MONTHLY AND ANNUAL SUSPENDED-SEDIMENT LOADS IN THE BRAZOS RIVER AT RICHMOND, TEXAS, 1966-86 WATER YEARS

By Freeman L. Andrews

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CONVERSION FACTORS

Values in this report are given in inch-pound units. Conversion factors for metric (International System) units are listed below:

Multiply inch-pound units	By	To obtain metric units
acre-foot (acre-ft)	0.001233	cubic hectometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
ounce, fluid (fl. oz)	0.02957	liter
pound (lb)	0.4536	kilogram
square mile (mi^2)	2.590	square kilometer
ton (short)	0.9072	megagram

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

MONTHLY AND ANNUAL SUSPENDED-SEDIMENT LOADS IN THE BRAZOS RIVER AT RICHMOND, TEXAS, 1966-86 WATER YEARS

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ABSTRACT

Sampling to determine suspended-sediment concentrations at the Brazos River at Richmond, Texas, began in January 1966 and ended in September 1986. Depth-integrated samples were collected during all flow conditions. The records for this station are considered good.

The mean monthly suspended-sediment loads in the Brazos River at Richmond ranged from 2,500 to 91,000 tons during the period of record. The annual suspended-sediment load ranged from 404,500 to 30,800,000 tons and averaged about 10,900,000 tons. The minimum annual load of 404,500 tons occurred during the 1984 water year, and the maximum annual load of 30,800,000 tons occurred during the 1968 water year.

Suspended-sediment load and discharge varied throughout the period of study. A double-mass curve indicated that the relation between discharge and sediment load remained constant.

The data collected annually during the study were used to develop a regression model. The model was determined to be an accurate predictor of annual suspended-sediment load by using annual discharge as the independent variable.

INTRODUCTION

The U.S. Geological Survey has operated a streamflow-gaging station from January 1903 to June 1906 and from October 1922 to the current year (1986) on the Brazos River at Richmond, Fort Bend County, Texas (fig. 1). This station is identified as station 08114000 in reports by the U.S. Geological Survey (1967-87). Prior to September 1931, the record for station 08114000 was published as Brazos River "at Rosenberg." Suspended-sediment data were collected at station 08114000 from January 1966 to September 30, 1986. The data have been published annually by the Geological Survey and include particle-size data, daily concentrations, daily loads, and annual loads. Prior to this report, suspended-sediment load data had not been analyzed.

Purpose and Scope

In September 1986, collection of daily suspended-sediment data ended at the Brazos River at Richmond station. The purpose of this report is to describe the suspended-sediment data and to describe mean monthly and annual suspended-sediment loads for the Brazos River at Richmond. An additional purpose was to develop a regression relation for estimating annual suspended-sediment loads, based on annual discharge as the independent variable. These data are limited to suspended-sediment-loads for the Brazos River at Richmond, station 08114000, collected during the 1966-86 water years. It is beyond the scope of this report to calculate total sediment loads (which require bedload data).

General Description of the Brazos River Basin

The Brazos River basin upstream from Richmond includes approximately 41,192 mi^2 of which 9,566 mi^2 probably is noncontributing. The gaging station is located in Fort Bend County, on the right bank of the downstream side of the downstream bridge on U.S. Highway 59 (90A) in Richmond, 925 ft downstream from the Texas and New Orleans Railroad Co. bridge, and at river mile 92.0 (fig. 1).

The Richmond station is located in the lower Brazos River basin, which for the purpose of this report, extends from Lake Whitney to the mouth of the Brazos River (figs. 2a, b). Most of the major impoundments and the study area are located in the central and lower Brazos River basins (figs. 2a, b). Principal tributaries to the Brazos River in downstream order are Clear Fork Brazos River and Bosque River in the central basin, and Little River and its tributaries (Leon, Lampasas, and San Gabriel Rivers), Yegua Creek, and Navasota River in the lower basin. The latter three tributaries join the Brazos River downstream from Lake Whitney.

The altitude of the Brazos River basin ranges from about 4,200 ft above sea level in the High Plains (headwaters) to sea level at the mouth. Average annual precipitation ranges from 15 in. in the headwater to about 45 in. in the lower reaches of the basin (U.S. Department of Commerce, 1984). In the lower basin, precipitation is greatest in the spring and fall. Precipitation of 2 to 6 in. from a single storm is not unusual, and occasionally 10 in. or more may fall in a 24-hour period. Precipitation produces flood runoff and increased sediment loads.

Considerable water is diverted upstream from above the Richmond station for irrigation and municipal supply. Streamflow often is affected by reservoirs

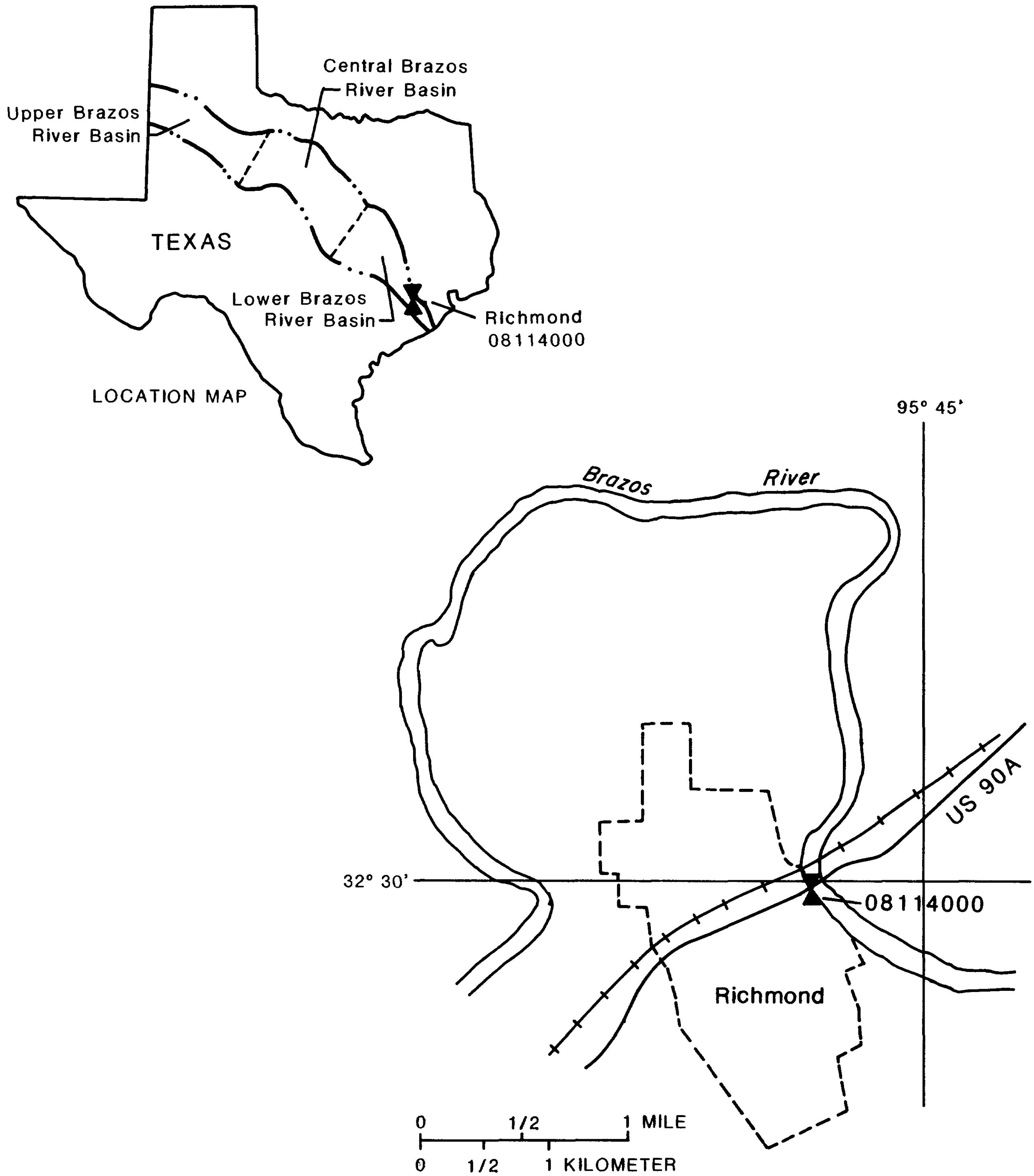

Figure 1.--Location of station 08114000, Brazos River at Richmond.

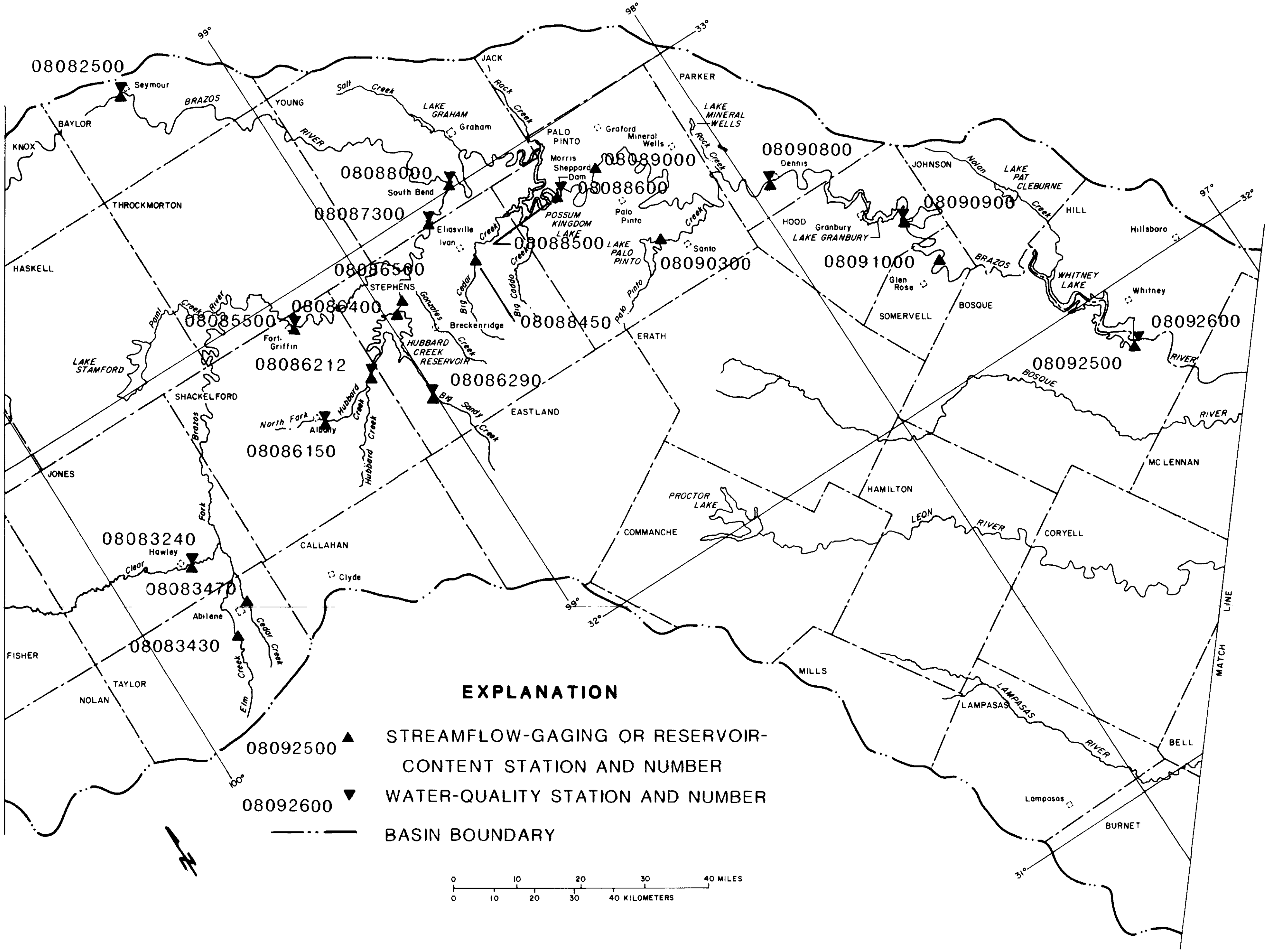

Figure 2a.--Location of streamflow-gaging or reservoir-content stations, central Brazos River basin.

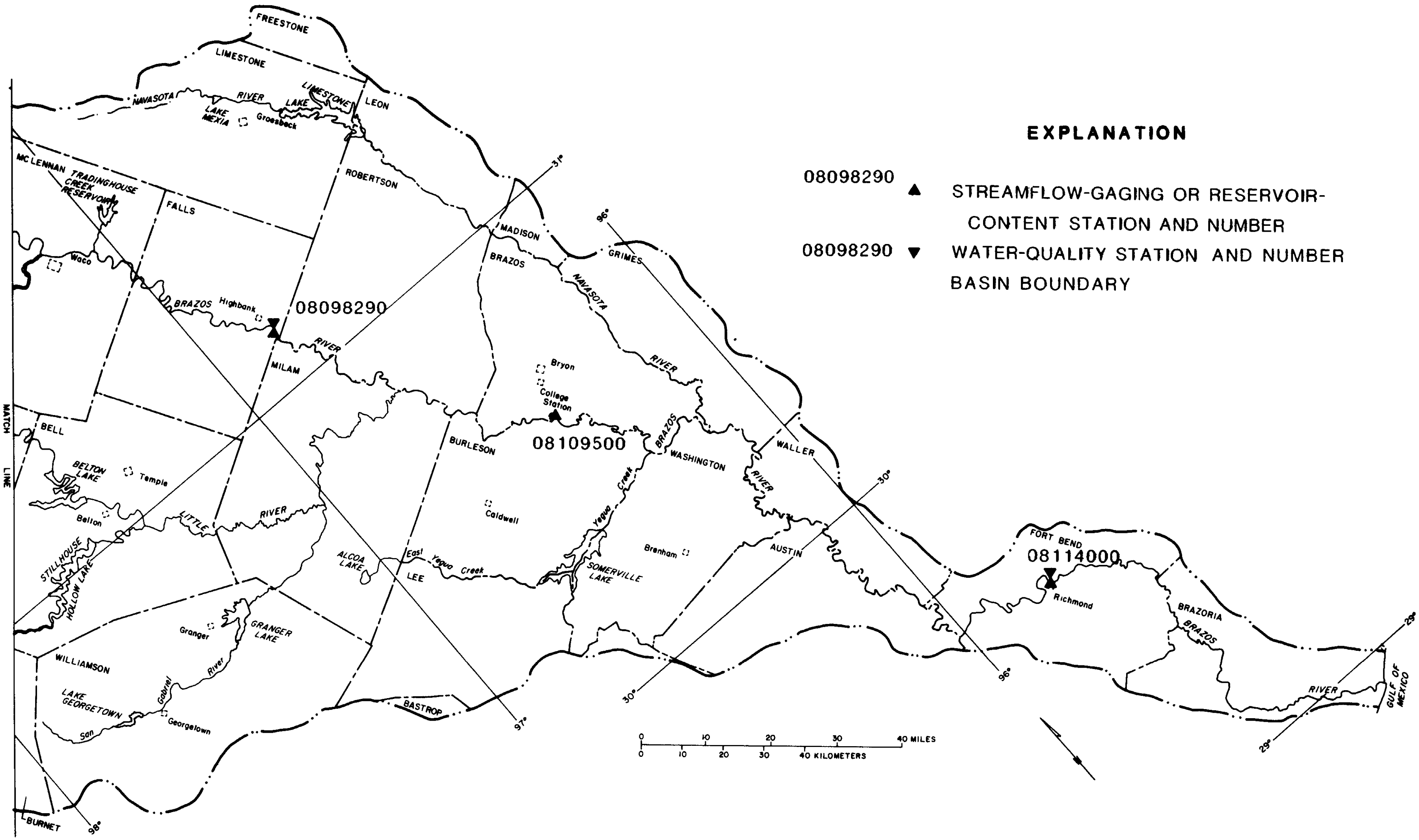

Figure 2b.--Location of streamflow-gaging or reservoir-content stations, lower Brazos River basin.

on the Brazos River upstream from Waco, reservoirs on the Lampasas and Little Rivers, reservoirs on the Navasota River and Yegua Creek, and numerous floodwater-retarding structures. Total capacities of the reservoirs (table 1) and floodwater-retarding structures are approximately 5,100,000 acre-ft (U.S. Geological Survey, 1985).

COLLECTION AND EVALUATION OF DATA

Sampling to determine daily suspended-sediment concentrations in the Brazos River at Richmond began in January 1966 and ended in September 1986. Sampling to determine suspended-sediment particle size began in 1967 and continued through 1986. All suspended-sediment sampling was done from the bridge on U.S. Highway 59 (90A) in Richmond.

The U.S. D-49 depth-integrating suspended-sediment sampler was used at this station by the daily observer throughout the period of record. The development and use of suspended-sediment sampling equipment is described in a series of reports by the U.S. Interagency Committee on Water Resources (1952, 1961, and 1963). Depth-integrated samples were collected for a variety of flow conditions.

During the study period, there were no significant changes in sampling, laboratory, streamflow-measuring, and recording equipment. Data collected are considered reliable and accurate. However, sampling during storms often resulted in storm loads that could not be calculated without some extrapolation, making these data less accurate. Records for this station are considered good.

Brazos River flows were analyzed by using flow-duration curves for two record periods: 1952-65 and 1966-86 (fig. 3). The 1952-65 period includes a time after the closure and impoundment of water in most of the major reservoirs in the Brazos River basin. The slope of the flow-duration curve is an indicator of the characteristics of discharge at a station. When discharge is influenced mostly by surface runoff, the flow-duration curve will have a steep slope. A flat slope generally is indicative of the influence of surface- or ground-water storage. The slope decreased during 1966-86, reflecting the storage of water in upstream reservoirs. Also, the lower part of the curve is somewhat flatter, reflecting water storage. Comparison of the two periods shows a difference in the shape and magnitude of the two curves. The frequency of discharges above 30,000 ft^3/s was less during 1966-86 than during 1952-65. As expected, the frequency of lower discharges below reservoirs was increased during the study period, indicating that regulation may have helped reduce low-flow conditions by creating more constant-flow conditions at Richmond.

SUSPENDED-SEDIMENT LOADS

Mean Monthly Suspended-Sediment Loads, 1966-86 Water Years

The mean monthly suspended-sediment loads in the Brazos River at Richmond station 08114000 ranged from 2,500 to 91,000 tons during the period of record. The minimum mean monthly load of 2,500 tons occurred in August and the maximum mean monthly load of 91,000 tons occurred in May. These results are as expected because precipitation in the basin is greater in the spring and fall contributing to runoff and increased sediment loads. These mean monthly sediment loads were directly related to mean monthly discharges for the period of record (figs. 4 and 5).

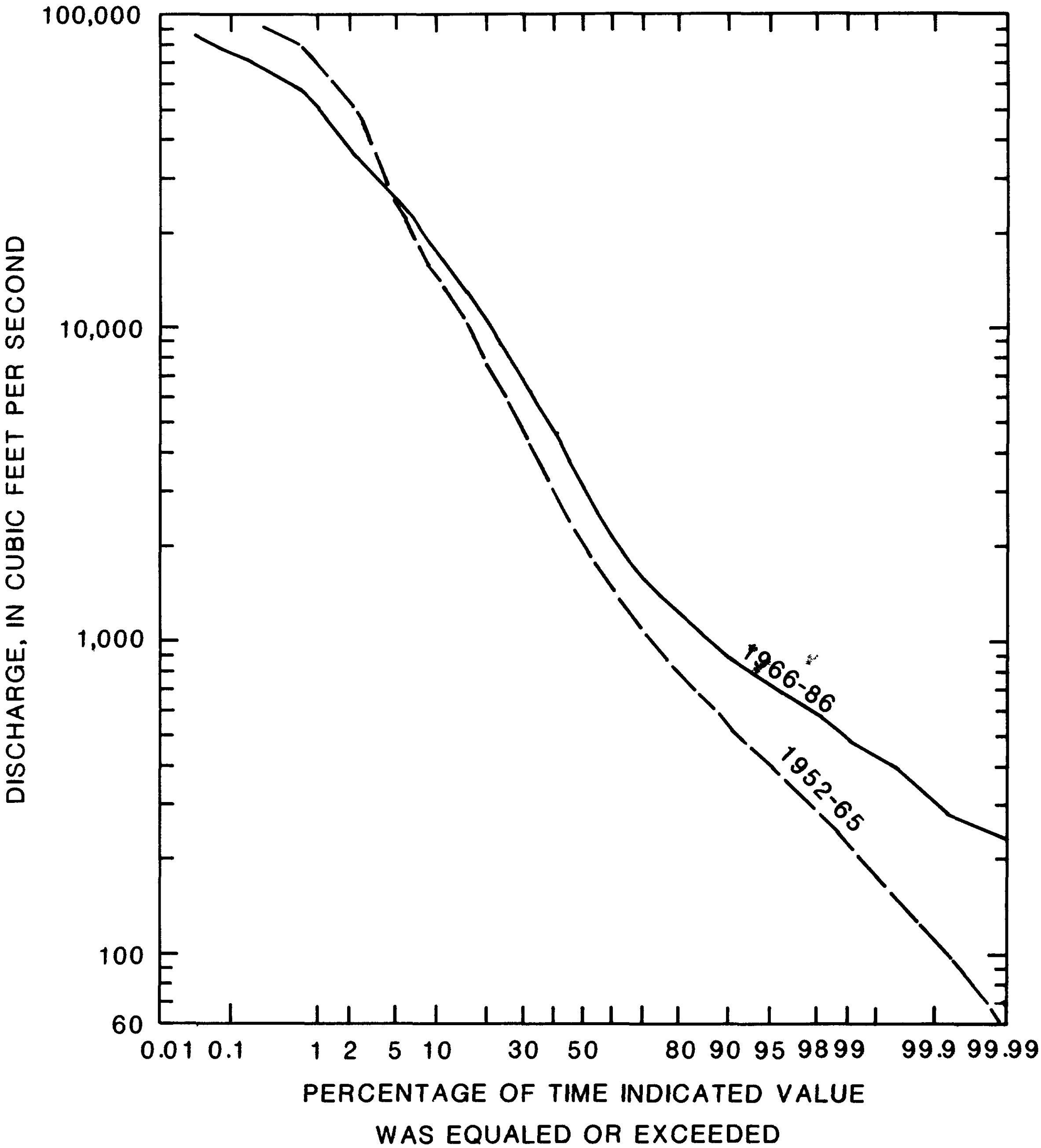

Figure 3.--Flow-duration curves for Brazos River at Richmond.

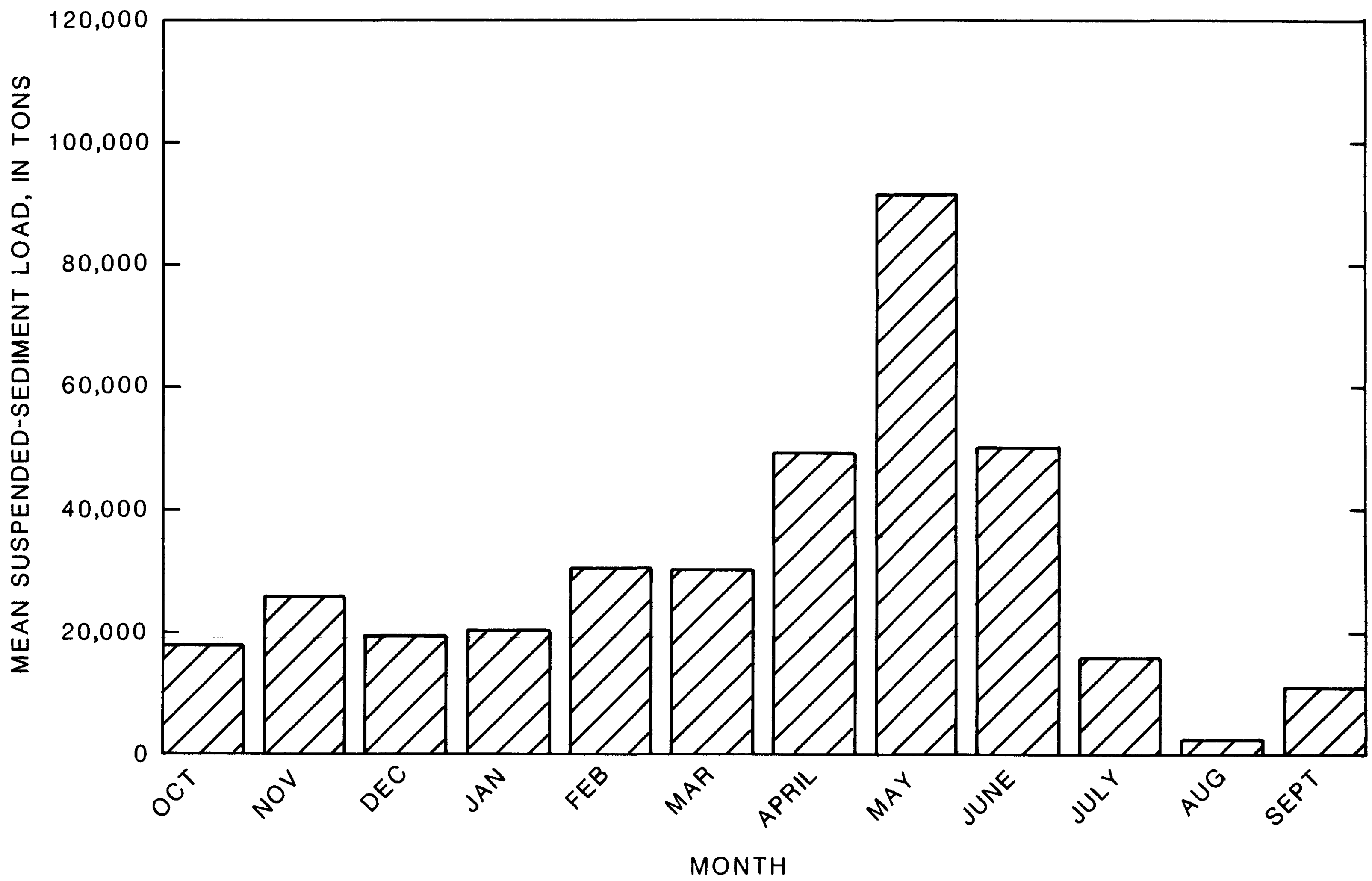

Figure 4.--Mean monthly suspended-sediment load of Brazos River at Richmond, 1966-86 water years.

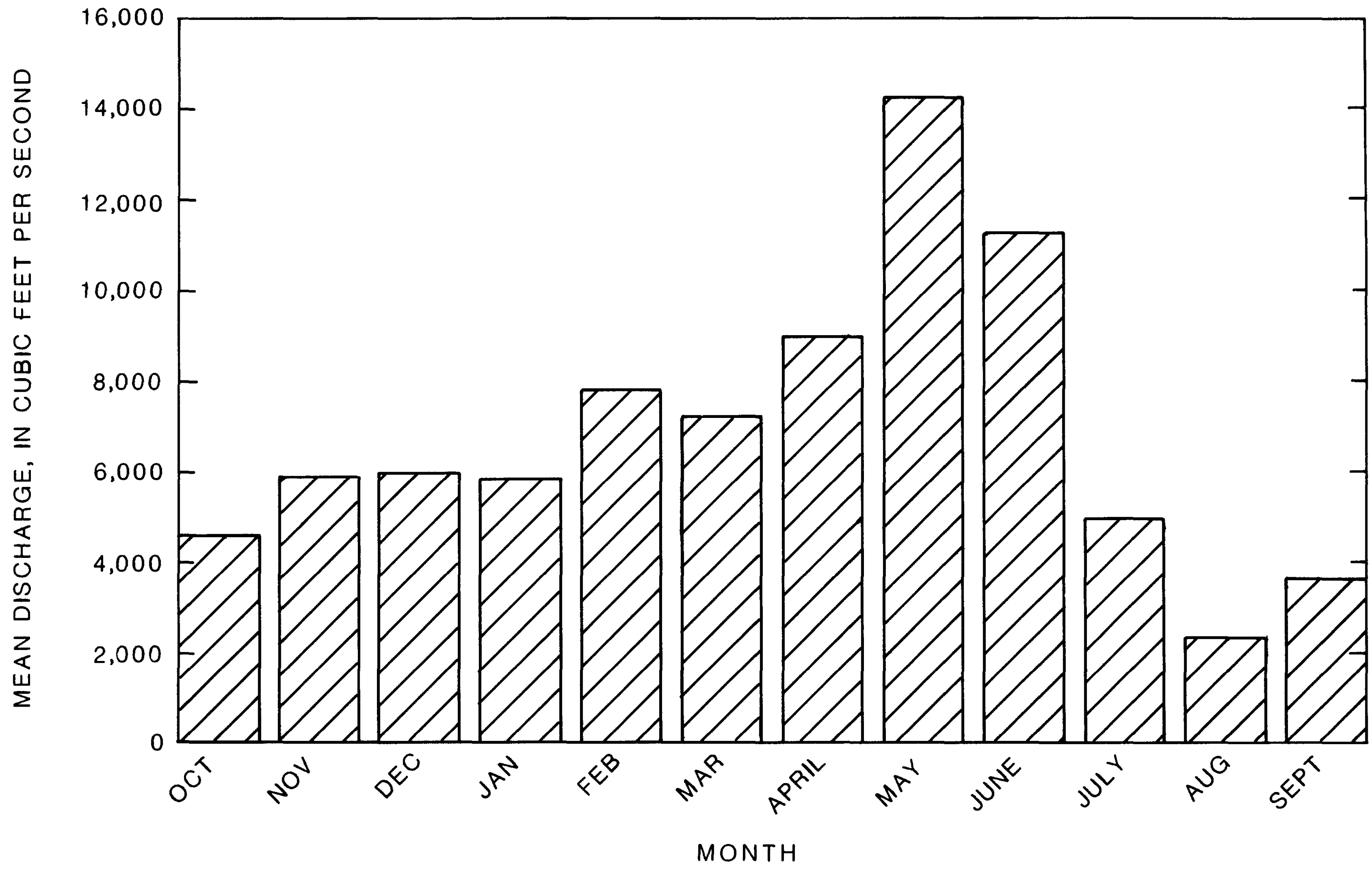

Figure 5.--Mean monthly discharge of Brazos River at Richmond, 1966-86 water years.

Table 1.--Conservation-storage capacity of major lakes and reservoirs of central and lower Brazos River basins

Lake or reservoir	Year of initial impoundment	Conservation-storage capacity (acre-feet)
Alcoa Lake	1952	14,750
Belton Lake	1954	457,300
Lake Georgetown	1980	37,080
Lake Graham	1929	45,000
Lake Granbury	1969	153,500
Granger Lake	1980	65,510
Hubbard Creek Reservoir	1962	320,000
Lake Limestone	1978	225,445
Lake Mexia	1961	10,000
Lake Mineral Wells	1920	6,760
Lake Palo Pinto	1964	42,200
Lake Pat Cleburne	1964	25,445
Lake Whitney	1951	627,100
Possum Kingdom Lake	1941	724,464
Proctor Lake	1963	53,900
Somerville Lake	1966	160,100
Lake Stamford	1953	52,700
Stillhouse Hollow Lake	1968	204,900
Tradinghouse Creek Reservoir	1968	35,124
Waco Lake	1965	151,900
Total		3,413,178

Annual Suspended-Sediment Loads, 1966-86 Water Years

The annual suspended-sediment load in the Brazos River at Richmond ranged from 404,500 tons in 1984 to 30,800,000 tons in 1968 and averaged about 10,900,000 tons for the period of record.

Suspended-sediment load is directly related to stream discharge. Suspended-sediment load and annual stream discharge varied throughout the period of study (figs. 6 and 7). Even though streamflow in the Brazos River at Richmond is regulated by upstream reservoirs and flood-control structures, the effects of these regulations cannot be determined from these figures for annual loads.

The variation in annual stream discharge, which is the result of varying precipitation and runoff, seems to adequately account for the annual variability in suspended-sediment loads. Sediment loads are highest when precipitation rates are great enough to produce above average runoff. The double-mass curve (fig. 8) is a further indication that the relation between stream discharge and sediment load remained constant during the study period.

A break in the slope of the double-mass curve means that a change in the relation between the two variables had occurred and would indicate the time at which the change had occurred (Searcy and Hardison, 1960, p. 33). No definitive breaks were noted, indicating that no changes occurred in the relation. Initial observation of figure 8 would indicate that there may be a break sometime between 1967 and 1969. Although it is possible that this apparent break is the result of residual effect of reservoir closure, it most likely is a spurious break caused by varability in the data, in this case by nonlinearity between stream discharge and sediment load. During years of large flows such as in 1968, a larger proportional sediment load results than during years of small flows such as occurred in 1967 and 1971. Spurious breaks in the double-mass curve that should be recognized as such are caused by inherent variability in hydrologic data. Most users recognize that the year-to-year breaks are common, and thus, ignore any break that persists for less than 5 years. Breaks that persist for longer than 5 years are more subtle and may be caused by a real change (Searcy and Hardison, 1960, p. 34).

During the 1968 water year annual precipitation totaled about 51 inches, the largest annual precipitation recorded during the study period. The greater amount of precipitation resulted in above average runoff and sediment load. The occurrence of this combination of events, so close to the beginning of the data collection period, resulted in data variability and a spurious break.

Other Studies

During the period of study the Texas Water Development Board also operated a suspended-sediment sampling station at the Brazos River at Richmond. Streamflow records from the U.S. Geological Survey were used for sediment-load computations. Samples were collected using the "Texas Sampler" which consists of a 1/8 X 3/4 X 15-in. hanger bar fastened with a sheet-metal bottle holder over a 15-lb lead weight. Samples were taken in 8-fl. oz narrow-neck bottles at a position 1 ft below the water surface near midstream. The percentage of suspended sediment by weight obtained from the sample was multiplied by a

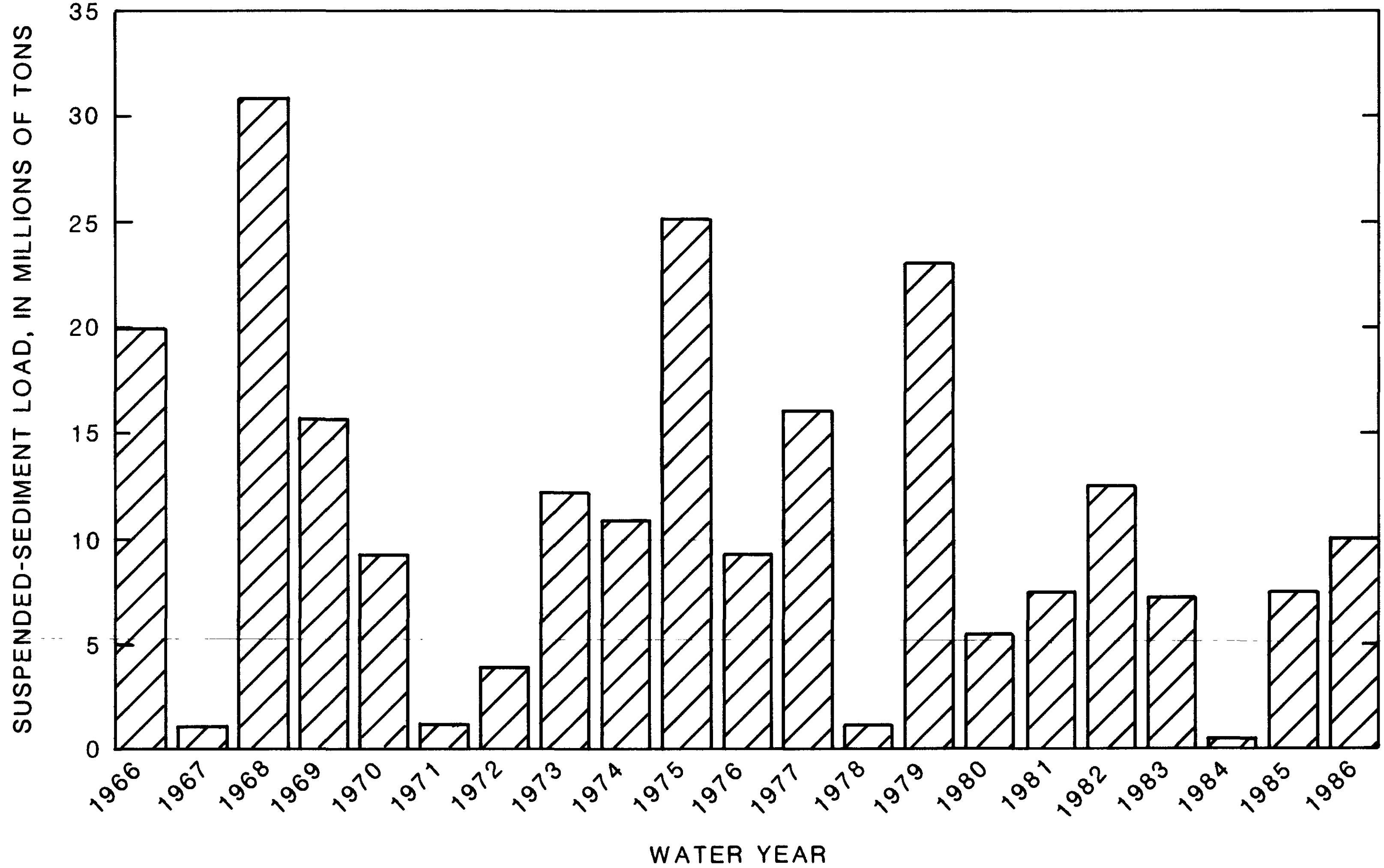

Figure 6.--Annual suspended-sediment load of Brazos River at Richmond, 1966-86 water years.

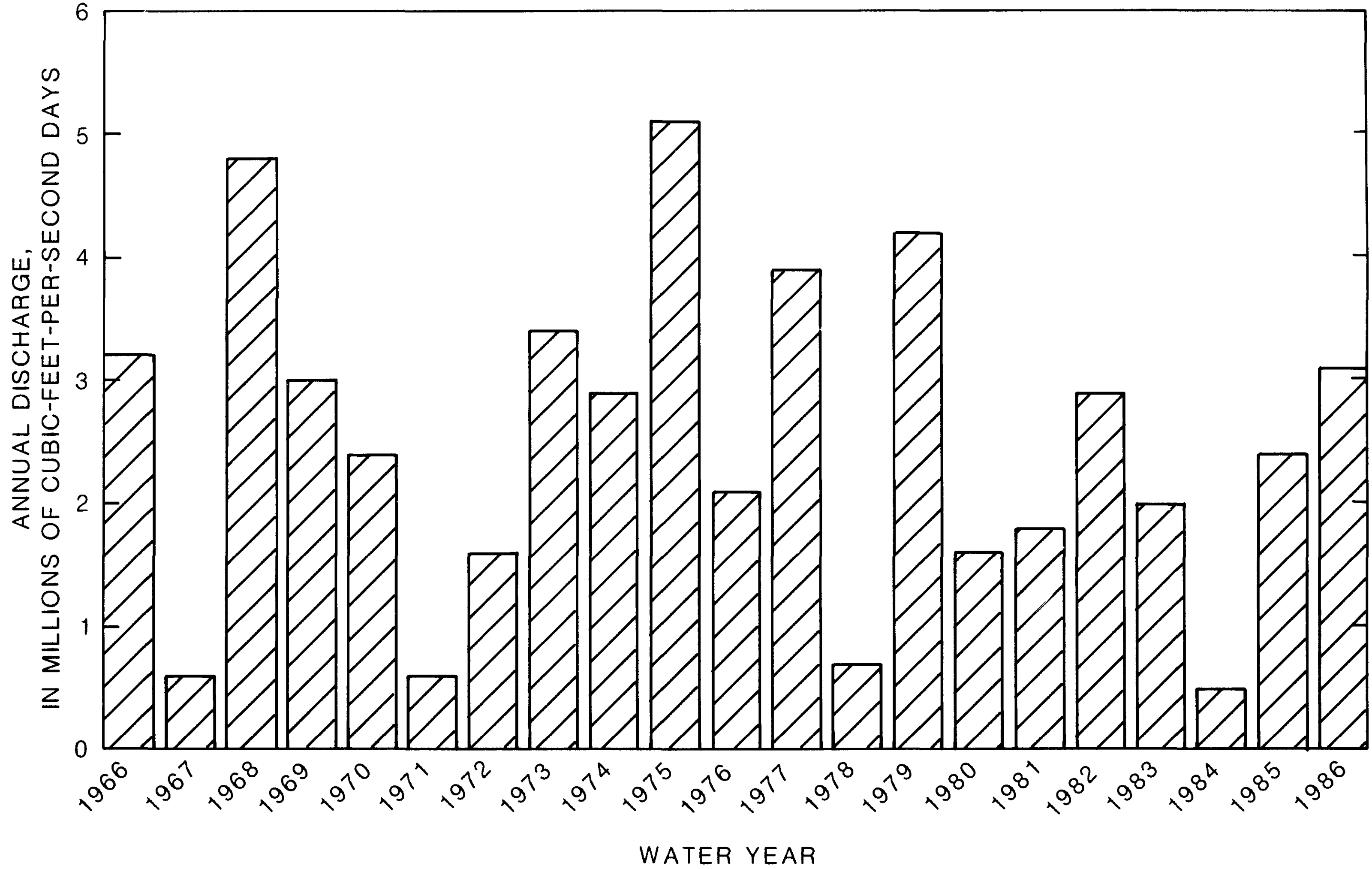

Figure 7.--Annual discharge of Brazos River at Richmond, 1966-86 water years.

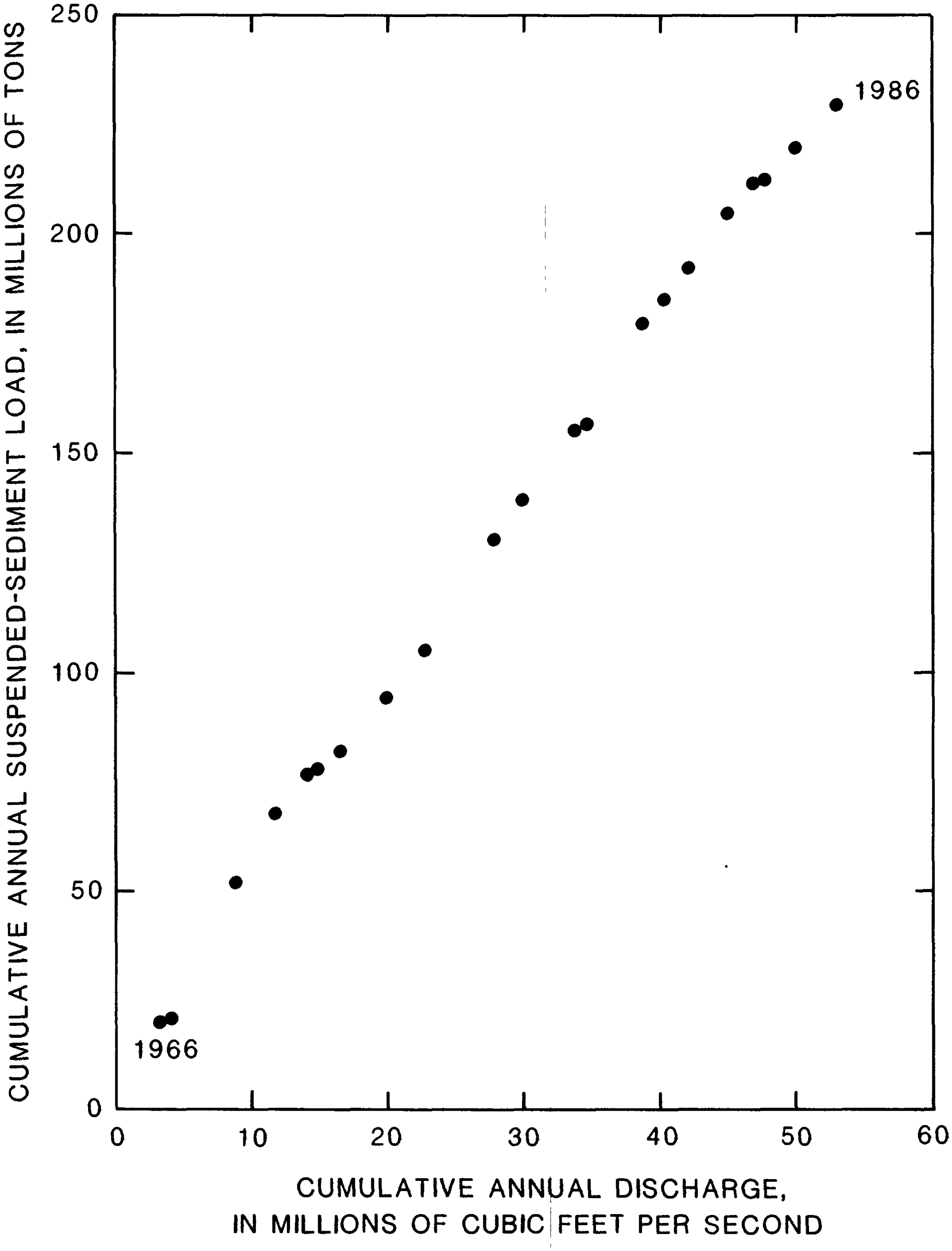

Figure 8.--Double-mass curve of annual suspended-sediment load and annual discharge of Brazos River at Richmond, 1966-86 water years.

factor of 1.102 to obtain the mean-percentage sediment in the vertical profile. Laboratory determinations were equated to the corresponding streamflow in determining the total suspended-sediment loads (Dougherty, 1979). A comparison of 14 years of data shows that the two methods compare fairly closely (table 2). However, most suspended-sediment loads reported by the Texas Water Development Board are smaller than those reported by the Geological Survey. Depth-integrating sampling procedures used by the Geological Survey are more likely to include sand particles than when sampling 1 ft below the water surface. Consequently, annual suspended-sediment loads reported by the Geological Survey are slightly larger. Comparison of the two sampling methods was discussed extensively by Welborn (1967).

Estimating Annual Suspended-Sediment Loads

The long-term relation between annual stream discharge and annual suspended sediment loads can be used to obtain estimates of annual suspended-sediment loads if only annual discharge is available. Future estimates would be less accurate if the relation between streamflow and suspended sediment changes or if variability between streamflow and suspended sediment significantly increases.

A change in the relation between annual discharge and annual suspended-sediment load was not detected during the study period (1966-86 water years). Therefore, the data were considered suitable for use in a predictive-regression model. Prior to regression analysis, the data were transformed to base 10 logarithms to provide for a normal distribution of data. A log-quadratic equation provided the best fit regression. Regression was done using annual discharge in cubic-feet-per-second-day and annual suspended-sediment load in tons, resulting in the following equation:

$$\begin{aligned} \text{Log}_{10}\ (\text{load}) &= 0.4771 \text{ X } \log_{10}\ (\text{discharge}) \\ &\quad + 0.0956 \text{ X } (\log_{10}(\text{discharge}))^2. \end{aligned}$$

For example, assuming an annual discharge of 1,000,000 ft^3/s-day, the load is computed as follows:

$$\begin{aligned} \text{Log}_{10}\ (\text{load}) &= 0.4771 \text{ X } 6 + 0.0956 \text{ X } (6)^2 \\ &= 2.8626 + 3.4416 \\ &= 6.3042 \\ \text{Load} &= 10^{6.3042} \\ \text{Load} &= 2{,}014{,}000 \text{ tons} \end{aligned}$$

The standard error of the estimate for this equation was between +26 percent and -21 percent. The equation was determined be an accurate predictor of annual suspended-sediment loads using annual discharge as the independent variable (fig. 9).

SUMMARY

The Brazos River at Richmond station is located in the lower Brazos River basin, which extends from Whitney Reservoir to the mouth of the Brazos River. The station is located in Fort Bend County and identified as station 08114000. Average annual precipitation ranges from about 15 in. in the headwater to about 45 in. in the lower reaches. Considerable water is diverted upstream

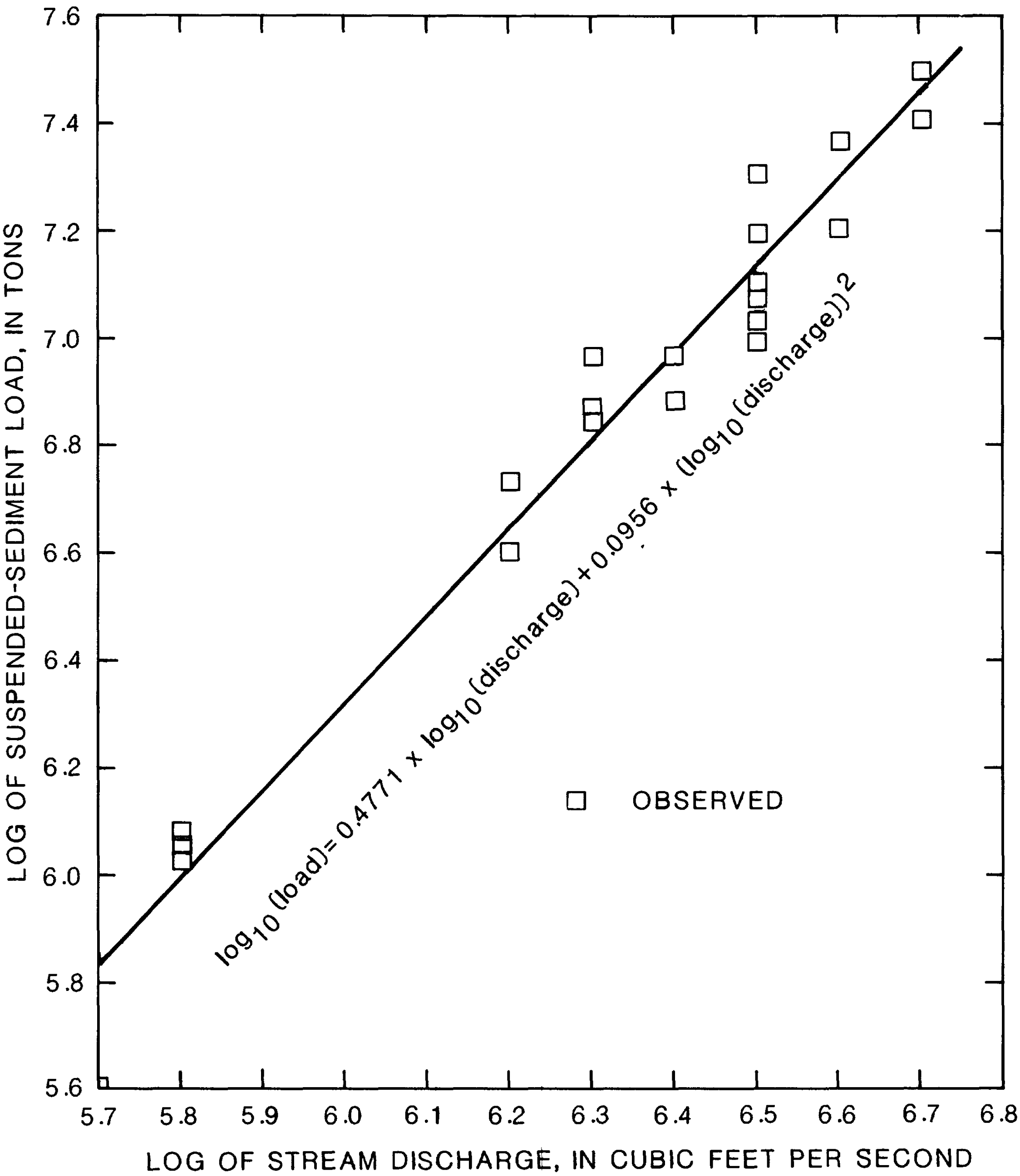

Figure 9.--Relation between predicted and observed annual suspended-sediment loads at Brazos River at Richmond, 1966-86 water years.

Table 2.--Comparison of results of suspended-sediment sampling with "Texas" sampler and depth-integrating samplers

Year	Annual suspended-sediment loads (tons)	
	Collected by Texas Water Development Board using "Texas" sampler	Collected by U.S. Geological Survey using depth-integrating samplers
1966	18,484,000	19,899,594
1967	982,600	1,071,952
1968	29,618,000	30,799,205
1969	14,341,000	15,635,604
1970	8,705,000	9,202,515
1971	1,044,000	1,172,919
1972	3,919,000	3,943,243
1973	11,800,000	12,140,975
1974	11,400,000	10,813,593
1975	23,055,000	25,146,463
1976	8,585,000	9,154,709
1977	17,211,000	16,023,057
1978	993,900	1,146,300
1979	23,243,000	23,045,200
1980	Discontinued	5,374,995

from Richmond for irrigation and municipal supply. Streamflow is affected by reservoirs on the Brazos River upstream from Waco.

Sampling to determine suspended-sediment concentrations in the Brazos River at Richmond began in January 1966 and ended in September 1986. All suspended-sediment sampling was done from the bridge on U.S. Highway 59 (90A) in Richmond, by use of the U.S. D-49 suspended-sediment sampler. Accurate depth-integrated samples were collected over a wide range of flow conditions. The records for this station are considered good.

The mean monthly suspended-sediment loads in the Brazos River at Richmond ranged from 2,500 to 91,000 tons during the period of record. The minimum mean monthly load of 2,500 tons occurred in August and the maximum mean monthly load of 91,000 tons occurred in May, and both were directly related to mean monthly stream discharge.

The annual suspended-sediment loads at the Brazos River at Richmond ranged from 404,500 tons for the 1984 water year to 30,800,000 tons for the 1968 water year and averaged about 10,900,000 tons during the period of record.

Suspended-sediment loads and annual discharge varied greatly throughout the study. The variation in annual discharge adequately accounted for the annual variability in suspended-sediment loads. The proportionality between annual discharge and sediment loads remained constant during the period. No definitive breaks were noted in the double-mass curve, indicating that no change occurred to disrupt the proportionality.

Data also have been collected at the Brazos River at Richmond by the Texas Water Development Board. Samples were collected in 8-fl.-oz narrow-neck bottles at a position 1 ft below the water surface at midstream. A comparison of loads computed by the Texas Water Development Board with loads computed by the Geological Survey showed that the two methods compared closely. However, loads calculated by the Texas Water Development Board generally were lower than those determined by the Geological Survey, which used data collected by depth-integrating samplers.

The data collected annually during the study were used to define a regression model. The model provides an accurate estimate of annual suspended-sediment loads using annual discharge as the independent variable.

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DEFINITION OF TERMS

Acre-foot.--The quantity of water required to cover 1 acre to a depth of 1 foot. It is equivalent to 43,560 cubic feet, about 326,000 gallons, or 1,233 cubic meters.

Bedload.--Material moving on or near the streambed by rolling or sliding. It sometimes makes brief excursions into the flow a few diameters above the bed.

Cubic foot per second.--The rate of discharge representing a volume of 1 cubic foot passing a given point during 1 second. It is equivalent to approximately 7.48 gallons per second, or 448.8 gallons per minute, or 0.02832 cubic meter per second.

Cubic-foot-per-second day.--The volume of water represented by a flow of 1 cubic foot per second for 24 hours. It is equivalent to 86,400 cubic feet, approximately 1.9835 acre-feet, about 646,000 gallons, or 2,445 cubic meters.

Depth-integrated sample.--A suspended-sediment sample that is accumulated continuously in a sampler, which is moved vertically at a constant transit rate and which admits the water-sediment mixture at a velocity equal to the stream velocity at every point of transit.

Discharge.--The volume of fluid passing a given point in a given period of time. As used in this report, the discharge that occurs in a natural channel.

Double-mass curve.--As used in this report, a double-mass curve is constructed by plotting cumulative annual stream discharge against cumulative annual suspended-sediment load.

Flow-duration curve.--A cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded.

Gaging station.--A site on a stream, canal, lake, or reservoir where systematic observations of hydrologic data are obtained.

Suspended sediment.--The sediment that at any given time is maintained in suspension by the upward components of turbulent currents or that exists in suspension as a colloid.

Suspended-sediment load.--The quantity of suspended-sediment that passes a section in a specified period, usually measured in tons.

Total sediment load.--The sum of (1) measured suspended-sediment load, (2) unmeasured suspended-sediment load, and (3) bedload. It is the total quantity of sediment, by dry weight, that passes a section, in a given time.

Water year.--A 12-month period from October 1 through September 30 that is designated by the calendar year in which it ends. Thus, the year ending September 30, 1982, is the "1982 water year."