CONVEYANCE CHARACTERISTICS OF THE NUECES RIVER , COTULLA TO SIMMONS, TEXAS

By Bernard C. Massey and William E. Reeves

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JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
Federal Building
300 East 8th Street
Austin, Texas 78701

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METRIC CONVERSIONS

Most units of measurement used in this report are inch-pound units. For those readers interested in using the metric system, the inch-pound units may be converted to metric units by the following factors:

From	Multiply by	To obtain
acre	0.4047	square hectometer
acre-foot	1,233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot	0.3048	meter
foot per mile	0.189	meter per kilometer
acre-foot per square mile (acre-ft/m^2)	476	cubic meter per square kilometer (m^3/km^2)
gallon per minute (gal/min)	0.06309	liter per second
inch	25.4	millimeter
mile	1.609	kilometer
square mile	2.590	square kilometer

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 "mean sea level."

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ABSTRACT

Analysis of discharge hydrographs for streamflow-gaging stations on the Nueces River at Cotulla, Tilden, and Simmons indicate that significant water losses occur along the 108-mile reach from Cotulla to Simmons during storm-runoff. Computed losses along the 83-mile reach from Cotulla to Tilden for 15 storm periods range from 32 to 59 percent of the total runoff volume passing the Cotulla gage. For six storm periods that occurred while the gage at Simmons was in operation, computed losses from Cotulla to Simmons averaged 48 percent of the storm runoff passing the Cotulla gage.

Estimates of total-annual losses were made with the aid of a regression model developed to relate monthly rainfall totals to monthly runoff. The model was calibrated using runoff data for San Casimiro Creek, the only gaged tributary in the study area, and monthly rainfall totals from nearby rain gages. The calibrated model was used with monthly rainfall totals from six National Weather Service rain gages in or near the study area to estimate monthly-runoff volumes for the ungaged area between Cotulla and Simmons. Total annual water losses, estimated with the aid of the regression model, ranged from 46,600 acre-feet during water years 1969 to 368,500 acre-feet during water year 1967, and averaged about 174,000 acre-feet for water years 1966-77.

INTRODUCTION

The Texas Water Plan, a guide for development of the State's water resources, indicates that the lower Nueces River basin will be a water-deficient area in the near future. The coastal areas of the lower Nueces River basin, which include the greater Corpus Christi area, are experiencing rapid urban and industrial growth. Increasing water supplies will be needed to support the economy required to fulfill the needs of that area's increasing population. Currently, these coastal areas get most of their water supplies from the surface-water resources in the Nueces River basin.

Upstream, principally in the Winter Garden area near the middle of the Nueces River basin, more than 500,000 acres of fertile land is suitable for irrigation. During 1974, about 300,000 acres were being irrigated, mostly from ground-water resources. However, existing ground-water resources are being depleted, and available surface-water resources are insufficient to sustain even the 1974 irrigation. Suggested solutions by State and local officials to the existing and anticipated water supplies and related problems of the Nueces River basin include importing large quantities of water from outside the basin along with optimum development and wise use of existing water supplies within the basin.

To accomplish the latter, the U.S. Bureau of Reclamation, Department of the Interior, has undertaken a study to identify the long-term water needs and available water resources of the Nueces River basin. This report was prepared in cooperation with the Bureau of Reclamation as part of their overall study.

PURPOSE AND SCOPE OF THIS REPORT

The purpose of this study is to provide data and hydrologic interpretations for use by the Bureau of Reclamation in evaluating and quantifying natural water losses that are known to occur along some reaches of the Nueces River. Specifically, this report presents data and analyses describing the conveyance characteristics of that reach of the Nueces River from Cotulla to Simmons. A proposed reservoir on the Nueces River at Cotulla would be located at the upstream end of the study reach. The efficiency of the river channel for transporting reservoir releases through the study reach to downstream water-users may be a prime factor in determining the feasibility of constructing the reservoir. To aid the Bureau of Reclamation in determining the feasibility of this project, the U.S. Geological Survey determined the efficiency of the river channel for transfer of water through the reach. The magnitude of the losses expected to occur during periods of continued reservoir release were estimated.

DESCRIPTION OF THE BASIN

The Nueces River basin is located in south-central Texas and extends from the deeply dissected limestone plains of the Edwards Plateau in Edwards County across the Balcones Fault zone and the Gulf Coastal Plains to the Gulf of Mexico in the vicinity of Corpus Christi (fig. 1). The basin is bounded on the north and east by the Colorado and Guadalupe River basins and the San Antonio-Nueces coastal basin, and on the west and south by the Rio Grande basin and the Nueces-Rio Grande coastal basin. Total basin drainage area is about 16,950 square miles. Principal streams in the Nueces River basin include the Atascosa and Frio Rivers, which enter the Nueces River upstream from Lake Corpus Christi but downstream from the study area.

The headwaters of the Nueces River originate at an elevation of about 1,220 feet in Edwards County. The river crosses the Balcones Fault Zone downstream from Laguna and flows generally southeasterly through the coastal plain into Nueces Bay, an arm of Corpus Christi Bay.

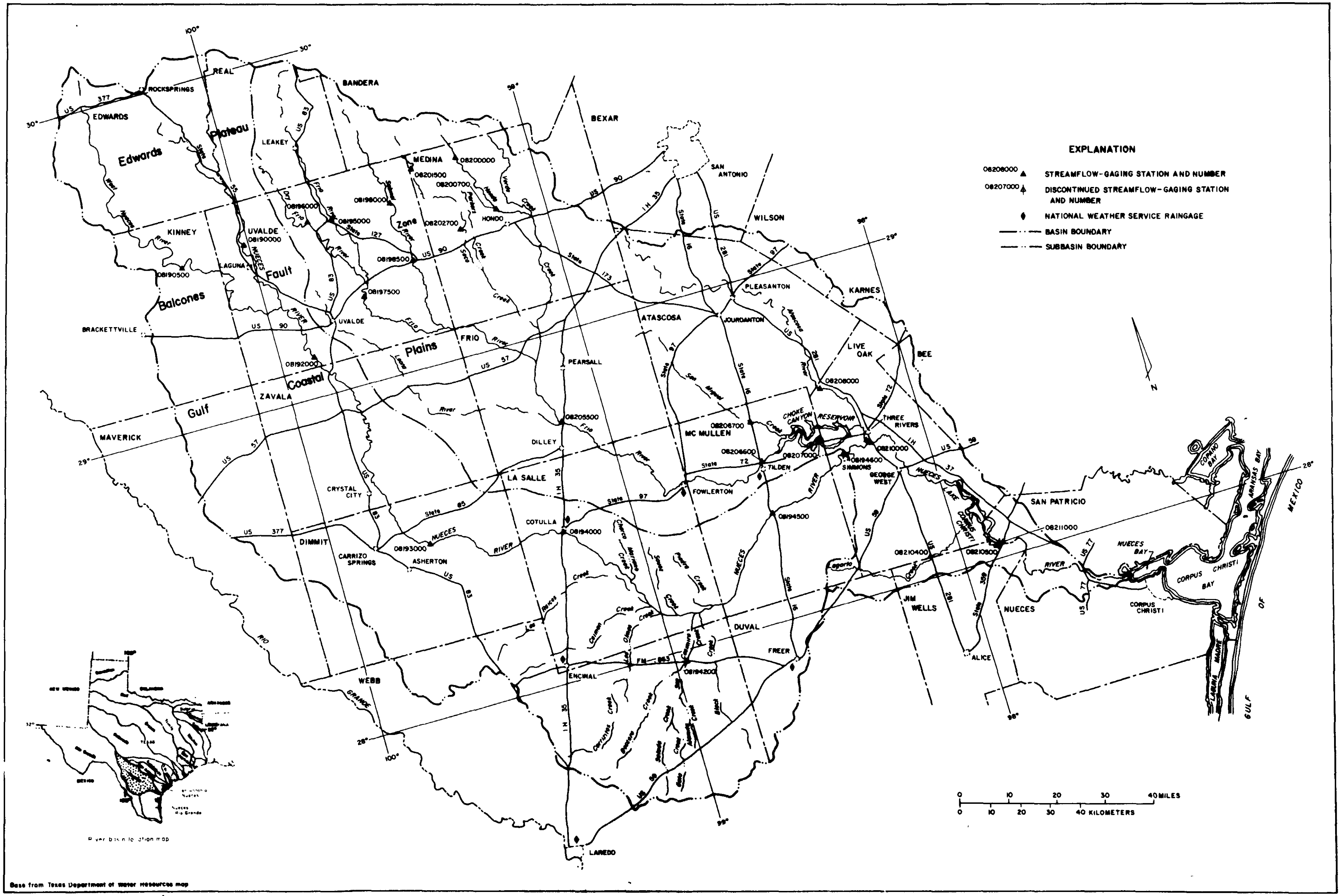

Figure 1.-Nueces River basin

Geology

The upper reach of the Nueces River basin is underlain by Cretaceous limestone that forms the Edwards Plateau. South of the plateau are younger Cretaceous chalk, clay, and limestone beds. The entire sequence dips to the southeast.

The greater part of the basin is underlain by a Tertiary sequence of southeasterly dipping sand, clay, silt, glauconite, volcanic ash, and lignite beds, and sand, clay, and gravel of the Goliad Sand. These are overlain by sand, gravel, and clay of the Willis Sand and Lissie Formation of Pleistocene age. The coastal region of the basin is underlain by clay, silt, and fine-grained sand of the Beaumont Formation of Pleistocene age and by alluvium along the streams and flood plains.

The upland soils are dark, calcareous to slightly acid clays, loams, and sands. Bottomlands have brown to gray, calcareous, alluvial soils. In the coastal regions, saline and sodic soils are extensive.

Several major aquifers underlie the Nueces River basin. The Edwards-Trinity and Trinity Group aquifers underlie the upper part of the basin and yield minimal quantities of water to wells. The Edwards aquifer extends across the upper middle part of the basin. This aquifer consists of hard, massive limestone, dolomitic limestone, and marly limestone with secondary fractures and solution porosity, ranging in total thickness from about 400 to 900 feet. Yields of large-capacity wells average about 900 gal/min. The Carrizo-Wilcox aquifer extends across most of the central part of the Nueces River basin. This aquifer is composed of the Wilcox Group and the overlying Carrizo Sand of Tertiary age. Total thickness of the Carrizo-Wilcox is as much as 3,000 feet, of which about 50 percent is water-bearing sand. Yields of large-capacity wells average about 700 gal/min. The Gulf Coast aquifer extends across the lower part of the Nueces River basin. The aquifer consists of a complex system of interbedded sand and clay extending to a maximum depth of about 1,600 feet. Net water-bearing sand thickness ranges from 200 to 400 feet. Yields of large-capacity wells average about 500 gal/min.

Climatology

The climate of the Nueces River basin is humid subtropical. Hot, humid summers and mild, dry winters are typical of the area. Annual precipitation in the basin ranges from about 20 inches in the northwest to about 32 inches in the southeast. The average net lake-surface evaporation exceeds precipitation by about 30 inches per year in the extreme eastern part of the basin and by approximately 60 inches in the westernmost areas.

Much of the annual precipitation is produced by thunderstorms that occur mostly during the warm season (May through September). Precipitation during the cool season usually occurs as steady, light rain. Because of its proximity to the Gulf of Mexico, the entire Nueces River basin is vulnerable to torrential rainfall associated with tropical storms and hurricanes.

Surface-Water Hydrology

Surface-water runoff from all parts of the Nueces River basin varies widely from year to year. Streamflow records from gaging stations on the Nueces River and its tributaries in the Edwards Plateau upstream from the Balcones Fault Zone show an average-annual runoff rate of about 180 acre-ft/mi^2. The Balcones Fault Zone crosses the Nueces River basin along an approximate east-west line from San Antonio to Del Rio, passing just north of Uvalde (Maclay and Rettman, 1976). A substantial part of the flows of the Nueces River and its tributaries enter the fractured and cavernous limestone formation as they cross the fault zone.

Streamflow records collected on the Nueces River at Three Rivers (station 08210000) about 25 miles upstream from the upper end of Lake Corpus Christi show the average annual runoff for that part of the Nueces River basin downstream from the Balcones Fault Zone to Three Rivers to be less than 40 acre-ft/mi^2.

Although the average yearly rainfall and runoff are relatively small for the Nueces River basin, many heavy rainfalls and large floods have been recorded on the river and its tributaries, especially in the upper part of the basin that drains the Edwards Plateau. As examples, Seco Creek in Medina County (station 08202700) had a maximum discharge of 230,000 ft^3/s on May 31, 1935, from a drainage area of 142 square miles. The West Nueces River in Edwards County, 33 miles upstream from station 08190500, had a maximum discharge of 580,000 ft^3/s on June 14, 1935, from a drainage area of 402 square miles.

The maximum discharge of the Nueces River at Laguna (station 08190000) for the 57 water years of record (1924-80) was 307,000 ft^3/s on September 24, 1955, from a drainage area of 764 square miles. During this same period, flood discharges at this site exceeded 100,000 ft^3/s six times.

Downstream from the Edwards Plateau, the streambed gradients become flatter and the flood plains become wider. Floods move more slowly and have smaller maximum unit discharges than on the Edwards Plateau.

The maximum discharge on the Nueces River below Uvalde (station 08192000) during the 53 water years of record (1928-80) was 616,000 ft^3/s on June 14, 1935, from a drainage area of 1,947 square miles. During this same period, flood discharges at this site exceeded 100,000 ft^3/s six times.

The maximum discharge of the Nueces River at Three Rivers (station 0821000) during water years 1916-80 was 141,000 ft^3/s on September 23, 1967, from a drainage area of 15,600 square miles. No other flood discharge exceeding 100,000 ft^3/s has occurred at this site since about 1875.

Flow rates in the river are affected at times by many small diversions for irrigation and municpal supply and by several small reservoirs on the Nueces River upstream from Three Rivers.

DESCRIPTION OF THE STUDY REACH

This study is that reach of the Nueces River extending from Cotulla to Simmons. This 108-mile reach of the Nueces River, commonly known as the "Big Bend of the Nueces," is in the Gulf Coastal Plains and is located between river miles 114 and 222 (fig. 2).

The drainage area of the Nueces River at Cotulla is 5,260 square miles, the elevation of the streambed is about 375 feet, and the basin width is about 100 miles. Downstream at Simmons, the drainage area is 8,561 square miles, the streambed elevation is about 116 feet, and the basin width is approximately 65 miles (fig. 2).

The streambed elevation decreases by about 260 feet from Cotulla to Simmons, resulting in an average streambed slope of about 2.4 feet per mile. The single channel in the vicinity of Cotulla changes to a system of interconnected braided channels about 15 miles downstream. The stream continues with interconnected braided channels until about 12 miles upstream from Simmons. Flow occurs in most of the channels at discharge rates greater than about 200 ft^3/s. Flood-plain width ranges from less than 1 mile at Simmons to more than 4 miles in the braided-channel section. A channel profile showing the approximate streambed elevation for the reach from Cotulla to Simmons is given in figure 3. The streambed elevations were obtained from U.S. Geological Survey topographic maps (scale 1:24,000) and from records of streamflow-gaging stations at Cotulla (08194000), near Tilden (08194500), and at Simmons (08194600).

Water is diverted for small-scale irrigation at many points along the study reach. Several low-head channel dams have been constructed along the reach to form pools from which irrigation water is diverted.

Vegetation

Dense growths of native grasses are prevelant in flood plains along most of the study reach. Thick bunchgrasses such as Gulf cordgrass, switchgrass, and alkali sacaton grow to heights of as much as 6 feet in dense stands that may cover several thousands of acres. Long-continued cattle grazing of the desirable grasses in the area have so altered the vegetation patterns that the region is now known as the "brush country." Dense thickets of brush are common along the ridges and near the streams. Post oak, live oak, mesquite, and cacti also are common to the area.

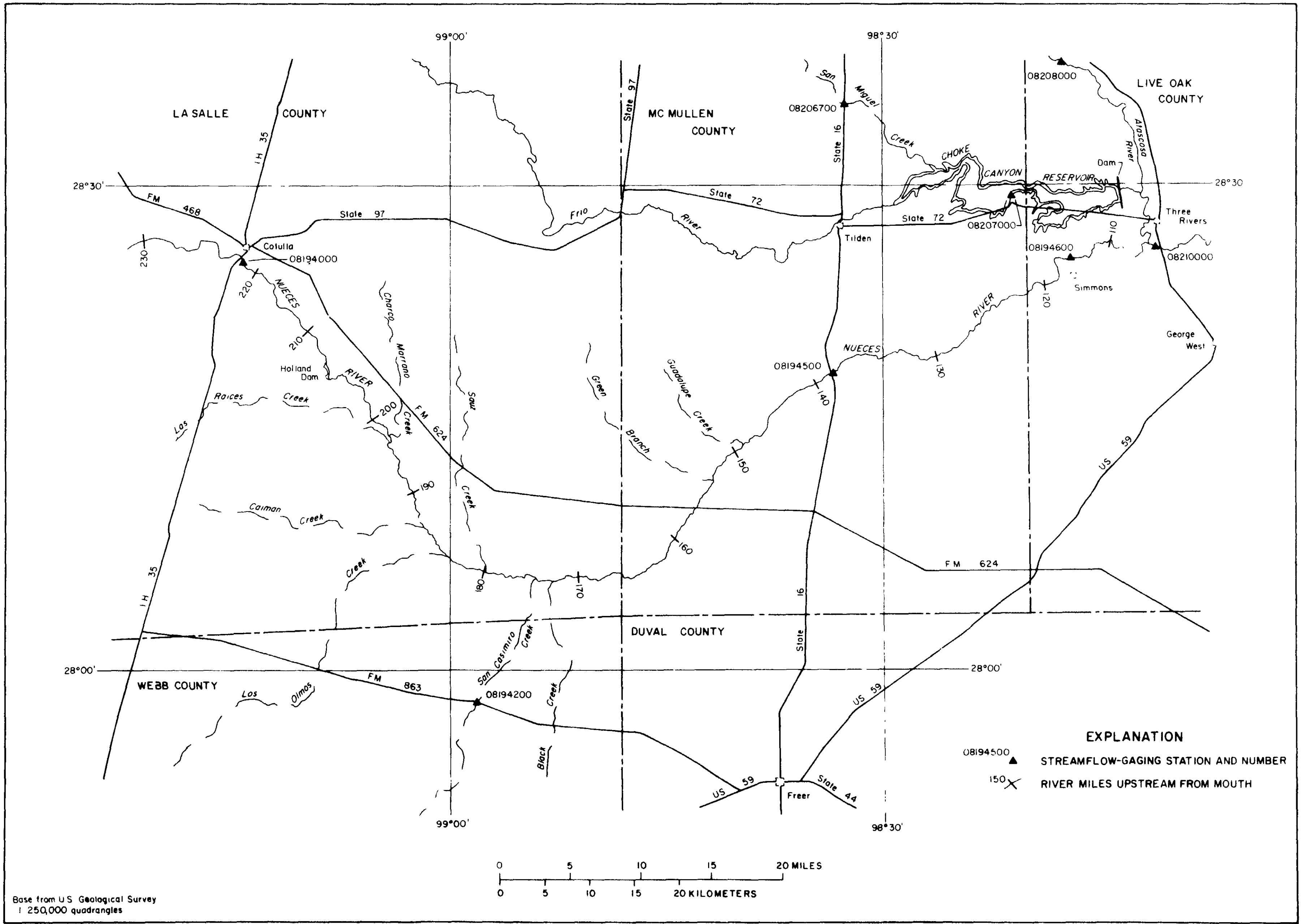

Figure 2.-Nueces River reach extending from Cotulla to Simmons

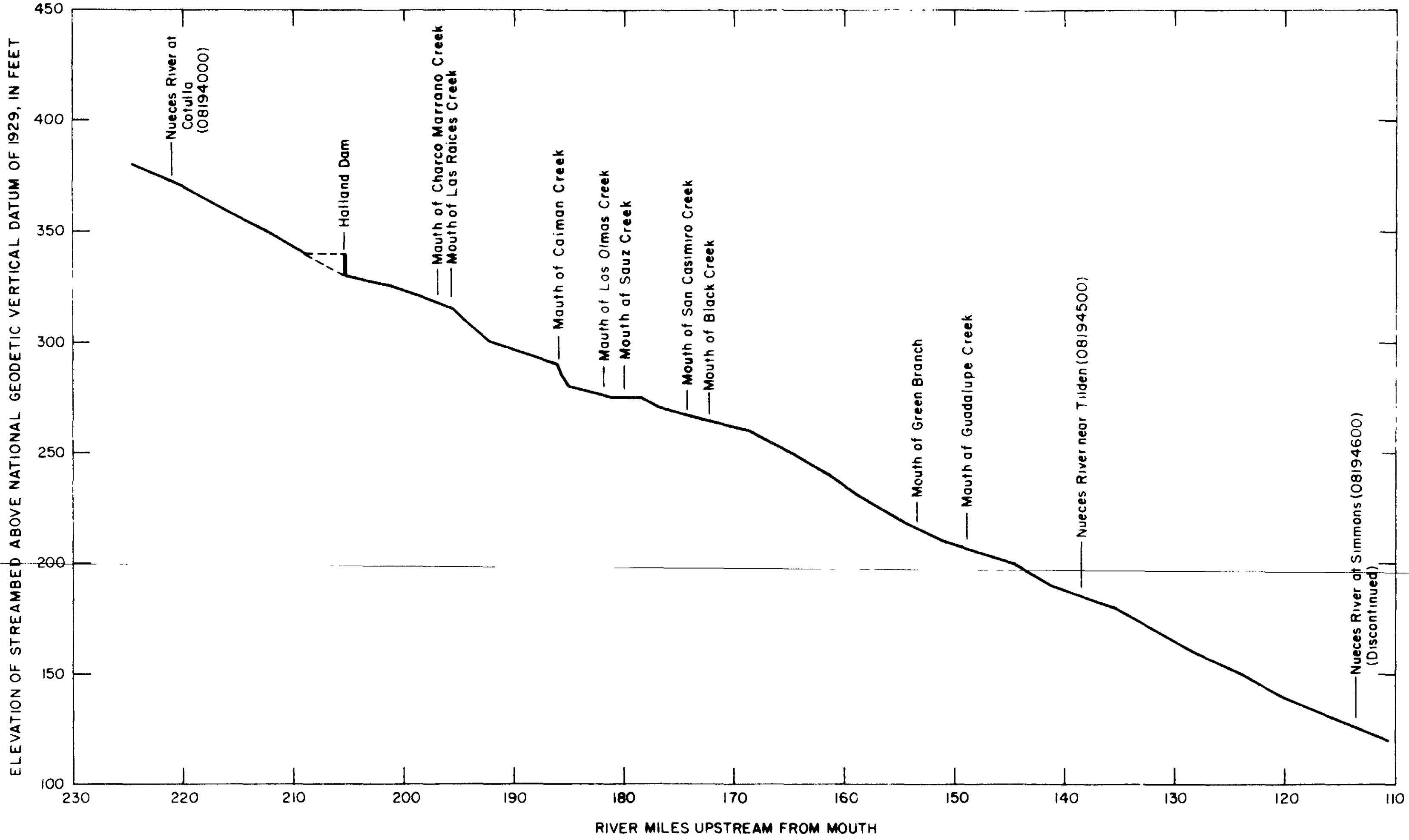

Figure 3.-Profile of the streambed elevation for the Nueces River from Cotulla to Simmons

Soils

Soils along the flood plain from Cotulla to Simmons are mostly fertile, sandy loams and clays. They range in color from chocolate brown to dark gray and black. The slightly saline soils absorb large quantities of water during periods of overbank flow. They dry fairly quickly following stream recessions, losing the water through seepage to deeper zones and through evapotranspiration.

HYDROLOGIC DATA USED

Daily discharge records from seven U.S. Geological Survey streamflow-gaging stations located in and near the study area (fig. 2) were used for analysis in this report. These stations are described below:

Streamflow-gaging station		Drainage area (square miles)	Period of record
08194000	Nueces River at Cotulla	5,260	Oct. 1926 to Sept. 1980
08194200	San Casimiro Creek near Freer	469	Jan. 1962 to Sept. 1980
08194500	Nueces River near Tilden	8,192	Nov. 1942 to Sept. 1980
08194600	Nueces River at Simmons	8,561	Apr. 1965 to Sept. 1977
08206700	San Miguel Creek near Tilden	793	Jan. 1964 to Sept. 1980
08207000	Frio River at Calliham	5,491	Apr. 1932 to Sept. 1980
08208000	Atascosa River at Whitsett	1,171	Sept. 1924 to May 1926, May 1932 to Sept. 1980

Rainfall data used in the analysis were obtained from publications of the National Weather Service. Daily and monthly rainfall totals were obtained from National Weather Service stations in Cotulla, Fowlerton, Tilden, Freer, Laredo, and Encinal (fig. 1).

Channel cross sections used in estimating the total area submerged in the flood plain between Cotulla and Simmons for several flow ranges were available in the records for the Cotulla, Tilden, and Simmons stations. Additional cross sections used in developing the relationships were determined by surveys and from Geological Survey topographic maps (scale 1:24,000).

WATER LOSSES

Discharge records for streamflow-gaging stations at Cotulla, Tilden, and Simmons show large water losses at times in the study reach. An analysis of these losses, however, is complicated by lack of streamflow data for the 2,932-square mile contributing drainage area between Cotulla and Tilden. The only gaged area in this reach is a 469-square-mile drainage area on San Casimiro Creek, which enters the Nueces River about midway between Cotulla and Simmons.

Water losses were first analyzed for floodflows passing through the reach and secondly from the mass balance of annual flows. Losses from flood flows were determined by analyzing discharge hydrographs recorded at the Cotulla, Tilden, and Simmons gaging stations for floods that originated in the basin upstream from Cotulla. To estimate the annual losses, data were available on the volume of flow into (Cotulla) and out of (Simmons) the reach. However, the intervening flow volume is not known. To estimate the intervening flow, the discharge record for San Casimiro Creek was used as an index. A regression model was developed relating monthly rainfall from National Weather Service rain gages at Freer, Encinal, and Laredo to monthly runoff at the San Casimiro gage (station 08194200). National Weather Service rainfall records for Tilden, Fowlerton, and Cotulla along with the three previously mentioned, were then used in conjunction with the model to estimate monthly and yearly runoff for the ungaged area between Cotulla and Simmons.

Losses During Storm Periods

Records of mean daily discharge resulting from storms originating in the Nueces River basin upstream from Cotulla for periods when little or no runoff occurred in the intervening area upstream from Simmons were selected for this analysis. In addition, several storms were selected for periods when contributing flow from the ungaged area could be estimated with reasonable accuracy by hydrograph-separation techniques (Linsley, Kohler, and Paulhus, 1958).

A list of the storm periods is given in table 1 along with the computed storm runoff and water-loss values for each period. Six of the 15 storm periods used in the analysis occurred during the period when the gaging station on the Nueces River at Simmons was in operation. For these storm periods, computed water losses are given for the channel reach between Cotulla and Simmons. For the remaining storm periods, water losses are given only for the reach between Cotulla and Tilden. Discharge hydrographs are shown in figures 4-8 for several selected storm periods. These storm periods were selected to include the range in discharge for those used in the analysis and to illustrate the hydrograph-separation techniques used to determine the volume of runoff from the intervening area between Cotulla and Tilden. These gains in streamflow volume were deducted from the total runoff volumes at Tilden and Simmons before water losses for the storm periods were computed.

Total water losses between Cotulla and Tilden ranged from 32 to 59 percent of the total runoff at Cotulla for the 15 storm periods shown in table 1. Total water losses in the reach from Cotulla to Simmons averaged 48 percent of the total flow at Cotulla for the six storm periods occurring when flow records were available for Simmons.

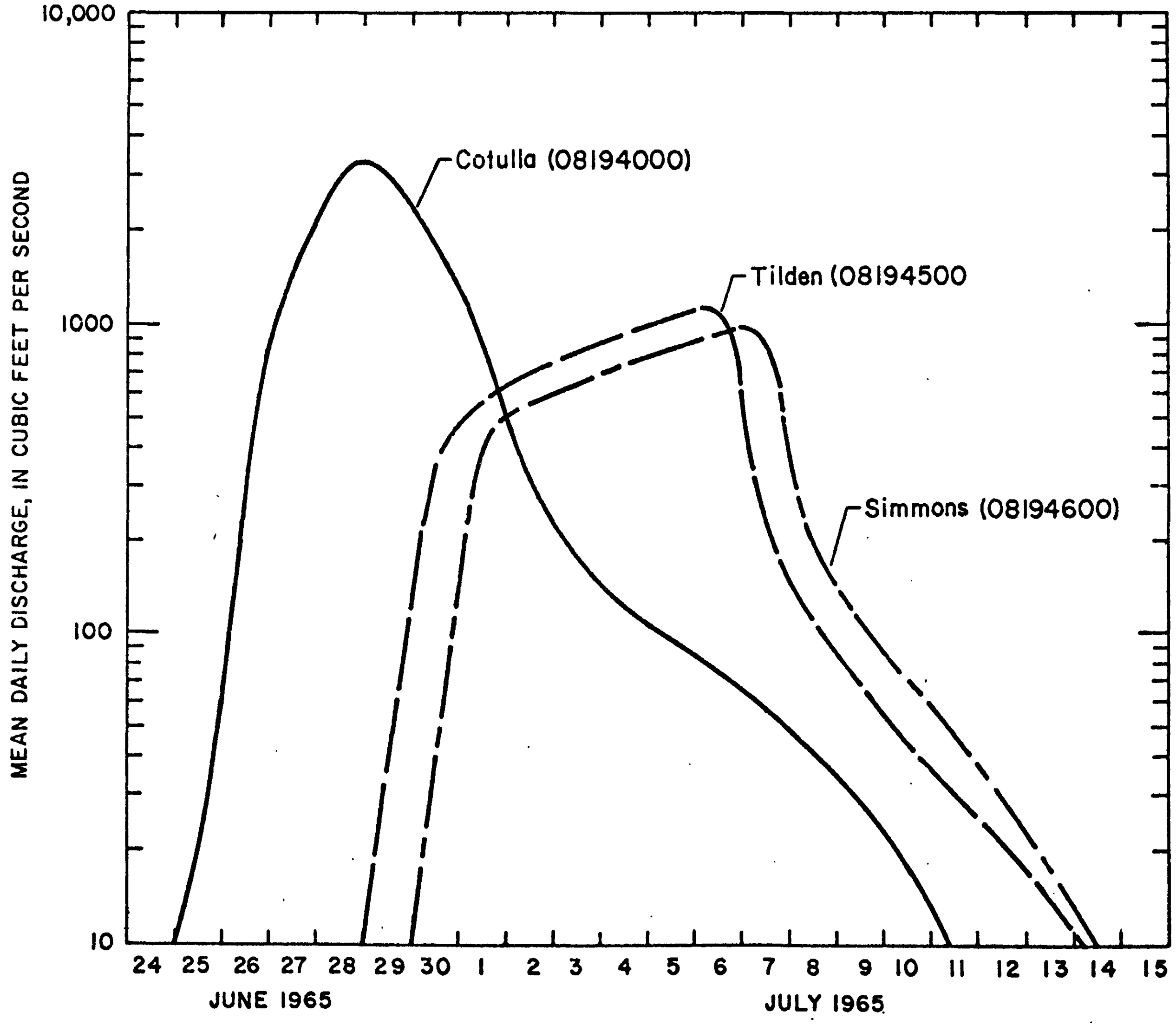

Figure 4.-Discharge hydrographs for the Nueces River at Cotulla, Tilden, and Simmons for storm runoff from June 25 to July 14, 1965

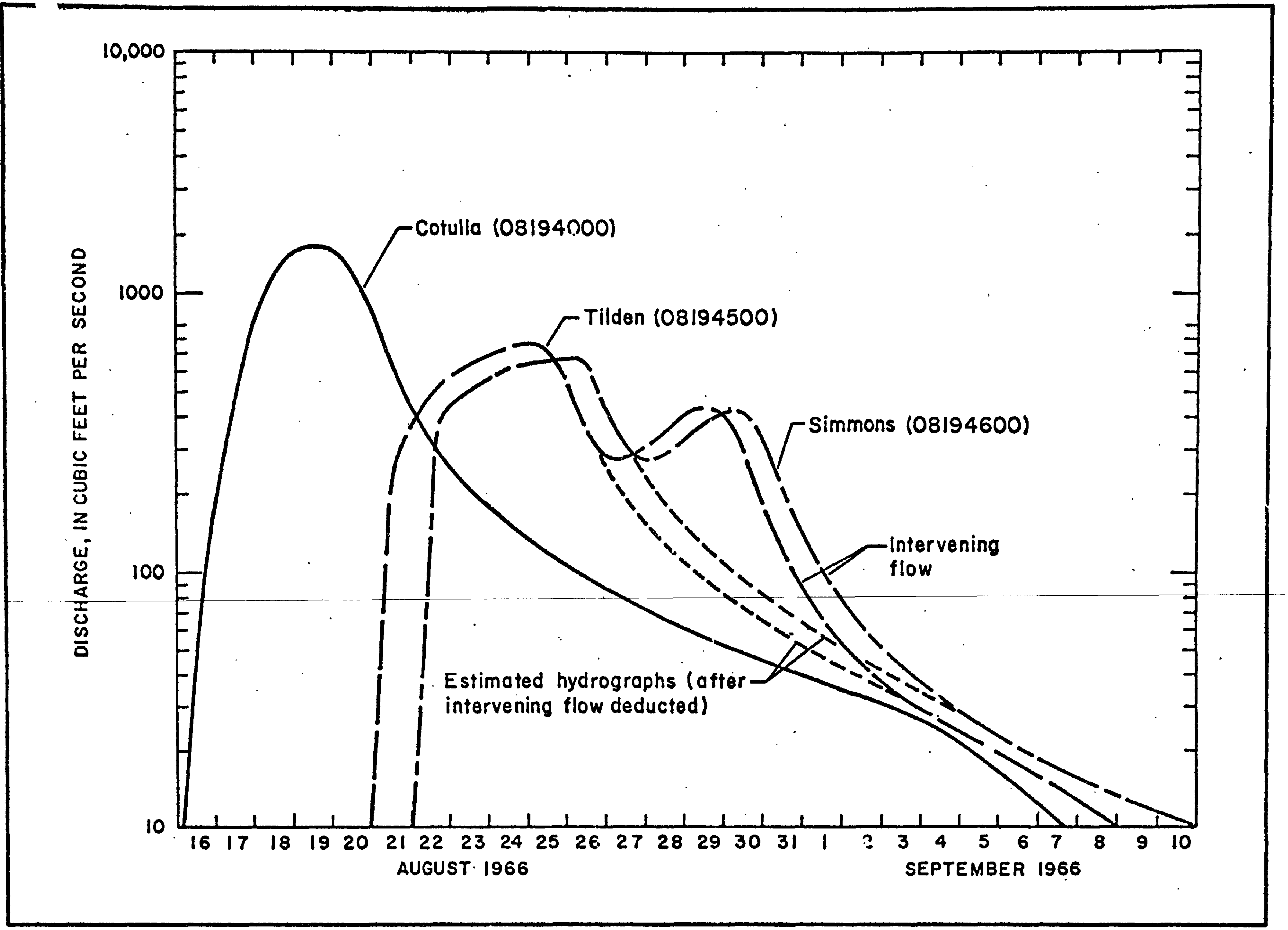

Figure 5.-Discharge hydrographs for the Nueces River at Cotulla, Tilden, and Simmons for Storm runoff from August 16 to September 10, 1966

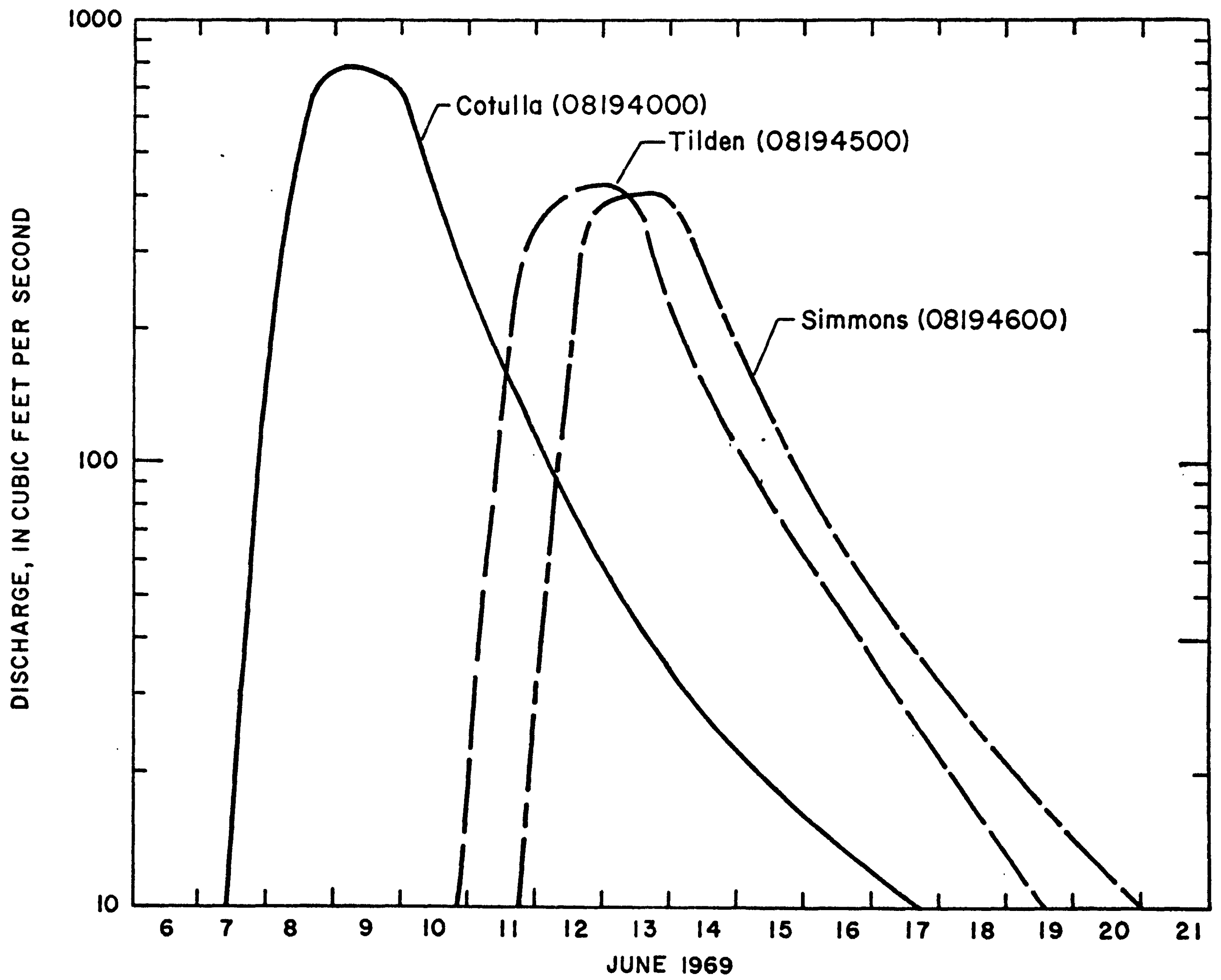

Figure 6.-Discharge hydrographs for the Nueces River at Cotulla, Tilden, and Simmons for storm runoff from June 7-20, 1969

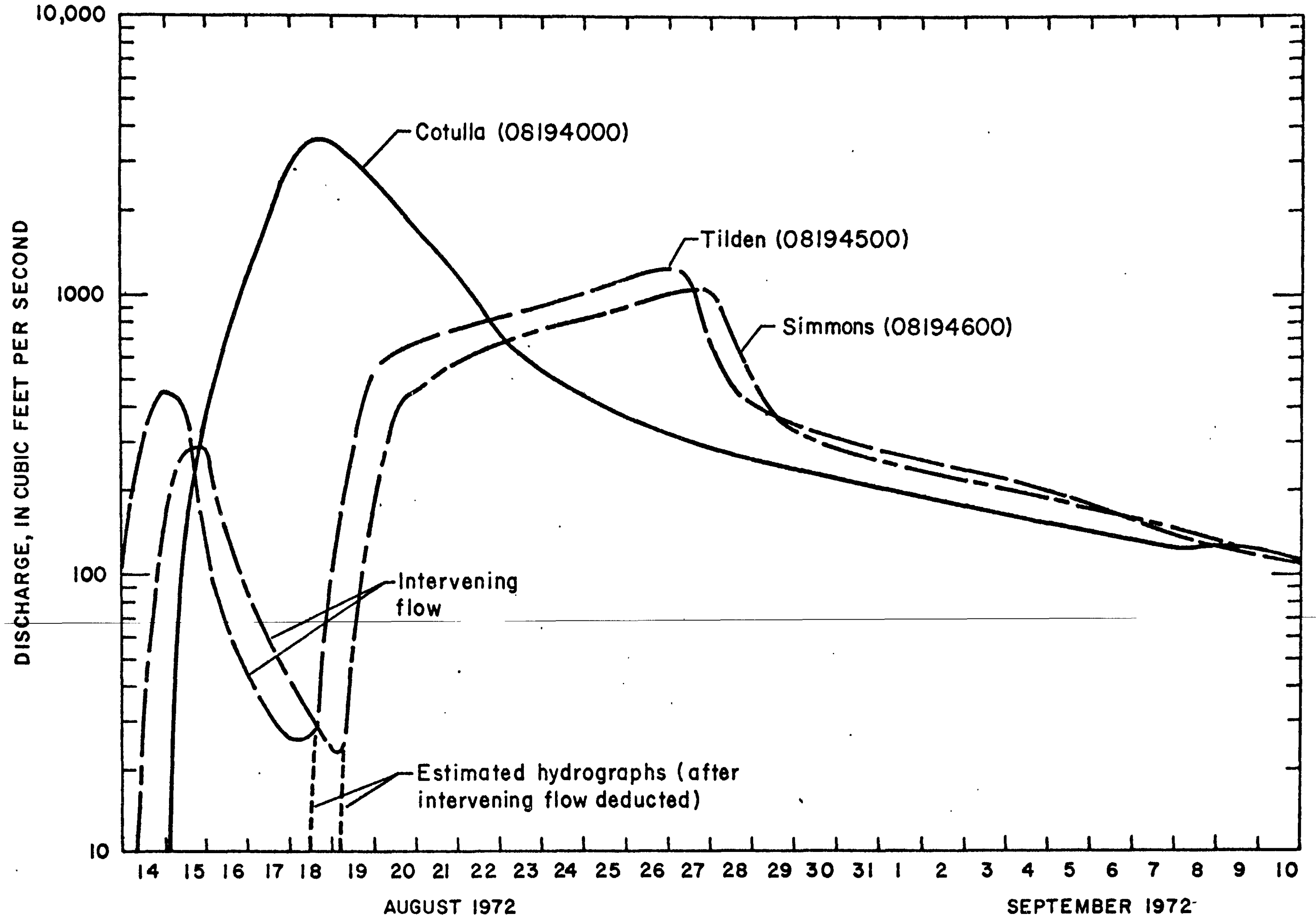

Figure 7.-Discharge hydrographs for the Nueces River at Cotulla, Tilden, and Simmons for storm runoff from August 14 to September 10, 1972

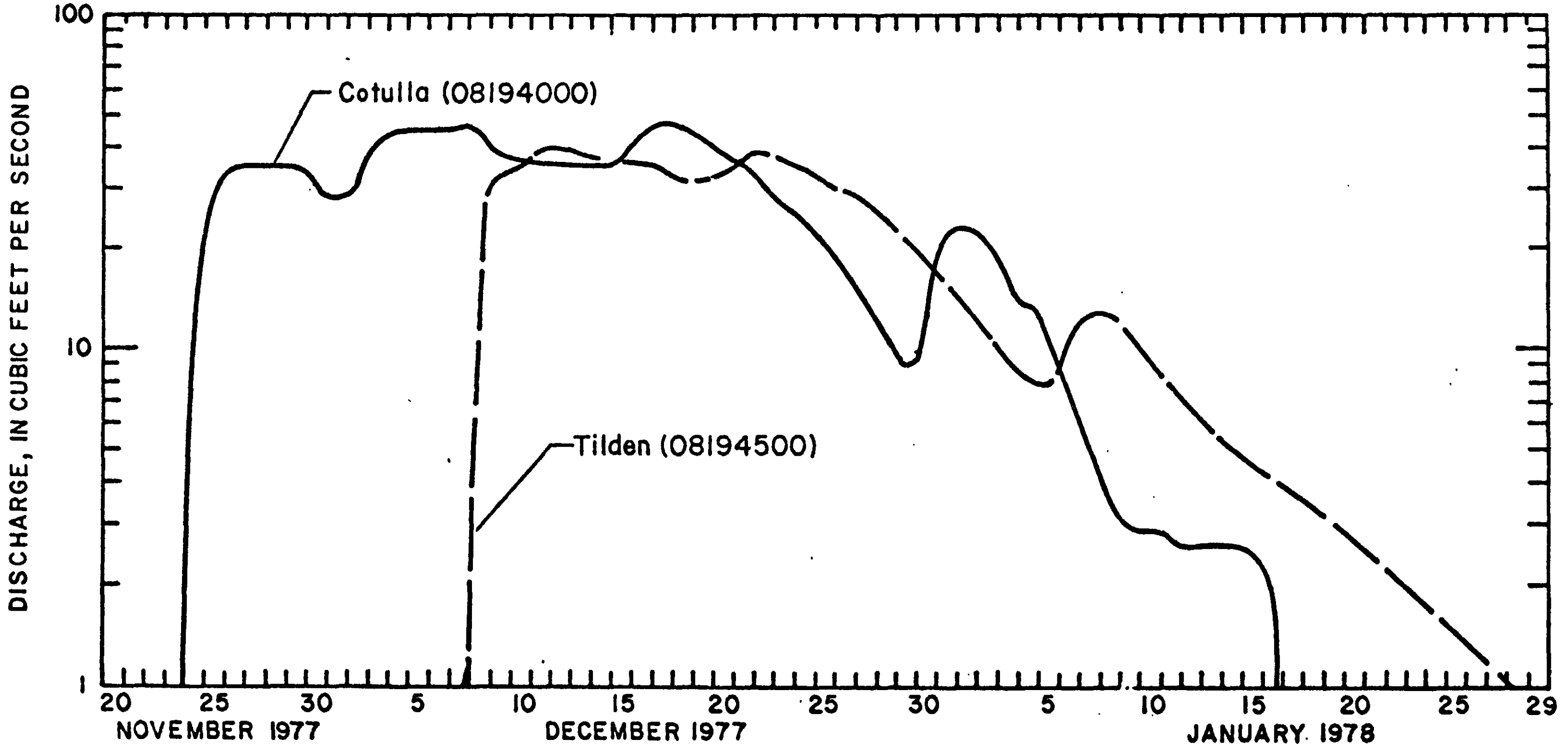

Figure 8.-Discharge hydrographs for the Nueces River at Cotulla, and Tilden for storm runoff from November 24, 1977 to January 28, 1978

Table 1.--Water-loss computations for storm periods

Period no.	Runoff period	Storm runoff (acre-feet)					Water loss (acre-feet)	
		Cotulla (station 08194000)	Net in-flow a/	Tilden (station 08194500)	Total net inflow b/	Simmons (station 08194600) c/	Cotulla to Tilden	Cotulla to Simmons
1	July 22 to Aug. 12, 1955	13,820	60	6,140	--	--	7,740	--
2	Sept. 27 to Oct. 27, 1955	66,030	0	42,300	--	--	23,730	--
3	Nov. 13, 1961 to Jan. 23, 1962	2,010	0	990	--	--	1,020	--
4	Nov. 8 to Dec. 28, 1962	3,350	100	1,640	--	--	1,810	--
5	Apr. 6 to 25, 1963	3,900	50	1,670	--	--	2,280	--
6	May 6 to 30, 1963	10,630	3,770	9,790	--	--	4,610	--
7	Oct. 26 to Nov. 16, 1963	2,100	0	870	--	--	1,230	--
8	Aug. 24 to Sept. 16, 1964	35,530	2,290	18,430	--	--	19,390	--
9	June 25 to July 21, 1965	22,380	0	11,770	0	10,600	10,610	11,780
10	Aug. 16 to Sept. 18, 1966	14,500	1,840	9,620	1,610	8,970	6,720	7,140
11	May 14 to June 15, 1969	6,930	930	5,180	1,720	5,690	2,680	2,960
12	June 7 to 29, 1969	4,240	150	2,580	120	2,460	1,810	1,900
13	Sept. 2 to 26, 1969	6,210	940	4,030	860	3,780	3,120	3,290
14	Aug. 14 to Sept. 22, 1972	37,600	1,610	25,230	1,210	21,960	13,980	16,850
15	Nov. 24, 1977 to Jan. 30, 1978	2,680	20	1,840	--	--	860	--

a/ Intervening area--Cotulla to Tilden.
b/ Intervening area--Cotulla to Simmons.
c/ Period of record Apr. 1965 to Sept. 1977.

Relationships of storm runoff at Cotulla to those at Tilden and Simmons are presented in figure 9. Note that the percentage of loss was greater for small storm runoffs than for the large storm runoffs. Prolonged periods of sustained flow seldom occur in the study reach and sufficient data are not available for determining water losses for such periods.

Annual Losses

To estimate annual water losses which occur along the channel from Cotulla to Simmons, the annual inflow and outflow need to be known. The inflow consists of the flow at Cotulla plus runoff from the 3,301-square-mile intervening area between Cotulla and Simmons. The outflow is the flow measured at Simmons. Flow records are available for Cotulla and Simmons, but the only runoff records available for the intervening area are those for a 469-square-mile drainage area on San Casimiro Creek (station 08194200). Runoff from the remaining 2,832 square miles must be estimated before annual losses can be determined. Data available for making runoff estimates for the ungaged area include records of discharge at the San Casimiro Creek gaging station and limited climatological data which include daily-rainfall totals published by the National Weather Service for Cotulla, Fowlerton, Tilden, Freer, Laredo, and Encinal.

These data obviously are insufficient for the use of parametric rainfall-runoff models to estimate peak discharge rates or total runoff from the ungaged area on a daily or storm basis. Further, to assume that unit runoff from the San Casimiro Creek basin is representative of the runoff from the ungaged area would discount the effect of differences in average annual rainfall across the study area. Because of the absence of other methods to obtain more reliable estimates of runoff from the ungaged area, the technique described below was used.

Based on the authors' knowledge of the area, the assumption was made that the runoff characteristics for the ungaged streams were similar to those for San Casimiro Creek. A regression model was developed for the gaged San Casimiro Creek drainage area and applied to the ungaged area. The model relates monthly weighted-mean rainfall in the San Casimiro Creek basin to monthly runoff at the San Casimiro Creek gaging station. Data for October 1965 through September 1977 were selected for the model development because it corresponded to the period of record for the Nueces River at Simmons gage. The selected regression model had the following form:

$$R = aP^{b_1}M^{b_2} \tag{1}$$

where R = total monthly runoff, in acre feet, at the San Casimiro Creek gaging station,
a = the regression constant,
P = the monthly weighted-mean rainfall, in inches,
M = the rainfall, in inches, for the previous month (an indicator of the soil-moisture index), with M ranging from $0.3 < M < P$, and
b_1, b_2 = regression coefficients.

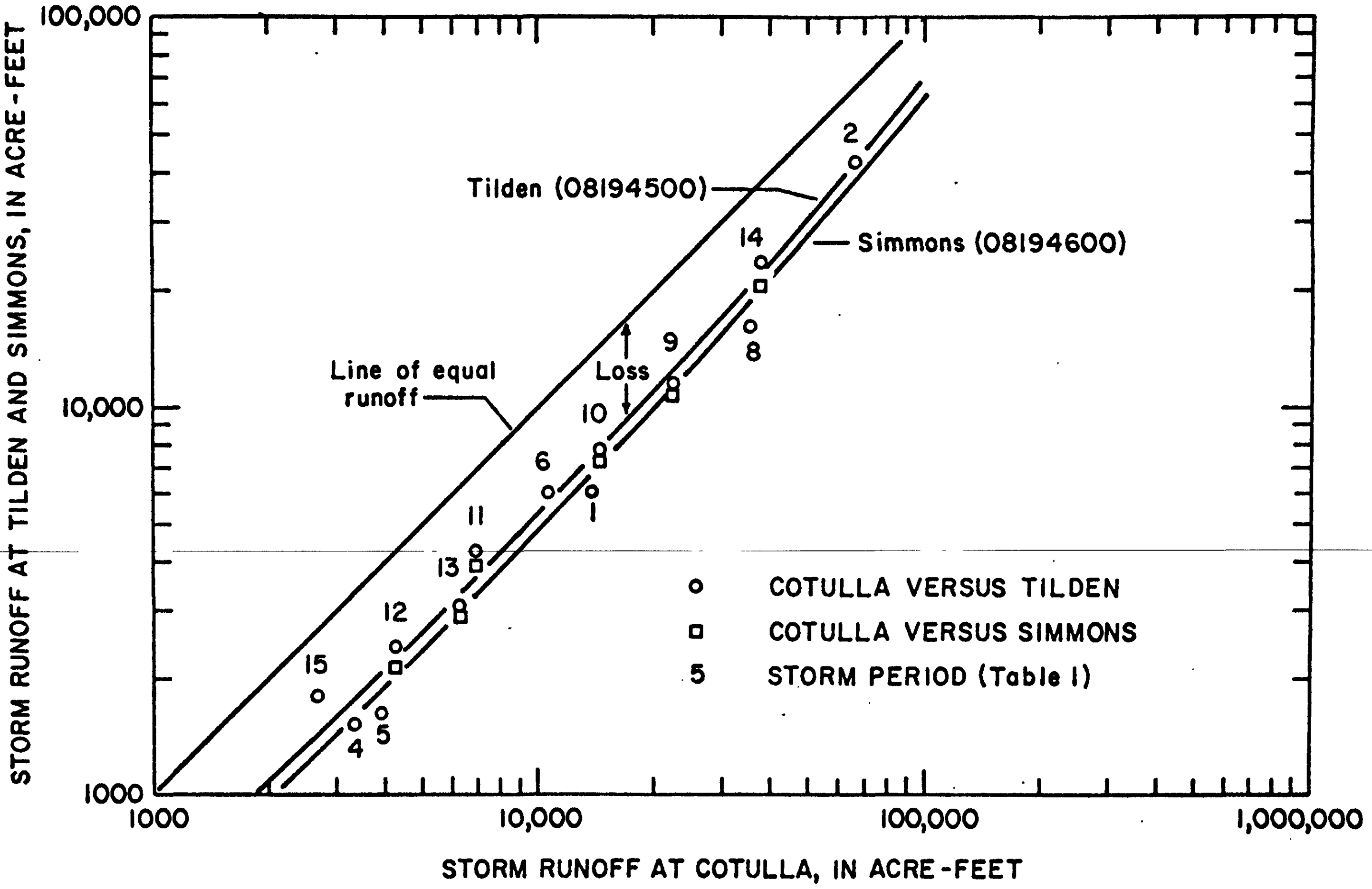

Figure 9.-Relationship between storm runoff at Cotulla and storm runoff at Simmons and Tilden

These rain gages are located outside the San Casimiro Creek basin at distances ranging from 22 to 45 miles from the gaging station. They form a triangle around the basin encompassing more than 800 square miles. The assumption that this weighted rainfall record is representative of the rainfall that fell throughout the San Casimiro basin may limit the reliability of the regression equation. Multiple-regression analysis defined the regression equation as follows:

$$R = 255\ P^{1.89}\ M^{0.71}.$$

The computed standard error of estimate (96 percent) indicates the lack of use of representative rainfall records to develop the relation.

The ungaged area was then subdivided on the basis of the six available rain gages using the Thiessen weighting method to determine the catchment area for each rain gage. Monthly runoff estimates were made for each subarea by applying monthly rainfall totals to the regression model. Because the regression model was calibrated to the 469 square miles San Casimiro Creek basin, the computed runoff values for each raingage catchment area required an adjustment for catchment-area size. The size of the catchment areas ranged from 52 to 905 square miles and the corresponding adjustment factors ranged from 0.11 to 1.93. Estimated monthly runoff totals for the ungaged area were determined by summing the adjusted monthly runoff for the six catchment areas. Total inflow to the study reach was determined by adding the annual runoff totals for the Cotulla and San Casimiro gages to the estimated annual runoff for the intervening area. Annual water losses were then determined by subtracting the basin outflow (from Simmons gage) from the total inflow.

The accuracy of the runoff estimates obtained by this technique is limited by the inherent assumption that the monthly rainfall totals collected by a single rain gage are representative of that which fell throughout the entire subarea. Most of the rainfall that occurs in the study area is produced by thunderstorms, and large areal variations in storm-rainfall quantities and intensities are known to occur. Another inherent assumption in the use of this technique is that runoff per square mile does not vary with the drainage area size of individual streams in the ungaged area. About one-half the area is drained by streams having drainage areas similar in size to San Casimiro Creek. Streams in the remainder of the ungaged area have drainage areas less than 200 square miles. For the smaller streams, the unit runoff may be greater than predicted, and the monthly runoff totals estimated by using the regression model may be slightly less than actual totals. Because of these accuracy limitations, the runoff estimates for any given month may be considerably in error. The yearly estimate and the average for the 12 years should be more reliable. These estimates are needed for computation of losses for the channel reach from Cotulla to Simmons.

Estimated-annual water losses for water years 1966-77 are given in table 2. The total-annual runoff values given in table 2 are the sum of the measured values for the Cotulla gage and the estimated values for the ungaged

Table 2.--Annual water budget for Nueces River from Cotulla to Simmons, water years 1966-77

Water year	Annual runoff (acre-feet)				Losses (acre-feet, estimated, Cotulla to Simmons)
	Cotulla (measured) 08194000	Inflow from intervening area (estimated)	Total inflow to reach	Simmons (measured) 08194600	
1966	98,900	454,300	553,200	266,000	287,200
1967	115,000	1,052,000	1,167,000	798,500	368,500
1968	164,000	96,800	260,800	131,200	129,600
1969	28,900	65,100	94,000	29,080	64,900
1970	233,000	219,800	452,800	284,500	168,300
1971	728,000	523,400	1,251,400	1,178,000	73,400
1972	274,000	867,800	1,141,800	842,900	298,900
1973	62,200	393,900	456,100	155,400	300,700
1974	267,000	295,100	562,100	447,500	114,600
1975	225,000	160,500	385,500	251,100	134,400
1976	140,000	227,800	367,800	267,400	100,400
1977	248,000	268,800	516,800	470,200	46,600

area. Estimated-annual losses were obtained by subtracting the measured annual-runoff values for the Simmons gage site from the estimated total-runoff values. The data in table 2 show estimated-annual losses in the Cotulla to Simmons reach ranged from 46,600 acre-feet during water year 1977 to 368,500 acre-feet during water year 1967. The average-annual losses are approximately 174,000 acre-feet, of which about 130,000 acre-feet are lost between Cotulla and Tilden.

CHANNEL CONVEYANCE

Flood Flow Characteristics

Bankfull discharge for the Nueces River at Cotulla is about 300 ft^3/s. Downstream from Holland Dam (river mile 205.6) a network of braided channels begins and the bankful discharge increases to about 800 ft^3/s. The braided-channel drainage pattern continues through most of the study reach, reverting back to a single channel just upstream from Simmons (near river mile 122). A storm-produced peak discharge of 20,000 ft^3/s at Cotulla will inundate about 210 square miles as the flow moves through the reach from Cotulla to Simmons, covering most of the flood plain. A peak discharge of 82,600 ft^3/s that occurred at Cotulla in June 1935, inundated about 270 square miles in the study reach. An approximate relationship between the peak discharge at Cotulla and the total area inundated in the Cotulla to Simmons reach is given in figure 10. This relationship was determined using stage-discharge relationships for the Cotulla, Tilden, and Simmons gaging stations, along with estimated stage discharge relatioships for several cross sections between Cotulla and Tilden. Inundated areas were delineated on topographic maps of the Cotulla to Simmons reach for several storms which produced peak discharges at Cotulla ranging from 4,000 to 82,600 ft^3/s. The relationship is applicable only to those storms originating upstream from Cotulla for which contributing runoff from the intervening area between Cotulla and Simmons is minimal.

Conveyance characteristics vary through the study reach. Roughness coefficients (Mannings n), computed from high-stage discharge measurements, range from about 0.10 at Simmons to about 0.20 at Tilden and Cotulla. For example, the composite roughness coefficient was computed for a typical channel cross section (fig. 11) taken from a Geological Survey topographic map at river mile 137.5, 0.9 mile downstream from the Tilden gage site. The stage for the flood of September 24, 1967, at this location was determined by adjusting the peak stage at Tilden for channel slope. The flood-plain width at the peak stage was about 3.5 miles and the computed cross-sectional area was 157,000 square feet. Using the peak discharge at Tilden with the Chezy-Manning formula (Linsley, Kohler, and Paulhus, 1958, p. 69), a composite roughness coefficient of 0.23 was computed. Similar roughness coefficients were computed for high stages at other selected cross sections in the braided-channel reach. The values are extremely large and are greater than the range of roughness estimates commonly used in computing open-channel flow. In contrast, a roughness coefficient of 0.057 was computed from discharge measurements for a main-channel flow rate of 600 ft^3/s at the Tilden gage site.

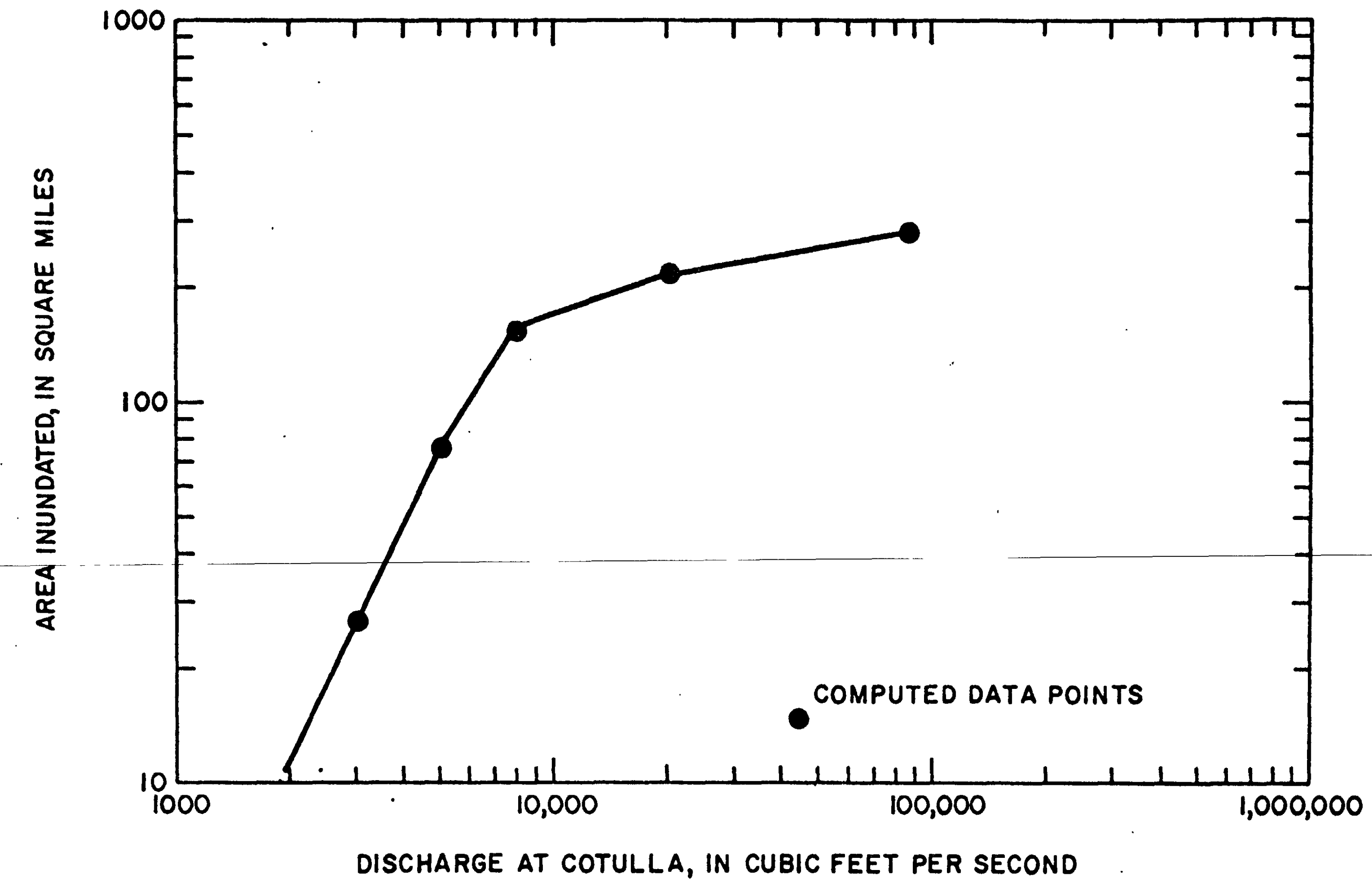

Figure 10.–Relationship between discharge at Cotulla and total area inundated in the Cotulla to Simmons reach

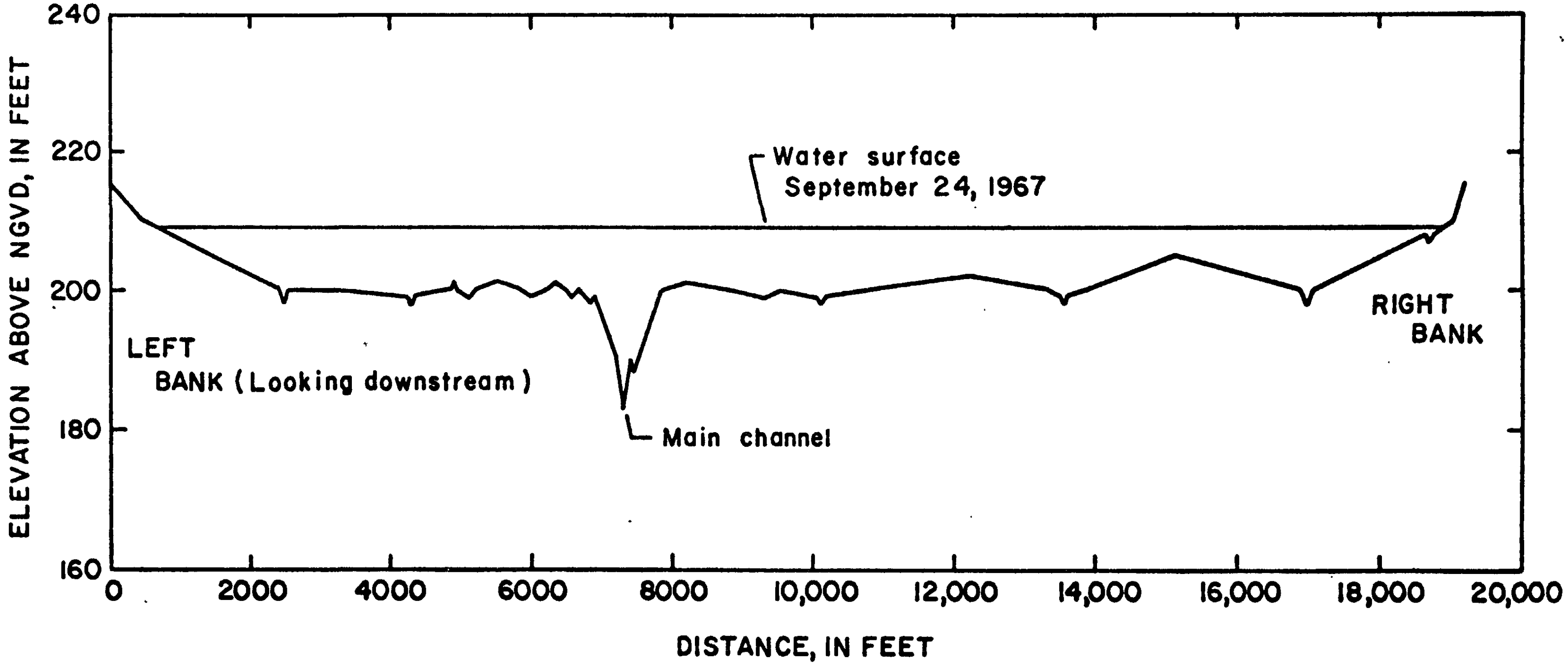

Figure 11.-Cross section of the Nueces River, 0.9 mile downstream from the Tilden gage site

Travel Time

To evaluate the effect of the channel geometry on the speed of a flood wave moving through the reach, relationships between maximum-daily discharges for storm periods and travel time from Cotulla to Tilden and Cotulla to Simmons were developed (figure 12). The relationships should give a good approximation of travel time for flood peaks because instantaneous peak discharges at these stations usually are not significantly different from the maximum-mean daily discharges. The travel times shown are those of the flood wave, not the water particles themselves.

The unusual shapes of the travel-time curves shown in figure 12 reflect the large volume of storage and the retarding effects of the broad flood plain and its dense vegetation on the movement of flood discharges through the reach. The effect of soil-moisture conditions is variable, and travel times are difficult to estimate for maximum-daily discharge rates of less than 100 ft^3/s at Cotulla. As the magnitude of maximum-daily discharges for storm periods increases to more than 100 ft^3/s at Cotulla, the travel time to Simmons decreases, reaching a minimum of about 4.7 days when the discharge at Cotulla is from 400 to 600 ft^3/s. At greater discharges, overbank flows result downstream from Cotulla, and travel times for flood discharges increase.

The maximum effect of the broad flood plain and its dense vegetation on time-of-travel for floodflow through the reach occurs for storms having maximum-daily discharges at Cotulla of between 5,000 and 7,000 ft^3/s. Maximum travel time from Cotulla to Simmons is about 10.8 days (fig. 12).

As maximum-daily discharges for storm periods increase to greater than about 7,000 ft^3/s at Cotulla, flood-plain vegetation near the channels become submerged, water velocities increase, and time of travel decreases. For maximum-daily discharges exceeding about 30,000 ft^3/s at Cotulla, the maximum-daily discharge at Simmons will occur about 5.5 days later. The retarding effect of the flood plain on the movement of flood discharges through the study reach is evident on the storm hydrographs shown in figures 4, 5, and 7.

Reduction in Flow

Storm hydrographs for runoff periods given in table 1 show large reductions in maximum-daily discharges for storms originating upstream from Cotulla as they move through the study reach. The relationship between the maximum-daily discharges at Cotulla and the maximum-daily discharges at Tilden and Simmons is presented in figure 13. These reductions in maximum-daily discharges are caused by the storage characteristics of the channel and flood plain and water losses to infiltration and evapotranspiration.

No effort was made in this study to develop a relationship between the reduction in maximum-daily discharge through the reach and channel losses. The similarity of figures 9 and 13 indicates that maximum daily discharges for storm periods at Cotulla may be a fair indicator of the magnitude of water losses through the reach.

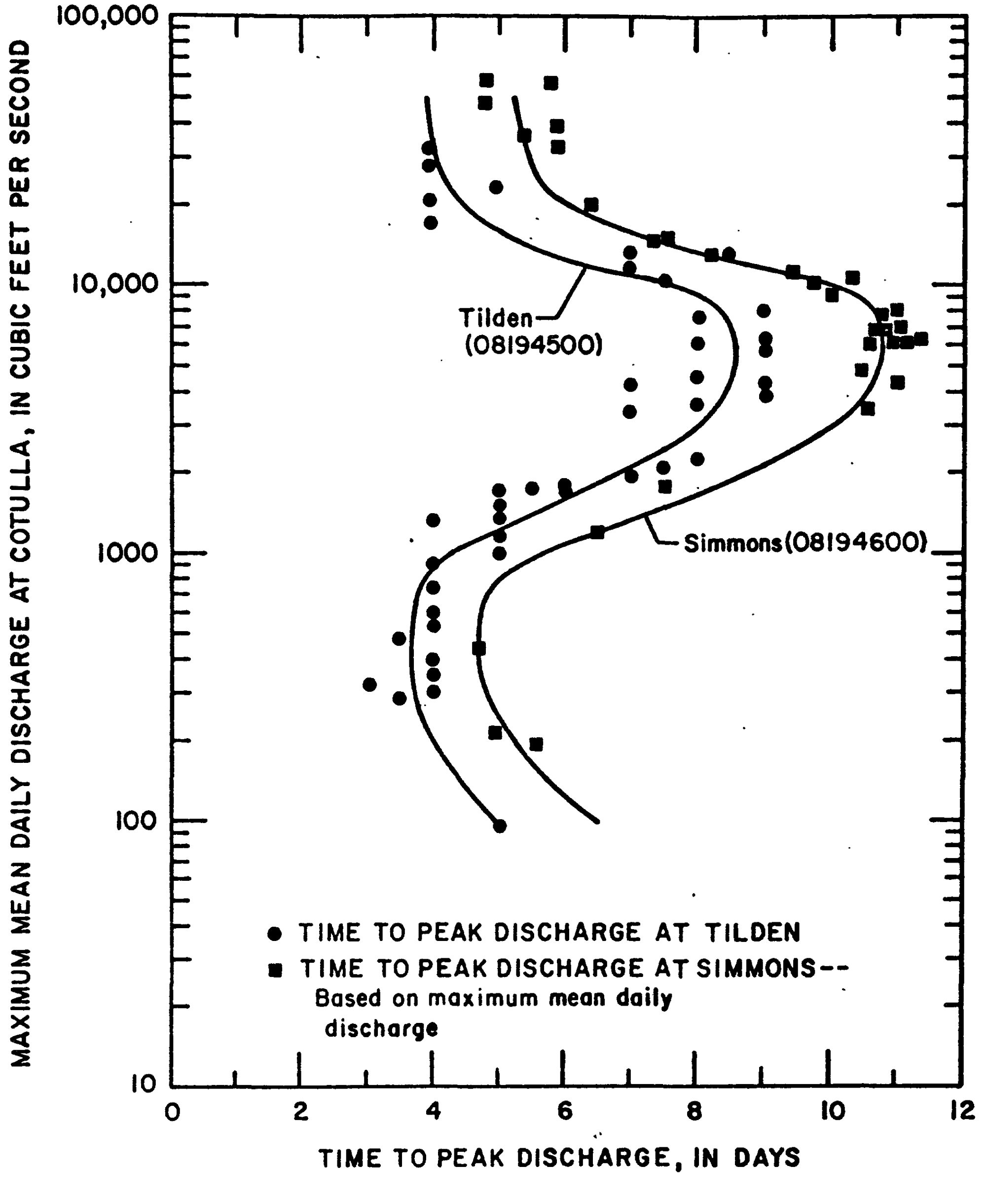

Figure 12.-Relationship between maximum daily discharges for storm runoff and traveltime from Cotulla to Tilden and Cotulla to Simmons

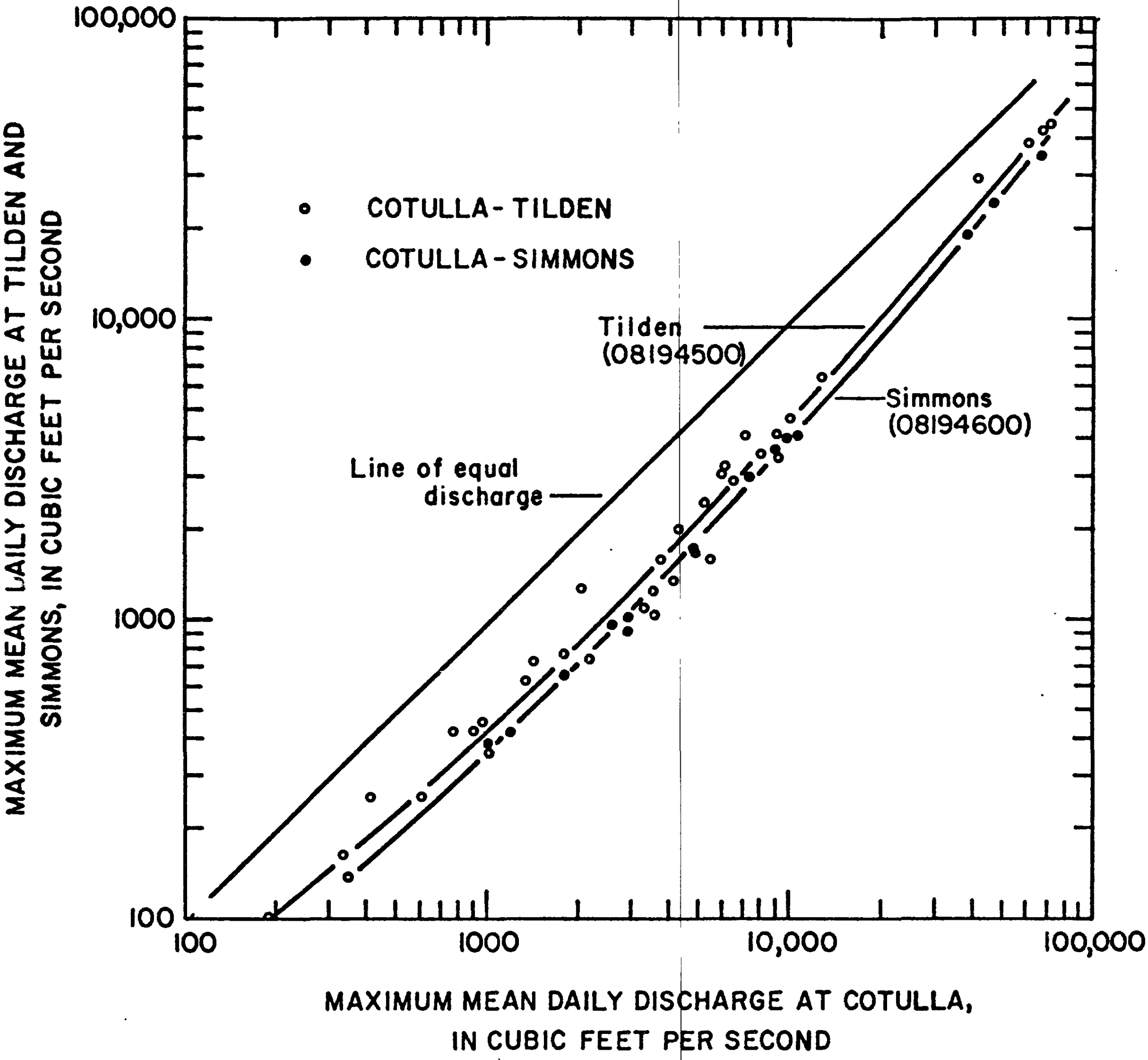

Figure 13.-Realtionship between maximum-daily discharges at Cotulla and maximum-daily discharges at Tilden and Simmons

The relationships shown in figure 13 were developed from data from selected storms originating upstream from Cotulla for which inflow into the study reach downstream from Cotulla did not have a significant effect upon the magnitude of peak flow rates at Tilden and Simmons. Obviously, if the discharge rate at Cotulla could be maintained for a sufficient length of time, the discharge rate at Simmons would be equal to that at Cotulla minus losses in the reach. No such periods of steady-flow conditions occur on the Nueces River in this area.

Flow Duration

A commonly used tool in water-related studies is the flow-duration curve. Such a curve can be prepared for any period of continuous daily-discharge records by arranging the daily values in duration form. The duration curve is a cumulative-frequency curve that shows the percent of time specified discharges are equaled or exceeded. It combines in one curve the flow characteristics of a stream throughout the range of discharge, without regard to the sequence of occurrence. It is emphasized that the flow-duration curve does not represent the distribution of yearly flow, but rather the distribution of flow for the entire period used in the analysis.

The shape of the flow-duration curve is determined by the hydrologic and geologic characteristics of the drainage basin. A curve with a steep slope throughout denotes a stream with variable discharge that is largely from direct storm runoff. A curve with a flat slope shows the presence of surface- or ground-water storage, which tends to equalize the flow. The slope of the lower end of the duration curve reveals the characteristic of perennial storage in the drainage basin. A flat slope at the lower end would indicate considerable storage while a steep slope would indicate negligible storage.

Flow-duration curves were prepared and are included (figs. 14-20) for all stations listed in the section "Data Availability." Curves shown for the Cotulla and Tilden sites were based on records for October 1943 to September 1980. The curve for Simmons was based on the period of record (water years 1966-77) and adjusted on the basis of the Tilden curve to represent the long-term period, October 1943 to September 1980. This adjustment was made using the indexstation method (Searcy, 1959, p. 12). Duration curves shown in figures 18-20 are included only to provide a comparison of low-flow characteristics of the Nueces River stations with those from nearby stations.

An examination of the flow-duration curves for Cotulla, Tilden, and Simmons clearly shows the absence of any significant ground-water contribution to low flows, as indicated by the steep slopes of the lower part of the curves. Some evidence of the effects of overbank storage is noted by the somewhat flatter slopes at the upper end of the curves.

Records of daily-discharge values for Cotulla for October 1943 through September 1980 show that extended periods of no flow have occurred in every season of the year. No-flow periods occurred in 36 years of the 37 years of record.

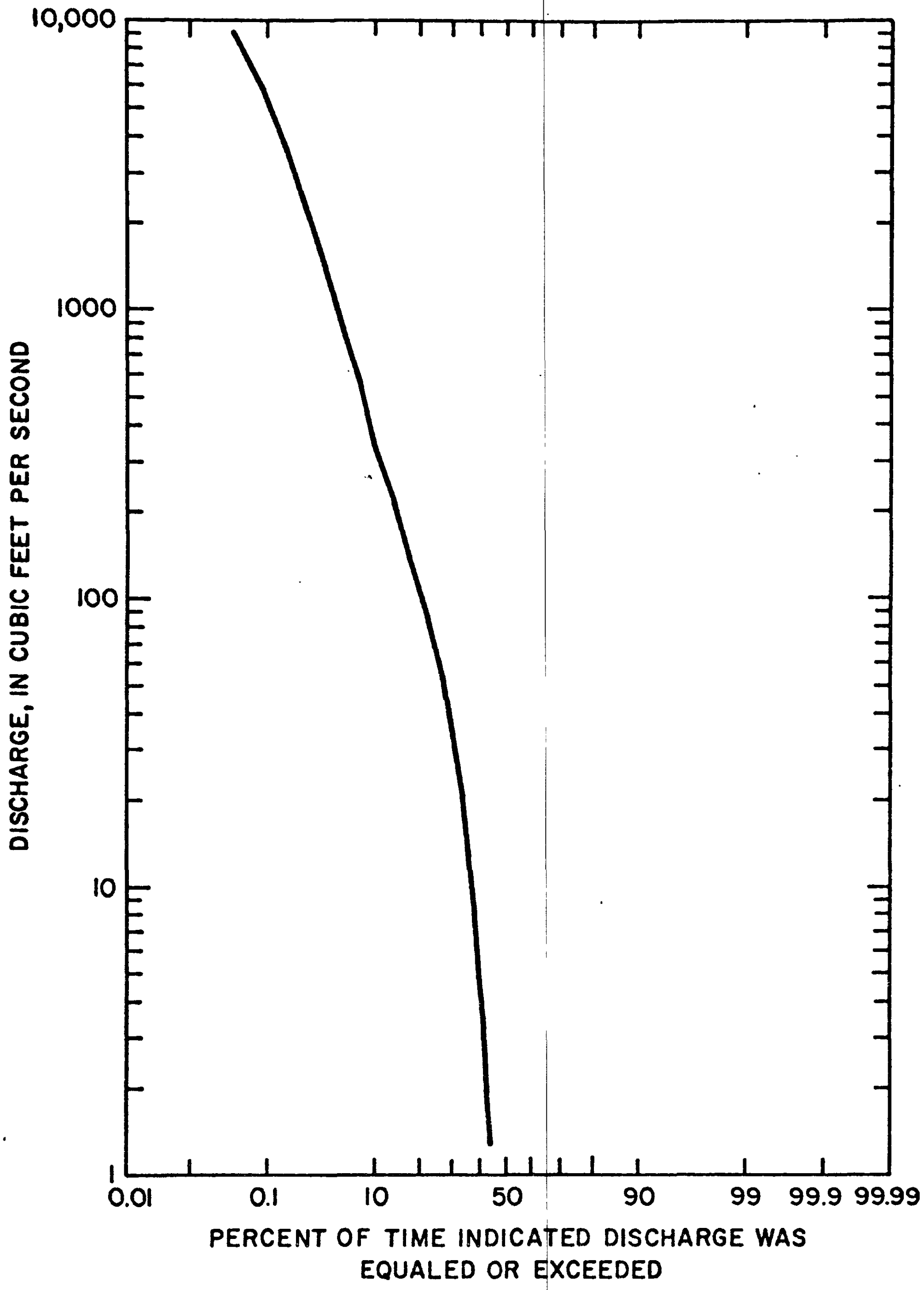

Figure 14.-Flow-duration curve for station 08194000, Nueces River at Cotulla

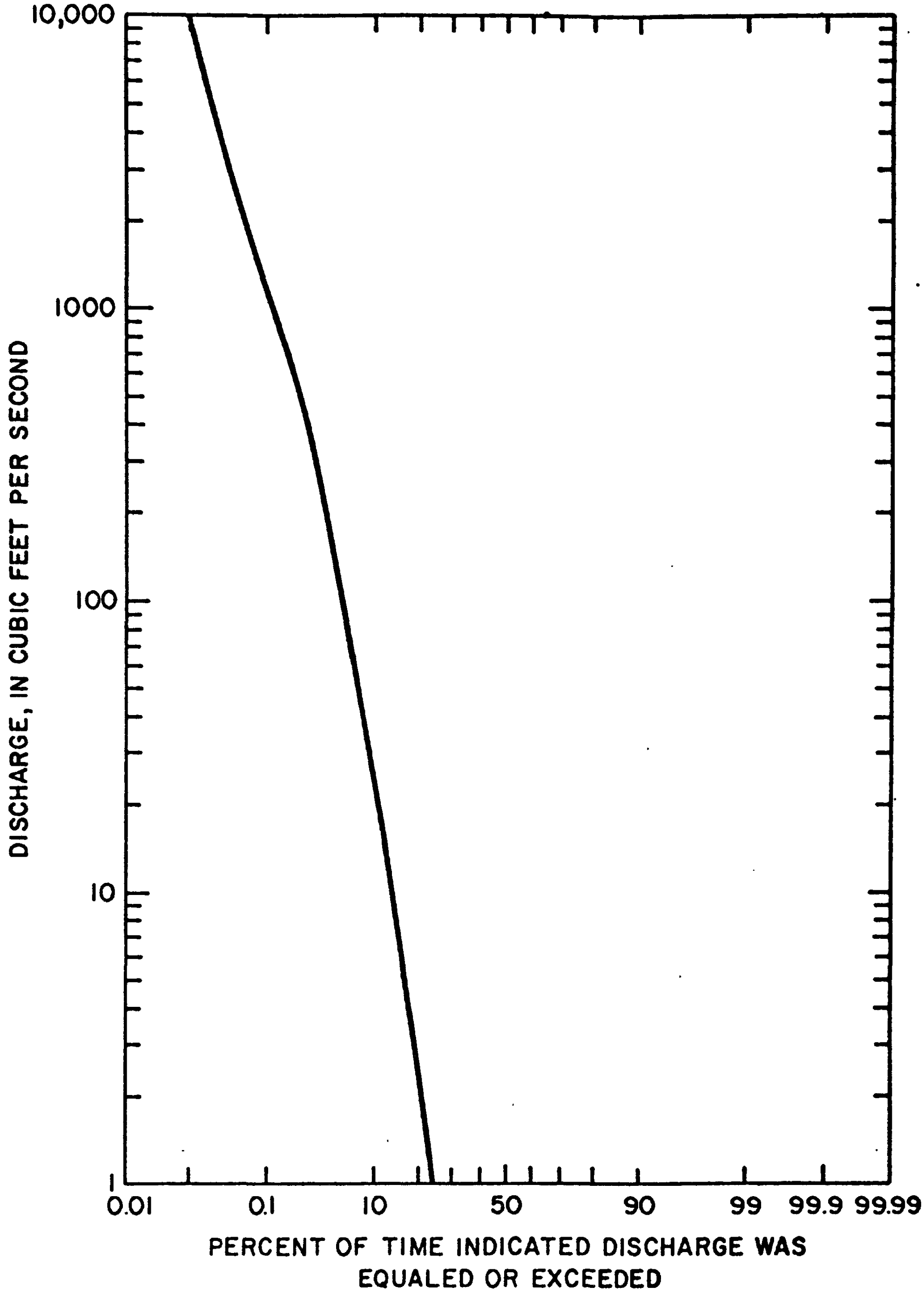

Figure 15.-Flow-duration curve for station 08194200, San Casimiro Creek near Freer

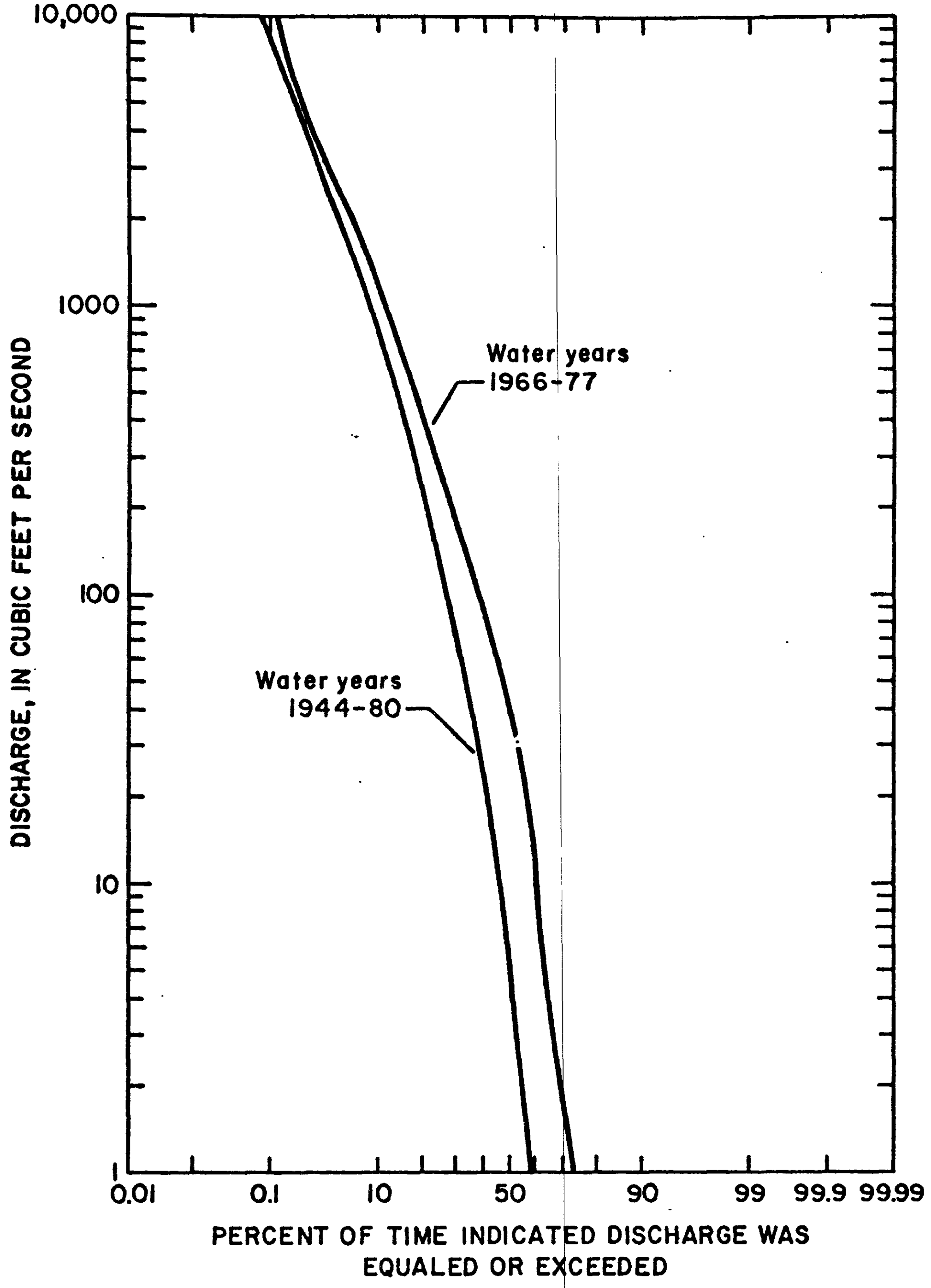

Figure 16.-Flow-duration curve for station 08194500, Nueces River near Tilden

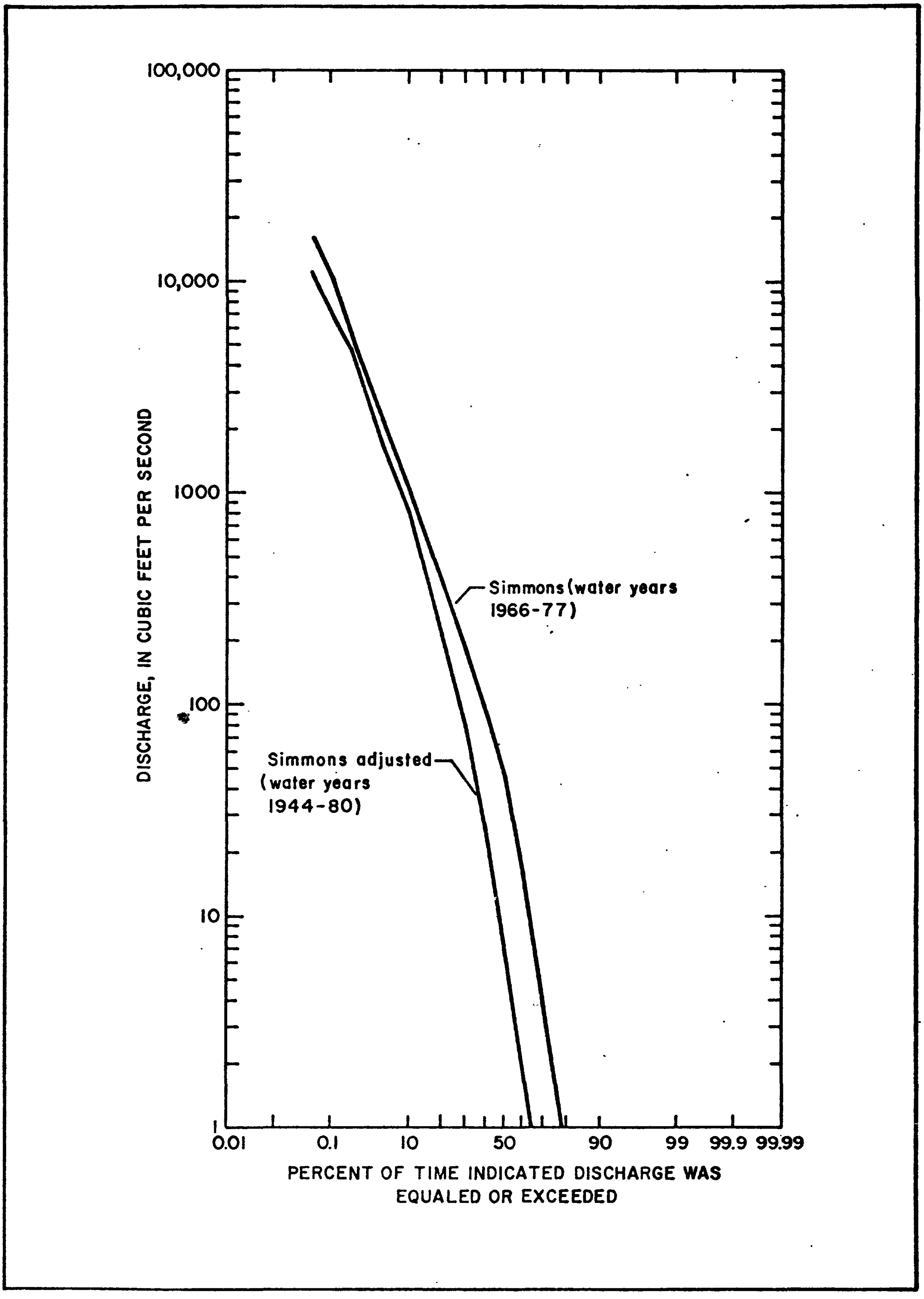

Figure 17.-Flow-duration curve for station 08194600, Nueces River at Simmons

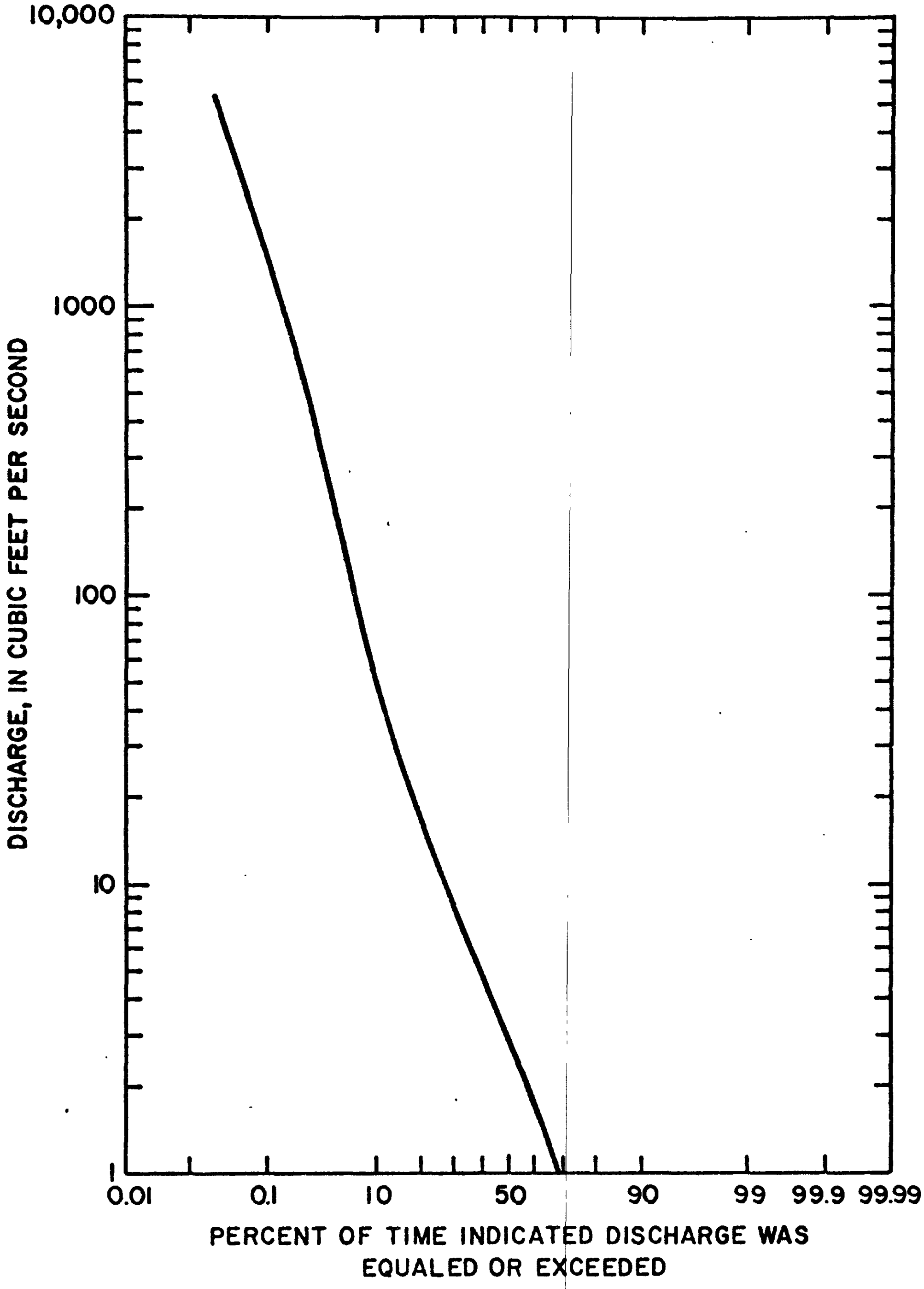

Figure 18.-Flow-duration curve for station 08206700, San Miguel Creek near Tilden

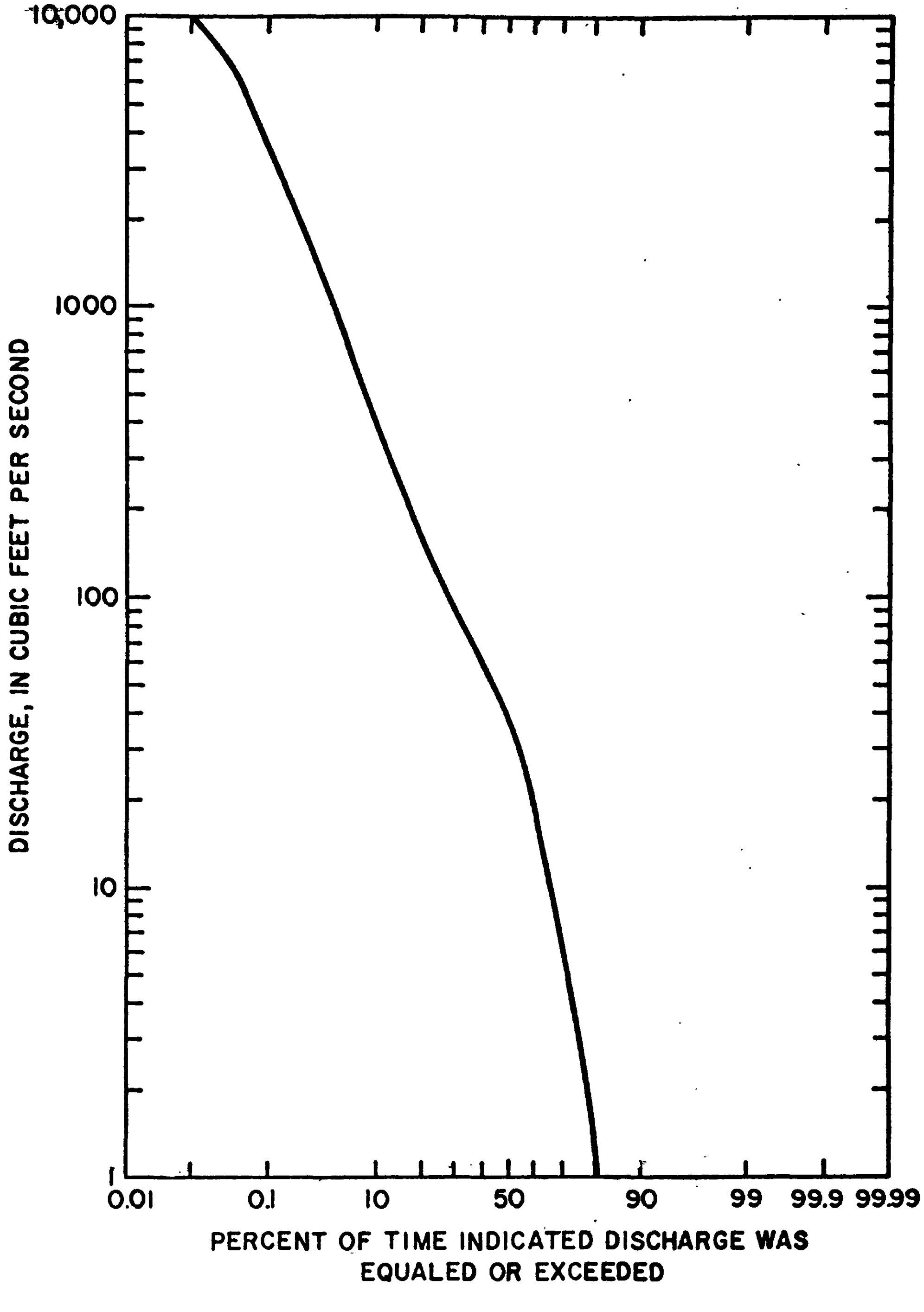

Figure 19.-Flow-duration curve for station 08207000, Frio River at Calliham

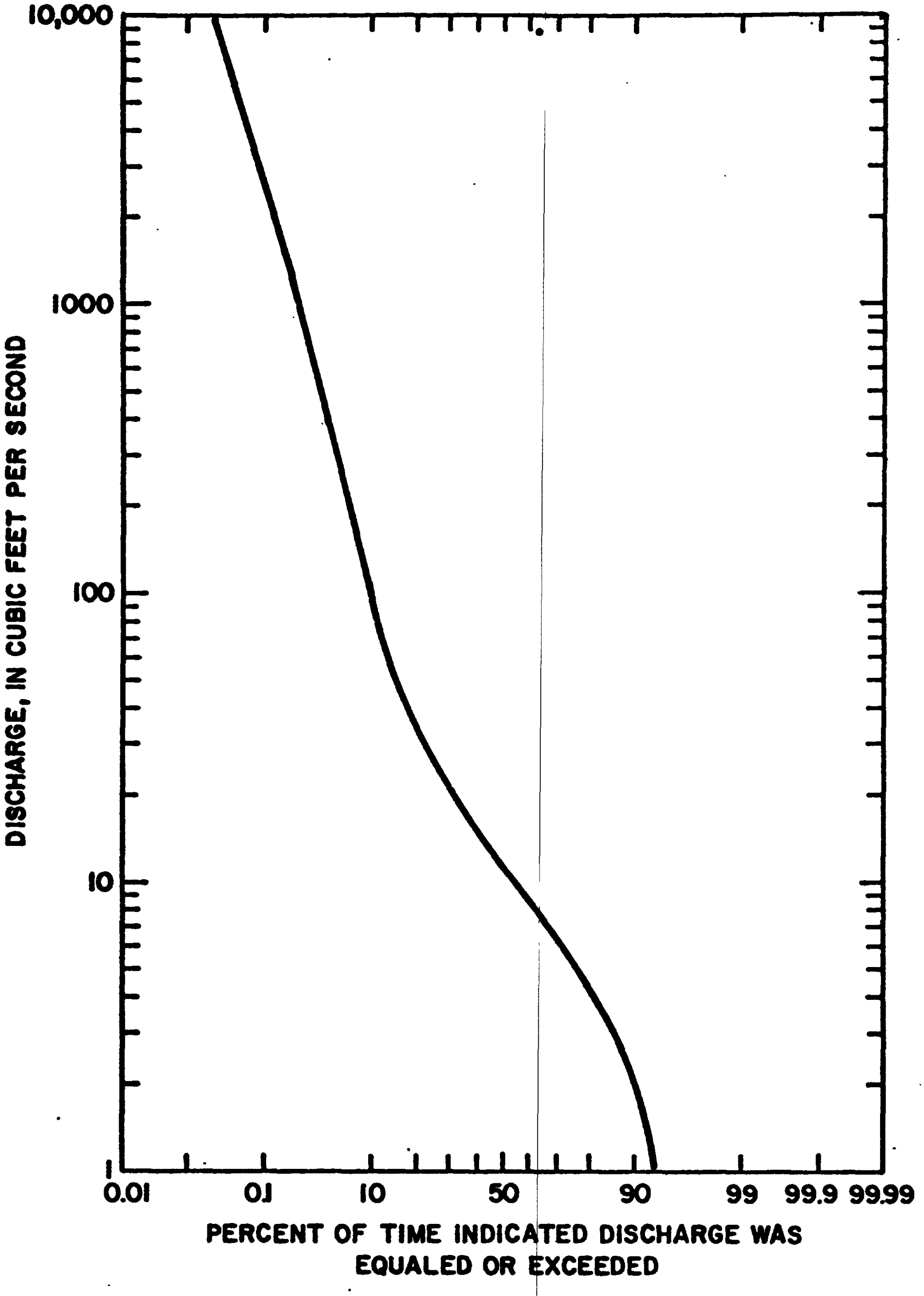

Figure 20.-Flow-duration curve for station 08208000, Atascosa River at Whitsett

Annual distribution of no-flow days ranged from none in 1975 to 332 in 1953, with the average being 165 days a year.

The occurrence of such extended periods of no flow in the study area indicates that the water table is below the streambed much of the time. Any return flow from bank storage will likely occur only after extended periods of overbank flow.

DISCUSSION OF LOSSES

Large water losses occur along the Nueces River from Cotulla to Simmons during periods of storm runoff. Much of this loss is by infiltration through the permeable alluvium that forms the channel and flood plains. Although the magnitude of infiltration losses logically should depend upon antecedent conditions, no relationship could be developed. For several storm periods listed in table 1, storm runoff had occurred in the prior month. The flood periods of May 14 to June 15 and June 7-29, 1969 at Cotulla are very close in time, yet significant losses occurred during the latter storm period. An example of initial losses for a runoff period that followed a long period of no flow is shown in figure 8. Initial runoff for this storm reached Tilden 14 days after it had occurred at Cotulla. A later rise during the same storm period but on a wet channel showed a travel time of only 7 days.

Evapotranspiration losses are particularly significant during periods of overbank flow. The dense stands of bunchgrasses that occupy much of the flood plain (fig. 21) not only are a retardant to water velocities, but also retain large quantities of water following overbank flow, thus increacing water losses by infiltration and evapotranspiration. For flow rates between 200 and 800 ft^3/s at Cotulla, the rate of travel through the reach is faster than that for flood flows, and losses to evapotranspiration are less.

Because of the variability in flood-plain geometry and vegetation in the study reach, estimating evapotranspiration rates for floods of different magnitudes was not attempted. The estimates of water losses presented in this report (tables 1 and 2) are assumed to be a combination of infiltration and evapotranspiration losses. Separating the estimated losses into these components is not within the scope of this study.

NEED FOR ADDITIONAL DATA

These analyses show that large water losses occur along the Nueces River between Cotulla and Simmons. The accurracy of the results, however, is severely limited by the shortage of hydrologic and climatic data available for the study. Many of the uncertainties involved in these analyses could be greatly minimized or eliminated by additional data collection. Stream-gaging stations located on three tributaries to the Nueces River between Cotulla and Simmons would provide data needed to define runoff characteristics for streams having from 25 to 100 square mile of drainage area. These gaging-stations would not only provide data needed for future water-loss studies on the Nueces River, but

Figure 21.--Vegetation along the Nueces River flood plain in the study reach

also would provide much needed data on runoff from small watersheds which is lacking in this general area. Recording rain gages installed in each of the three small drainage basins, in the San Casimiro Creek basin, and at the stream-gaging stations at Cotulla and Tilden would provide data to calibrate rainfall-runoff models for use in estimating runoff for ungaged tributaries between Cotulla and Simmons.

In addition, a network of about eight observation wells located on both banks, on and adjacent to the flood plain along the braided channel between Cotulla and Tilden would permit the definition of the streamflow and ground-water interchange along the reach, a prerequisite to more reliable water-loss studies.

EFFICIENT TRANSFER OF WATER THROUGH THE STUDY REACH

The magnitude and timing of releases from the proposed Cotulla Reservoir will be significant factors affecing the efficient transfer of water through the Cotulla to Simmons reach. The results of the water loss analysis in this study indicate that the river channel is most efficient when flow rates through the reach range from 400 to 600 ft^3/s. A reservoir-release pattern designed to maintain the optimum flow rate (400 to 600 ft^3/s) through the reach would be most efficient in mimimizing water-losses. A release started after storm runoff from the intervening area would sustain smaller initial losses than one made after a period of no flow.

The maximum release rate from the proposed Cotulla reservoir to attain the most efficient transfer of water through the reach is about 800 ft^3/s. Larger flow rates through the reach cause overbank flow, increasing water losses to both infiltration and evapotranspiration.

Sustained releases from the proposed reservoir should result in significantly smaller water losses than those shown for runoff periods listed in table 1. Water losses in the Cotulla to Simmons reach probably will range from 15 to 25 percent of reservoir releases. Losses are estimated to be in the 15- to 20-percent range for releases made during the winter months and in the 20- to 25-percent range for summer releases. These estimates are based on a study of discharge hydrographs for Cotulla, Tilden, and Simmons for runoff periods which occurred shortly after periods of high flows through the reach. Water losses for two such runoff periods were determined to show the variation in losses from winter to summer months.

The first runoff period selected occurred in July and August 1958, after 2 weeks of relatively high flow (500 to 13,000 ft^3/s) at Cotulla. Mean-daily discharges were as much as 1,500 ft^3/s and averaged 276 ft^3/s at Cotulla for the 37 days. The discharge hydrograph for the Tilden gage, adjusted for travel time based on data in figure 12, showed a 20-percent loss in total runoff from Cotulla to Tilden. Because the gage at Simmons was not yet in operation, losses from Tilden to Simmons could not be determined for this period.

The second runoff period selected extended from November 8, 1973 to January 26, 1974 at Cotulla. Mean-daily discharges at Cotulla ranged from 93 to

588 ft^3/s and averaged 249 ft^3/s for the 80 days. Before computing losses for this period, the discharge hydrograph for the Simmons gage was adjusted for travel time and for local inflow. Inflow from the ungaged area, as estimated based on the flow at the San Casimiro Creek gage, averaged 6.2 ft^3/s for the period. The difference between the Cotulla and the adjusted Simmons hydrographs showed losses for this period to be about 15 percent of the flow past the Cotulla gage.

SUMMARY

Analysis of discharge hydrographs for streamflow-gaging stations on the Nueces River at Cotulla, Tilden, and Simmons indicates that significant water losses occur along that reach during storm-runoff periods. Computed losses along the channel reach, from Cotulla to Tilden for 15 storm periods, ranged from 32 to 59 percent of the total runoff volume passing the Cotulla gage. Additional losses in the Tilden to Simmons reach for six storm periods that occurred when the gage at Simmons was in operation ranged from 2 to 8 percent of the total runoff at Cotulla.

Estimates of total-annual losses were made with the aid of a regression model developed to relate total monthly rainfall to monthly runoff. The model was calibrated using runoff data for the San Casimiro Creek gage and monthly rainfall totals for nearby rain gages. The calibrated model was used with monthly rainfall values for Cotulla, Fowlerton, Tilden, Freer, Laredo, and Encinal to estimate annual-runoff volumes for the ungaged area between Cotulla and Simmons. Total annual water losses in the study reach, estimated with the aid of the regression model, ranged from 46,600 acre-feet during water year 1969 to 368,500 acre-feet during water year 1967, and averaged about 174,000 acre-feet for water years 1966-77. The results of the water-loss analysis indicate that the river channel between Cotulla and Simmons is most efficient when flow rates at Cotulla range from 400 to 600 ft^3/s.

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