STATE OF LOUISIANA
DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT
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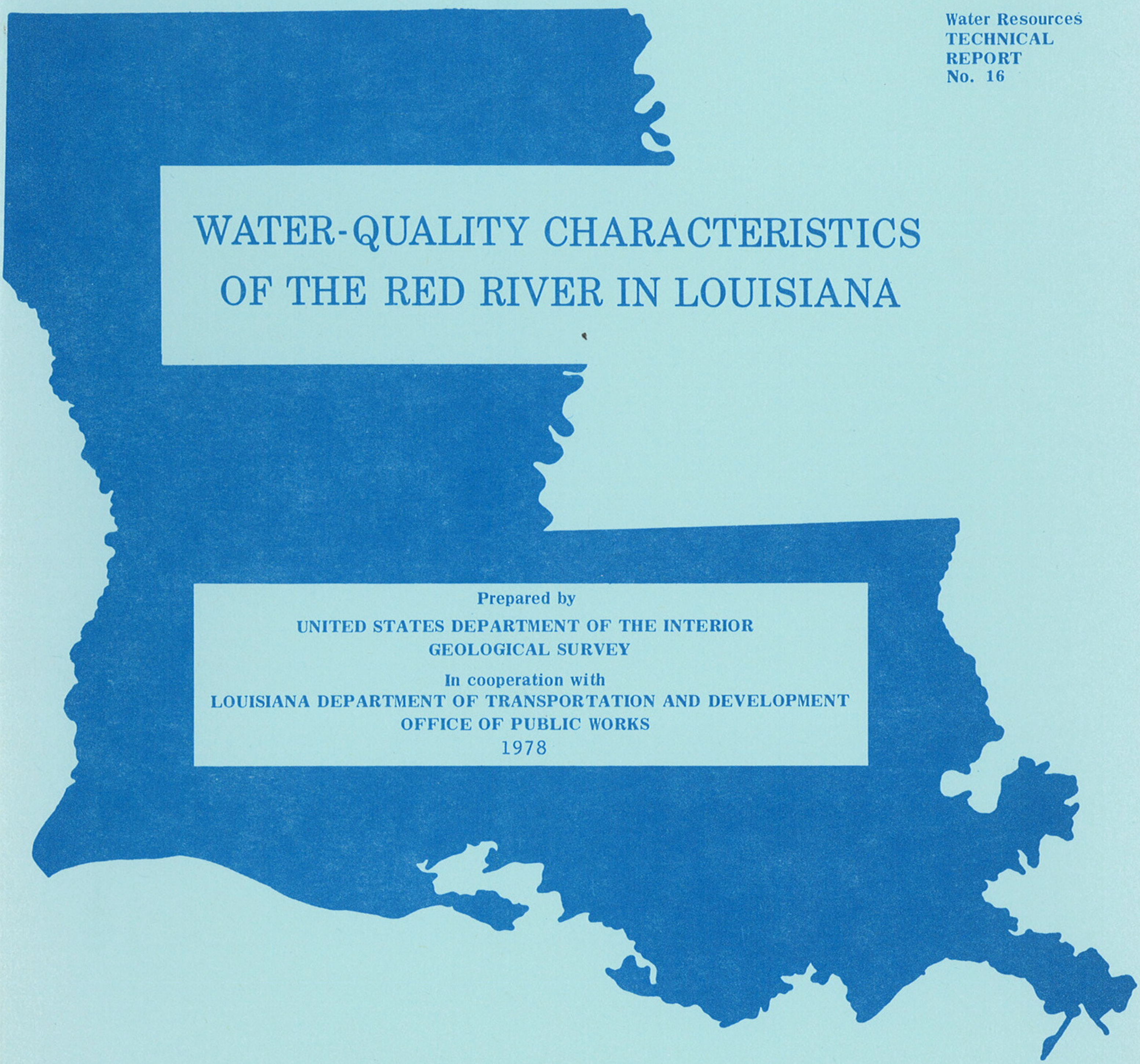
Water Resources
TECHNICAL
REPORT
No. 16



WATER-QUALITY CHARACTERISTICS OF THE RED RIVER IN LOUISIANA

Prepared by
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
In cooperation with
LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT
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1978

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By

Robert F. Martien
U.S. Geological Survey

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FACTORS FOR CONVERTING U.S. CUSTOMARY UNITS TO INTERNATIONAL SYSTEM (SI) UNITS

For use of those readers who may prefer metric units rather than U.S. customary units, the conversion factors for the terms used in this report are listed below:

Multiply U.S. customary units	By	To obtain metric units
acre-feet (acre-ft)	0.0000012	cubic kilometers (km^3)
cubic feet per second (ft^3/s)	.02832	cubic meters per second (m^3/s)
feet (ft)	.3048	meters (m)
feet per second (ft/s)	.3048	meters per second (m/s)
gallons (gal)	3.785	liters (L)
miles (mi)	1.609	kilometers (km)
million gallons per day (Mgal/d)	.04381	cubic meters per second (m^3/s)
pounds (lb)	.4536	kilograms (kg)
	453.6	grams (g)
square miles (mi^2)	2.590	square kilometers (km^2)
tons per day	.9072	metric tons per day
tons per year	.9072	metric tons per year

(To convert temperature in °C to °F, multiply by 9/5 and add 32.)

WATER-QUALITY CHARACTERISTICS OF THE RED RIVER IN LOUISIANA

By Robert F. Martien

ABSTRACT

The average discharge of the Red River for the period 1928-75 was 24,900 ft^3/s (cubic feet per second) or 705 m^3/s (cubic meters per second) at Shreveport and 31,900 ft^3/s (903 m^3/s) at Alexandria. A mean annual flood (1-day Q_2 high flow) at Shreveport and Alexandria is about 105,000 ft^3/s (3,060 m^3/s) and 108,000 ft^3/s (2,970 m^3/s), respectively. The 7-day Q_2 low flow, which is generally used in designing water-supply systems, was about 3,340 ft^3/s (95 m^3/s) at Shreveport and 4,440 ft^3/s (126 m^3/s) at Alexandria. The 7-day Q_{10} low flow used in determining waste-loading restrictions for Shreveport and Alexandria was 1,490 ft^3/s (42 m^3/s) and 1,950 ft^3/s (55 m^3/s), respectively. The mean daily suspended-sediment discharge at Alexandria (1964-74) was 103,000 tons per day.

There has been a general decrease in the concentration of dissolved solids, chloride, and sulfate measured at Hosston in the past several years. A significant decrease in the concentration of dissolved solids is observed as the river flows through the State. Bacterial pollution is a serious problem in the entire reach of the river, especially at low flow. *Salmonella*, a pathogen of fecal origin, was isolated from a river sample below Shreveport. Dissolved-oxygen concentrations are usually near saturation despite the addition of large amounts of oxygen-consuming wastes. Light-dark bottle studies revealed that in October 1975, under low-flow conditions, oxygenation due to photosynthesis was about 10 times greater than reaeration due to mechanical diffusion. At increased flows the biological oxygenation rate was insignificant. The addition of large amounts of acidic or basic wastes would have a deleterious effect on water quality at low flows.

Water-tracer studies were made to enable the estimation of travel-time, concentration, and duration of solutes injected into the river at any point on the river between Spring Bank Ferry, Ark., (river mile 334) and Moncla, La. (river mile 66). These estimates can be made for stable flow conditions ranging from 2,000 to 10,000 ft^3/s (57 to 283 m^3/s) at Shreveport (river mile 278). Studies show that when the river is flowing at 6,000 ft^3/s (170 m^3/s), a spill of 1,000 pounds (453.6 kilograms) of contaminant at Shreveport would have a peak concentration of 113 micrograms per liter when the contaminant reached Coushatta (river mile 219) 48 hours later.

INTRODUCTION

The Red River originates in eastern New Mexico and the Texas Panhandle. It flows eastward to southeastward into Louisiana where it forms, in part, the headwaters of the Atchafalaya River. The Red River at Alexandria, La., (river mile 105) has a drainage area of 61,000 mi^2 (158,000 km^2). The area studied (fig. 1) extends from the Arkansas-Louisiana State line (river mile 328) to the mouth of the Black River (river mile 35). [River miles are numbered from the mouth of Old River (U.S. Army Corps of Engineers, 1970).]

The river flows through a major part of the State and two of the State's larger metropolitan areas. These areas are experiencing rapid population and industrial growth, and the Red River is a potential water-supply source and shipping route. An improvement in water quality would increase the suitability of the river for industrial and municipal development. Construction of a planned lock and dam system will allow navigation as far upstream as Shreveport.

The purpose of this report is to define the chemical and physical characteristics of the Red River in Louisiana, the long-term trends in water quality, the ability of the river to assimilate wastes, and the rate at which solutes are transported by the river.

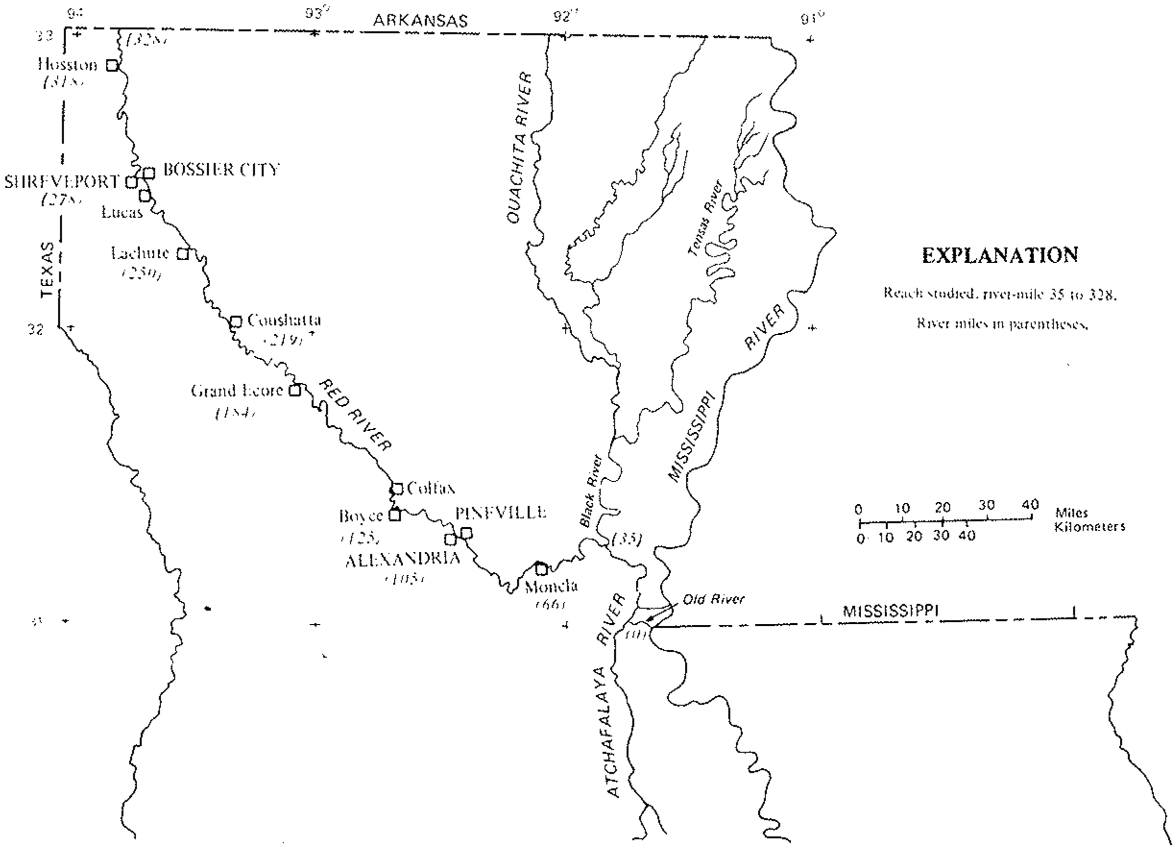

Figure 1.--Study reach of the Red River.

Except as acknowledged below, all data used in this report were collected and analyzed by the U.S. Geological Survey.

Acknowledgments and Cooperation

This report was prepared as a part of the cooperative program between the U.S. Geological Survey and the Louisiana Department of Transportation and Development, Office of Public Works. All of the suspended-sediment and streamflow data were collected and furnished by the U.S. Army Corps of Engineers, New Orleans District. Information regarding sewage wastes was furnished by the city of Shreveport, Department of Water and Utilities, and the city of Alexandria.

STREAMFLOW

Streamflow data have been collected at Shreveport, La., (river mile 278) and Alexandria, La., (river mile 105) since 1928. The maximum discharge (1928-75) was 303,000 ft^3/s (8,570 m^3/s) at Shreveport on April 5, 1945, and 233,000 ft^3/s (6,590 m^3/s) at Alexandria on April 17, 1945. The minimum discharge of 690 ft^3/s (20 m^3/s) at Shreveport and 870 ft^3/s (25 m^3/s) at Alexandria was observed on October 30, 1956. The average discharge for the period 1928-75 was 24,900 ft^3/s (705 m^3/s) at Shreveport and 31,900 ft^3/s (903 m^3/s) at Alexandria.

Streamflow regulation began in October 1943 with the formation of Lake Texoma (capacity, 5,390,000 acre-ft or 6.47 km^3). Since then, Texarkana Reservoir (completed July 1953; capacity, 2,640,000 acre-ft or 3.17 km^3) and Millwood Lake (completed August 1966; capacity, 1,860,000 acre-ft or 2.23 km^3) have been established as flood-control structures. The effect of these structures on streamflow has been to increase low flows through controlled releases and to reduce peak discharges through storage of runoff (fig. 2).

Hydrographs were plotted to summarize daily flow duration at Shreveport and Alexandria (fig. 3). They show the expected high and low daily flow that will be equaled or exceeded for 20, 50, and 80 percent of days. These hydrographs are based on 19 years of record beginning October 1955 and include the effects of all major reservoirs except Millwood Lake.

Log-Pearson type III frequency analysis of streamflow records for the above period (fig. 4) indicates a 1-day Q_2 high flow of 105,000 ft^3/s (2,970 m^3/s) at Shreveport and 111,000 ft^3/s (3,120 m^3/s) at Alexandria. This means there is a 50-percent chance that a flow of 105,000 ft^3/s (2,970 m^3/s) may be exceeded in any given year at Shreveport. On a large river, such as the Red River, the daily peak discharge is approximately equal to the daily mean discharge. The 1-day Q_2 high flow is used as an estimate of the magnitude of a mean annual flood. Neely (1976) summarizes the magnitude and frequency of floods other than the mean annual flood for the Red River and other Louisiana streams.

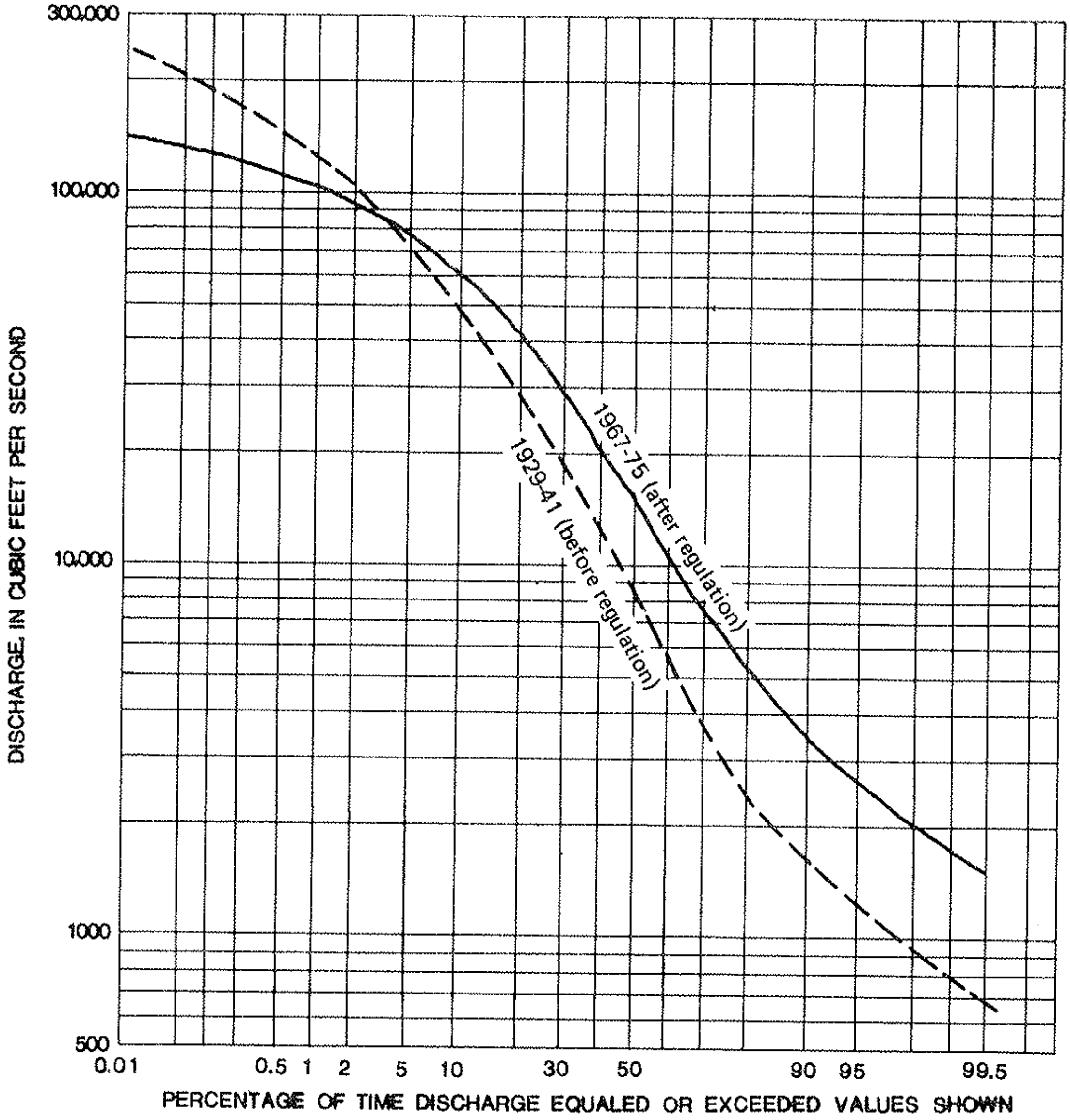

Figure 2.--Flow-duration curves before and after streamflow regulation, Red River at Shreveport.

The magnitude and frequency of low-flow events is of concern to many municipal and industrial designers and planners. They need an estimate of these events for water-supply and waste-disposal purposes. The 7-day Q_2 low-flow value is generally used in designing water-supply systems. This term is defined as the lowest expected average flow for 7 consecutive days having a 50-percent chance of occurrence each year. The 7-day Q_2 low flow is estimated to be 3,340 ft^3/s (95 m^3/s) at Shreveport and 4,440 ft^3/s (126 m^3/s) at Alexandria (fig. 4). The 7-day Q_{10} low-flow estimate (10-percent chance of occurrence per year) is used in determining waste-loading restrictions (Dale Givens, Louisiana Stream Control Commission, oral commun., 1977). When the flow falls below this value, the stream's ability to assimilate wastes is reduced to the point where restrictions could be placed on waste discharges to the stream.

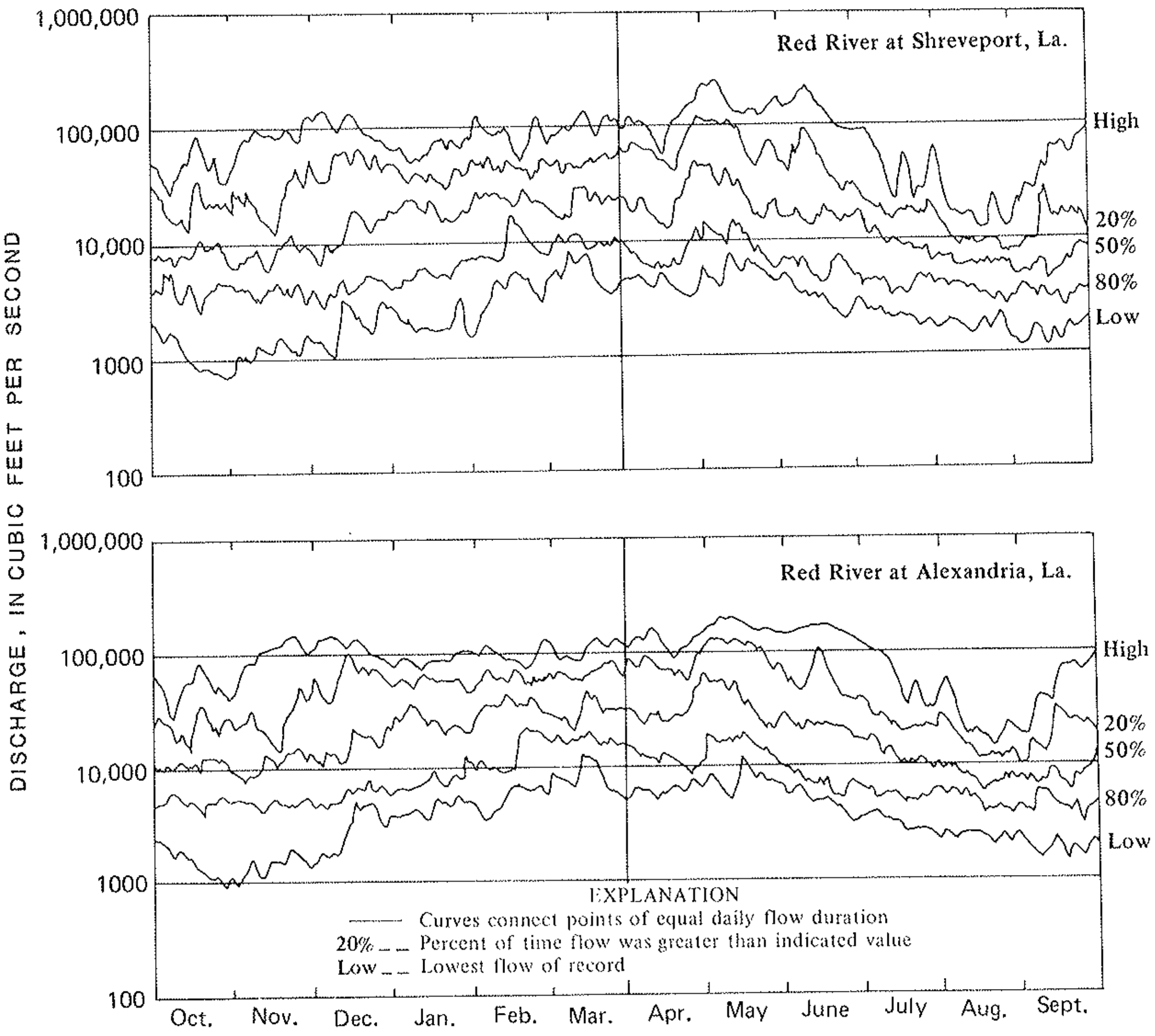

Figure 3.--Daily flow-duration hydrographs, Red River at Shreveport and Alexandria, October 1955-September 1975.

The 7-day Q_{10} low-flow values for Shreveport and Alexandria are 1,490 ft^3/s ($42\ m^3/s$) and 1,950 ft^3/s ($55\ m^3/s$), respectively (fig. 4). The 7-day Q_{20} low-flow value is an estimate of an extreme low flow that has a 5-percent chance of occurrence each year. This is estimated to be 1,090 ft^3/s ($31\ m^3/s$) and 1,440 ft^3/s ($41\ m^3/s$) for Shreveport and Alexandria, respectively (fig. 4).

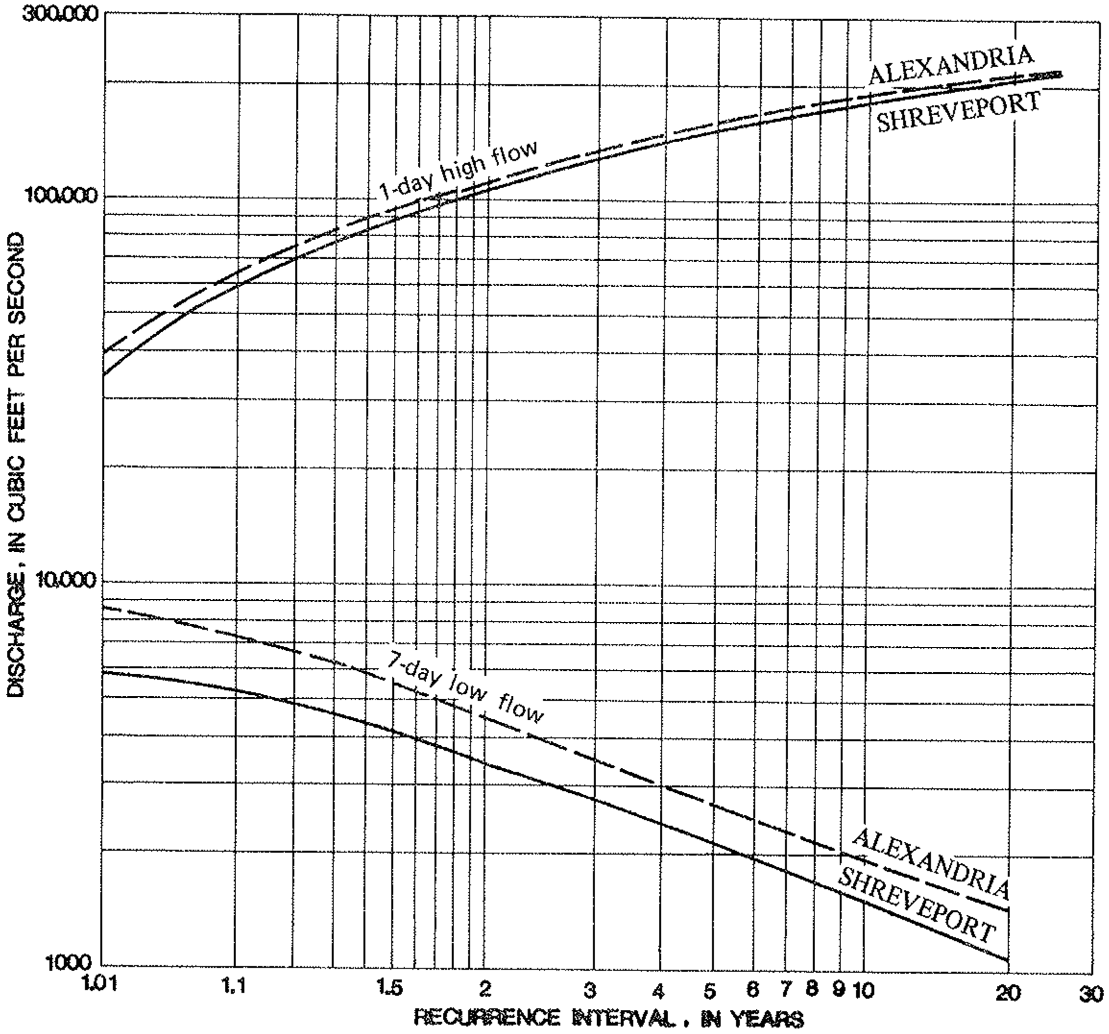

Figure 4.--1-day high flow and 7-day low flow, Red River at Shreveport and Alexandria, October 1955-September 1975.

SUSPENDED SEDIMENT

The U.S. Army Corps of Engineers, New Orleans District, has been collecting suspended-sediment samples from the Red River at Alexandria since October 1963. Bedload is not included in the sampling program. An average suspended-sediment load of about 103,000 tons per day is transported past Alexandria and deposited in the Atchafalaya River basin and the Gulf of Mexico. The maximum daily load was 2,020,000 tons per day on December 19, 1971, and the minimum daily load was 220 tons per day on several days in August 1972. (See table 1.) The average distribution of clay-silt and sand is about 77 percent clay-silt and 23 percent sand. Clay-silt is classified as particles smaller than 0.062 millimeter in diameter.

Table 1.--Suspended-sediment discharge, Red River at Alexandria, La.

Water year	Suspended-sediment (sand and silt) discharge				Mean annual water discharge (ft^3/s)
	Maximum	Minimum	Mean	Annual total	
	Tons per day			Tons per year	
1964	765,000	229	29,000	10,600,000	11,500
1965	875,000	430	63,300	23,100,000	18,800
1966	561,000	1,480	81,300	29,700,000	22,000
1967	841,000	714	44,200	16,100,000	18,600
1968	1,350,000	731	195,000	71,200,000	44,200
1969	1,500,000	653	176,000	64,200,000	40,600
1970	728,000	928	77,300	28,200,000	23,800
1971	213,000	626	18,100	6,590,000	13,500
1972	2,020,000	220	95,500	34,900,000	21,200
1973	558,000	574	142,200	51,900,000	49,100
1974	495,000	1,810	211,000	77,100,000	49,500

Suspended-sediment discharge is a function of the suspended-sediment concentration and streamflow. The following tabulation for the water years 1964-74 at Alexandria shows the percentage of time that the suspended-sediment concentration was equal to or greater than those values shown.

Percentage of time	Sediment concentration (milligrams per liter)
95	60
90	84
80	140
70	190
50	350
30	700
20	1,000
10	1,800
5	2,500

Most of the suspended-sediment discharge occurs from December to May, which is the annual high-flow period. The maximum sediment discharge usually occurs in May when the sediment discharge is equal to or greater than 400,000 tons per day 25 percent of the time (fig. 5).

The amount of suspended material carried by the river is dependent upon velocity, availability of sediment, turbulence, particle size, and water temperature. Although the sediment load for a given discharge may vary because of antecedent conditions, in general, the load increases as flow increases and decreases as flow decreases (fig. 6). During the initial increase in flow the concentration of sediment increases rapidly, and as long as the supply of sediment particles of a size that the river is capable of transporting is sufficient to meet the carrying capacity of the river, the concentration will continue to rise at a rapid rate (fig. 6).

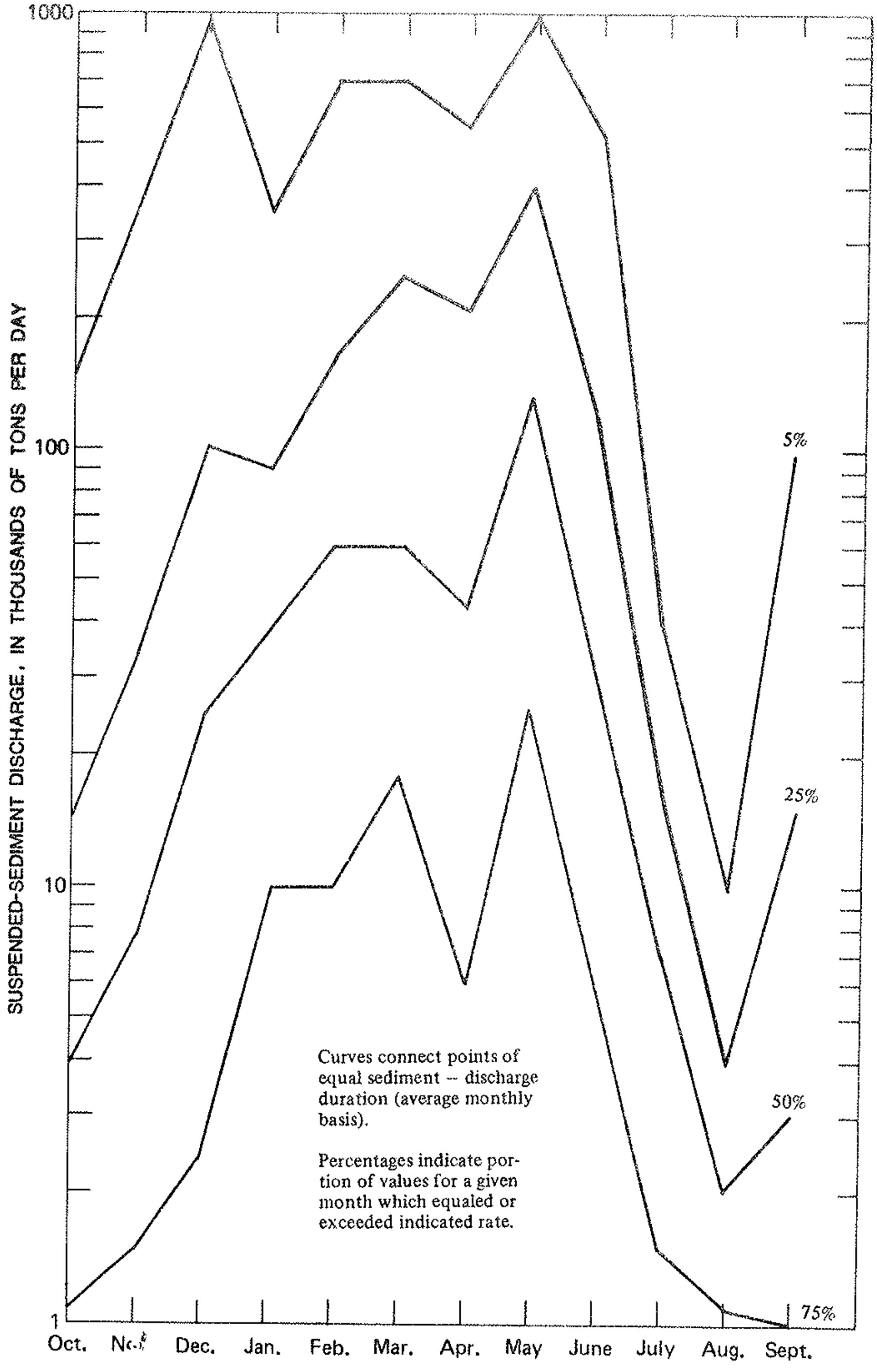

Figure 5.--Duration of suspended-sediment discharge, Red River at Alexandria, October 1963-September 1974.

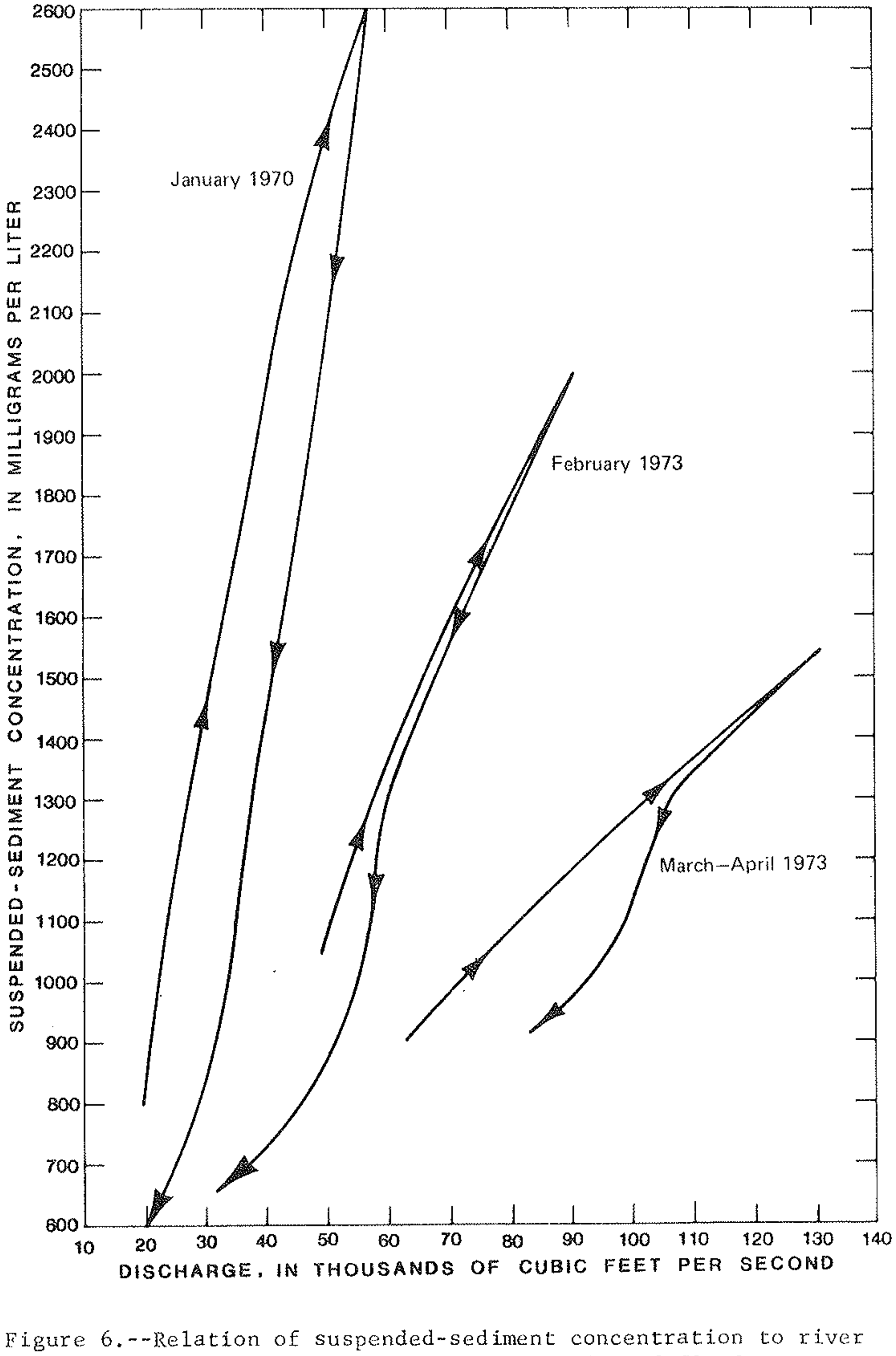

Figure 6.--Relation of suspended-sediment concentration to river discharge at Alexandria for three selected floods.

The Red River, because of the pronounced meandering nature of its channel in soft, unconsolidated sediments, is afforded a continuous supply of sediment. This ample supply of sediment, in conjunction with the rapid rising and falling stages characteristic of the river, determines the shape and size of the curves in figure 6. By contrast, Everett (1971, p. 9-10) has shown for the Mississippi River that because the sediment supply generally is less than the amount that the river can transport, the concentration of sediment will decrease as the flow continues to increase and will continue to decrease as the discharge decreases.

CHEMICAL QUALITY

The chemical quality of Red River water, which is a calcium bicarbonate type, varies with streamflow. Daily variations in specific conductance commonly range from 25 to 100 micromhos/cm (micromhos per centimeter) and have been as great as 200 to 250 micromhos/cm.

Cursory examination of historical data collected at Hosston and above Shreveport since 1958 suggests there has been a change in water quality in the last several years. In order to detect trends in water quality over a period of record, changes in streamflow as well as changes in major constituents must be examined. A method for examining changes in these two variables is the double-mass curve (Searcy and Hardison, 1960) often used in hydrologic investigations. Using this method, observed values of two variables are accumulated and plotted against each other. Any change in their relation will be reflected as a change in the slope of the plotted line. In this case, yearly mean discharge was plotted against yearly mean dissolved-solids load for the Red River at Hosston (fig. 7). After 1967 there is a definite decrease

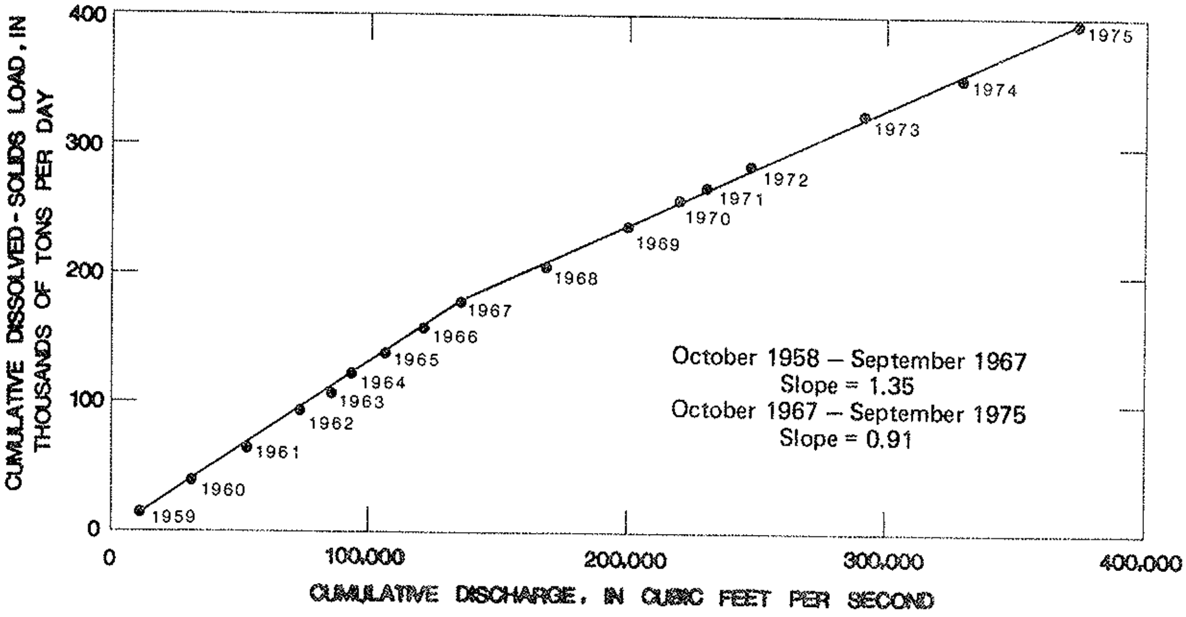

Figure 7.--Double-mass curve of cumulative discharge and cumulative dissolved-solids load, Red River at Hosston, October 1958-September 1975.

in the slope of the line. The period 1959-67 has a slope of 1.35, and the period 1968-75 has a slope of 0.91. An analysis of variance shows the slopes to be significantly different at the 0.025 probability level.

Comparing periods of equal cumulative streamflow before and after 1967 with the corresponding cumulative dissolved-solids load, it can be seen that there has been a decrease in the dissolved-solids concentration. For example, the period 1959-64 has a cumulative streamflow of 93,000 ft^3/s (2,600 m^3/s) and a cumulative dissolved-solids load of 123,000 tons per day (fig. 7). The period 1968-71 has a cumulative streamflow of 95,000 ft^3/s (2,700 m^3/s) and a cumulative dissolved-solids load of 89,000 tons per day. This shows that while the cumulative streamflow remains almost constant, there is a 25- to 30-percent decrease in the cumulative dissolved-solids load and, therefore, a similar reduction in dissolved-solids concentration. This reduction is due to the presence of less mineralized water in the upper Red River.

The period of record at Hosston was divided into two parts, 1958-67 and 1968-75, in view of the evidence from the double-mass curve analysis. Ranges in concentrations of the chemical and physical characteristics and their durations of occurrence for the two periods are given in table 2. Differences are reflected mainly in decreased concentrations of the sodium, sulfate, and chloride ions.

There is a significant decrease in the concentration of some major constituents from Hosston to Alexandria (fig. 8). For example, in the period 1973-75 the dissolved-solids concentration at Hosston was equal to or less than 280 mg/L (milligrams per liter) 50 percent of the time. For the same period at Alexandria, the dissolved-solids concentration was equal to or less than 210 mg/L 50 percent of the time. A similar reduction was observed in chloride and sulfate concentrations. Inorganics are generally conservative and, therefore, are cumulative in amount. The only way that the concentration of inorganic constituents is significantly reduced in the reach below Hosston is by dilution. The influx of less mineralized water from tributaries is reducing the inorganic concentration as the river flows through the State.

Most of the ground water discharging to the river in Louisiana has a chloride concentration of 20-50 mg/L, but some of the ground water has a chloride concentration as high as 250 mg/L (M. S. Whitfield, Jr., U.S. Geological Survey, unpub. data, 1977); however, the quantities apparently are insufficient to make a substantial impact on the quality of Red River water.

Calandro (1973) analyzed stream temperatures for a number of streams in the State, including the Red River at Hosston and at Alexandria. He shows an average 2.2°C (4.0°F) increase in stream temperature from Hosston to Alexandria. Data from his report were used to construct a curve of monthly temperature duration for the Red River at Hosston (fig. 9).

Table 2.--Variation in chemical and physical constituents with duration of streamflow, Red River at Hosston, 1958-67 and 1968-75

[Chemical constituents are in milligrams per liter]

Parameter	Period	Range in concentration		Percentage of time values were equal to or less than those shown				
		Maximum	Minimum	90	70	50	30	10
Silica, dissolved	1958-67	16	1.7	12	10	8.5	6.8	4.4
	1968-75	13	.5	8.5	7.0	6.0	5.3	4.3
Calcium, dissolved	1958-67	136	21	87	66	49	38	28
	1968-75	96	17	70	50	37	29	23
Magnesium, dissolved	1958-67	53	.6	26	17	10	7.2	4.2
	1968-75	30	3.3	20	12	8.6	6.0	4.0
Sodium, dissolved	1958-67	246	9.0	180	114	68	43	20
	1968-75	160	4.4	98	66	42	28	16
Bicarbonate	1958-67	266	48	178	140	113	94	75
	1968-75	268	54	190	135	105	85	67
Sulfate, dissolved	1958-67	258	12	180	114	70	45	24
	1968-75	136	9.4	90	56	40	28	17
Chloride, dissolved	1958-67	388	11	280	180	105	64	33
	1968-75	260	5.3	155	100	72	45	22
Fluoride, dissolved	1958-67	1.0	.0	--------	--------	--------	-------	-------
	1968-75	1.4	.0	--------	--------	--------	-------	-------
Nitrate, dissolved	1958-67	3.3	.0	--------	--------	--------	-------	-------
	1968-75	4.3	.0	--------	--------	--------	-------	-------
Hardness as $CaCO_3$ (Ca, Mg)	1958-67	395	62	330	250	169	123	87
	1968-75	340	46	235	160	115	90	70
Dissolved solids, residue at 180°C	1958-67	1,190	117	900	610	405	280	175
	1968-75	838	128	580	430	290	220	155
Specific conductance (micromhos/cm at 25°C)	1958-67	1,950	164	1,460	1,000	670	450	290
	1968-75	1,560	152	980	720	480	330	230
Color (platinum-cobalt units)	1958-67	80	5	--------	--------	--------	-------	-------
	1968-75	200	5	--------	--------	--------	-------	-------
Discharge (ft^3/s)	1958-67	-------	-----	40,000	17,000	10,000	5,300	3,100
	1968-75	-------	-----	78,000	37,000	18,000	8,800	4,600

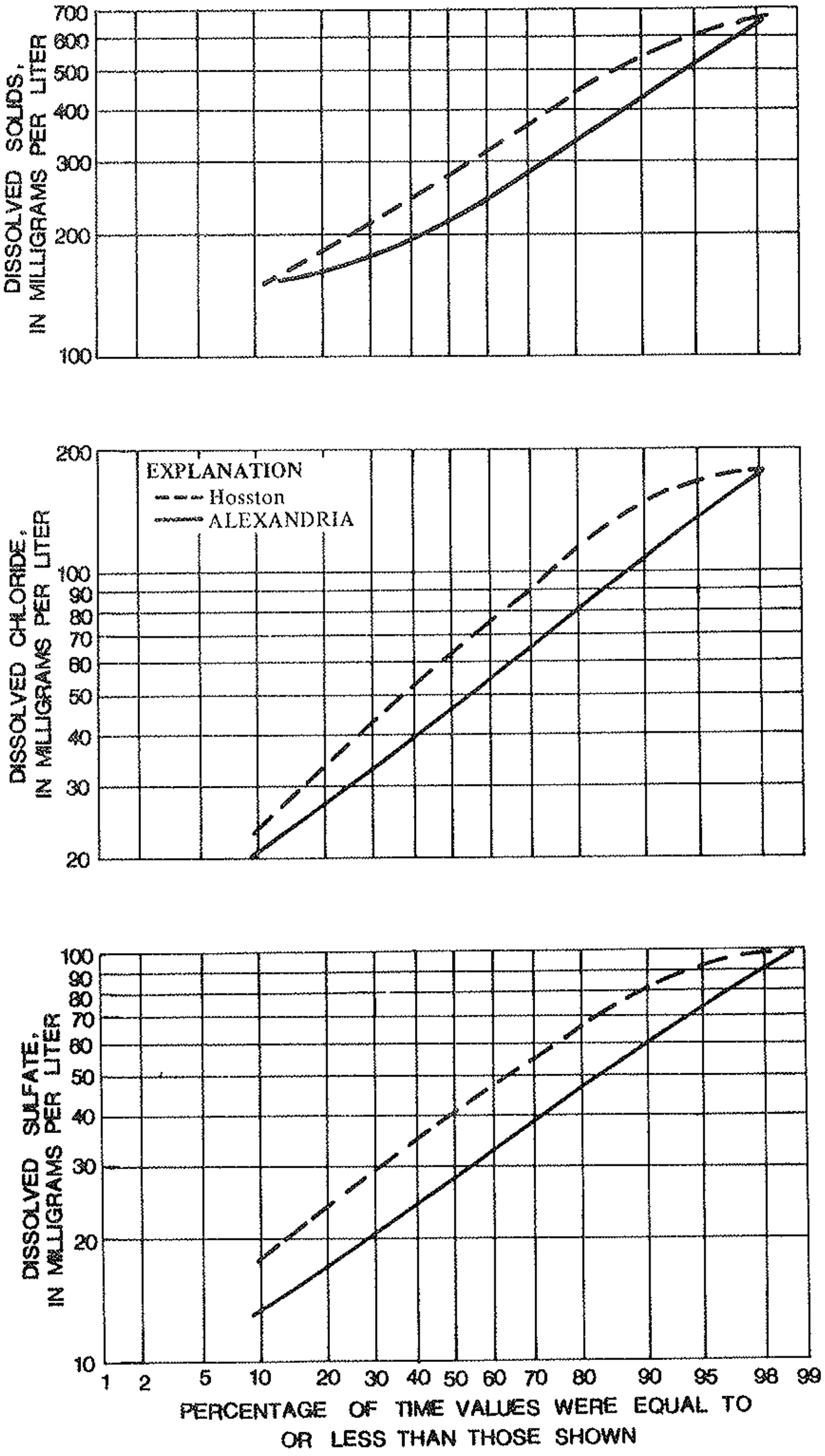

Figure 8.--Duration curves of concentration of dissolved solids, chloride, and sulfate, Red River at Hosston and Alexandria, October 1973-September 1975.

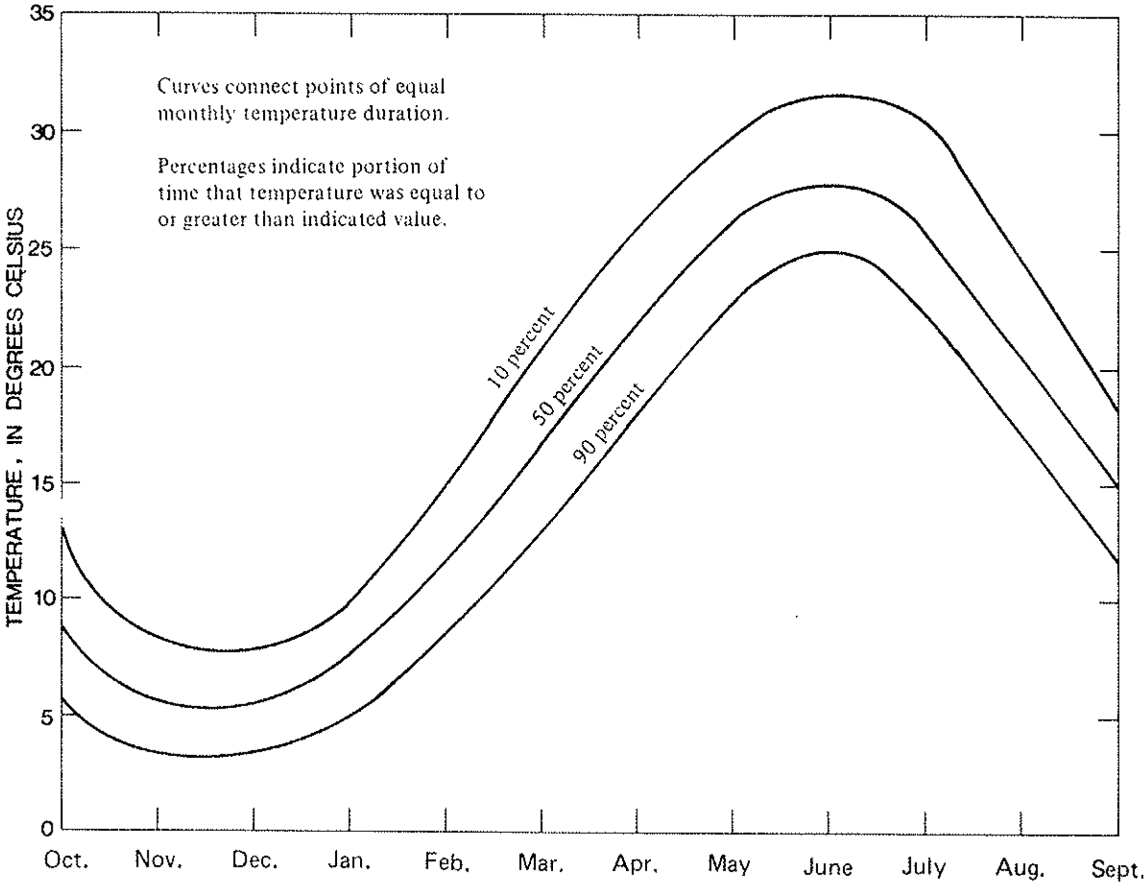

Figure 9.--Monthly temperature duration, Red River at Hosston.

Concentrations of metals in the Red River have been very low since analyses of metals began in November 1972. Since October 1974, total cadmium concentrations at Moncla have equaled the recommended limits for maximum concentration in domestic water-supply sources (U.S. Environmental Protection Agency, 1976) on two occasions, once in December 1974 and again in January 1975. On both occasions the concentration was 10 micrograms per liter. Concentrations of lead (total) at Coushatta exceeded the recommended limits once in April 1975 when the concentration was 61 micrograms per liter. A summary of concentrations of selected metals (total) in samples collected October 1974-September 1976 is presented in table 3 along with the recommended limits for maximum concentration of constituents in domestic water-supply sources (U.S. Environmental Protection Agency[1]). Analyses of bed material also showed low concentrations of metals.

Pesticide data collected since November 1972 showed no significant concentrations of selected herbicides or insecticides in Red River water. Analyses of samples collected at Hosston and above Shreveport showed that

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[1] The recommended limits in this publication meet the Federal standards for drinking water. This publication also lists guideline levels for the protection of aquatic life.

Table 3.--Concentrations of selected metals (total) at four sites on the Red River, October 1974-September 1976

[Concentrations are in micrograms per liter]

	Arsenic	Cadmium	Chromium[1]	Copper	Lead	Mercury	Zinc
			ABOVE SHREVEPORT				
Maximum ------------	10	4	30	55	22	0.7	140
Minimum------------	1	0	2	2	0	0	4
Mean ----------------	2.9	.5	--	8.5	6.8	.17	30.8
Standard deviation-----	2.1	.8	--	9.3	5.3	.18	26.3
Number of samples-----	39	39	39	37	38	39	39
			COUSHATTA				
Maximum ------------	7	5	30	-------	61	0.7	150
Minimum------------	0	0	1	-------	2	0	5
Mean ----------------	2.8	.8	--	-------	11.7	.13	41.6
Standard deviation-----	1.8	1.3	--	-------	12.5	.16	34.6
Number of samples-----	26	26	26	-------	25	26	26
			BOYCE				
Maximum ------------	9	5	40	-------	26	0.5	80
Minimum------------	1	0	<10	-------	0	0	10
Mean ----------------	3.2	.6	--	-------	10.0	.15	32
Standard deviation-----	1.9	1.2	--	-------	6.0	.13	19.6
Number of samples-----	21	20	20	-------	20	23	20
			MONCLA				
Maximum ------------	8	10	30	-------	[2]15	0.4	140
Minimum------------	2	0	<10	-------	0	0	10
Mean ----------------	3.3	1.5	--	-------	7.4	.11	35.9
Standard deviation-----	1.6	.7	--	-------	4.2	.12	26.5
Number of samples-----	21	21	21	-------	19	22	22
Recommended limits---	50	10	50	1,000	50	2	5,000

[1] Mean concentrations and standard deviations for chromium not given because "less than" values were reported for many analyses.

[2] Value of less than 100 micrograms per liter reported on two occasions.

only two herbicides are usually detectable in the water column, 2,4-D and 2,4,5-T (chlorophenoxy-acid herbicides). Other pesticides such as organochlorine and organophosphorus insecticides are usually not detectable. The maximum concentrations of 2,4-D and 2,4,5-T were 0.5 and 0.22 microgram per liter, respectively. About 90 percent of the time these herbicides showed concentrations below 0.05 microgram per liter. Samples of bed material collected for organochlorine analysis showed only small amounts of the insecticide DDT and its related compounds DDD and DDE. Maximum DDT, DDD, and DDE concentrations were 7.8, 1.5, and 5.5 micrograms per kilogram, respectively. The concentration of these substances was less than 1.0 microgram per kilogram approximately 80-90 percent of the time. No significant departure from the preceding ranges of herbicide and insecticide concentrations either in the water column or in bed material in downstream reaches of the river was observed.

WASTE DISPOSAL AND REAERATION

Municipal wastes, wastes from petroleum operations, and papermill wastes are the principal sources of pollution of the Red River. Three types of wastes are discharged from these sources--chemical (inorganic and organic), bacterial, and thermal. The inorganic and bacterial wastes significantly affect the quality of the river water.

Inorganic Wastes

Historically, chloride and sulfate have been major constituents affecting water quality in the Red River (U.S. Public Health Service, 1964). The major sources of these constituents in the upper basin are natural salt deposits, brine seeps, and brine wastes from petroleum operations. Contamination from sources in the lower basin are insignificant. Efforts to control these contaminants at the source were increased during the 1960's. These efforts included the control of natural brine seeps by storage or diversion of brine and improved waste management in petroleum operations.

Chloride, sulfate, and bicarbonate are the major anions found in the Red River. Regression analysis of the relation of these anions and specific conductance at Hosston, October 1958 to September 1975, indicates a shift in the relation of each to specific conductance (fig. 10). For example, in the period October 1958 to September 1967 when the specific conductance was 1,000 micromhos/cm, the dissolved chloride, sulfate, and bicarbonate concentrations were 180, 115, and 135 mg/L, respectively. In the period October 1972 to September 1975 at the same specific conductance, the dissolved chloride, sulfate, and bicarbonate concentrations were 145, 90, and 180 mg/L, respectively. This shows a shift in the relation among the major anions and a resulting change in the type of water in the river. This shift, as well as the reduction in dissolved-solids concentration, indicates some success in the effort to control brine releases in the upper reaches of the Red River.

Acidic- and Basic-Waste Assimilation

At present little or no acidic or basic wastes are discharged into the Red River. However, the discharge of such wastes could have a deleterious effect on the pH of the water below the injection site.

The buffering capacity of water, the ability of the water to resist a change in pH, is measured by the quantity of acid or base required to produce a change in the pH of the water. Acid- and base-buffering curves were prepared (fig. 11) to show the potential effect of disposal of

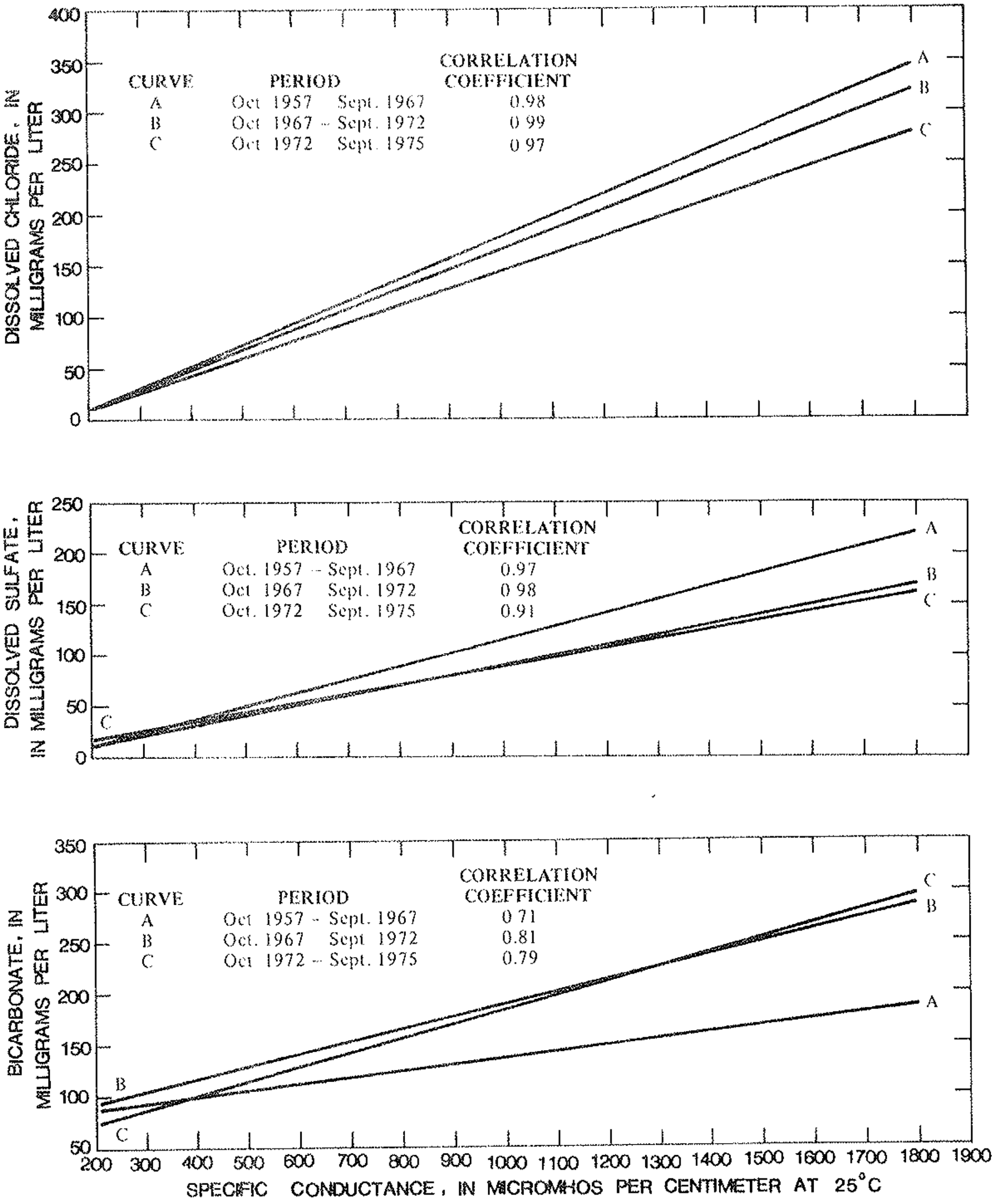


Figure 10.--Relation of concentration of dissolved chloride, sulfate, and bicarbonate to specific conductance, Red River at Hosston, October 1957-September 1975.

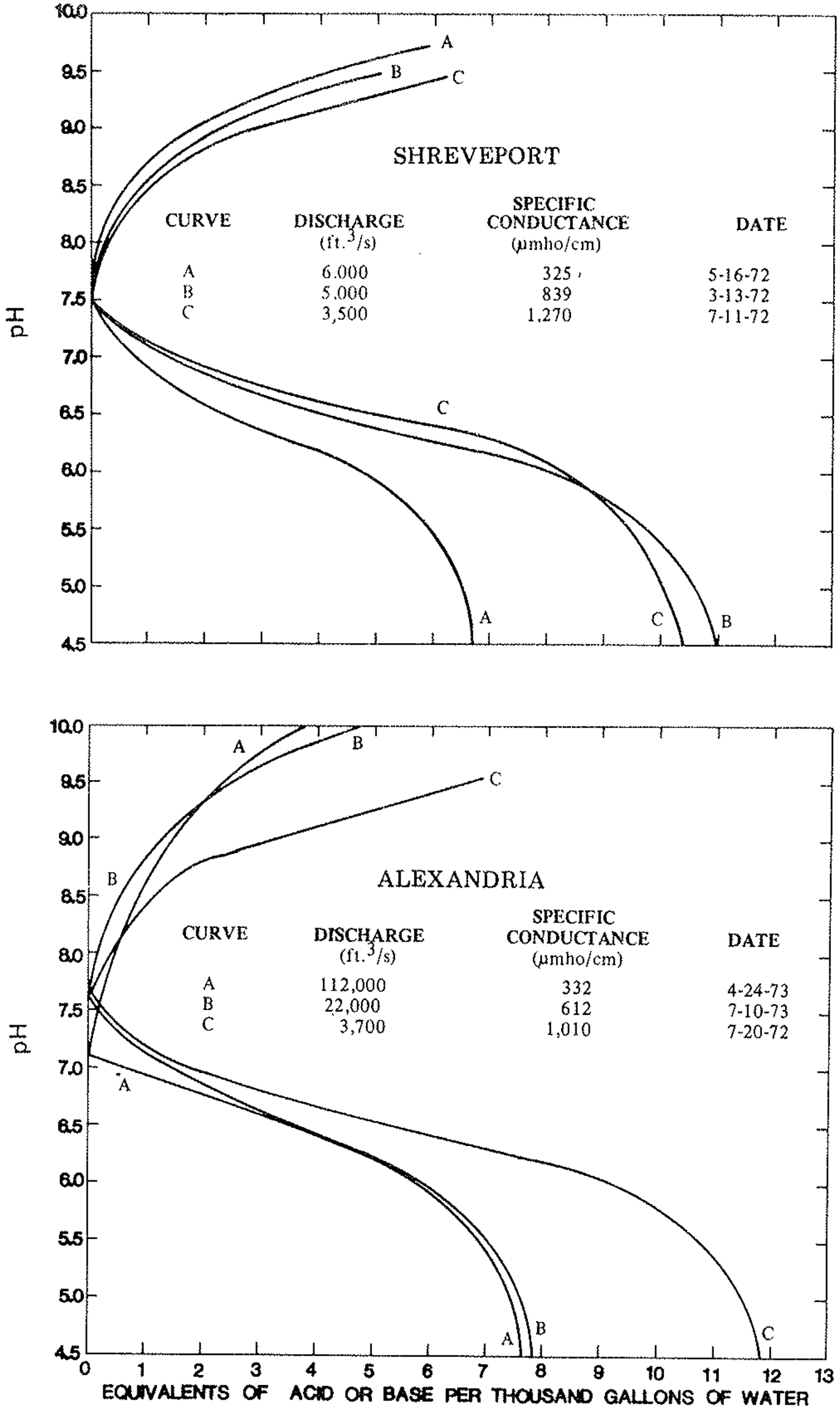


Figure 11.--Buffering-capacity curves, Red River at Shreveport and Alexandria.

acidic or basic wastes on the pH of Red River water at Shreveport and Alexandria at various flow and quality conditions. The buffering capacity of the water is greatest during low-flow conditions when the dissolved-solids concentration and alkalinity are highest. For example, the addition of six equivalents of acid as hydrogen ion at Shreveport would lower the pH of 1,000 gal (3,785 L) of water approximately 1.0 and 2.0 pH units when the discharge is 3,500 and 6,000 ft^3/s (99 and 170 m^3/s), respectively. Normally, Red River water tends to be neutral to slightly basic. About 90 percent of the time the pH ranges from 7.0 to 8.0. Buffering curves for basic wastes show the effect of hydroxyl ions on the pH of the river water. For example, at discharges of 3,500 and 6,000 ft^3/s (99 and 170 m^3/s) at Shreveport, the addition of five equivalents of base as hydroxyl ion would raise the pH of 1,000 gal (3,785 L) of water 1.7 and 1.9 pH units, respectively.

The ability of the river to assimilate acidic and basic wastes at certain discharges can be estimated from the buffering-capacity curves in figures 12 and 13. For example, a continuous discharge of 1,000 tons per day of 40 percent hydrochloric acid at Shreveport would lower the pH, after complete mixing, approximately 3.1 and 1.9 pH units when the discharge is 3,500 and 6,000 ft^3/s (99 and 170 m^3/s), respectively. The pH of the river water would be lowered even further in the area immediately downstream from the discharge site. Although the buffering capacity of Red River water is greatest per unit volume during low-flow periods when the dissolved-solids concentration and alkalinity are highest, the ability to assimilate acidic or basic wastes is a function of dissolved-solids and alkalinity loads, which are greatest during high-flow periods. At higher flows the dilution factor plays a major role in the assimilation of acidic or basic wastes.

Bacterial Wastes

The municipal wastes of Shreveport (raw), Bossier City (raw), Alexandria (treated), and Pineville (treated) are discharged into the Red River. All the raw wastes from Bossier City and about 75 percent of the raw wastes from Shreveport enter the river within the corporate boundaries. The remainder of Shreveport's wastes are discharged at Lucas (river mile 266).1/ Alexandria employs secondary treatment and effluent chlorination, and Pineville uses a modified oxidation pond. Effluents from both communities are discharged into the river within their corporate boundaries.

Counts of fecal coliform bacteria and fecal streptococcal bacteria were used to determine bacterial pollution of fecal origin. The limit of 200 fecal coliform bacteria colonies per 100 mL (milliliters) as set forth for primary contact water sports in "Quality Criteria for Water" (U.S. Environmental Protection Agency, 1976) generally has been exceeded at most sampling sites on the Red River for the period October 1972 to September 1975 (table 4).

1/ The city of Shreveport has completed a secondary-waste-treatment plant at Lucas that uses effluent chlorination. This began operation in June 1976. The capacity of the plant is 30-35 Mgal/d (1.3-1.5 m^3/s), and the 1976 load was about 20 to 25 percent of this. The remaining municipal sewage is diverted to the river with no treatment.

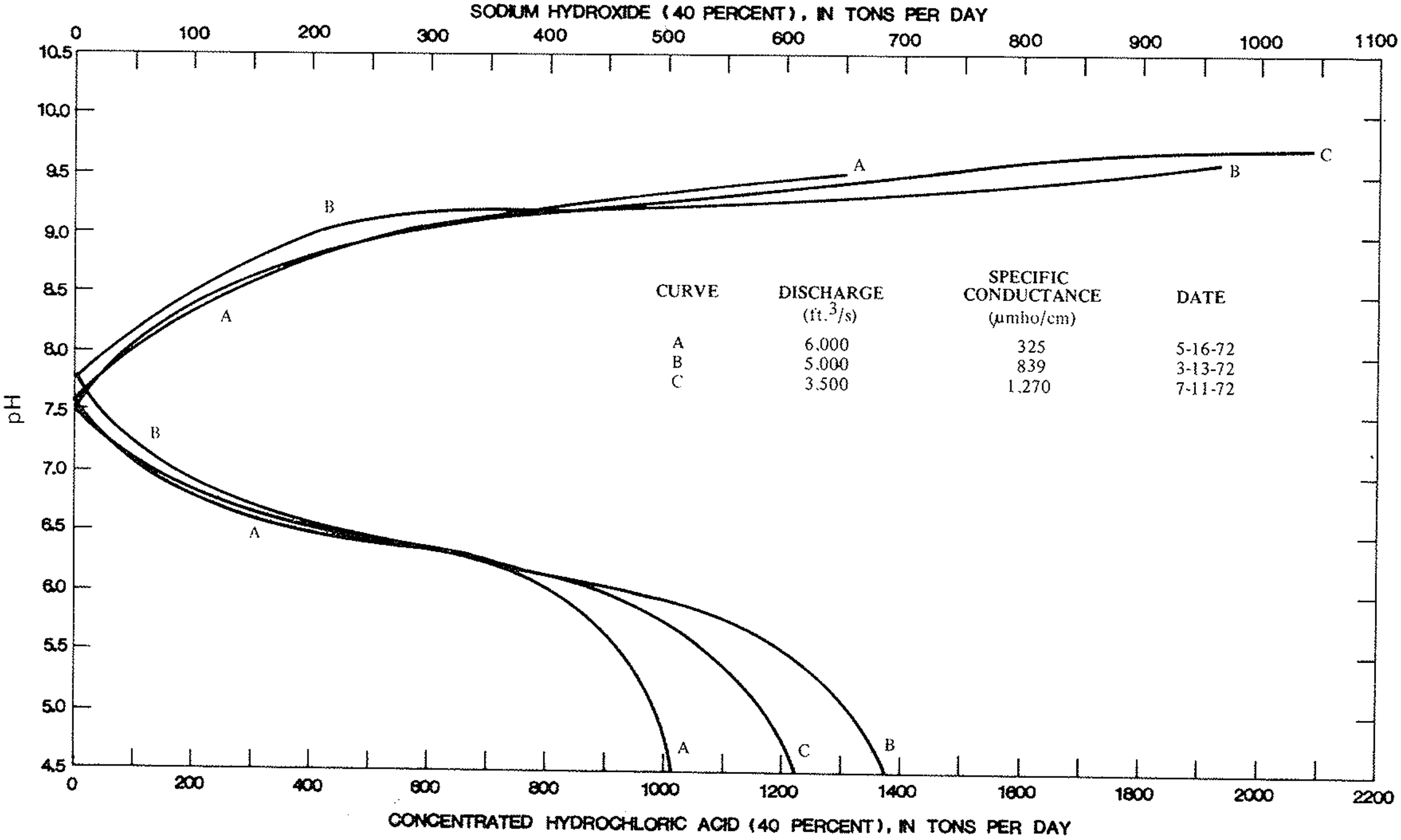
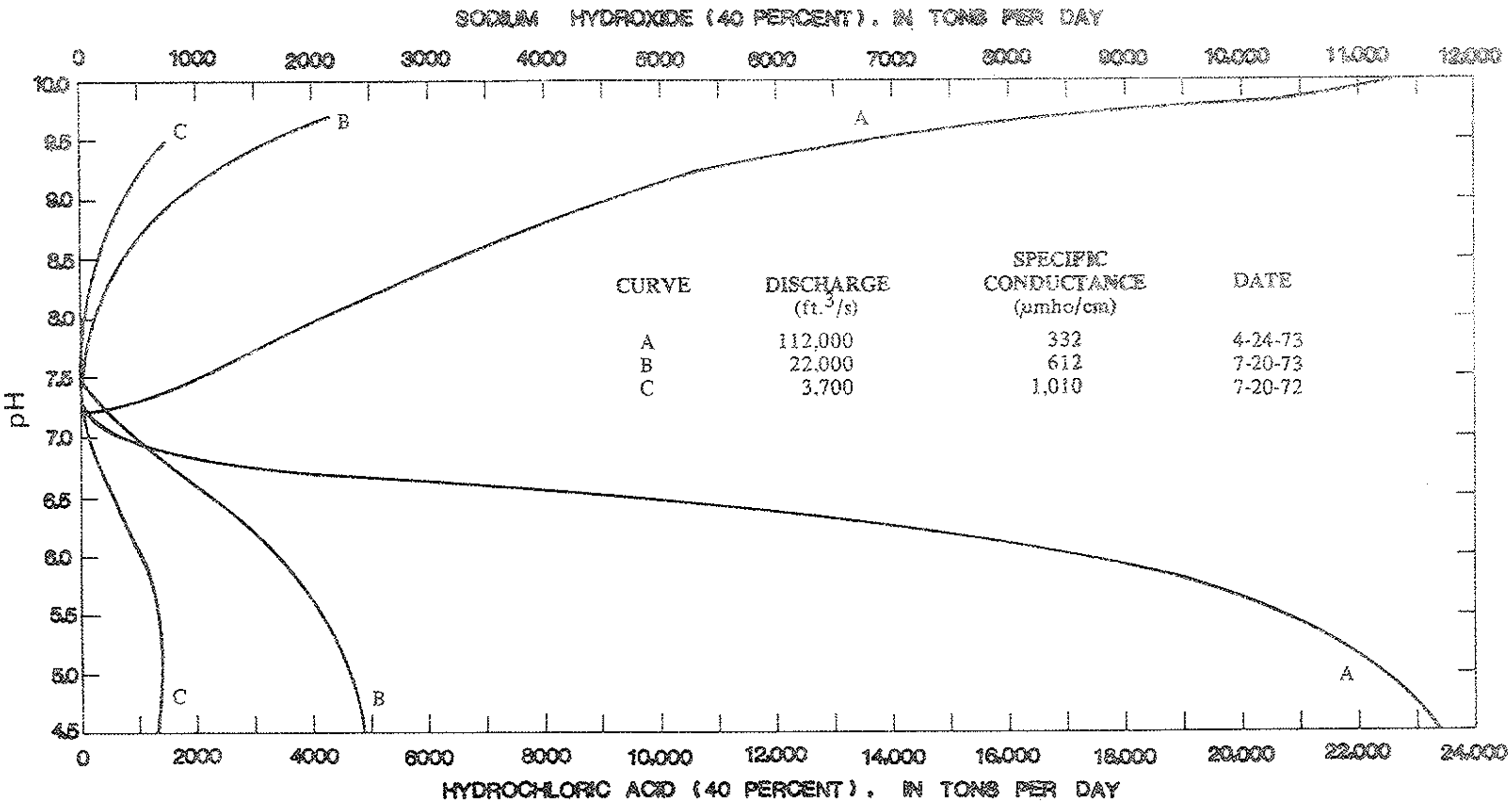


Figure 12.--Acidic- and basic-waste assimilation curves, Red River at Shreveport.



CURVE	DISCHARGE (ft.^{3}/s)	SPECIFIC CONDUCTANCE (µmho/cm)	DATE
A	112,000	332	4-24-73
B	22,000	612	7-20-73
C	3,700	1,010	7-20-72

Figure 13.--Acidic- and basic-waste assimilation curves, Red River at Alexandria.

Table 4.--Percentage of samples containing more than 200 fecal coliform bacteria colonies per 100 milliliters and the range of fecal coliform bacteria counts by site

[Based on monthly and biweekly samples collected by the U.S. Geological Survey]

Period of collection	Site	Percentage of samples (>200 colonies per 100 mL)	Range (colonies per 100 mL)
October 1972-September 1975----	Hosston----------	73	<5-19,000
July 1974-September 1975-------	Above Shreveport--	43	<5- 3,400
November 1972-September 1975--	Coushatta--------	96	110-38,000
November 1972-September 1975--	Boyce -----------	95	100-14,000
January 1973-September 1975----	Alexandria-------	100	350- 5,000
November 1972-September 1975--	Moncla----------	99	140-12,000

Several attempts to determine the death rates of fecal coliform and fecal streptococcal bacteria were made during various flow conditions. Although an overall downstream decrease in fecal bacteria counts was shown, die-off could not be predicted accurately because of the many undefined sources of fecal contamination in the study reach of the river. Runoff from batture lands heavily grazed by livestock and contamination from individual dwellings would serve to maintain an elevated "residual" fecal bacteria population and produce a false k value (death rate constant) in Chick's equation (Velz, 1970, p. 242).

Samples were collected, beginning in March 1976, to check for the presence of Salmonella (a pathogen of fecal origin) in the Red River in the vicinity of Shreveport. (Analytical procedure is by T. A. Ehlke, written commun., 1975.) Geldreich (1969) determined a correlation between fecal coliform concentration and Salmonella presence. He found a 98-percent occurrence of Salmonella when the fecal coliform concentration exceeded 2,000 colonies per 100 mL. Four sampling sites were selected: (1) above Shreveport (river mile 283), (2) at Lucas (river mile 266), (3) at Gayles (river mile 259), and (4) at Crosskeys (river mile 247). Salmonella was isolated only from a sample from the site at Lucas. (The fecal coliform count per 100 mL above Shreveport and at Lucas, Gayles, and Crosskeys was 104, 28,000, 3,600, and 5,600, respectively.) A much more extensive sampling program would have to be undertaken to fully evaluate the relation between fecal coliform and Salmonella in the Red River.

Reaeration

The three dominant factors influencing the dynamics of dissolved oxygen (hereafter referred to as DO) in water from the Red River are (1) the concentration of oxygen-consuming wastes in the stream, (2) reaeration through mechanical diffusion of atmospheric oxygen, and (3) oxygenation through the photosynthetic addition of oxygen by algae and other plants.

In general, when large amounts of oxygen-consuming wastes enter a stream, there is a reduction in DO downstream from the entry point. The degree of reduction in the reach is chiefly dependent on water temperature, the amount and type of waste, and river discharge. Despite the addition of over 30 Mgal/d (1.3 m^3/s) of raw sewage at Shreveport, the DO downstream has not been significantly depressed, as shown by data collected by the city of Shreveport (Department of Water and Utilities, unpub. data, 1968) and data collected by the Geological Survey, 1973-74. At low flow the biochemical oxygen demand (a measure of the amount of oxygen required to stabilize organic matter in the presence of biochemical acitvity) sometimes reaches 5-7 mg/L while the DO remains about 70 to 80 percent of saturation. For this to occur, oxygen must be replaced rapidly. Both reaeration and photosynthesis play major roles in the placement of consumed oxygen. It is not within the scope of this report to provide a detailed analysis of these means of reaeration, but a general comparison is presented.

Estimation of reaeration involves empirical analysis of several physical characteristics of a stream. A simple empirical method is the Langbein-Durum method (Langbein and Durum, 1967). This approach employs stream velocity (v) and depth (H) in the equation

$$k_2=7.6v/H^{1.33} \tag{1}$$

to compute the reaeration coefficient, k_2 (Napierian log base), which is then used in the equation

$$dc/dt=k_2(C_s-C) \tag{2}$$

where C is the observed DO concentration (milligrams per liter), C_s is the DO concentration for saturation at the given temperature, t is time (days), and k_2 is the previously computed reaeration coefficient. This equation will then allow an estimation of the rate of absorption of atmospheric oxygen in terms of milligrams per liter per day. For the purpose of comparison it is assumed that there is no additional deoxygenation taking place.

Biological oxygenation may be measured in several ways. The light bottle-dark bottle technique is one of the simplest methods (Slack and others, 1973, p. 93-99). This method measures photosynthesis and respiration of phytoplankton or free-floating algae. The euphotic zone (light-penetrating zone) is determined, and samples from this zone are placed in both transparent (light) and opaque (dark) bottles. The initial DO is determined, and the samples are incubated at the depth from which they were taken. After a suitable period (6-24 hours) the bottles are removed, and the DO concentrations are determined.

The change in DO in the light bottle is due to photosynthetic production of oxygen and depletion of oxygen by respiration. This is net primary production and is expressed in milligrams per liter per unit of time. The change in DO in the dark bottle is due to respiration alone. Gross primary production is computed as the difference in DO between the light and dark bottles.

In October 1975 several light-dark bottle studies were carried out in various reaches of the Red River. The results are given in table 5. The station at Moncla was chosen arbitrarily to compare the reaeration rate and the biological oxygenation rate. The reaeration coefficient (k_2) was calculated by estimating the mean depth (H) to be about 10 ft (3.048 m) and the mean velocity (v) to be about 1 ft/s (0.3048 m/s). The values used in equation 1 produce a reaeration coefficient of 0.36. The water temperature at the time of the study was 20.0°C and the DO (C) was 8.0 mg/L. At this temperature the oxygen concentration at saturation (C_s) is 9.2 mg/L. Therefore, the DO deficit is 1.2 mg/L. Substituting the above DO values in equation 2, the reaeration rate is 0.43 mg/L per day. Under existing low-flow conditions the biological oxygenation rate (net primary production) was 4.8 mg/L per day, which is about 10 times greater than the reaeration rate.

Table 5.--Results of studies of primary productivity in the Red River using the light-dark bottle technique, October 1975

[DO, dissolved oxygen; DO_i, initial dissolved oxygen; LB, light bottle; DB, dark bottle]

Station	DO_i at start of incubation	Final DO of LB	Final DO of DB	Gross primary productivity, $\frac{\text{LB-DB}}{\text{time}}$	Net primary productivity, $\frac{\text{LB-DO}_i}{\text{time}}$	Respiration, gross-net	Discharge (ft^3/s)	Water temperature (°C)
	Milligrams per liter			Milligrams per liter per day				
Above Shreveport----	10.1	11.2	8.9	2.3	1.1	1.2	3,000	20.0
At Coushatta--------	9.4	14.6	8.4	6.2	5.2	1.0	3,000	20.0
Above Alexandria----	8.2	12.6	7.6	5.0	4.4	.6	5,500	20.0
At Moncla----------	8.0	12.8	7.0	5.8	4.8	1.0	5,500	20.0

Another set of light-dark bottle studies was done in March 1976 at a much higher discharge (about 39,000 ft^3/s or 1,100 m^3/s). These studies showed the biological oxygenation rate to be practically zero in all cases. This was probably due to increased turbidity, which decreases light penetration and "washout" of the phytoplankton by higher streamflow.

The results of these studies explain some of the factors that govern DO dynamics in the Red River. Most of the time, reaeration and dilution of waste are the dominant factors influencing DO. During the annual low-flow period when discharge decreases, the river becomes less turbid, allowing the euphotic zone to increase and phytoplankton populations to rise to as many as 400,000 cells per milliliter (fig. 14). The river then becomes more productive, and photosynthesis becomes a major influence affecting DO.

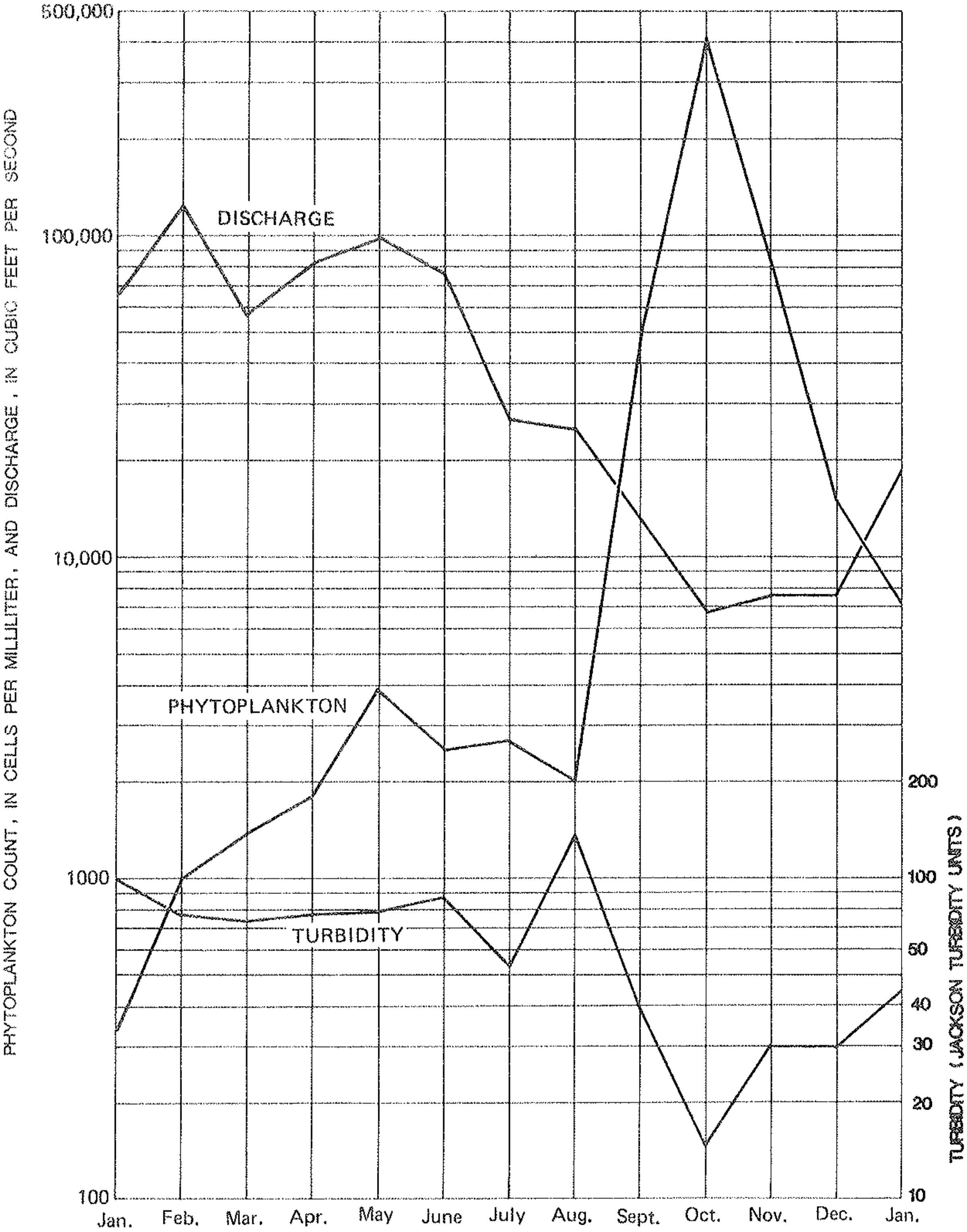


Figure 14.--Monthly phytoplankton concentration, level of turbidity, and discharge, Red River at Alexandria, January 1975-January 1976.

Diel measurements of DO were made at several different flows to determine the effect of the phytoplankton community on daily DO regimes at Moncla (fig. 15). Any sizable increase in phytoplankton density is usually referred to as an "algal bloom." These blooms usually cause the DO to fluctuate widely. During the day when photosynthesis is dominant, the DO may increase to supersaturation; and at night when respiration becomes dominant, the DO may be depressed severely. At flows above 5,500 ft^3/s (156 m^3/s) only small fluctuations were observed. At a flow of 3,000 ft^3/s (85 m^3/s) a significant fluctuation was noted. Even though the DO was affected greatly by photosynthesis and respiration, the minimum DO observed was about 5.5 mg/L (56-percent saturation) (fig. 15), which is sufficient to maintain aquatic animal life. However, if the biological oxygen demand were increased by the addition of wastes, under conditions similar to those when the flow was 3,000 ft^3/s (85 m^3/s), the lowered DO could affect aquatic animal populations adversely.

TIME OF TRAVEL

The rate and dispersion characteristics of solutes in a stream is necessary information for water users downstream from a contaminant spill. They must know the traveltime and duration time of a contaminant as it moves downstream so that contamination of water-supply systems can be avoided. A fluorometric technique for tracing dye in water (Wilson, 1968) facilitates the measurement of the above characteristics. Using this technique the longitudinal (downstream) dispersion and velocity of the Red River from above the Arkansas-Louisiana State line at Spring Bank Ferry, Ark., (river mile 334) to Moncla, La., (river mile 66) were determined in April 1971 and March and June 1972 (A. J. Calandro, U.S. Geological Survey, unpub. data, 1977).

As a solute moves downstream it becomes longitudinally dispersed. Estimation of the rate of dispersion necessitates determination of traveltime for the leading edge, peak, and trailing edge (defined as the point on the upstream end of the cloud at which the concentration is 5 percent of the peak) of the cloud between sites (fig. 16).

The duration (time of passage at a point) of a contaminant is inversely related to discharge. As discharge increases, velocity increases and logitudinal dispersion decreases at any downstream location because the contaminant has less time to disperse. Because of this, all traveltime determinations are based on the assumption of stable flow conditions. The duration of a contaminant can be estimated by subtracting the time the leading edge passes from the time the trailing edge passes (fig. 16). If an accidental spill of contaminant occurred at Shreveport (river mile 278) when the discharge was 6,000 ft^3/s (170 m^3/s), the leading edge and peak would reach Coushatta (river mile 219) in about 46 and 48 hours, respectively, and the trailing edge would pass in 60 hours; hence, the duration or passage time would be 14 hours.

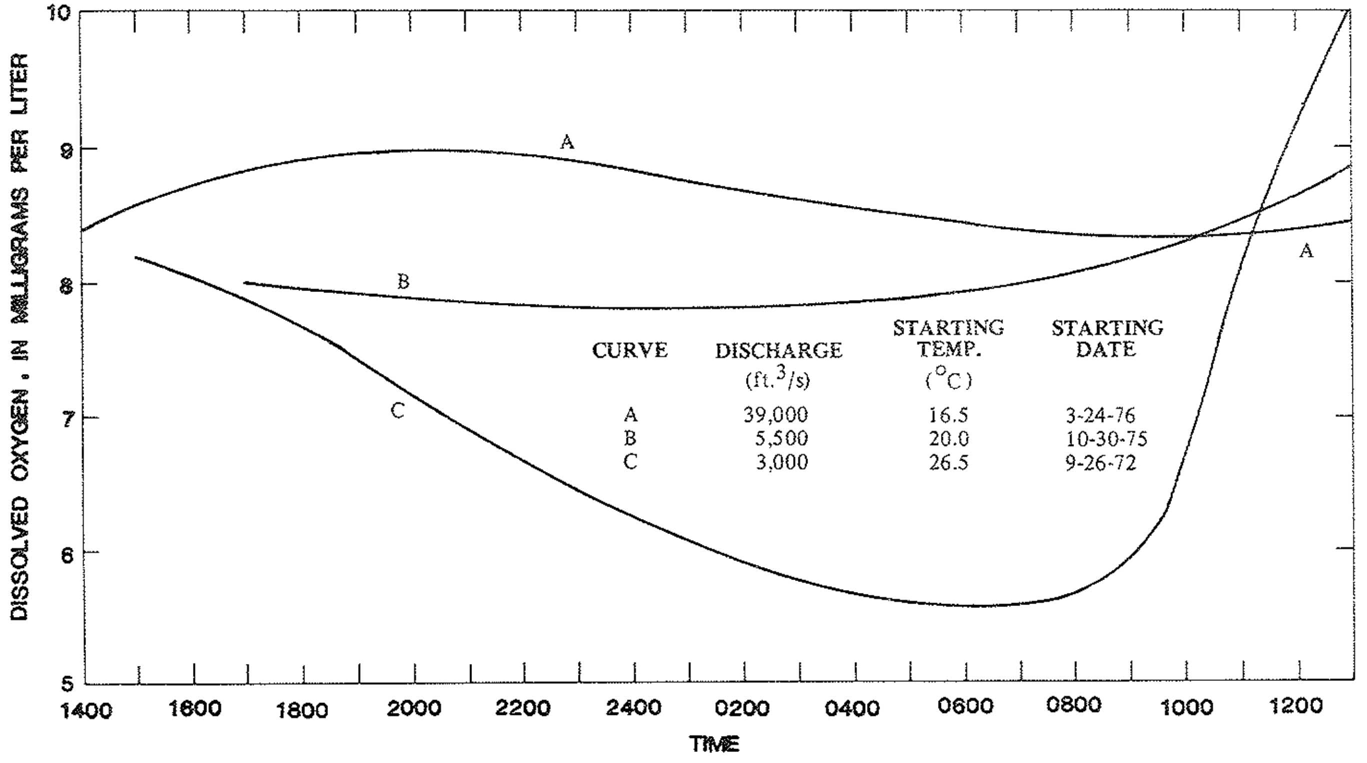


Figure 15.--Diel variation in dissolved oxygen at three different flows, Red River at Moncla.

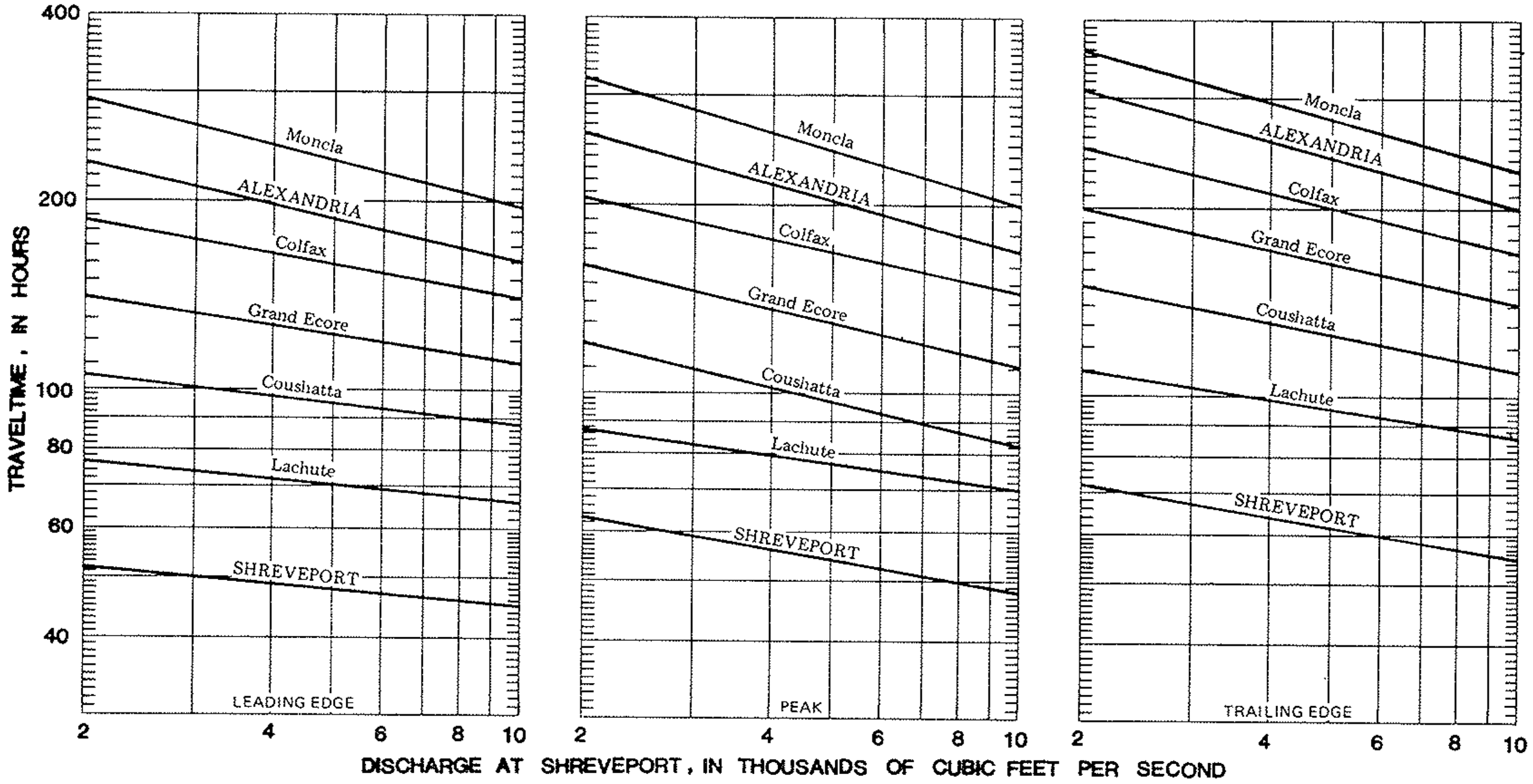


Figure 16.--Variation in traveltime with discharge for the leading edge, peak, and trailing edge of dye cloud from Spring Bank Ferry, Ark., to downstream sampling sites.

The peak concentration at any point downstream from a waste spill can be calculated using the equation

$$\text{Peak concentration} = \frac{\text{unit concentration times weight of contaminant spilled}}{\text{discharge at sampling site}}$$

where unit concentration is the peak concentration resulting from 1 lb (453.6 g) of contaminant in 1 ft^3/s (0.0283 m^3/s) of water, assuming the contaminant is 100 percent conservative. Knowing the elapsed time a contaminant has been in the water from figure 16, the unit concentration (fig. 17), and the river discharge at the sampling site, the peak concentration can be computed. For example, if 1,000 lb (453.6 kg) of contaminant were spilled at Shreveport when the discharge was 6,000 ft^3/s (170 m^3/s), the peak would arrive at Coushatta in 48 hours (fig. 16) and the unit concentration would be 680 micrograms per liter (fig. 17). The peak concentration at Coushatta would be about 113 micrograms per liter.

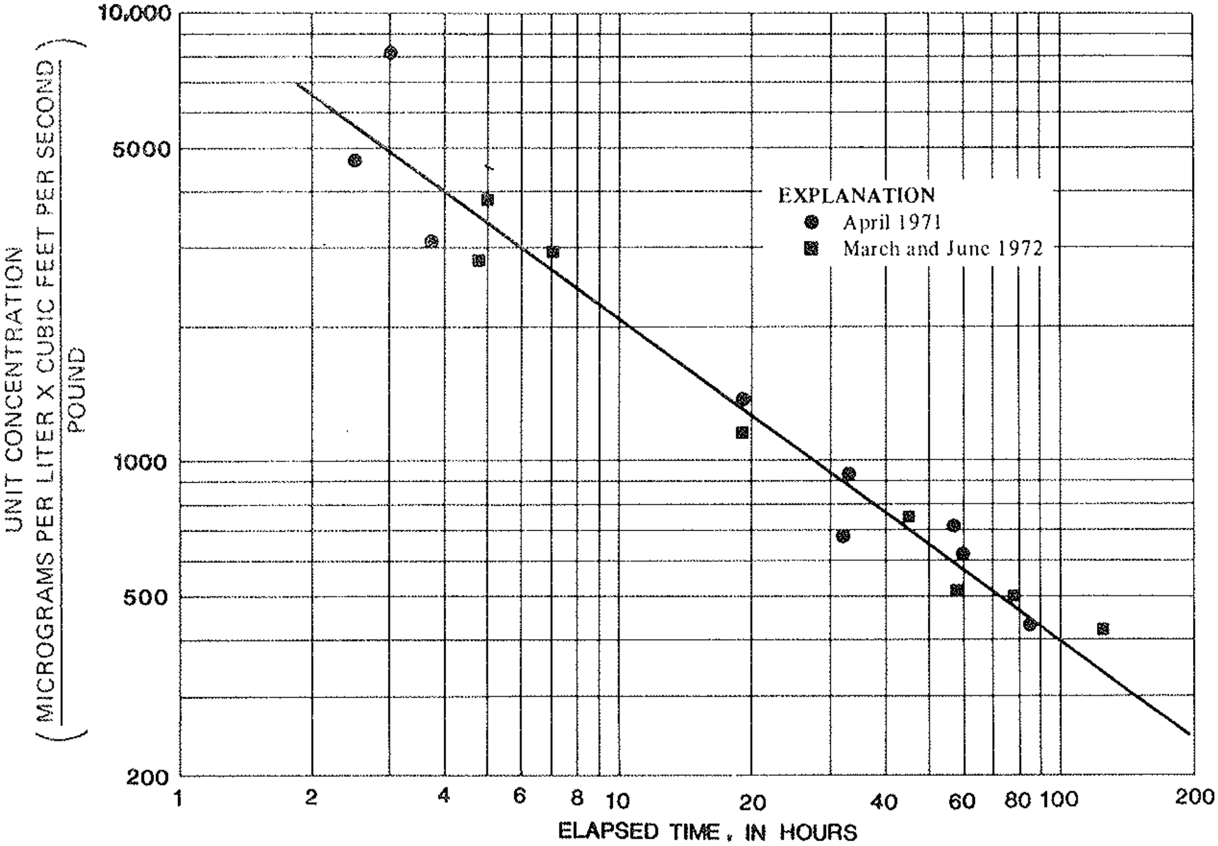


Figure 17.--Relation of the unit concentration of a solute to its residence time in the Red River.

SUMMARY

The average discharge of the Red River for the period 1928-75 was 24,900 ft^3/s (705 m^3/s) and 31,900 ft^3/s (903 m^3/s) at Shreveport and Alexandria, respectively. Log-Pearson type III frequency analysis shows a mean annual flood (1-day Q_2 high flow) to be about 105,000 ft^3/s (3,060 m^3/s) at Shreveport and 108,000 ft^3/s (2,970 m^3/s) at Alexandria. The 7-day Q_2 low flow, which is generally used in designing water-supply systems, was about 3,340 ft^3/s (95 m^3/s) at Shreveport and 4,440 ft^3/s (126 m^3/s) at Alexandria. The 7-day Q_{10} low flow used in determining waste-loading restrictions for Shreveport and Alexandria was about 1,490 ft^3/s (42 m^3/s) and 1,950 ft^3/s (55 m^3/s), respectively.

Maximum sediment discharge at Alexandria usually occurs in May when the sediment discharge is equal to or greater than 400,000 tons per day 25 percent of the time. An average sediment discharge of about 103,000 tons per day is transported past Alexandria.

Variations in daily observation of specific conductance usually range from 25 to 100 micromhos/cm and have been as great as 200-250 micromhos/cm. There has been a general decrease in dissolved-solids concentration at Hosston over the past several years. Due to the inflow of less mineralized water there is a significant decrease in the concentrations of dissolved solids, chloride, and sulfate as the river flows through the State. A 2.2°C (4.0°F) average increase in temperature is observed from Hosston to Alexandria. Only trace concentrations of heavy metals and certain pesticides are present in the water and bed material.

High concentrations of chloride and sulfate have been a problem. Since the late 1960's there has been a general reduction in chloride and sulfate concentrations. This indicates some success in controlling brine releases in the upper basin.

At the present time little or no basic or acidic wastes are discharged to the river. However, injection of these types of wastes could have an adverse effect on the river. For example, when the streamflow at Shreveport is 3,500 ft^3/s (99 m^3/s), a continuous discharge of 1,000 tons per day of hydrochloric acid would lower the pH of the river, after mixing, about 3.1 pH units.

Fecal coliform density is a serious problem in the Red River because the high fecal counts indicate the probable presence of pathogens. Several sampling stations along the river consistently exceed the reccommended limit of 200 fecal coliform bacteria per 100 mL set forth for primary contact water sports by the U.S. Environmental Protection Agency (1976). _Salmonella_, a pathogen of fecal origin, was isolated from a sample collected below Shreveport.

In spite of the addition of large amounts of oxygen-consuming wastes, the dissolved-oxygen concentration remains near saturation. Biological oxygenation plays a major role in replacing consumed oxygen at low flows when phytoplankton populations sometimes reach densities of 400,000 cells per milliliter. Mechanical diffusion is the dominant method of reaeration at most flows.

Dye-tracer studies were done to provide an estimate of traveltime, duration, and concentration of wastes injected into the river for a discharge range of 2,000 to 10,000 ft^3/s (57 to 283 m^3/s) and at any place on the river between Spring Bank Ferry, Ark., and Moncla, La. These studies show that when the river is flowing at 6,000 ft^3/s (170 m^3/s), a spill of 1,000 lb (453.6 kg) of contaminant at Shreveport would have a peak concentration of 113 micrograms per liter when the contaminant reached Coushatta 48 hours later.

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