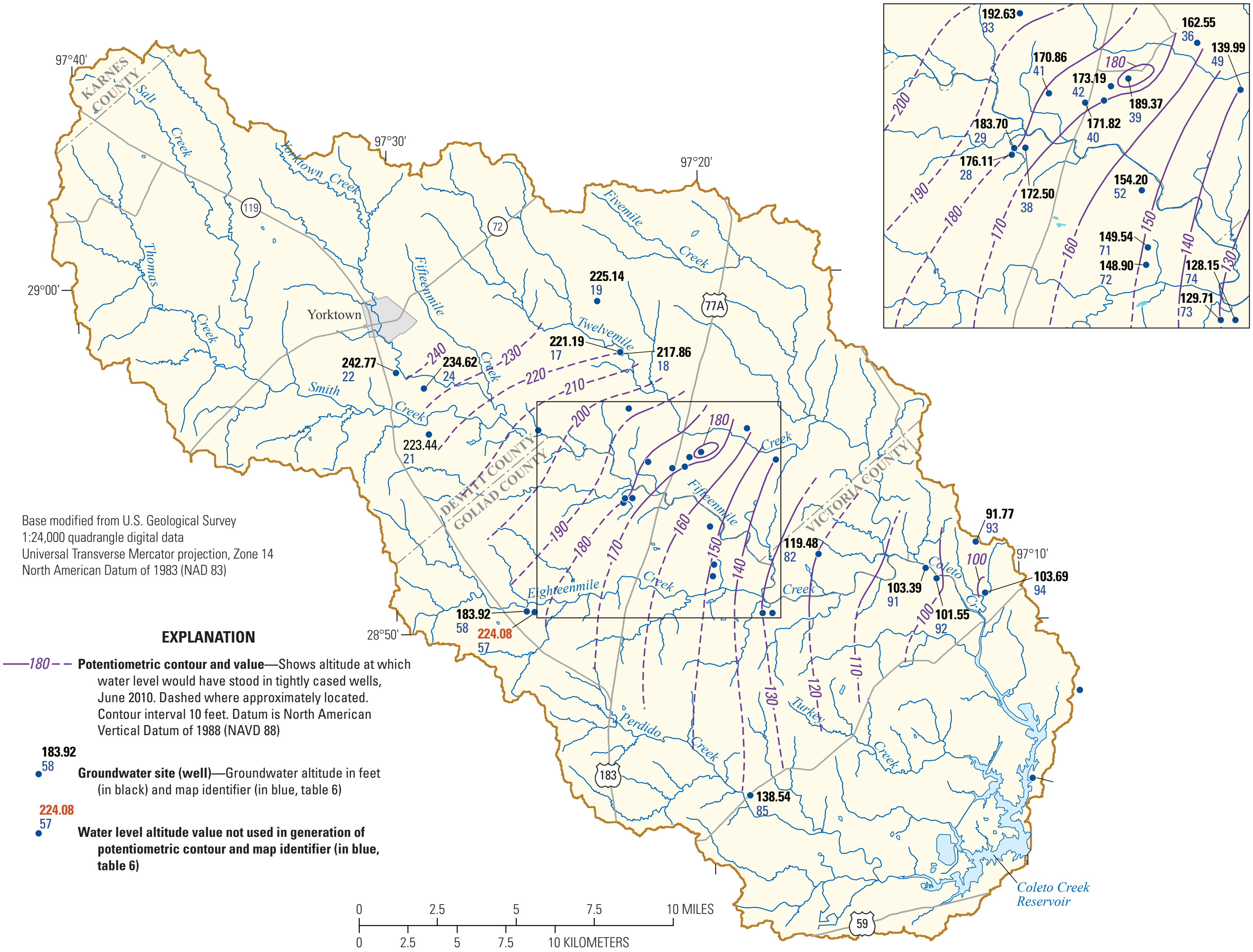
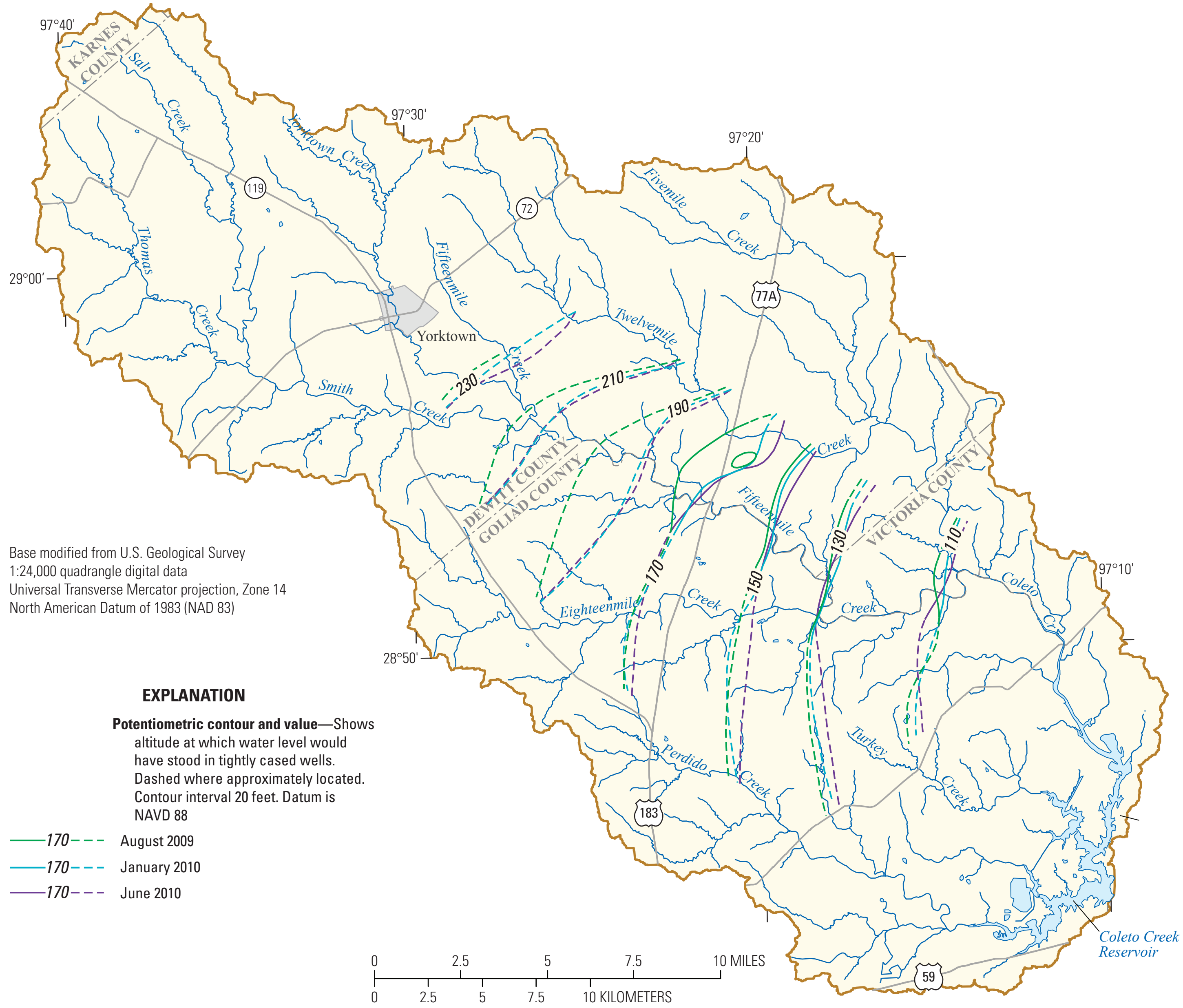


Figure 9. Potentiometric surface of the Evangeline aquifer in the upper Coleto Creek watershed, southeast Texas, June 2010.



Base modified from U.S. Geological Survey
1:24,000 quadrangle digital data
Universal Transverse Mercator projection, Zone 14
North American Datum of 1983 (NAD 83)

EXPLANATION

Potentiometric contour and value—Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval 20 feet. Datum is NAVD 88

170 - - -	August 2009
170 - - -	January 2010
170 - - -	June 2010

Figure 10. Comparison of potentiometric contours of the Evangeline aquifer in the upper Coleto Creek watershed, southeast Texas, during three synoptic measurement events, August 2009, January 2010, and June 2010.

Table 6. Groundwater-level altitude measurements at selected wells in the upper Coleto Creek watershed, southeast Texas, August 2009–June 2010.

[USGS, U.S. Geological Survey; NAVD 88, North American Vertical Datum of 1988; --, not measured; n/a, not available]

Site identifier (figs. 4, 6, 12–15)	County	USGS station number	State well number	Elevation of land surface (feet above NAVD 88)[1]	Well depth (feet)	Date of measurement during the first round of sampling	First round, water level (feet below land surface)	First round, groundwater-level altitude (feet above NAVD 88)	Date of measurement during the second round of sampling	Second round, water level (feet below land surface)	Second round, groundwater-level altitude (feet above NAVD 88)	Date of measurement during the third round of sampling	Third round, water level (feet below land surface)	Third round, groundwater-level altitude (feet above NAVD 88)
17	De Witt	285750097224001	79-05-303	244.36	148	8/4/2009	26.29	218.07	1/12/2010	23.45	220.91	6/23/2010	23.17	221.19
18	De Witt	285752097224201	79-05-304	248.30	44	8/4/2009	--	--	1/12/2010	30.37	217.93	6/23/2010	30.44	217.86
19	De Witt	285919097232301	79-05-305	296.87	200	--	--	--	1/12/2010	71.30	225.57	6/23/2010	71.73	225.14
21	De Witt	285541097285301	79-05-407	280.23	130	8/12/2009	58.63	221.60	1/22/2010	56.06	224.17	6/23/2010	56.79	223.44
22	De Witt	285726097295301	79-05-406	251.56	160	8/12/2009	12.36	239.20	1/12/2010	9.19	242.37	6/23/2010	8.79	242.77
24	De Witt	285658097290101	79-05-408	252.08	181	8/4/2009	21.40	230.68	1/12/2010	18.06	234.02	6/23/2010	17.46	234.62
25	De Witt	285543097252301	79-05-505	210.88	--	8/4/2009	15.30	195.58	n/a[2]	--	--	n/a[2]	--	--
28	Goliad	285337097224301	79-05-903	217.33	280	8/12/2009	44.92	172.41	1/13/2010	42.31	175.02	6/22/2010	41.22	176.11
29	Goliad	285344097224001	79-05-904	199.37	164	8/12/2009	18.16	181.21	1/13/2010	16.64	182.73	6/22/2010	15.67	183.70
33	De Witt	285616097222801	79-06-411	272.23	230	8/5/2009	82.90	189.33	1/12/2010	80.14	192.09	6/23/2010	79.60	192.63
36	De Witt	285537097184201	79-06-506	219.68	120	8/12/2009	62.57	157.11	1/12/2010	57.83	161.85	6/23/2010	57.13	162.55
38	Goliad	285345097222501	79-06-712	211.87	103	8/12/2009	42.06	169.81	1/13/2010	38.99	172.88	6/22/2010	39.37	172.50
39	De Witt	285459097201101	79-06-703	243.19	73	8/12/2009	56.34	186.85	1/22/2010	55.69	187.50	6/23/2010	53.82	189.37
40	De Witt	285434097191901	79-06-807	212.03	113	8/5/2009	43.37	168.66	1/12/2010	40.47	171.56	6/23/2010	40.21	171.82
41	De Witt	285445097215301	79-06-709	219.61	120	8/5/2009	51.74	167.87	1/12/2010	48.73	170.88	6/23/2010	48.75	170.86
42	De Witt	285451097203401	79-06-710	229.95	137	8/12/2009	59.88	170.07	1/22/2010	57.55	172.40	6/23/2010	56.76	173.19
43	De Witt	285435097204301	79-06-707	202.19	125	8/12/2009	36.14	166.05	1/22/2010	32.57	169.62	6/23/2010	--	--
49	De Witt	285443097174801	79-06-808	201.64	150	8/6/2009	64.10	137.54	1/12/2010	62.54	139.10	6/23/2010	61.65	139.99
50	De Witt	285443097174802	79-06-809	199.72	125	8/6/2009	63.30	136.42	1/12/2010	61.74	137.98	6/23/2010	--	--
52	Goliad	285254097195801	79-06-810	192.97	180	8/5/2009	41.25	151.72	1/13/2010	39.08	153.89	6/22/2010	38.77	154.20
56	Goliad	285037097253901	79-13-231	233.86	--	--	--	--	1/13/2010	10.95	222.91	6/22/2010	9.41	224.45
57	Goliad	285038097255402	79-13-224	234.62	--	8/5/2009	23.01	211.61	n/a[3]	--	--	6/22/2010	10.54	224.08
58	Goliad	285038097255401	79-13-225	233.37	65	8/5/2009	50.62	182.75	1/13/2010	50.41	182.96	6/22/2010	49.45	183.92
71	Goliad	285149097195201	79-14-204	231.42	122	8/6/2009	83.60	147.82	1/13/2010	82.68	148.74	6/22/2010	81.88	149.54
72	Goliad	285129097195401	79-14-202	182.66	88	8/12/2009	35.39	147.27	1/13/2010	33.86	148.80	6/23/2010	33.76	148.90
73	Goliad	285025097182101	79-14-205	168.74	346	8/6/2009	40.11	128.63	1/14/2010	39.37	129.37	6/22/2010	39.03	129.71
74	Goliad	285025097180201	79-14-203	172.09	380	8/12/2009	45.54	126.55	--	--	--	6/22/2010	43.94	128.15
82	Victoria	285203097163001	79-14-303	204.51	222	8/12/2009	87.16	117.35	1/13/2010	85.56	118.95	6/21/2010	85.03	119.48
85	Goliad	284518097185401	79-14-804	169.16	270	8/6/2009	32.96	136.20	1/11/2010	31.11	138.05	6/24/2010	30.62	138.54
91	Goliad	285134097130601	79-15-101	127.02	133	8/6/2009	25.05	101.97	1/14/2010	23.62	103.40	6/24/2010	23.63	103.39
92	Goliad	285116097124501	79-15-102	125.12	132	8/12/2009	25.27	99.85	1/13/2010	23.73	101.39	6/22/2010	23.57	101.55
93	Victoria	285216097112801	79-15-205	189.55	--	8/7/2009	99.58	89.97	1/13/2010	98.91	90.64	6/21/2010	97.78	91.77
94	Victoria	285049097111201	79-15-206	147.86	121	8/7/2009	41.45	106.41	1/13/2010	48.51	99.35	6/21/2010	44.17	103.69
98	Victoria	284801097081601	79-15-604	133.50	--	8/7/2009	62.31	71.19	n/a[3]	--	--	n/a[3]	--	--
100	Victoria	284535097095101	79-15-904	106.67	--	8/7/2009	35.91	70.76	1/14/2010	34.11	72.56	6/21/2010	33.88	72.79
108	Goliad	285345097215201	79-06-713	206.30	--	--	--	--	1/13/2010	32.60	173.70	6/22/2010	34.89	171.41

[1] Elevation obtained from digital elevation model data.

[2] Well deactivated by Texas Commission of Environmental Quality (TCEQ) on 10/18/2009.

[3] Well deactivated by TCEQ on 11/4/2009.

Nutrients

Compounds rich in nitrogen and phosphorous, which are also referred to as nutrients, are essential to the health of plants and animals and occur naturally in water. Elevated concentrations of nutrients such as nitrate, which has a USEPA MCL of 10.0 mg/L, can cause adverse affects in humans, particularly infants (U.S. Environmental Protection Agency, 2010). In 1999, the USGS reported on a study that investigated nutrient data from natural settings across the country and estimated a national average concentration of naturally occurring nitrate (sum of nitrate plus nitrite; contribution of nitrite to sum commonly is negligible) in groundwater of 2.0 mg/L, reported as nitrogen. The same study also indicated that human activities have increased nutrients above background concentrations, and nitrate concentrations greater than 2.0 mg/L are often a result of livestock operations, proximity of wells to septic systems, irrigation intensity, and application and storage of fertilizers and manure. The effects of these anthropogenic activities on nitrate concentrations in groundwater might also be modified by soil characteristics, topography, precipitation quantity, and the presence or absence of confining layers above the aquifer (U.S. Geological Survey, 1999).

Nitrite was detected in 8 of the 42 samples collected, including 6 of 8 surface-water samples. Nitrite concentrations were very low (less than 0.04 mg/L as nitrogen in all cases) for all detections. Nitrate (as nitrate plus nitrite) was detected in all but three samples (fig. 13); nitrite contributions to nitrate were negligible (table 7). Nitrate concentrations exceeded the threshold concentration (2.0 mg/L as nitrogen) associated with anthropogenic sources at only 3 of the 19 sites (State wells 79-06-411, 79-14-204, and Audilet Spring. State wells 79-06-411 and 79-14-204 are within about a 3-mi radius of Audilet Spring; all other sites within that radius exhibited slightly elevated nitrate concentrations (1.07 to 1.52 mg/L) relative to the remaining sites in the study area, and nitrate concentrations less than 1.00 mg/L were measured in 24 out of 29 samples collected at these other sites.

Trace Elements

Many trace elements are beneficial in small quantities to the health of living things, but small increases in concentrations can result in negative health impacts (Maugh, 1973). Trace elements typically occur naturally in water at concentrations much less than 1 mg/L and are caused by water interacting with surrounding geological deposits (Hem, 1985). Anthropogenic sources of trace elements include pesticides, fossil fuels, paints, construction and plumbing materials, and corrosion inhibitors. Because of wide distribution of both natural and anthropogenic sources of trace elements, the possibility exists for either the occurrence or increased occurrence of some trace elements in water. Of the 23 trace elements for which water was analyzed as part of this study (table 7), all but selenium are classified as metals or metalloids.

The following trace elements were detected in all 42 of the samples: barium, cobalt, lithium, molybdenum, nickel, strontium, vanadium, arsenic, boron, selenium, and uranium. The detection frequencies for the remaining trace elements were as follows: manganese (40), chromium (39), lead (38), antimony (30), zinc (28), copper (27), iron (21), aluminum (16), cadmium (14), beryllium (13), silver (4), and thallium (1).

Public drinking-water standards or guidelines have not yet been established for 3 of the 23 trace elements on the analytical schedule: cobalt, lithium, and vanadium. Of the 20 remaining trace elements, measured concentrations were less than established public drinking-water standards in all samples for all but 2 elements, arsenic and manganese. Arsenic concentrations exceeded the USEPA Maximum Contaminant Level (MCL) (2010) of 10 µg/L (U.S. Environmental Protection Agency, 2010) in two samples (one collected at station 08177300 on Perdido Creek on June 21, 2010, and one collected from Audilet Spring on January 13, 2010). Potential health effects associated with excessive arsenic concentrations in drinking water include cardiovascular disease, increased cancer risk, diabetes, and anemia (U.S. Environmental Protection Agency, 2000). Arsenic occurs naturally, particularly in sulfide-rich rocks, and might also be associated with iron oxides on mineral surfaces. Potential anthropogenic sources of arsenic in the study area include pesticides, food additives for swine and poultry, wood preservatives, and petroleum products (Welch and others, 2000). Manganese concentrations exceeded the USEPA SMCL of 50 µg/L (U.S. Environmental Protection Agency, 2000) in seven of the 42 samples collected; these included both samples collected at USGS station 08176540 Yorktown Creek at County Road 452 near Yorktown, Tex., both samples collected at station 08177300 on Perdido Creek, and all three samples collected at State well 79-15-904. Manganese is ubiquitous in the environment and might be found in many types of rock and soil; it might also be released into the air by iron and steel production plants, powerplants, and coke ovens (Agency for Toxic Substances and Disease Registry, 2008). Manganese can impart a color, odor, or taste to drinking water at concentrations greater than 50 µg/L, but health effects are not a concern until concentrations are approximately 10 times higher (Connecticut Department of Public Health, 2011). All three samples collected from State well 79-15-904 had concentrations in excess of 500 µg/L (716 µg/L on August 7, 2009; 1,970 µg/L on January 14, 2010; and 2,460 µg/L on June 21, 2010).

Table 7. Water-quality data collected from surface-water, groundwater, and spring sites, upper Coleto Creek watershed, southeast Texas, August 2009–June 2010.

[USGS, U.S. Geological Survey; --, no data or not applicable; <, less than; E, estimated; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter]

Station number	State well number	USGS station --me	Date	Time	Barometric pressure, millimeters of mercury
08176540	--	Yorktown Creek at County Road 452 near Yorktown, Tex.	1/12/2010	1400	770
08176540	--	Yorktown Creek at County Road 452 near Yorktown, Tex.	6/23/2010	1530	762
08176590	--	Fifteenmile Creek below Eighteenmile Creek near Ander, Tex.	1/13/2010	1100	770
08176590	--	Fifteenmile Creek below Eighteenmile Creek near Ander, Tex.	6/22/2010	1430	763
08176900	--	Coleto Creek at Arnold Road Crossing near Schroeder, Tex.	1/14/2010	1210	764
08176900	--	Coleto Creek at Arnold Road Crossing near Schroeder, Tex.	6/24/2010	1130	766
08177300	--	Perdido Creek at Farm Road 622 near Fannin, Tex.	1/11/2010	1650	770
08177300	--	Perdido Creek at Farm Road 622 near Fannin, Tex.	6/21/2010	1630	765
284528097095400	--	Coleto Creek Reservoir near Victoria, Tex.	1/14/2010	900	--
284240097112201	79-23-205	--	1/14/2010	1630	761
284518097185401	79-14-804	--	8/6/2009	1400	--
284518097185401	79-14-804	--	1/11/2010	1500	--
284518097185401	79-14-804	--	6/24/2010	900	764
284535097095101	79-15-904	--	8/7/2009	1100	--
284535097095101	79-15-904	--	1/14/2010	830	--
284535097095101	79-15-904	--	6/21/2010	1445	766
285025097182101	79-14-205	--	8/6/2009	1200	--
285025097182101	79-14-205	--	1/14/2010	1400	760
285025097182101	79-14-205	--	6/22/2010	830	764
285049097111201	79-15-206	--	8/7/2009	930	763
285134097130601	79-15-101	--	8/6/2009	1530	764
285134097130601	79-15-101	--	1/14/2010	1100	--
285134097130601	79-15-101	--	6/24/2010	1230	768
285149097195201	79-14-204	--	8/6/2009	915	760
285149097195201	79-14-204	--	1/13/2010	1300	--
285149097195201	79-14-204	--	6/22/2010	1030	761
285216097112801	79-15-205	--	8/7/2009	1300	765
285254097195801	79-06-810	--	8/5/2009	1500	--
285345097215201	79-06-713	--	1/13/2010	1500	765
285345097215201	79-06-713	--	6/22/2010	1715	762
285354097215401	79-06-711 (Audilet Spring)	--	8/5/2009	1330	760
285354097215401	79-06-711 (Audilet Spring)	--	1/13/2010	830	769
285354097215401	79-06-711 (Audilet Spring)	--	6/22/2010	1530	764
285443097174801	79-06-808	--	8/6/2009	1700	--
285443097174801	79-06-808	--	1/12/2010	1130	772
285443097174801	79-06-808	--	6/23/2010	1045	763
285445097215301	79-06-709	--	8/5/2009	900	--
285616097222801	79-06-411	--	8/5/2009	1200	--
285616097222801	79-06-411	--	1/12/2010	1000	--
285616097222801	79-06-411	--	6/23/2010	900	760
285658097290101	79-05-408	--	8/4/2009	1730	--
285658097290101	79-05-408	--	1/12/2010	1500	--
285658097290101	79-05-408	--	6/23/2010	1400	764
285750097224001	79-05-303	--	8/4/2009	1500	760

Table 7. Water-quality data collected from surface-water, groundwater, and spring sites, upper Coleto Creek watershed, southeast Texas, August 2009–June 2010.—Continued

[USGS, U.S. Geological Survey; --, no data or not applicable; <, less than; E, estimated; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter]

Station number	Date	Dissolved oxygen, water, unfiltered (mg/L)	pH, water, unfiltered, field, standard units	pH, water, unfiltered, lab, standard units	Specific conductance, water, unfiltered, field, microsiemens per centimeter at 25°C	Specific conductance, water, unfiltered, lab, microsiemens per centimeter at 25°C	Temperature, water, °C	Turbidity, water, unfiltered, formazin nephelometric units (FNU)
08176540	1/12/2010	13.5	7.9	8.0	1,090	1,120	11.1	12
08176540	6/23/2010	7.7	7.9	8.0	1,320	1,310	31.3	6.0
08176590	1/13/2010	10.5	8.0	8.1	894	921	11.0	18
08176590	6/22/2010	7.1	7.9	8.2	1,030	1,030	30.9	8.4
08176900	1/14/2010	10.9	8.2	8.2	793	817	12.3	6.3
08176900	6/24/2010	6.6	7.9	8.2	980	987	29.2	5.6
08177300	1/11/2010	12.8	7.8	8.0	747	746	8.8	15
08177300	6/21/2010	6.6	7.9	7.9	595	1040	35.4	.4
284528097095400	1/14/2010	--	--	--	--	--	--	--
284240097112201	1/14/2010	2.4	7.1	--	1,160	--	24.1	--
284518097185401	8/6/2009	6.0	E 6.7	7.4	718	729	24.5	17
284518097185401	1/11/2010	5.8	E 7.1	7.4	726	715	24.4	16
284518097185401	6/24/2010	6.0	E 7.1	7.4	715	716	24.4	2.5
284535097095101	8/7/2009	.2	E 6.3	7.2	881	916	23.3	--
284535097095101	1/14/2010	.7	E 6.9	7.4	821	818	23.1	4.4
284535097095101	6/21/2010	.3	E 6.9	7.3	827	836	23.2	6.8
285025097182101	8/6/2009	3.8	E 6.3	7.5	1,160	1,160	25.5	<.3
285025097182101	1/14/2010	4.2	E 7.1	7.5	1,140	1,140	25.1	<.3
285025097182101	6/22/2010	3.9	E 7.0	7.4	1,150	1,170	25.2	<.3
285049097111201	8/7/2009	--	E 6.3	7.2	1,190	1,190	24.0	<.3
285134097130601	8/6/2009	.2	6.5	7.6	1,040	1,060	22.9	--
285134097130601	1/14/2010	.6	7.2	7.5	1,040	1,050	22.8	<.3
285134097130601	6/24/2010	.3	7.1	7.5	1,050	1,060	22.9	<.3
285149097195201	8/6/2009	6.3	E 6.5	7.3	752	760	24.8	4
285149097195201	1/13/2010	6.9	E 7.0	7.3	736	734	23.2	<.3
285149097195201	6/22/2010	6.6	E 6.9	7.3	724	725	24.7	<.3
285216097112801	8/7/2009	--	E 6.6	7.5	1,050	1,080	26.2	--
285254097195801	8/5/2009	--	E 6.7	7.5	897	917	23.9	.9
285345097215201	1/13/2010	7.9	7.3	7.3	955	964	22.6	4.2
285345097215201	6/22/2010	7.0	7.1	7.3	1,140	985	23.8	8.5
285354097215401	8/5/2009	4.2	E 6.4	7.2	1,380	1,410	23.3	1.5
285354097215401	1/13/2010	5.8	7.0	7.2	1,290	1,300	23.6	<.3
285354097215401	6/22/2010	6.2	7.2	7.1	1,220	1,220	22.2	12
285443097174801	8/6/2009	5.9	E 6.1	7.4	834	854	23.9	--
285443097174801	1/12/2010	6.3	E 7.0	7.4	774	823	23.8	<.3
285443097174801	6/23/2010	6.1	E 7.0	7.4	830	844	23.9	2.8
285445097215301	8/5/2009	--	E 6.5	7.5	803	861	23.9	<.3
285616097222801	8/5/2009	4.3	E 6.7	7.4	979	996	24.5	2.7
285616097222801	1/12/2010	4.5	E 7.1	7.5	1,000	979	24.3	17
285616097222801	6/23/2010	4.4	E 7.0	7.4	983	1000	24.3	2.1
285658097290101	8/4/2009	3.1	E 6.3	7.2	1,470	1,510	24.2	17
285658097290101	1/12/2010	3.4	E 6.9	7.4	1,460	1,460	24.1	.6
285658097290101	6/23/2010	3.2	E 6.8	7.3	1,470	1,500	24.1	1.8
285750097224001	8/4/2009	--	E 6.3	7.5	796	825	24.1	<.3

Table 7. Water-quality data collected from surface-water, groundwater, and spring sites, upper Coleto Creek watershed, southeast Texas, August 2009–June 2010.—Continued

[USGS, U.S. Geological Survey; --, no data or not applicable; <, less than; E, estimated; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter]

Station number	Date	Dissolved solids dried at 180°C, water, filtered (mg/L)	Hardness, water, (mg/L as $CaCO_3$)	Calcium, water, filtered (mg/L)	Magnesium, water, filtered (mg/L)	Potassium, water, filtered (mg/L)	Sodium adsorption ratio, water, number	Sodium, water, filtered (mg/L)	Alkalinity, water, filtered, field (mg/L as $CaCO_3$)
08176540	1/12/2010	710	280	94.9	10.3	7.69	2.93	113	274
08176540	6/23/2010	769	331	111	13.0	8.62	3.43	143	286
08176590	1/13/2010	566	296	101	10.2	3.40	1.58	62.2	271
08176590	6/22/2010	613	328	111	11.9	4.31	2.09	87.0	275
08176900	1/14/2010	498	263	91.1	8.39	3.24	1.43	53.1	243
08176900	6/24/2010	583	319	108	11.7	4.11	2.00	82.1	258
08177300	1/11/2010	469	253	81.2	12.1	3.13	1.30	47.3	221
08177300	6/21/2010	636	310	92.0	19.2	3.34	2.32	93.7	201
284528097095400	1/14/2010	--	--	--	--	--	--	--	--
284240097112201	1/14/2010	--	--	--	--	--	--	--	--
284518097185401	8/6/2009	435	249	78.2	12.9	2.88	1.47	53.4	260
284518097185401	1/11/2010	449	241	75.4	12.5	2.96	1.46	51.9	274
284518097185401	6/24/2010	444	262	82.0	13.7	3.10	1.48	55.1	276
284535097095101	8/7/2009	541	358	120	14.0	2.15	1.13	49.2	329
284535097095101	1/14/2010	518	321	109	11.5	1.79	.93	38.1	322
284535097095101	6/21/2010	457	347	119	12.1	1.76	.94	40.4	--
285025097182101	8/6/2009	665	296	88.7	17.7	3.26	2.86	113	248
285025097182101	1/14/2010	677	288	86.0	17.5	3.27	2.78	108	254
285025097182101	6/22/2010	689	310	93.0	18.6	3.51	2.98	120	254
285049097111201	8/7/2009	726	394	132	15.7	2.85	1.75	79.9	286
285134097130601	8/6/2009	608	162	--	--	--	--	--	258
285134097130601	1/14/2010	607	260	81.4	13.5	3.34	2.74	101	262
285134097130601	6/24/2010	591	282	88.0	14.9	3.59	2.91	112	262
285149097195201	8/6/2009	480	292	102	8.96	2.02	1.07	42.0	303
285149097195201	1/13/2010	490	274	95.2	8.75	2.13	1.10	41.9	315
285149097195201	6/22/2010	465	297	104	8.97	2.12	1.10	43.5	305
285216097112801	8/7/2009	592	252	75.3	15.2	3.38	3.15	115	253
285254097195801	8/5/2009	529	310	101	14.0	3.35	1.63	66.1	265
285345097215201	1/13/2010	597	295	92.1	15.7	3.23	2.05	80.9	276
285345097215201	6/22/2010	585	315	98.1	16.8	3.21	2.15	87.8	292
285354097215401	8/5/2009	846	401	128	19.2	2.23	2.70	124	345
285354097215401	1/13/2010	814	367	118	17.3	2.45	2.62	115	329
285354097215401	6/22/2010	743	377	122	17.7	2.36	2.60	116	324
285443097174801	8/6/2009	501	263	90.3	8.94	2.43	1.78	66.3	273
285443097174801	1/12/2010	519	252	86.3	8.83	2.39	1.71	62.4	291
285443097174801	6/23/2010	503	282	97.1	9.47	2.60	1.81	69.7	292
285445097215301	8/5/2009	493	253	83.8	10.4	3.51	2.08	76.0	267
285616097222801	8/5/2009	586	285	92.8	12.9	4.22	2.23	86.6	260
285616097222801	1/12/2010	610	264	85.5	12.1	4.17	2.19	81.8	267
285616097222801	6/23/2010	587	299	97.1	13.5	4.60	2.32	91.9	268
285658097290101	8/4/2009	851	367	123	14.5	4.13	3.47	153	313
285658097290101	1/12/2010	871	361	120	14.4	4.32	3.55	155	320
285658097290101	6/23/2010	850	385	129	15.0	4.40	3.58	161	326
285750097224001	8/4/2009	474	229	77.9	8.18	2.40	2.13	73.8	278

Table 7. Water-quality data collected from surface-water, groundwater, and spring sites, upper Coleto Creek watershed, southeast Texas, August 2009–June 2010.—Continued

[USGS, U.S. Geological Survey; --, no data or not applicable; <, less than; E, estimated; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter]

Station number	Date	Bicarbonate, water, filtered (mg/L)	Bromide, water, filtered (mg/L)	Carbon dioxide, water, unfiltered (mg/L)	Carbonate, water, filtered, field (mg/L)	Chloride, water, filtered (mg/L)	Fluoride, water, filtered (mg/L)	Silica, water, filtered (mg/L as SiO_2)	Sulfate, water, filtered (mg/L)	Ammonia, water, filtered (mg/L as NH_4)
08176540	1/12/2010	331	0.56	6.8	1	170	0.27	26.5	54.9	0.092
08176540	6/23/2010	345	.73	7.7	2	218	.43	34.0	53.3	.141
08176590	1/13/2010	329	.42	4.9	<1	117	.31	23.6	36.4	<.026
08176590	6/22/2010	333	.54	6.3	1	147	.41	37.4	30.8	.044
08176900	1/14/2010	293	.36	3.4	2	98.7	.28	20.8	31.7	<.026
08176900	6/24/2010	309	.52	5.9	2	139	.39	38.0	28.6	E .023
08177300	1/11/2010	268	.37	7.5	<1	100	.31	20.8	26.4	<.026
08177300	6/21/2010	245	.78	5.1	<1	196	.53	48.8	29.0	E .023
284528097095400	1/14/2010	--	--	--	--	--	--	--	--	--
284240097112201	1/14/2010	--	--	--	--	--	--	--	--	--
284518097185401	8/6/2009	317	.19	E 105	<1	57.1	.65	48.8	20.0	<.026
284518097185401	1/11/2010	334	.18	E 39	<1	59.4	.65	45.3	19.9	<.026
284518097185401	6/24/2010	336	.17	E 46	<1	56.5	.70	48.1	18.1	<.026
284535097095101	8/7/2009	400	.42	E 289	<1	81.5	.24	38.5	14.8	<.026
284535097095101	1/14/2010	393	.43	E 80	<1	77.2	.22	33.4	6.73	<.026
284535097095101	6/21/2010	--	.40	--	--	73.8	.25	35.4	5.98	<.026
285025097182101	8/6/2009	302	.57	E 251	<1	190	.51	32.6	39.8	<.026
285025097182101	1/14/2010	309	.56	E 38	<1	194	.51	30.2	39.8	<.026
285025097182101	6/22/2010	309	.54	E 46	<1	193	.56	32.6	37.3	<.026
285049097111201	8/7/2009	348	.78	E 252	<1	192	.22	37.3	22.9	<.026
285134097130601	8/6/2009	314	.53	157	<1	167	.37	15.6	26.9	<.026
285134097130601	1/14/2010	319	.48	37	<1	168	.41	26.7	26.8	<.026
285134097130601	6/24/2010	319	.46	42	<1	169	.43	26.3	24.8	<.026
285149097195201	8/6/2009	369	.30	E 198	<1	38.3	.35	55.7	18.6	<.026
285149097195201	1/13/2010	384	.27	E 65	<1	37.0	.38	50.7	18.4	<.026
285149097195201	6/22/2010	E 372	.25	E 76	<1	34.1	.42	56.2	16.4	<.026
285216097112801	8/7/2009	306	.52	E 133	<1	172	.31	26.3	17.5	<.026
285254097195801	8/5/2009	323	.35	E 102	<1	112	.51	36.5	27.3	<.026
285345097215201	1/13/2010	336	.39	25	<1	125	.65	39.5	38.7	<.026
285345097215201	6/22/2010	E 356	.38	42	<1	123	.72	42.4	36.2	<.026
285354097215401	8/5/2009	420	.80	E 271	<1	200	.72	58.6	48.0	<.026
285354097215401	1/13/2010	401	.76	68	<1	195	.69	53.3	47.0	<.026
285354097215401	6/22/2010	395	.63	39	<1	165	.73	53.5	47.1	<.026
285443097174801	8/6/2009	332	.29	E 458	<1	90.4	.31	44.8	18.5	<.026
285443097174801	1/12/2010	354	.28	E 53	<1	90.6	.31	40.6	17.9	<.026
285443097174801	6/23/2010	E 355	.27	E 58	<1	89.2	.33	44.7	16.3	<.026
285445097215301	8/5/2009	325	.30	E 187	<1	90.9	.48	38.0	21.3	<.026
285616097222801	8/5/2009	317	.49	E 96	<1	133	.53	43.8	27.8	<.026
285616097222801	1/12/2010	325	.49	E 39	<1	138	.54	44.6	27.8	<.026
285616097222801	6/23/2010	326	.46	E 49	<1	132	.57	44.6	26.0	<.026
285658097290101	8/4/2009	381	.74	E 289	<1	259	.42	36.6	35.8	<.026
285658097290101	1/12/2010	390	.74	E 79	<1	271	.41	34.0	35.8	<.026
285658097290101	6/23/2010	397	.69	E 91	<1	269	.47	36.2	33.7	<.026
285750097224001	8/4/2009	339	.28	E 269	<1	81.8	.41	39.2	22.0	<.026

Table 7. Water-quality data collected from surface-water, groundwater, and spring sites, upper Coleto Creek watershed, southeast Texas, August 2009–June 2010.—Continued

[USGS, U.S. Geological Survey; --, no data or not applicable; <, less than; E, estimated; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter]

Station number	Date	Ammonia, water, filtered (mg/L as N)	Nitrate plus nitrite, water, filtered (mg/L as N)	Nitrate, water, filtered (mg/L)	Nitrate, water, filtered (mg/L as N)	Nitrite, water, filtered (mg/L)	Nitrite, water, filtered (mg/L as N)	Organic nitrogen, water, filtered (mg/L)	Organic nitrogen, water, unfiltered (mg/L)
08176540	1/12/2010	0.072	1.79	7.77	1.750	0.105	0.032	--	0.42
08176540	6/23/2010	.110	.22	.890	.201	.053	.016	--	.75
08176590	1/13/2010	<.020	.29	1.28	.289	.019	.006	--	<.28
08176590	6/22/2010	.035	.05	.209	.047	.009	.003	--	.35
08176900	1/14/2010	<.020	.17	.713	.161	.013	.004	--	<.31
08176900	6/24/2010	E .018	E .03	E .128	E .029	<.007	<.002	--	E .28
08177300	1/11/2010	<.020	.14	.575	.130	.017	.005	--	<.29
08177300	6/21/2010	E .018	<.04	<.177	<.040	<.007	<.002	--	<.21
284528097095400	1/14/2010	--	--	--	--	--	--	--	--
284240097112201	1/14/2010	--	--	--	--	--	--	--	--
284518097185401	8/6/2009	<.020	.60	2.64	.597	<.007	<.002	--	--
284518097185401	1/11/2010	<.020	.60	2.66	.600	<.007	<.002	--	--
284518097185401	6/24/2010	<.020	.58	2.55	.576	<.007	<.002	<0.02	--
284535097095101	8/7/2009	<.020	.21	.942	.213	.007	.002	<.12	--
284535097095101	1/14/2010	<.020	.06	.248	.056	<.007	<.002	<.07	--
284535097095101	6/21/2010	<.020	<.04	<.177	<.040	<.007	<.002	<.14	--
285025097182101	8/6/2009	<.020	1.28	5.68	1.28	<.007	<.002	<.05	--
285025097182101	1/14/2010	<.020	1.33	5.90	1.33	<.007	<.002	--	--
285025097182101	6/22/2010	<.020	1.29	5.72	1.29	<.007	<.002	<.03	--
285049097111201	8/7/2009	<.020	1.52	6.71	1.52	<.007	<.002	<.03	--
285134097130601	8/6/2009	<.020	E .02	E .097	E .022	<.007	<.002	<.08	--
285134097130601	1/14/2010	<.020	E .02	E .106	E .024	<.007	<.002	<.08	--
285134097130601	6/24/2010	<.020	<.04	<.177	<.040	<.007	<.002	<.10	--
285149097195201	8/6/2009	<.020	3.16	14.0	3.16	<.007	<.002	--	--
285149097195201	1/13/2010	<.020	3.42	15.1	3.42	<.007	<.002	<.03	--
285149097195201	6/22/2010	<.020	2.74	12.1	2.74	<.007	<.002	<.08	--
285216097112801	8/7/2009	<.020	E .02	E .093	E .021	<.007	<.002	<.08	--
285254097195801	8/5/2009	<.020	1.07	4.73	1.07	<.007	<.002	--	--
285345097215201	1/13/2010	<.020	1.10	4.87	1.10	<.013	<.004	--	--
285345097215201	6/22/2010	<.020	1.17	5.17	1.17	<.007	<.002	<.09	--
285354097215401	8/5/2009	<.020	3.44	15.2	3.44	.010	.003	<.03	--
285354097215401	1/13/2010	<.020	3.79	16.8	3.79	<.007	<.002	--	--
285354097215401	6/22/2010	<.020	4.23	18.7	4.23	<.007	<.002	--	--
285443097174801	8/6/2009	<.020	.83	3.67	.829	<.007	<.002	<.02	--
285443097174801	1/12/2010	<.020	.87	3.84	.867	<.007	<.002	--	--
285443097174801	6/23/2010	<.020	.85	3.75	.848	<.007	<.002	<.06	--
285445097215301	8/5/2009	<.020	1.09	4.83	1.09	<.007	<.002	<.05	--
285616097222801	8/5/2009	<.020	2.15	9.52	2.15	<.007	<.002	<.01	--
285616097222801	1/12/2010	<.020	2.37	10.5	2.37	<.007	<.002	--	--
285616097222801	6/23/2010	<.020	2.31	10.2	2.31	<.007	<.002	<.08	--
285658097290101	8/4/2009	<.020	.69	3.06	.691	<.007	<.002	<.02	--
285658097290101	1/12/2010	<.020	.69	3.05	.690	<.007	<.002	--	--
285658097290101	6/23/2010	<.020	.67	2.95	.666	<.007	<.002	<.02	--
285750097224001	8/4/2009	<.020	.90	4.00	.904	<.007	<.002	--	--

Table 7. Water-quality data collected from surface-water, groundwater, and spring sites, upper Coleto Creek watershed, southeast Texas, August 2009–June 2010.—Continued

[USGS, U.S. Geological Survey; --, no data or not applicable; <, less than; E, estimated; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter]

Station number	Date	Orthophosphate, water, filtered (mg/L)	Orthophosphate, water, filtered (mg/L as P)	Phosphorus, water, unfiltered (mg/L as P)	Total nitrogen (nitrate + nitrite + ammonia + organic-N), water, filtered (mg/L)	Total nitrogen (nitrate + nitrite + ammonia + organic-N), water, unfiltered (mg/L)	Aluminum, water, filtered (µg/L)
08176540	1/12/2010	1.94	0.632	0.682	--	2.28	13.3
08176540	6/23/2010	2.15	.701	.725	--	1.08	E 3.0
08176590	1/13/2010	.131	.043	.058	--	.58	21.0
08176590	6/22/2010	.338	.110	.124	--	.43	<3.4
08176900	1/14/2010	.082	.027	.042	--	.48	8.6
08176900	6/24/2010	.247	.081	.079	--	.33	E 2.1
08177300	1/11/2010	.028	.009	.009	--	.42	7.8
08177300	6/21/2010	.088	.029	E .007	--	.23	7.8
284528097095400	1/14/2010	--	--	--	--	--	--
284240097112201	1/14/2010	--	--	--	--	--	--
284518097185401	8/6/2009	.063	.021	--	--	--	<4.0
284518097185401	1/11/2010	.061	.020	--	0.56	--	<3.4
284518097185401	6/24/2010	.102	.033	--	.60	--	<3.4
284535097095101	8/7/2009	.172	.056	--	.34	--	<4.0
284535097095101	1/14/2010	.200	.065	--	.12	--	<3.4
284535097095101	6/21/2010	.225	.074	--	.14	--	E 2.7
285025097182101	8/6/2009	.049	.016	--	1.33	--	<4.0
285025097182101	1/14/2010	.052	.017	--	1.22	--	<10.2
285025097182101	6/22/2010	.082	.027	--	1.33	--	<3.4
285049097111201	8/7/2009	.060	.020	--	1.55	--	<4.0
285134097130601	8/6/2009	.045	.015	--	<.10	--	8.5
285134097130601	1/14/2010	.047	.015	--	<.10	--	4.0
285134097130601	6/24/2010	.068	.022	--	<.10	--	<3.4
285149097195201	8/6/2009	.092	.030	--	3.03	--	<4.0
285149097195201	1/13/2010	.089	.029	--	3.45	--	12.6
285149097195201	6/22/2010	.134	.044	--	2.82	--	5.1
285216097112801	8/7/2009	.052	.017	--	<.10	--	<4.0
285254097195801	8/5/2009	.055	.018	--	1.03	--	<4.0
285345097215201	1/13/2010	.052	.017	--	1.01	--	<3.4
285345097215201	6/22/2010	.086	.028	--	1.26	--	<3.4
285354097215401	8/5/2009	.086	.028	--	3.48	--	<4.0
285354097215401	1/13/2010	.067	.022	.012	--	3.71	<10.2
285354097215401	6/22/2010	.126	.041	.011	--	4.17	E 2.8
285443097174801	8/6/2009	.067	.022	--	.85	--	<4.0
285443097174801	1/12/2010	.076	.025	--	.77	--	<3.4
285443097174801	6/23/2010	.111	.036	--	.90	--	<3.4
285445097215301	8/5/2009	.059	.019	--	1.14	--	<4.0
285616097222801	8/5/2009	.064	.021	--	2.16	--	E 2.4
285616097222801	1/12/2010	.065	.021	--	2.17	--	7.9
285616097222801	6/23/2010	.093	.030	--	2.39	--	3.7
285658097290101	8/4/2009	.058	.019	--	.71	--	<4.0
285658097290101	1/12/2010	.059	.019	--	.61	--	<10.2
285658097290101	6/23/2010	.081	.027	--	.69	--	<3.4
285750097224001	8/4/2009	.060	.020	--	.90	--	<4.0

Table 7. Water-quality data collected from surface-water, groundwater, and spring sites, upper Coleto Creek watershed, southeast Texas, August 2009–June 2010.—Continued

[USGS, U.S. Geological Survey; --, no data or not applicable; <, less than; E, estimated; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter]

Station number	Date	Barium, water, filtered (µg/L)	Beryllium, water, filtered (µg/L)	Cadmium, water, filtered (µg/L)	Chromium, water, filtered (µg/L)	Cobalt, water, filtered (µg/L)	Copper, water, filtered (µg/L)	Iron, water, filtered (µg/L)	Lead, water, filtered (µg/L)	Lithium, water, filtered (µg/L)
08176540	1/12/2010	206	<0.04	<0.06	<0.36	0.70	7.1	29	E 0.08	26.5
08176540	6/23/2010	248	<.01	<.02	.21	.70	<1.0	8	.06	36.5
08176590	1/13/2010	354	<.01	E .01	.17	.76	<1.0	11	E .02	12.2
08176590	6/22/2010	365	<.01	<.02	.14	.70	<1.0	<6	E .02	16.6
08176900	1/14/2010	316	<.01	<.02	.18	.76	E .53	22	E .02	10.2
08176900	6/24/2010	366	<.01	<.02	.16	.61	<1.0	6	E .02	13.9
08177300	1/11/2010	426	E .01	<.02	.18	.97	E .55	44	E .02	8.9
08177300	6/21/2010	613	E .01	E .01	.22	.49	<1.0	11	<.03	16.3
284528097095400	1/14/2010	--	--	--	--	--	--	--	--	--
284240097112201	1/14/2010	--	--	--	--	--	--	--	--	--
284518097185401	8/6/2009	184	<.02	E .01	.68	.09	1.7	<4	2.87	15.8
284518097185401	1/11/2010	175	<.01	<.02	.83	.63	1.1	9	.44	16.5
284518097185401	6/24/2010	163	<.01	<.02	.73	.20	E .78	<6	.28	18.2
284535097095101	8/7/2009	376	<.02	<.02	E .08	.58	E .91	E 3	.19	9.5
284535097095101	1/14/2010	491	E .01	E .02	.31	1.7	1.9	E 5	.21	4.5
284535097095101	6/21/2010	549	E .01	.03	E .08	2.2	E .80	<6	.11	4.6
285025097182101	8/6/2009	113	<.02	<.02	.78	.32	2.2	E 2	.70	26.8
285025097182101	1/14/2010	105	<.04	<.06	.74	.63	E 2.9	<6	.44	25.7
285025097182101	6/22/2010	106	<.01	E .01	.82	.32	<1.0	<6	.34	27.4
285049097111201	8/7/2009	242	<.02	<.02	.17	.59	2.0	<4	.07	15.3
285134097130601	8/6/2009	155	<.02	.04	.14	.11	3.3	5	.59	15.3
285134097130601	1/14/2010	244	E .01	<.02	.26	.55	<1.0	<6	.35	24.3
285134097130601	6/24/2010	245	E .01	<.02	.21	.25	<1.0	<6	.25	27.4
285149097195201	8/6/2009	352	<.02	<.02	E .07	.19	1.6	E 4	.08	9.5
285149097195201	1/13/2010	337	<.01	E .01	.28	.79	3.0	10	.18	9.3
285149097195201	6/22/2010	352	E .01	<.02	E .08	.36	E .81	<6	.07	10.6
285216097112801	8/7/2009	279	<.02	<.02	.20	.21	<1.0	<4	<.06	24.9
285254097195801	8/5/2009	140	<.02	<.02	.55	.22	<1.0	<4	.70	18.7
285345097215201	1/13/2010	97	<.01	E .02	.84	.50	3.8	35	.04	20.6
285345097215201	6/22/2010	92	E .01	.02	.82	.35	2.4	31	.04	24.7
285354097215401	8/5/2009	175	<.02	<.02	<.12	.18	<1.0	E 4	<.06	13.8
285354097215401	1/13/2010	147	<.04	<.06	<.36	.47	<3.0	E 4	<.09	14.2
285354097215401	6/22/2010	138	E .01	<.02	.22	.40	<1.0	<6	E .03	13.4
285443097174801	8/6/2009	198	<.02	<.02	.26	.13	1.0	E 4	.42	11.2
285443097174801	1/12/2010	188	E .01	<.02	.37	.71	E .85	<6	.28	12.1
285443097174801	6/23/2010	197	<.01	E .01	.37	.16	1.2	<6	.43	13.5
285445097215301	8/5/2009	133	<.02	<.02	.38	.18	E .80	<4	.15	14.1
285616097222801	8/5/2009	95	<.02	<.02	.45	.25	E .64	E 3	.18	17.0
285616097222801	1/12/2010	92	E .01	E .01	2.8	.69	E .91	13	.11	16.9
285616097222801	6/23/2010	95	E .01	E .01	.52	.27	<1.0	<6	.08	22.8
285658097290101	8/4/2009	132	<.02	<.02	.34	.20	1.2	<4	.20	21.6
285658097290101	1/12/2010	128	<.04	<.06	.47	.40	<3.0	<6	E .07	21.9
285658097290101	6/23/2010	126	E .01	E .02	.35	.33	E .64	<6	.10	23.8
285750097224001	8/4/2009	103	<.02	<.02	.51	.32	E .88	<4	.14	12.1

Table 7. Water-quality data collected from surface-water, groundwater, and spring sites, upper Coleto Creek watershed, southeast Texas, August 2009–June 2010.—Continued

[USGS, U.S. Geological Survey; --, no data or not applicable; <, less than; E, estimated; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter]

Station number	Date	Manganese, water, filtered (µg/L)	Molybdenum, water, filtered (µg/L)	Nickel, water, filtered (µg/L)	Silver, water, filtered (µg/L)	Strontium, water, filtered (µg/L)	Thallium, water, filtered (µg/L)	Vanadium, water, filtered (µg/L)	Zinc, water, filtered (µg/L)
08176540	1/12/2010	62.3	1.3	2.5	<0.03	496	<0.06	7.7	E 4.9
08176540	6/23/2010	92.5	1.5	2.2	<.01	578	<.02	10.2	<2.8
08176590	1/13/2010	32.1	1.1	3.9	.02	390	<.02	7.1	<2.8
08176590	6/22/2010	38.6	1.1	1.8	<.01	432	<.02	10.1	E 2.3
08176900	1/14/2010	20.2	.9	3.5	<.01	333	<.02	5.9	<2.8
08176900	6/24/2010	25.7	.9	1.5	<.01	417	<.02	8.4	2.9
08177300	1/11/2010	172	.8	3.4	<.01	303	<.02	7.6	<2.8
08177300	6/21/2010	100	.8	1.4	<.01	426	<.02	10.3	E 1.9
284528097095400	1/14/2010	--	--	--	--	--	--	--	--
284240097112201	1/14/2010	--	--	--	--	--	--	--	--
284518097185401	8/6/2009	E .1	1.3	.35	<.01	459	<.04	12.0	3.5
284518097185401	1/11/2010	.8	1.4	2.3	<.01	482	<.02	12.1	E 1.6
284518097185401	6/24/2010	E .3	1.4	.53	<.01	433	<.02	12.0	<2.8
284535097095101	8/7/2009	716	1.7	2.7	<.01	396	<.04	9.5	<2.0
284535097095101	1/14/2010	1,970	1.6	8.5	<.01	302	E .01	8.4	<2.8
284535097095101	6/21/2010	2,460	1.4	7.4	<.01	287	<.02	8.2	<2.8
285025097182101	8/6/2009	.5	2.4	.42	<.01	969	<.04	9.7	6.3
285025097182101	1/14/2010	E .8	2.2	1.4	<.03	890	<.06	10.6	<8.4
285025097182101	6/22/2010	.4	2.4	.66	<.01	909	<.02	10.2	E 1.6
285049097111201	8/7/2009	.3	.7	.68	<.01	722	<.04	7.0	20.8
285134097130601	8/6/2009	30.6	.7	2.2	<.01	547	<.04	1.4	11.5
285134097130601	1/14/2010	.9	1.3	2.6	<.01	940	<.02	2.5	<2.8
285134097130601	6/24/2010	.9	1.3	.63	<.01	908	<.02	2.7	<2.8
285149097195201	8/6/2009	E .2	.5	.41	<.01	291	<.04	12.9	3.0
285149097195201	1/13/2010	.8	.5	2.9	.01	302	<.02	12.8	2.9
285149097195201	6/22/2010	.4	.5	.58	E .01	274	<.02	13.5	E 2.3
285216097112801	8/7/2009	1.2	.8	.35	<.01	1,120	<.04	4.6	E 1.3
285254097195801	8/5/2009	3.8	1.5	.40	<.01	456	<.04	18.3	2.8
285345097215201	1/13/2010	.9	1.8	2.8	<.01	528	<.02	23.5	122
285345097215201	6/22/2010	1.2	1.7	1.0	<.01	494	<.02	26.4	99.8
285354097215401	8/5/2009	2.0	1.1	.54	<.01	491	<.04	31.4	<2.0
285354097215401	1/13/2010	2.8	1.1	1.8	<.03	495	<.06	32.1	<8.4
285354097215401	6/22/2010	.5	1.3	1.6	<.01	465	<.02	32.4	<2.8
285443097174801	8/6/2009	E .2	1.0	.36	<.01	293	<.04	10.9	E 1.6
285443097174801	1/12/2010	.6	1.0	2.7	<.01	323	<.02	11.2	E 1.4
285443097174801	6/23/2010	<.3	1.1	.69	<.01	324	<.02	12.1	5.2
285445097215301	8/5/2009	E .2	1.8	.34	<.01	380	<.04	9.9	2.3
285616097222801	8/5/2009	.3	2.0	.41	<.01	465	<.04	20.2	2.0
285616097222801	1/12/2010	.7	2.0	3.2	E .01	498	<.02	19.3	5.3
285616097222801	6/23/2010	E .2	2.0	1.0	<.01	491	<.02	21.8	E 2.7
285658097290101	8/4/2009	E .2	1.7	.72	<.01	687	<.04	10.8	6.7
285658097290101	1/12/2010	<.8	1.6	1.9	<.03	730	<.06	12.5	E 5.0
285658097290101	6/23/2010	1.1	1.7	1.0	<.01	719	<.02	12.0	4.5
285750097224001	8/4/2009	.4	1.6	.35	<.01	367	<.04	8.2	E 1.1

Table 7. Water-quality data collected from surface-water, groundwater, and spring sites, upper Coleto Creek watershed, southeast Texas, August 2009–June 2010.—Continued

[USGS, U.S. Geological Survey; --, no data or not applicable; <, less than; E, estimated; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter]

Station number	Date	Antimony, water, filtered (µg/L)	Arsenic, water, filtered (µg/L)	Boron, water, filtered (µg/L)	Selenium, water, filtered (µg/L)	Uranium (natural), water, filtered (µg/L)	Deuterium/ Protium ratio, water, unfiltered, per mil	Oxygen-18/ Oxygen-16 ratio, water, unfiltered, per mil	Strontium-87/ Strontium-86 ratio, water, filtered, per mil
08176540	1/12/2010	E 0.14	3.9	226	0.73	1.53	-22.60	-4.35	0.70905
08176540	6/23/2010	.18	5.8	307	.44	1.17	-19.65	-3.35	.70909
08176590	1/13/2010	.24	4.6	125	.88	1.87	-22.50	-4.16	.70957
08176590	6/22/2010	.17	8.0	196	.44	1.22	-18.95	-3.23	.70948
08176900	1/14/2010	.22	4.1	112	.78	1.67	-22.50	-4.39	.70966
08176900	6/24/2010	.14	7.4	153	.39	1.17	-17.40	-3.08	.70951
08177300	1/11/2010	.14	5.2	86	.97	1.31	-24.50	-4.42	.71003
08177300	6/21/2010	.09	13.0	185	.37	.68	-10.75	-1.31	.71000
284528097095400	1/14/2010	--	--	--	--	--	-15.90	-2.41	--
284240097112201	1/14/2010	--	--	--	--	--	-22.60	-4.18	--
284518097185401	8/6/2009	<.04	1.6	134	.79	1.52	-23.50	-4.27	.70910
284518097185401	1/11/2010	.06	1.7	147	.92	1.63	-24.30	-4.18	.70905
284518097185401	6/24/2010	E .04	1.6	133	.78	1.60	-24.10	-4.24	.70902
284535097095101	8/7/2009	E .04	4.7	138	.20	2.87	-8.10	-1.12	.70950
284535097095101	1/14/2010	.14	4.4	136	.12	1.54	-1.80	0.14	.70975
284535097095101	6/21/2010	.08	7.4	144	.09	1.45	-1.68	0.33	.70977
285025097182101	8/6/2009	E .03	.57	240	3.9	3.38	-23.40	-4.31	.70854
285025097182101	1/14/2010	<.16	.90	223	4.0	3.30	-23.60	-4.32	.70855
285025097182101	6/22/2010	E .03	.83	237	3.5	3.24	-23.00	-4.32	.70852
285049097111201	8/7/2009	E .02	3.0	115	1.9	1.56	-21.30	-4.08	.70882
285134097130601	8/6/2009	.04	.73	128	.13	.91	-24.00	-4.25	.70832
285134097130601	1/14/2010	.18	1.4	200	.17	1.45	-24.20	-4.41	.70832
285134097130601	6/24/2010	E .04	1.4	216	.13	1.49	-24.20	-4.36	.70829
285149097195201	8/6/2009	E .04	6.0	135	2.4	1.35	-24.10	-4.41	.70983
285149097195201	1/13/2010	.10	6.6	147	3.0	1.36	-23.80	-4.40	.70989
285149097195201	6/22/2010	.06	6.2	148	2.9	1.33	-23.74	-4.26	.70987
285216097112801	8/7/2009	<.04	1.8	217	.14	2.11	-23.80	-4.39	.70815
285254097195801	8/5/2009	<.04	2.1	158	2.3	2.89	-23.10	-4.45	.70925
285345097215201	1/13/2010	.16	8.1	190	2.2	2.44	-24.60	-4.34	.70955
285345097215201	6/22/2010	E .04	7.6	208	1.8	2.43	-23.80	-4.20	.70958
285354097215401	8/5/2009	.04	9.8	146	3.3	1.73	-22.20	-4.06	.70997
285354097215401	1/13/2010	<.16	10.1	150	3.6	1.66	-22.30	-4.04	.70997
285354097215401	6/22/2010	.06	9.6	151	2.7	1.59	-22.11	-4.04	.70998
285443097174801	8/6/2009	<.04	2.1	106	.84	.85	-23.90	-4.34	.70951
285443097174801	1/12/2010	.14	2.3	116	1.0	.84	-23.80	-4.35	.70956
285443097174801	6/23/2010	<.05	2.4	126	.84	.86	-23.40	-4.34	.70955
285445097215301	8/5/2009	<.04	1.5	142	1.2	1.90	-23.50	-4.34	.70929
285616097222801	8/5/2009	E .02	2.9	140	2.0	1.90	-22.60	-4.24	.70916
285616097222801	1/12/2010	.15	3.2	138	2.1	1.77	-22.70	-4.22	.70917
285616097222801	6/23/2010	<.05	3.2	172	1.9	1.86	-24.10	-4.19	.70918
285658097290101	8/4/2009	<.04	.75	236	1.6	3.33	-25.40	-4.68	.70923
285658097290101	1/12/2010	<.16	3.0	257	1.8	3.44	-26.30	-4.67	.70933
285658097290101	6/23/2010	E .03	1.1	262	1.5	3.32	-26.30	-4.65	.70926
285750097224001	8/4/2009	<.04	.58	111	1.4	1.46	-24.20	-4.59	.70902

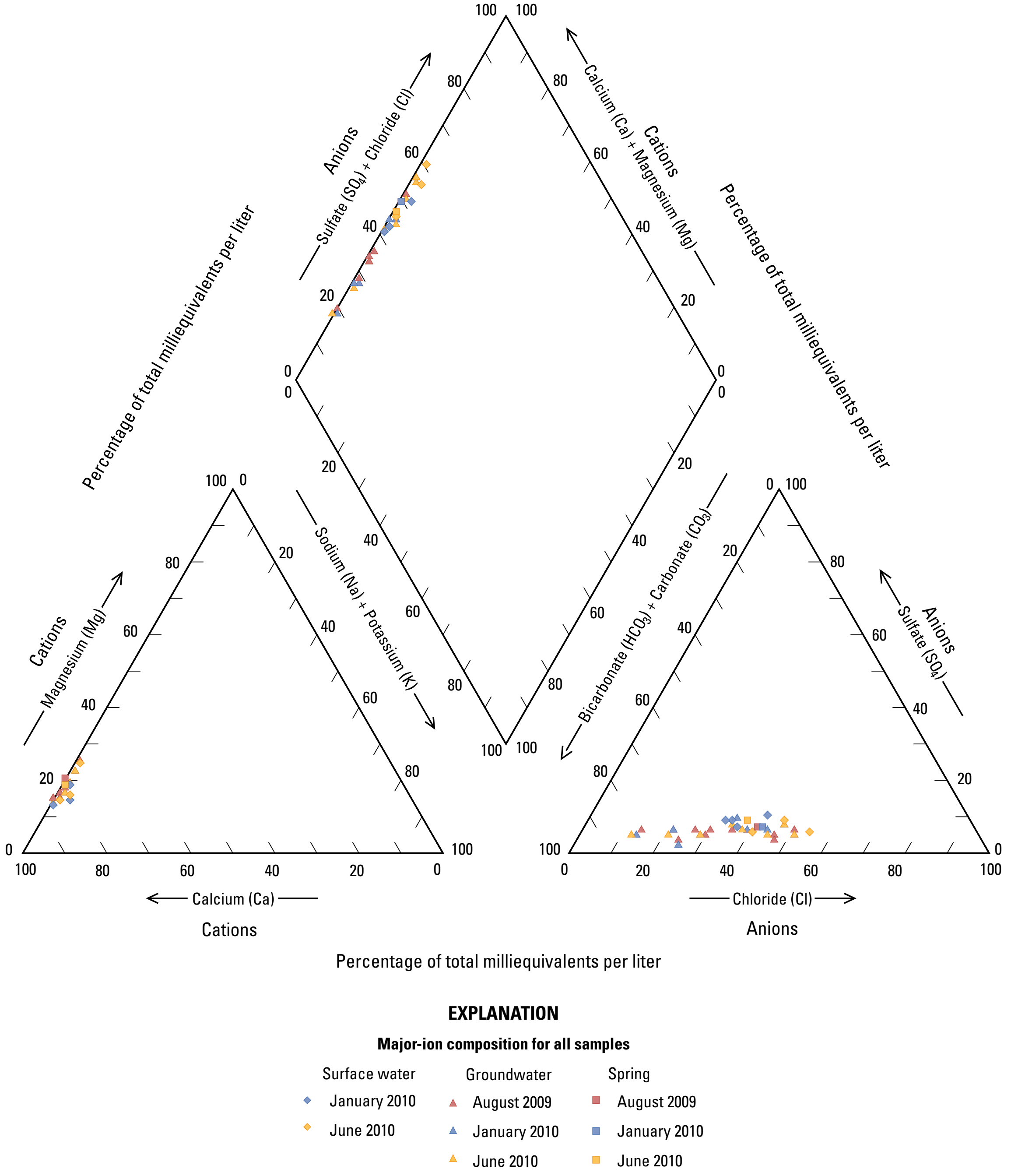
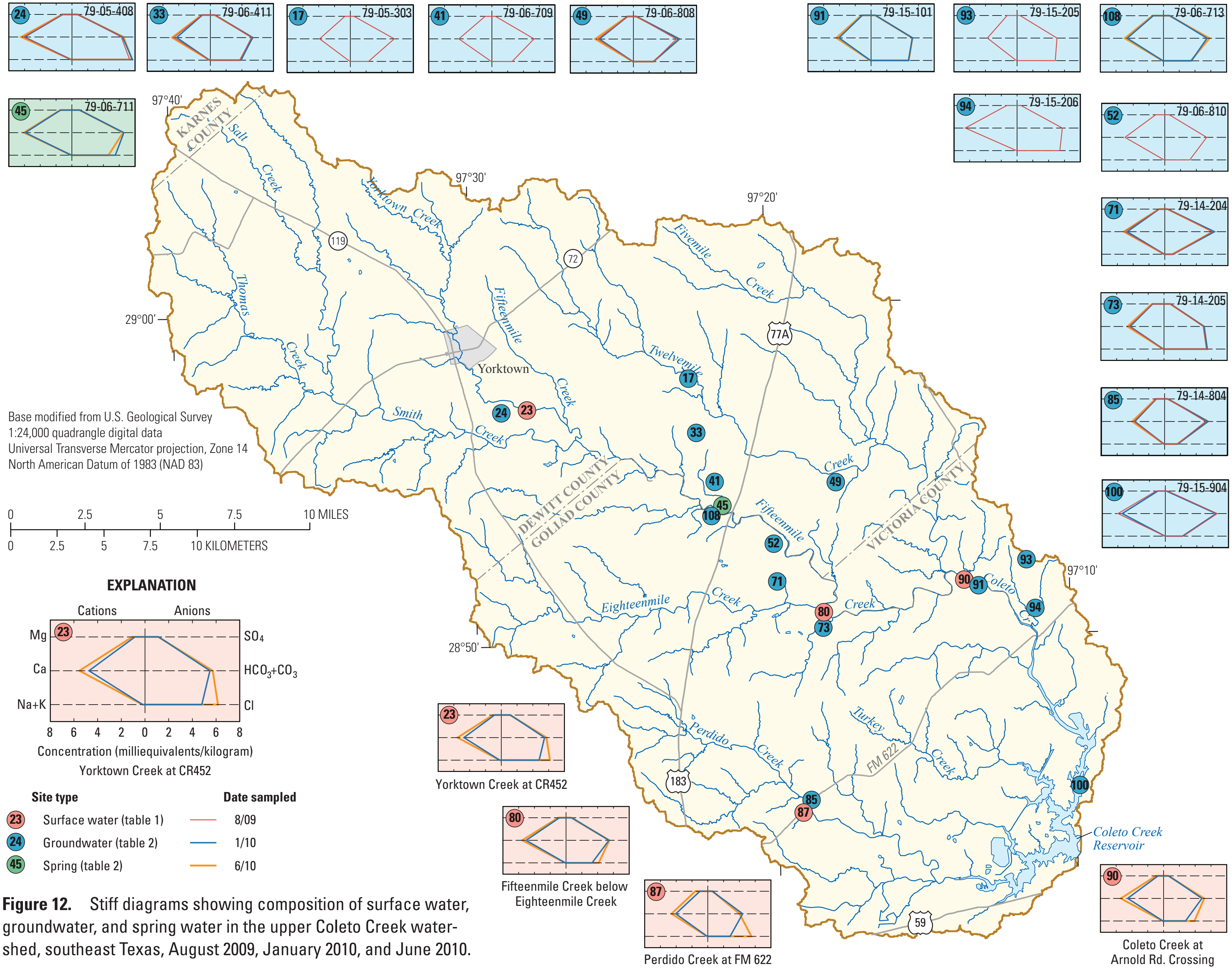
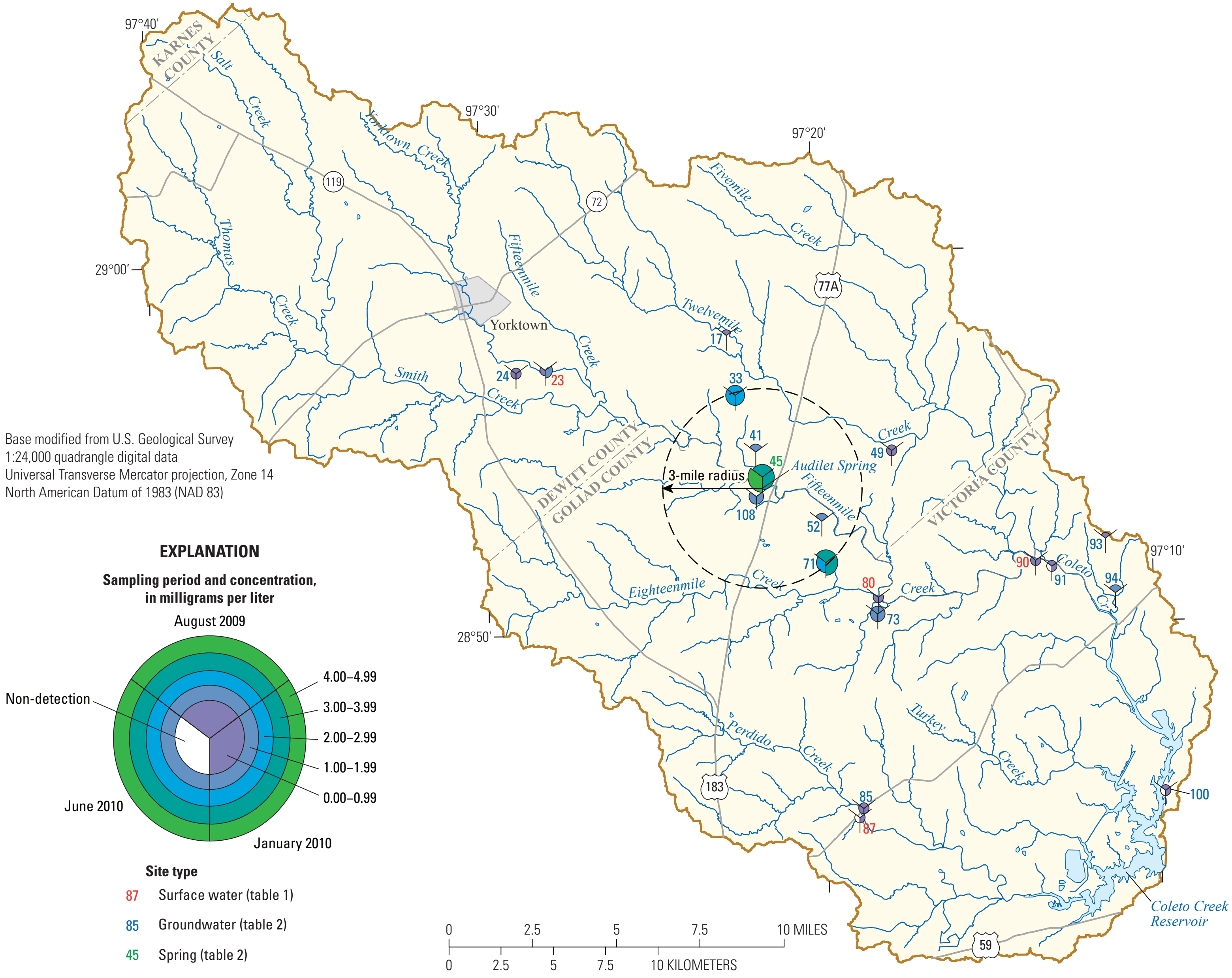


Figure 11. Trilinear diagrams showing composition of surface water, groundwater, and spring water in the upper Coleto Creek watershed, southeast Texas, August 2009, January 2010, and June 2010.



Base modified from U.S. Geological Survey
1:24,000 quadrangle digital data
Universal Transverse Mercator projection, Zone 14
North American Datum of 1983 (NAD 83)

Figure 12. Stiff diagrams showing composition of surface water, groundwater, and spring water in the upper Coleto Creek watershed, southeast Texas, August 2009, January 2010, and June 2010.



Base modified from U.S. Geological Survey
1:24,000 quadrangle digital data
Universal Transverse Mercator projection, Zone 14
North American Datum of 1983 (NAD 83)

Figure 13. Nitrate concentrations (as nitrogen) in surface water, groundwater, and spring water in the upper Coleto Creek watershed, southeast Texas, August 2009, January 2010, and June 2010.

Isotopes

Hydrogen and oxygen isotopes of water can be used to assess groundwater sources and recharge processes, thereby enhancing the knowledge of processes related to water quality. In the absence of thermal effects, evaporation and mixing are the primary processes that affect the isotopic composition of groundwater (Clark and Fritz, 1997). Figure 14 shows the relation of the ratio of oxygen-18 to oxygen-16 ($\delta^{18}O$, in per mil) to the ratio of deuterium to protium (δD, in per mil) in samples collected for this study, relative to Vienna Standard Mean Ocean Water (VSMOW) isotopic standard (Baertschi, 1976; Hagemann and others, 1970).

The consistent proportionality between δD and $\delta^{18}O$ in meteoric waters provides the basis for many hydrologic applications and is defined by a best-fit regression line known as the global meteoric water line (Craig, 1961) expressed by the equation

$$\delta D = 8\,\delta^{18}O + 10 \tag{3}$$

where

δD is the ratio of hydrogen-2 to hydrogen-1 isotopes reported as the relative difference in parts per thousand (per mil) between the sample isotope ratio and the isotope ratio of a known standard, and

$\delta^{18}O$ is the ratio of oxygen-18 to oxygen-16 isotopes reported as the relative difference in parts per thousand (per mil) between the sample isotope ratio and the isotope ratio of a known standard.

A local meteoric water line (LMWL) was developed by Otero (2007) using isotopic signatures from south-central Texas precipitation data. All of the samples collected during this study plotted below the LMWL of $\delta D = 8.8032\,\delta^{18}O + 17.825$, which indicates that the lighter water molecules associated with precipitation might have been preferentially removed as a result of evapotranspiration before they could enter the aquifer as recharge.

The majority of the water samples (36 out of 44) that were analyzed for δD and $\delta^{18}O$ during the three sampling events plotted in a relatively tight cluster centered near the global meteoric water line (fig. 14); this finding indicates that these sites are most likely not heavily influenced by evaporative processes. The eight remaining samples, which include the four surface-water samples collected in June 2010, the sample collected from Coleto Creek Reservoir site in January 2010, and all three samples collected at State well 79-15-904 (site 100), deviate from the global meteoric water line in a way that indicates evaporative losses, with the largest losses occurring at station 08177300 on Perdido Creek. The surface-water samples collected from those same four locations in January 2010 did not exhibit signs of evaporative losses; rather, they exhibited an isotopic signature more closely related to that which was observed in the wells (other than State well 79-15-904). Isotopic signatures indicative of evaporative losses were also measured in the sample collected at the Coleto Creek Reservoir site and in the three samples collected from State well 79-15-904. As a surface-water body, this response is expected for the samples collected from Coleto Creek Reservoir site, but this type of response is atypical of wells in this area (as evidenced by the isotopic signatures observed at the remaining wells sampled in this study). The isotopic signatures of the three samples collected at State well 79-15-904, when taken in conjunction with its proximity to Coleto Creek Reservoir, indicate that there is likely a hydraulic connection between the two. The fact that the isotopic signatures at State well 79-15-904 represent water that is even heavier isotopically than the reservoir itself might be due to the proximity (less than 1,000 ft) of 79-15-904 to two backwater areas where evaporative loss rates are likely much higher than that of Coleto Creek Reservoir as a whole. State well 79-23-205 (107 in the bottom frame of fig. 14) is also close to Coleto Creek Reservoir but has an isotopic signature that more closely resembles those of the remaining wells (other than State well 79-15-904). This relation indicates that the groundwater at State well 79-23-205 does not have a hydraulic connection to Coleto Creek Reservoir under the hydrologic conditions observed over the course of this study.

Strontium is a minor component of most groundwater and a divalent cation that readily substitutes for the divalent calcium ion (Ca^{2+}) in carbonates and other rock-forming minerals (Clark and Fritz, 1997). Strontium isotopes—specifically, the ratio of strontium-87 to strontium-86 ($\delta^{87}Sr$, per mil)—act as a reactive tracer that can be used to indicate water-rock interactions or to trace groundwater movement. In general, strontium concentrations were consistent in all samples collected at individual wells (with the exception of the samples from State wells 79-15-904 and 79-15-101 in August 2009, table 7). Individual surface-water sites also exhibited consistent chemistry with regards to $\delta^{87}Sr$ but varied widely between January 2010 and June 2010 with respect to the inverse of strontium concentrations (1/Sr), which were higher in January 2010 than in June 2010 at all four sites (fig. 15). This means that strontium concentrations were higher in June 2010 than in January 2010, as would be expected considering that elevated streamflow in January 2010 relative to June 2010 was influenced to some extent by additional precipitation (fig 5*C*), which would likely have lower strontium concentrations.

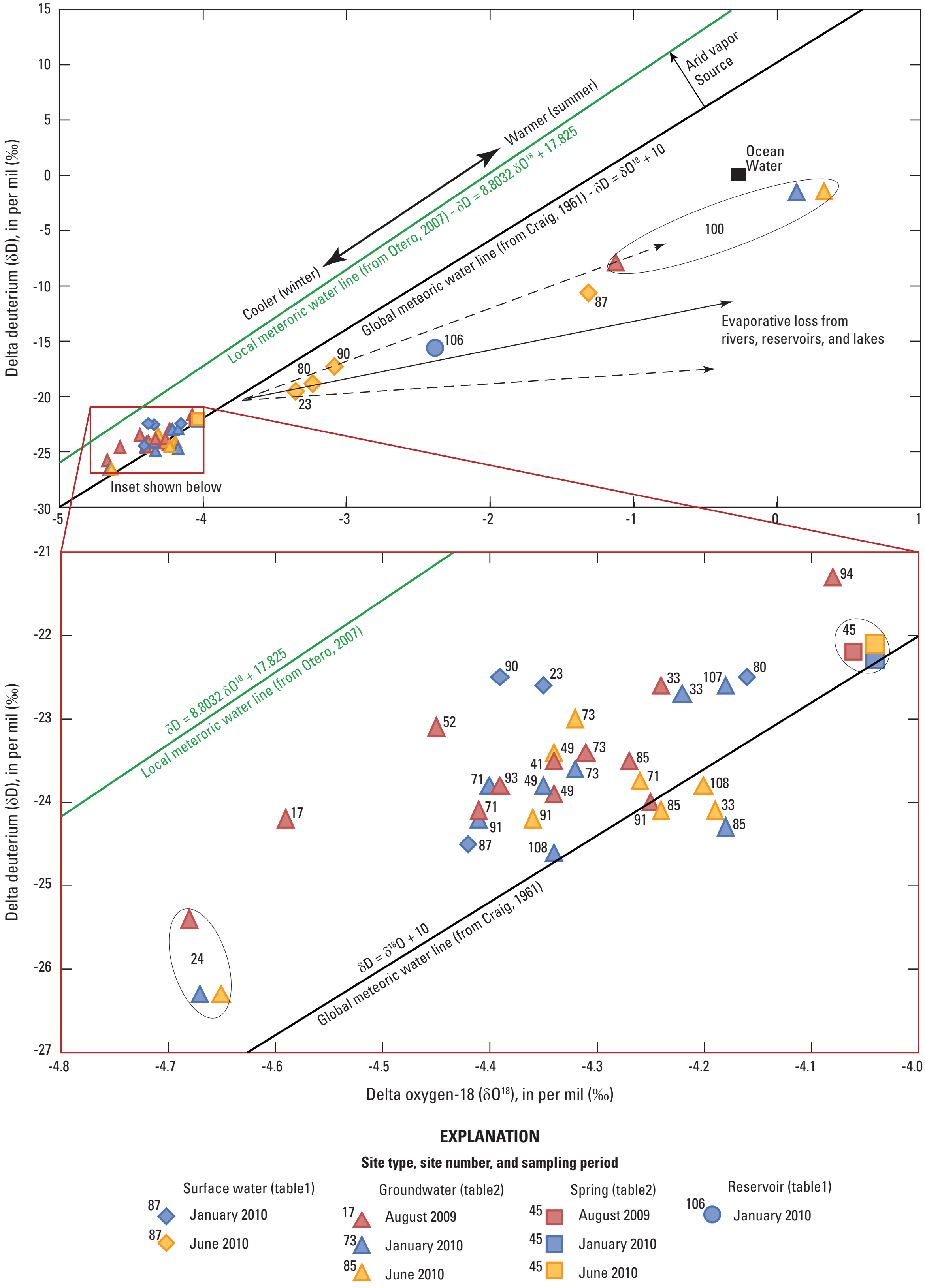


Figure 14. Relation between delta oxygen-18 and delta deuterium in samples collected from selected surface-water, groundwater, and spring sites in the upper Coleto Creek watershed, southeast Texas, August 2009, January 2010, and June 2010.

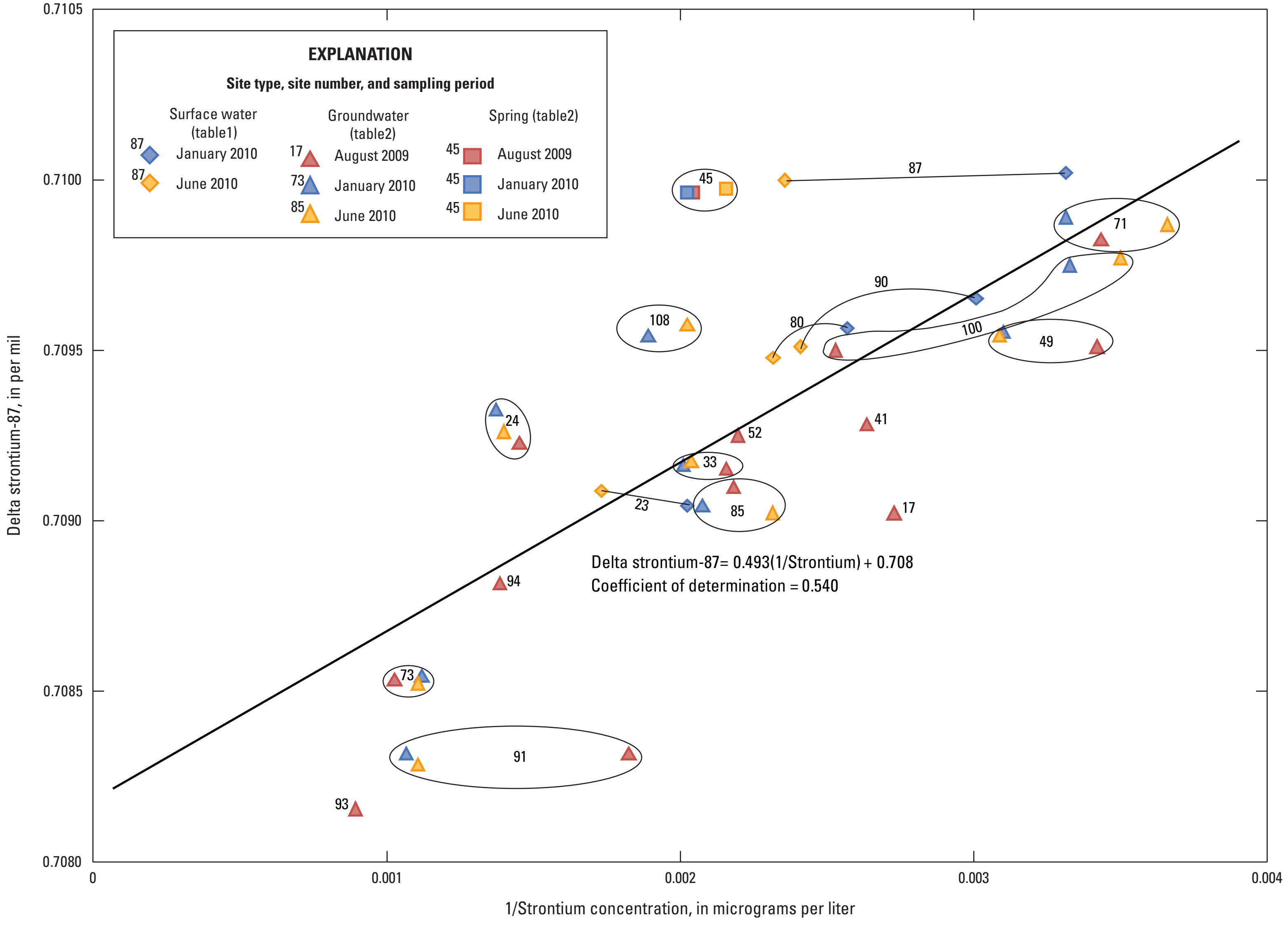


Figure 15. Relation between the inverse of strontium concentrations and delta strontium-87 in samples collected from surface-water, groundwater, and spring sites in the upper Coleto Creek watershed, southeast Texas, August 2009, January 2010, and June 2010.

Examination of all the sites as a whole reveals a general pattern in strontium concentrations across the entire upper Coleto Creek watershed (fig. 15), as indicated by the best-fit regression line

$$\delta^{87}Sr = 0.493/Sr + 0.708 \quad (4)$$

where

$\delta^{87}Sr$ is the ratio of strontium-87 to strontium-86, and

Sr is the concentration of strontium, in micrograms per liter.

This pattern might indicate that most surface-water and groundwater samples derive primarily from a single source with relatively uniform water-rock interactions, the Evangeline aquifer. For samples collected from the following sites, one or more data values of the relation between the inverse of strontium concentration and $\delta^{87}Sr$ differ appreciably from the best-fit regression line ($\delta^{87}S$ values plot more than about 0.0003 per mil from the regression line) and thus do not closely fit the general pattern: site 17 (State well 79-05-303), site 24 (State well 79-05-408), site 45 (Audilet Spring), site 87 (station 08177300 on Perdido Creek), and sites 91, 93, and 108 (State wells 79-15-101, 79-15-205, and 79-06-713, respectively). The reasons one or more of the samples collected from these sites do not closely fit the general pattern are not fully understood. The samples collected at these sites might represent a mix of water sources rather than water exclusively from the Evangeline aquifer, and the relative contributions from these different water sources might have varied by sampling period because each sampling period represented different hydrologic conditions.

Summary

The U.S. Geological Survey, in cooperation with the Goliad County Groundwater Conservation District, Victoria County Groundwater Conservation District, Pecan Valley Groundwater Conservation District, Guadalupe-Blanco River Authority, and San Antonio River Authority, examined streamflow, groundwater hydrology, and water quality in the upper Coleto Creek watershed. Findings of the study will enhance the scientific understanding of the study-area hydrology and be used to support water-management decisions in the study area. This report describes the results of streamflow measurements, groundwater-level altitude measurements, and water-quality analyses (from both surface water and groundwater sites) from three sampling events (July–August 2009, January 2010, and June 2010) designed to characterize groundwater (from the Evangeline aquifer) and surface water, and the interaction between them, in the upper Coleto Creek watershed upstream from Coleto Creek Reservoir in southeast Texas.

Three surface-water gain-loss surveys—July 29–30, 2009, January 11–13, 2010, and June 21–22, 2010—were done under different hydrologic conditions to determine the locations and amounts of streamflow recharging or discharging from the Evangeline aquifer. During periods when flow in the reaches of the upper Coleto Creek watershed was common (such as June 2010, when 12 of 25 reaches were flowing) or likely (such as January 2010, when 22 of 25 reaches were flowing) most of the reaches appeared to be gaining; however, during droughtlike conditions (July 2009), there was virtually no streamflow in the entire upper Coleto Creek watershed. In July 2009, the only streamflow observed was in two reaches that either received inflow directly from Audilet Spring or were immediately downstream from Audilet Spring. Water levels in the Evangeline aquifer at this time seemed to have been reduced to the point that the aquifer could no longer provide sufficient quantities of water to sustain streamflow.

Groundwater-level altitudes were measured at as many as 33 different wells in the upper Coleto Creek watershed during three survey events: August 4–7 and 12, 2009; January 12–14 and 22, 2010; and June 21–24, 2010. These data were used in conjunction with groundwater-level altitudes from three wells continuously monitored by the Texas Commission of Environmental Quality to generate potentiometric surface maps for each of the three sampling events to help characterize groundwater hydrology of the Evangeline aquifer in the study area. The direction of groundwater flow shifts from southeast to east across the upper Coleto Creek watershed, roughly coinciding with the general flow direction of the main stem of Coleto Creek. Groundwater-level altitudes increased an average of 2.35 in. between the first and third sampling events as drought conditions in the summer of 2009 were followed by consistent rains the subsequent fall and winter.

A total of 44 water-quality samples were collected at 21 different sites over the course of the three sampling events. Major-ion compositions were relatively consistent among most of the samples (generally calcium bicarbonate waters, often with chloride making a major contribution), and dissolved solids concentrations were high (greater than 500 mg/L) in 74 percent of them. Of the 23 trace elements that were analyzed in water samples as part of this study, only arsenic (in two samples) and manganese (in seven samples) had concentrations that exceeded public drinking-water standards or guidelines. Arsenic concentrations exceeded the U.S. Environmental Protection Agency (USEPA) Maximum Contaminant Level (MCL) of 10 µg/L in two samples (station 08177300 on Perdido Creek on June 21, 2010, and Audilet Spring on January 13, 2010), whereas manganese concentrations exceeded public drinking-water guidelines (50 µg/L) in both samples collected at Yorktown Creek at CR 452, both samples collected at station 08177300 on Perdido Creek, and all three samples collected at State well 79-15-904. At 3 of the 19 sites sampled—State wells 79-06-411, 79-14-204, and Audilet Spring—nitrate concentrations exceeded the threshold associated with anthropogenic contributions (2.0 mg/L), but all were less than the USEPA MCL. All three sites are within about a 3-mi radius surrounding Audilet Spring; all other sites within that radius exhibited slightly elevated nitrate concentrations relative to the remaining sites in the study area. The majority of the water samples (36 out of 44) that were analyzed for δD and δ^{18}O during the three sampling events plotted in a relatively tight cluster centered near the global meteoric water line; this finding indicates that these sites are most likely not heavily influenced by evaporative processes. The eight remaining samples, which include the four surface-water samples collected in June 2010, the sample collected from Coleto Creek Reservoir site in January 2010, and all three samples collected at State well 79-15-904, deviate from the global meteoric water line in a way that indicates evaporative losses. The isotopic signatures of the three samples collected at State well 79-15-904, when taken in conjunction with its proximity to Coleto Creek Reservoir site, indicate that there is likely a hydraulic connection between the two. When all of the sites are examined as a whole, there is a pattern in strontium concentrations (as indicated by the best-fit regression line $\delta^{87}\mathrm{Sr} = 0.493/\mathrm{Sr} + 0.708$) across the entire upper Coleto Creek watershed that might indicate both the surface-water and groundwater samples derive from a single source with relatively uniform water-rock interactions, the Evangeline aquifer.

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Appendixes

Appendix 1. Quality control and quality assurance data, including an equipment blank and relative percent difference for sequential-replicate samples, upper Coleto Creek watershed, southeast Texas, August 2009–June 2010.

Appendix 2. Calculation of estimated evaporative losses within stream reaches, upper Coleto Creek watershed, southeast Texas, August 2009–June 2010.

Appendix 1–1. Quality control and quality assurance data, including an equipment blank and relative percent difference for sequential-replicate samples, upper Coleto Creek watershed, southeast Texas, August 2009–June 2010.

[SR, sequential replicate; RPD, relative percent difference; E, estimated; -- , not computed or not analyzed; mg/L, milligrams per liter; °C, degrees Celsius; µg/L, micrograms per liter; <, less than]

Station number State well number	285616097222801 79-06-411	285616097222801 79-06-411	285616097222801 79-06-411	284518097185401 79-14-804	284518097185401 79-14-804	284518097185401 79-14-804	Blank
Date Time	8/5/2009 1200	8/5/2009 SR 1201	RPD	1/11/2010 1500	1/11/2010 SR 1501	RPD	8/10/2009 1403
Dissolved oxygen, water, unfiltered (mg/L)	4.3	4.3	--	5.8	5.8	--	--
pH, water, unfiltered, field, standard units	E 6.7	E 6.7	--	E 7.1	7.1	--	--
pH, water, unfiltered, laboratory, standard units	7.4	7.4	--	7.4	7.5	--	7.5
Specific conductance, water, unfiltered, laboratory, microsiemens per centimeter at 25°C	996	998	--	715	712	--	<5
Specific conductance, water, unfiltered, microsiemens per centimeter at 25°C	979	979	--	726	726	--	--
Temperature, water °C	24.5	24.5	--	24.4	24.4	--	--
Turbidity, water, unfiltered, formazin nephelometric units (FNU)	2.7	2.7	--	16	16	--	--
Dissolved solids dried at 180°C, water, filtered (mg/L)	586	583	0.51	449	460	2.42	10
Hardness, water (mg/L as $CaCO_3$)	285	296	3.79	241	245	1.65	<.10
Noncarbonate hardness, water, filtered, field (mg/L as $CaCO_3$)	25	36	36.07	--	--	--	--
Calcium, water, filtered (mg/L)	92.8	96.8	4.22	75.4	76.6	1.58	<.02
Magnesium, water, filtered (mg/L)	12.9	13.2	2.30	12.5	12.9	3.15	<.012
Potassium, water, filtered (mg/L)	4.22	4.44	5.08	2.96	3.00	1.34	<.06
Sodium adsorption ratio, water, number	2.23	2.24	.45	1.46	1.44	1.38	--
Sodium, water, filtered (mg/L)	86.6	88.5	2.17	51.9	51.9	0	<.12
Alkalinity, water, filtered, field (mg/L as $CaCO_3$)	260	260	0	274	267	2.59	--
Bicarbonate, water, filtered, field (mg/L)	317	317	0	334	325	2.73	--
Bromide, water, filtered (mg/L)	.49	.45	8.51	.18	.18	0	<.02
Carbon dioxide, water, unfiltered (mg/L)	E 96	E 96	--	E 39	38	--	--
Carbonate, water, filtered, field (mg/L)	<1	<1	--	<1	<1	--	--
Chloride, water, filtered (mg/L)	133	133	0	59.4	59.3	.17	<.12
Fluoride, water, filtered (mg/L)	.53	.54	1.87	.65	.67	3.03	<.08
Silica, water, filtered (mg/L as SiO_2)	43.8	46.0	4.90	45.3	46.2	1.97	<.02
Sulfate, water, filtered (mg/L)	27.8	27.8	0	19.9	20.0	.50	<.18

Appendix 1–1. Quality control and quality assurance data, including an equipment blank and relative percent difference for sequential-replicate samples, upper Coleto Creek watershed, southeast Texas, August 2009–June 2010.—Contined

[SR, sequential replicate; RPD, relative percent difference; E, estimated; nc, not computed or not analyzed; mg/L, milligrams per liter; °C, degrees Celsius; µg/L, micrograms per liter; <, less than]

Station number	285616097222801	285616097222801	285616097222801	284518097185401	284518097185401	284518097185401	Blank
State well number	79-06-411	79-06-411	79-06-411	79-14-804	79-14-804	79-14-804	
Date	8/5/2009	8/5/2009 SR	RPD	1/11/2010	1/11/2010 SR	RPD	8/10/2009
Time	1200	1201		1500	1501		1403
Ammonia, water, filtered (mg/L as NH_4)	<0.026	<0.026	--	<0.026	<0.026	--	<0.026
Ammonia, water, filtered (mg/L as N)	<.020	<.020	--	<.020	<.020	--	<.020
Nitrate plus nitrite, water, filtered (mg/L as N)	2.15	2.12	1.41	.60	.60	0	<.04
Nitrate, water, filtered (mg/L)	9.52	9.38	1.48	2.66	2.66	0	<.177
Nitrate, water, filtered (mg/L as N)	2.15	2.12	1.41	.600	.602	.33	<.040
Nitrite, water, filtered (mg/L)	<.007	<.007	--	<.007	<.013	--	<.007
Nitrite, water, filtered (mg/L as N)	<.002	<.002	--	<.002	<.004	--	<.002
Organic nitrogen, water, filtered (mg/L)	<.01	--	--	--	--	--	<.07
Orthophosphate, water, filtered (mg/L)	.064	.063	1.57	.061	.067	9.38	<.025
Orthophosphate, water, filtered (mg/L as P)	.021	.020	4.88	.020	.022	9.52	<.008
Total nitrogen (nitrate + nitrite + ammonia + organic-N), water, filtered (mg/L)	2.16	2.09	3.29	.56	.55	1.80	E .07
Aluminum, water, filtered (µg/L)	E 2.4	<4	--	<3.4	<3.4	--	<4.0
Barium, water, filtered (µg/L)	95	94	1.06	175	176	.57	<.4
Beryllium, water, filtered (µg/L)	<.02	<.02	--	<.01	E .01	--	<.02
Cadmium, water, filtered (µg/L)	<.02	<.02	--	<.02	<.02	--	<.02
Chromium, water, filtered (µg/L)	.45	.41	9.30	.83	.80	3.68	<.12
Cobalt, water, filtered (µg/L)	.25	.10	85.71	.63	.33	62.50	.08
Copper, water, filtered (µg/L)	E .64	E .62	--	1.1	1.1	0	<1.0
Iron, water, filtered (µg/L)	E 3.0	<4	--	9	<6	--	E 2
Lead, water, filtered (µg/L)	.18	.20	10.53	.44	.63	35.51	<.06
Lithium, water, filtered (µg/L)	17.0	16.8	1.18	16.5	17.2	4.15	<1.0
Manganese, water, filtered (µg/L)	.3	<.2	--	.8	<.3	--	E .2
Molybdenum, water, filtered (µg/L)	2.00	1.80	10.53	1.40	1.50	6.90	<.02
Nickel, water, filtered (µg/L)	.41	.41	0	2.3	2.3	0	<.12
Silver, water, filtered (µg/L)	<.01	<.01	--	<.01	<.01	--	<.01
Strontium, water, filtered (µg/L)	465	444	4.62	482	488	1.24	<.8
Thallium, water, filtered (µg/L)	<.04	<.04	--	<.02	<.02	--	<.04
Vanadium, water, filtered (µg/L)	20.2	19.3	4.56	12.1	12.3	1.64	<.16

Appendix 1–1. Quality control and quality assurance data, including an equipment blank and relative percent difference for sequential-replicate samples, upper Coleto Creek watershed, southeast Texas, August 2009–June 2010.—Contined

[SR, sequential replicate; RPD, relative percent difference; E, estimated; nc, not computed or not analyzed; mg/L, milligrams per liter; °C, degrees Celsius; µg/L, micrograms per liter; <, less than]

Station number State well number	285616097222801 79-06-411	285616097222801 79-06-411	285616097222801 79-06-411	284518097185401 79-14-804	284518097185401 79-14-804	284518097185401 79-14-804	Blank
Date Time	**8/5/2009 1200**	**8/5/2009 SR 1201**	**RPD**	**1/11/2010 1500**	**1/11/2010 SR 1501**	**RPD**	**8/10/2009 1403**
Zinc, water, filtered (µg/L)	2.0	E 1.9	--	E 1.6	<2.8	--	<2.0
Antimony, water, filtered (µg/L)	E .02	<.04	--	.06	E .03	--	<.04
Arsenic, water, filtered (µg/L)	2.9	2.8	3.51	1.7	1.8	5.71	<.06
Boron, water, filtered (µg/L)	140	134	4.38	147	138	6.32	<4
Selenium, water, filtered (µg/L)	2.0	2.0	0	.92	.94	2.15	<.06
Uranium (natural), water, filtered (µg/L)	1.90	1.78	6.52	1.63	1.64	.61	<.01
Deuterium/Protium ratio, water, unfiltered, per mil	-22.60	-23.30	-3.05	-24.30	-23.40	-3.77	--
Oxygen-18/Oxygen-16 ratio, water, unfiltered, per mil	-4.24	-4.25	-.24	-4.18	-4.25	-1.66	--
Strontium-87/Strontium-86 ratio, water, filtered, per mil	.70916	.70915	0	.70905	.70909	.01	--

Appendix 2–1. Calculation of estimated evaporative losses within stream reaches, upper Coleto Creek watershed, southeast Texas, June 2009.

[km, kilometers; ft, feet; in/d, inches per day; ft/s, feet per second; ft^3/s, cubic feet per second]

Reach	Reach length (km)	Reach length (ft)	Stream width at upstream boundary of reach (ft)	Stream width at downstream boundary of reach (ft)	Average stream width for entire reach (ft)	Evaporative loss (in/d)	Evaporative loss (ft/s)	Estimated evaporation loss within reach (ft^3/s)
C1	5.828	19,121	0	0	0	0.17	0.00000017	0
C2	5.694	18,681	0	0	0	.17	.00000017	0
C3	7.022	23,038	0	0	0	.17	.00000017	0
C4	17.07	56,004	0	0	0	.17	.00000017	0
C5	14.06	46,129	0	0	0	.17	.00000017	0
C6	16.729	54,885	0	0	0	.17	.00000017	0
C7	17.215	56,480	0	0	0	.17	.00000017	0
C8	8.761	28,743	0	0	0	.17	.00000017	0
C9	7.662	25,138	0	2.2	1.1	.17	.00000017	.00458
C10	7.922	25,991	2.2	0	1.1	.17	.00000017	.00473
C11 and C14	12.136	39,816	0	0	0	.17	.00000017	0
C12	10.445	34,268	0	0	0	.17	.00000017	0
C13	8.893	29,177	0	0	0	.17	.00000017	0
C15	12.29	40,322	0	0	0	.17	.00000017	0
C16	16.367	53,698	0	0	0	.17	.00000017	0
C17	9.851	32,320	0	0	0	.17	.00000017	0
C18	4.838	15,873	0	0	0	.17	.00000017	0
C19	14.742	48,366	0	0	0	.17	.00000017	0
C20	9.214	30,230	0	0	0	.17	.00000017	0
C21	6.026	19,770	0	0	0	.17	.00000017	0
C22	7.481	24,544	0	0	0	.17	.00000017	0
T1	11.593	38,035	0	0	0	.17	.00000017	0
P1	14.838	48,681	0	0	0	.17	.00000017	0
P2	13.088	42,940	0	0	0	.17	.00000017	0

Appendix 2–2. Calculation of estimated evaporative losses within stream reaches, upper Coleto Creek watershed, southeast Texas, January 2010.

[km, kilometers; ft, feet; in/d, inches per day; ft/s, feet per second; ft^3/s, cubic feet per second]

Reach	Reach length (km)	Reach length (ft)	Stream width(s) at upstream boundary of reach (ft)	Stream width at downstream boundary of reach (ft)	Average stream width for entire reach (ft)	Evaporative loss (in/d)	Evaporative loss (ft/s)	Estimated evaporation loss within reach (ft^3/s)
C1	5.828	19,121	0	0	0	0.086	0.000000083	0
C2	5.694	18,681	0	4.1	2.1	.086	.000000083	.0032
C3	7.022	23,038	4.1	4.3	4.2	.086	.000000083	.0080
C4	17.07	56,004	8.4/4.3	2.4	5.1	.086	.000000083	.0236
C5	14.06	46,129	0	2.6	1.3	.086	.000000083	.0050
C6	16.729	54,885	1.5/2.6	3.2	2.1	.086	.000000083	.0095
C7	17.215	56,480	0	1.5	0.8	.086	.000000083	.0035
C8	8.761	28,743	3.2	8.4	5.8	.086	.000000083	.0138
C9	7.662	25,138	2.4	15	8.7	.086	.000000083	.0181
C10	7.922	25,991	15	17	16	.086	.000000083	.0344
C11	11.561	37,930	17/7	12.25	9.6	.086	.000000083	.0300
C12	10.445	34,268	0	2.6	1.3	.086	.000000083	.0037
C13	8.893	29,177	2.6	7	4.8	.086	.000000083	.0116
C14	0.575	1,886	12.25	17	14.6	.086	.000000083	.0023
C15	12.29	40,322	17/10.7	20	17.1	.086	.000000083	.0570
C16	16.367	53,698	0	3.2	1.6	.086	.000000083	.0071
C17	9.851	32,320	3.2	0	1.6	.086	.000000083	.0043
C18	4.838	15,873	0	4.1	2.1	.086	.000000083	.0027
C19	14.742	48,366	4.1/4	10.7	7.2	.086	.000000083	.0288
C20	9.214	30,230	0	0	0	.086	.000000083	0
C21	6.026	19,770	0	0	0	.086	.000000083	0
C22	7.481	24,544	0	4	2	.086	.000000083	.0041
T1	11.593	38,035	0	0.9	0.5	.086	.000000083	.0014
P1	14.838	48,681	0	6.7	3.4	.086	.000000083	.0135
P2	13.088	42,940	6.7	0	3.4	.086	.000000083	.0119

Appendix 2–3. Calculation of estimated evaporative losses within stream reaches, upper Coleto Creek watershed, southeast Texas, June 2010.

[km, kilometers; ft, feet; in/d, inches per day; ft/s, feet per second; ft^3/s, cubic feet per second]

Reach	Reach length (km)	Reach length (ft)	Stream width(s) at upstream boundary of reach (ft)	Stream width at downstream boundary of reach (ft)	Average stream width for entire reach (ft)	Evaporative loss (in/d)	Evaporative loss (ft/s)	Estimated evaporation loss within reach (ft^3/s)
C1	5.828	19,121	0	0	0	0.19	0.00000018	0
C2	5.694	18,681	0	4	2	.19	.00000018	.0068
C3	7.022	23,038	4	6.8	5.4	.19	.00000018	.0226
C4	17.07	56,004	8/6.8	8.6	7.9	.19	.00000018	.0803
C5	14.06	46,129	0	0	0	.19	.00000018	0
C6	16.729	54,885	0	0	0	.19	.00000018	0
C7	17.215	56,480	0	0	0	.19	.00000018	0
C8	8.761	28,743	0	8	4	.19	.00000018	.0209
C9	7.662	25,138	8.6	10	9.3	.19	.00000018	.0424
C10	7.922	25,991	10	14	12	.19	.00000018	.0566
C11	11.561	37,930	1.9/14	12	5.6	.19	.00000018	.0385
C12	10.445	34,268	0	3.8	1.9	.19	.00000018	.0118
C13	8.893	29,177	3.8	1.9	2.85	.19	.00000018	.0151
C14 and C15	12.865	42,208	0/12	17	12.1	.19	.00000018	.0927
C16	16.367	53,698	0	0	0	.19	.00000018	0
C17	9.851	32,320	0	0	0	.19	.00000018	0
C18	4.838	15,873	0	0	0	.19	.00000018	0
C19	14.742	48,366	0	0	0	.19	.00000018	0
C20	9.214	30,230	0	0	0	.19	.00000018	0
C21	6.026	19,770	0	0	0	.19	.00000018	0
C22	7.481	24,544	0	0	0	.19	.00000018	0
T1	11.593	38,035	0	0	0	.19	.00000018	0
P1	14.838	48,681	0	1.05	.525	.19	.00000018	.0046
P2	13.088	42,940	1.05	0	.525	.19	.00000018	.0041

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