Prepared in cooperation with the Texas Water Development Board

Trends in Selected Streamflow Statistics at 19 Long-Term Streamflow-Gaging Stations Indicative of Outflows from Texas to Arkansas, Louisiana, Galveston Bay, and the Gulf of Mexico, 1922–2009

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U.S. Department of the Interior
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Background, Looking towards the right bank of the Sabine River during a flood measurement at streamflow-gaging station 08030500 - Sabine River near Ruliff, Texas, on October 23, 2006. Photograph by Doug McGhee, U.S. Geological Survey.

Front cover:

Left, Discharge measurement at streamflow-gaging station 08117500 - San Bernard River near Boling, Texas. Photograph by Mac Cherry, U.S. Geological Survey on April 1, 2007.

Right, Gage shelter raised above 200-year flood-plain level at 08114000 - Brazos River at Richmond, Texas, January 15, 2007. Photograph by Joe Stuart, U.S. Geological Survey.

Back cover:

Left, U.S. Geological Survey streamflow-gaging station 08475000 - Rio Grande near Brownsville, Texas, August 18, 2010. Photograph by Jaimie Ingold, U.S. Geological Survey.

Right, Gage shelter and wire-weight gage at 08041000 - Neches River near Evadale, Texas. Photograph by Joe Stuart, November 17, 2006.

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
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).

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

Trends in Selected Streamflow Statistics at 19 Long-Term Streamflow-Gaging Stations Indicative of Outflows from Texas to Arkansas, Louisiana, Galveston Bay, and the Gulf of Mexico, 1922–2009

By Dana L. Barbie and Loren L. Wehmeyer

Abstract

Trends in selected streamflow statistics during 1922–2009 were evaluated at 19 long-term streamflow-gaging stations considered indicative of outflows from Texas to Arkansas, Louisiana, Galveston Bay, and the Gulf of Mexico. The U.S. Geological Survey, in cooperation with the Texas Water Development Board, evaluated streamflow data from streamflow-gaging stations with more than 50 years of record that were active as of 2009. The outflows into Arkansas and Louisiana were represented by 3 streamflow-gaging stations, and outflows into the Gulf of Mexico, including Galveston Bay, were represented by 16 streamflow-gaging stations. Monotonic trend analyses were done using the following three streamflow statistics generated from daily mean values of streamflow: (1) annual mean daily discharge, (2) annual maximum daily discharge, and (3) annual minimum daily discharge. The trend analyses were based on the nonparametric Kendall's Tau test, which is useful for the detection of monotonic upward or downward trends with time. A total of 69 trend analyses by Kendall's Tau were computed—19 periods of streamflow multiplied by the 3 streamflow statistics plus 12 additional trend analyses because the periods of record for 2 streamflow-gaging stations were divided into periods representing pre- and post-reservoir impoundment. Unless otherwise described, each trend analysis used the entire period of record for each streamflow-gaging station. The monotonic trend analysis detected 11 statistically significant downward trends, 37 instances of no trend, and 21 statistically significant upward trends. One general region studied, which seemingly has relatively more upward trends for many of the streamflow statistics analyzed, includes the rivers and associated creeks and bayous to Galveston Bay in the Houston metropolitan area. Lastly, the most western river basins considered (the Nueces and Rio Grande) had statistically significant downward trends for many of the streamflow statistics analyzed.

Introduction

The major river basins in Texas include the Red River, Sabine River, Neches River, Trinity River, San Jacinto River, Brazos River, Colorado River, Guadalupe River, San Antonio River, Nueces River, and the Rio Grande (fig. 1). The Red River flows into Arkansas and then into Louisiana; one of its tributaries (Big Cypress Creek) flows directly from Texas into Louisiana. The Sabine, Neches, Brazos, San Bernard, Colorado, Guadalupe, and Nueces Rivers and the Rio Grande flow directly into the Gulf of Mexico. The Trinity and San Jacinto Rivers flow into Galveston Bay, which is part of the Gulf of Mexico. Fresh surface-water usage in Texas is about two-thirds of the total freshwater usage in Texas (Kenny and others, 2009, p. 6). As a result, studies of streamflow statistics for outflows from Texas are useful in resource assessments, such as water-supply studies, as well as useful to hydrologists, biologists, and ecologists. Accordingly, the U.S. Geological Survey (USGS), in cooperation with the Texas Water Development Board, evaluated streamflow data from streamflow-gaging stations with more than 50 years of record that were active as of 2009.

Purpose and Scope

The purpose of this report is to assess monotonic trends in streamflow to determine whether statistically significant monotonic changes in selected streamflow statistics have occurred over time for streamflow records likely indicative of outflows from Texas. Streamflow data were evaluated and annual streamflow statistics were computed for 18 selected USGS stations and one International Boundary Water Commission (IBWC) station with more than 50 years of record and active as of 2009. Examination of historical patterns, cycles, and possible reasons for the trends in streamflow such as trends in precipitation, changes in quantified water use, reservoir operation, or other

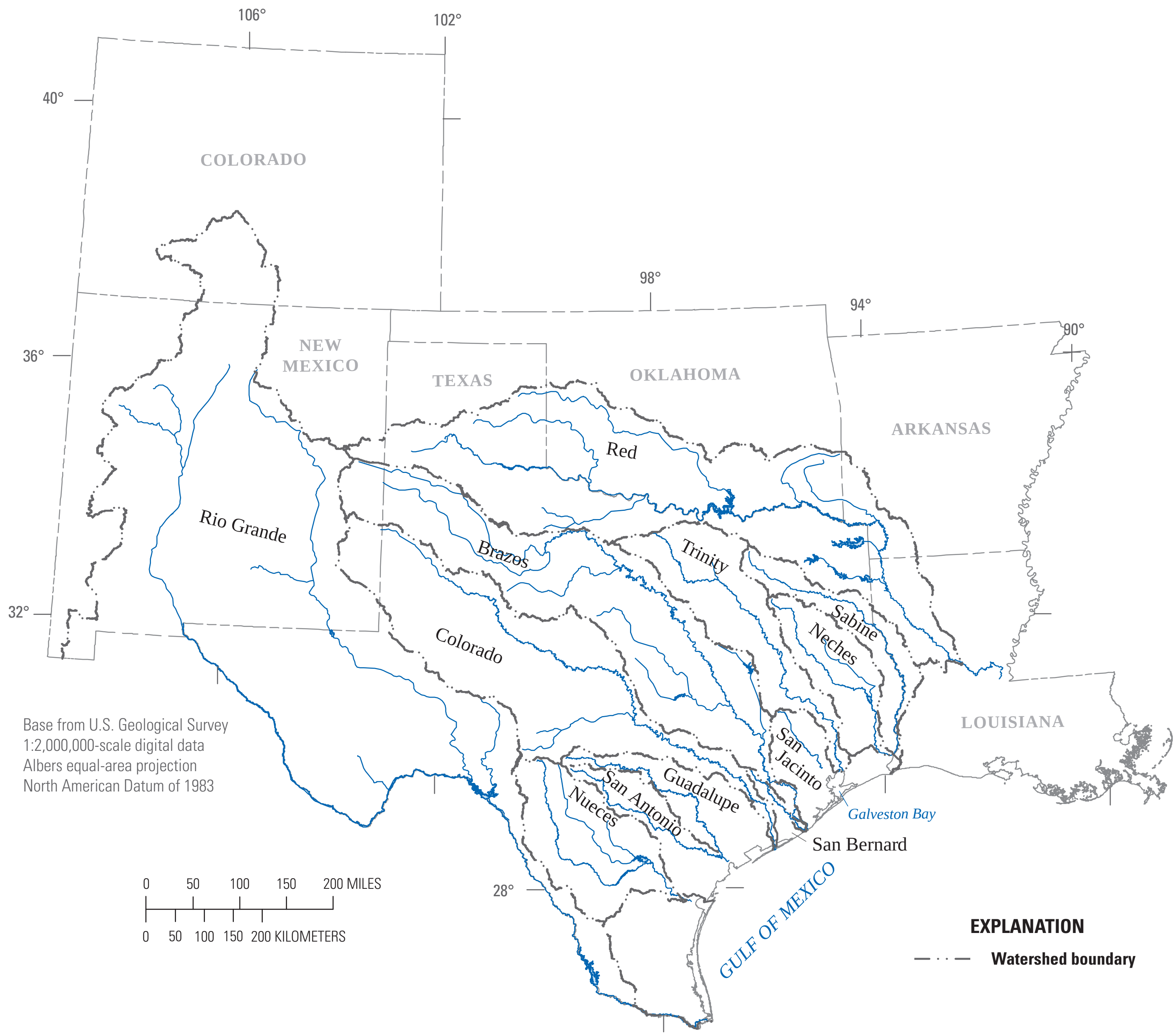

Figure 1. Basin boundaries for major rivers in Texas that outflow to Arkansas, Louisiana, Galveston Bay, and the Gulf of Mexico.

human-related changes, or the effects of direct groundwater contributions (gains or losses) to streamflow was beyond the scope of this study.

Description of Study Area

Streamflow outflow from Texas occurs in the eastern part of the State. The locations of streamflow-gaging stations and selected reservoirs discussed in this report are shown in figure 2.

The stations used for this study, along with ancillary information pertaining to each station including the period of record, are listed in table 1. Collectively, the stations discussed in this report monitor streamflow from Texas into Arkansas, Louisiana, Galveston Bay (and subsequently the Gulf of Mexico), and the Gulf of Mexico directly. Outflow trends to Arkansas were evaluated using two stations (table 1, Outflows to Arkansas). Outflow trends to Louisiana were evaluated using one station (table 1, Outflows to Louisiana). Outflow trends to the Gulf of Mexico on the upper coast (near Louisiana) were computed at two stations (table 1, Outflows to upper coast Gulf of Mexico). Outflow trends to the Gulf of Mexico through Galveston Bay were computed using eight stations (table 1, Outflows to Gulf of Mexico through Galveston Bay). Outflow trends to the Gulf of Mexico on the middle coast were computed at three stations (table 1, Outflows to middle-coast Gulf of Mexico). Lastly, outflow trends to the Gulf of Mexico on the lower coast were computed at three stations (table 1, Outflows to lower-coast Gulf of Mexico).

Previous Studies

Several statistical and historical summaries of streamflow data in Texas have previously been done by the USGS (Asquith and others, 2007a, 2007b; Asquith and Heitmuller, 2008). Lanning-Rush (2000) also provided regional regression equations to estimate mean annual discharge (the arithmetic mean of the annual mean discharges) as well as mean seasonal discharge for unmonitored stream sites throughout Texas. Lastly, Asquith (2001) did a statewide study on the effects of flood-control regulation on statistics of annual peak streamflow time series for hundreds of streamflow-gaging stations in Texas.

Methods

Streamflow data were evaluated and annual streamflow statistics were computed for 19 streamflow-gaging stations consisting of 18 USGS stations and 1 IBWC station with more than 50 years of record and active since 2009. Streamflow data used in this study are published in the USGS National Water Information System (U.S. Geological Survey, 2012a) with the exception of the streamflow data for the Rio Grande near Brownsville, Tex., station that is assigned an eight-digit station identification number consistent with USGS station numbers but is operated by the IBWC. Streamflow data collected at the Rio Grande station are published by the IBWC (International Boundary and Water Commission, 2012).

The daily mean discharges for each station (365 to 366 values per year) were used in the analyses. These data were subsequently converted to the annual streamflow statistics of (1) annual mean daily discharge, (2) annual maximum daily discharge, and (3) annual minimum daily discharge.

The Kendall’s Tau statistical test was used to detect monotonic trends in annual mean daily, annual maximum daily, and annual minimum daily streamflow over time (Helsel and Hirsch, 2002). Specifically, the test uses the relation (trend) between time and ranked discharges as opposed to discharge magnitude. The trend analyses reported in this report thus refer to the direction and not the magnitude of streamflow change. A statistically significant positive Kendall’s Tau value indicates an upward monotonic streamflow trend; conversely, a statistically significant negative Tau indicates a downward monotonic streamflow trend. The probability value or p-value of Kendall’s Tau is a measure of the statistical significance of the trend. For this study, a p-value of less than 0.05 indicates a statistically significant trend, whereas, a p-value of 0.05 or greater indicates no significant trend.

Annual mean daily discharge is computed as the average of all the 365 or 366 daily discharges during a water year (a water year is defined as the 12-month period from October 1 to September 30). The annual minimum daily discharge is the discharge on the day of lowest daily mean discharge in a given water year. The annual maximum daily discharge is the discharge on the day of largest daily mean discharge in a given water year. The software package Statistica (StatSoft, 2009) was used to calculate the Kendall’s Tau test statistic. For each station, Kendall’s Tau statistics were computed using the three streamflow statistics calculated for each station (annual mean, maximum, and minimum daily streamflow). The period of records evaluated for each station is listed in table 1.

A total of 69 trend analyses by Kendall’s Tau were computed—19 periods of streamflow from USGS or IBWC stations multiplied by 3 streamflow statistics plus 12 additional trend analyses because the periods of record for 2 USGS stations were analyzed for trends pre- and post-reservoir impoundment, resulting in 4 periods of streamflow multiplied by 3 streamflow statistics. The period of post-reservoir impoundment was defined as when at least 10 percent of contributing drainage area was regulated. Unless otherwise indicated, each trend analysis used the entire period of record for each station. Some additional remarks concerning methods and decisions made for the presentation of the trend analysis results are required. There are many stations with one or more upstream reservoirs. However, for circumstances in which there were no changes in streamflow trends pre- or post-reservoir impoundment, the entire period of record was used for the trend analysis. Also, there are circumstances in which a reservoir was impounded near the beginning of the streamflow record—leaving perhaps only a few years prior to

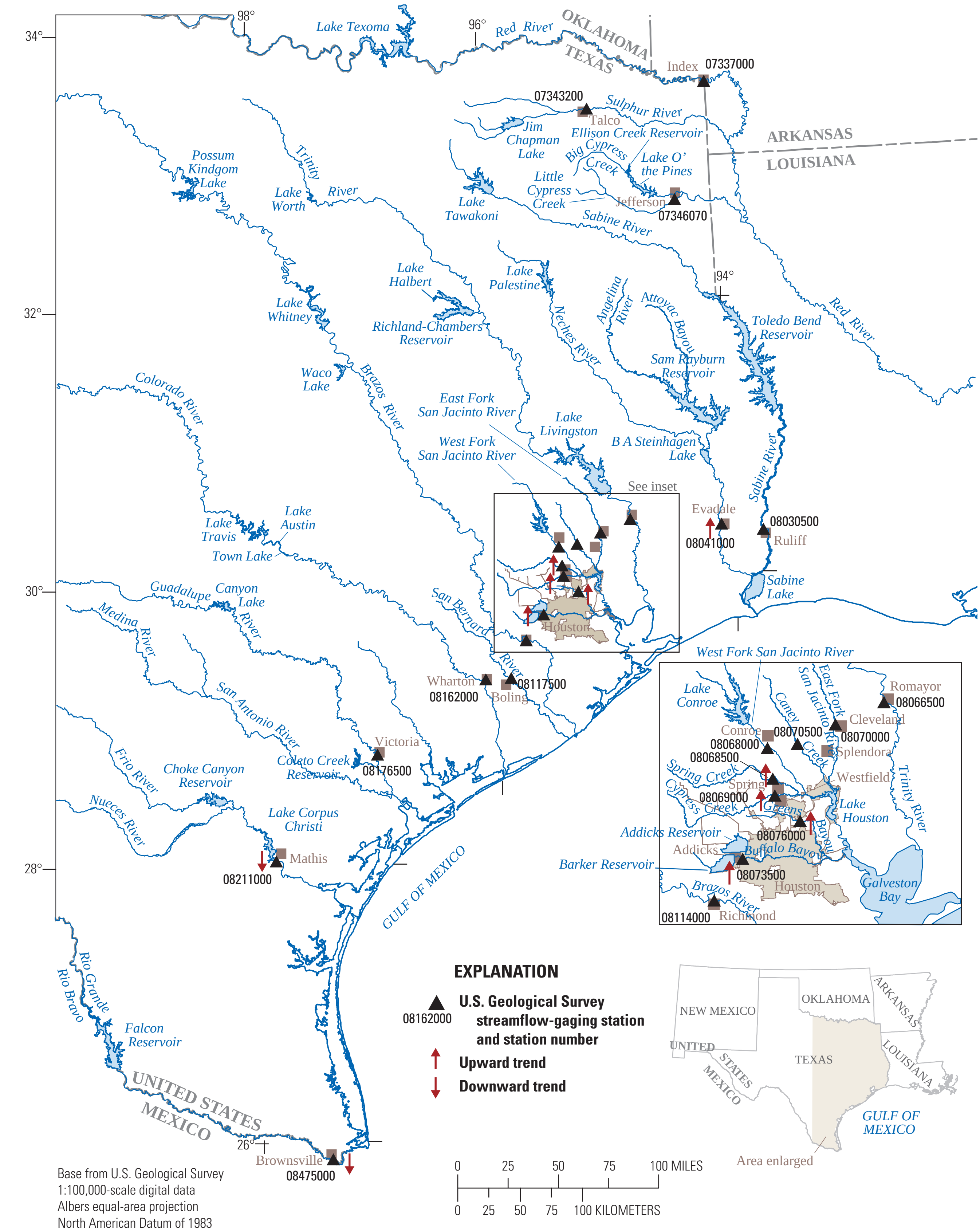

Figure 2. Statistically-significant trends in the annual mean daily discharge for the period of record through 2009 for streamflow-gaging stations with more than 50 years of record indicative of outflows from Texas.

Table 1. Selected U.S. Geological Survey or International Boundary and Water Commission streamflow-gaging stations with more than 50 years of record that were used to assess trends in outflows from Texas to Arkansas, Louisiana, and the Gulf of Mexico.

[mi; square miles; --, not applicable]

Station number	Station name	Period of record[1]	Year of first substantial reservoir impoundment[2]	Latitude (decimal degrees)	Longitude (decimal degrees)	Drainage area (mi²)	Contributing drainage area (mi²)
Outflows to Arkansas (Red and Sulphur River Basins—table 2)							
07337000	Red River at Index, Ark.	1937–2009	1943	33.55207	94.04130	48,030	42,094
07343200	Sulphur River near Talco, Tex.	1957–2009	1991	33.39067	95.06244	1,405	1,405
Outflows to Louisiana (Little Cypress Creek Basin—table 3)							
07346070	Little Cypress Creek near Jefferson, Tex.	1947–2009	--	32.71292	94.34603	675	675
Outflows to the upper coast of the Gulf of Mexico (Sabine and Neches River Basins—table 4)							
08030500	Sabine River near Ruliff, Tex.	1925–2009	1961	30.30382	93.74378	9,329	9,329
08041000	Neches River at Evadale, Tex.	1922–2009	1951	30.35576	94.09324	7,951	7,951
Outflows to the Gulf of Mexico through Galveston Bay (Trinity and San Jacinto River Basins, and Associated Creeks and Bayous—table 5)							
08066500	Trinity River at Romayor, Tex.	1925–2009	before 1925	30.42521	94.85076	17,186	17,186
08068000	West Fork San Jacinto River near Conroe, Tex.	1940–2009	1973	30.24466	95.45716	828	828
08068500	Spring Creek near Spring, Tex.	1940–2009	--	30.11050	95.43633	409	409
08069000	Cypress Creek near Westfield, Tex.	1945–2009	--	30.03578	95.42883	285	285
08070000	East Fork San Jacinto River near Cleveland, Tex.	1940–2009	--	30.33660	95.10410	325	325
08070500	Caney Creek near Splendora, Tex.	1945–2009	--	30.25966	95.30244	105	105
08073500	Buffalo Bayou near Addicks, Tex.	1946–2009	before 1946	29.76190	95.60578	277	277
08076000	Greens Bayou near Houston, Tex.	1953–2009	--	29.91828	95.30688	69	69
Outflows to the middle coast of the Gulf of Mexico (Brazos, Sen Bernard, and Colorado River Basins—table 6)							
08114000	Brazos River at Richmond, Tex.	1923–2009	1941	29.58246	95.75773	45,107	35,541
08117500	San Bernard River near Boling, Tex.	1955–2009	--	29.31358	95.89384	727	727
08162000	Colorado River at Wharton, Tex.	1939–2009	before 1939	29.30914	96.10385	42,003	30,600
Outflows to the lower coast of the Gulf of Mexico (Guadalupe and Nueces River Basins, and Rio Grande Basin—table 7)							
08176500	Guadalupe River at Victoria, Tex.	1936–2009	before 1936	28.79305	97.01304	5,198	5,198
08211000	Nueces River near Mathis, Tex.	1940–2009	before 1940	28.03835	97.86028	16,503	16,503
08475000	Rio Grande near Brownsville, Tex.[3]	1935–2009	1953	25.87675	97.45443	176,333	176,333

[1]Period of record is shown in water years; a water year is defined as the 12-month period October 1 through September 30 designated by the calendar year in which it ends.

[2]Year reservoir impoundment first appreciably affected streamflow (Dowell, 1964).

[3]Station operated by the International Boundary and Water Commission. All other stations are operated by the U.S. Geological Survey.

impoundment—for this study, the entire period of record was used for the trend analysis. Lastly, time series plots of annual mean daily discharge for six selected stations are provided to illustrate this streamflow statistic. Similar plots to the time series figures introduced later can be readily generated through the USGS National Water Information System Web (NWISWeb) Internet portal (http://waterdata.usgs.gov).

Table 1 lists the year of the first large reservoir impoundment upstream from the station. For several stations, this year predates the activation of the station, for example USGS streamflow-gaging station 082111000 Nueces River near Mathis, Tex. However, for two stations, where the period of record was sufficient and the effect of impoundment on streamflow characteristics was evident (USGS streamflow-gaging station 08041000 Neches River at Evadale, Tex., and IBWC streamflow-gaging station 08475000 Rio Grande near Brownsville, Tex.), the streamflow record was divided into pre- and post-impoundment periods. Trend analysis subsequently was performed for the entire period of record, including the years before reservoir impoundment.

Trends in Selected Streamflow Statistics

This section is divided into six subsections that correspond to logical and convenient groupings of stations. Each section provides salient but limited background, summarizes the stations involved, and concludes with reporting of the analysis to detect monotonic trends for each of the three streamflow statistics.

For the overall assessment in trends in selected streamflow statistics during 1922–2009 at 19 long-term streamflow-gaging stations considered indicative of outflows from Texas to Arkansas, Louisiana, Galveston Bay, and the Gulf of Mexico, monotonic trend analysis detected 11 statistically significant downward trends, 37 instances of no trend, and 21 statistically significant upward trends. Annual mean daily discharge is especially diagnostic because this statistic can be used to compute mean annual discharge over long periods of time and represents the expectation of the annual volume of water measured by a station and, therefore, water yields from a basin. Trends in annual mean daily discharge can be summarized as follows; (1) annual outflow volumes from Texas into Arkansas and Louisiana as well as the Gulf of Mexico (upper Texas coast) lack statistically significant trends; (2) annual inflows into Galveston Bay (Houston metropolitan area) show upward trends for four of eight stations; (3) annual outflow volumes from the Brazos River (east of Houston metropolitan area) to the Guadalupe River lack statistically significant trends; and (4) annual outflow volumes from the two most westerly stations on the Nueces River and Rio Grande show downward trends.

Outflows to Arkansas (Red and Sulphur River Basins)

Streamflows at USGS streamflow-gaging stations 07337000 Red River at Index, Ark. (Red River at Index station), and 07343200 Sulphur River near Talco, Tex. (Sulphur River near Talco station), are indicative of outflow from Texas to Arkansas. After exiting Texas and flowing through the southwest corner of Arkansas, the Sulphur River flows into the Red River in Louisiana.

The Red River at Index station is located at the Texas-Arkansas State boundary in far northeast Texas and is more than 500 miles downstream from the Red River's headwaters in New Mexico. The Red River Basin upstream from the Red River at Index station includes parts of New Mexico, Texas, and Oklahoma. A particularly important reservoir in terms of its effect on regulating flow in the Red River is Lake Texoma on the Texas–Oklahoma border. Since 1944, Lake Texoma, which is about 241 miles upstream from Index, Ark., has potentially affected general streamflow characteristics at the Red River at Index station (Dowell, 1964; U.S. Geological Survey, 2012b). The time period analyzed for this study is 1937–2009 (table 2), which includes a few years prior to completion of Lake Texoma. A downward trend for annual maximum daily discharge was detected at this station. A time series of the annual mean daily discharge is shown in figure 3.

The Sulphur River near the Talco station is 2.8 miles northeast of Talco, Tex. Jim Chapman Lake (fig. 2) was impounded in 1991 and has potentially affected streamflow

Table 2. Monotonic trends in outflows from the Red and Sulphur River Basins in Texas, 1937–2009.

[USGS, U.S. Geological Survey; p-value, probability value; <, less than; --, no statistically significant trend was detected (p-value <0.05)]

USGS station number	USGS station name	Time period analyzed	Streamflow statistic (discharge)	Kendall's tau	p-value	Trend direction
07337000	Red River at Index, Ark.	1937–2009	Annual mean daily	0.04	0.65	--
07337000	Red River at Index, Ark.	1937–2009	Annual maximum daily	-0.25	<0.05	downward
07337000	Red River at Index, Ark.	1937–2009	Annual minimum daily	0.10	0.20	--
07343200	Sulphur River near Talco, Tex.	1957–2009	Annual mean daily	-0.13	0.17	--
07343200	Sulphur River near Talco, Tex.	1957–2009	Annual maximum daily	-0.18	0.054	--
07343200	Sulphur River near Talco, Tex.	1957–2009	Annual minimum daily	0.33	<0.05	upward

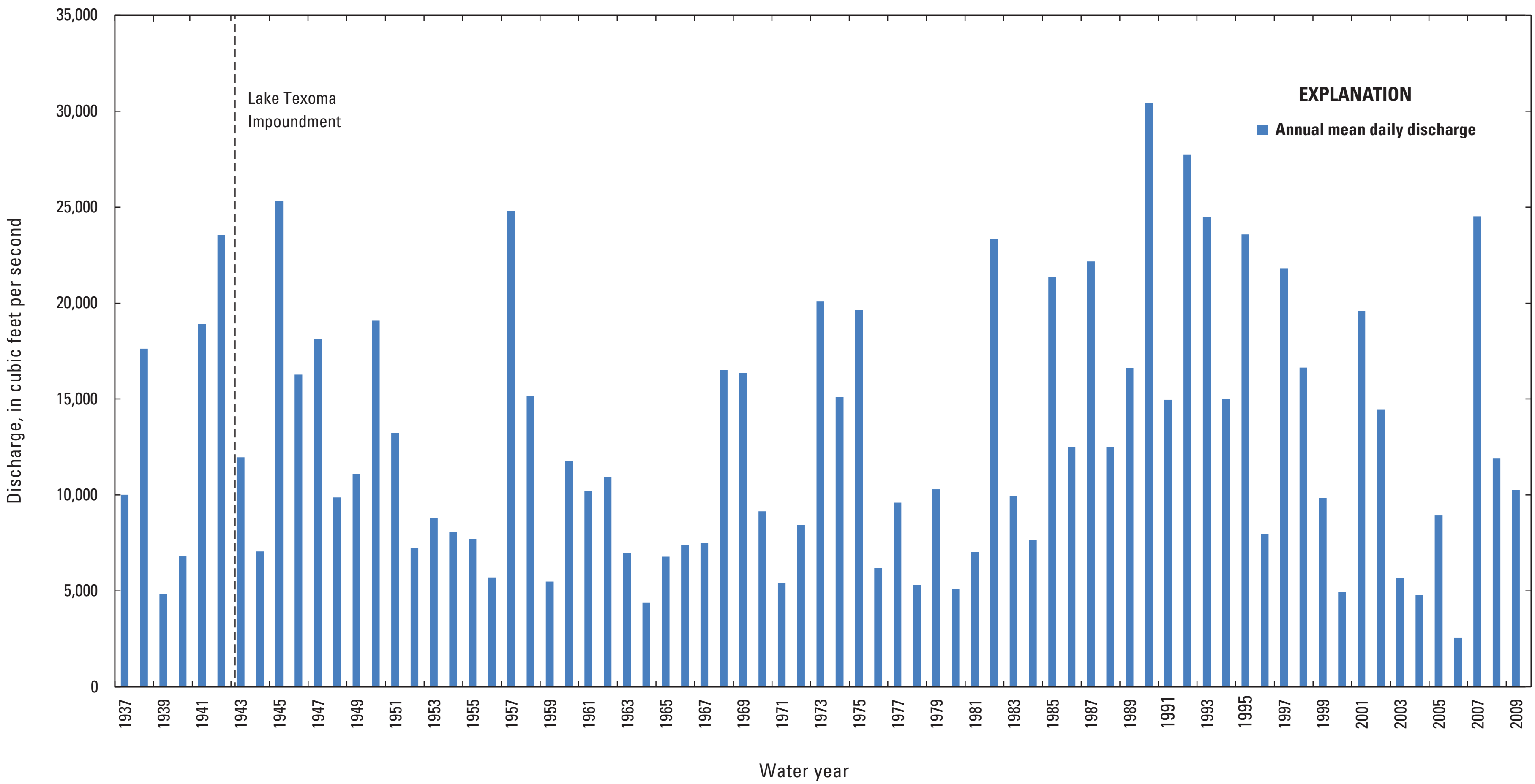

Figure 3. Annual mean daily discharge for the period of record through 2009 for U.S. Geological Survey streamflow-gaging station 07337000 Red River at Index, Arkansas.

characteristics of the Sulphur River since its impoundment (U.S. Geological Survey, 2012b). The station is about 35 miles downstream from Jim Chapman Lake and about 70 miles upstream from Texas-Louisiana State boundary. The time period analyzed for this study is 1957–2009 (table 2). An upward trend for annual minimum daily discharge was detected at this station.

Outflows to Louisiana (Little Cypress Creek Basin)

Streamflow at USGS streamflow-gaging station 07346070 Little Cypress Creek near Jefferson, Tex. (Little Cypress Creek station), is indicative of the unregulated contribution to outflows from Texas to Louisiana through Big Cypress Creek, the only stream in Texas that flows directly into Louisiana. Little Cypress Creek flows into the Big Cypress Creek, which flows into the Red River in Louisiana (fig. 2). Little Cypress Creek streamflows were analyzed for trends because Big Cypress Creek has been highly regulated by Lake O' the Pines after it was impounded in 1958 (Dowell, 1964; U.S. Geological Survey, 2012b). The streamflow in Little Cypress Creek can be considered reasonably natural. Most streams in Texas are affected by regulation, but Little Cypress Creek represents one of the few opportunities to analyze for trends in a reasonably natural stream.

The Little Cypress Creek station is 3.5 miles south of Jefferson, Tex. The station is about 65 miles downstream from the headwaters of Little Cypress Creek and about 7 miles upstream from Big Cypress Creek. The time period analyzed for this study is 1947–2009 (table 3). No trends were detected in streamflow at this station.

Outflows to Upper Coast Gulf of Mexico (Sabine and Neches River Basins)

The Sabine and Neches Rivers flow directly into the Gulf of Mexico along the upper coastline of Texas. The two river basins drain the heavily forested east Texas region noted for its humid, subtropical climate (Larkin and Bomar, 1983). Three principle reservoirs are Toledo Bend Reservoir on the Sabine River (impounded in 1966), Sam Rayburn Reservoir on a tributary to the Neches River (impounded in 1965), and B.A. Steinhagen Lake on the Neches River (impounded in 1951) (fig. 2); other reservoirs depicted on figure 2 include Lake Tawakoni on the Sabine River (impounded in 1960) and Lake Palestine on the Neches River (impounded in 1962) (Dowell, 1964; U.S. Geological Survey, 2012b).

USGS streamflow-gaging station 08030500 Sabine River near Ruliff, Tex. (Sabine River near Ruliff station), is about 2 miles north of Ruliff and about 45 miles upstream from the mouth with Sabine Lake that in turn drains into the Gulf of Mexico. This station is about 300 miles downstream from the headwaters of the Sabine River. Streamflow in the Sabine River has been potentially affected by regulated outflows from Lake Tawakoni (fig. 2) since 1961 (Dowell, 1964; U.S. Geological Survey, 2012b). More importantly, the station is about 50 miles downstream from the relatively large Toledo Bend Reservoir. The time period analyzed was 1925–2009 (table 4). An upward trend for annual minimum daily discharge was detected at this station.

USGS streamflow-gaging station 08041000 Neches River at Evadale, Tex. (Neches River at Evadale station), is about 200 miles downstream from the headwaters of the river and about 40 miles upstream from the mouth of the river. The mouth of the Neches River empties into Sabine Lake, which drains into the Gulf of Mexico. Since 1951, streamflow in the Neches River has been appreciably regulated by B.A. Steinhagen Lake, which is about 32 miles upstream from the Neches River at Evadale station. The Sam Rayburn Reservoir on the Angelina River, a major tributary of the Neches River, is about 15 miles upstream from B.A. Steinhagen Lake (fig. 2), and has affected streamflow along the lower Neches River since 1965 (Dowell, 1964; U.S. Geological Survey, 2012b).

A time series of the annual mean daily discharge is shown in figure 4 and includes the timing of impoundment by B.A. Steinhagen Lake and Sam Rayburn Reservoir. A distinction of pre- and post-regulation at 1950 and 1951, respectively, is made for this analysis. The time periods analyzed for this study were 1922–2009, 1922–50, and 1951–2009 (table 4).

Table 3. Monotonic trends in outflows from the Little Cypress Creek Basin in Texas, 1947–2009.

[USGS, U.S. Geological Survey; p-value, probability value; <, less than; --, no statistically significant trend was detected (p-value <0.05)]

USGS station number	USGS station name	Time period analyzed	Streamflow statistic (discharge)	Kendall's tau	p-value	Trend direction
07346070	Little Cypress Creek near Jefferson, Tex.	1947–2009	Annual mean daily	0.02	0.82	--
07346070	Little Cypress Creek near Jefferson, Tex.	1947–2009	Annual maximum daily	0.01	0.88	--
07346070	Little Cypress Creek near Jefferson, Tex.	1947–2009	Annual minimum daily	0.12	0.18	--

Table 4. Monotonic trends in outflows from the Sabine and Neches River Basins in Texas, 1925–2009.

[USGS, U.S. Geological Survey; p-value, probability value; <, less than; --, no statistically significant trend was detected (p-value <0.05)]

USGS station number	USGS station name	Time period analyzed	Streamflow statistic (discharge)	Kendall's tau	p-value	Trend direction
08030500	Sabine River near Ruliff, Tex.	1925–2009	Annual mean daily	-0.02	0.79	--
08030500	Sabine River near Ruliff, Tex.	1925–2009	Annual maximum daily	-0.05	0.49	--
08030500	Sabine River near Ruliff, Tex.	1925–2009	Annual minimum daily	0.29	<0.05	upward
08041000	Neches River at Evadale, Tex.	1922–2009	Annual mean daily	0.0005	1.0	--
08041000	Neches River at Evadale, Tex.	1922–2009	Annual maximum daily	-0.16	<0.05	downward
08041000	Neches River at Evadale, Tex.	1922–2009	Annual minimum daily	0.4	<0.05	upward
08041000	Neches River at Evadale, Tex.	1922–1950	Annual mean daily	0.06	0.65	--
08041000	Neches River at Evadale, Tex.	1922–1950	Annual maximum daily	0.02	0.85	--
08041000	Neches River at Evadale, Tex.	1922–1950	Annual minimum daily	0.14	0.27	--
08041000	Neches River at Evadale, Tex.	1951–2009	Annual mean daily	0.23	<0.05	upward
08041000	Neches River at Evadale, Tex.	1951–2009	Annual maximum daily	0.04	0.67	--
08041000	Neches River at Evadale, Tex.	1951–2009	Annual minimum daily	0.46	<0.05	upward

A downward trend for annual maximum daily discharge and conversely an upward trend for annual minimum daily discharge were detected for Neches River at Evadale station for the period 1922–2009 (period of record). No trends were detected for the Neches River at Evadale, Tex., station for the period 1922–50; however, upward trends for annual mean daily and annual minimum daily discharge were detected for the period 1951–2009.

Outflows to Gulf of Mexico through Galveston Bay (Trinity and San Jacinto Rivers and Associated Creeks and Bayous)

Galveston Bay is a large estuary on the Texas coast and has substantial and varied sources of inflow. The Trinity River, with its headwaters in north Texas adjacent to the Red River Basin (fig. 1), is the largest tributary to the bay. The Trinity River is followed in size by the San Jacinto River and its associated tributaries in the Houston metropolitan area, including West Fork San Jacinto River, Spring Creek, Cypress Creek, East Fork San Jacinto River, Caney Creek, Buffalo Bayou, and Greens Bayou.

USGS streamflow-gaging station 08066500 Trinity River at Romayor, Tex. (Trinity River at Romayor station), is about 45 miles upstream from Galveston Bay and about 300 miles downstream from the headwaters of this river. Lake Livingston, about 20 miles upstream, is the reservoir nearest the station (fig. 2) and was impounded in 1969 (U.S. Geological Survey, 2012b). The time period analyzed for the Trinity River at Romayor station is 1925–2009 (table 5). In addition to Lake Livingston, there are other reservoirs regulating flow on the Trinity River upstream from the Trinity River at Romayor station, including some that were impounded as early as 1916 (Lake Worth) and 1921 (Lake Halbert) (Texas Historical Association, 2012a, b; Dowell, 1964). An upward trend for annual minimum daily discharge was detected at the Trinity River at Romayor station. A time series of the annual mean daily discharge is shown in figure 5.

San Jacinto River flows from Lake Houston into Galveston Bay. Major inflows into Lake Houston are West Fork San Jacinto River, Spring Creek, Cypress Creek, East Fork San Jacinto River, and Caney Creek. USGS streamflow-gaging station 08068000 West Fork San Jacinto River near Conroe, Tex. (West Fork San Jacinto River near Conroe station), is about 4 miles south of Conroe. The station is about 40 miles downstream from the headwaters of the river and about 10 miles downstream from Lake Conroe. Since 1973, Lake Conroe has potentially affected streamflow in the West Fork San Jacinto River (U.S. Geological Survey, 2012b). The time period analyzed for this study is 1940–2009 (table 5). An upward trend for annual minimum daily discharge was detected at this station.

USGS streamflow-gaging station 08068500 Spring Creek near Spring, Tex. (Spring Creek near Spring station),

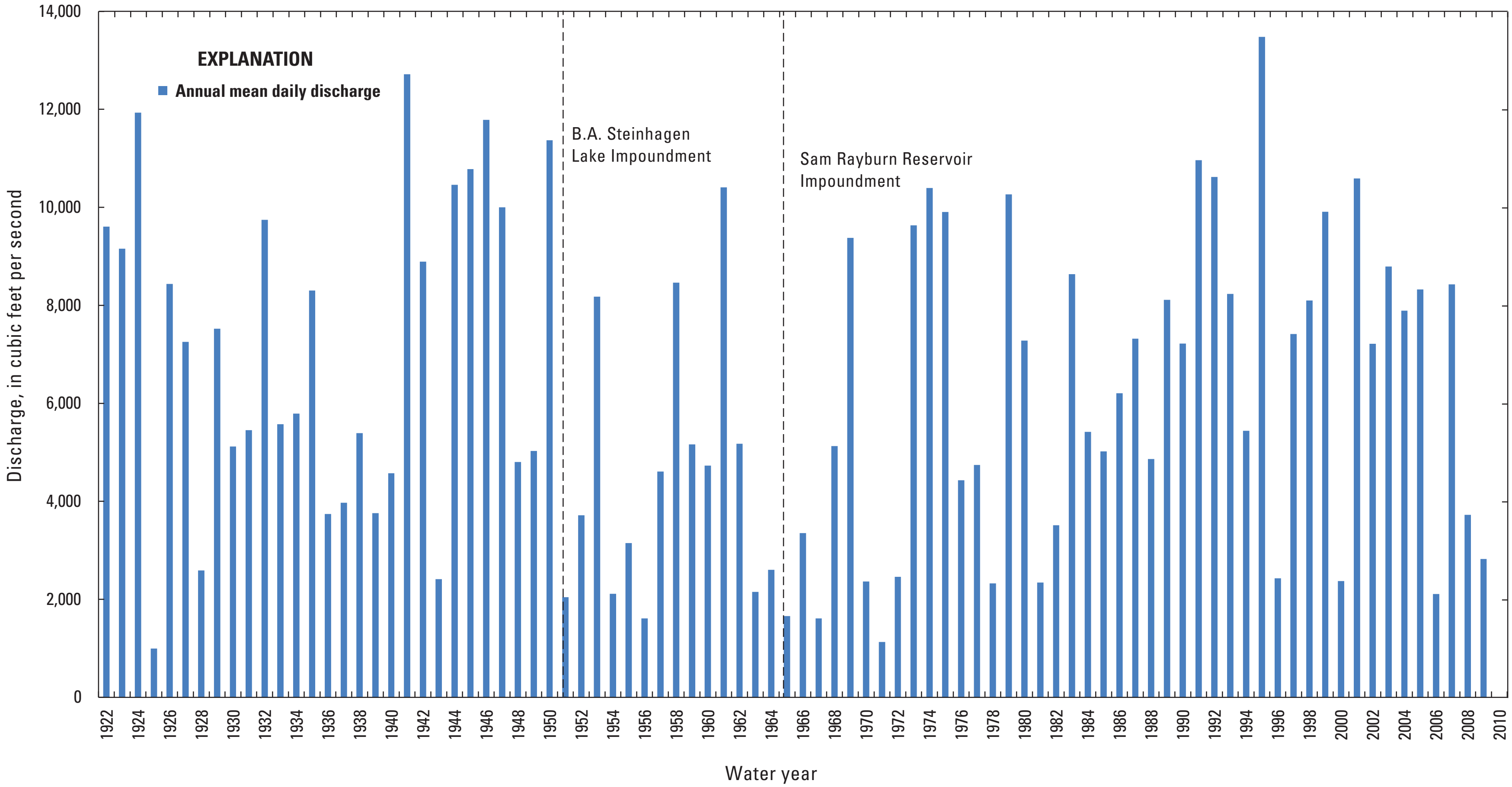

Figure 4. Annual mean daily discharge for the period of record through 2009 for U.S. Geological Survey streamflow-gaging station 08041000 Neches River at Evadale, Texas.

Table 5. Monotonic trends in outflows from the Trinity and San Jacinto River Basins and associated creeks and bayous to Galveston Bay in Texas, 1925–2009.

[USGS, U.S. Geological Survey; p-value, probability value; <, less than; --, no statistically significant trend was detected (p-value <0.05)]

USGS station number	USGS station name	Time period analyzed	Streamflow statistic (discharge)	Kendall's tau	p-value	Trend direction
08066500	Trinity River at Romayor, Tex.	1925–2009	Annual mean daily	0.09	0.25	--
08066500	Trinity River at Romayor, Tex.	1925–2009	Annual maximum daily	0.12	0.10	--
08066500	Trinity River at Romayor, Tex.	1925–2009	Annual minimum daily	0.51	<0.05	upward
08068000	West Fork San Jacinto River near Conroe, Tex.	1940–2009	Annual mean daily	0.04	0.60	--
08068000	West Fork San Jacinto River near Conroe, Tex.	1940–2009	Annual maximum daily	-0.06	0.43	--
08068000	West Fork San Jacinto River near Conroe, Tex.	1940–2009	Annual minimum daily	0.20	<0.05	upward
08068500	Spring Creek near Spring, Tex.	1940–2009	Annual mean daily	0.23	<0.05	upward
08068500	Spring Creek near Spring, Tex.	1940–2009	Annual maximum daily	0.10	0.23	--
08068500	Spring Creek near Spring, Tex.	1940–2009	Annual minimum daily	0.25	<0.05	upward
08069000	Cypress Creek near Westfield, Tex.	1945–2009	Annual mean daily	0.29	<0.05	upward
08069000	Cypress Creek near Westfield, Tex.	1945–2009	Annual maximum daily	0.20	<0.05	upward
08069000	Cypress Creek near Westfield, Tex.	1945–2009	Annual minimum daily	0.74	<0.05	upward
08070000	East Fork San Jacinto River near Cleveland, Tex.	1940–2009	Annual mean daily	0.09	0.25	--
08070000	East Fork San Jacinto River near Cleveland, Tex.	1940–2009	Annual maximum daily	-0.01	0.88	--
08070000	East Fork San Jacinto River near Cleveland, Tex.	1940–2009	Annual minimum daily	0.18	<0.05	upward
08070500	Caney Creek near Splendora, Tex.	1945–2009	Annual mean daily	0.16	0.053	--
08070500	Caney Creek near Splendora, Tex.	1945–2009	Annual maximum daily	0.09	0.27	--
08070500	Caney Creek near Splendora, Tex.	1945–2009	Annual minimum daily	0.18	<0.05	upward
08073500	Buffalo Bayou near Addicks, Tex.	1946–2009	Annual mean daily	0.34	<0.05	upward
08073500	Buffalo Bayou near Addicks, Tex.	1946–2009	Annual maximum daily	-0.19	<0.05	downward
08073500	Buffalo Bayou near Addicks, Tex.	1946–2009	Annual minimum daily	0.69	<0.05	upward
08076000	Greens Bayou near Houston, Tex.	1953–2009	Annual mean daily	0.59	<0.05	upward
08076000	Greens Bayou near Houston, Tex.	1953–2009	Annual maximum daily	0.29	<0.05	upward
08076000	Greens Bayou near Houston, Tex.	1953–2009	Annual minimum daily	0.83	<0.05	upward

is about 2 miles northeast of Spring, Tex., and northwest of Houston. The station is about 50 miles downstream from the headwaters of this stream and about 15 miles upstream from Cypress Creek. Although development has been occurring in the Spring Creek watershed for several years, the streamflow in Spring Creek was considered reasonably natural for the period of record analyzed because there are no documented impoundments on Spring Creek (U.S. Geological Survey, 2012b). The time period analyzed for this study is 1940–2009 (table 5). Upward trends for annual mean daily and annual minimum daily discharges were detected at this station.

USGS streamflow-gaging station 08069000 Cypress Creek near Westfield, Tex. (Cypress Creek near Westfield station), is about 2 miles northwest of Westfield. The station is about 55 miles downstream from the headwaters and about 11 miles upstream from West Fork San Jacinto River. The streamflow in Cypress Creek can be considered reasonably natural (U.S. Geological Survey, 2012b). The time period analyzed for this study is 1945–2009 (table 5). Upward trends in annual mean, maximum, and minimum daily discharges were detected at this station.

USGS streamflow-gaging station 08070000 East Fork San Jacinto River near Cleveland, Tex. (East Fork San Jacinto River near Cleveland station), is about 1 mile west of Cleveland, Tex. The station is about 35 miles downstream from the headwaters of the river and 20 miles upstream from

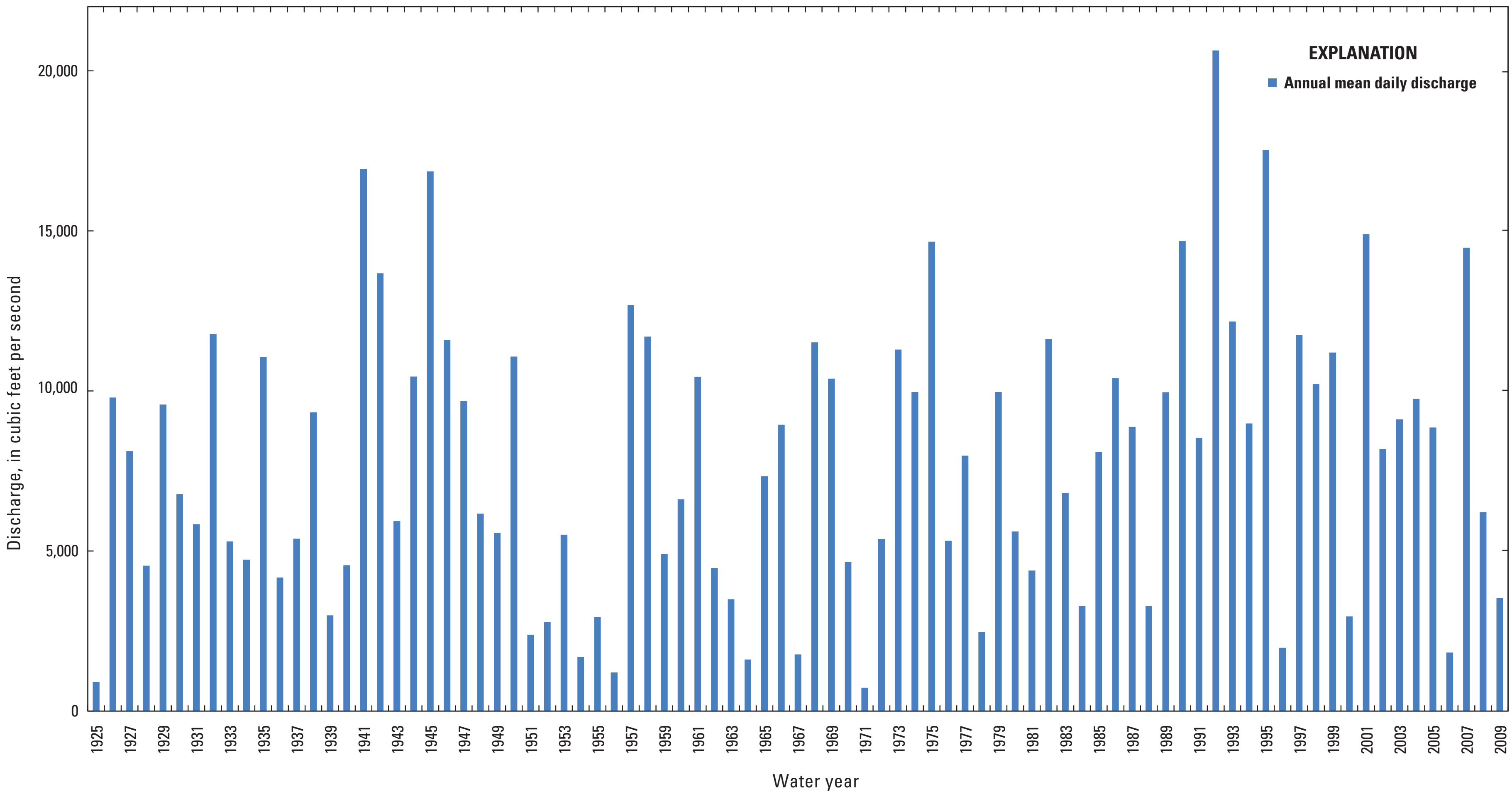

Figure 5. Annual mean daily discharge for the period of record through 2009 for U.S. Geological Survey streamflow-gaging station 08066500 Trinity River at Romayor, Texas.

Lake Houston. The streamflow in the East Fork San Jacinto River can be considered reasonably natural (U.S. Geological Survey, 2012b). The time period analyzed for this study is 1940–2009 (table 5). An upward trend for annual minimum daily discharge was detected at this station.

USGS streamflow-gaging station 08070500 Caney Creek near Splendora, Tex. (Caney Creek near Splendora station), is about 8 miles west of Splendora, Tex. The station is about 25 miles downstream from the headwaters of the stream and about 20 miles upstream from East Fork San Jacinto River. The streamflow in Caney Creek can be considered reasonably natural (U.S. Geological Survey, 2012b). The time period analyzed for this study is 1945–2009 (table 5). An upward trend for annual minimum daily discharge was detected at this station.

USGS streamflow-gaging station 08073500 Buffalo Bayou near Addicks, Tex. (Buffalo Bayou near Addicks station), is about 3 miles southeast of Addicks, Tex. The station is downstream from Barker and Addicks Reservoirs in the western part of Houston and is about 45 miles upstream from Galveston Bay. Barker Reservoir has regulated streamflow for the station over the entire period of record. Barker Reservoir was impounded in 1945 and Addicks Reservoir was impounded in 1948. Both reservoirs generally are empty and function as large detention reservoirs for flood-peak attenuation for the large and densely populated greater Houston area. The time period analyzed for this study is 1946–2009 (table 5). Upward trends in annual mean daily and minimum discharges were detected at this station, whereas, a downward trend for the annual maximum daily discharge was detected. A time series of the annual mean daily discharge is shown in figure 6.

USGS streamflow-gaging station 08076000 Greens Bayou near Houston, Tex. (Greens Bayou near Houston station), is about 1 mile northeast of Houston. The station is about 25 miles downstream from the bayou’s headwaters and about 25 miles upstream from Buffalo Bayou. The streamflow in Greens Bayou is unregulated (U.S. Geological Survey, 2012b), but because the watershed of Greens Bayou has become increasingly developed since the station was installed, streamflow might deviate from the characteristics of reasonably natural flow. Konrad and Booth (2005, p. 157) reported that “urban development modifies the production and delivery of runoff to streams and the resulting rate, volume, and timing of streamflow” and identified “four hydrologic changes resulting from urban development: increased frequency of high flows, redistribution of water from base flow to stormflow, increased daily variation in streamflow, and reduction in low flow.” The time period analyzed for this study is 1953–2009 (table 5). Upward trends for annual mean, maximum, and minimum daily discharges were detected for the Greens Bayou near Houston. Tex., station. A time series of the annual mean daily discharge is shown in figure 7. Channel rectification occurred during 1974–75 (U.S. Geological Survey, 2012b); channel rectification is typically done by the U.S. Army Corps of Engineers (USACE) to improve channel conveyance and mitigate flood risks (U.S. Army Corps of Engineers, 2012).

Outflows to Middle Coast Gulf of Mexico (Brazos, San Bernard, and Colorado River Basins)

The Brazos, San Bernard, and Colorado Rivers flow directly into the Gulf of Mexico along the middle coastline of Texas. The Brazos and Colorado River Basins extend across Texas into New Mexico (fig. 1). The lower parts of these basins narrow as the rivers flow towards the Gulf of Mexico, particularly near about the 98th meridian. The San Bernard River Basin is much smaller and is located between the Brazos and Colorado River Basins.

USGS streamflow-gaging station 08114000 Brazos River at Richmond, Tex. (Brazos River at Richmond station), is more than 500 miles downstream from the headwaters of the Brazos River in New Mexico and about 70 miles upstream from the Gulf of Mexico. Although it is about 300 miles upstream, Possum Kingdom Lake, which was impounded in 1941, is the main reservoir affecting streamflow at the Brazos River at Richmond station (Dowell, 1964; U.S. Geological Survey, 2012b). There are additional reservoirs on the main stem and major tributaries of the Brazos River, including Lake Whitney and Waco Lake. The time period analyzed for this study is 1923–2009 (table 6). No trends were detected at this station.

USGS streamflow-gaging station 08117500 San Bernard River near Boling, Tex. (San Bernard River near Boling station), is about 5 miles northeast of Boling, Tex. The station is about 90 miles downstream from the headwaters and about 45 miles upstream from the mouth with the Gulf of Mexico. The streamflow for the San Bernard River can be considered reasonably natural (U.S. Geological Survey, 2012b). The time period analyzed for this study is 1955–2009 (table 6). No trends were detected at this station.

USGS streamflow-gaging station 08162000 Colorado River at Wharton, Tex. (Colorado River at Wharton station), is more than 500 miles downstream from the headwaters in north Texas and about 65 miles upstream from the Gulf of Mexico. Although numerous reservoirs have been constructed along the Colorado River and many of its principle tributaries, the main reservoir for flood control and volume storage is Lake Travis, which is about 150 miles upstream from the Wharton station. The streamflow recorded by this station has been affected by reservoir operations (mostly by Lake Travis) over the entire period of record. The time period analyzed for this study is 1939–2009 (table 6). A downward trend in annual minimum daily discharge was detected at this station.

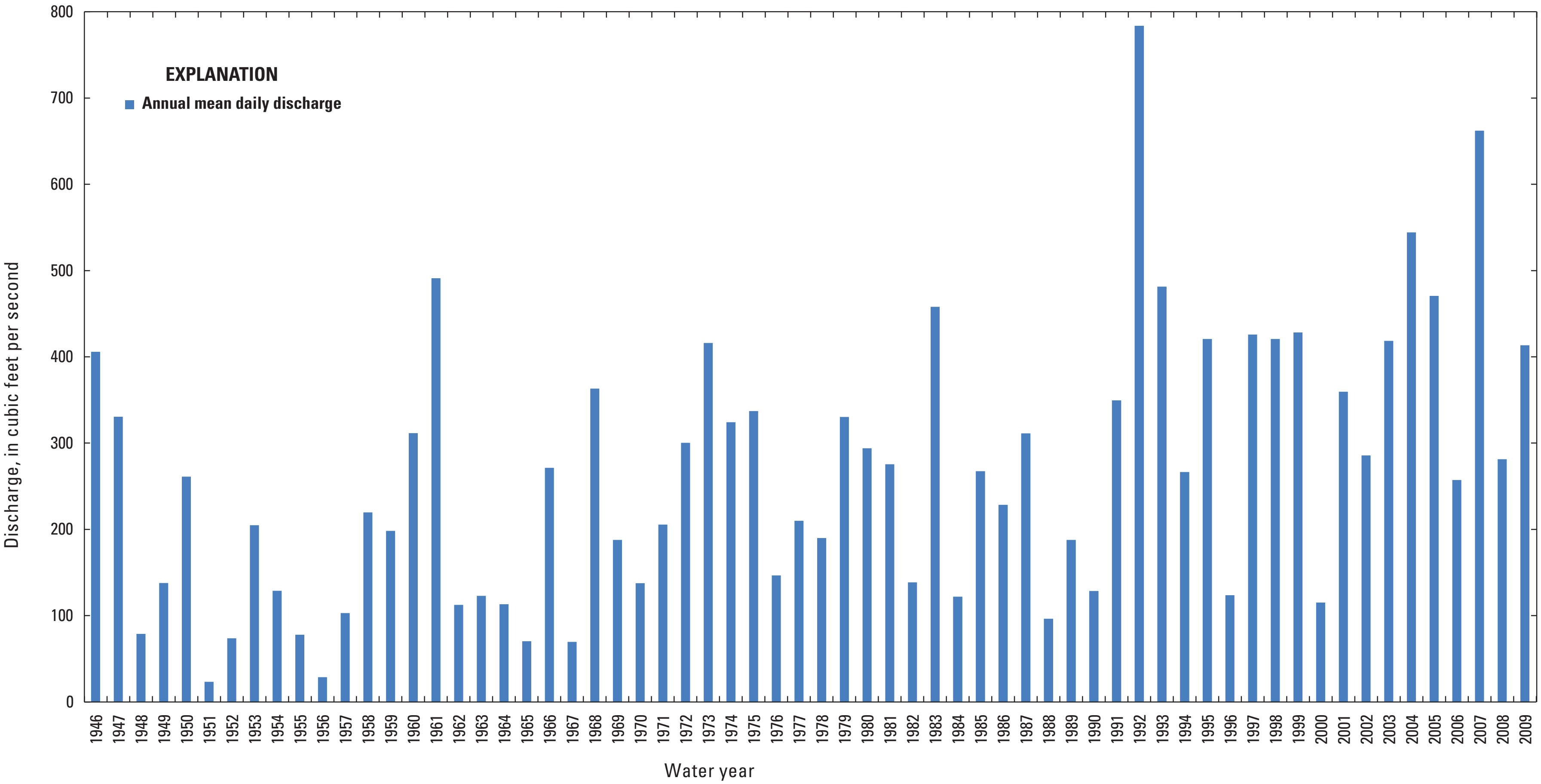

Figure 6. Annual mean daily discharge for the period of record through 2009 for U.S. Geological Survey streamflow-gaging station 08073500 Buffalo Bayou near Addicks, Texas.

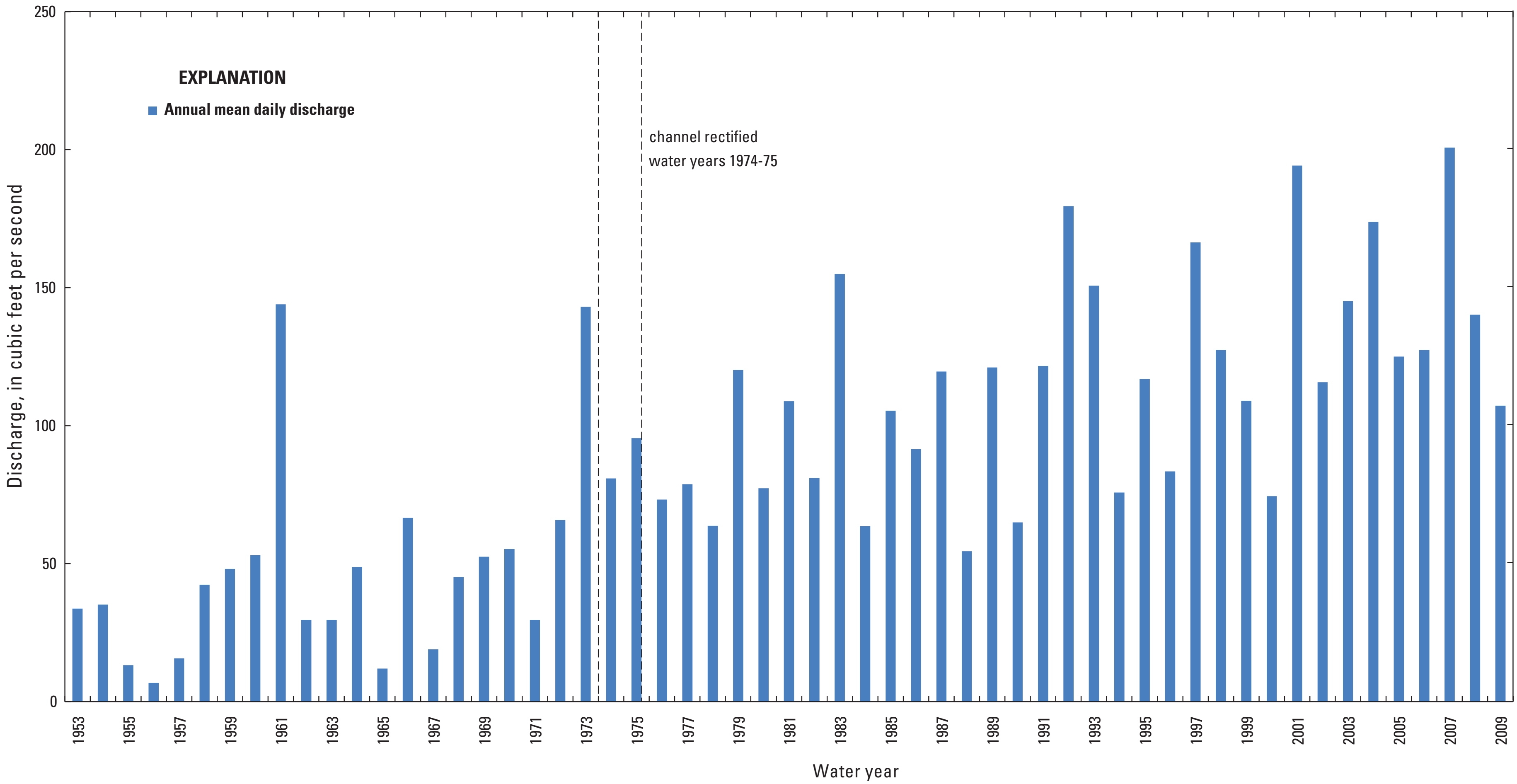

Figure 7. Annual mean daily discharge for the period of record through 2009 for U.S. Geological Survey streamflow-gaging station 08076000 Greens Bayou near Houston, Texas.

Table 6. Monotonic trends in outflows from the Brazos, San Bernard, and Colorado River Basins in Texas, 1923–2009.

[USGS, U.S. Geological Survey; p-value, probability value; <, less than; --, no statistically significant trend was detected (p-value <0.05)]

USGS station number	USGS station name	Time period analyzed	Streamflow statistic (discharge)	Kendall's tau	p-value	Trend direction
08114000	Brazos River at Richmond, Tex.	1923–2009	Annual mean daily	-0.01	0.88	--
08114000	Brazos River at Richmond, Tex.	1923–2009	Annual maximum daily	-0.12	0.095	--
08114000	Brazos River at Richmond, Tex.	1923–2009	Annual minimum daily	0.07	0.35	--
08117500	San Bernard River near Boling, Tex.	1955–2009	Annual mean daily	0.14	0.12	--
08117500	San Bernard River near Boling, Tex.	1955–2009	Annual maximum daily	0.15	0.11	--
08117500	San Bernard River near Boling, Tex.	1955–2009	Annual minimum daily	0.14	0.12	--
08162000	Colorado River at Wharton, Tex.	1939–2009	Annual mean daily	-0.02	0.78	--
08162000	Colorado River at Wharton, Tex.	1939–2009	Annual maximum daily	0.002	0.98	--
08162000	Colorado River at Wharton, Tex.	1939–2009	Annual minimum daily	-0.22	<0.05	downward

Outflows to Lower Coast Gulf of Mexico (Guadalupe and Nueces River Basins and Rio Grande Basin)

The Guadalupe River at Victoria streamflow-gaging station 08176500 Guadalupe River at Victoria, Tex. (Guadalupe River at Victoria station), is about 250 miles downstream from the headwaters and about 30 miles upstream from the Gulf of Mexico. The time period analyzed for this station is 1936-2009, and streamflow recorded by this station has been affected by reservoir operations over the entire period of record (table 1) (Dowell, 1964). No trends were detected at this station.

USGS streamflow-saging station 08211000 Nueces River near Mathis, Tex. (Nueces River near Mathis station), is about 4 miles southwest of Mathis, Tex. The station is about 200 miles downstream from the headwaters and about 30 miles upstream from the Gulf of Mexico. Lake Corpus Christi is less than 1 mile upstream and has maintained a pool in some form throughout the entire period of record of the station (Dowell, 1964; U.S. Geological Survey, 2012b).

The Frio River is a major tributary to the Nueces River. Additional regulation of flow at the Nueces River near Mathis station is provided by Choke Canyon Reservoir, which is upstream from this station on the Frio River near the confluence of the Frio and Nueces Rivers (fig. 2). The time period analyzed for this study is 1940–2009 (table 7). Downward trends for annual mean and maximum daily discharges were detected at this station, whereas, an upward trend for annual minimum daily discharge was detected.

Streamflow-gaging station 08475000 Rio Grande near Brownsville, Tex. (Rio Grande near Brownsville station), is operated by IBWC and is more than 1,000 miles downstream from the headwaters and about 25 miles upstream from the Gulf of Mexico. Discharge at the Rio Grande near Brownsville station has been substantially affected by Falcon Reservoir since 1953 (Dowell, 1964; U.S. Geological Survey, 2012b). Falcon Reservoir is about 120 miles upstream from the station.

A time series of the annual mean daily discharge is shown in figure 8 and includes the timing of the Falcon Reservoir impoundment. The time periods analyzed were 1935–2009, 1935–54, and 1955–2009 (table 7). Downward trends for annual mean and maximum daily discharges were detected at this station, whereas, an upward trend for annual minimum daily discharge was detected for 1935–2009. Additionally, downward trends for annual mean daily, maximum, and minimum discharges were detected at this station for the period 1935–54. No trends were detected at this station for the period 1955–2009.

Table 7. Monotonic trends in outflows from the Guadalupe and Nueces River Basins, and the Rio Grande Basin in Texas, 1926–2009.

[USGS, U.S. Geological Survey; IBWC, International Boundary and Water Commission; p-value, probability value; <, less than; --, no statistically significant trend was detected (p-value <0.05)]

Station number	Station name	Agency	Time period analyzed	Streamflow statistic (discharge)	Kendall's tau	p-value	Trend direction
08176500	Guadalupe River at Victoria, Tex.	USGS	1936–2009	Annual mean daily	0.11	0.16	--
08176500	Guadalupe River at Victoria, Tex.	USGS	1936–2009	Annual maximum daily	-0.006	0.94	--
08176500	Guadalupe River at Victoria, Tex.	USGS	1936–2009	Annual minimum daily	0.02	0.75	--
08211000	Nueces River near Mathis, Tex.	USGS	1940–2009	Annual mean daily	-0.20	<0.05	downward
08211000	Nueces River near Mathis, Tex.	USGS	1940–2009	Annual maximum daily	-0.25	<0.05	downward
08211000	Nueces River near Mathis, Tex.	USGS	1940–2009	Annual minimum daily	0.26	<0.05	upward
08475000	Rio Grande near Brownsville, Tex.[1]	IBWC	1935–2009	Annual mean daily	-0.38	<0.05	downward
08475000	Rio Grande near Brownsville, Tex.[1]	IBWC	1935–2009	Annual maximum daily	-0.49	<0.05	downward
08475000	Rio Grande near Brownsville, Tex.[1]	IBWC	1935–2009	Annual minimum daily	0.15	<0.05	upward
08475000	Rio Grande near Brownsville, Tex.[1]	IBWC	1935–1954	Annual mean daily	-0.62	<0.05	downward
08475000	Rio Grande near Brownsville, Tex.[1]	IBWC	1935–1954	Annual maximum daily	-0.35	<0.05	downward
08475000	Rio Grande near Brownsville, Tex.[1]	IBWC	1935–1954	Annual minimum daily	-0.43	<0.05	downward
08475000	Rio Grande near Brownsville, Tex.[1]	IBWC	1955–2009	Annual mean daily	-0.08	0.39	--
08475000	Rio Grande near Brownsville, Tex.[1]	IBWC	1955–2009	Annual maximum daily	-0.17	0.064	--
08475000	Rio Grande near Brownsville, Tex.[1]	IBWC	1955–2009	Annual minimum daily	0.05	0.61	--

[1]Streamflow data for Rio Grande near Brownsville, Tex., are currently (2012) operated and data published by the International Boundary and Water Commission (2012).

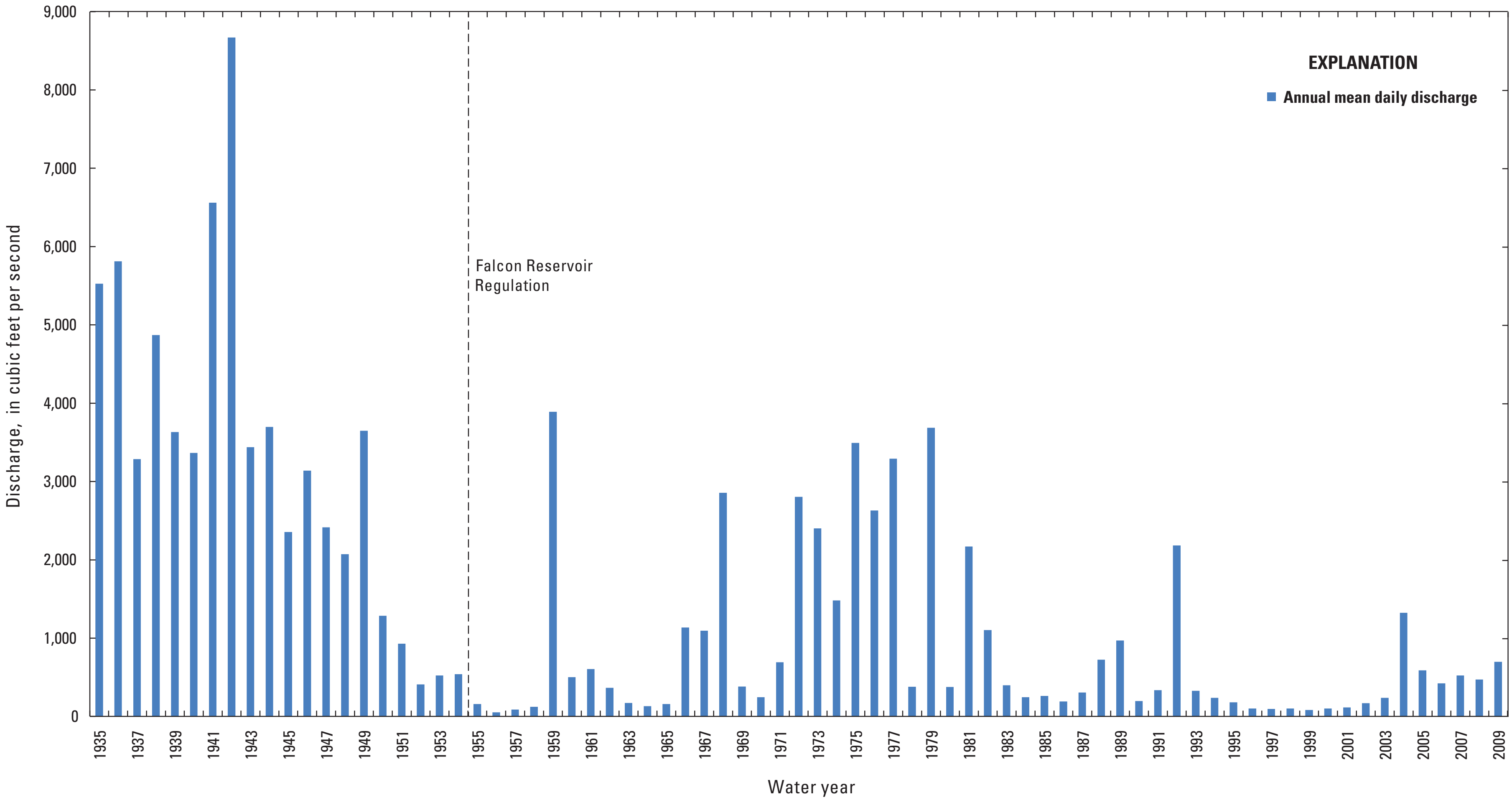

Figure 8. Annual mean daily discharge for the period of record through 2009 for U.S. Geological Survey streamflow-gaging station 08475000 Rio Grande at Brownsville, Texas.

Summary

The major river basins in Texas include the Red River, Sabine River, Neches River, Trinity River, San Jacinto River, Brazos River, Colorado River, Guadalupe River, San Antonio River, Nueces River, and the Rio Grande. The Red River flows into Arkansas and then into Louisiana. The Sabine, Neches, Brazos, San Bernard, Colorado, Guadalupe, and Nueces Rivers and Rio Grande all flow directly into the Gulf of Mexico. The Trinity River, San Jacinto River, and Buffalo Bayou flow into Galveston Bay, which subsequently flows into the Gulf of Mexico. Fresh surface-water usage in Texas is about two-thirds of the total freshwater usage in Texas. As a result, studies of streamflow statistics, likely indicative of outflows from Texas, are useful in resource assessments, such as water-supply studies, as well as useful to hydrologists, biologists, and ecologists. Accordingly, the U.S. Geological Survey, in cooperation with the Texas Water Development Board, evaluated streamflow data from streamflow-gaging stations with more than 50 years of record that were active as of 2009.

The streamflow data for 18 selected U.S. Geological Survey and one International Boundary Water Commission streamflow-gaging stations were used to compute selected streamflow statistics for trend analysis. The outflows into Arkansas and Louisiana were represented by streamflow records from 3 stations, and outflows into the Gulf of Mexico were represented by streamflow records from 16 stations.

Monotonic trend analyses were performed on the following three annual streamflow statistics: (1) annual mean daily discharge, (2) annual maximum daily discharge, and (3) annual minimum daily discharge. Trends were determined using the nonparametric Kendall's Tau test, which is useful for the detection of monotonic upward or downward trends with time. A positive Kendall Tau value indicates an upward trend and a negative Tau value indicates a downward trend. The p-value for the test is a measure of the statistical significance of the trend. Small p-values (less than 0.05) indicate a statistically significant trend for purposes of this study.

A total of 69 trend analyses by Kendall's Tau were computed—19 periods of streamflow from USGS stations multiplied by 3 streamflow statistics (annual mean, maximum, and minumum discharge) plus 12 additional trend analyses because the periods of record for 2 stations were further analyzed for trends pre- and post-reservoir impoundment. Unless otherwise described, each trend analysis used the entire period of record for each station. The monotonic trend analysis detected 11 statistically significant downward trends, 37 instances of no trend, and 21 statistically significant upward trends. Statistically significant trends follow for each station and organized by a logical grouping according to river system.

Outflows to Arkansas (Red and Sulphur River Basins)—A downward trend for annual maximum daily discharge was detected for the Red River at Index, Ark., station. An upward trend for annual minimum daily discharge was detected for the Sulphur River near Talco, Tex., station.

Outflows to Louisiana (Little Cypress Creek Basin)—No trends were detected for the Little Cypress Creek near Jefferson, Tex., station.

Outflows to the upper coast of the Gulf of Mexico (Sabine and Neches River Basins)—An upward trend for annual minimum daily discharge was detected for the Sabine River near Ruliff, Tex., station. A downward trend for annual maximum daily discharge and conversely an upward trend for annual minimum daily discharge were detected for Neches River at Evadale, Tex., station for the period 1922–2009 (period of record). No trends were detected for the Neches River at Evadale, Tex., station for the period 1922–50; however, upward trends for annual mean and minimum daily discharges were detected for the period 1951–2009.

Outflows to the Gulf of Mexico through Galveston Bay (Trinity and San Jacinto River Basins, and associated Creeks and Bayous [Galveston Bay inflows])—An upward trend for annual minimum daily discharge was detected for the Trinity River at Romayor, Tex., station. An upward trend for annual minimum daily discharge was detected for the West Fork San Jacinto River near Conroe, Tex., station. Upward trends for annual mean and minimum daily discharges were detected for the Spring Creek near Spring, Tex., station. Upward trends in annual mean, maximum, and minimum daily discharges were detected for the Cypress Creek near Westfield, Tex., station. An upward trend for annual minimum daily discharge was detected for the East Fork San Jacinto River near Cleveland, Tex., station. An upward trend for annual minimum daily discharge was detected for the Caney Creek near Splendora, Tex., station. Upward trends in annual mean and minimum daily discharges were detected for the Buffalo Bayou near Addicks, Tex., station, whereas, a downward trend for the annual maximum daily discharge was detected. Upward trends for annual mean, maximum, and minimum daily discharges were detected for the Greens Bayou near Houston, Tex., station.

Outflows to the middle coast of the Gulf of Mexico (Brazos, San Bernard, and Colorado River Basins)—No trends in streamflow were detected for the Brazos River at Richmond, Tex., or for San Bernard River near Boling, Tex., stations. A downward trend in annual minimum daily discharge was detected for the Colorado River at Wharton, Tex., station.

O*utflows to the lower coast of the Gulf of Mexico (Guadalupe and Nueces River Basins, and Rio Grande Basin)*—No trends were detected for the Guadalupe River at Victoria, Tex., station. Downward trends for annual mean and maximum daily discharges were detected for the Nueces River near Mathis, Tex., station, whereas, an upward trend for annual minimum daily discharge was detected. Downward trends for annual mean and maximum daily discharges were detected for the Rio Grande near Brownsville, Tex., station, whereas, an upward trend for annual minimum daily discharge was detected for 1935–2009. Additionally, downward trends for annual mean, maximum, and minimum daily discharges were detected for the Rio Grande near Brownsville, Tex., station for the period 1935–54. No trends were detected for the Rio Grande near Brownsville, Tex., station for the period 1955–2009.

Annual mean daily discharge is especially diagnostic because this statistic can be used to compute annual mean discharge over long periods of time and represents the expectation of the annual volume of water measured by a station. Trends in annual mean daily discharge can be summarized as follows: (1) annual outflow volumes from Texas into Arkansas and Louisiana as well as the Gulf of Mexico (upper Texas coast) lack statistically significant trends; (2) annual inflows into Galveston Bay (Houston metropolitan area) show upward trends for four of eight stations; (3) annual outflow volumes from the Brazos River (east of Houston metropolitan area) to the Guadalupe River lack statistically significant trends; and (4) annual outflow volumes from the two most westerly stations on the Nueces River and Rio Grande show downward trends.

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