Prepared in cooperation with the Texas Water Development Board

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Scientific Investigations Report 2011–5224
Version 1.1, June 2016

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

Front cover: Looking downstream from Highway 16 and U.S. Geological Survey streamflow-gaging station 08088610 Brazos River near Graford, Texas

Back cover: Looking downstream from U.S. Geological Survey streamflow-gaging station 08091500 Paluxy River at Glen Rose, Texas, April 27, 2010

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SALLY JEWELL, Secretary

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	Flow rate	
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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

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

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

A water year is the 12-month period October 1 through September 30 designated by the calendar year in which it ends.

Base Flow (1966–2009) and Streamflow Gain and Loss (2010) of the Brazos River from the New Mexico–Texas State Line to Waco, Texas

By Stanley Baldys III and Frank E. Schalla

Abstract

During 2010–11, the U.S. Geological Survey (USGS), in cooperation with the Texas Water Development Board, used hydrograph separation to quantify historical base flow at 11 USGS streamflow-gaging stations between water years 1966–2009 and streamflow gains and losses from two sets of synoptic measurements of streamflow and specific conductance (the first in June 2010, followed by another set in October 2010) in the upper Brazos River Basin from the New Mexico–Texas State line to Waco, Texas. The following subbasins compose the study area: Salt Fork Brazos River Basin, Double Mountain Fork Brazos River Basin, Clear Fork Brazos River Basin, North Bosque River Basin, and the Brazos River Basin (main stem) (including its tributaries). Base-flow analysis was done using historical streamflow data from 11 USGS streamflow-gaging stations in the upper Brazos River Basin to compute yearly base-flow indexes (base flow divided by total streamflow) for each station. The base-flow index was used to indicate the fraction of flow consisting of base flow on an annual basis for the period of record evaluated at each streamflow-gaging station. At nine stations there were long-term streamflow data from water years 1966–2009 (October 1965 through September 2009); at two stations slightly shorter periods of record (water years 1967–2009 and 1969–2009) were available. The median base-flow indexes were 0.16 and 0.15 at USGS streamflow-gaging stations 08082000 Salt Fork Brazos River near Aspermont, Tex., and 08080500 Double Mountain Fork Brazos River near Aspermont, Tex., respectively. The amount of the total streamflow consisting of base flow was larger at sites in the Clear Fork Brazos River Basin compared to sites in the Salt Fork Brazos River Basin or Double Mountain Fork Brazos River Basin; at USGS streamflow-gaging stations 08084000 Clear Fork Brazos River at Nugent, Tex., and at 08085500 Clear Fork Brazos River at Fort Griffin, Tex., the median base-flow indexes were 0.28 and 0.23, respectively. The largest median base-flow index for any station was 0.35 at USGS streamflow-gaging station 08091500 Paluxy River at Glen Rose, Tex. The second largest base-flow index was 0.30 at USGS streamflow-gaging station 08095000 North Bosque River near Clifton, Tex. Median base-flow indexes on the main stem of the Brazos River upstream from Possum Kingdom Lake were 0.22 at USGS streamflow-gaging station 08082500 Brazos River at Seymour, Tex., and 0.24 at USGS streamflow-gaging station 08088000 Brazos River near South Bend, Tex. The base-flow indexes for stations between Possum Kingdom Lake and Lake Granbury were 0.19 and 0.27 at USGS streamflow-gaging stations 08089000 Brazos River near Palo Pinto, Tex., and 08090800 Brazos River near Dennis, Tex., respectively. A median base-flow index of 0.19 was also measured at USGS streamflow-gaging station 08091000 Brazos River near Glen Rose, Tex., located between Lake Granbury and Lake Whitney. A Mann-Kendall trend analysis test was performed on annual base-flow index values from each of the 11 streamflow records that were analyzed. Upward trends in base-flow index values indicating increasing flows during the study period were found for USGS streamflow-gaging stations 08080500 Double Mountain Fork Brazos River near Aspermont, Tex., 08089000 Brazos River near Palo Pinto, Tex., and 08090800 Brazos River near Dennis, Tex. Flows at these three streamflow-gaging stations are regulated by reservoir releases, and additional analyses are needed before these streamflow trends can be characterized as indicative of changes in base flow over time.

Streamflow was measured at 66 sites from June 6–9, 2010, and at 68 sites from October 16–19, 2010, to identify reaches in the upper Brazos River Basin that were gaining or losing streamflow. Gaining reaches were identified in each of the five subbasins. The gaining reach in the Salt Fork Brazos River Basin began at USGS streamflow-gaging station 08080940 Salt Fork Brazos River at State Highway 208 near Clairemont, Tex. (site SF–6), upstream from where Duck Creek flows into the Salt Fork Brazos River and continued downstream past USGS streamflow-gaging station 08082000 Salt Fork Brazos River near Aspermont, Tex. (site SF–9), to the outlet of the basin. In the Double Mountain Fork Brazos River Basin, a gaining reach from near Post, Tex., downstream to the outlet of the basin was identified. Two gaining reaches were identified in the Clear Fork Brazos River Basin—one

from near Roby, Tex., downstream to near Noodle, Tex., and second from Hawley, Tex., downstream to Nugent, Tex. Most of the North Bosque River was characterized as gaining streamflow. Streamflow gains were identified in the main stem of the Brazos River from where the Brazos River main stem forms at the confluence of the Salt Fork Brazos River and Double Mountain Fork Brazos River near Knox City, Tex., downstream to near Seymour, Tex.

Introduction

The Brazos River is the longest river in Texas and the 11th longest river in the United States. The Brazos River system extends about 1,280 miles (mi) from its source at the head of Blackwater Draw in eastern New Mexico to its mouth at the Gulf of Mexico near Freeport, Tex. (Kammerer, 1990) (fig. 1). Blackwater Draw crosses the New Mexico–Texas border about 186 mi west of the confluence of Salt Fork Brazos River and Double Mountain Fork Brazos River, where the Brazos River main stem begins west of Lubbock, Tex., at river mile 923.2 from the mouth on the Gulf of Mexico (U.S. Geological Survey, 2001). The Brazos River continues in an easterly direction towards the Dallas–Fort Worth, Tex., metropolitan area. The Brazos River then turns south for about 90 mi towards Waco in McLennan County, Tex., where it is joined by outflows of the North Bosque River from Waco Lake 4.6 mi from the North Bosque mouth on the Brazos River upstream from Waco at river mile 404.9 (fig. 1). The Brazos River is an important resource to agricultural, municipal, and industrial users of water in the Brazos River Basin in Texas. Ashworth and Hopkins (1995) classified the major and minor aquifers of Texas, and described the major and minor aquifers in the upper Brazos River Basin that are hydraulically connected to the Brazos River. The major aquifers are the Seymour, Ogallala, Edwards-Trinity (Plateau), and Trinity. Minor aquifers are the Brazos River Alluvium, Woodbine, Edwards-Trinity (High Plains), Dockum, and Blaine (figs. 2 and 3). Some of the State's largest declines in groundwater altitudes (350 to more than 1,000 feet [ft]), have occurred in an area extending from approximately Waco, Tex., to the northern Dallas-Fort Worth, Tex., metropolitan area (Texas Water Development Board, 2007b).

Surface-water and groundwater interactions in the upper Brazos River Basin upstream from Waco, Tex., to near the New Mexico–Texas State line are poorly understood, and base flows in the upper basin have not been adequately quantified. Slade and others (2002, p. 3) noted "relatively few studies have been done involving reaches that intersect the outcrops of …the Ogallala aquifer and none involving the Seymour aquifer," both of which underlie parts of the upper Brazos River Basin. A better quantification of base flow in the upper Brazos River Basin and the exchange of water between the upper Brazos River and the underlying aquifers could assist water managers and planners responsible for the long-term sustainability of surface-water and groundwater resources in this part of the basin.

The Texas Water Development Board (TWDB) is a State agency whose goal is to "provide leadership, planning, financial assistance, information, and education for the conservation and responsible development of water for Texas" (Texas Water Development Board, 2010, p. 1). The population of Texas exceeded 25 million in 2010, a 20.6 percent increase from 2000 and the fastest growth rate in the United States (U.S. Census Bureau, 2011). In an October 2011 newsletter published by Texas A&M University, Texas State Climatologist John Nielsen-Gammon notes Texas has experienced droughts lasting several years, and currently (2011) about 95 percent of Texas is in either a severe or exceptional drought status; the past year has been the worst one-year drought in the state's history (Texas A&M University, 2011). The population of Texas continues to grow rapidly, and with the continual threat of severe drought, the need for the TWDB to accomplish its goals in an effective and efficient manner intensifies (Texas Water Development Board, 2010). To provide information regarding flow characteristics of the upper Brazos River Basin to water managers, the USGS, in cooperation with the TWDB, quantified base flows in the upper Brazos River Basin using the results of base-flow analysis (hydrograph separation) from the New Mexico–Texas State line downstream to near Waco, Tex., and synoptic measurements of streamflow and specific conductance. Synoptic measurements are described by Beck and Wilson (2006, p. 1) as "those done concurrently over a broad area at a set time to give a "snap shot" of hydrologic conditions." This study complements previous work that quantified base flows in part of the lower Brazos River Basin from near Waco downstream to near Freeport, Tex., using base-flow analysis and synoptic streamflow measurements (Turco and others, 2007).

Purpose and Scope

This report describes the results of base-flow analysis of historical streamflow data at 11 long-term USGS streamflow-gaging stations for water years 1966–2009 (October 1965 through September 2009) and two synoptic streamflow gain loss surveys during June and October 2010 in the upper Brazos River Basin from the New Mexico–Texas State line downstream to near Waco, Tex. For each of the 11 long-term USGS streamflow-gaging stations, base-flow indexes were determined and statistically tested to assess if they changed over time. Streamflow gains and losses based on streamflow data collected from 66 measurement sites (June 2010) and 68 measurement sites (October 2010) on the Brazos River and selected tributaries are presented, and the respective gaining and losing reaches are identified. Contributions of streamflow to the main channels of each of the five subbasins composing the upper Brazos River Basin are described.

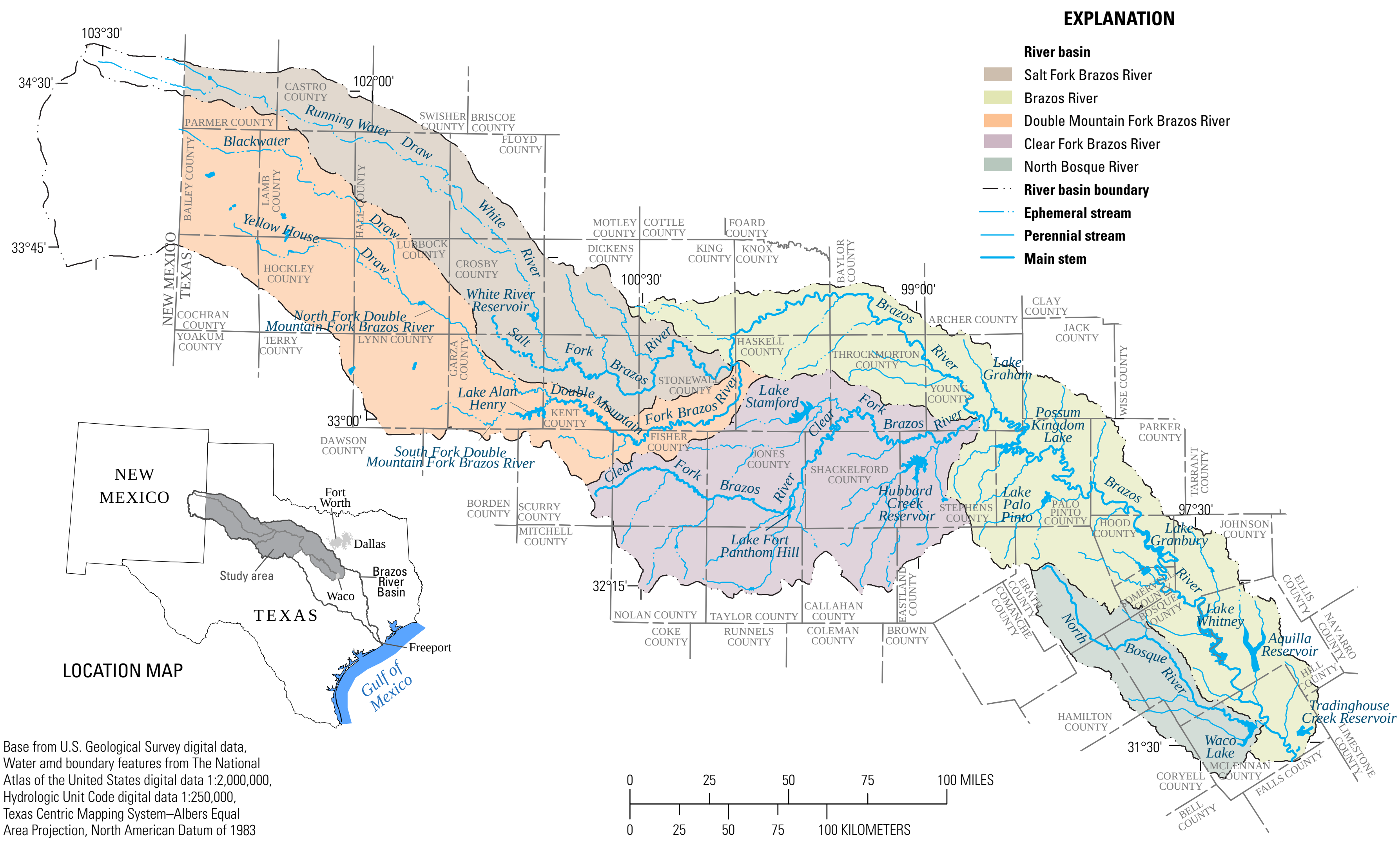


Figure 1. Upper Brazos River Basin, Texas.

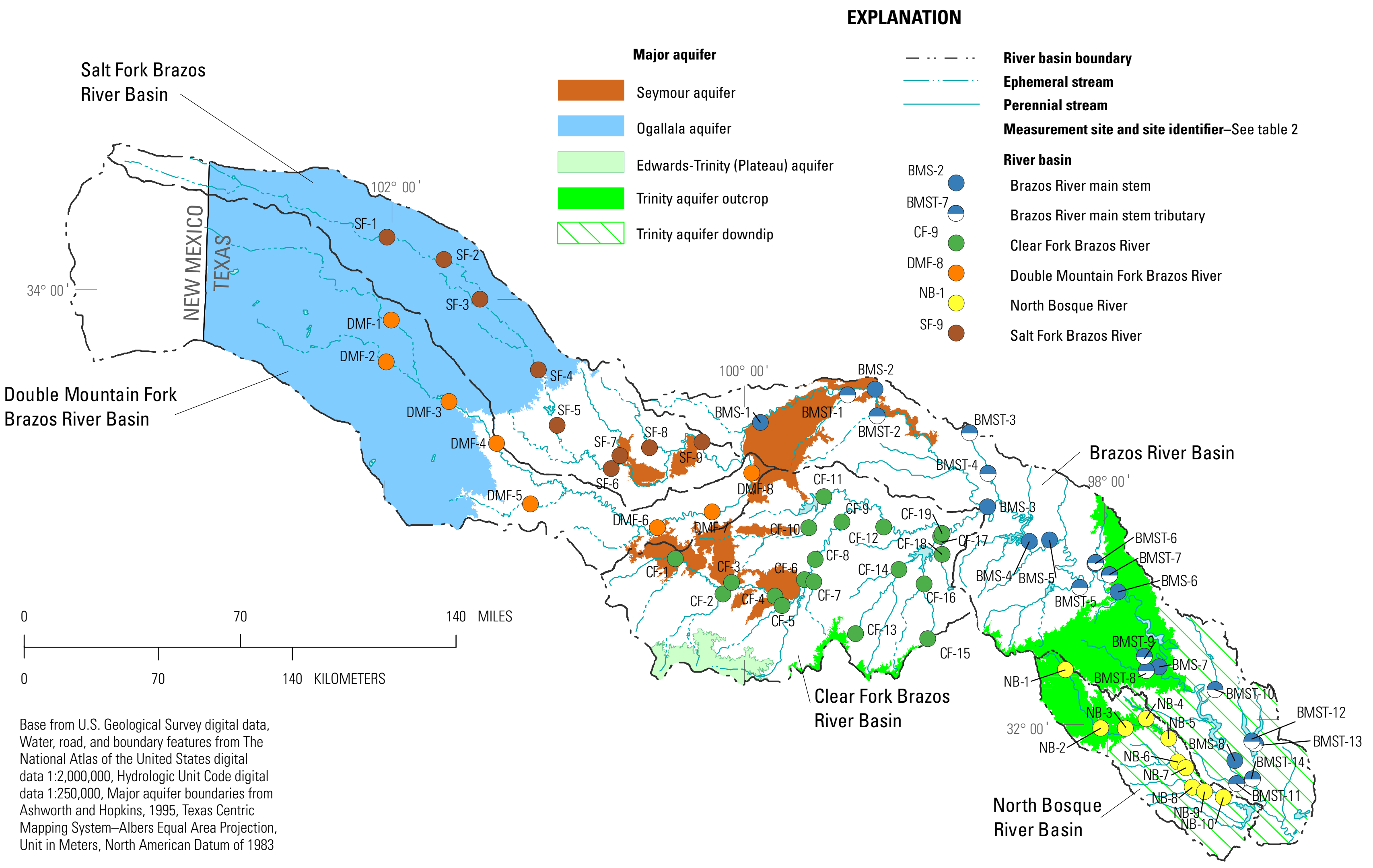


Figure 2. Major-aquifer boundaries and sites where streamflow and specific conductance were measured, June and October 2010, upper Brazos River Basin, Texas.

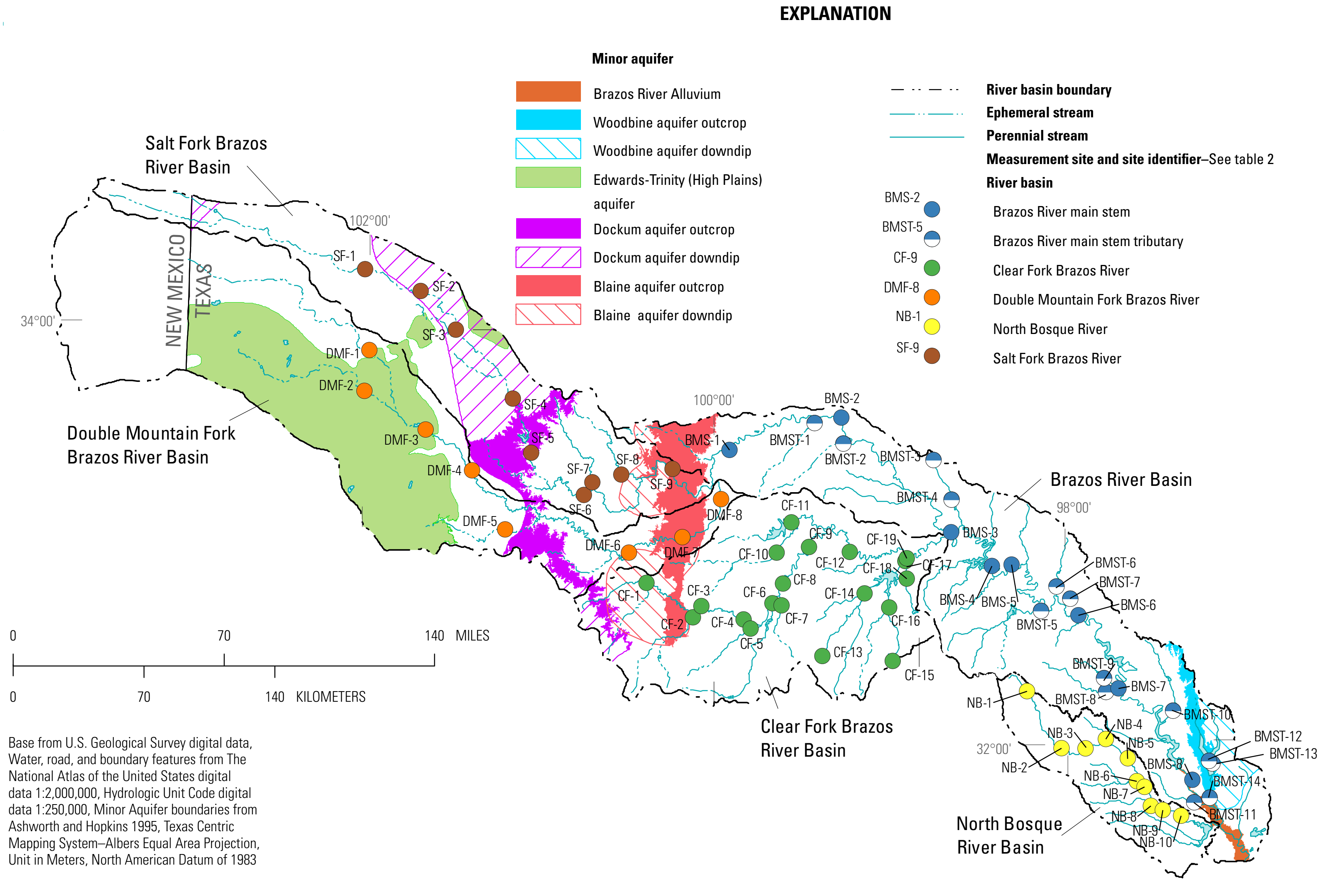


Figure 3. Minor-aquifer boundaries and sites where streamflow and specific conductance were measured, June and October 2010, upper Brazos River Basin, Texas.

Description of Study Area

The study area is the part of the upper Brazos River Basin in Texas from the Texas-New Mexico State line boundary in Bailey, Cochran, and Parmer Counties, Tex., downstream to near Waco Tex., in McLennan County, Tex. (fig. 1). The following subbasins compose the study area: Salt Fork Brazos River Basin, Double Mountain Fork Brazos River Basin, Clear Fork Brazos River Basin, North Bosque River Basin, and the Brazos River Basin (main stem) (including its tributaries) (figs. 4–8, respectively).

The headwaters of Salt Fork Brazos River (hereinafter Salt Fork) and the Double Mountain Fork Brazos River (hereinafter Double Mountain Fork) are small ephemeral streams such as Running Water Draw and Blackwater Draw, which drain relatively large amounts of land but do not produce much streamflow (U.S. Geological Survey, 2009). Running Water Draw flows into the White River in Floyd County, Tex., and the White River in turn combines with other small ephemeral streams to form the Salt Fork in Crosby County, Tex. The main reservoir in the Salt Fork Basin is the White River Reservoir on the White River east of Lubbock (fig. 4). Lubbock is in the Double Mountain Fork Basin (fig. 5); it has an average annual rainfall of 18 inches (in.) (National Weather Service, 2009). Blackwater Draw combines with Yellow House Draw in Lubbock County, Tex., to form the North Fork Double Mountain Fork Brazos River (fig.1). The main reservoir in the Double Mountain Fork Basin is Lake Alan Henry southeast of Lubbock on the South Fork Double Mountain Fork Brazos River (fig. 5).The Double Mountain Fork begins in Kent County at the confluence of the North and South Forks of the Double Mountain Fork Brazos River. The contributing drainage areas of the Salt Fork and Double Mountain Fork Basins are estimated as 2,496 square miles (mi^2) and 1,864 mi^2, respectively (U.S. Geological Survey, 2009).

The Seymour, Ogallala, Edwards-Trinity (High Plains), Dockum, and Blaine aquifers underlie parts of the Salt Fork and Double Mountain Fork Basins, with the Ogallala the most widespread aquifer underlying these basins (fig. 2). The dissolved-solids concentration in the Ogallala aquifer are generally less than 500 milligrams per liter (mg/L) in the Salt Fork and Double Mountain Fork Basins; in some areas of Texas concentrations of dissolved-solids concentrations in the Ogallala aquifer exceed 1,000 mg/L but are generally less than 3,000 mg/L (Ryder, 1996). The Edwards-Trinity (High Plains) aquifer is hydrologically connected to the overlying Ogallala aquifer and flows in a general southeast direction (Ashworth and Hopkins, 1995). Water from the Edwards-Trinity (High Plains) aquifer usually is slightly to moderately saline (dissolved-solids concentrations are 3,000 to 10,000 mg/L), but the chemical quality is suitable for irrigation and secondary oil recovery (Ryder, 1996). The chemical quality of the groundwater from the Seymour aquifer is extremely variable. Concentrations of dissolved solids range from 300 to 3,000 mg/L; most values are between 400 and 1,000 mg/L (Ryder, 1996).The Dockum aquifer underlies parts of the Ogallala aquifer in the Salt Fork Basin, and dissolved-solids concentration of the water ranges from less than 100 to more than 4,000 mg/L (Ryder, 1996). Water in the Blaine aquifer is primarily found in numerous solution channels formed by dissolved evaporite deposits of anhydrite and halite. As water recharged to the aquifer moves along solution channels, dissolved solids from the evaporite deposits increase the salinity, resulting in relatively saline groundwater. Dissolved-solids concentrations in the Blaine increase with depth of the aquifer and in natural discharge areas along surface drainages and are as high as almost 10,000 mg/L. The primary use of groundwater from the Blaine aquifer is irrigation of highly salt-tolerant crops (Ashworth and Hopkins, 1995).

The headwaters of the Clear Fork Brazos River (hereinafter Clear Fork) are in Scurry County, Tex. The Clear Fork Basin has three large reservoirs: Lake Fort Phantom Hill, Lake Stamford, and Hubbard Creek Reservoir (fig. 6). Abilene, Tex., near Lake Fort Phantom, has an average annual rainfall of 24 in. (National Weather Service, 2009). The Clear Fork flows into the Brazos River in Young County, Tex. The estimated contributing drainage area of the Clear Fork Basin is 5,697 mi^2 (U.S. Geological Survey, 2009).

The Clear Fork Basin overlies parts of the Seymour and Blaine aquifers (figs. 2–3). The Seymour aquifer is composed of discontinuous beds of poorly sorted alluvial material (Ashworth and Hopkins, 1995) and underlies the Clear Fork Basin in Fisher, Jones, Knox, and Haskell Counties. The chemical quality of water in this alluvial aquifer ranges from fresh to slightly saline. In some areas, the water is hard and unsuitable for some uses because it contains dissolved-solids concentrations in excess of 2,500 mg/L (Ryder, 1996). The part of the Seymour aquifer in Haskell and Knox Counties, Tex., is the largest continuous part of the aquifer and the most intensively developed. Dissolved-solids concentrations range from about 300 to 3,000 mg/L in the Seymour aquifer; most values are between 400 and 1,000 mg/L (Ryder, 1996). Water from the Blaine aquifer in the Clear Fork Basin is generally not suitable for public supply or for many industrial uses because of its mineral content. Concentrations of dissolved solids measured in water from the Blaine aquifer are generally between 2,000 and 6,000 mg/L (Ryder, 1996).

The headwaters of the North Bosque River are in Erath County, Tex. The North Bosque River flows into the Brazos River in McLennan County, Tex. (figs. 1, 8). The North Bosque Basin has an estimated contributing drainage area of 1,146 mi^2 (U.S. Geological Survey, 2009).

The Trinity aquifer underlies the entire North Bosque Brazos River Basin (figs 2–3). Dissolved-solids concentrations in water from the Trinity aquifer typically range from 500 to 1,500 mg/L (Ryder, 1996). The average annual rainfall of Stephenville, Tex. (near the headwaters of the North Bosque River), is 30 in., and the average annual rainfall of Waco (near the outlet of the North Bosque River basin) is 36 in. (National Weather Service, 2009). The North Bosque River flows into the western end of Waco Lake (fig. 7).

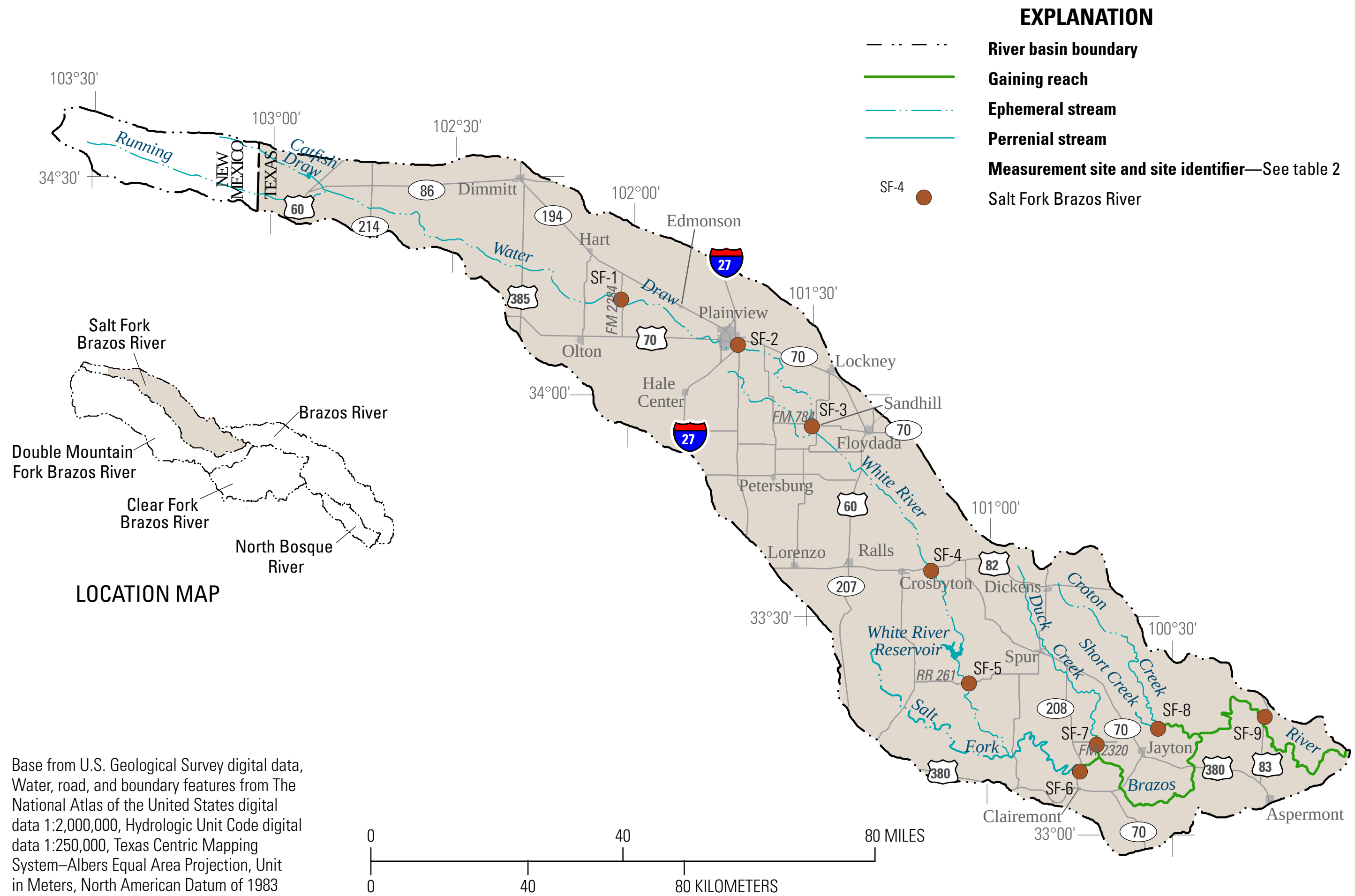


Figure 4. Sites where streamflow and specific conductance were measured in June and October 2010, Salt Fork Brazos River Basin, Texas.

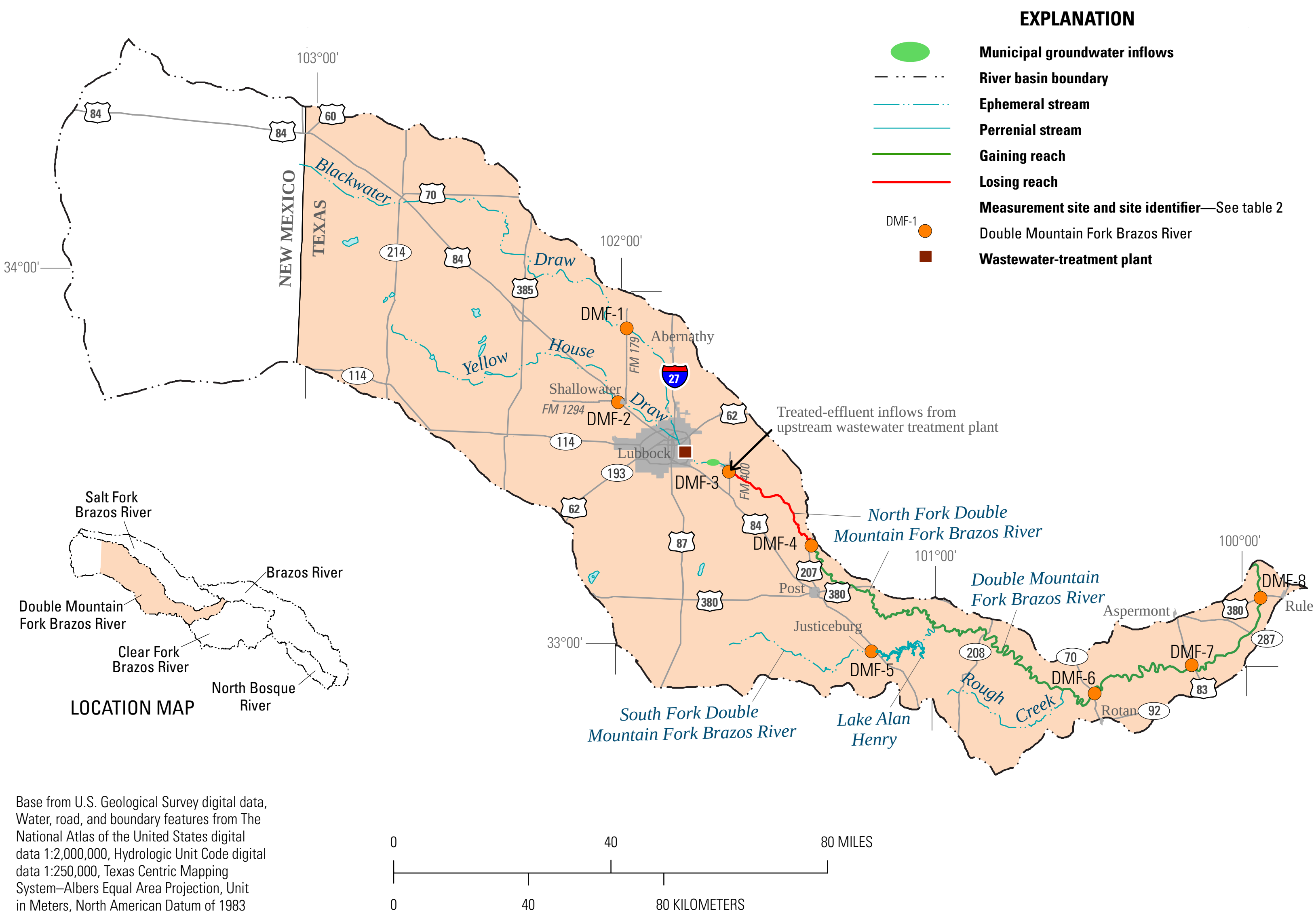


Figure 5. Sites where streamflow and specific conductance were measured in June and October 2010, Double Mountain Fork Brazos River Basin, Texas.

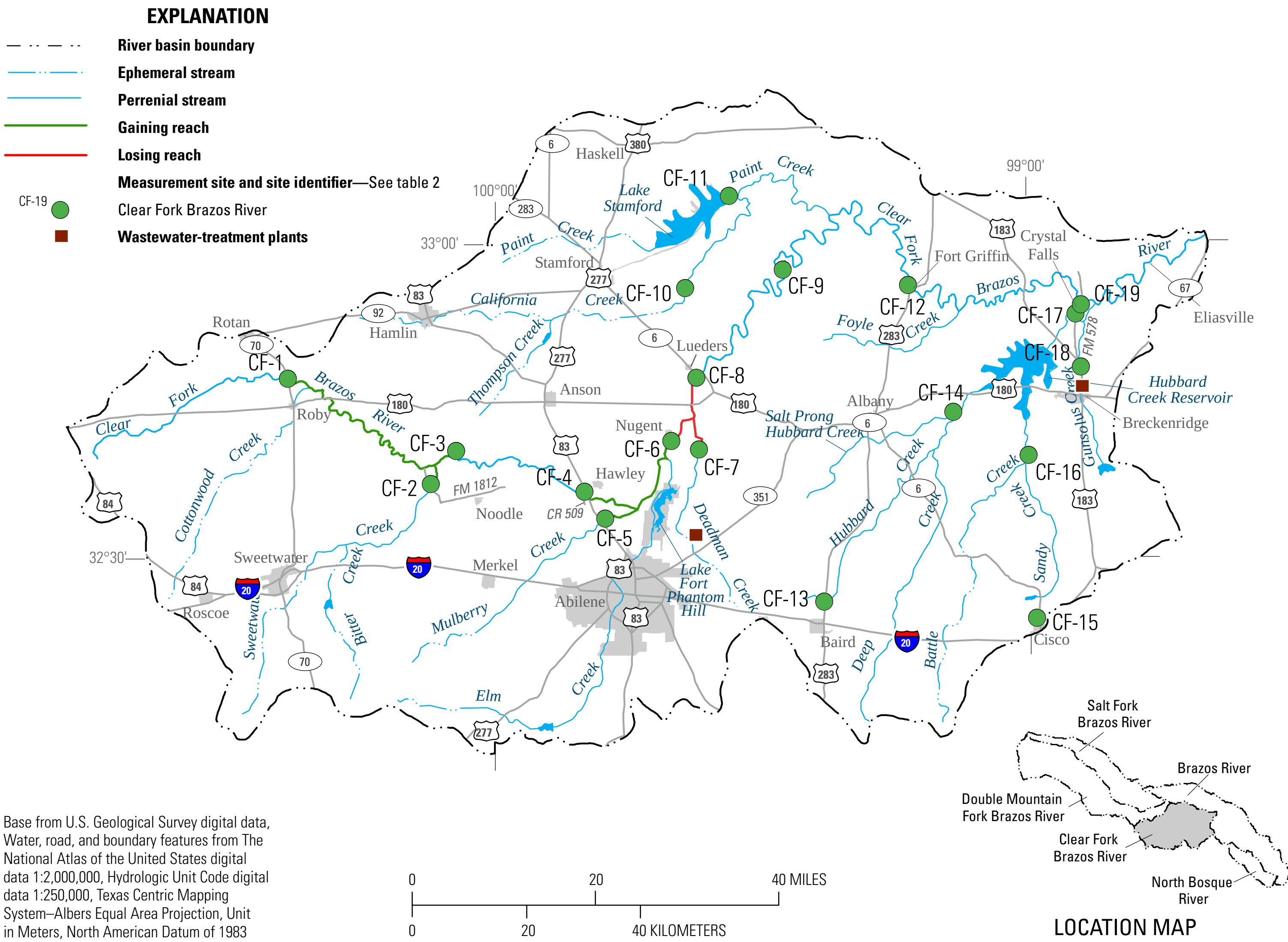
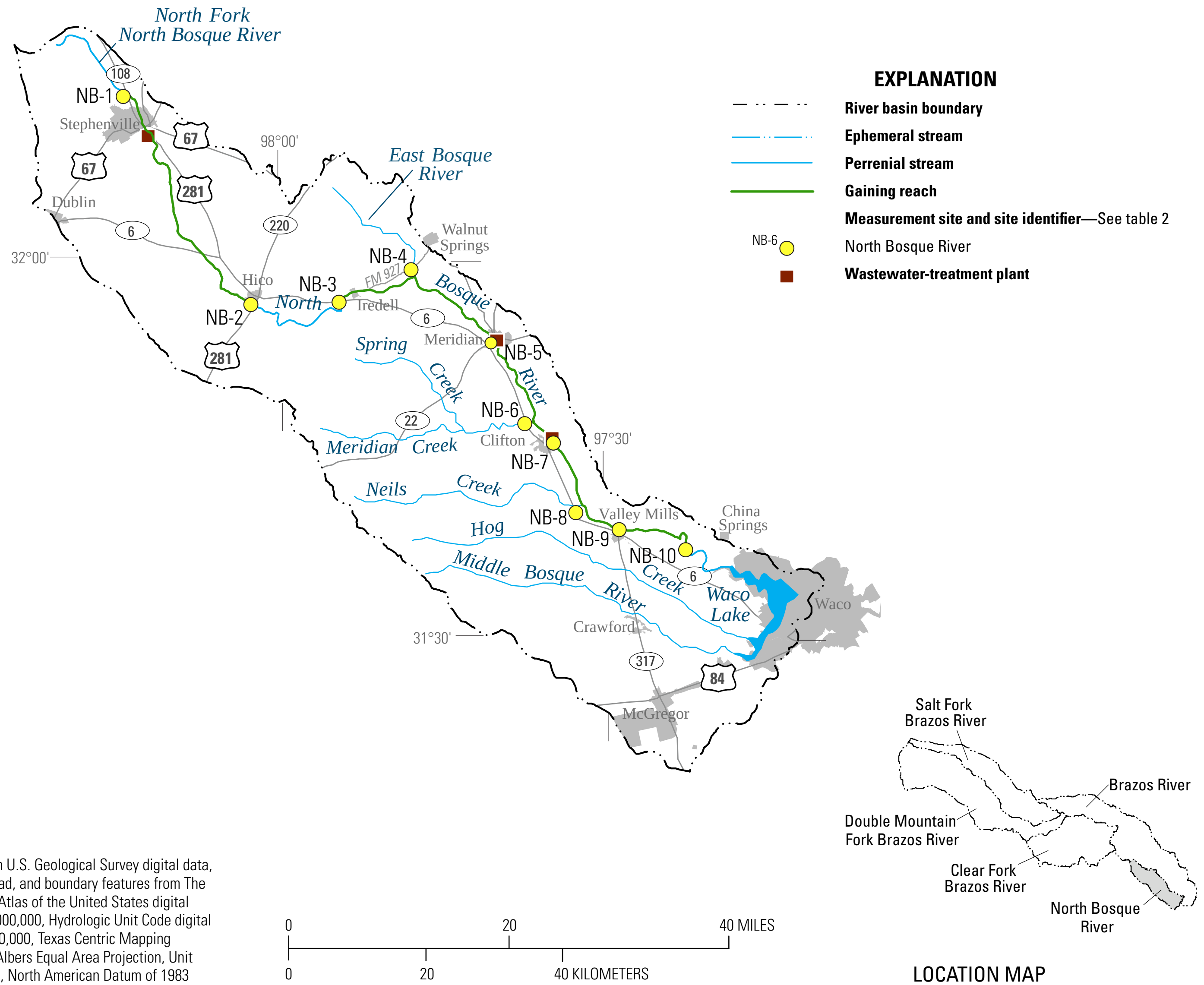


Figure 6. Sites where streamflow and specific conductance were measured in June and October 2010, Clear Fork Brazos River Basin, Texas.



Base from U.S. Geological Survey digital data,
Water, road, and boundary features from The
National Atlas of the United States digital
data 1:2,000,000, Hydrologic Unit Code digital
data 1:250,000, Texas Centric Mapping
System–Albers Equal Area Projection, Unit
in Meters, North American Datum of 1983

Figure 7. Sites where streamflow and specific conductance were measured in June and October 2010, North Bosque River Basin, Texas.

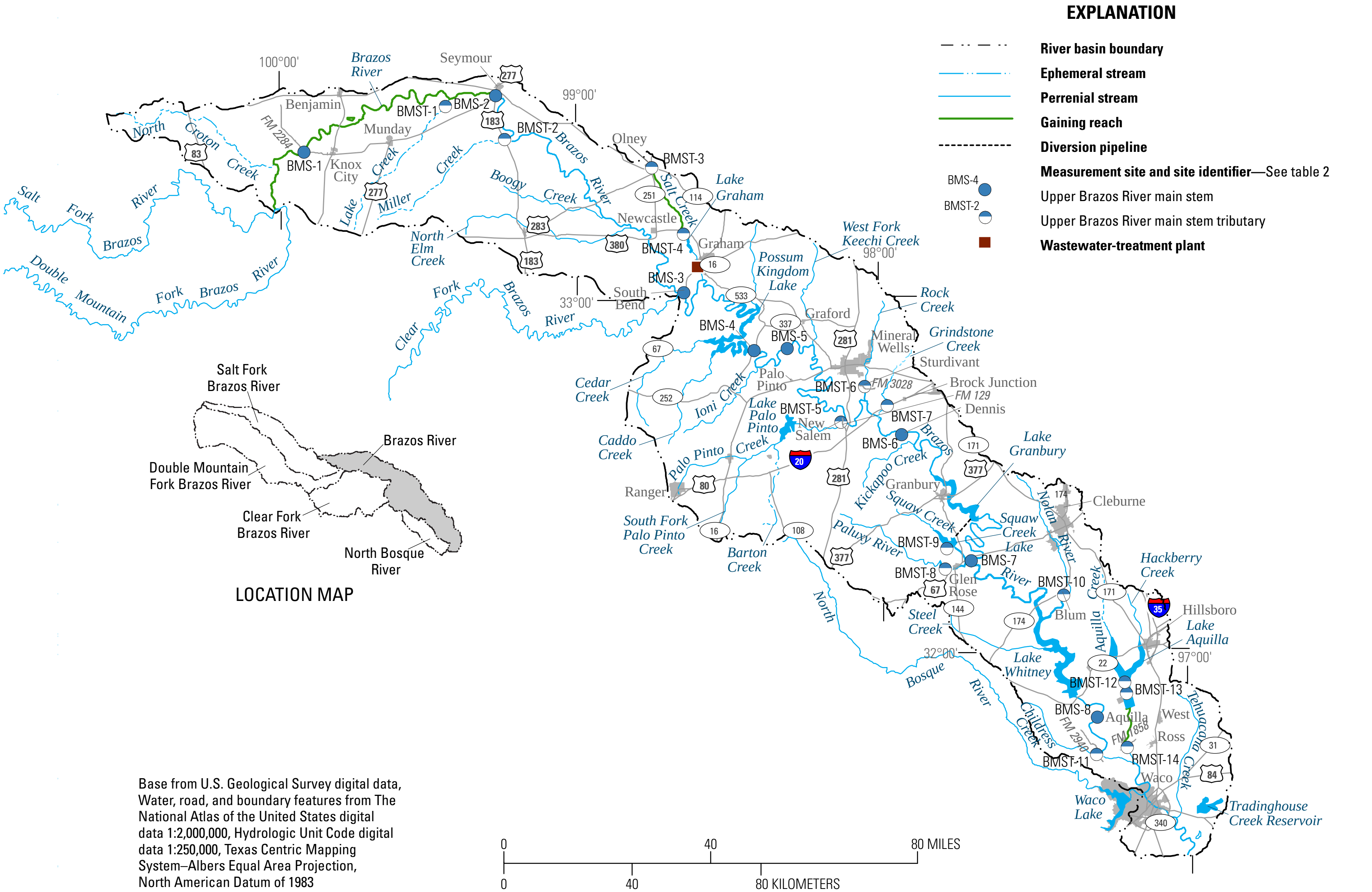


Figure 8. Sites where streamflow and specific conductance were measured in June and October 2010, main stem of the Brazos River and tributaries to the main stem, Texas.

The Brazos River main stem is formed by the confluence of the Salt Fork and Double Mountain Fork in Stonewall County, Tex. Major reservoirs in the watershed in downstream order are Possum Kingdom Lake, Lake Palo Pinto, Lake Granbury, Lake Aquilla, and Waco Lake. There are three major reservoirs on the Brazos River main-stem north of Waco: Possum Kingdom Lake near Graford, Tex., Lake Granbury near Granbury, Tex., and Lake Whitney. There are several smaller reservoirs on tributaries to the Brazos. Four streamflow-gaging stations are located in this reach on the main stem of the Brazos River (fig. 1, table 1) for which long-term data exist. The Brazos River Basin (main stem) has an estimated contributing drainage area of 20,007 mi^2 plus an additional 9,566 mi^2 that is noncontributing (U.S. Geological Survey, 2009).

The Trinity and Woodbine aquifers (figs. 2–3) underlie the Brazos River Basin (main stem) approximately from Glen Rose, Tex., downstream to Waco. The Trinity aquifer is mostly composed of alluvium (sand and gravel) and marine carbonate limestone (Ashworth and Hopkins, 1995). Although the outcrop regions of the Trinity aquifer are favorable for the infiltration of precipitation, groundwater-movement rates are typically no more than a few feet per year (Cronin and others, 1963). The concentration of dissolved solids in water from the Trinity aquifer typically ranges from 500 to 1,500 mg/L (Ryder, 1996). The Trinity aquifer is one of the most areally extensive and highly used aquifers in Texas. Its primary use is to supply water for municipalities, but the aquifer also is used for irrigation, livestock, and other rural domestic purposes. Water from the Woodbine aquifer in the outcrop area has an average dissolved-solids concentration of about 550 mg/L; the concentration increases downdip to more than 3,000 mg/L (Ryder, 1996). A small part of the study area receives groundwater from the Brazos River alluvium aquifer, which is present in the main channel of the Brazos River from Waco north to Lake Whitney (Texas Water Development Board, 2007a).

Methods

Streamflow was measured using methods approved by the USGS (Turnipseed and Sauer, 2010). Specific-conductance values were measured using methods approved by the USGS (U.S. Geological Survey, variously dated). Base flow was estimated by applying hydrograph separation techniques (Sloto and Crouse, 1996) to historical data from 11 long-term streamflow-gaging sites in the study area (table 1). At most sites where streamflow was measured, specific-conductance values were determined from grab samples collected from the centroid of flow or measured by placing a hand-held meter in the centroid of flow. Meters used to measure specific-conductance values were calibrated following established guidelines (U.S. Geological Survey, variously dated). Specific-conductance data collected in conjunction with streamflow measurements in 2010 are used to help understand observed changes in flow in gaining and losing reaches. Analyses of streamflow gains and losses were done for each of the five subbasins composing the upper Brazos River Basin. The basin designated as the main stem of the Brazos River was subdivided into four reaches separated by three reservoirs: upstream from Possum Kingdom Reservoir, from the outflow of Possum Kingdom Reservoir to the headwaters of Lake Granbury, from the outflow of Lake Granbury to the headwaters of Lake Whitney, and from the outflow from Lake Whitney to the mouth of the North Bosque River on the Brazos River north of Waco, Tex. Synoptic-streamflow measurements were used to estimate streamflow gains and losses in the five subbasins. The specific-conductance data collected concurrently with synoptic-streamflow measurements were used in the analyses of streamflow gains and losses; specific conductance is an indicator of the concentration of dissolved solids in the water, so changes in specific conductance can help identify the reasons for gains or losses in streamflow.

Hydrograph Separation and Trend Analysis

Hydrograph separation is the method of separating measured streamflow into components resulting from direct surface runoff or from groundwater discharge (base flow). Hydrograph separation was done using the USGS computer program Hydrograph Separation and Analysis (HYSEP) (Sloto and Crouse, 1996). HYSEP provides three methods of hydrograph separation that are referred to in literature as the fixed-interval, sliding-interval, and local-minimum methods (Sloto and Crouse, 1996). The local-minimum method was selected for this analysis. The local-minimum method is an algorithm that systematically draws connecting lines between the low points of the streamflow hydrograph; an example of the hydrograph separation for USGS streamflow-gaging station 08089000 Brazos River near Palo Pinto, Tex. (hereinafter the Brazos Palo Pinto gage), for the 1978 water year is provided (fig. 9).

The data used in HYSEP were historical (water years 1966–2009) streamflow from 11 USGS streamflow-gaging stations in the upper Brazos River Basin (table 1) with the exception of data from USGS streamflow-gaging stations 08082500 Brazos River at Seymour, Tex. (1967–2009), and 08090800 Brazos River near Dennis, Tex. (1969–2009). The HYSEP program makes the hydrograph separation process more precise by removing inconsistencies inherent in manual methods. The input to the HYSEP program consisted of the daily mean streamflow values measured at each streamflow-gaging station. Output from the program includes the two components of the annual mean streamflow—annual mean surface runoff and annual mean base flow. Additionally, HYSEP provides the base-flow index (BFI), which is the

Table 1. U.S. Geological Survey streamflow-gaging stations in the upper Brazos River Basin that provided data for hydrographic separation, water years 1966–2009 (October 1965 through September 2009).

[P-value considered statistically significant if <0.05; mi², square miles; <, less than]

Station number	Station name	County	Contributing drainage area (mi²)	Begin and end year[1]			Period of record used	Mann Kendall upward trend analysis (gaining)	
				First unregulated	First regulated	Last year[2]		p-value	Statistically significant
08082000	Salt Fork Brazos River near Aspermont, Tex.	Stonewall	2,500	1940	1964	2009	1966–2009	0.26	No
08080500	Double Mountain Fork Brazos River near Aspermont, Tex.	Stonewall	1,860	1925	--	2009	1966–2009	<0.01	Yes
08084000	Clear Fork Brazos River at Nugent, Tex.	Jones	2,200	1925	1940	2009	1966–2009	0.81	No
08085500	Clear Fork Brazos River at Fort Griffin, Tex.	Shackelford	3,990	1925	1940	2009	1966–2009	0.68	No
08095000	North Bosque River near Clifton, Tex.	Bosque	968	1924	1968	2009	1966–2009	0.69	No
08082500	Brazos River at Seymour, Tex.	Baylor	5,970	1925	1974	2009	1967–2009	0.10	No
08088000	Brazos River near South Bend, Tex.	Young	13,100	1939	1962	2009	1966–2009	0.34	No
08089000	Brazos River near Palo Pinto, Tex.	Palo Pinto	14,200	1925	1941	2009	1966–2009	<0.01	Yes
08090800	Brazos River near Dennis, Tex.	Parker	15,700	--	1969	2009	1969–2009	<0.01	Yes
08091000	Brazos River near Glen Rose, Tex.	Somervell	16,300	1924	1941	2009	1966–2009	0.74	No
08091500	Paluxy River at Glen Rose, Tex.	Somervell	410	1925	1982	2009	1966–2009	0.26	No

[1] Record might not be continuous from begin year to end year. Partial-record data exist for some stations outside period of record indicated.

[2] Inventory includes data through 2009 water year. Most stations with end year of 2009 are still in operation.

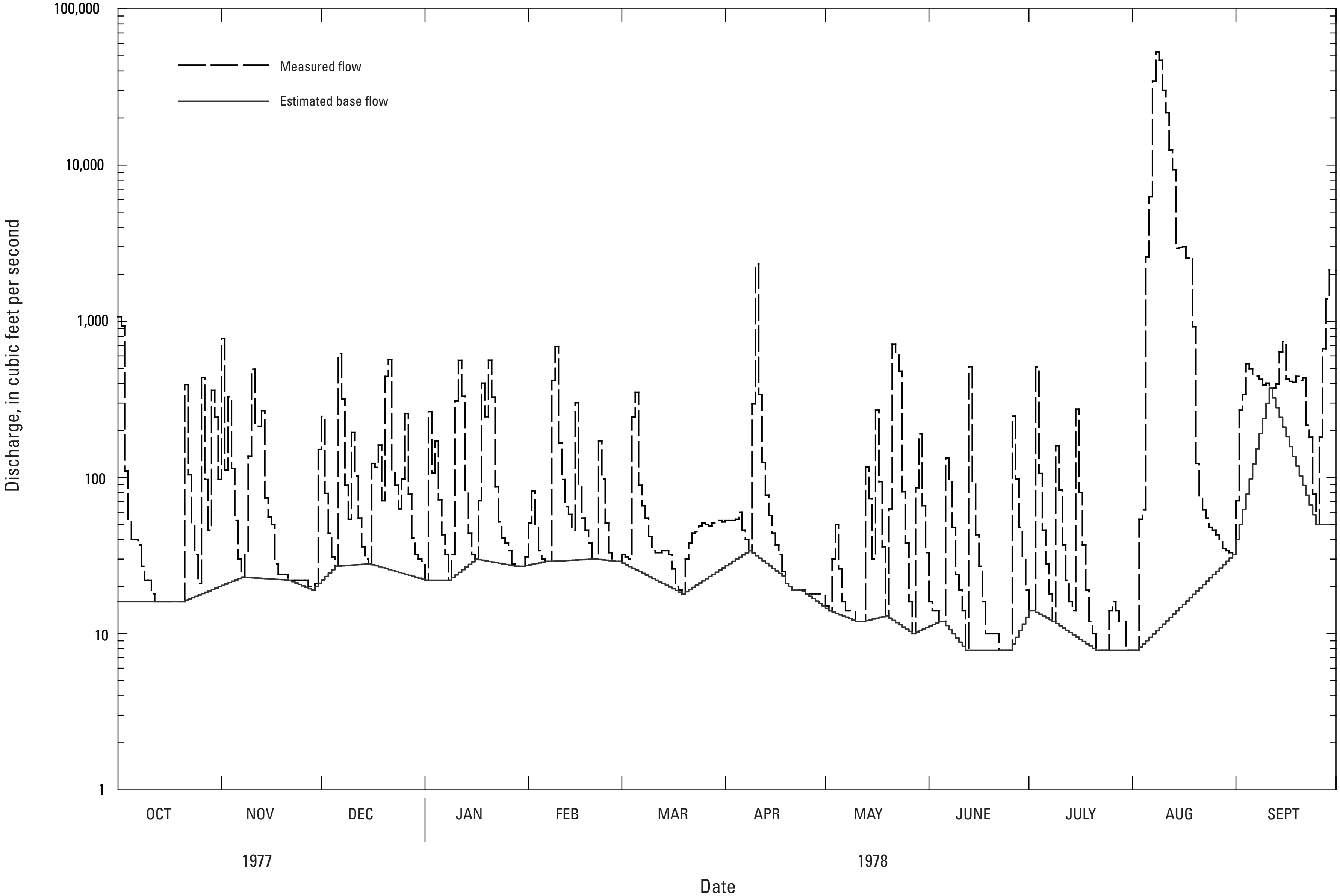


Figure 9. Hydrograph separation of streamflow for U.S. Geological Survey streamflow-gaging station 08089000 Brazos River near Palo Pinto, Texas, 1978 water year.

ratio of the annual mean base flow to the annual mean streamflow. The BFI was used to graphically compare four pairings of streamflow data (hydrographs) from eight Brazos River streamflow-gaging stations, where each pair of stations were on the same stream reach with no reservoirs between them, or paired in adjacent basins with similar hydrologic characteristics. The graphical comparisons for the stations on the same reach indicate whether the reach between two stations is gaining or losing flow. The graphical comparisons for stations in adjacent basins of similar hydrologic characteristics indicate which basin has a larger contribution of the total flow as base flow measured at the site.

Wahl and Wahl (1995) state that caution is needed when applying hydrograph separation to streamflow resulting from short-duration storms or to streamflow affected by upstream regulation, such as reservoir releases, and there are large number of reservoirs regulating streamflow in the study area. Reservoir releases in the study area are often made in response to storm runoff, so from the perspective of the HYSEP model, a reservoir release differing from base flow is categorized as storm runoff. After HYSEP was used to make hydrograph separation computations, the results were analyzed and judgments made in an attempt to determine whether upward trends in flow over time were a result of increases in reservoir releases rather than increases in base flow. When judged necessary, HYSEP program input can be adjusted by varying the runoff-timing and rerunning the program. This iterative process was continued until periods of reservoir releases were categorized by HYSEP as storm runoff and not as base flow. In some cases where the flow in a reach is regulated by reservoir releases, additional analyses beyond the scope of this study would be required before apparent streamflow trends can be characterized as indicative of changes in base flow over time.

Results of the HYSEP analysis were further tested for trends in BFI values by using the Mann-Kendall trend analysis test. The Mann-Kendall trend test is a nonparametric test used to analyze for changes in the median BFI for each site over time (Helsel and Hirsch, 2002). When the p-value for the Mann-Kendall test was less than 0.05, the identified trend (gaining or losing) was considered statistically significant.

Data Collection

To compute streamflow gains and losses, synoptic streamflow measurements were made in the spring and fall of 2010. The measurement sites consisted of long-term USGS streamflow-gaging stations (identified with 8-digit station numbers) and temporary measurement stations (identified with 15-digit station numbers). Specific-conductance values were measured at most sites where streamflow was measured (table 2). The first set of synoptic measurements were made during June 6–9, 2010 (the June survey), and the second in October 16–19, 2010 (the October survey). Early June (spring) and mid October (fall) were selected as the data-collection periods because they were representative of low-flow conditions in different seasons. Hydrologic conditions in the spring and fall typically are different; spring is usually wetter than fall in the study area (Texas State Climatologist, 2010). Prior to the June survey, precipitation during the first 5 months of 2010 varied in the upper Brazos River Basin. Precipitation measured at Abilene, Tex. (3.6 in.), was 127 percent of normal for May; however, precipitation measured at Waco, Tex., (0.89 in.) was only 20 percent of the average for May (Texas State Climatologist, 2010). Several days without measureable rainfall occurred throughout the study area before the June survey. For example, the last time recorded rainfall of more than a trace occurred in the study area was on May 17, 2010, at Abilene (0.16 in.), and on May 21, 2010, at Waco (0.82 in). The month preceding the October survey is usually hotter and drier compared to the month preceding the June survey, and demand on water resources (pumpage from the river, the alluvial aquifer, and the underlying major and minor aquifers) is relatively high. Precipitation measured in September 2010 at Abilene (2.44 in.) was 84 percent of normal, however, 9.49 in. was recorded at Waco, which was 330 percent of normal (Texas State Climatologist, 2010). Most precipitation in September 2010 occurred during the first 8 days of the month (National Climatic Data Center, 2010). Prior to the October survey, the last substantial rainfall (more than a trace) was recorded on September 25, 2010 (0.71 in. at Abilene and 0.12 in. at Waco) (National Climatic Data Center, 2010), which allowed for 11 to 14 days for streams to return to base flow before measurements of streamflow were made.

In the June survey, streamflow was measured at 58 sites that were not on the main stem of the Brazos River (including 15 observations of no flow), and at 8 on the main stem of the Brazos River (table 2). During the October survey, streamflow measurements were made at 60 sites that were not on the main stem of the Brazos River (including 13 observations of no flow), and at 8 sites on the main stem of the Brazos River (table 2). Replicate streamflow measurements were made at five randomly selected sites for the June survey and at seven randomly selected sites for the October survey (table 2). Substantial changes in specific-conductance values between sites measured during the same set of synoptic measurements might indicate inputs to streamflow of water from discharging aquifer systems. Hem (1985) states that generally there is a strong relation between dissolved solids concentration and specific-conductance values as expressed by the equation:

$$KA = S \tag{1}$$

where

K is specific conductance, in microsiemens per centimeter at 25 degrees Celsius,
S is dissolved solids in milligrams per liter, and
A is a constant ranging from 0.55 and 0.75.

Table 2. Streamflow and specific-conductance values measured during June and October 2010 in the upper Brazos River Basin, Texas.

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; FM, Farm Road; SF, Salt Fork Brazos River Basin; no flow, discharge equal to zero; -, no data collected; est., estimated; RR, Ranch Road; SH, State Highway; /, replicate measurement except as noted; DMF, Double Mountain Fork Brazos River Basin; Hwy, Highway; CF, Clear Fork Brazos River Basin; CR, County Road; SR, State Route; NB, North Bosque River Basin; BMS, Brazos River Main Stem; BMST, Brazos River Main Stem Tributary]

USGS station name	USGS station number	Site identifier (figs. 4–8)	Latitude	Longitude	Discharge (ft^3/s) June 6-9, 2010	Discharge (ft^3/s) October 16-19, 2010	Specific conductance (µS/cm) June 6-9, 2010	Specific conductance (µS/cm) October 16-19, 2010
Running Water Draw at FM 2884 near Edmonson, Tex.	341643102013700	SF-1	34°16’44”	102°01’37”	no flow	no flow	-	-
Running Water Draw at Plainview, Tex.	08080700	SF-2	34°10’44”	101°42’08”	no flow	no flow	-	-
Running Water Draw at FM 784 at Sandhill, Tex.	335939101293500	SF-3	33°59’40”	101°29’36”	no flow	no flow	-	-
White River below falls near Crosbyton, Tex.	08080900	SF-4	33°39’58”	101°09’37”	0.06	0.07 (est.)	9,590	1,060
White River at RR 261 near Spur, Tex.	332426101030700	SF-5	33°24’26”	101°03’08”	no flow	0.05	no flow	2,640
Salt Fork Brazos River at SH 208 near Clairemont, Tex.	08080940	SF-6	33°12’26”	100°44’47”	1.06/0.85	2.86	34,450	22,940
Duck Creek at FM 2320 near Jayton, Tex.	331608100420100	SF-7	33°16’09”	100°42’02”	1.56	1.75	3,640	3,630
Croton Creek below Short Creek near Jayton, Tex.	08081100	SF-8	33°18’23”	100°31’55”	-	0.1	-	35,600
Salt Fork Brazos River near Aspermont, Tex.	[1]08082000	SF-9	33°20’02”	100°14’16”	9.41	10.9/11.5	53,000	48,670
Blackwater Draw at FM 179 near Abernathy, Tex.	335325101593700	DMF-1	33°53’25”	101°59’38”	no flow	no flow	-	-
Yellow House Draw at FM 1294 at Shallowater, Tex.	334137102005900	DMF-2	33°41’38”	102°00’59”	no flow	no flow	-	-
North Fork Double Mountain Fork Brazos River at FM 400 near Lubbock, Tex.	333047101393300	DMF-3	33°30’48”	101°39’34”	[2]2.83/6.90	2.28/7.86	2,000	2,030
North Fork Double Mountain Fork Brazos River at FM 207 near Post, Tex.	331909101232900	DMF-4	33°19’10”	101°23’30”	2.78	3.17	-	1,110
Double Mountain Fork Brazos River at Justiceburg, Tex.	08079600	DMF-5	33°02’18”	101°11’50”	no flow	0.20	-	14,190
Double Mountain Fork Brazos River near Rotan, Tex.	08080000	DMF-6	32°55’50”	100°29’17”	36.8	22.8/23.5	5,690	7,950
Double Mountain Fork Brazos River near Aspermont, Tex.	[1]08080500	DMF-7	33°00’29”	100°10’49”	43.3/41.8	27.3	5,670	7,790
Double Mountain Fork Brazos River at Hwy 380 near Rule, Tex.	331116099573600	DMF-8	33°11’17”	99°57’36”	52.5	36.5	4,400	7,070

Table 2. Streamflow and specific-conductance values measured during June and October 2010 in the upper Brazos River Basin, Texas.—Continued

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; FM, Farm Road; SF, Salt Fork Brazos River Basin; no flow, discharge equal to zero; -, no data collected; est., estimated; RR, Ranch Road; SH, State Highway; /, replicate measurement except as noted; DMF, Double Mountain Fork Brazos River Basin; Hwy, Highway; CF, Clear Fork Brazos River Basin; CR, County Road; SR, State Route; NB, North Bosque River Basin; BMS, Brazos River Main Stem; BMST, Brazos River Main Stem Tributary]

USGS station name	USGS station number	Site identifier (figs. 4–8)	Latitude	Longitude	Discharge (ft^3/s) June 6-9, 2010	Discharge (ft^3/s) October 16-19, 2010	Specific conductance (µS/cm) June 6-9, 2010	Specific conductance (µS/cm) October 16-19, 2010
Clear Fork Brazos River near Roby, Tex.	08083100	CF-1	32°47’15”	100°23’18”	0.77	1.04	11,200	10,530
Sweetwater Creek at FM 1812 near Noodle, Tex.	323720100071200	CF-2	32°37’20”	100°07’13”	0.85	1.46	5,000	4,750
Clear Fork Brazos River near Noodle, Tex.	08083230	CF-3	32°40’28”	100°04’20”	5.15	6.75	9,030	6,060
Clear Fork Brazos River at CR 509 at Hawley, Tex.	323635099495800	CF-4	32°36’36”	99°49’58”	4.39	10.8	7,160	5,470
Mulberry Creek near Hawley, Tex.	08083245	CF-5	32°34’03”	99°47’35”	no flow	no flow	-	-
Clear Fork Brazos River at Nugent, Tex.	[1]08084000	CF-6	32°41’24”	99°40’09”	5.64	14.6	5,740	4,590
Deadman Creek near Nugent, Tex.	08084100	CF-7	32°40’36”	99°37’04”	19.8	14.1	1,630	1,520
Clear Fork Brazos River at Hwy 6 at Lueders, Tex.	324701099362000	CF-8	32°47’41”	99°36’20”	19.8	26.5	2,830	2,690
Clear Fork Brazos River near Lueders, Tex.	325732099273200	CF-9	32°57’32”	99°27’33”	20.3	27.1	2,120	2,160
California Creek near Stamford, Tex.	08084800	CF-10	32°55’51”	99°38’32”	3.61	4.70	7,200	639
Paint Creek below Lake Stamford near Haskell, Tex.	330433099333300	CF-11	33°04’33”	99°33’34”	5.15	5.45	4,500	3,000
Clear Fork Brazos River at Fort Griffin, Tex.	[1]08085500	CF-12	32°56’04”	99°13’27”	26.1	32.4	2,300	710
Hubbard Creek at Hwy 283 near Baird, Tex.	322606099230400	CF-13	32°26’07”	99°23’05”	no flow	no flow	-	-
Hubbard Creek near Albany, Tex.	08086100	CF-14	32°43’58”	99°08’25”	no flow	no flow	-	-
Sandy Creek at Hwy 6 at Cisco, Tex.	322424098591200	CF-15	32°26’17”	98°58’51”	0.06	no flow	533	-
Big Sandy Creek near Breckenridge, Tex.	08086300	CF-16	32°39’54”	99°00’01”	0.88	no flow	685	-
Hubbard Creek at FM 578 at Crystal Falls, Tex.	325310098543200	CF-17	32°53’11”	98°54’32”	no flow	no flow	-	-
Gonzales Creek near Breckenridge, Tex.	324812098535800	CF-18	32°48’12”	98°53’59”	no flow	0.24	-	2,540

Table 2. Streamflow and specific-conductance values measured during June and October 2010 in the upper Brazos River Basin, Texas.—Continued

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; FM, Farm Road; SF, Salt Fork Brazos River Basin; no flow, discharge equal to zero; -, no data collected; est., estimated; RR, Ranch Road; SH, State Highway; /, replicate measurement except as noted; DMF, Double Mountain Fork Brazos River Basin; Hwy, Highway; CF, Clear Fork Brazos River Basin; CR, County Road; SR, State Route; NB, North Bosque River Basin; BMS, Brazos River Main Stem; BMST, Brazos River Main Stem Tributary]

USGS station name	USGS station number	Site identifier (figs. 4–8)	Latitude	Longitude	Discharge (ft^3/s)		Specific conductance (µS/cm)	
					June 6-9, 2010	October 16-19, 2010	June 6-9, 2010	October 16-19, 2010
Clear Fork Brazos River at FM 578 at Crystal Falls, Tex.	325406098535700	CF-19	32°54’07”	98°53’57”	26.3	29.9/31.3	1,980	653
North Fork North Bosque River at State Route 108 near Stephenville, Tex.	321513098133100	NB-1	32°15’14”	98°13’31”	no flow	no flow	-	-
North Bosque River at Hico, Tex.	08094800	NB-2	31°58’35”	98°01’57”	11.7	4.16	414	522
North Bosque River at Hwy 6 near Iredell, Tex.	315839097534200	NB-3	31°58’40”	97°53’43”	14.2	4.85	292	429
East Bosque River at FM 927 near Walnut Springs, Tex.	320106097465700	NB-4	32°01’06”	97°46’58”	0.87	0.26	-	495
North Bosque River at Hwy 22 at Meridian, Tex.	315510097394300	NB-5	31°55’10”	97°39’43”	26.1	7.60/7.59	-	459
Meridian Creek at Hwy 6 near Clifton, Tex.	314842097364100	NB-6	31°48’42”	97°36’42”	10.3/8.37	3.70/3.52	407	433
North Bosque River near Clifton, Tex.	[1]08095000	NB-7	31°47’09”	97°34’04”	47.9	17.6	522	510
Neils Creek at Hwy 6 near Valley Mills, Tex.	314136097320700	NB-8	31°41’37”	97°32’07”	18.2	6.84	486	464
North Bosque River at Valley Mills, Tex.	08095200	NB-9	31°40’10”	97°28’09”	86.7	39.1	514	539
North Bosque River near China Springs, Tex.	313830097220100	NB-10	31°38’30”	97°22’01”	103/107	41.4	464	511
Brazos River at Hwy 143/222 near Knox City, Tex.	332533099544100	BMS-1	33°25’33”	99°54’41”	86.2	61.9	15,070	17,550
Brazos River at Seymour, Tex.	[1]08082500	BMS-2	33°34’51”	99°16’02”	142	93.7	16,630	14,680
Brazos River near South Bend, Tex.	[1]08088000	BMS-3	33°01’27”	98°38’37”	163	127	8,940	8,600
Brazos River near Graford, Tex.	08088610	BMS-4	32°51’29”	98°24’41”	105	156	2,510	3,080
Brazos River near Palo Pinto, Tex.	[1]08089000	BMS-5	32°51’45”	98°18’08”	138/132	164	2,410	3,090
Brazos River near Dennis, Tex.	[1]08090800	BMS-6	32°36’56”	97°55’32”	192	172	-	2,970
Brazos River near Glen Rose, Tex.	[1]08091000	BMS-7	32°15’30”	97°42’10”	99	62.4	-	2,260
Brazos River near Aquilla, Tex.	08093100	BMS-8	31°48’46”	97°17’52”	252	252	998	2,380
Lake Creek at FM 2070 near Seymour, Tex.	333323099263000	BMST-1	33°33’23”	99°26’30”	-	0.33	-	3,950

Table 2. Streamflow and specific-conductance values measured during June and October 2010 in the upper Brazos River Basin, Texas.—Continued

[USGS, U.S. Geological Survey; ft³/s, cubic feet per second; μS/cm, microsiemens per centimeter at 25 degrees Celsius; FM, Farm Road; SF, Salt Fork Brazos River Basin; no flow, discharge equal to zero; -, no data collected; est., estimated; RR, Ranch Road; SH, State Highway; /, replicate measurement except as noted; DMF, Double Mountain Fork Brazos River Basin; Hwy, Highway; CF, Clear Fork Brazos River Basin; CR, County Road; SR, State Route; NB, North Bosque River Basin; BMS, Brazos River Main Stem; BMST, Brazos River Main Stem Tributary]

USGS station name	USGS station number	Site identifier (figs. 4–8)	Latitude	Longitude	Discharge (ft^3/s)		Specific conductance (μS/cm)	
					June 6-9, 2010	October 16-19, 2010	June 6-9, 2010	October 16-19, 2010
Millers Creek at Hwy 183/283 near Seymour, Tex.	332744099144300	BMST-2	33°27'45"	99°14'44"	no flow	no flow	-	-
Salt Creek at Olney, Tex.	08088100	BMST-3	33°22'14"	98°44'41"	0.06	0.05	14,240	7,870
Salt Creek at Hwy 380 near Newcastle, Tex.	331140098390300	BMST-4	33°11'41"	98°39'04"	12.8	2.16	523	393
Palo Pinto Creek at FM 129 near New Salem, Tex.	323932098072300	BMST-5	32°39'33"	98°07'23"	4.56	2.20/3.19	578	450
Rock Creek at FM 3028 near Sturdivant, Tex.	324456098025900	BMST-6	32°44'56"	98°02'59"	2.28	1.10	-	464
Grindstone Creek at I-20 near Brock Junction, Tex.	324151097581900	BMST-7	32°41'51"	97°58'20"	0.05	0.06	-	1,160
Paluxy River at Glen Rose, Tex.	[1]08091500	BMST-8	32°13'53"	97°46'37"	35.4	9.84	-	508
Squaw Creek near Glen Rose, Tex.	08091750	BMST-9	32°16'12"	97°47'12"	15.6	4.45	-	4,470
Nolan River at Blum, Tex.	08092000	BMST-10	32°09'02"	97°43'56"	6.63	8.76	-	812
Childress Creek at FM 2490 near Waco, Tex.	314220097174100	BMST-11	31°42'21"	97°17'41"	3.54	4.33/5.02	313	310
Aquilla Creek above Aquilla, Tex.	08093360	BMST-12	31°53'43"	97°12'10"	2.26	14.0	-	491
Cobb Creek near Aquilla, Tex.	315300097114200	BMST-13	31°53'01"	97°11'43"	no flow	no flow	-	-
Aquilla Creek at FM 1858 near Ross, Tex.	08093560	BMST-14	31°43'33"	97°12'39"	15.5	22.1	967	446

[1] Data used on Hydrograph Separation and Analyses (HYSEP) (Sloto and Crouse, 1996) to calculate base flow index values.

[2] Consecutive measurements upstream and downstream from inflows that might contain treated effluent at Farm Road 400 at site DMF-3 (fig. 5).

Streamflow Gain and Loss Computation

The amount of streamflow that varies from the upstream end to the downstream end of a reach can be categorized as gain, loss, or no change in base flow for that particular reach. This amount is computed by using the following equation:

$$Q_u + Q_t + Q_r = Q_d + Q_w + Q_e + Q_g \qquad (2)$$

where

Q_u is streamflow in at upstream end of reach,
Q_t is streamflow from tributaries into reach,
Q_r is return flows to reach,
Q_d is streamflow out at downstream end of reach,
Q_w is withdrawals from reach,
Q_e is evapotranspiration from reach, and
Q_g is gain (positive) or loss (negative) in reach.

Thus,

$$Q_g = Q_u + Q_t + Q_r - Q_d - Q_w - Q_e \qquad (3)$$

The study area was divided into the five subbasins described in the Description of Study Area section for the purpose of measuring streamflow gains or losses, and each subbasin has a main-stem stream. Any tributary inflows to the main stem in each subbasin were measured (many tributaries were dry streambeds). However, return flows (Q_r), withdrawals (Q_w), and evapotranspiration (Q_e) generally were not measured, and those components were excluded from equation 3.The error in Q_g associated with these exclusions is believed to be minor when compared to potential errors associated with the flow measurements. Return flows of treated effluent (wastewater) from the following cities in the study area were included in the analysis: Abilene, Lubbock, Breckenridge, Graham, Stephenville, and Meridian, Tex.

Quality Assurance

For this report, a stream reach is characterized as verifiably gaining or losing only when the difference between streamflow at the upstream and downstream measuring sites that define the reach is greater than the potential error associated with the streamflow measurements. Measurement error is based on the rating of the streamflow measurement (excellent, good, fair, or poor) by the streamgager (Turnipseed and Sauer, 2010). The rating is based on factors such as orientation of cross section relative to the channel, number of depth and velocity observations, cross-section uniformity, velocity homogeneity, streambed conditions, and other factors that might affect the accuracy of the measurement. Measurements were assigned a rating based on USGS guidelines (Turnipseed and Sauer, 2010) of excellent, within 2 percent of the actual flow; good, within 5 percent; fair, within 8 percent; and poor, differs from the actual flow by more than 8 percent. The potential errors associated with each pair (upstream and downstream) of streamflow measurements for a given reach were summed to obtain the potential composite error for each measurement. USGS guidelines (Turnipseed and Sauer, 2010) for operation and maintenance of streamflow measuring equipment and techniques of making streamflow measurements were followed. Because most streamflow measurements were rated as fair or better, reaches were identified as gaining or losing if the measured differences were more than 8 percent.

Replicate streamflow measurements were made at randomly selected sites during the June and October surveys (table 2). Replicate streamflow measurements during June 6–9, 2010, were made at USGS stations 08080940 Salt Fork Brazos River at State Highway 208 near Clairemont, Tex., 314842097364100 Meridian Creek at Highway 6 near Clifton, Tex., 313830097220100 North Bosque River near China Springs, Tex., 08080500 Double Mountain Fork Brazos River near Aspermont, Tex., and 08089000 Brazos River near Palo Pinto, Tex. Replicate streamflow measurements during October 16–19, 2010, were made at the following USGS stations: 08082000 Salt Fork Brazos River near Aspermont, Tex., 08080500 Double Mountain Fork Brazos River near Rotan, 325406098535700 Clear Fork Brazos River at Farm Road 578 at Crystal Falls, Tex., 315510097394300 North Bosque River at Highway 22 at Meridian, Tex., 314842097364100 Meridian Creek at Highway 6 near Clifton, Tex., 323932098072300 Palo Pinto Creek at Farm Road 129 near New Salem, Tex., and 314220097174100 Childress Creek at Farm Road 2490 near Waco, Tex. Two streamflow measurements were made in June and October 2010 at USGS station 333047101393300 North Fork Double Mountain Fork Brazos River at Farm Road 400 near Lubbock, Tex. (site DMF–3) to measure differences in streamflow resulting from changes in treated-effluent inflows; the Lubbock wastewater-treatment plant discharges effluent upstream from site DMF–3 (fig. 5). Consecutive streamflow measurements were made upstream and downstream from Farm Road 400 at site DMF–3.

Base Flow

Analysis of base flow as an index of streamflow (BFI), determined by dividing the amount of base flow by the total amount of flow each water year, was done at 11 USGS streamflow-gaging stations in the upper Brazos River Basin for which there were long-term data from water years 1966–2009 at 9 stations and slightly shorter periods of record at 2 stations (1967–2009 and 1969–2009) (table 1). The number of USGS streamflow-gaging stations in each subbasin were as follows: one in each the Salt Fork and Double Mountain Fork basins, two in the Clear Fork basin, one in the North Bosque River basin, and six in the Brazos River Basin (main stem) (table 1; appendix 1).

Salt Fork and Double Mountain Fork Brazos River Basin

In the Salt Fork Basin, the BFI was calculated using data from USGS streamflow-gaging station 08082000 Salt Fork Brazos River near Aspermont, Tex. (hereinafter Salt Fork Aspermont gage, site SF-9), which is 27.3 mi upstream from the confluence with the Double Mountain Fork north of Aspermont (U.S. Geological Survey, 2009). The annual BFI for the Salt Fork Aspermont gage ranged from a minimum of 0.03 in 2000 to a maximum of 0.46 in 1973 (fig. 10) with a median BFI value of 0.16. The drainage area for this part of the upper Brazos River Basin overlies parts of the Seymour and Ogallala major aquifers (fig. 2), as well as the Edwards-Trinity (High Plains), Dockum, and Blaine minor aquifers (fig. 3).

In the Double Mountain Fork Basin, the BFI was calculated using data from USGS streamflow-gaging station 08080500 Double Mountain Fork Brazos River near Aspermont, Tex. (hereinafter Double Mountain Fork Aspermont gage, site DMF-7) (fig. 11), which is 34.5 mi upstream from the confluence of Double Mountain Fork Brazos River with the Salt Fork north of Aspermont in Stonewall County, Tex. (U.S. Geological Survey, 2009). The annual BFI for the Double Mountain Fork Aspermont gage ranged from a minimum of 0.01 in 1995 to a maximum of 0.62 in 2001, and the median BFI was 0.15. This part of the upper Brazos River Basin is similar to the Salt Fork Basin in that part of the basin overlies sections of the Seymour and Ogallala major aquifers (fig. 2) and the Edwards-Trinity (High Plains), Dockum, and Blaine minor aquifers (fig. 3).

The Salt Fork and Double Mountain Fork Basins were compared because they are adjacent to each other with similar east-west orientations and similar climatic conditions. A comparison of corresponding BFI values (fig. 12) indicates that small differences exist between the two stations. Corresponding BFI values for the Double Mountain Fork gage are larger than BFI values for the Salt Fork gage 52 percent of the time during the study period (fig. 12*A*). BFI values for each station plotted in relation to each other (fig. 12*B*) indicate that neither station is substantially different from the other with about the same distribution on either side of the equal BFI line. About water year 2000, the Double Mountain Fork appears to gain in base flow while base flow in the Salt Fork remains constant (figs. 12*A* and 12*B*).

Clear Fork Brazos River Basin

BFIs were calculated using data from two streamflow-gaging stations in the Clear Fork Brazos River Basin, USGS streamflow-gaging station 08084000 Clear Fork Brazos River at Nugent, Tex., (hereinafter the Clear Fork Nugent gage, site CF–6) and USGS streamflow-gaging station 08085500 Clear Fork Brazos River at Fort Griffin, Tex., (hereinafter the Clear Fork Fort Griffin gage, site CF–12) (fig. 6; table 2). The Clear Fork Nugent gage and Clear Fork Fort Griffin gage are 93.2 river miles apart. The BFI for the Clear Fork Nugent gage ranged from 0.02 in 2000 to 0.79 in 1998, and the median BFI was 0.28 (fig. 13). The BFI at the Clear Fork Fort Griffin gage ranged from 0.02 in 1978 to 0.55 in 1983 with a median BFI of 0.23 (fig. 14). The plot of the BFI values for both sites by year (fig. 15*A*) shows the BFIs for Clear Fork Nugent were greater than for Clear Fork Fort Griffin about 50 percent of the time. When the BFI for Clear Fork Fort Griffin is greater than that for Clear Fork Nugent, the difference is generally small (less than 0.08 (fig. 15*B*). The Clear Fork Nugent gage (site CF–6) is relatively near the areal extents of the Seymour, Edwards-Trinity (Plateau), and Blaine aquifers in the Clear Fork Basin and the stream at site CF–7 probably receives larger amounts of base flow from these aquifers compared to the stream at the Clear Fork Fort Griffin gage (site CF–12); the reach between the Clear Fork Nugent gage and the Clear Fork Fort Griffin gage is not close to any major or minor aquifers.

North Bosque River Basin

USGS streamflow-gaging station 08095000 North Bosque River near Clifton, Tex., (hereinafter North Bosque Clifton gage, site NB–7) is 42 mi upstream from the mouth of the North Bosque River near Waco (fig. 16). The cities of Meridian, Stephenville, and Clifton discharge treated effluent into the river upstream from this station (fig. 7).

The annual BFI for the North Bosque Clifton gage ranged from 0.07 in 1986 to 0.57 in 1978 with a median BFI of 0.30 (fig. 16). The northern part of the North Bosque River drainage basin overlies the Trinity aquifer (fig. 2). The median BFI at the North Bosque Clifton gage, while not as large as the median BFI of 0.35 at USGS streamflow-gaging station 08091500 Paluxy River at Glen Rose, Tex. (hereinafter the Paluxy gage), is larger than median BFIs determined for all of the other long-term streamflow records evaluated in this study. This finding indicates that a substantial amount of the total flow in the North Bosque River Basin might come from groundwater, treated effluent from the Meridian, Stephenville, and Clifton wastewater-treatment plants, or a combination of groundwater and treated effluent. The North Bosque River is impounded by Waco Lake; regulated releases from Waco Lake provide flow to the main stem of the Brazos River north of Waco (fig. 1).

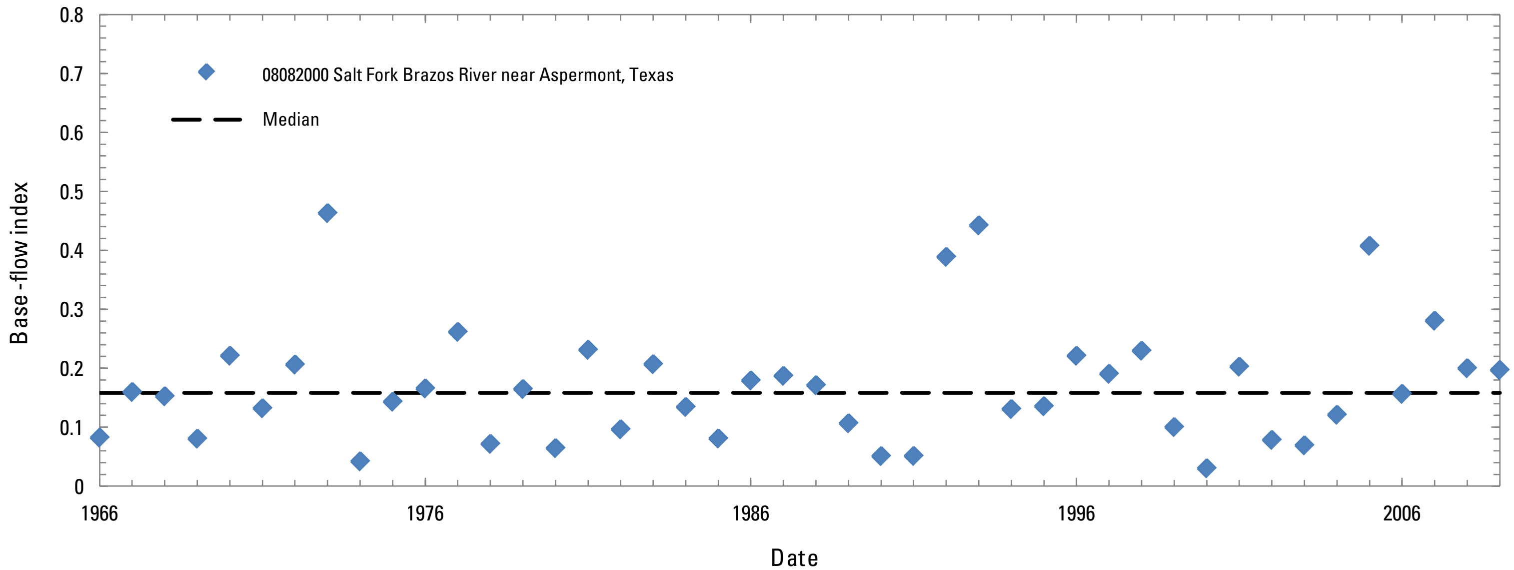


Figure 10. Annual base-flow index for U.S. Geological Survey streamflow-gaging station 08082000 Salt Fork Brazos River near Aspermont, Texas, 1966–2009.

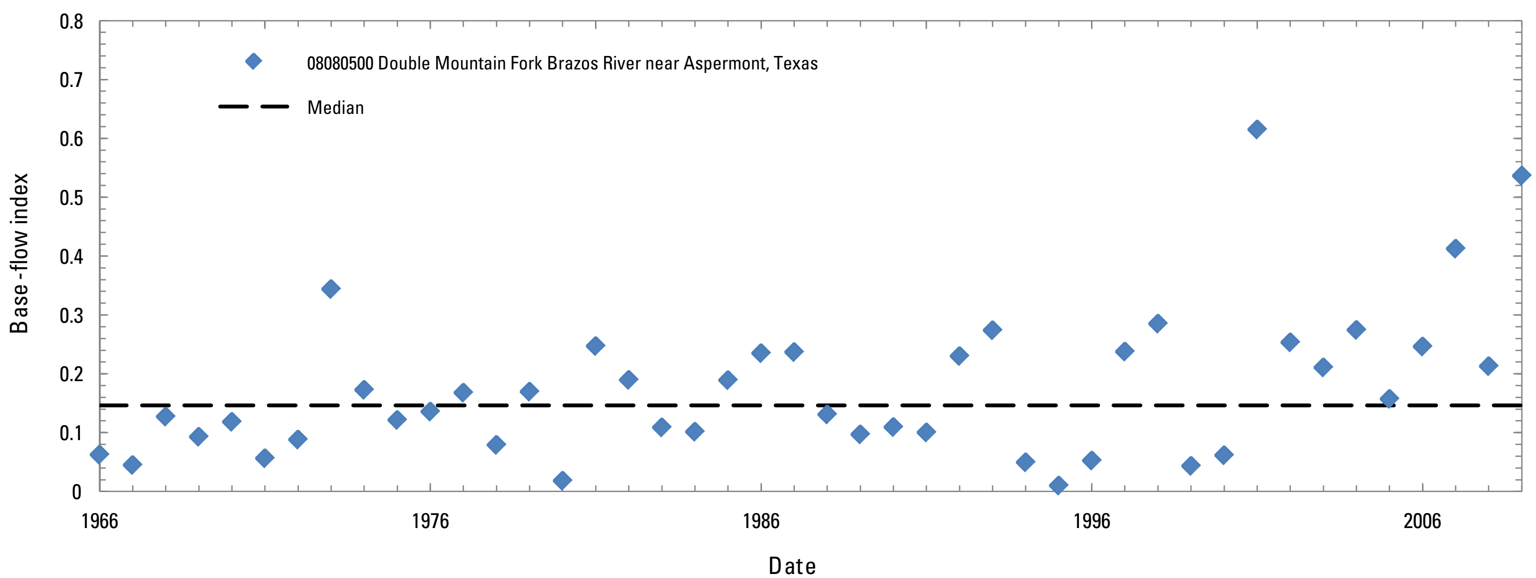


Figure 11. Annual base-flow index for U.S. Geological Survey streamflow-gaging station 08080500 Double Mountain Fork Brazos River near Aspermont, Texas, 1966–2009.

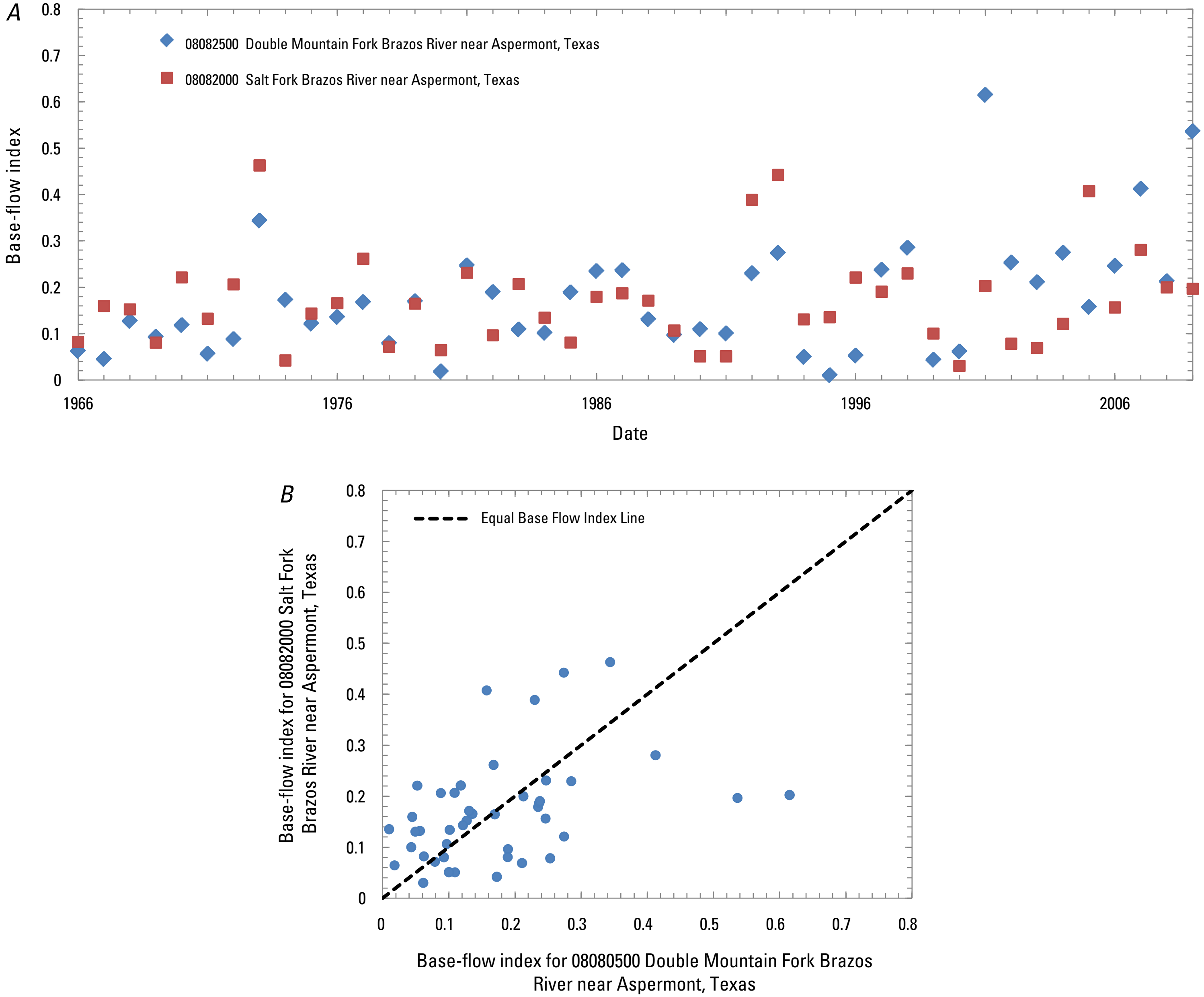


Figure 12. *A*, Time series of annual base-flow index and *B*, Relation between annual base-flow index for U.S. Geological Survey streamflow-gaging stations 08080500 Double Mountain Fork Brazos River near Aspermont, Texas, and 08082000 Salt Fork Brazos River near Aspermont, Tex., 1966–2009.

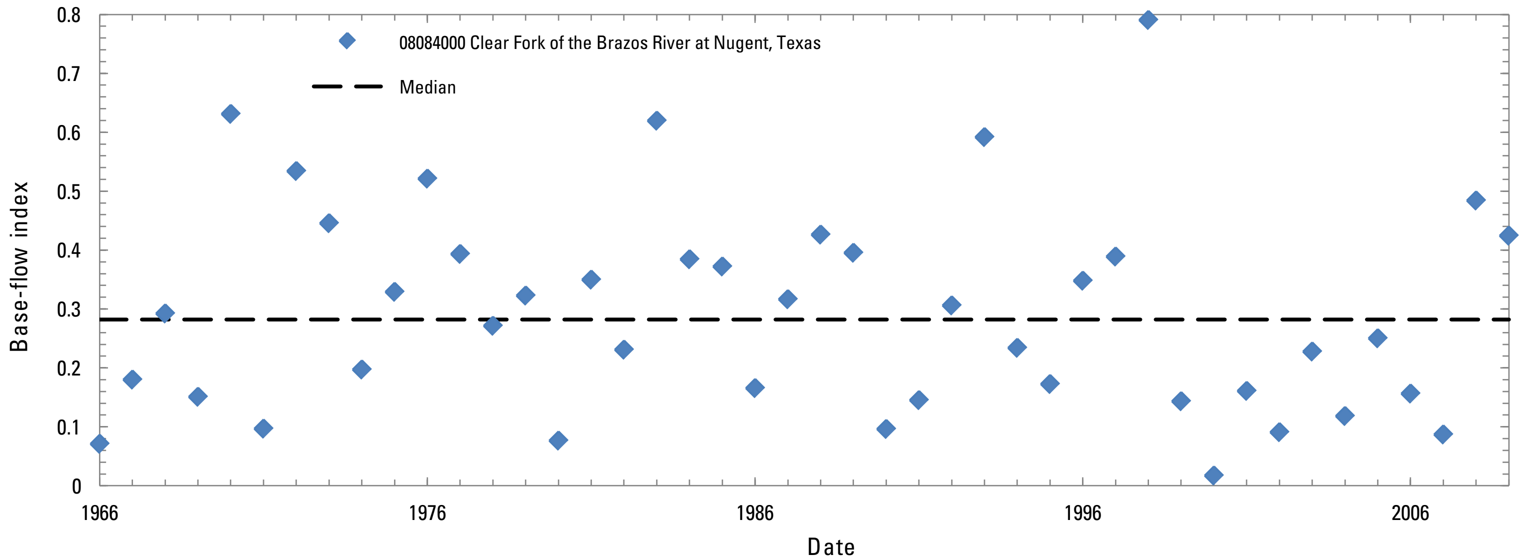


Figure 13. Annual base-flow index for U.S. Geological Survey streamflow-gaging station 08084000 Clear Fork Brazos River at Nugent, Texas, 1966–2009.

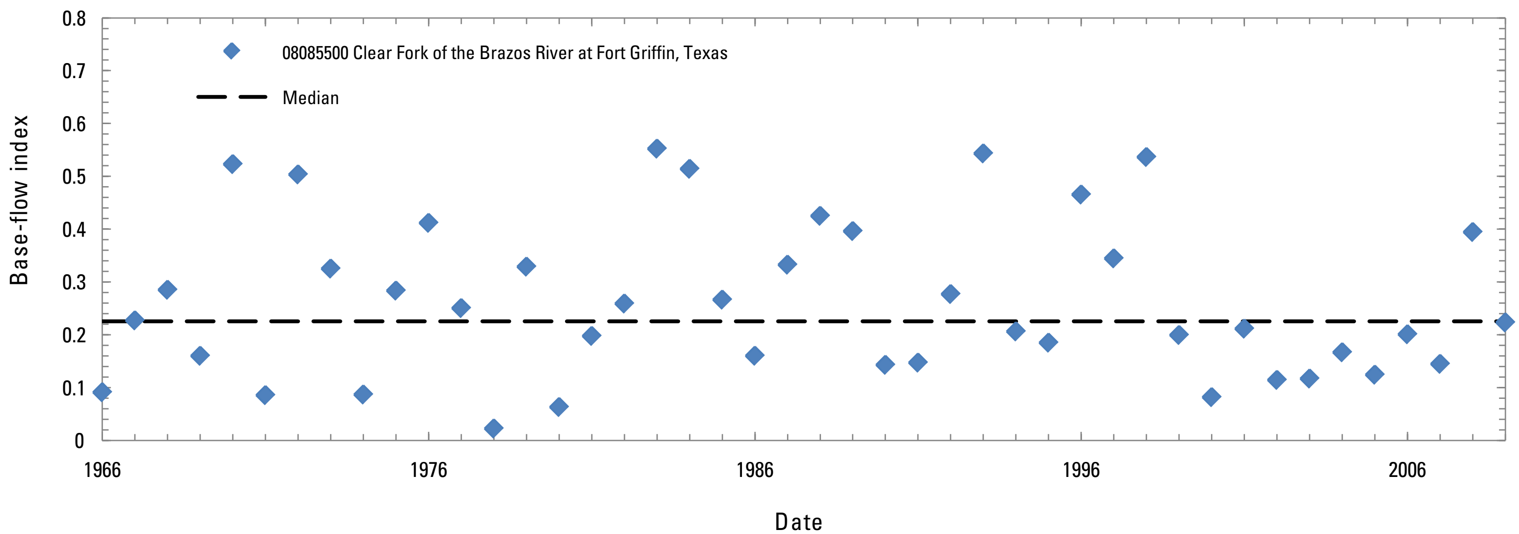


Figure 14. Annual base-flow index for U.S. Geological Survey streamflow-gaging station 08085500 Clear Fork Brazos River at Fort Griffin, Texas, 1966–2009.

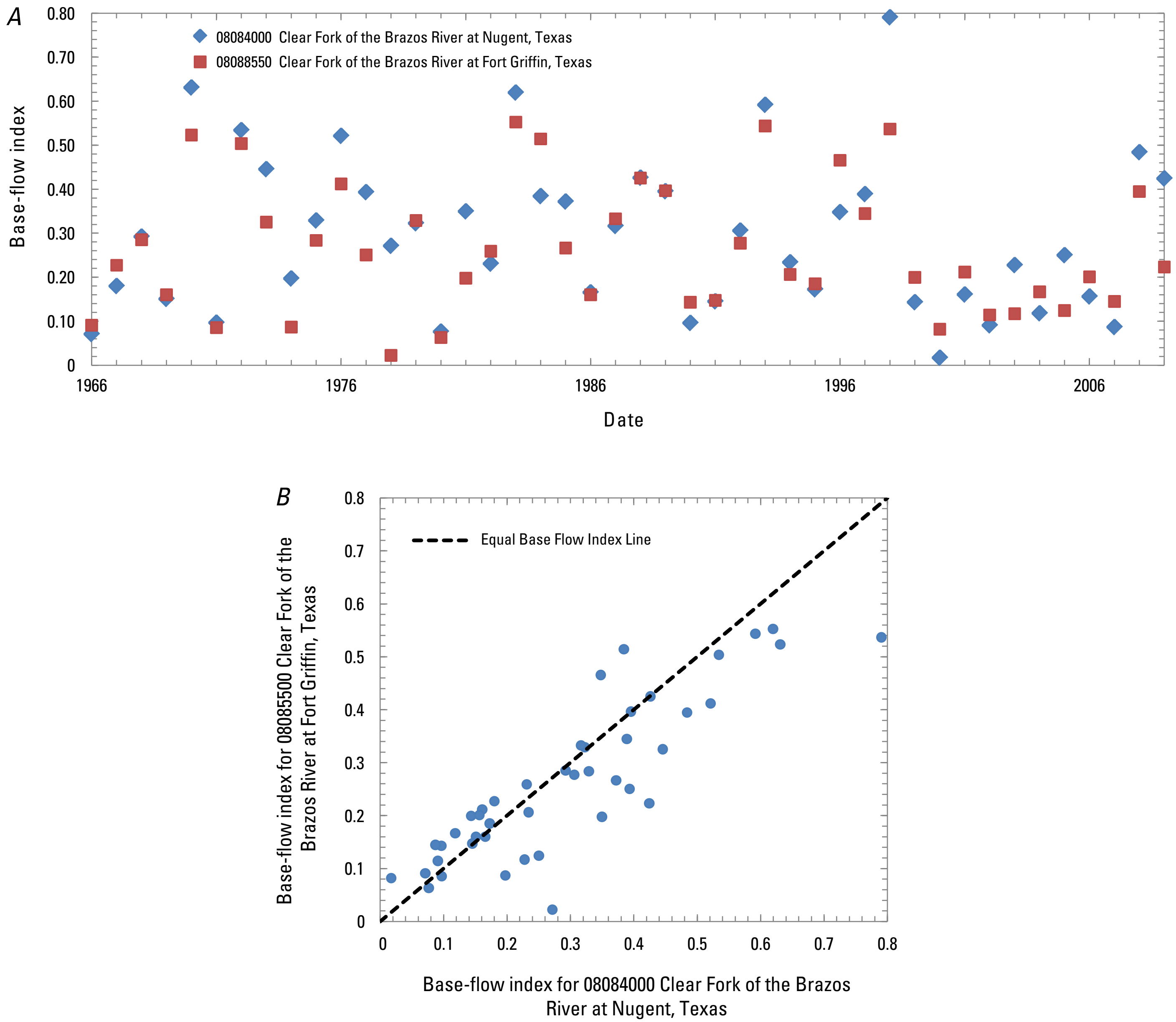


Figure 15. *A*, Time series of annual base-flow index and *B*, Relation between annual base-flow index for U.S. Geological Survey streamflow-gaging station 08084000 Clear Fork Brazos River near Nugent, Texas and U.S. Geological Survey streamflow-gaging station 08085500 Clear Fork Brazos River at Fort Griffin, Tex., 1966–2009.

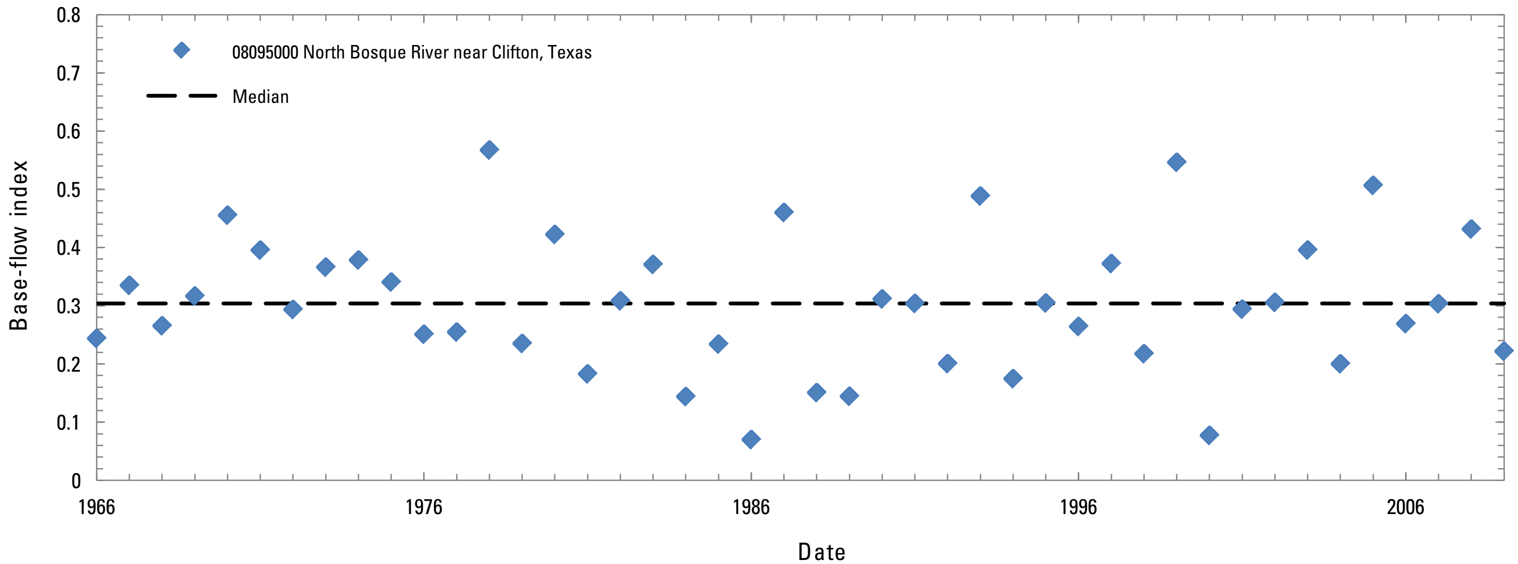


Figure 16. Annual base-flow index for U.S. Geological Survey streamflow-gaging station 08095000 North Bosque River near Clifton, Texas, 1966–2009.

Brazos River Basin (main stem)

Long-term streamflow records were analyzed for six USGS streamflow-gaging stations in the Brazos River Basin (main stem) (table 1; fig. 8):

- 08082500 Brazos River at Seymour, Tex. (hereinafter the Brazos Seymour gage, site BMS–2)
- 08088000 Brazos River near South Bend, Tex. (hereinafter Brazos South Bend gage, site BMS–3)
- 08089000 Brazos River near Palo Pinto, Tex. (hereinafter Brazos Palo Pinto gage, site BMS–5)
- 08090800 Brazos River near Dennis, Tex. (hereinafter Brazos Dennis gage, site BMS–6)
- 08091000 Brazos River near Glen Rose, Tex. (hereinafter Brazos Glen Rose gage, site BMS–7)
- 08091500 Paluxy River at Glen Rose, Tex., (hereinafter Paluxy gage, site BMST–8)

The Paluxy gage (site BMST–8) is on a major tributary to main stem of the Brazos River (fig. 8, table 2). There are other sites in the upper Brazos River Basin present with sufficient data for long-term analysis, however, they were not chosen for analysis because of various reasons such as unstable rating curves or instrument problems.

The Brazos Seymour gage (site BMS–2) and Brazos South Bend gage (site BMS–3) are 89.2 river miles apart on the main stem of the Brazos River in the upper reaches of the drainage basin (table 2; fig. 8). The Brazos Seymour gage is 847.4 river miles upstream from the mouth of the Brazos River, and is the farthest upstream site where BFI values were determined. The BFI values at The Brazos Seymour gage (fig. 17) ranged from 0.04 in 1974 to 0.47 in 2009 with the median BFI of 0.22 for the period of record. The BFI values at the Brazos South Bend gage ranged from 0.03 in 1978 to 0.56 in 1993 with the median BFI of 0.24 for the period of record used (1966–2009) (fig. 18). An analysis of the plot of the BFI values for these two stations by year (fig. 19*A*) indicates that for the same year, the BFI at the Brazos South Bend gage was larger than the BFI at the Brazos Seymour gage 74 percent of the time (BFI values mostly plot to the left of the equal BFI line) (fig. 19*B*), a pattern that indicates base flow composes a larger amount of total streamflow at the Brazos South Bend gage than at the Brazos Seymour gage. The Brazos South Bend gage is downstream from a part of the main-stem basin that overlies the Seymour aquifer (fig. 2).

Possum Kingdom Lake, formed by Morris Sheppard Dam at river mile 687.5 upstream from the mouth of the Brazos River, is the farthest upstream major reservoir on the main stem of the Brazos River, and impounds the Brazos River between the Brazos South Bend gage (site BMS–3) and the Brazos Palo Pinto gage (site BMS–5) (fig. 8). Constructed in 1941, the conservation pool storage of Possum Kingdom Lake is 556,220 acre-ft (U.S. Geological Survey, 2001). Water stored in Possum Kingdom Lake is used for power generation, irrigation, municipal, industrial, and recreational purposes, and releases from Possum Kingdom Lake for these purposes contribute to the base flow of the Brazos River upstream from Lake Granbury. BFI values were computed for the two long-term USGS streamflow-gaging stations on this reach of the river, the Brazos Palo Pinto gage (fig. 20), and the Brazos Dennis gage (fig. 21).

The Brazos Palo Pinto gage (site BMS–5) is at river mile 667.3 upstream from the mouth, 20.0 mi downstream from Possum Kingdom Lake outflows. The Brazos Dennis gage (site BMS–6) is at river mile 589.8; 77.5 river miles separate the two gages (U.S. Geological Survey, 2001) (fig. 8). The annual BFI for the Brazos Palo Pinto gage (fig. 20) ranged from 0.04 in 1978 to 0.61 in 2009 with a median BFI of 0.19. The annual BFI for the Brazos Dennis gage (fig. 21) ranged from 0.06 in 1978 to 0.50 in 2009 with a median BFI of 0.27, indicating base flow composed a larger percentage of the total flow at the Brazos Dennis gage than at the Brazos Palo Pinto gage. About 90 percent of the time, the BFI at the Brazos Dennis gage is greater compared to the BFI at the Brazos Palo Pinto gage (fig. 22*A*) and plots to the left of the equal BFI line on fig. 22*B*. There does not appear to be an appreciable contribution to flow from aquifers in the drainage basin to the main stem of the Brazos River between the Brazos Palo Pinto gage and the Brazos Dennis gage (site BMS–6) (figs. 2 and 3). Because streamflow data collection at the Brazos Dennis gage began in May 1968, annual base-flow index data from the two gages could not be compared for 1966 through 1968.

Downstream from the Brazos Dennis gage (site BMS–6) is a reach of the Brazos River (extending from Lake Granbury at river mile 542.5; U.S. Geological Survey, 2009) downstream to Lake Whitney (formed by Whitney Dam at river mile 442.4; U.S. Geological Survey, 2009) (fig. 8). The annual base-flow indexes for two long-term USGS streamflow-gaging stations used to measure flows in this reach—one on the main stem of the Brazos River, the Brazos Glen Rose gage (site BMS–7; fig. 8, table 2) and one on tributary to the main stem, the Paluxy gage (site BMST–8 fig. 8, table 2)—are shown in figures 23 and 24, respectively.

The Paluxy River, which enters the Brazos River downstream from the Brazos Glen Rose gage, contributes to the base flow in this reach of the Brazos River. BFI values at the Brazos Glen Rose gage ranged from 0.04 in 1984 to 0.37 in 1972, with a median BFI of 0.19 (fig. 23). BFI values at the Paluxy gage were higher than those at the Brazos Glen Rose gage, ranging from 0.11 in 1989 to 0.75 in 1983 with a median BFI of 0.35 (fig. 24), indicating a larger amount of the streamflow at the Paluxy gage consisted of base flow compared to streamflow at the Brazos Glen Rose gage.

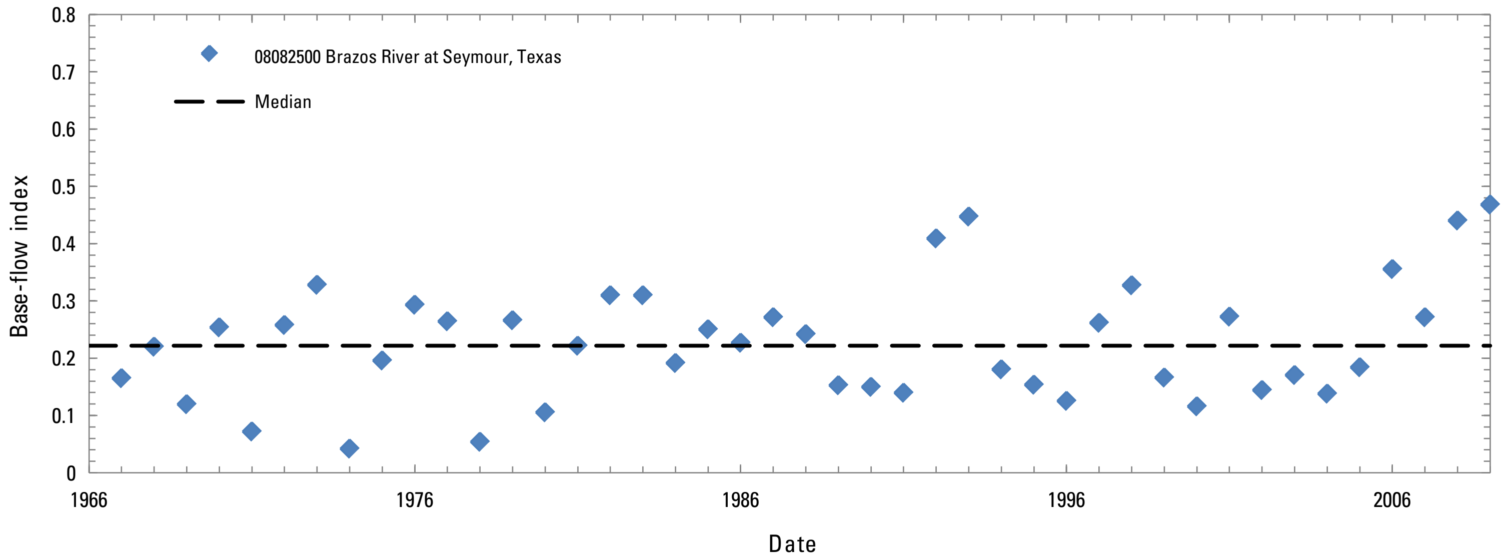


Figure 17. Annual base-flow index at U.S. Geological Survey streamflow-gaging station 08082500 Brazos River at Seymour, Texas, 1967–2009.

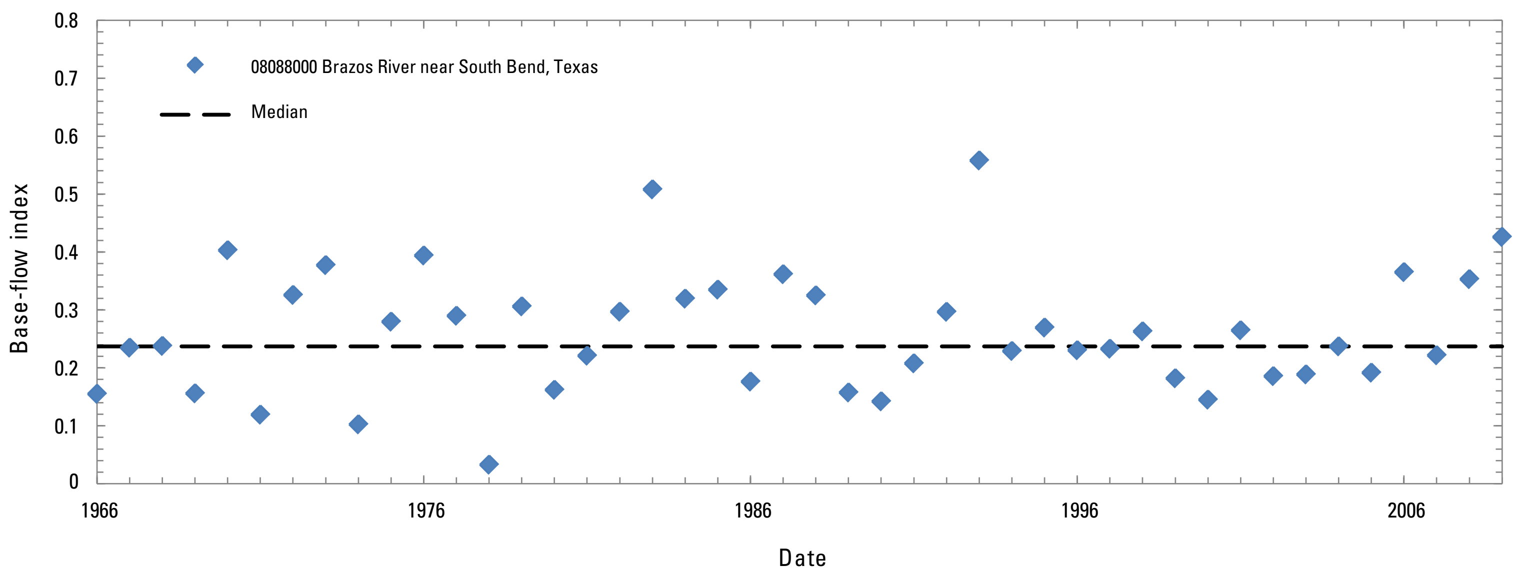


Figure 18. Annual base-flow index at U.S. Geological Survey streamflow-gaging station 08088000 Brazos River near South Bend, Texas, 1966–2009.

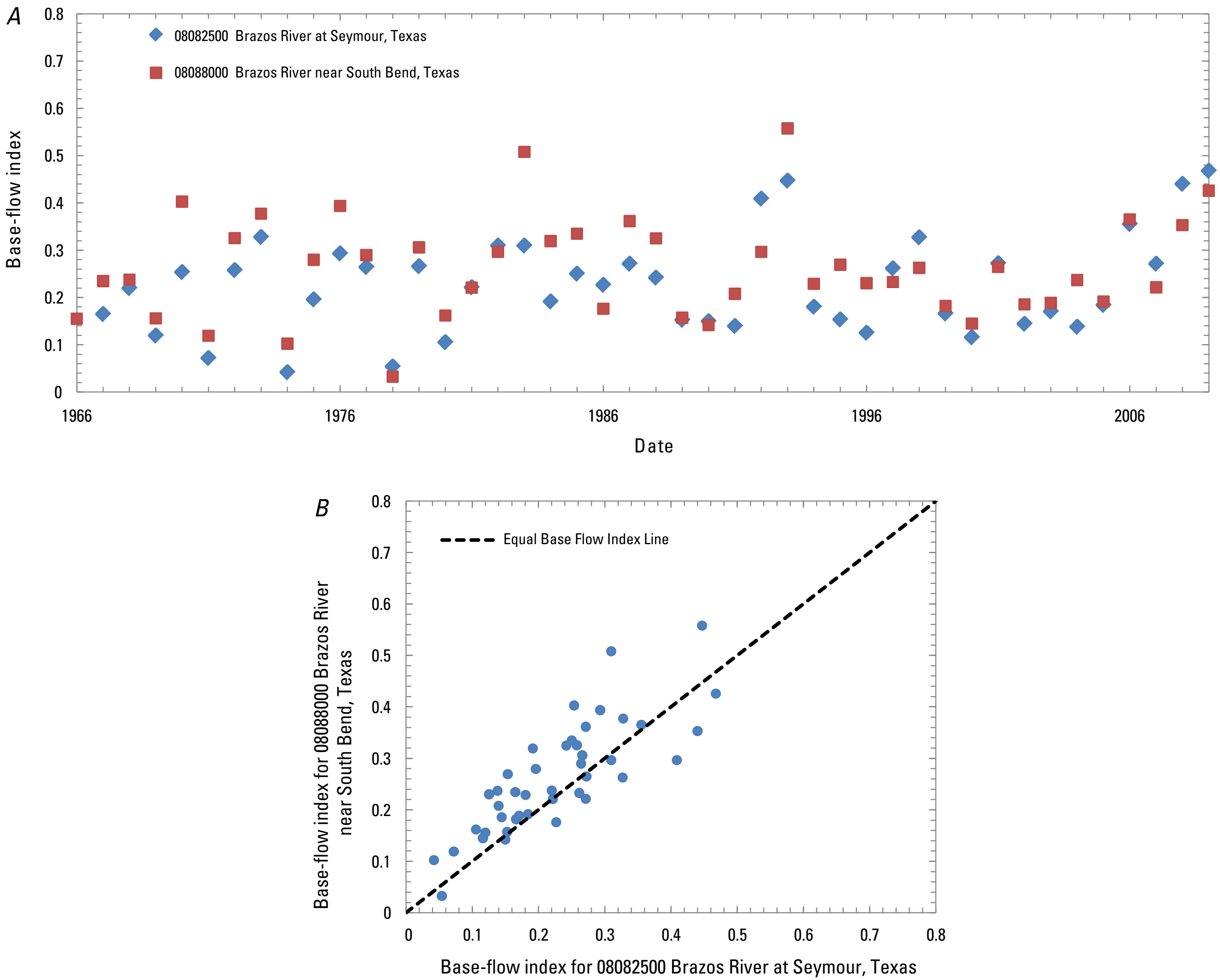


Figure 19. *A*, Time series of annual base-flow index and *B*, Relation between annual base-flow index for U.S. Geological Survey streamflow-gaging station 08082500 Brazos River at Seymour, Texas, and U.S. Geological Survey streamflow-gaging station 0808800 Brazos River near South Bend, Tex., 1967–2009.

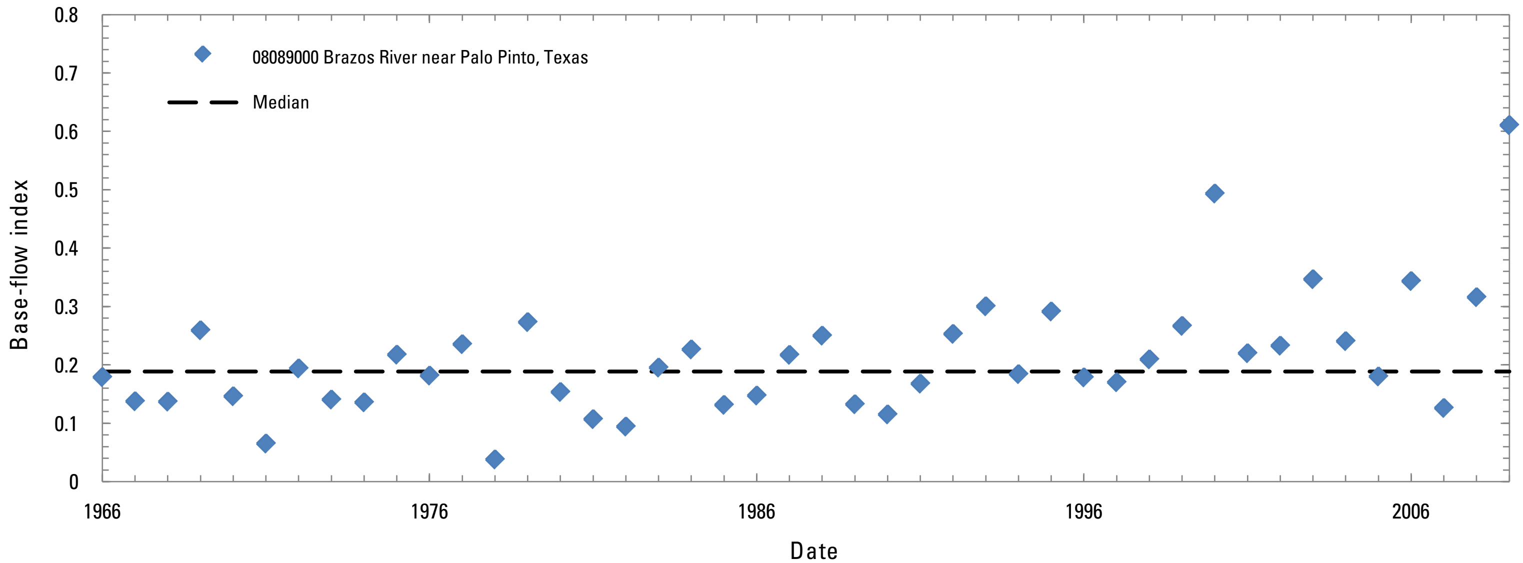


Figure 20. Annual base-flow index for U.S. Geological Survey streamflow-gaging station 08089000 Brazos River near Palo Pinto, Texas, 1966–2009.

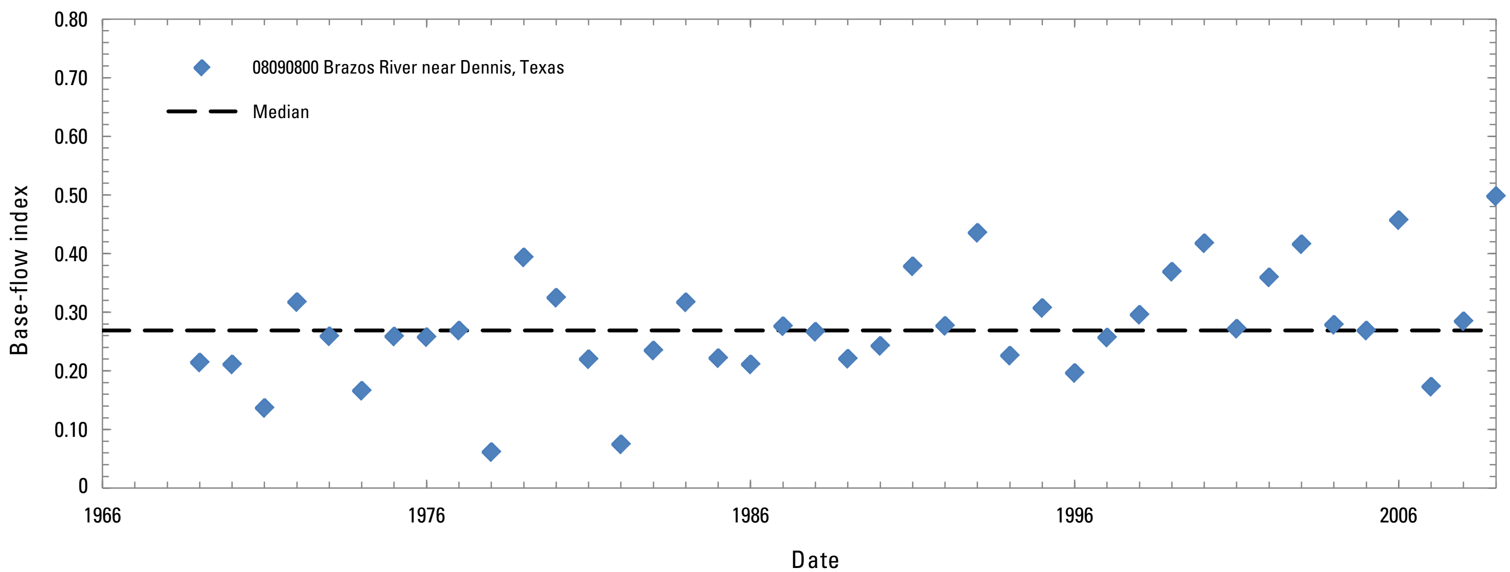


Figure 21. Annual base-flow index for U.S. Geological Survey streamflow-gaging station 08090800 Brazos River near Dennis, Texas, 1969–2009.

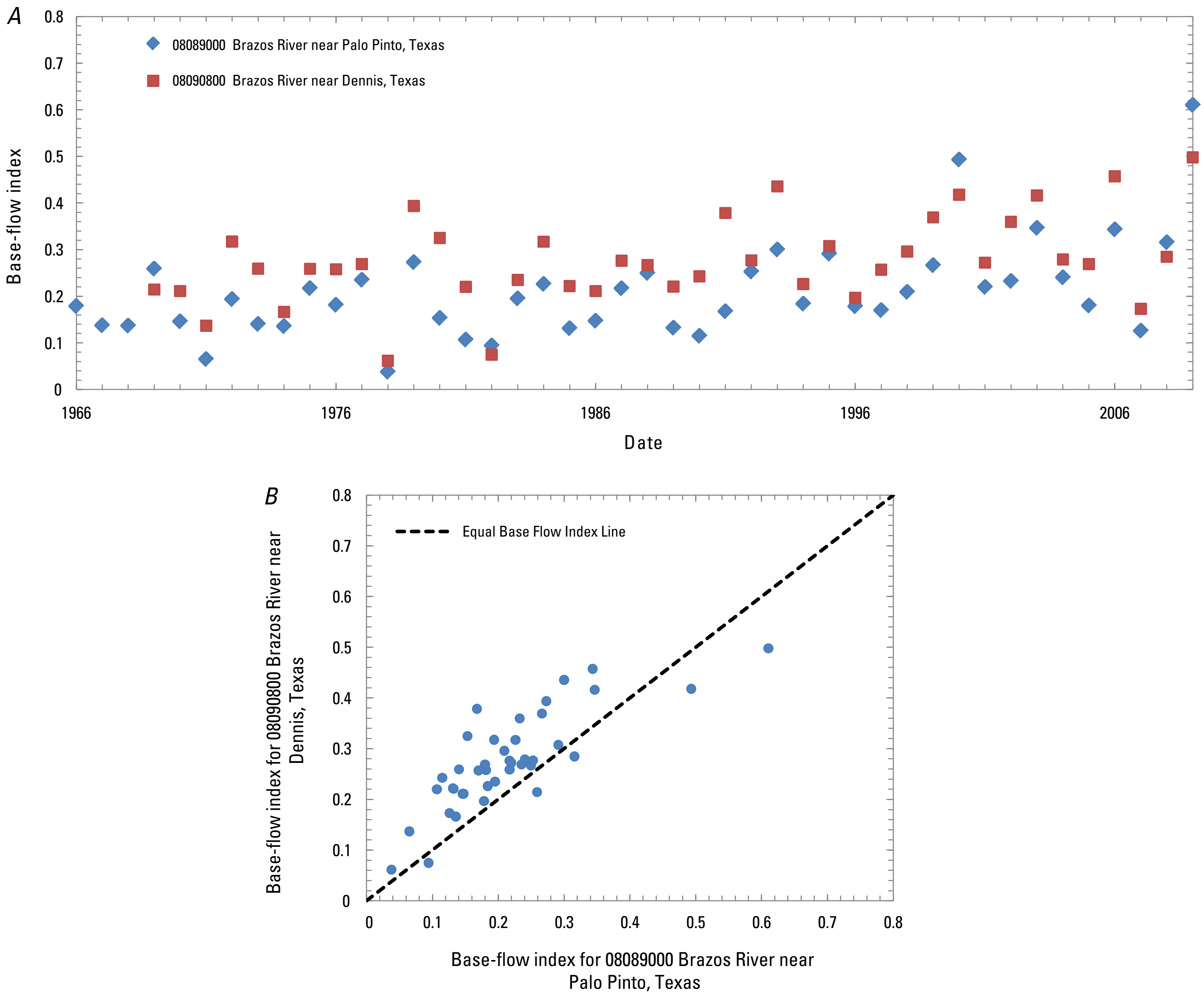


Figure 22. *A*, Time series of annual base-flow index and *B*, Relation between annual base-flow index for U.S. Geological Survey streamflow-gaging station 08089000 Brazos River near Palo Pinto, Texas, 1966–2009, and U.S. Geological Survey streamflow-gaging station 08090800 Brazos River near Dennis, Tex., 1969–2009.

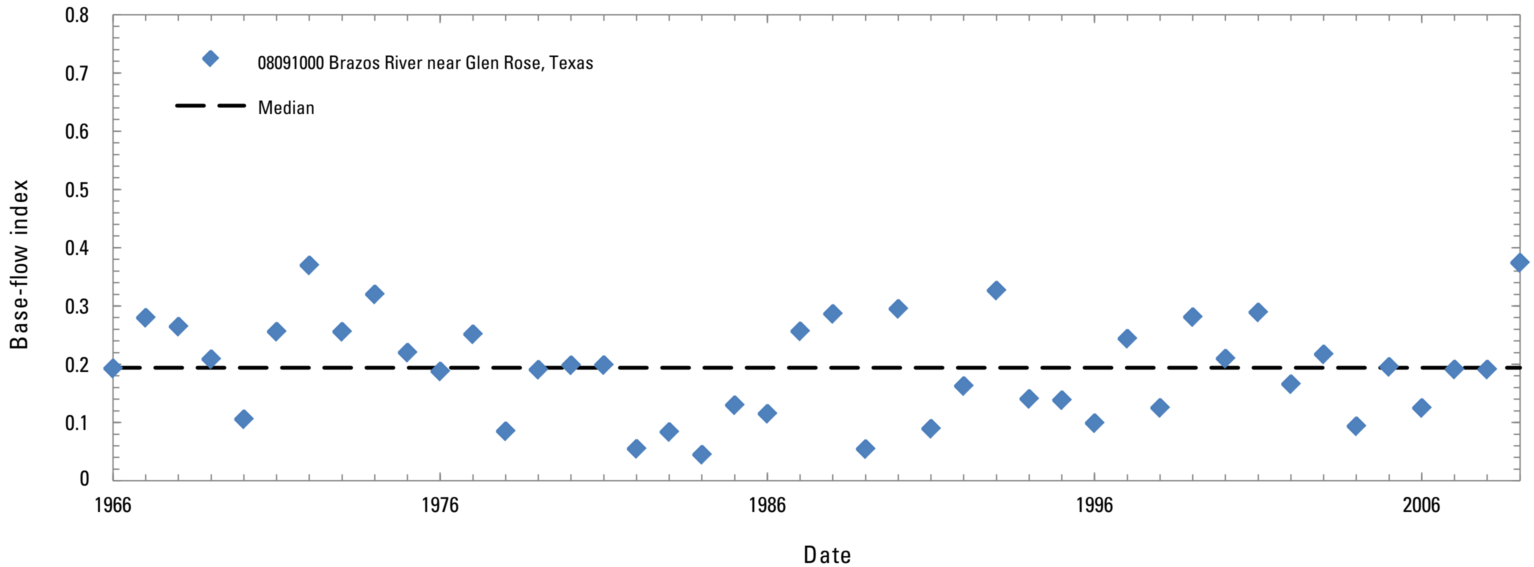


Figure 23. Annual base-flow index for U.S. Geological Survey streamflow-gaging station 08091000 Brazos River near Glen Rose, Texas, 1966–2009.

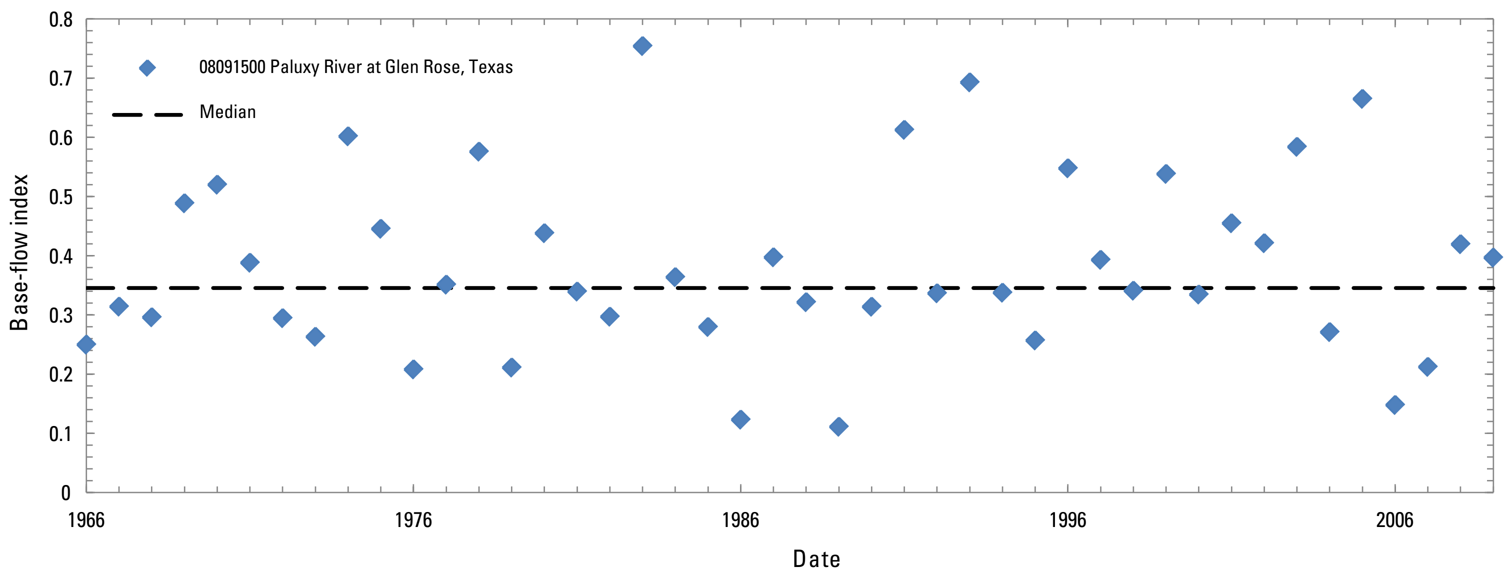


Figure 24. Annual base-flow index for U.S. Geological Survey streamflow-gaging station 08091500 Paluxy River at Glen Rose, Texas, 1966–2009.

Mann-Kendall trend analysis is a nonparametric test used for non-normally distributed data to analyze the changes in the median over time (Helsel and Hirsch, 2002). The Mann-Kendall trend analysis test was performed on annual BFI values (one value per year for the study period) for each long-term streamflow-gaging station, and a p-value of less than or equal to 0.05 ($p \leq 0.05$) was used to assign statistical significance to temporal trends in the BFI values. Upward (increasing) trends in BFI values were found at three USGS streamflow-gaging stations: the Double Mountain Fork Aspermont gage ($p<0.01$), the Brazos River Palo Pinto gage ($p<0.01$), and the Brazos River Dennis gage at each gage ($p<0.01$). Lake Alan Henry is upstream from the Double Mountain Fork Aspermont gage. Possum Kingdom Lake is upstream from the Brazos River Palo Pinto and Brazos River Dennis gages and Lake Granbury is downstream from the Brazos River Palo Pinto and Brazos River Dennis gages. As stated in the Hydrograph Separation and Trend Analysis section, judgment is needed to determine if upward trends in flow over time are caused by changes in reservoir releases or by increases in base flow. Flows at the Double Mountain Fork Aspermont, Brazos River Palo Pinto, and Brazos River Dennis gages are all regulated by reservoir releases, and additional analyses are needed before these streamflow trends can be characterized as indicative of changes in base flow over time. For example, releases from Lake Alan Henry, which was impounded in October 1993 (U.S. Geological Survey, 2001), might be increasing flow in the Double Mountain Fork at certain times of the year, giving the perception of increasing base flow in this stream.

Streamflow Gain and Loss Assessment

Streamflow gain and loss amounts were determined for each of the five subbasins of the upper Brazos River Basin (figs. 4-8). Streamflow gain and loss amounts were determined during the June and October surveys (June 6–9, 2010, and October 16–19, 2010) when no substantial rainfall (more than 0.10 in.) occurred and base-flow conditions were stable.

Salt Fork Brazos River Basin

Streamflow in the Salt Fork Brazos River Basin (fig. 4) was measured at eight sites during June 6–9, 2010, and nine sites during October 16–19, 2010. The USGS station names and corresponding site identifiers where streamflow was measured in the Salt Fork River Basin in June and October 2010 are as follows:

- 341643102013700 Running Water Draw at Farm Road 2884 near Edmonson, Tex. (site SF–1; fig. 4, table 2)
- 08080700 Running Water Draw at Plainview, Tex. (site SF–2; fig. 4, table 2)
- 335939101293500 Running Water Draw at Farm Road 784 at Sandhill, Tex. (site SF–3; fig. 4, table 2)
- 08080900 White River below falls near Crosbyton, Tex. (site SF–4; fig. 4, table 2)
- 332426101030700 White River at Ranch Road 261 near Spur, Tex. (site SF–5; fig. 4, table 2)
- 08080940 Salt Fork Brazos River at State Highway 208 near Clairemont, Tex. (site SF–6; fig. 4, table 2)
- 331608100420100 Duck Creek at Farm Road 2320 near Jayton, Tex. (site SF–7; fig. 4, table 2)
- 08082000 Salt Fork Aspermont gage (site SF–9; fig. 4 table 2)

In June 2010, no flow was observed at sites SF–1 through SF–3 or at site SF–5, and scant flow (0.06 ft^3/s) was measured at site SF–4. At site SF–6, flow of 1.06 ft^3/s was measured; this site is downstream from the White River Reservoir. The replicate streamflow measurement at site SF–6 was 0.85 ft^3/s. Flows of 1.56 ft^3/s were added to the main stem of the Salt Fork Brazos River from Duck Creek (as measured at site SF–7). Upstream from the confluence of the Salt Fork and Double Mountain Fork, 9.41 ft^3/s was measured on the Salt Fork at site SF–9. The specific-conductance value for the flow measured at SF–9 was 53,000 microsiemens per centimeter at 25 degrees Celsius (µS/cm), the largest specific-conductance value measured at any site during the study. The Salt Fork watershed is underlain by the Seymour and Ogallala major aquifers (fig. 2) and by the Edwards-Trinity (High Plains), Dockum, and Blaine minor aquifers (fig. 3).

Streamflow was measured during October 16–19, 2010, at the same eight sites on the Salt Fork Brazos River Basin measured during June 6–9, 2010, and one new site (USGS streamflow-gaging station 08081100 Croton Creek below Short Creek near Jayton, Tex. [site SF-8; fig. 4, table 2]). As in the June survey, no flow was again measured at the three farthest upstream sites, SF–1 through SF–3, and less than 0.10 ft^3/s was measured at site SF–4 upstream from White River Reservoir and at site SF–5 downstream from White River Reservoir. The specific-conductance value at site SF–4 was 1,060 µS/cm compared to 2,640 µS/cm at site SF–5. Streamflow of 2.86 ft^3/s and specific conductance of 22,940 µS/cm were measured at site SF–6 (upstream from the confluence of the Salt Fork with Duck Creek). On Duck Creek at site SF–7, streamflow of 1.75 ft^3/s and specific conductance of 3,630 µS/cm were measured. Streamflow at site SF–9 on the Salt Fork upstream from its confluence with Double Mountain Fork was 10.9 ft^3/s (the replicate measurement was 11.5 ft^3/s), and specific conductance was measured as 48,670 µS/cm. Small amounts of inflows with relatively high specific-conductance values (more than 20,000 µS/cm) occurred in the reach downstream from sites SF–7 and SF–8. The streamflow at site SF–8 was 0.10 ft^3/s and the specific conductance was 35,600 µS/cm. Croton Creek is a tributary to the reach of the Salt Fork between sites SF–6 and SF–9. From the data collected in the June and October surveys, a gaining reach in the Salt Fork Brazos River Basin began upstream from where Duck Creek flows into the Salt Fork Brazos River at site SF–6 and continued downstream past site SF–9 to the outlet of the basin. The Dockum, Blaine, and Seymour aquifers underlie the basin between sites SF–6 and SF–9 (figs. 2 and 3) and might contribute to the additional base flow measured downstream from site SF–6 to site SF–9.

Double Mountain Fork Brazos River Basin

Streamflow in the Double Mountain Fork Brazos River Basin was measured at eight sites during June 6–9, 2010, and again during October 16-19, 2010. The USGS station names and corresponding site identifiers where streamflow was measured in the Double Mountain Fork Brazos River Basin are as follows:

- 335325101593700 Blackwater Draw at Farm Road 179 near Abernathy, Tex. (site DMF-1; fig. 5, table 2)
- 334137102005900 Yellow House Draw at Farm Road 1294 at Shallowater, Tex. (site DMF–2; fig. 5, table 2)
- 333047101393300 North Fork Double Mountain Fork Brazos River at Farm Road 400 near Lubbock, Tex. (site DMF–3; fig. 5, table 2)
- 331909101232900 North Fork Double Mountain Fork Brazos River at Farm Road 207 near Post, Tex. (site DMF–4; fig. 5, table 2)
- 08079600 Double Mountain Fork Brazos River at Justiceburg, Tex. (site DMF-5, fig. 5, table 2)
- 08080000 Double Mountain Fork Brazos River near Rotan, Tex. (site DMF-6, fig. 5, table 2)
- 08080500 Double Mountain Fork Aspermont gage (site DMF-7, fig. 5, table 2)
- 331116099573600 Double Mountain Fork Brazos River at Highway 380 near Rule, Tex. (site DMF-8, fig. 5, table 2)

The two sites west of Lubbock (DMF–1 and 2) had no measurable streamflow during the June survey; these are the two farthest upstream sites on the North Fork Double Mountain Fork. Consecutive streamflow measurements on June 7, 2010, at site DMF–3, on the North Fork Double Mountain Fork Brazos River (hereinafter North Fork Double Mountain Fork) measured the flow as 2.83 ft^3/s (upstream from Farm Road 400) and 6.90 ft^3/s (downstream from Farm Road 400). The City of Lubbock discharges groundwater to the North Fork Double Mountain Fork for municipal purposes upstream from site DMF–3; these discharges from the City of Lubbock's well field (fig. 5) were consistently 3.1 ft^3/s in the reach downstream from the City of Lubbock wastewater-treatment plant and upstream from Farm Road 400 (Aubrey A. Spear, Lubbock Director of Water Resources, oral commun., January 24, 2011), and account for the measured streamflow of 2.83 ft^3/s on June 7 upstream from Farm Road 400 because the stream is normally dry upstream from these municipal discharges. Discharges of treated effluent from the Lubbock wastewater-treatment plant occur at Farm Road 400 (fig. 5), and range from 0 to 14 ft^3/s; as much as 10.8 ft^3/s of this effluent might be diverted before being discharged at Farm Road 400 for use in a nearby powerplant (Aubrey A. Spear, Lubbock Director of Water Resources, oral commun., January 24, 2011). Discharges of treated effluent at site DMF–3 account for the additional 4.17 ft^3/s measured downstream from Farm Road 400 at site DMF–3 on June 7, 2010. Streamflow measured at site DMF–4 north of Post, Tex., was 2.78 ft^3/s, indicating a losing reach between sites DMF–3 and DMF–4. During the June survey, no flow was measured at site DMF–5, near Justiceburg, on the South Fork Double Mountain Fork Brazos River (South Fork). The flow during the June survey at site DMF–6 was 36.8 ft^3/s. Site DMF–6 is on the Double Mountain Fork near Rotan, downstream from the confluence of the North and South Forks of the Double Mountain Fork, and downstream from the mapped areal extent of the Dockum aquifer (fig. 3). The flow at site DMF–6 represents a substantial gain compared to the 2.78 ft^3/s measured at the closest upstream site, DMF–4. Flow continued to increase downstream from site DMF–6; the flow at site DMF–7 was 43.3 ft^3/s (replicate measurement was 41.8 ft^3/s). Specific-conductance values of 5,690 and 5,670 µS/cm were measured at sites DMF–6 and DMF–7, respectively, representing a large increase compared to the 2,000 µS/cm measured at upstream site DMF–3, possibly because of contributions of relatively saline groundwater to the base flow at sites DMF–6 and DMF–7. Although measured flow increased at least 5 ft^3/s from the 36.8 ft^3/s at site DMF–6 to the 41.8 and 43.3 ft^3/s measured at site DMF–7, specific-conductance values were essentially the same at sites DMF–6 and DMF–7, indicating the same likely source of water to the stream as the one accounting for the increase in streamflow between sites DMF–4 and DMF–6. Measured flow increased approximately 10 ft^3/s during the June survey between site DMF–7 and site DMF–8 near Rule, Tex., upstream from the confluence of the Double Mountain Fork and the Salt Fork; specific-conductance values decreased from 5,670 µS/cm to 4,400 µS/cm, indicating additional base flow consisting of somewhat less saline water was added to the Double Mountain Fork between sites DMF–7 and DMF–8.

The eight sites in the Double Mountain Fork Basin measured during June 6–9, 2010, were measured again during October 16-19, 2010 (table 2). No-flow conditions were once again observed at the two farthest upstream sites on the North Fork Double Mountain Fork west of Lubbock, sites DMF–1 and 2. Streamflow entering site DMF–3 was 2.28 ft^3/s

and leaving site DMF–3 was 7.86 ft^3/s with a mean specific conductance of 2,030 µS/cm. Streamflow on the North Fork Double Mountain Fork at site DMF–4 was 3.17 ft^3/s, with a specific conductance of 1,110 µS/cm, corroborating the losing reach observed between sites DMF–3 and DMF–4 during the June survey. A gaining reach in the North Fork Double Mountain Fork from site DMF–4 near Post, Tex., downstream to site DMF–8 near the outlet of the basin was identified from the June and October survey results. A small amount of streamflow, 0.20 ft^3/s, was measured at site DMF–5 during the October survey on the South Fork Double Mountain Fork upstream from its confluence with the North Fork Double Mountain Fork (specific conductance of 14,190 µS/cm), indicating the increase in streamflow from the 3.17 ft^3/s measured at site DMF–4 to the 22.8 ft^3/s measured at site DMF–6 (with a replicate measurement of 23.5 ft^3/s) might consist of inputs from the Dockum aquifer, which underlies part of this reach. Specific conductance at site DMF–6 during the October survey was 7,950 µS/cm. Streamflow continued to increase downstream from site DMF–6 to site DMF–7 (27.3 ft^3/s) and site DMF–8 (36.5 ft^3/s). Specific conductance remained in a range from 7,000 to 8,000 µS/cm at sites DMF–7 and DMF–8. Similar to the June survey results, these results indicate that the increase in base flow observed beginning at site DMF–6 downstream through site DMF–8 might originate from the same source, possibly the Blaine aquifer which underlies this reach. In addition to the Blaine aquifer, the Double Mountain Fork watershed also is underlain by the Seymour, Ogallala, Edwards-Trinity (High Plains), and Dockum aquifers (figs. 2–3), and combinations of waters from these aquifers might contribute to the gains in streamflow observed in the June and October surveys in the Double Mountain Fork Basin.

Clear Fork Brazos River Basin

Nineteen sites (CF–1–19) were measured in the Clear Fork Brazos River Basin (fig. 6) during June 6–9, 2010 (table 2). The USGS station names and corresponding site identifiers where streamflow was measured in the Clear Fork Brazos River Basin are as follows:

- 08083100 Clear Fork Brazos River near Roby, Tex. (site CF-1, fig. 6, table 2)
- 323720100071200 Sweetwater Creek at Farm Road 1812 near Noodle, Tex. (site CF-2, fig. 6, table 2)
- 08083230 Clear Fork Brazos River near Noodle, Tex. (CF-3, fig. 6, table 2)
- 323635099495800 Clear Fork Brazos River at County Road 509 at Hawley, Tex. (site CF-4, fig. 6, table 2)
- 08083245 Mulberry Creek near Hawley, Tex. (site CF-5, fig. 6, table 2)
- 08084000 Clear Fork Brazos River at Nugent, Tex. (site CF-6, fig. 6, table 2)
- 08084100 Deadman Creek near Nugent, Tex. (site CF-7, fig. 6, table 2)
- 324701099362000 Clear Fork Brazos River at Highway 6 at Lueders, Tex. (site CF-8, fig. 6, table 2)
- 325732099273200 Clear Fork Brazos River near Lueders, Tex. (site CF-9, fig. 6, table 2)
- 08084800 California Creek near Stamford, Tex. (site CF-10, fig. 6, table 2)
- 330433099333300 Paint Creek below Lake Stamford near Haskell, Tex. (site CF-11, fig. 6, table 2)
- 08085500 Clear Fork Brazos River at Fort Griffin, Tex. (site CF-12, fig. 6, table 2)
- 322606099230400 Hubbard Creek at Highway 283 near Baird, Tex. (site CF-13, fig. 6, table 2)
- 08086100 Hubbard Creek near Albany, Tex. (site CF-14, fig. 6, table 2)
- 322424098591200 Sandy Creek at Highway 6 at Cisco, Tex. (site CF-15, fig. 6, table 2)
- 08086300 Big Sandy Creek near Breckenridge, Tex. (site CF-16, fig. 6, table 2)
- 325310098543200 Hubbard Creek at Farm Road 578 at Crystal Falls, Tex. (site CF-17, fig. 6, table 2
- 324812098535800 Gonzales Creek near Breckenridge, Tex. (site CF-18, fig. 6, table 2)
- 325406098535700 Clear Fork Brazos River at Farm Road 578 at Crystal Falls, Tex. (site CF-19, fig. 6, table 2)

During the June survey, streamflow at the westernmost and farthest upstream site in the Clear Fork Basin, site CF–1, was 0.77 ft^3/s, and the specific conductance was 11,200 µS/cm. Streamflow in Sweetwater Creek at Farm Road 1812 near Noodle (site CF–2), just upstream from the confluence of Sweetwater Creek and Clear Fork, was 0.85 ft^3/s and the specific conductance was 5,000 µS/cm. Streamflow of 5.15 ft^3/s was measured at site CF–3 (specific conductance at site CF–3 was 9,030 µS/cm, an intermediate value compared to the larger and smaller specific-conductance values measured at sites CF–1 and CF–2, respectively). During the June survey, streamflow increased between sites CF–1 and CF–3; groundwater inflows from the Seymour aquifer or other groundwater sources might account for this gain in streamflow (fig. 3). No gain in streamflow was realized between sites CF–3 (5.15 ft^3/s) and CF–4 (4.39 ft^3/s), and there were no measureable inflows to the Clear Fork from Mulberry

Creek (as measured at site CF–5). Streamflow at site CF–6, Clear Fork Brazos at Nugent (composed of streamflow from site CF–5 and releases from Lake Fort Phantom Hill) was 5.64 ft^3/s, representing a small gain of 1.25 ft^3/s compared to streamflow at upstream site CF–4. Streamflow measured at site CF–7 on Deadman Creek was 19.8 ft^3/s, with a specific conductance of 1,630 µS/cm. Streamflow in Deadman Creek consists primarily of treated effluent from the City of Abilene; during the June survey, average daily releases ranged from a minimum of 10.5 ft^3/s on June 7 to a maximum of 17.2 ft^3/s on June 8 (Mickey Chaney, Wastewater Superintendent, City of Abilene, written commun., February 22, 2011). Despite receiving flow of 5.64 ft^3/s from site CF–6 and 19.8 ft^3/s from site CF–7, flow at site CF–8 was the same as the flow at site CF–7 (19.8 ft^3/s), indicating losing reaches from site CF–8 to these upstream sites (fig. 6). The reach of the Clear Fork Brazos River Basin from sites CF–4 through CF–8 is probably more affected by discharges of treated effluent from Abilene, Tex., and less by contributions from the Seymour aquifer (fig. 2).

Sites CF–10 on California Creek, a tributary to Paint Creek, and CF–11, Paint Creek downstream from Lake Stamford, measure the flows that combine to form Clear Fork Brazos River upstream from site CF–9. Streamflow at site CF–10 was 3.61 ft^3/s, and streamflow at site CF–11, downstream from Lake Stamford, was 5.15 ft^3/s. Streamflow at site CF–9 was 20.3 ft^3/s with a specific conductance of 2,120 µS/cm, which similar to the streamflow and specific-conductance measured at CF–8, except specific conductance at site CF–8 was 710 µS/cm higher compared to site CF–9. Streamflow measured at site CF–12 was 26.1 ft^3/s, reflecting inflows from Paint Creek (8.76 ft^3/s, which is the combined flow from sites CF-10, 3.61 ft^3/s, and CF-11, 5.15 ft^3/s) and Clear Fork Brazos River at site CF–9 (20.3 ft^3/s); comparing the combined flows measured at sites CF–11 and CF–9 with the flow measured at site CF–12, there was not any substantial increase or decrease in the flow of the Clear Fork Brazos River from groundwater inputs. The reach of the Clear Fork Brazos River between CF-8 to the confluence with the Brazos River near South Bend does not overlie any of the major or minor aquifers (figs. 2 and 3). Specific conductance at site CF–12 was 2,300 µS/cm. There were no substantial measured inflows to Clear Fork Brazos River between sites CF–12 (26.1 ft^3/s, 2,300 µS/cm) and CF–19 (26.3 ft^3/s, 1,980 µS/cm), which is upstream from the confluence of Clear Fork Brazos River with Hubbard Creek.

The Hubbard Creek drainage basin makes up the eastern third of the Clear Fork Brazos River drainage, joining the Clear Fork Brazos River north of Breckenridge, Tex., and sites CF–13 through CF–18 are within its boundaries. Sites CF–13 and CF–14, on Hubbard Creek upstream from Hubbard Creek Reservoir, had no flow. Sites CF–15 and CF–16, on Sandy Creek and Big Sandy Creek, respectively, had less than 1 ft^3/s. Site CF–18, which sometimes carries treated effluent from the City of Breckenridge, and site CF–17, just upstream from the confluence of Hubbard Creek with Clear Fork Brazos River, had no flow, indicating streamflow in Clear Fork Brazos River upstream from its confluence with the main stem of the Brazos River are mostly from the western part of the drainage basin.

The same 19 sites measured in the Clear Fork Brazos River Basin (fig. 6) during June 2010 (sites CF–1 through CF–19) (table 2) were measured again in October 2010. Similar patterns in streamflow amounts were observed, with generally larger amounts of streamflow measured during the October survey compared to the June survey. From the June and October surveys, a gaining reach was identified in the Clear Fork Brazos River from near Roby, Tex., downstream to near Noodle, Tex. (flows of 0.77 and 1.04 ft^3/s were measured at site CF–1 in the June and October surveys, respectively, and flows of 5.15 and 6.75 ft^3/s were measured at site CF–3 in the June and October surveys, respectively). Between sites CF–3 and CF–4, an increase of 4.05 ft^3/s was measured during October 2010 (about a 60 percent increase in flow) compared to a decrease of 0.76 ft^3/s during the June survey for the same stream reach (about a 15 percent decrease in flow). Upstream from site CF–7, streamflow in Deadman Creek was composed of treated effluent from the City of Abilene ranging from 11.1 ft^3/s to 13.0 ft^3/s during October 16–19, 2010 (Mickey Chaney, Wastewater Superintendent, City of Abilene, written commun., Feb. 22, 2011). A second gaining reach was observed in the Clear Fork Brazos River from Hawley, Tex., downstream to Nugent, Tex. As during the June survey, larger flows were measured at downstream site CF–6 compared to upstream site CF–4 (flows of 4.39 and 10.8 ft^3/s were measured at site CF–4 in June and October respectively, and flows of 5.64 and 14.6 ft^3/s were measured at site CF–6 in the June and October surveys, respectively). In the October survey, a larger amount of streamflow was measured at site CF–8 compared to site CF–6, but the combined flows from sites CF–6 (14.6 ft^3/s) and CF–7 (14.1 ft^3/s) of 28.7 ft^3/s in the October survey were slightly more than the streamflow measured at site CF–8 (26.5 ft^3/s)—indicating that the stream reaches between sites CF–6 and CF–8 and between sites CF–7 and CF–8 were losing reaches. At site CF–9, 27.1 ft^3/s was measured in the October survey, compared to 20.3 ft^3/s measured at this site in the June survey. At site CF–19, the farthest downstream site in the basin, 29.9 ft^3/s was measured during the October synoptic measurements (a replicate measurement of 31.3 ft^3/s was within 5 percent), compared to 26.3 ft^3/s measured during the June survey. Specific-conductance values measured during June at site CF–9 were essentially the same as those measured during October (2,120 µS/cm in June, and 2,160 µS/cm in October) and were much higher at site CF–19 in June (1,980 µS/cm) compared to October (653 µS/cm).

North Bosque River Basin

Ten sites (NB–1–10) were measured in the North Bosque River Basin (fig. 7) during June 6–9, 2010 (table 2). The USGS station names and corresponding site identifiers where streamflow was measured in the North Bosque River Basin are as follows:

- 321513098133100 North Fork North Bosque River at State Route 108 near Stephenville, Tex. (site NB-1, fig. 7, table 2)
- 08094800 North Bosque River at Hico, Tex. (site NB–2, fig. 7, table 2)
- 315839097534200 North Bosque River at Highway 6 near Iredell, Tex. (site NB-3, fig. 7, table 2
- 320106097465700 East Bosque River at Farm Road 927 near Walnut Springs, Tex. (site NB–4, fig. 7, table 2)
- 315510097394300 North Bosque River at Highway 22 at Meridian, Tex. (site NB–5, fig. 7, table 2)
- 314842097364100 Meridian Creek at Highway 6 near Clifton, Tex. (site NB–6, fig. 7, table 2)
- 08095000 North Bosque River near Clifton, Tex. (site NB-7, fig. 7, table 2)
- 314136097320700 Neils Creek at Highway 6 near Valley Mills, Tex. (site NB-8, fig. 7, table 2)
- 08095200 North Bosque River at Valley Mills, Tex. (site NB-9, fig. 7, table 2)
- 313830097220100 North Bosque River near China Springs, Tex. (site NB-10, fig. 7, table 2)

No flow was measured during the June survey at the most upstream site on the North Fork North Bosque River, site NB–1, north of Stephenville, Tex. Streamflow at site NB–2, just upstream from Hico, Tex., was 11.7 ft^3/s and the specific conductance was 414 µS/cm. The basin from site NB–1 to site NB–2 overlies the Trinity aquifer (fig. 2), which might be a source of some of the base flow to this reach; treated effluent from Stephenville also is added to the North Bosque River upstream from site NB–2. The Stephenville wastewater-treatment plant has a capacity of 3 million gallons per day (4.64 ft^3/s) but typically processes 1.5 million gallons per day (2.32 ft^3/s) (City of Stephenville, 2009). The streamflow at site NB–3, North Bosque River near Iredell, Tex., was 14.2 ft^3/s and the specific conductance was 292 µS/cm. Streamflow increased to 26.1 ft^3/s at the next site downstream on the main stem of North Bosque River, site NB–5 (specific conductance was not measured at site NB–5 during the June survey). At site NB–4 on the East Bosque River, the largest tributary to the North Bosque River in the reach between Iredell and Meridian, measured streamflow was less than 1 ft^3/s, indicating groundwater from the underlying Trinity aquifer and not inflow from East Bosque River was likely the main source of streamflow to the main channel of the North Bosque River. Gains in streamflow in the downstream direction on the main channel to NB–5 were probably from a combination of groundwater sources and a small amount of treated effluent (less than 0.70 ft^3/s) from Meridian, Tex. (City of Meridian, 2010). Streamflow at site NB–7 on the main stem of the North Bosque was 47.9 ft^3/s. Flow at site NB–7includes the 10.3 ft^3/s (8.37 ft^3/s replicate measurement) of tributary inflow from Meridian Creek (measured at site NB–6) and treated effluent from the Clifton wastewater-treatment plant. The Clifton wastewater-treatment plant has a capacity of 650,000 gallons per day (1.01 ft^3/s) but typically processes about 261,000 gallons per day (0.40 ft^3/s); batches of treated effluent are released about every 2 hours when holding tanks reach capacity (Robin Harvey, Public Works Director, City of Clifton, written commun., December 6, 2011). An inflow of 18.2 ft^3/s was measured at site NB–8 on the tributary Neils Creek, which, when added to the 47.9 ft^3/s measured at site NB–7, yields 66.1 ft^3/s —an amount that is almost 20 ft^3/s less than the measured streamflow at downstream site NB–9 at Valley Mills (86.7 ft^3/s). Downstream from site NB–9, streamflow increased from 86.7 to 103 ft^3/s at site NB–10 (107 ft^3/s replicate measurement), upstream from any possible backwater from Waco Lake. The difference between the combined flows from sites NB–7 and NB–8 compared to the flow at site NB–9, and the increase in flow from site NB–9 to NB–10 indicate a gaining reach, and the gains in streamflow are likely caused by groundwater inflows. Specific-conductance values decreased slightly from 514 µS/cm at site NB–9 to 464 µS/cm at site NB–10.

The same 10 sites measured in the North Bosque River Basin in June 2010 were measured in October 2010 (NB–1 through NB–10) (table 2). Streamflow amounts generally were much less during the October survey but still followed the patterns observed in the June survey. As in June, no flow was observed at site NB–1 in October. Streamflow at site NB–2 during October was 4.16 ft^3/s, compared to 11.7 ft^3/s during June. Streamflow at site NB–7 (near Clifton) during October was 17.6 ft^3/s compared to 47.9 ft^3/s in June. Streamflow at site NB–10 was 41.4 ft^3/s in October compared to 103 ft^3/s in June. Flow in the tributaries to the North Bosque showed similar patterns of more flow in June compared to October at sites on the main stem, with streamflow at site NB–8 on Neils Creek decreasing from 18.2 ft^3/s (June survey) to 6.84 ft^3/s (October survey). Although the downstream gains were smaller in October compared to June, the pattern of increasing flow in the downstream direction was similar in each survey. Specific-conductance values measured at sites NB–2 and NB–3 increased by about 100 µS/cm at each site in October compared to June, possibly because dissolved solids were more concentrated in the smaller streamflow amounts measured in October compared to June. However, specific-conductance values in the lower North Bosque reach (measured at sites NB–6 through NB–10) did not differ appreciably between the June and October surveys, with specific-conductance values generally in the 400–550 µS/cm range during both June and October. Specific conductance for North Bosque River Basin ranged from 292–522 µS/cm for June and 429–539 µS/cm for October, indicating there was likely no change in the source of the additional streamflow. Based on the June and October survey results, most of the North Bosque River was characterized as gaining streamflow, beginning with no flow north of Stephenville, Tex., increasing downstream to more than 100 ft^3/s and 41.4 ft^3/s near China Springs, Tex., in the June and October surveys, respectively (flow during the June survey at site NB–10 was 103 ft^3/s [replicate measurement was 107 ft^3/s] and the flow at site NB–10 was 41.4 ft^3/s during the October survey).

Brazos River Basin (main stem)

Streamflow in Brazos River Basin from west of Knox City, Tex., to north of Waco (fig. 8) was measured at 8 sites on the main stem of the Brazos River and 14 sites on tributaries to the main stem of the Brazos River. The USGS station names and corresponding site identifiers where streamflow was measured in the Brazos River Basin are as follows:

- 332533099544100 Brazos River at Highway 143/222 near Knox City, Tex. (site BMS-1; fig. 8, table 2)
- 08082500 Brazos River at Seymour, Tex. (site BMS-2; fig. 8, table 2)
- 08088000 Brazos River near South Bend, Tex. (site BMS-3; fig. 8, table 2)
- 08088610 Brazos River near Graford, Tex. (site BMS-4; fig. 8, table 2)
- 08089000 Brazos River near Palo Pinto, Tex. (site BMS-5; fig. 8, table 2
- 08090800 Brazos River near Dennis, Tex. (site BMS-6; fig. 8, table 2)
- 08091000 Brazos River near Glen Rose, Tex. (site BMS-7; fig. 8, table 2)
- 08093100 Brazos River near Aquilla, Tex. (site BMS-8; fig. 8, table 2)
- 333323099263000 Lake Creek at Farm Road 2070 near Seymour, Tex. (site BMST-1; fig. 8, table 2)
- 332744099144300 Millers Creek at Highway 183/283 near Seymour, Tex. (site BMST-2; fig. 8, table 2)
- 08088100 Salt Creek at Olney, Tex. (site BMST-3; fig. 8, table 2)
- 331140098390300 Salt Creek at Highway 380 near Newcastle, Tex. (site BMST-4; fig. 8, table 2)
- 323932098072300 Palo Pinto Creek at Farm Road 129 near New Salem, Tex. (site BMST-5; fig. 8, table 2)
- 324456098025900 Rock Creek at Farm Road 3028 near Sturdivant, Tex. (site BMST-6; fig. 8, table 2)
- 324151097581900 Grindstone Creek at I-20 near Brock Junction, Tex. (site BMST-7; fig. 8, table 2)
- 08091500 Paluxy River at Glen Rose, Tex. (site BMST-8; fig. 8, table 2)
- 08091750 Squaw Creek near Glen Rose, Tex. (site BMST-9; fig. 8, table 2)
- 08092000 Nolan River at Blum, Tex. (site BMST-10; fig. 8, table 2)
- 314220097174100 Childress Creek at Farm Road 2490 near Waco, Tex. (site BMST-11; fig. 8, table 2)
- 08093360 Aquilla Creek above Aquilla, Tex. (site BMST-12; fig. 8, table 2)
- 315300097114200 Cobb Creek near Aquilla, Tex. (site BMST-13; fig. 8, table 2)
- 08093560 Aquilla Creek at Farm Road 1858 near Ross, Tex. (site BMST-14; fig. 8, table 2)

With the exception of site BMST–1, streamflow was measured at all of the main-stem Brazos River Basin sites in June and October 2010. Streamflow was measured during the October survey at site BMST–1 but not during the June survey. Specific conductance was measured at all main-stem Brazos River Basin sites with measurable flow in June and October with the following exceptions: sites BMS–6 and BMS–7 (October only), BMST–1 (October only), BMST–2 (no measurements), BMST–6 through BMST-10 (October only), BMST-12 (October only), and BMST- 13 (no measurements).

Because of the number of reservoirs in this part of the Brazos River Basin, flow in individual reaches of the Brazos River separated by Possum Kingdom Lake, Lake Granbury, and Lake Whitney is described. Streamflow in the reach from the confluence of the Salt and Double Mountain Forks to upstream from Possum Kingdom Lake, including streamflow from the Clear Fork Brazos River, which enters the Brazos River near South Bend, was quantified from data collected at sites BMS–1 through BMS–3 and sites BMST–1 through BMST–4. Streamflow at site BMS–1 in the June survey was 86.2 ft^3/s; this site is downstream from the confluence of the Salt Fork and the Double Mountain Fork. The flow at site BMS–1 during the June survey was 39 percent larger than the combined flows measured at sites SF–9 and DMF–8 during the same survey (61.91 ft^3/s). This increase in streamflow might be from groundwater inflows from the Seymour (fig. 2) and Blaine (fig. 3) aquifers. Streamflow continued to increase between sites BMS–1 (near Knox City, Tex.) and BMS–2 (at Seymour, Tex.); flow of 142 ft^3/s was measured at site BMS–2. Millers Creek provided no tributary inflow to the Brazos River (there was no flow at site BMST–2). Specific-conductance values measured at sites BMS–1 and BMS–2 (15,070 and 16,630 µS/cm, respectively) were fairly consistent, indicating there was likely no change in the source of the additional streamflow, just an increase in quantity. Streamflow at site BMS–3 was 163 ft^3/s; this site is upstream from Possum Kingdom Lake and downstream from the confluence of the Clear Fork and the main stem Brazos River. The flow at site BMS–3 was 3 percent smaller than the combined flows measured at sites BMS–2 and CF–19, indicating that an appreciable loss or gain of streamflow did not occur between sites BMS–2 and BMS–3. Specific conductance of the streamflow at site BMS–3 was 8,940 µS/cm, a large decrease from site BMS–2 reflecting the addition of water with lower specific conductance at site CF–19 on the Clear Fork (1,980 µS/cm) to the streamflow in the main stem. Sites BMST–3 and BMST–4 are on Salt Creek, upstream from Lake Graham (fig. 8). Flows of 0.06 and 12.8 ft^3/s were measured at sites BMST–3 and BMST–4, respectively, indicating a gaining reach. Streamflow from Salt Creek is usually stored in Lake Graham; releases downstream to the Brazos River from Lake Graham only occur during rare periods of abundant runoff. Downstream from Lake Graham, some of the flow in Salt Creek is treated effluent from Graham, Tex., which operates a wastewater-treatment plant that is permitted to treat as much as 3.2 ft^3/s (City of Graham, 2011). Flow in Salt Creek downstream from Lake Graham to Possum Kingdom Lake was not measured.

Analysis of data collected during the October gain-loss measurements showed similar results although at lower levels of streamflow. Streamflow was 61.9 ft^3/s during the October survey at site BMS–1, which was 28 percent less than the streamflow of 86.2 ft^3/s measured at this site in June. From site BMS–1, streamflow during the October survey increased in the downstream direction to 93.7 ft^3/s at site BMS–2 and to 127 ft^3/s at site BMS–3. Streamflows during the October survey at site BMS–2 (142 ft^3/s) and site BMS–3 (163 ft^3/s) were 34 and 22 percent less, respectively, compared to the streamflows measured at these sites during the June survey. In the October survey, specific-conductance values measured at the three main-stem sites (BMS–1, BMS-2, and BMS–3), were 17,550, 14,680, and 8,600 µS/cm, respectively, and follow the same pattern of generally decreasing in the downstream direction observed during the June survey. Groundwater inflows (possibly from the underlying Seymour aquifer) likely cause specific conductance to generally decrease in the downstream direction in the reach from site BMS–1 to BMS–3.

Streamflow in the second reach of the main stem, Brazos River from Possum Kingdom Reservoir to Lake Granbury, was characterized by using data collected at the following sites: BMS–4, which measures releases from Possum Kingdom Dam, BMS–5, which is upstream from Palo Pinto Creek, and BMS–6, which is downstream from Palo Pinto Creek and upstream from Lake Granbury (fig. 8). All three of these sites are continuous streamflow-gaging stations operated by the USGS. Inflows to the Brazos River from Palo Pinto Creek are measured at site BMST–5, and flow past this site consists mostly of releases from Lake Palo Pinto. Data collected at measurement sites on tributaries, sites BMST–5 through BMST-7, also were used for this reach. During the June survey, the streamflow was 105 ft^3/s at site BMS–4 and the specific conductance was 2,510 µS/cm; water was being released from Possum Kingdom Dam at the time this measurement was made. The specific conductance at site BMS–4 of 2,510 µS/cm was markedly lower compared to the specific conductance of 8,940 µS/cm measured during the same set of synoptic measurements at site BMS–3 upstream from Possum Kingdom Lake, indicating that water being released from Possum Kingdom Dam was of different quality compared to inflow to Possum Kingdom Lake during this time, as measured at site BMS–3. The reason for this difference might be that the reservoir has impounded large amounts of storm runoff over time with much lower levels of specific conductance compared to the specific conductance measured in typical base flow. Streamflow measured at BMS–5 during the June survey was 138 ft^3/s (verified with a replicate measurement of 132 ft^3/s), indicating an increase of 33 ft^3/s or 31 percent from flows also measured in June at site BMS–4. Gage height is continuously recorded at this site and varied less than 0.1 ft throughout the June survey. There was scant variation in specific conductance from site BMS–4 to site BMS–5 in June 2010 (2,510 and 2,410 µS/cm, respectively), indicating the same quality water, likely from the same source, was flowing past both sites. Specific-conductance values for site BMS–6 were not measured. Tributary inflows measured at sites BMST–5, BMST–6, and BMST–7 totaled 6.89 ft^3/s, amounts that were much less than the 54 ft^3/s increase in flow measured in June 2010 at site BMS–6 compared to the flow at site BMS–5 (192 ft^3/s were measured at site BMS–6 in June 2010). The gage height record at site BMS–6 showed a continual decrease of about 0.10 ft/d during June 6–9, 2010, indicating that flow in the reach was still receding from a May 29, 2010, storm (Texas State Climatologist, 2010). Evaluating the reach between sites BMS–5 and BMS–6 as a gaining reach on the basis of the June survey might be erroneous because of the ongoing runoff in this reach from the May 2010 storm (Texas State Climatologist, 2010).

The October 2010 survey was done during a period when mean daily gage height at the three study sites (BMS-4 through BMS-6) was nearly constant, varying less than 0.05 ft among the sites for all of the days in the survey. Streamflow being released from Possum Kingdom Dam (measured at site BMS–4) was 156 ft^3/s and increased to 164 ft^3/s at site BMS–5 and then to 172 ft^3/s at site BMS–6. No substantial streamflow from tributaries was identified between sites BMS–4 and BMS–5. Tributary inflow between sites BMS–5 and BMS–6 totaled 3.36 ft^3/s from the following sites: BMST–5 on Palo Pinto Creek, 2.20 ft^3/s (replicate measurement 3.19 ft^3/s), BMST–6 on Rock Creek, 1.10 ft^3/s, and BMST–7 on Grindstone Creek, 0.06 ft^3/s. Streamflow at site BMS–6 was 172 ft^3/s, only 4.64 ft^3/s greater than the combined streamflow measured at site BMS–5 plus inflows from the tributaries, well within a measurement error of

8 percent (Turnipseed and Sauer, 2010); therefore, this reach does not appear to be gaining or losing if more emphasis is given to the streamflow measurements made during the October survey than to streamflow measurements made during the June survey. The reach from site BMS–4 through site BMS–6 does not overlie any major (fig. 2) or minor (fig. 3) aquifers. Specific-conductance values measured at the main-stem study sites ranged from 2,970 µS/cm at site BMS–6 to 3,080 µS/cm at site BMS–4 during the October survey. Specific-conductance values were not measured during the June survey at sites BMS–6 or BMS–7.

Streamflow in the Brazos River reach between Lake Granbury and Lake Whitney (fig. 8) was characterized from data collected at site BMS–7 near Glen Rose, Tex., and sites on tributaries on the Paluxy River at Glen Rose (BMST–8), Squaw Creek near Glen Rose (BMST–9), and Nolan River at Blum (BMST–10). Base flows in this reach are dominated by tributary inflows from the Paluxy River and Squaw Creek. Much of the flow in Squaw Creek consists of regulated releases from Squaw Creek Lake, which is sustained in part by diversions from Lake Granbury. The Nolan River, which flows directly into Lake Whitney, is another noteworthy tributary to this part of the basin. Streamflow measured during then June survey at site BMS–7 was 99 ft^3/s, and tributary inflows to the Brazos main stem downstream from site BMS–7 from Paluxy River and Squaw Creek totaled 51.0 ft^3/s. In June, streamflow at site BMST–10 on the Nolan River was 6.63 ft^3/s. No specific-conductance values were obtained for sites BMST–8 through BMST-10 during the June synoptic measurements. Streamflow measured in October at main-stem site BMS–7 was 62.4 ft^3/s, with tributary flow from the Paluxy River and Squaw Creek contributing 14.29 ft^3/s. The streamflow measured at site BMST–10 on the Nolan River in October was 8.76 ft^3/s, and the specific conductance was 812 µS/cm. Specific conductance in October at site BMS–7 was 2,260 µS/cm, a reduction of 710 µS/cm compared to the specific-conductance value of 2,970 µS/cm measured during October at site BMS–6, further indicating that releases from reservoirs can appreciably affect water quality in the upper Brazos River Basin. This reach of the main stem of the Brazos River could not be characterized as gaining or losing because there was only one measurement site on the Brazos River in this reach. Flow in the main stem increased from tributary inflows from the Paluxy River and Squaw Creek, and the Brazos might receive groundwater inflows from the Trinity aquifer in this reach as well. Additional measurements (upstream and downstream sites on this reach) are necessary to confirm if this reach is a gaining reach.

The Brazos River reach between Lake Whitney and the mouth of the North Bosque River north of Waco contained one main-stem measurement site near the outflow from Lake Whitney, BMS–8. Tributary inflow was measured at sites BMST–12 and 14 on Aquilla Creek and site BMST–13 Cobb Creek which enters Aquilla Creek between sites BMST–12 and 14 and at site BMST–11 on Childress Creek. By coincidence, flows of 252 ft^3/s were measured at site BMS–8 during the June and October surveys (flow at site BMS–8 typically varies from 200 to 2,000 ft^3/s most days because of large changes in the amount of water released from the dam impounding Lake Whitney [U.S. Geological Survey, 2009]). Substantial increases in streamflow were measured in June from site BMST–12 (outlet of Aquilla Lake) of 2.26 ft^3/s to site BMST–14 of 15.5 ft^3/s with no additional streamflow added from Cobb Creek (BMST–13, no flow). Childress Creek (site BMST–11) added 3.54 ft^3/s to the main stem. Streamflow measured in October in Aquilla Creek followed similar patterns, with 14 ft^3/s (BMST–12) being released from Aquilla Lake and Childress Creek (site BMST–11) contributing 4.33 ft^3/s (replicate measurement of 5.02 ft^3/s). The Woodbine aquifer underlies part of the Aquilla Creek Basin. The reach of the main stem of the Brazos River from Lake Whitney to Waco increased in flow from tributary inflows and groundwater inputs. This reach of the main stem of the Brazos River could not be characterized as gaining or losing because there was only one measurement site on the Brazos River in this reach. Additional measurements (upstream and downstream sites on this reach) are necessary to confirm if this reach is a gaining reach.

Based on the results of the June and October surveys, streamflow gains were identified in the reach of the main stem of the Brazos River from where the Brazos River main stem forms at the confluence of the Salt Fork Brazos River and Double Mountain Fork Brazos River near Knox City, Tex., downstream to near Seymour, Tex. Increases in flow were observed in the main stem downstream from Lake Granbury to Lake Whitney, and downstream from Lake Whitney to the confluence of the Brazos River and Childress Creek, but because there was only one main-stem measurement site in each of these reaches, there was insufficient data to characterize these reaches as gaining reaches. Flow in the Brazos River increased from 86.2 ft^3/s near Knox City to 142 ft^3/s near Seymour during the June survey, and from 61.9 ft^3/s to 93.7 ft^3/s during the October survey. The flows near Knox City and Seymour were measured at USGS stations 332533099544100 Brazos River at Highway 143/222 near Knox City, Tex. (site BMS–1), and 08082500 Brazos River near Seymour, Tex. (site BMS–2), respectively. Flow was measured at one site on the main stem of the Brazos River in the Lake Granbury to Lake Whitney reach, at USGS streamflow-gaging station 08091000 Brazos River near Glen Rose, Tex. (site BMS–7). Substantial tributary flows to the Brazos River from the Paluxy River, Nolan River, and Squaw Creek increased flow in this reach. Inflows of 35.4 ft^3/s (June) and 9.84 ft^3/s (October) were measured at USGS streamflow-gaging station 08091500 Paluxy River at Glen Rose, Tex. (site BMST–8). Inflows from Nolan River of 6.63 ft^3/s (June) and 8.76 ft^3/s (October) were measured at USGS streamflow-gaging station 08092000 Nolan River at Blum, Tex. (site BMST–10), which flows directly into Lake Whitney. Inflows of 15.6 ft^3/s (June) and 4.45 ft^3/s (October) from Squaw Creek to the Brazos River were measured at USGS streamflow-gaging station 08091750 Squaw Creek near Glen Rose, Tex. (site BMST–9). The inflows from the Paluxy River, Nolan River, and Squaw Creek are downstream from the 99 ft^3/s (June) and 62.4 ft^3/s (October) measured at site BMS–7. Downstream from site BMS–7, flow in the main stem increased to 252 ft^3/s at USGS streamflow-gaging station 08093100 Brazos River near Aquilla, Tex. (site BMS–8), during both the June and October surveys.

Contributions of Streamflow to the Main Channels of Each of the Five Subbasins

Contributions of streamflow to the main channels of each of the five subbasins during the June survey ranged from less than 15 ft^3/s in the Salt Fork Brazos River Basin to more than 100 ft^3/s for the North Bosque Brazos River Basin (fig. 25). While an overall increase in streamflow was measured from the headwaters of the Clear Fork Brazos River Basin to the outlet, a large part of 26.3 to 29.9 ft^3/s measured at the most downstream site in the basin was likely treated effluent from the Abilene, Tex., wastewater-treatment plant. Releases from the three main-stem reservoirs in the upper Brazos River Basin—Possum Kingdom Lake, Lake Granbury, and Lake Whitney—dominated the quantity of flows in the Brazos main-stem reach downstream from Possum Kingdom Lake.

Contributions of streamflow to the main channels of each designated basin (fig. 26) measured in the October survey were less than those measured in June, and varied from less than 12 ft^3/s for the Salt Fork Brazos River Basin to 41.4 ft^3/s for the North Bosque River Basin. BFI values for the Double Mountain Fork near Aspermont gage (site DMF–7) indicated an upward trend from 1966–2009 in the base-flow component of the total streamflow amount. BFI values for the Brazos River near Palo Pinto (site BMS–5) and the Brazos River near Dennis (site BMS–6) indicated statistically significant upward trends in the base-flow components for these two sites located in the stream reach between Possum Kingdom Lake and Lake Granbury, indicating that releases from Possum Kingdom Lake and Lake Palo Pinto Reservoir are comprising an increasingly large part of flows in this part of the main stem of the Brazos River.

Summary

During 2010–11, the U.S. Geological Survey (USGS), in cooperation with the Texas Water Development Board, used hydrograph separation to quantify historical base flow at 11 USGS streamflow-gaging stations between water years 1966–2009 and used two sets of synoptic measurements of streamflow and specific conductance (the first in June 2010, followed by another set in October 2010) to quantify streamflow gains and losses in the upper Brazos River Basin from the New Mexico–Texas State line to Waco, Texas. This study complements previous work that quantified base flows in part of the lower Brazos River Basin downstream from Waco to near Freeport, Tex., using base-flow analysis and synoptic streamflow measurements. The following subbasins compose the study area: Salt Fork Brazos River Basin, Double Mountain Fork Brazos River Basin, Clear Fork Brazos River Basin, North Bosque River Basin, and the Brazos River Basin (main stem) (including its tributaries). Several underlying major and minor aquifers are in the upper Brazos River Basin that are hydraulically connected to the Brazos River might add streamflow in the upper Brazos River Basin. Major aquifers are the Seymour, Ogallala, Edwards-Trinity (Plateau), and Trinity, and minor aquifers are the Brazos River Alluvium, Woodbine, Edwards-Trinity (High Plains), Dockum, and Blaine.

Base-flow analysis was done using historical streamflow data from 11 USGS streamflow-gaging stations in the upper Brazos River Basin (5 on the main stem of the Brazos River and 6 on tributaries to the Brazos River) to compute yearly base-flow indexes (base flow divided by total streamflow) for each station. The base-flow index was used to indicate the fraction of flow consisting of base flow on an annual basis for the period of record evaluated at each streamflow-gaging station. At nine stations there were long-term streamflow data from water years 1966–2009 (October 1965 through September 2009); at two stations slightly shorter periods of record (water years 1967–2009 and 1969–2009) were available. Hydrograph separation was done to calculate base-flow indexes for each year of streamflow record using the USGS computer program Hydrograph Separation and Analysis. The median base-flow indexes were 0.16 and 0.15 at USGS streamflow-gaging stations 08082000 Salt Fork Brazos River near Aspermont, Tex., and 08080500 Double Mountain Fork Brazos River near Aspermont, Tex., respectively. At USGS streamflow-gaging stations 08084000 Clear Fork Brazos River at Nugent, Tex., and 08085500 Clear Fork Brazos River at Fort Griffin, Tex., the median baseflow-indexes were 0.28 and 0.23, respectively, indicating the amount of streamflow consisting of base flow was larger in the Clear Fork Brazos River Basin compared to the Salt Fork Brazos River Basin or Double Mountain Fork Brazos River Basin.

The largest median base-flow index for any station was 0.35 at USGS streamflow-gaging station 08091500 Paluxy River at Glen Rose, Tex. The second largest base-flow index was 0.30 at USGS streamflow-gaging station 08095000 North Bosque River near Clifton, Tex. Median base-flow indexes on the main stem of the Brazos River upstream from Possum Kingdom Lake were 0.22 at USGS streamflow-gaging station 08082500 Brazos River at Seymour, Tex., and 0.24 at USGS streamflow-gaging station 08088000 Brazos River at South Bend, Tex. The base-flow indexes for stations between Possum Kingdom Lake and Lake Granbury were 0.19 and 0.27 at USGS streamflow-gaging stations 08089000 Brazos River near Palo Pinto, Tex., and 08090800 Brazos River near Dennis, Tex., respectively. A median base-flow index of 0.19 was also measured at USGS streamflow-gaging station 08091000 Brazos River near Glen Rose, Tex., located between

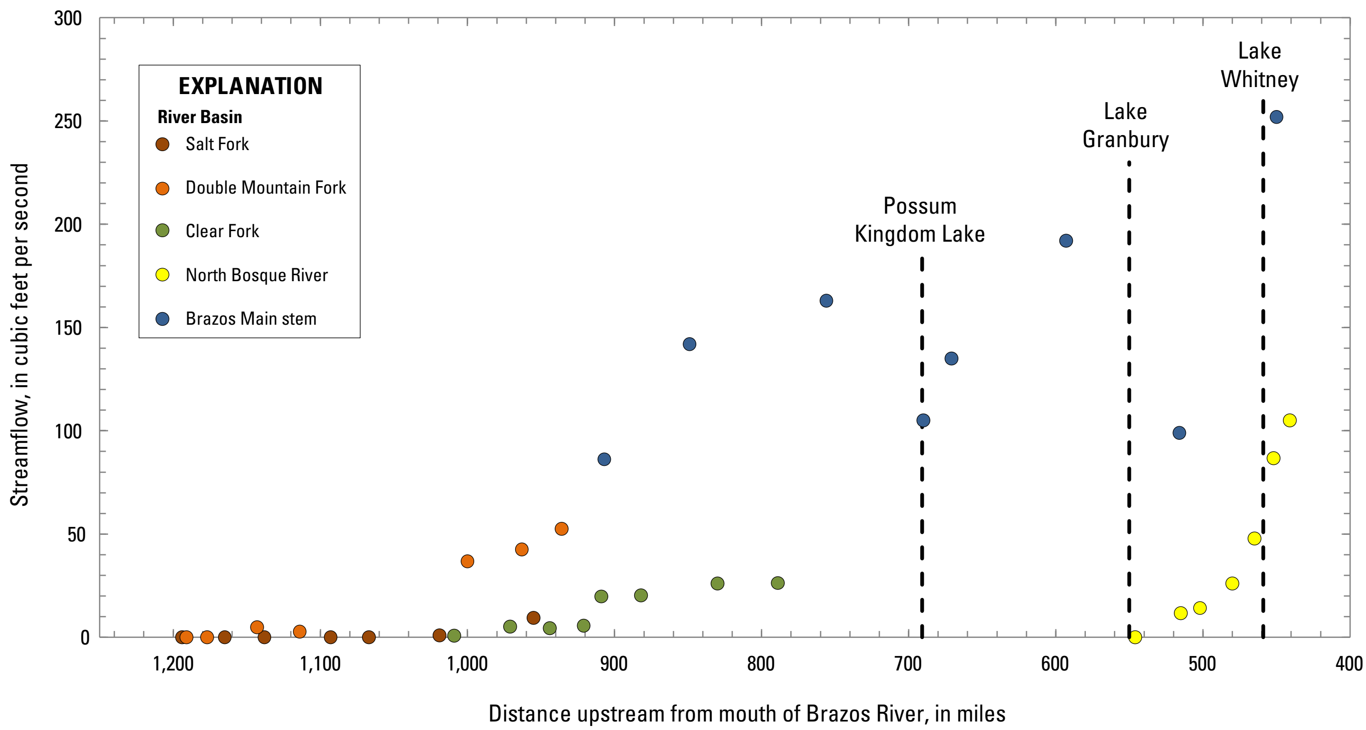


Figure 25. Instantaneous streamflow measured during June 2010 at U.S. Geological Survey streamflow-gaging stations in the five subbasins of the upper Brazos River Basin, Texas (Salt Fork Brazos River, Double Mountain Fork Brazos River, Clear Fork Brazos River, North Bosque River, and the main stem of Brazos River and its tributaries).

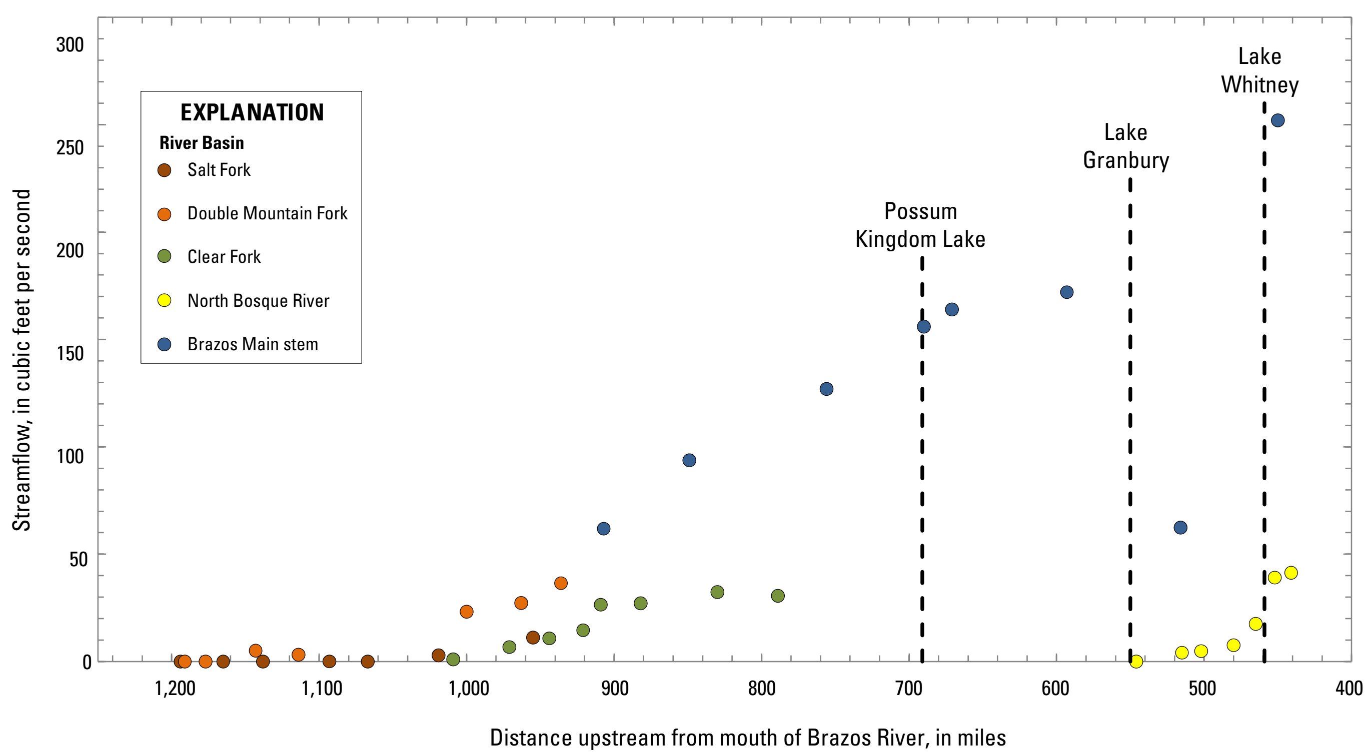


Figure 26. Instantaneous streamflow measured during October 2010 at U.S. Geological Survey streamflow-gaging stations in the five subbasins of the upper Brazos River Basin, Texas (Salt Fork Brazos River, Double Mountain Fork Brazos River, Clear Fork Brazos River, North Bosque River, and the main stem of Brazos River and its tributaries).

Lake Granbury and Lake Whitney. A Mann-Kendall trend analysis test was performed on annual base-flow index values (one value per year for the study period) for each of the 11 streamflow records that were analyzed, and a p-value of 0.05 used to assign statistical significance for the occurrence of a trend in the base-flow index data set for each historical period of record analyzed. Upward trends in base-flow index values indicating increasing flows during the study period were found for USGS streamflow-gaging stations 08080500 Double Mountain Fork Brazos River near Aspermont, Tex., 08089000 Brazos River near Palo Pinto, Tex., and 08090800 Brazos River near Dennis, Tex. Flows at these three streamflow-gaging stations are regulated by reservoir releases, and additional analyses are needed before these streamflow trends can be characterized as indicative of changes in base flow over time.

Streamflow gains and losses were characterized in each of the five subbasins composing the upper Brazos River Basin using data from two synoptic measurements (surveys) of streamflow and specific conductance in 2010. Data were collected from 66 sites during June 6–9, 2010 (June survey) and from 68 sites during October 16–19, 2010 (October survey). Gaining reaches were characterized in the Salt Fork Brazos River Basin and Double Mountain Fork Brazos River Basin during both surveys. The gaining reach in the Salt Fork Brazos River Basin began at USGS streamflow-gaging station 08080940 Salt Fork Brazos River at State Highway 208 near Clairemont, Tex. (site SF–6), upstream from where Duck Creek flows into the Salt Fork Brazos River and continued downstream past USGS streamflow-gaging station 08082000 Salt Fork Brazos River near Aspermont, Tex. (site SF–9), to the outlet of the basin. The streamflows of 1.06 and 2.86 ft^3/s were measured in the June and October surveys, respectively, at site SF–6. At downstream site SF–9, streamflows of 9.41 and 10.9 ft^3/s were measured during the June and October surveys, respectively. In the Double Mountain Fork Brazos River Basin, a gaining reach from near Post, Tex., downstream to the outlet of the basin was identified. Flow increased from about 3 ft^3/s during the June (2.78 ft^3/s) and October (3.17 ft^3/s) surveys at USGS station 331909101232900 North Fork Double Mountain Fork Brazos River at Farm Road 207 near Post, Tex. (site DMF–4), to about 36–53 ft^3/s near the outlet of the Double Mountain Fork Brazos River Basin during the June (36.5 ft^3/s) and October (52.5 ft^3/s) surveys at USGS station 331116099573600 Double Mountain Fork Brazos River at Highway 380 near Rule, Tex. (site DMF–8). A gaining reach was identified in the Clear Fork Brazos River from near Roby, Tex., downstream to near Noodle, Tex. (flows of 0.77 and 1.04 ft^3/s were measured at USGS streamflow-gaging 08083100 Clear Fork Brazos River near Roby, Tex. [site CF–1], in the June and October surveys, respectively, and flows of 5.15 and 6.75 ft^3/s were measured at USGS streamflow-gaging 08083230 Clear Fork Brazos River near Noodle, Tex. [site CF–3], in the June and October surveys, respectively). A second gaining reach was observed in the Clear Fork Brazos River from Hawley, Tex., downstream to Nugent, Tex. (flows of 4.39 and 10.8 ft^3/s were measured at USGS station 323635099495800 Clear Fork Brazos River at County Road 509 at Hawley, Tex. [site CF–4], in June and October respectively, and flows of 5.64 and 14.6 ft^3/s were measured at USGS streamflow-gaging 08084000 Clear Fork Brazos River at Nugent, Tex. [site CF–6], in the June and October surveys, respectively). Most of the North Bosque River was characterized as gaining streamflow, beginning with no flow north of Stephenville, Tex., increasing downstream to more than 100 ft^3/s and 41.4 ft^3/s near China Springs, Tex., in the June and October surveys, respectively (flow during the June survey at USGS station 313830097220100 North Bosque River near China Springs, Tex. [site NB–10], was 103 ft^3/s [replicate measurement was 107 ft^3/s] and the flow at site NB–10 was 41.4 ft^3/s during the October survey).

Based on the results of the June and October surveys, streamflow gains were identified in the reach of the main stem of the Brazos River from where the Brazos River main stem forms at the confluence of the Salt Fork Brazos River and Double Mountain Fork Brazos River near Knox City, Tex., downstream to near Seymour, Tex. Increases in flow were observed in the main stem downstream from Lake Granbury to Lake Whitney, and downstream from Lake Whitney to the confluence of the Brazos River and Childress Creek, but because there was only one main-stem measurement site in each of these reaches, there was insufficient data to characterize these reaches as gaining reaches. Flow in the Brazos River increased from 86.2 ft^3/s near Knox City to 142 ft^3/s near Seymour during the June survey, and from 61.9 ft^3/s to 93.7 ft^3/s during the October survey. The flows near Knox City and Seymour were measured at USGS stations 332533099544100 Brazos River at Highway 143/222 near Knox City, Tex. (site BMS–1), and 08082500 Brazos River near Seymour, Tex. (site BMS–2), respectively. Flow was measured at one site on the main stem of the Brazos River in the Lake Granbury to Lake Whitney reach, at USGS streamflow-gaging station 08091000 Brazos River near Glen Rose, Tex. (site BMS–7). Substantial tributary flows to the Brazos River from the Paluxy River, Nolan River, and Squaw Creek increased flow in this reach. Inflows of 35.4 ft^3/s (June) and 9.84 ft^3/s (October) were measured at USGS streamflow-gaging station 08091500 Paluxy River at Glen Rose, Tex. (site BMST–8). Inflows from Nolan River of 6.63 ft^3/s (June) and 8.76 ft^3/s (October) were measured at USGS streamflow-gaging station 08092000 Nolan River at Blum, Tex. (site BMST–10), which flows directly into Lake Whitney. Inflows of 15.6 ft^3/s (June) and 4.45 ft^3/s (October) from Squaw Creek to the Brazos River were measured at USGS streamflow-gaging station 08091750 Squaw Creek near Glen Rose, Tex. (site BMST–9). The inflows from the Paluxy River, Nolan River, and Squaw Creek are downstream from the 99 ft^3/s (June) and 62.4 ft^3/s (October) measured at site BMS–7. Downstream from site BMS–7, flow in the main stem increased to 252 ft^3/s at USGS streamflow-gaging station 08093100 Brazos River near Aquilla, Tex. (site BMS–8), during both the June and October surveys.

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Appendix 1. Hydrographic Separation Results

Appendix 1. Hydrographic separation results for long-term annual streamflow amounts measured at selected U.S. Geological Survey (USGS) streamflow-gaging stations in the upper Brazos River Basin, Texas.

[DMF, Double Mountain Fork; Q, annual mean streamflow; ft³/s, cubic feet per second; BF, base flow; RO, runoff; BFI, base-flow index (defined as BF/Q); -, no data available]

	USGS station 08082000 Salt Fork Brazos River near Aspermont, Tex.				USGS station 08080500 DMF Brazos River near Aspermont, Tex.				USGS station 08084000 Clear Fork Brazos River at Nugent, Tex.			
Water year	**Q (ft³/s)**	**BF (ft³/s)**	**RO (ft³/s)**	**BFI**	**Q (ft³/s)**	**BF (ft³/s)**	**RO (ft³/s)**	**BFI**	**Q (ft³/s)**	**BF (ft³/s)**	**RO (ft³/s)**	**BFI**
1966	164.1	13.5	150.6	0.08	138.4	8.6	129.7	0.06	87.3	6.2	81.1	0.07
1967	54.3	8.7	45.7	0.16	195.5	8.7	186.8	0.04	22.7	4.1	18.6	0.18
1968	66.6	10.1	56.4	0.15	86.8	11.0	75.8	0.13	53.7	15.7	38.0	0.29
1969	53.2	4.3	49.0	0.08	163.8	15.2	148.6	0.09	99.7	15.0	84.6	0.15
1970	42.1	9.3	32.8	0.22	76.9	9.1	67.8	0.12	36.6	23.1	13.5	0.63
1971	72.1	9.5	62.6	0.13	211.2	11.9	199.3	0.06	103.7	10.1	93.7	0.10
1972	130.6	26.9	103.7	0.21	312.7	27.5	285.2	0.09	55.4	29.6	25.8	0.53
1973	47.8	22.1	25.7	0.46	81.3	28.0	53.3	0.34	54.5	24.3	30.2	0.45
1974	52.4	2.2	50.2	0.04	51.8	8.9	42.9	0.17	61.4	12.1	49.3	0.20
1975	64.9	9.3	55.6	0.14	129.6	15.7	113.9	0.12	183.4	60.3	123.1	0.33
1976	39.9	6.6	33.3	0.17	53.7	7.3	46.4	0.14	31.3	16.3	15.0	0.52
1977	65.5	17.1	48.3	0.26	58.0	9.7	48.3	0.17	50.8	20.0	30.8	0.39
1978	26.7	1.9	24.8	0.07	51.0	4.0	46.9	0.08	24.7	6.7	18.0	0.27
1979	35.4	5.8	29.6	0.16	102.5	17.4	85.2	0.17	28.7	9.3	19.5	0.32
1980	48.0	3.1	44.9	0.06	167.8	3.0	164.8	0.02	47.0	3.6	43.4	0.08
1981	26.2	6.1	20.2	0.23	86.8	21.4	65.3	0.25	127.4	44.6	82.8	0.35
1982	120.2	11.6	108.7	0.10	219.7	41.6	178.1	0.19	155.3	35.9	119.4	0.23
1983	21.1	4.4	16.7	0.21	58.3	6.3	52.0	0.11	24.5	15.2	9.3	0.62
1984	89.1	12.0	77.2	0.13	91.2	9.2	82.0	0.10	15.1	5.8	9.3	0.38
1985	54.8	4.4	50.4	0.08	176.5	33.4	143.1	0.19	39.4	14.6	24.7	0.37
1986	117.9	21.1	96.8	0.18	224.1	52.6	171.5	0.23	59.0	9.8	49.2	0.17
1987	212.2	39.7	172.6	0.19	226.9	53.7	173.2	0.24	317.4	100.5	216.9	0.32
1988	13.8	2.4	11.4	0.17	45.9	6.0	39.9	0.13	40.5	17.3	23.3	0.43
1989	26.8	2.9	23.9	0.11	53.7	5.2	48.5	0.10	25.1	9.9	15.2	0.40
1990	121.2	6.2	115.0	0.05	157.5	17.2	140.3	0.11	99.0	9.5	89.4	0.10
1991	139.1	7.1	132.0	0.05	146.1	14.6	131.4	0.10	115.8	16.8	98.9	0.15
1992	175.1	68.1	107.0	0.39	284.9	65.5	219.4	0.23	324.7	99.4	225.3	0.31
1993	21.6	9.6	12.0	0.44	31.6	8.7	23.0	0.27	40.5	24.0	16.5	0.59
1994	23.2	3.0	20.2	0.13	16.6	0.8	15.8	0.05	49.7	11.6	38.1	0.23
1995	51.8	7.0	44.8	0.14	60.2	0.6	59.6	0.01	48.4	8.4	40.0	0.17
1996	55.2	12.2	43.0	0.22	32.5	1.7	30.8	0.05	24.2	8.4	15.8	0.35
1997	73.3	14.0	59.4	0.19	85.9	20.4	65.5	0.24	74.1	28.8	45.3	0.39
1998	11.7	2.7	9.0	0.23	7.5	2.2	5.4	0.29	6.5	5.1	1.4	0.79

Appendix 1. Hydrographic separation results for long-term annual streamflow amounts measured at selected U.S. Geological Survey (USGS) streamflow-gaging stations in the upper Brazos River Basin, Texas.—Continued

[DMF, Double Mountain Fork; Q, annual mean streamflow; ft^3/s, cubic feet per second; BF, base flow; RO, runoff; BFI, base-flow index (defined as BF/Q); -, no data available]

	USGS station 08082000 Salt Fork Brazos River near Aspermont, Tex.				USGS station 08080500 DMF Brazos River near Aspermont, Tex.				USGS station 08084000 Clear Fork Brazos River at Nugent, Tex.			
Water year	**Q (ft^3/s)**	**BF (ft^3/s)**	**RO (ft^3/s)**	**BFI**	**Q (ft^3/s)**	**BF (ft^3/s)**	**RO (ft^3/s)**	**BFI**	**Q (ft^3/s)**	**BF (ft^3/s)**	**RO (ft^3/s)**	**BFI**
1999	56.0	5.6	50.4	0.10	128.9	5.6	123.4	0.04	8.8	1.3	7.5	0.14
2000	29.8	0.9	28.9	0.03	86.5	5.3	81.2	0.06	17.9	0.3	17.6	0.02
2001	22.4	4.5	17.8	0.20	60.7	37.3	23.4	0.62	23.9	3.9	20.1	0.16
2002	17.0	1.3	15.7	0.08	28.9	7.3	21.6	0.25	18.9	1.7	17.2	0.09
2003	28.7	2.0	26.7	0.07	43.1	9.1	34.0	0.21	14.7	3.4	11.4	0.23
2004	74.7	9.0	65.7	0.12	76.6	21.0	55.6	0.27	11.2	1.3	9.9	0.12
2005	87.4	35.6	51.8	0.41	237.1	37.3	199.9	0.16	20.7	5.2	15.5	0.25
2006	22.6	3.5	19.1	0.16	48.0	11.8	36.2	0.25	20.1	3.2	17.0	0.16
2007	81.9	23.0	58.9	0.28	155.6	64.2	91.4	0.41	135.7	11.8	123.9	0.09
2008	41.5	8.3	33.2	0.20	76.6	16.3	60.3	0.21	33.8	16.3	17.4	0.48
2009	37.3	7.3	30.0	0.20	57.2	30.7	26.5	0.54	10.7	4.5	6.1	0.42
Mean	**64.0**	**11.0**	**53.0**	**0.17**	**111.1**	**18.0**	**93.0**	**0.17**	**64.6**	**17.6**	**47.0**	**0.30**
Median	**52.8**	**7.2**	**45.3**	**0.16**	**86.2**	**11.4**	**66.7**	**0.15**	**40.5**	**10.8**	**24.0**	**0.28**
Minimum	**11.7**	**0.9**	**9.0**	**0.03**	**7.5**	**0.6**	**5.4**	**0.01**	**6.5**	**0.3**	**1.4**	**0.02**
Maximum	**212.2**	**68.1**	**172.6**	**0.46**	**312.7**	**65.5**	**285.2**	**0.62**	**324.7**	**100.5**	**225.3**	**0.79**

Appendix 1. Hydrographic separation results for long-term annual streamflow amounts measured at selected U.S. Geological Survey (USGS) streamflow-gaging stations in the upper Brazos River Basin, Texas.—Continued

[DMF, Double Mountain Fork; Q, annual mean streamflow; ft^3/s, cubic feet per second; BF, base flow; RO, runoff; BFI, base-flow index (defined as BF/Q); -, no data available]

	USGS station 08085500 Clear Fork Brazos River at Fort Griffin, Tex.				USGS station 08095000 North Bosque River near Clifton, Tex.				USGS station 08082500 Brazos River at Seymour, Tex.			
Water year	**Q (ft^3/s)**	**BF (ft^3/s)**	**RO (ft^3/s)**	**BFI**	**Q (ft^3/s)**	**BF (ft^3/s)**	**RO (ft^3/s)**	**BFI**	**Q (ft^3/s)**	**BF (ft^3/s)**	**RO (ft^3/s)**	**BFI**
1966	179.6	16.4	163.2	0.09	163.7	39.9	123.8	0.24	-	-	-	-
1967	29.3	6.7	22.6	0.23	29.9	10.0	19.9	0.34	350.3	57.8	292.5	0.17
1968	139.3	39.7	99.6	0.29	557.6	148.0	409.5	0.27	230.7	50.7	179.9	0.22
1969	226.0	36.2	189.9	0.16	165.4	52.4	113.0	0.32	258.0	30.9	227.2	0.12
1970	69.6	36.4	33.2	0.52	302.2	137.6	164.6	0.46	148.0	37.5	110.4	0.25
1971	274.8	23.5	251.2	0.09	32.8	13.0	19.9	0.40	311.1	22.4	288.7	0.07
1972	106.1	53.4	52.6	0.50	264.9	77.8	187.2	0.29	527.2	135.9	391.3	0.26
1973	174.5	56.8	117.7	0.33	189.7	69.5	120.2	0.37	304.3	99.8	204.5	0.33
1974	106.3	9.2	97.1	0.09	45.7	17.3	28.4	0.38	112.4	4.7	107.6	0.04
1975	311.1	88.2	222.9	0.28	212.7	72.4	140.2	0.34	296.4	58.1	238.3	0.20
1976	46.7	19.2	27.5	0.41	60.0	15.1	45.0	0.25	106.8	31.3	75.5	0.29
1977	116.2	29.1	87.1	0.25	403.5	102.8	300.8	0.25	202.4	53.5	148.9	0.26
1978	544.6	12.2	532.4	0.02	15.6	8.9	6.7	0.57	167.2	9.0	158.2	0.05
1979	102.6	33.8	68.9	0.33	187.3	44.0	143.3	0.24	161.3	42.9	118.4	0.27
1980	159.7	10.1	149.7	0.06	32.1	13.6	18.6	0.42	295.4	31.2	264.2	0.11
1981	355.1	70.2	284.9	0.20	64.3	11.8	52.5	0.18	161.9	35.9	126.0	0.22
1982	446.5	115.7	330.8	0.26	124.5	38.4	86.1	0.31	606.8	187.9	418.9	0.31
1983	61.6	34.0	27.5	0.55	14.7	5.5	9.3	0.37	113.7	35.2	78.5	0.31
1984	24.2	12.5	11.8	0.51	11.7	1.7	10.1	0.14	278.9	53.4	225.5	0.19
1985	202.4	53.9	148.5	0.27	64.9	15.2	49.7	0.23	340.8	85.3	255.5	0.25
1986	127.2	20.4	106.8	0.16	187.7	13.1	174.6	0.07	434.0	98.4	335.6	0.23
1987	620.6	206.5	414.1	0.33	284.9	131.1	153.8	0.46	742.3	201.5	540.8	0.27
1988	80.5	34.2	46.3	0.43	88.3	13.3	75.0	0.15	104.3	25.2	79.0	0.24
1989	68.7	27.2	41.5	0.40	362.6	52.4	310.2	0.14	212.2	32.4	179.8	0.15
1990	385.7	55.2	330.5	0.14	375.1	116.9	258.2	0.31	537.2	80.5	456.7	0.15
1991	339.6	50.0	289.6	0.15	102.4	31.1	71.3	0.30	461.2	64.4	396.8	0.14
1992	951.0	263.5	687.5	0.28	1366.2	273.9	1092.3	0.20	702.7	287.3	415.4	0.41
1993	99.4	54.0	45.4	0.54	197.4	96.4	101.0	0.49	133.7	59.8	73.9	0.45
1994	132.4	27.3	105.1	0.21	243.7	42.6	201.2	0.17	103.1	18.6	84.5	0.18
1995	146.6	27.1	119.5	0.19	602.1	183.4	418.7	0.30	255.0	39.2	215.8	0.15
1996	52.9	24.6	28.3	0.47	103.6	27.4	76.2	0.26	178.5	22.4	156.1	0.13
1997	175.3	60.4	114.9	0.34	747.2	278.3	468.9	0.37	259.6	67.9	191.7	0.26
1998	33.2	17.8	15.4	0.54	328.0	71.4	256.7	0.22	61.1	20.0	41.1	0.33
1999	42.0	8.4	33.6	0.20	32.8	17.9	14.9	0.55	260.2	43.2	217.0	0.17
2000	31.2	2.6	28.6	0.08	39.1	3.0	36.1	0.08	154.0	17.9	136.2	0.12
2001	71.7	15.2	56.6	0.21	219.8	64.6	155.1	0.29	175.6	47.8	127.7	0.27
2002	119.2	13.6	105.6	0.11	175.0	53.5	121.5	0.31	134.0	19.3	114.6	0.14
2003	76.8	9.0	67.8	0.12	67.6	26.8	40.9	0.40	117.3	20.0	97.3	0.17
2004	56.5	9.4	47.1	0.17	332.6	66.6	266.0	0.20	268.6	37.1	231.6	0.14

Appendix 1. Hydrographic separation results for long-term annual streamflow amounts measured at selected U.S. Geological Survey (USGS) streamflow-gaging stations in the upper Brazos River Basin, Texas.—Continued

[DMF, Double Mountain Fork; Q, annual mean streamflow; ft³/s, cubic feet per second; BF, base flow; RO, runoff; BFI, base-flow index (defined as BF/Q); -, no data available]

	USGS station 08085500 Clear Fork Brazos River at Fort Griffin, Tex.				USGS station 08095000 North Bosque River near Clifton, Tex.				USGS station 08082500 Brazos River at Seymour, Tex.			
Water year	Q (ft^3/s)	BF (ft^3/s)	RO (ft^3/s)	BFI	Q (ft^3/s)	BF (ft^3/s)	RO (ft^3/s)	BFI	Q (ft^3/s)	BF (ft^3/s)	RO (ft^3/s)	BFI
2005	340.0	42.3	297.7	0.12	364.9	184.9	180.0	0.51	516.6	95.1	421.5	0.18
2006	42.0	8.4	33.5	0.20	23.5	6.3	17.2	0.27	106.2	37.8	68.5	0.36
2007	382.7	55.4	327.3	0.14	879.8	266.8	612.9	0.30	404.3	109.7	294.6	0.27
2008	106.2	41.9	64.3	0.39	100.3	43.3	57.0	0.43	98.3	43.3	55.1	0.44
2009	34.6	7.7	26.9	0.22	24.6	5.5	19.2	0.22	99.6	46.6	53.0	0.47
Mean	**186.2**	**41.8**	**144.4**	**0.26**	**231.7**	**67.4**	**164.3**	**0.30**	**267.3**	**60.4**	**206.8**	**0.23**
Median	**117.7**	**28.2**	**98.3**	**0.23**	**170.2**	**42.9**	**116.6**	**0.30**	**230.7**	**43.2**	**179.9**	**0.22**
Minimum	**24.2**	**2.6**	**11.8**	**0.02**	**11.7**	**1.7**	**6.7**	**0.07**	**61.1**	**4.7**	**41.1**	**0.04**
Maximum	**951.0**	**263.5**	**687.5**	**0.55**	**1366.2**	**278.3**	**1092.3**	**0.57**	**742.3**	**287.3**	**540.8**	**0.47**

Appendix 1. Hydrographic separation results for long-term annual streamflow amounts measured at selected U.S. Geological Survey (USGS) streamflow-gaging stations in the upper Brazos River Basin, Texas.—Continued

[DMF, Double Mountain Fork; Q, annual mean streamflow; ft³/s, cubic feet per second; BF, base flow; RO, runoff; BFI, base-flow index (defined as BF/Q); -, no data available]

	USGS station 08088000 Brazos River near South Bend, Tex.				USGS station 08089000 Brazos River near Palo Pinto, Tex.				USGS station 08090800 Brazos River near Dennis, Tex.			
Water year	**Q (ft³/s)**	**BF (ft³/s)**	**RO (ft³/s)**	**BFI**	**Q (ft³/s)**	**BF (ft³/s)**	**RO (ft³/s)**	**BFI**	**Q (ft³/s)**	**BF (ft³/s)**	**RO (ft³/s)**	**BFI**
1966	1103.1	170.9	932.2	0.15	1275.1	228.0	1047.1	0.18	-	-	-	-
1967	517.9	121.5	396.4	0.23	522.6	71.8	450.8	0.14	-	-	-	-
1968	680.2	161.6	518.6	0.24	1015.9	139.0	876.9	0.14	-	-	-	-
1969	889.2	138.5	750.7	0.16	1173.2	303.9	869.3	0.26	1556.8	333.8	1223.0	0.21
1970	404.9	163.1	241.8	0.40	568.4	83.0	485.4	0.15	1073.5	226.6	846.9	0.21
1971	744.9	88.6	656.2	0.12	362.3	23.6	338.8	0.07	365.8	50.0	315.7	0.14
1972	744.3	242.3	501.9	0.33	664.6	128.7	535.9	0.19	776.4	246.4	530.0	0.32
1973	613.2	231.2	381.9	0.38	794.5	111.5	683.0	0.14	958.7	248.4	710.3	0.26
1974	298.5	30.5	268.0	0.10	202.2	27.4	174.8	0.14	271.7	45.2	226.6	0.17
1975	859.3	240.2	619.1	0.28	1177.9	255.9	922.1	0.22	1566.4	405.4	1161.0	0.26
1976	203.6	80.2	123.5	0.39	213.2	38.7	174.6	0.18	283.9	73.2	210.7	0.26
1977	424.8	123.1	301.7	0.29	588.1	138.3	449.8	0.24	903.3	242.9	660.4	0.27
1978	900.9	29.5	871.5	0.03	765.3	28.9	736.4	0.04	794.3	48.9	745.4	0.06
1979	355.2	108.7	246.6	0.31	417.7	114.0	303.6	0.27	567.8	223.6	344.3	0.39
1980	383.6	62.1	321.5	0.16	317.4	48.7	268.8	0.15	361.1	117.3	243.8	0.32
1981	804.8	177.7	627.1	0.22	966.9	103.3	863.6	0.11	948.1	208.6	739.5	0.22
1982	2188.6	649.4	1539.3	0.30	2889.3	271.9	2617.4	0.09	4139.2	309.6	3829.6	0.07
1983	225.9	114.7	111.2	0.51	287.5	56.1	231.4	0.20	437.0	102.7	334.4	0.23
1984	262.8	83.9	178.9	0.32	213.2	48.2	165.0	0.23	258.1	81.9	176.3	0.32
1985	803.0	268.8	534.1	0.33	741.3	97.3	644.1	0.13	1001.0	222.0	779.0	0.22
1986	650.0	114.5	535.5	0.18	527.4	77.6	449.8	0.15	630.3	133.1	497.2	0.21
1987	1479.8	534.8	945.0	0.36	2100.1	455.5	1644.6	0.22	2166.0	598.5	1567.5	0.28
1988	206.6	67.1	139.5	0.32	98.5	24.6	73.9	0.25	120.0	32.0	88.0	0.27
1989	467.1	73.5	393.6	0.16	577.6	76.4	501.2	0.13	1183.1	261.2	921.9	0.22
1990	1712.7	243.2	1469.5	0.14	2176.8	250.1	1926.7	0.11	2949.0	715.7	2233.3	0.24
1991	925.3	192.1	733.2	0.21	1256.4	210.6	1045.9	0.17	1142.9	432.6	710.3	0.38
1992	2965.7	879.3	2086.4	0.30	3339.4	844.2	2495.2	0.25	4054.4	1122.7	2931.7	0.28
1993	378.0	210.8	167.2	0.56	455.7	136.8	318.9	0.30	529.2	230.5	298.7	0.44
1994	314.5	72.0	242.5	0.23	353.3	65.0	288.4	0.18	577.2	130.5	446.7	0.23
1995	482.1	129.8	352.2	0.27	632.2	184.1	448.1	0.29	899.7	276.6	623.1	0.31
1996	296.7	68.3	228.4	0.23	415.4	74.1	341.4	0.18	512.6	100.7	411.9	0.20
1997	929.1	216.3	712.8	0.23	1380.2	234.6	1145.6	0.17	2231.5	573.5	1658.0	0.26
1998	188.7	49.6	139.1	0.26	367.3	76.8	290.5	0.21	432.3	127.9	304.4	0.30
1999	278.9	50.7	228.2	0.18	201.4	53.7	147.7	0.27	246.5	91.0	155.5	0.37
2000	174.5	25.3	149.2	0.14	113.7	56.1	57.6	0.49	134.5	56.2	78.3	0.42
2001	405.3	107.3	298.1	0.26	535.0	117.5	417.5	0.22	792.4	215.5	576.9	0.27
2002	307.4	57.0	250.4	0.19	239.7	55.8	184.0	0.23	288.5	103.7	184.7	0.36
2003	214.7	40.5	174.3	0.19	222.0	76.9	145.1	0.35	231.8	96.4	135.3	0.42
2004	514.9	122.0	392.9	0.24	281.0	67.6	213.4	0.24	354.8	98.9	255.9	0.28

Appendix 1. Hydrographic separation results for long-term annual streamflow amounts measured at selected U.S. Geological Survey (USGS) streamflow-gaging stations in the upper Brazos River Basin, Texas.—Continued

[DMF, Double Mountain Fork; Q, annual mean streamflow; ft^3/s, cubic feet per second; BF, base flow; RO, runoff; BFI, base-flow index (defined as BF/Q); -, no data available]

	USGS station 08088000 Brazos River near South Bend, Tex.				USGS station 08089000 Brazos River near Palo Pinto, Tex.				USGS station 08090800 Brazos River near Dennis, Tex.			
Water year	Q (ft^3/s)	BF (ft^3/s)	RO (ft^3/s)	BFI	Q (ft^3/s)	BF (ft^3/s)	RO (ft^3/s)	BFI	Q (ft^3/s)	BF (ft^3/s)	RO (ft^3/s)	BFI
2005	1278.2	244.8	1033.4	0.19	1137.9	204.7	933.2	0.18	1006.4	270.6	735.7	0.27
2006	203.8	74.4	129.4	0.37	261.6	89.8	171.8	0.34	250.4	114.5	135.9	0.46
2007	1376.9	305.0	1071.9	0.22	1736.9	218.7	1518.3	0.13	2497.2	432.3	2064.9	0.17
2008	264.4	93.3	171.1	0.35	293.2	92.6	200.6	0.32	444.7	126.6	318.1	0.28
2009	160.7	68.4	92.3	0.43	141.3	86.2	55.0	0.61	177.7	88.5	89.2	0.50
Mean	**672.4**	**166.5**	**505.9**	**0.26**	**772.8**	**139.7**	**633.0**	**0.21**	**978.4**	**234.5**	**743.9**	**0.28**
Median	**474.6**	**118.1**	**367.1**	**0.24**	**531.2**	**91.2**	**449.0**	**0.19**	**630.3**	**208.6**	**497.2**	**0.27**
Minimum	**160.7**	**25.3**	**92.3**	**0.03**	**98.5**	**23.6**	**55.0**	**0.04**	**120.0**	**32.0**	**78.3**	**0.06**
Maximum	**2965.7**	**879.3**	**2086.4**	**0.56**	**3339.4**	**844.2**	**2617.4**	**0.61**	**4139.2**	**1122.7**	**3829.6**	**0.50**

Appendix 1. Hydrographic separation results for long-term annual streamflow amounts measured at selected U.S. Geological Survey (USGS) streamflow-gaging stations in the upper Brazos River Basin, Texas.—Continued

[DMF, Double Mountain Fork; Q, annual mean streamflow; ft^3/s, cubic feet per second; BF, base flow; RO, runoff; BFI, base-flow index (defined as BF/Q); -, no data available]

	USGS station 08091000 Brazos River near Glen Rose, Tex.				USGS station 08091500 Paluxy River at Glen Rose, Tex.			
Water year	Q (ft^3/s)	BF (ft^3/s)	RO (ft^3/s)	BFI	Q (ft^3/s)	BF (ft^3/s)	RO (ft^3/s)	BFI
1966	1870.1	360.7	1509.3	0.19	49.7	12.4	37.3	0.25
1967	677.7	189.7	488.0	0.28	23.2	7.3	15.9	0.31
1968	1743.5	461.5	1282.0	0.26	195.0	57.7	137.4	0.30
1969	1606.0	335.3	1270.7	0.21	121.7	59.4	62.3	0.49
1970	888.8	94.0	794.9	0.11	109.9	57.1	52.8	0.52
1971	330.4	84.6	245.8	0.26	28.5	11.0	17.4	0.39
1972	936.7	346.5	590.2	0.37	74.4	21.9	52.5	0.29
1973	1222.0	312.7	909.3	0.26	123.9	32.6	91.4	0.26
1974	277.4	88.8	188.6	0.32	17.4	10.5	6.9	0.60
1975	1921.5	422.9	1498.6	0.22	69.1	30.8	38.3	0.45
1976	342.0	64.2	277.7	0.19	39.1	8.1	31.0	0.21
1977	915.8	230.4	685.4	0.25	94.9	33.3	61.6	0.35
1978	676.5	57.6	618.9	0.09	8.8	5.1	3.7	0.58
1979	769.1	146.7	622.4	0.19	103.7	21.9	81.8	0.21
1980	284.7	56.5	228.2	0.20	14.7	6.4	8.3	0.44
1981	942.9	187.4	755.5	0.20	8.7	2.9	5.7	0.34
1982	4384.0	240.7	4143.3	0.05	98.3	29.2	69.1	0.30
1983	374.5	31.4	343.1	0.08	10.1	7.6	2.5	0.75
1984	262.5	11.8	250.7	0.04	6.2	2.3	4.0	0.36
1985	1076.4	139.7	936.7	0.13	37.3	10.4	26.9	0.28
1986	736.2	84.7	651.5	0.12	76.2	9.4	66.9	0.12
1987	2365.0	607.1	1757.9	0.26	75.8	30.1	45.7	0.40
1988	115.2	33.0	82.2	0.29	17.1	5.5	11.6	0.32
1989	1424.2	77.6	1346.6	0.05	203.0	22.5	180.5	0.11
1990	3252.1	960.0	2292.1	0.30	193.8	60.8	133.0	0.31
1991	1277.4	114.2	1163.2	0.09	29.0	17.8	11.3	0.61
1992	4605.1	749.3	3855.9	0.16	361.3	121.5	239.9	0.34
1993	551.3	180.1	371.2	0.33	78.0	54.0	24.0	0.69
1994	643.2	90.4	552.7	0.14	56.1	18.9	37.2	0.34
1995	1033.8	143.1	890.7	0.14	235.0	60.3	174.7	0.26
1996	486.0	48.1	437.8	0.10	34.2	18.7	15.5	0.55
1997	2774.5	677.0	2097.5	0.24	244.4	96.0	148.4	0.39
1998	656.0	82.1	573.9	0.13	99.1	33.8	65.4	0.34
1999	196.3	55.2	141.1	0.28	19.5	10.5	9.0	0.54
2000	122.8	25.8	97.0	0.21	17.3	5.8	11.5	0.33
2001	1074.6	310.8	763.8	0.29	106.0	48.2	57.8	0.45
2002	326.3	54.1	272.2	0.17	58.1	24.4	33.6	0.42
2003	169.8	36.9	132.9	0.22	29.0	16.9	12.1	0.58
2004	473.6	44.4	429.3	0.09	67.2	18.2	49.0	0.27

Appendix 1. Hydrographic separation results for long-term annual streamflow amounts measured at selected U.S. Geological Survey (USGS) streamflow-gaging stations in the upper Brazos River Basin, Texas.—Continued

[DMF, Double Mountain Fork; Q, annual mean streamflow; ft^3/s, cubic feet per second; BF, base flow; RO, runoff; BFI, base-flow index (defined as BF/Q); -, no data available]

	USGS station 08091000 Brazos River near Glen Rose, Tex.				USGS station 08091500 Paluxy River at Glen Rose, Tex.			
Water year	Q (ft^3/s)	BF (ft^3/s)	RO (ft^3/s)	BFI	Q (ft^3/s)	BF (ft^3/s)	RO (ft^3/s)	BFI
2005	983.3	192.3	791.0	0.20	59.3	39.4	19.9	0.66
2006	218.4	27.3	191.1	0.13	23.1	3.4	19.7	0.15
2007	2910.3	556.4	2353.8	0.19	263.6	55.9	207.8	0.21
2008	406.5	77.7	328.8	0.19	43.5	18.3	25.3	0.42
2009	73.8	27.6	46.2	0.37	11.3	4.5	6.8	0.40
Mean	**1099.5**	**207.2**	**892.3**	**0.19**	**82.6**	**27.8**	**54.8**	**0.38**
Median	**752.7**	**104.1**	**620.7**	**0.19**	**58.7**	**18.8**	**35.4**	**0.35**
Minimum	**73.8**	**11.8**	**46.2**	**0.04**	**6.2**	**2.3**	**2.5**	**0.11**
Maximum	**4605.1**	**960.0**	**4143.3**	**0.37**	**361.3**	**121.5**	**239.9**	**0.75**

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