FINAL REPORT

Water-Resources Planning Studies

Oklahoma - Arkansas

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Oklahoma Water Resources Board

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WATER-RESOURCES PLANNING STUDY

OKLAHOMA AND ARKANSAS

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I. Introduction

This is the final report for the Research Project Water-Resources Planning Study, Oklahoma and Arkansas. The research project was undertaken to collect, correlate, and summarize all available hydrologic data in Oklahoma pertinent to the Arkansas River and its tributaries as they affect the water resources of Oklahoma and Arkansas. The data was then to be utilized by the compact commission to determine, predict and/or recommend the reliable conservation storage which may be equiably approtioned to each state in the light of present and future water requirements. All pertinent data relative to the present quality of water discharged to each state and further requirements to the development of the common water resources was also scrutinized. A detailed description of the proposed work was presented in the original proposal application.

It is felt that the objectives of the research project have been met. In January, 1969 the engineering advisory committee to the Arkansas - Oklahoma Arkansas River Compact Committee submitted a report in which the approtionment of the common waters of Oklahoma and Arkansas was set forth. This apportionment was based partially on data obtained through this research project and the companion project being conducted at the University of Arkansas. The state line flows that were developed are presented in Appendix A.

This research project not only provided the opportunity to obtain and analyze data which aided in apportioning the water usage between Oklahoma and Arkansas and the development of a better understanding of the quality of these waters; but also it provided an opportunity for the School of Civil Engineering to expand its graduate program in the area of water resources. Since this research project was initiated, five students have completed M. S. degrees and their thesis are listed in Appendix B. At the present time two students are working on the Master of Science degree and one student is working on the Ph D. degree in the area of water resources. This past year, the enrollment in the courses in the water resources area have greatly increased. During the spring semester, there were 23 students enrolled in the water resources engineering course.

The report submitted here included the findings for all three years of the study. The first two years dealt with the water quantity aspects of the study and the third year dealt with the water quality aspects. Although detailed progress reports were made at the end of the first year and also at the end of the second year, it was felt that a better understanding of the overall project would be available if the work completed during these first two years was also included in the final document.

II. Summary and Conclusions

A. Water Quantity Studies

The Arkansas River and its tributaries; the Spavinaw Creek, the Illinois River, Lee Creek, and the Poteau River, were studied for purposes of apportionment of the interstate water between the states of Oklahoma and Arkansas.

A base period was selected covering the water years 1938-1965. Missing mean monthly flows at various gaging stations were synthesized over the base period. Missing daily flood flows were also synthesized. State line flows for every tributary as well as for the Arkansas River were computed for the entire base period. These are given in Appendix A. The short length of available records posed some problems in flood and drought studies. A new approach for flood frequency analysis was advanced in an attempt to solve and overcome these problems. For analysis of low flows a statiscal model was selected which maintains the essential statistical parameters of each gaging station, and at the same time extends the record in the time dimension and renders it hydrologically stable. Both the Markov Chain method and the autoregression method were studied.

Use of the synthetic record, for low flow provide a more accurate prediction of the percent of time the flow is equal to or less than a stated magnitude on each tributary as well as on the Arkansas River itself. Using the duration curves plotted from the synthetic record, constitutes a better approach to the prediction of drought periods. From the duration curves, provided for six months, one, two, three, or five years for various gaging stations decisions concerning the apportioning of the flow on the basis of conservation storage could be made.

B. Water Quality Studies

Frequency analysis of the chemical quality of the Arkansas

River and its tributaries were made. Frequency analysis were made on the basis of all years of record, the last ten years of record, and the available records prior to the last ten years. It was found from this analysis that the quality of the water in regard to chlorides and total dissolved solids had improved in the last ten years over that of all years of record. The quality of the water in regard to sulfate concentration and hardness showed no change during the period of record available. It is felt that the improvement of the quality of the water in regard to chlorides and total dissolved solids was probably due to the cleaning up of oil field operations in the study area.

In the study it was felt that a better understanding of the quality-flow relationship would be helpful in planning the development, management and use of water resources of the area. In achieving that purpose, the regression analysis is applicable if characteristics of water quality data and streamflow data are examined and treated properly to meet the requirements of the statistical technique used. In this study four regression models in logrithmic form were used for expressing the relationship between the different parameters of chemical water quality and streamflow.

Although the concentration of chlorides, dissolved solids, hardness, and sulfate generally vary inversely with streamflow, it was found that the regression relationships for these parameters with streamflow were different. It was also found that the prevalence of the regression relationship between either chlorides or dissolved solids and streamflow was different for the five stations investigated. It was also found that the quality-flow relationship changes with the season; for clorides and dissolved solids prevalence of a relationship with streamflow was best in the summer, good in the spring, and fair in the winter and fall. For hardness, the summer was the only season in which the quality-flow relationship is significant. In addition to the influence of the current monthly streamflow, the antecedent streamflow also has significant influence on the variation of chemical quality of river water in many cases.

In collecting and analyzing the biochemical quality of the water in the study area, it was found that there is an acute shortage or lack of data on the biochemical quality of these waters. It has been proposed by many that the quality of the water in the study area is excellent and that there are no serious pollution problems at the present time. However, in this study, it was found that there are several serious biochemical quality problems within the area. It was found that in the year 1967, in one tributary, the nitrate concentration reached a maximum of 130 mg/l, and phosphate concentrations of 30 to 35 mg/l were quite common. This points to the possibility of a very serious problem for the future. The eutrophication of the lakes in the area could be greatly speeded up if such concentration of these nutritional constituents were permitted to exist. This is especially important when it is realized that Oklahoma has at the present time an active compaign to bring new industries into the state. Since one major facet of this research project was to provide data for the apportionment of the waters between Oklahoma and Arkansas, it was also very fitting to consider the quality of the waters in relation to their potential use.

The main conclusion drawn from this study, concerning the biochemical quality of the water is that there is a very serious shortage of biochemical quality data. However, from the scarce amount of data available it can be concluded that at the present time there are some serious water quality problems within the study area and there is the potential for very serious problems in the future.

C. Industrial and Agricultural Relationship to Water Quality

The existing industries in the study area were enumerated and located. From this phase of the study, it was found that there are several industries with a high potential for pollution of the waters. The study was not intended to determine the characteristics of the effluents from these industries. However, in the light of the biochemical water quality studies, it was felt that these industries could be the cause of possible pollution problems. The types of industries located in the study area are presented in Figure 44.

Since various agricultural activities are known to contribute possible stream pollutants it was felt that a survey of the agricultural activities in the study area would be beneficial. It was found that the agriculture of the study area in the past two or three decades has changed from a diversified type of farming with production of corn, cotton, oats, hogs, and cattle predominating to activites centered around beef cattle production. This has resulted in a very large reduction in the cultivated acreage of the area and increased acreages of seeded pastures, hay, and improved rangeland.

Fertilizers, mainly a nitrogen-phosphorus-potassium mixture, are applied to only 6 percent of the agricultural land area and lime is applied to about 1 percent of the agricultural land area.

Herbicides for seed and brush control are applied to about 1 percent of the agricultural land area. These herbicides are usually considered as non-poisonous and do not seem likely to present a serious problem to stream pollution.

Insecticides are used on about 0.5 percent of the agricultural land area. These are applied mostly to vegetables, fruit trees, and pecan trees. Most of the insecticides are poisonous and could cause a serious pollution problem if used in sufficient quantities.

The agriculture and agricultural land of the study area is probably not a contributor, to a significant extent, to water pollution in the study area at the present time. It is possible, however, that if the use of fertilizers and insecticides were increased many fold in the future, a pollution problem could develop.

III. Recommendations

One of the most striking situations encountered during the course of this research was the lack of water quality data. There were very few locations where adequate data on both water quantity and water quality were available. At many stations water quantity data would be available, but there was no water quality data. At another station there might be water quality data available, but no water quantity. Such a situation creates a very difficult problem in assessing the total water quality picture, in that total quantities of a pollutant can not be determined. This is especially acute when there are two or three tributaries flowing into a reservoir and the total quantities contributed by each reservoir are not available. In one stream (Pryor Creek) it has been pointed out that the nitrate concentration reached a maximum value of 130 mg/l. There were no water quantity data to correspond with this water quality data, and therefore, the total amount of nitrates carried down stream is unknown. It is obvious that this 130 mg/l nitrates would have a different significance depending upon the flow in the stream. Therefore, the major recommendation of this study is that an accelerated sampling program and a more coordinated gathering of water quantity and water quality data be initiated in the state of Oklahoma.

IV WATER QUANTITY STUDIES

A. GENERAL

The study area under investigation includes all the interstate water of the Arkansas River and its tributaries shown in Figure 1. The area is subdivided into 5 subbasins. These subbasins are

1. Illinois River
2. Spavinaw Creek
3. Lee Creek
4. Mainstem Arkansas River
5. Poteau River

The active gaging stations in and surrounding the study area are also shown in Figure 1. The average annual rainfall over the study area was superimposed (figure 2) to give an indication of the magnitude of the flows that could be expected.

Available Records

From the United States Geological Survey papers on Surface Water Records, the daily mean, monthly and extreme flow records and extreme flow records for the gaging stations in and around the the study area were collected. Table 1 shows the gaging station number, location, drainage area and the period covered by the record in the study area.

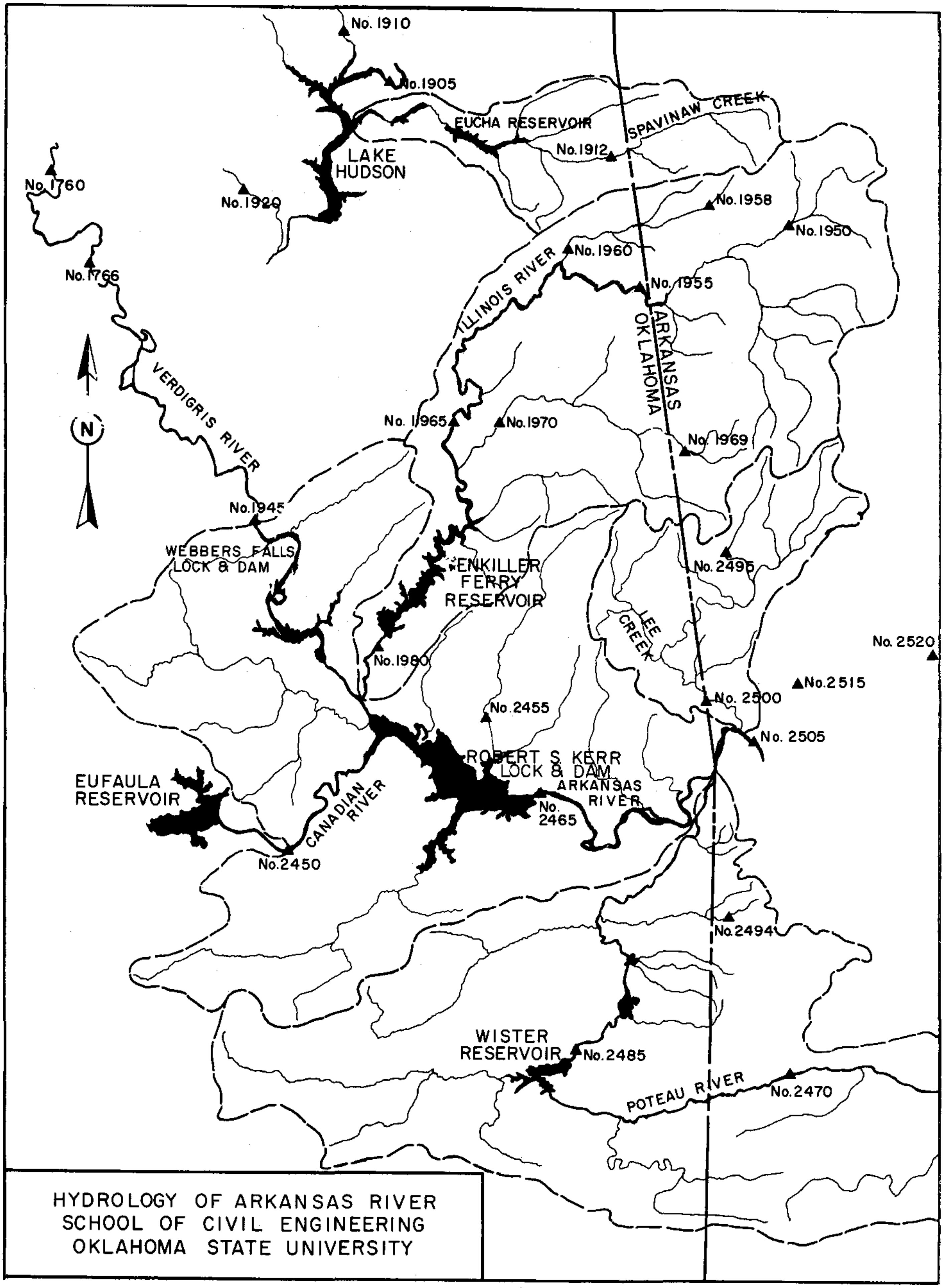
No. 1910
No. 1905
EUCHA RESERVOIR
SPAVINAW CREEK
No. 1912
LAKE HUDSON
No. 1760
No. 1920
No. 1958
No. 1950
No. 1766
ILLINOIS RIVER
No. 1960
No. 1955
ARKANSAS
OKLAHOMA
N
VERDIGRIS RIVER
No. 1965
No. 1970
No. 1969
No. 1945
WEBBERS FALLS LOCK & DAM
TENKILLER FERRY RESERVOIR
No. 2495
LEE CREEK
No. 2520
No. 1980
No. 2515
No. 2500
No. 2455
No. 2505
ROBERT S. KERR LOCK & DAM
EUFAULA RESERVOIR
CANADIAN RIVER
ARKANSAS RIVER
No. 2465
No. 2450
No. 2494
WISTER RESERVOIR
No. 2485
POTEAU RIVER
No. 2470
HYDROLOGY OF ARKANSAS RIVER
SCHOOL OF CIVIL ENGINEERING
OKLAHOMA STATE UNIVERSITY

Figure -1-

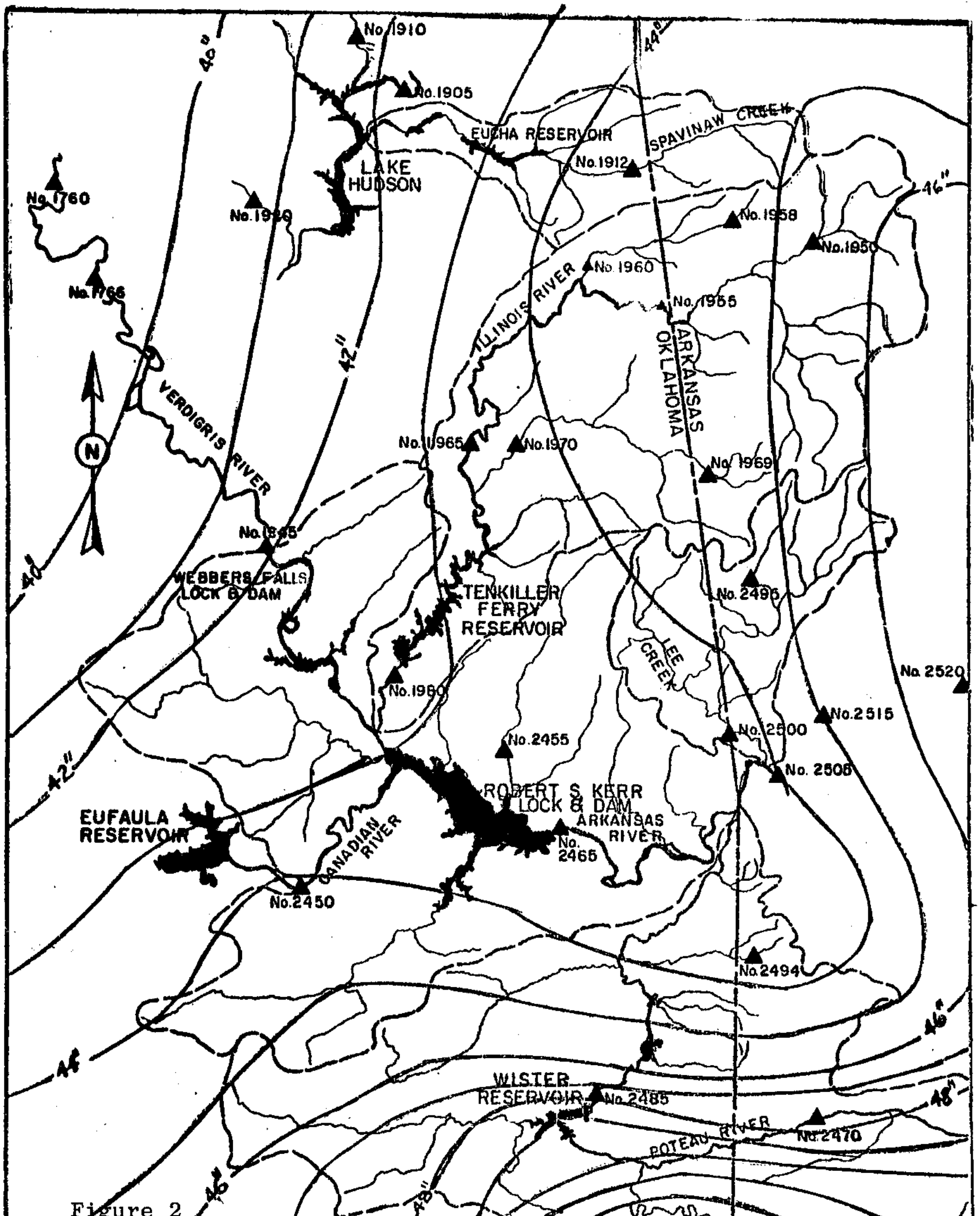

Figure 2

HYDROLOGY OF ARKANSAS RIVER
SCHOOL OF CIVIL ENGINEERING
OKLAHOMA STATE UNIVERSITY

Table -1-

Gaging Stations & Their Available Record

Station No.	Location	Drainage Area, Sq. mi.	Period of Record
Study Area			
Illinois River Subbasin			
7-1950	Osage Creek, Elms Spring, Ark.	129	Dec. 50 - Sept. 65
7-1955	Illinois River, Watts, Okla.	635	Aug. 55 - Sept. 65
7-1960	Flint Creek, Kansas, Okla.	110	Aug. 55 - Sept. 65
7-1965	Illinois River, Tahlequah, Okla.	959	Oct. 35 - Sept. 65
7-1969	Barren Fork, Dutch Mill, Ark.	43	Apr. 58 - Sept. 65
7-1970	Barren Fork, Eldon, Okla.	307	Oct. 48 - Sept. 65
7-1980	Illinois River, Gore, Okla.	1626	Apr. 39 - Sept. 65
Spavinaw Creek			
7-1912	Spavinaw Creek, Sycamore, Okla.	127	Oct. 59 - Sept. 62
7-1912.2	Spavinaw Creek, Sycamore, Okla. (1 mile D. S.)	133	Oct. 61 - Sept. 65
Lee Creek			
7-2495	Cove Creek, Ark.	36.9	May 50 - Sept. 65
7-2500	Lee Creek, Van Buren, Ark.	430	Sept. 30 - June 37 Oct. 50 - Sept. 65

continued Table 1

Station No.	Location	Drainage Area, Sq. mi.	Period of Record
	Mainstream Arkansas River		
7-1945	Arkansas River, Muskogee, Okla.	96,674	Oct. 25 - Sept. 65
7-2450	Canadian River, Whitefield, Okla.	47,576	July 38 - Sept. 65
7-2455	Sallisaw Creek, Sallisaw, Okla.	182	Oct. 42 - Sept. 65
7-2465	Arkansas River, Sallisaw, Okla.	147,757	Oct. 47 - Sept. 65
7-2505	Arkansas River, Van Buren, Ark.	150,483	Oct. 27 - Sept. 65
	Poteau River		
7-2470	Poteau River, Cauthron, Ark.	198	Feb. 39 - Sept. 65
7-2475	Fourche Maline, Red Oak, Okla.	121	March 39 - Sept. 65
7-2485	Poteau River, Wister, Okla.	1,015	May 38 - Sept. 65
7-2494	James Fork, Hackett, Ark.	148	Apr. 58 - Sept. 65

Records were also collected for gaging stations surrounding the study area for purposes of comparison and synthesis of missing flows. These surrounding gaging stations, in Oklahoma, are 1760, 1775, 1786 on the Verdigris River, 1900, 1905, 1910, 1920 on the Big Cabin Creek, 1850, 1880 on the Neosho River and 2320 on the Brushy Creek, in Missouri, station 1885 on Lost Creek and 1890 on Indian Creek, and in Arkansas, stations 480, 490, and 495 on the White River and its tributaries, and stations 2510, 2515, and 2520 on the Mulberry River and its tributaries.

B. ILLINOIS RIVER SUBBASIN

1. Description

A detailed map of the Illinois River is presented in figure 3. The Illinois River originates in Northwest Arkansas as Osage Creek and flows westward until it meets with Muddy Fork, which in turn drains Clear and Goose Creeks. The Muddy Fork system drains the southern portion of the tributary area of the Illinois River in the state of Arkansas while Osage Creek and the upper reaches of Flint Creek drain the northern portion of the tributary area. The Illinois River then crosses the Oklahoma Arkansas state line and continues running westward. It drains tributaries such as Wedington Creek and Ballard Creek. After Flint Creek joins the Illinois River, the river flows in a southerly direction into the Tenkiller Ferry Reservoir. The major tributaries joining into the river in this reach are Barren Fork, and Caney Creek. After leaving the Tenkiller Ferry Reservoir, the Illinois River flows southward for a distance of approximately 7 miles and drains into the Arkansas River just upstream of the Robert S. Kerr Lock and Dam.

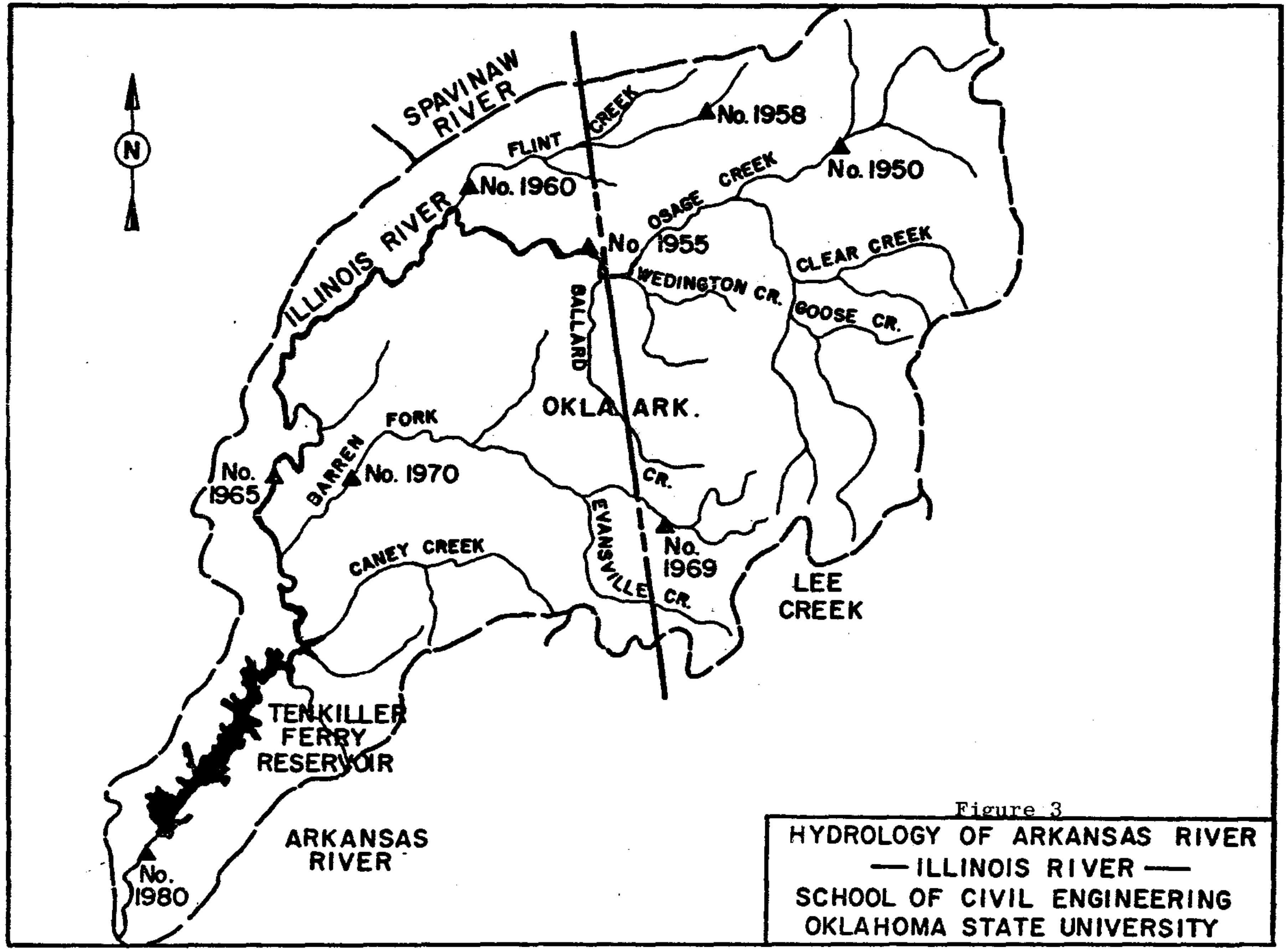

Figure 3
HYDROLOGY OF ARKANSAS RIVER
—ILLINOIS RIVER—
SCHOOL OF CIVIL ENGINEERING
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The entire drainage area of the subbasin is 1,660 square miles. The gaging stations on the Illinois River are Summarized in table 2.

2. Synthesis of Missing Data

a. Synthesis of Mean Monthly Flows

The Illinois River subbasin proved to be an ideal situation for synthesis of missing data due to the following advantages

1. The period of records available at Station 7-1965 and 7-1980 cover the entire base period selected for the study.
2. Station 7-1950, 7-1955 and 7-1965 are on the same channel as are station 7-1969 and 7-1970. Due to this fact, the correlation procedure usually gives more accurate results than those correlations derived for stations not on the same stream.
3. Station 7-1965 has no dams or reservoirs in its tributary area, thus there is no dampening of peak flood flows and no drastic change in the characteristics of the flow before it is recorded in the gaging station.

b. Synthesis of Station 7-1955, 7-1960, 7-1969, and 7-1970 from Station 7-1965

Procedure

The drainage area of station 7-1960 is 110 square miles, that of station 7-1955 is 635 square miles and that of station 7-1965 is 959 square miles. The ratio of drainage areas as compared to that of station 7-1965 are 11% and 66% for station 7-1960 and

Table -2-

Gaging Stations in the Illinois River Subbasin

Station No.	Location	Tributary Area, Sq. Mi.	Period of Record
7-1950	Osage Creek, Elm Spring, Arkansas	129	Dec. 50 - Sept. 65
7-1955	Illinois River, Watts, Oklahoma	635	Aug. 55 - Sept. 65
7-1960	Flint Creek, Kansas, Oklahoma	110	Aug. 55 - Sept. 65
7-1965	Illinois River, Tahlequah, Oklahoma	959	Aug. 55 - Sept. 65
7-1969	Barren Fork, Dutch Mill, Arkansas	43	Apr. 58 - Sept. 65
7-1970	Barren Fork, Eldon, Oklahoma	307	Oct. 48 - Sept. 65
7-1980	Illinois River, Gore, Oklahoma	1626	Apr. 39 - Sept. 65

and 7-1955 respectively. The available records for station 7-1965 and 7-1960 cover only the period of August, 1955 to September, 1965. Thus, we have 10 years of overlapping records between these three gaging stations.

For each month, the mean flow at station 7-1955 and 7-1960 was computed as a percent of the corresponding month at station 7-1965. Then the average value for each month over the entire period of overlapping record and the standard deviation were derived. These average values were then applied to the actual record of station 7-1965 during the period of missing flows at station 7-1955 and 7-1960; i.e., October, 35, July, 55, and the missing data was calculated. Table 3 gives the average percentage of the overlapping period of record and the standard deviations.

The same procedure was applied to correlate flows of station 7-1970, and 7-1969 to station 7-1965. The ratio of the tributary areas of station 7-1970 to station 7-1965 is 307 to 959 or .32, and that of station 7-1969 to 7-1970 to 307 or .14. Table 4 shows the correlation factors.

It is to be noted that station 7-1955 showed the best correlation as evidenced by the small value of the standard deviation. This is expected since the tributary areas are more or less of the same physical magnitude. Station 7-1960 showed a higher standard deviation since it is a small drainage area compared to a large drainage area. The response of a small drainage area to rainfall is quite different from that of a large drainage area and then, probably accounts for the increase in standard deviation. Station 7-1970 to 7-1965 showed a less accurate corre-

Table -3-

Cross Correlation of Monthly Records

Station 7-1955, 7-1960 to Station 7-1965

	7-1955/7-1965 = 635/959 = 66%			7-1960/7-1965 = 110/959 = 11%		
Month	Ave. Percentage	σ	σ as %	Ave. Percentage	σ	σ as %
Oct.	72.9	7.15	9.8	12.9	1.83	14.2
Nov.	77.6	9.40	12.1	12.6	2.22	17.6
Dec.	69.4	6.03	8.7	13.8	2.51	18.2
Jan.	74.6	6.00	8.1	11.9	2.36	19.9
Feb.	71.2	5.30	7.4	11.4	2.09	18.3
Mar.	67.1	5.63	8.4	11.3	2.12	18.8
Apr.	59.4	7.54	12.7	13.5	3.35	24.8
May	65.8	5.82	8.9	11.6	1.98	17.0
June	63.0	6.04	9.6	12.7	2.56	20.2
July	69.5	11.30	16.3	12.6	1.86	14.8
Aug.	75.5	6.78	9.0	13.5	3.15	23.3
Sept.	73.2	7.74	10.6	15.2	3.71	24.4

Period of overlapping records, years 10

Table -4-

Cross Correlation of Monthly Records

Station 7-1970/7-1965, Station 7-1969/7-1970

	7-1970/7-1965 = 307/959 = 32%			7-1969/7-1970 = 43/307 = 14%		
Month	Ave. Percentage	σ	σ as %	Ave. Percentage	σ	σ as %
Oct.	23.7	5.79	25.0	10.1	4.40	43.5
Nov.	24.6	7.29	29.6	10.8	3.84	35.7
Dec.	29.6	8.54	28.8	12.3	4.93	40.0
Jan.	31.4	7.51	23.9	14.0	3.43	24.5
Feb.	33.2	6.54	19.7	13.3	4.01	30.2
Mar.	36.3	7.06	19.5	14.3	3.72	26.0
Apr.	35.5	4.87	13.8	11.2	3.60	32.1
May	41.0	9.70	23.6	10.2	4.16	40.8
June	29.9	9.37	31.3	12.0	3.73	31.0
July	31.0	7.07	22.8	11.3	5.61	49.8
Aug.	23.5	7.96	33.8	9.3	4.75	51.0
Sept.	23.0	9.32	39.0	9.5	4.68	49.5

Period of overlapping
records years 17

lation, even though the overlapping record is much longer, mainly due to two reasons. The first is the ratio of the drainage areas and the second and more important is the fact that the two gaging stations are not on the same channel.

3. Flood Studies on the Illinois River

To investigate the floods on the Illinois River, station 7-1965 at Tahlequah, Oklahoma, with a drainage area of 959 square miles was again selected since the gaging records cover the entire base period selected for the study. At the station site, the maximum channel capacity is 8,000 cfs and any flow exceeding this amount will overtop the banks of the stream and is considered a flood. The annual maximum series of floods occuring at this location is presented in table 5.

The mean annual flood for this series is 22,280 cfs and the standard deviation is 20,780 cfs. Using this series and using frequency factors k (T,n), the magniture of floods corresponding to different return periods was derived as shown in table 6.

The return period for the maximum observed flood of 90,400 cfs, from the previous table is approximately 68 years. However, if we tried to calculate the return period $t_p = \frac{1}{p}$ for that same flood, where p is the probability and is equal to $1 - e^{-e^{-b}}$ as suggested by Fisher and Tippett, and where $b = \frac{1}{0.7797\sigma}(x - \bar{x} + 0.45\sigma)$

Where x is the flood magnitude with the probability p

$\bar{x}$ is the arithmetic average of all floods in the series

σ is the standard deviation of the series computed as $= \sqrt{\frac{\sum(x - \bar{x})^2}{N}}$

Table -6-

Floods of Various Return Periods as Derived From the Maximum Annual Series for Station 7-1965

Return Period yrs	Flood Magnitude cfs	Return Period yrs	Flood Magnitude cfs
5	40,330	30	75,680
10	54,480	50	85,280
15	62,280	60	88,780
20	67,880	75	92,980
25	72,180	100	98,480

where N is the number of years of record

it was found that the return period t_p is about 125 years from a curve relating b to t_p.

The floods occurring at station 7-1965 were further investigated using the partial duration series method. The maximum channel capacity at the gaging station site is around 8,000 cfs and flows exceeding that value will overtop the bank and subsequently are considered floods. In working with the partial duration series, periods of high flows of less than 8,000 cfs have been ignored. Table 7 shows the partial duration series floods.

It is of interest to note that the magnitude of the flood of one year return period is 12,700 cfs. This flood will be called the marginal flood.

Table -7-

Floods, Partial Duration Series

Station 7-1965 on the Illinois River

Year	Month	Day	Discharge	Partial Order	Return Period t_p, years
1937	Jan.	10	8,220	54	
		15	11,900	32	
1938	Feb.	18	34,700	7	4.28
	Mar.	30	11,400	35	
1941	Jan.	2	10,900	39	
	Apr.	20	30,600	10	3.00
	Oct.	17	10,000	43	
	Nov.	1	25,000	12	2.50
1942	Apr.	29	16,400	22	1.36
	Oct.	31	17,400	19	1.58
	Nov.	8	10,900	40	
	Dec.	28	22,300	14	2.14
1943	May	11	65,000	2	15.00
	May	20	12,800	29	1.04
1944	Mar.	20	17,300	19	1.58
1945	Feb.	22	14,200	25	1.20
		27	9,220	47	
	Mar.	3	15,200	23	1.30
		7	11,500	34	
		20	37,200	5	6.00
	Apr.	15	58,300	3	10.00
	May	17	9,910	44	
	June	12	11,800	33	
1946	Feb.	15	8,900	50	

Table -7-

Continued

Year	Month	Day	Discharge	Partial Order	Return Period t_p, years
	May	26	17,800	18	1.67
	Nov.	11	8,620	52	
	Dec.	11	16,600	21	1.43
1947	May	17	11,100	37	
1948	Aug.	15	29,200	11	2.73
1949	Feb.	16	13,300	27	1.11
	Mar.	30	8,510	53	
	May	20	13,800	26	1.15
1950	Jan.	14	10,500	41	
	May	11	90,400	1	30.00
1951	Feb.	21	31,400	8	3.75
1954	May	3	13,000	28	1.07
1955	Feb.	21	8,960	48	
	Mar.	22	8,930	49	
1957	Apr.	4	36,500	6	5.00
	May	19	18,000	17	1.76
		26	31,200	9	3.33
	June	3	12,700	30	1.00
		11	10,200	42	
1958	July	13	22,000	15	2.00
1959	July	24	8,900	51	
	Oct.	4	9,540	45	
	Nov.	5	14,800	24	1.25
1960	May	7	18,600	16	1.88
		21	9,450	46	

Table -7-

Continued

Year	Month	Day	Discharge	Partial Order	Return Period t_p, years
	July	26	23,200	13	2.30
1961	May	8	42,000	4	7.50
		21	12,600	31	
	Aug.	16	11,400	36	
1965	Apr.	7	11,000	38	

4. Flood Flows at Station 7-1955 and 7-1960 Synthesized from Station 7-1965

The overlapping period of record at both station 7-1955 and 7-1960 and station 7-1965 is 10 years. In trying to cross correlate flood flows, it is necessary to use the daily flows at the gaging stations. In using the daily flows, we are now dealing with a time unit that will be affected by the travel time of the flow between the gaging stations. Station 7-1955 and 7-1960 are approximately 43 and 36 miles respectively upstream of station 7-1965. In case of flood and assuming a flow velocity of 3-4 fps, then the time lag will be between 22-27 hours, or approximately one day. This means that the flow recorded at either gaging station 7-1955 and 7-1960 on a certain day will be recorded at station 7-1965 the succeeding day. Floods occurring during the overlapping period of record at station 7-1955 and 7-1960 was then compared to the corresponding floods at station 7-1965 and the flows are reported as percent of the flow at station 7-1965. The floods compared, their duration, and magnitude of the peak flow are reported in Table 8.

Plotting any of the preceeding flood waves at station 7-1955 and 7-1960 as percent of the flood wave at station 7-1965 for floods above 12,700 cfs, (the marginal flood) the graph was invariably the same for all floods and is illustrated in figure 4. Floods less than 12,700 cfs behaved a little differently as will be explained later.

In any river basin it is to be expected that the flow contribution per square mile of tributary area over the entire

Table -8-

Floods at Station 1955, 1960, and 1965

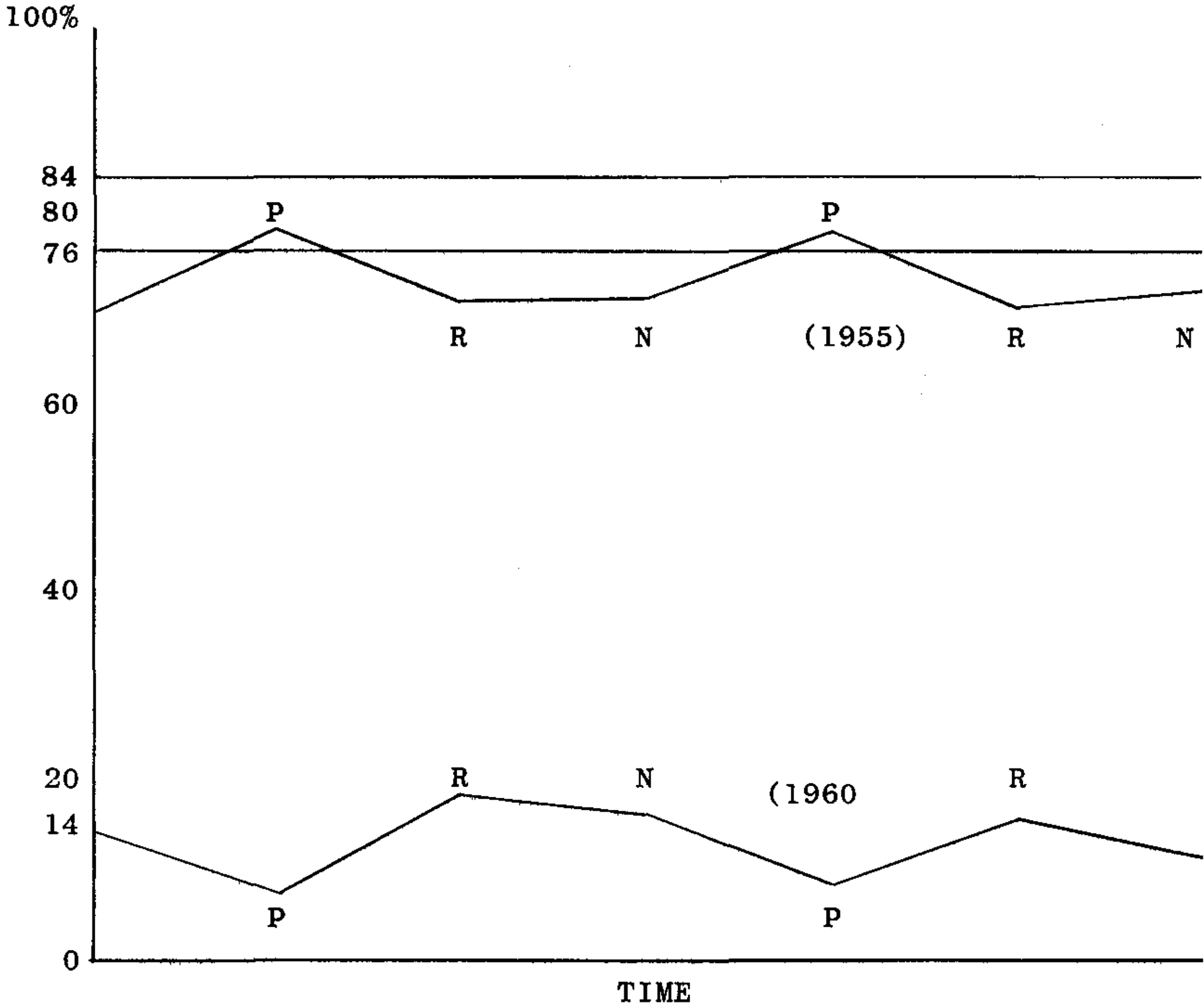
Duration, Days	Peak Flow, cfs		
	1955	1960	1965
Apr. 1-16, 1957	22,800	2,830	26,500
May 16-21, 1957	11,300	2,630	18,000
May 21-June 1, 1957	20,100	4,290	31,200
June 3-9, 1957	8,110	908	12,700
June 9-18, 1957	6,570	1,350	10,200
July 6-19, 1958	13,600	3,960	22,000
May 4-10, 1960	14,400	4,000	18,600
May 18-21, 1960	5,430	1,690	6,450
July 24,31, 1960	23,700	460	23,200
May 4-15, 1961	33,400	4,320	42,000

Figure -4-

Floods

Station 7-1955 & 7-1960

to Station 7-1965



P = Peak

R = Recess

N = Normal

basin is the same and this holds true for the Illinois River Basin under normal flow conditions. However, in case of floods, our study shows that the response of the basin depends upon the basin morphology and the length of the channel draining the basin. To evaluate the effect of the length of channel draining the basin, it is necessary to introduce an important parameter and that is the ratio of the length of channel to the tributary area of the basin. The value of this parameter for station 7-1955 is .46, for station 7-1960 is .50, and for station 7-1965 is .41. During floods, the flows at any station compared to the flows at another station will be proportional to the ratio of the tributary areas of both stations multiplied by the responective ratios of channel to tributary area of both stations. To further illustrate, the ratio of tributary area of station 7-1955 to station 7-1965 is 0.66, the ratio of length of channel to tributary area for station 7-1955 is .46 and that for station 7-1965 is .41. Then in comparing flood flows at station 7-1955 to flood flows at station 7-1965, the expected ratio of the flows should be .66 x .46/.41 = .14.

The behavior of flood waves depends on the relative magnitude of flows passing by each gaging station. For floods of larger magnitude than the marginal flood (12,700 cfs), the behavior was such that at the peak of the flood, a greater contribution (greater that the respective ratio fo drainage area) is provided from flows at station 7-1955 is increasing while that from station 7-1960 is decreasing. And after the peak, the contribution from station 7-1955 is decreasing while that of station 7-1960 is increasing. The range through which the percentages oscillated for station 7-1955 was between 65 and 80 percent. It was felt that at the peak station 7-1955 contributes most of the flow since it drains a larger area than does station 7-1960. This large volume of flow took the greatest portion of the channel capacity and increased the water level in the channel and caused the retardation of the flood flow from station 7-1960, thus causing lower flow to be drained and accounting for the low percentages. It is also felt that this is particularly true because station 7-1955 is on the main channel while station 6-1960 is on a tributary which facilitates the direct draining of flows at station 7-1955. After the peak subsides, flows from station 7-1960 increase due to the now available capacity of the channel and due to the extra flow that was kept in storage while the greater portion of the flow was passing through the channel.

To help explain the higher percentage contribution than the respective percentage of drainage areas, it is of interest to show again in a tabular form the morphology of the Illinois River Basin, its tributary areas, the length of channel draining each area and the ratios as compared to station 7-1965.

It is found that the morphology of the basin affects the response to high flows in such a fashion that the contribution from station 7-1955 is not directly proportional to the ratio of drainage areas multiplied by the ratio of the length of channel per square mile of both tributary areas. In other words, at times of high flows, the contribution is a function of the flows

Table -9-

Station	7-1955	Ratio to 65	7-1960	Ratio to 65	7-1965
Tributary Area, Sq. mi.	635	.66	110	.115	959
Length of Channel, mi.	290		55		390
L/T Ratio	.46		.50		.41

per square mile of tributary area multiplied by a factor which reflects the ratios of the length of the channel per square mile of tributary area.

The summation of flood flows at station 7-1955 and 7-1960 constitutes about 86 percent of the flood flows at station 7-1965. This percentage is arrived at in a similar fashion to the percentages derived for the individual station, i.e., the ratio of tributary areas multiplied by the ratio of length of channel to its tributary area for each station. In this case the tributary area of both stations (7-1955 and 7-1960) is 745 square mile, and that of station 7-1964 is 959 square mile or a ratio of .78. The length of channel draining both stations is 345 mile or a ratio of .46 and the length of channel draining station 7-1965 is 390 mile or a ratio of .41. Thus the ratio of flood contribution of both station 7-1955 and 7-1960 to station 7-1965 is $.68 \times \frac{.46}{.41} = .86$.

As a result, in synthesizing the missing flood flows at stations 7-1955 and 7-1960 from available flood flows at station 7-1965, the maximum flow at both stations is around 86 percent and the minimum is around 74 percent and the flows are divided among the stations according to the flood peak and to the prinicpals discussed earlier.

For floods under 12,700 cfs in magnitude it was found that the contribution of flows from station 7-1960 are high, in the vicinity of 58 percent. The reason for such behavior lies probably in the immediate and fast response to high flows from small tributary areas while large tributary areas tend to attenuate the peak of such flood. Another reason may lie in the fact that station

7-1960 lies on a creek with a smaller cross section than the cross section of the main channel thus creating higher flow velocities and immediate drainage of floods of relatively small magnitude.

5. Flood Synthesis at Station 7-1970 from Station 7-1965

Station 7-1970 was put in operation on Barren Fork, in 1948, and this provides a period of 17 years of overlapping records when compared to station 7-1965 on the mainstream Illinois River. The tributary area of station 7-1970 is 307 square miles or 32 percent of the tributary area of station 7-1965, and the length of the channel draining this area is approximately 150 miles yielding a ratio of length of channel to tributary area of about .49. The morphology of the basin is such that it contains numerous short arteries draining into the main channel at almost equal intervals thus forming a physical shape similar to the backbone of a fish, a situation that invites extremely fast and immediate response to high flows and flood flows.

To determine the time lag between station 7-1970 and 7-1965, based on an average velocity of 3-4 fps, it was found that flows at the farthest point on the basin contributing to station 7-1965 take 20 to 27 hours more to reach the gaging station than flows on the farthest point on the basin tributary to station 7-1970. In other words, during a flood, the flows recorded at station 7-1970 in any one day were corresponding to the flows recorded at station 7-1965 the succeeding day, i.e., there is a lag time of approximately one day.

The floods occurring in the overlapping period that were compared for purposes of cross correlation are presented in table 10 together with the ratio of the peaks and duration of the flood.

The correlation of the daily flows for these floods is illustrated in figure 5. There is a marked difference in the response to floods lower than the marginal flood (in our case 12,700 cfs, flood of one year return period in the partial duration series), and floods higher than the marginal flood. The ratio of the flows before the peak of the flood was more or less the same as the ratio of the tributary areas, i.e., .32. The ratio after the peak was much higher and varied between .38 and .45. This reflects the effect of the morphology of both basins and the faster response a small basin has to the higher flows. It is also important to notice that the average ratio of flow after the peak of 41 percent is equal to the basin tributary areas ratio of .32 multiplied by the ratio of length of the channel draining the small basin to its tributary area (.49) divided by the ratio of length of the channel draining the large basin to its tributary area (.41). In other words the average ratio of flow contribution after the flood is equal to $.32 \text{ X } \frac{.49}{.40} = .40$.

The value of the flood peak at station 7-1965 will determine if the flow at station 7-1970 is less than 30 percent or higher than 55 percent. If the flood peak at station 7-1965 is less than the marginal flood (13,00 cfs), the ratio of the flow at station 7-1970 is usually as large as 60 percent. If the flood peak at station 7-1965 is larger than the marginal flood, the ratio of the flow at station 7-1970 is usually as small as 20 percent. This is further evidence of the effect of the basin morphology on the

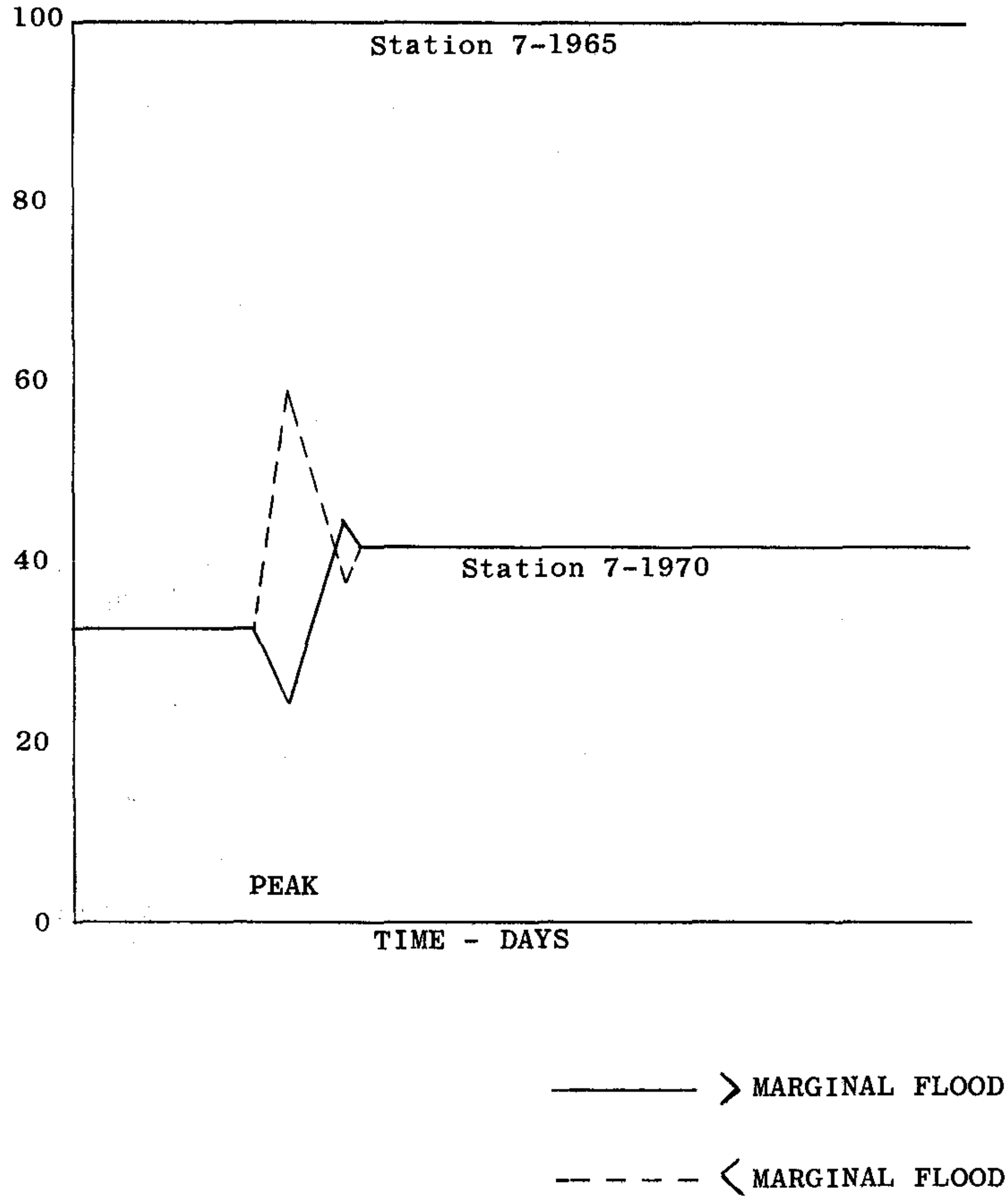
Table -10-

Cross Correlation of Floods at Station 7-1970 to Station 7-1965

Water Year	Date	Peak flow Station 1970 cfs	Peak Flow Station 1965	Ratio of Peak Flows
49-50	May 10,11	22,500	90.400	24.8%
50-51	Feb. 20,21	13,800	31.400	44.0%
53-54	May 2,3	9,730	13,000	74.8%
54-55	Mar. 20,21	4,780	6,930	68.9%
55-56	May 15,16	3,050	5,700	53.5%
56-57	Apr. 3,4	16,100	36,500	44.1%
57-58	July 13,14	7,970	22,000	36.1%
58-59	July 23,24	4,700	8,900	52.8%
60-61	May 7,8	12,500	42,000	29.8%
64-65	Apr. 6,7	4,780	11,000	43.4%

Figure -5-

Floods of Station 7-1970 to 7-1965



high flows. In case of floods less than the marginal flood, the small basin with the higher ratio of length of channel to square mile of drainage area responds much faster and carries the flood peak without much attenuation or delay of the peak, while the large basin flattens the peak and registers smaller peaks, so that the ratio of the peaks become greater. Also in case of floods of small magnitude, the channel capacity is not exceeded and no hindrance of flow is likely to occur at the confluence of the channels.

In case of floods of greater magnitude than the marginal flood, the flows of the Illinois River where station 7-1965 is located are so great and have such high velocities that they will soon reach the confluence of the two streams (6 miles downstream) and hinder the flows coming from Barren Fork (where station 7-1970 is located) and cause retardation of the flow and storage of the flow in the small basin until the peak had subsided and the channel capacity can handle the flows from the small basin.

6. Drought Studies

The hydrograph of mean monthly flows at station 1965 showed the presence of four periods of low flows or droughts. These periods are

October, 1935 - August, 1937

March, 1938 - November, 1940

April, 1955 - May, 1957

October, 1963 - May, 1965

A mass diagram was plotted for these periods shown in figure 6. A constant hypothetical demand of 300,000 acre feet was exerted

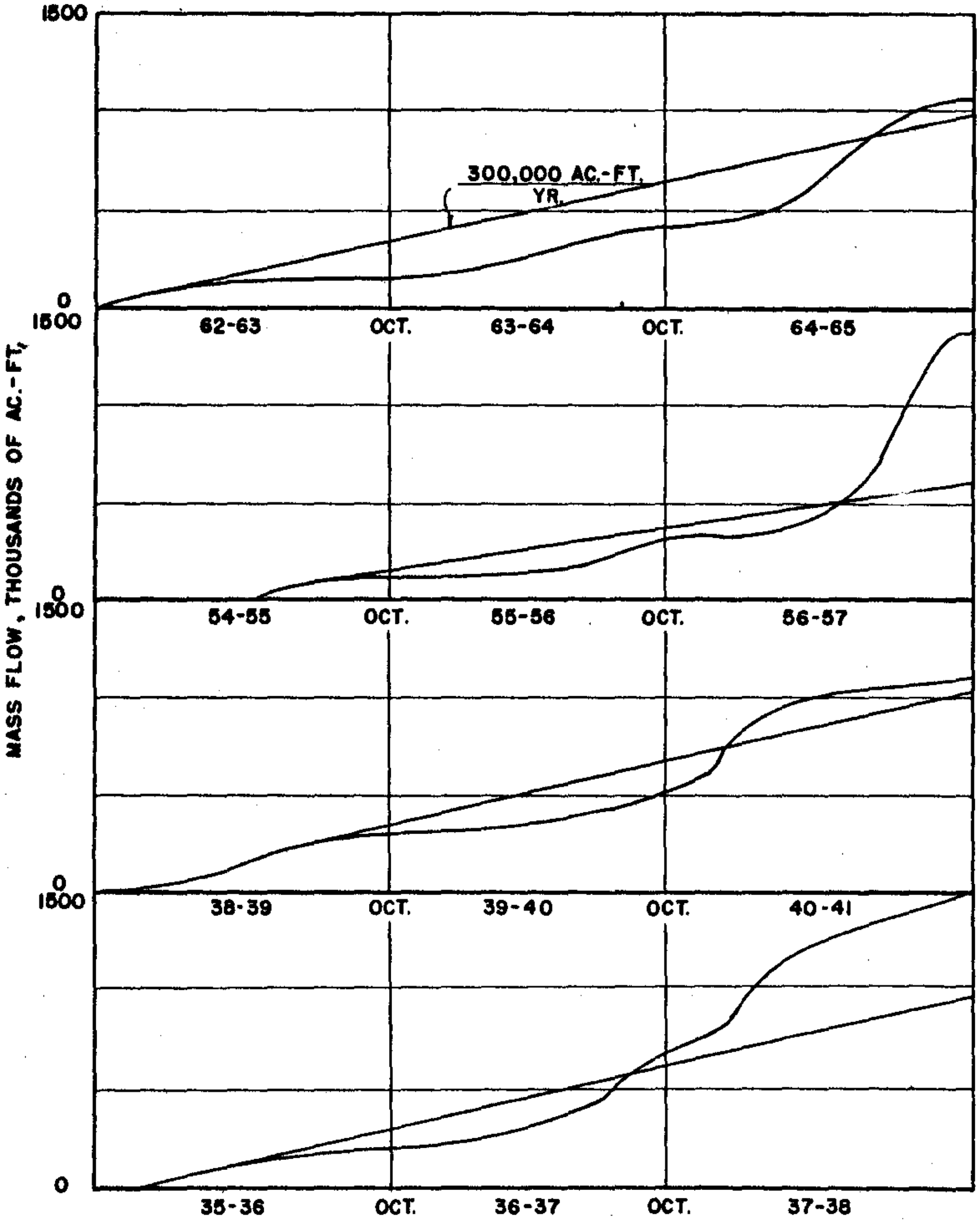


Fig. 6
Mass Curves on Illinois River

on the system. This demand showed that the drought period of April, 1955 to October, 1957 and October, 1962 to May, 1965 were the most severe and would have needed a reservoir capacity of 300,000 acre feet to handle such drought.

7. <u>Flood Routing - Tenkiller Ferry Reservoir</u>

The capacity of the Tenkiller Ferry Reservoir for flood control is approximately 600,000 acre feet. This capacity is stored between elevations 630.0 and 667.0 M.S.L. (Mean Sea Level). The surcharge storage lies between elevations 667.0 and 671.0 M.S.L. whereby the gates are raised one half a foot at a time. If the flood stage exceeds elevation 671.0 M.S.L., then the gates are thrown wide open. The downstream releases are governed by the channel capacity at this site, which is 16,000 cfs. The reservoir also operates in conjunction with Keystone, Oolagah, Eufaula, Fort Gibson, and Wister Reservoirs to assure that releases from these reservoirs added to the local inflow would not exceed 150,000 cfs at Van Buren, Arkansas.

When the reservoir elevation is below 630.0 M.S.L., the flows to the reservoir are diverted to the power pool which has a capacity of 630,000 acre feet.

The Tenkiller Ferry Reservoir was put in operation in the year 1952. The floods routed prior to 1952, their magnitudes and peaks compared to the channel capacity at station 1965 are shown in table 11. It is to be noted that the flood peaks are approximately $\frac{1}{2}$, 1, $1\frac{1}{2}$, and 3 times the channel capacity as well as the maximum flood of record.

Flood routing before 1952 served to determine the local inflow between stations 1965, 1970, and 1980 as well as to check the applicability of the chosen method of flood routing.

Table -11-

Floods Routed on the Illinois River

Prior to 1952

Date of Peak	Peak at Sta 1965 cfs	Ratio of Peak to Channel Capacity at Station 1965
April 26, 1947	3,840	0.49
Feb. 14, 1950	7,980	1.01
Feb. 16, 1949	13,300	1.68
Nov. 1, 1941	25,000	3.16
May 11, 1950	30,400	11.44

Routing Method

The method proposed by Wisler and Prater for flood routing was best suited for the available records on the Illinois River. Based on daily mean flows and rising flow hydrographs at both upstream and downstream ends of a reach, the local inflow hydrograph could be computed. The continuity equation used to derive the local inflow is as follows:

$$I^1 = \frac{(2S_2 + 0_1 + 0_2) - (2S_1 + I_1 + I_2)}{2}$$

Where I^1 = Local Inflow

S_1 = Storage on first day

S_2 = Storage on second day

I_1 = Inflow on first day

I_2 = Inflow on second day

0_1 = Outflow on first day

0_2 = Outflow on second day

Floods were routed from station 1955, 1960 to station 1965, then from station 1965 and 1970 to station 1980. After the reservoir was put in operation in 1952, it was possible to study the effect of the reservoir on floods of similar magnitude to those occurring prior to 1952.

8. Routing a Flood of 13,300 cfs - Station 1955, 1960 to Station 1965

The flood peak is about 1.68 the channel capacity at station 1965. The combined inflow from station 1955 and 1960 is plotted as the inflow hydrograph (I). The flow recorded at station 1965 is plotted as the outflow hydrograph (0). Table 12 shows the values of inflow and outflow during the flood.

Assuming a certain base flow, the inflow storage above base flow for the last day of the flood is determined and so on until the storage at the peak of the flood is also determined. The outflow storage is computed in a similar manner as those of the inflow storage.

Local storage is found by subtracting inflow storage from outflow storage and relationship was established between local storage and relationship was established between local storage and corresponding inflows and outflows.

For each daily value of inflow, outflow and storage the daily local inflows can be calculated using the continuity equation. The routing method is shown in figure 7.

9. Routing from Station 1965 and 1970 to Station 1980

The previous flood is also utilized in this case, the peak observed at station 1980 was 16,200 cfs due to peaks of 13,300 and 3,325 cfs at station 1965 and 1970 respectively. The routing method is reported to table 13 and shown in figure 8, using the same procedure described earlier.

Table -12-

Flood of February 16, 1949, at station 1965 from stations 1955 & 1960

(1) Day	(2) I	(3) O	(4) (I+O)	(5) SI	(6) So	(7) SI^1	(8) I^1	(9) O^1
0	725	700	1,425	---	---	7.0	77.5	777.5
1	1,164	907	2,071	---	---	67.0	263.0	988.0
2	5,854	1,420	7,274	---	---	1,170.0	500.0	1,664.0
3	11,438	6,970	13,408	7,224.0	18,723.0	11,499.0	1,400.0	7,254.0
4	4,410	13,300	17,710	2,954.5	8,318.0	5,363.5	1,607.0	13,135.0
5	2,899	5,150	8,049	1,878.5	3,368.0	1,489.5	997.0	5,407.0
6	2,258	3,400	5,658	1,333.5	2,123.0	789.5	684.0	3,583.0
7	1,809	2,660	4,469	1,016.5	1,493.0	476.5	608.0	2,417.0
8	1,624	2,140	3,764	827.5	1,128.0	300.5	406.0	2,215.0
9	1,441	1,930	3,371	713.5	913.0	204.5	378.0	2,002.0
10	1,386	1,720	3,106	612.5	783.0	171.0	355.0	1,796.0
11	1,238	1,660	2,898	510.5	668.0	157.5	287.0	1,673.0
12	1,183	1,490	2,673	472.5	553.0	80.5	114.0	1,352.0
13	1,162	1,430	2,592	406.5	313.0	-93.0	530.0	1,713.0
14	1,150	1,410	2,460	315.5	438.0	123.0	782.0	1,944.0
15	980	1,280	2,260	258.0	333.0	75.0	274.0	1,324.0
16	936	1,200	2,136	201.0	268.0	67.0	274.0	1,254.0
17	866	1,150	2,016	136.0	203.0	67.0	251.0	1,187.0
18	806	1,070	1,876	84.0	128.0	44.0	231.0	1,097.0
19	762	1,000	1,762	43.5	67.5	24.0	216.0	1,022.0
20	725	949	1,674	12.5	21.0	8.5	207.0	969.0
21	700	907	1,607	0.0	0.0	0.0	200.0	925.0

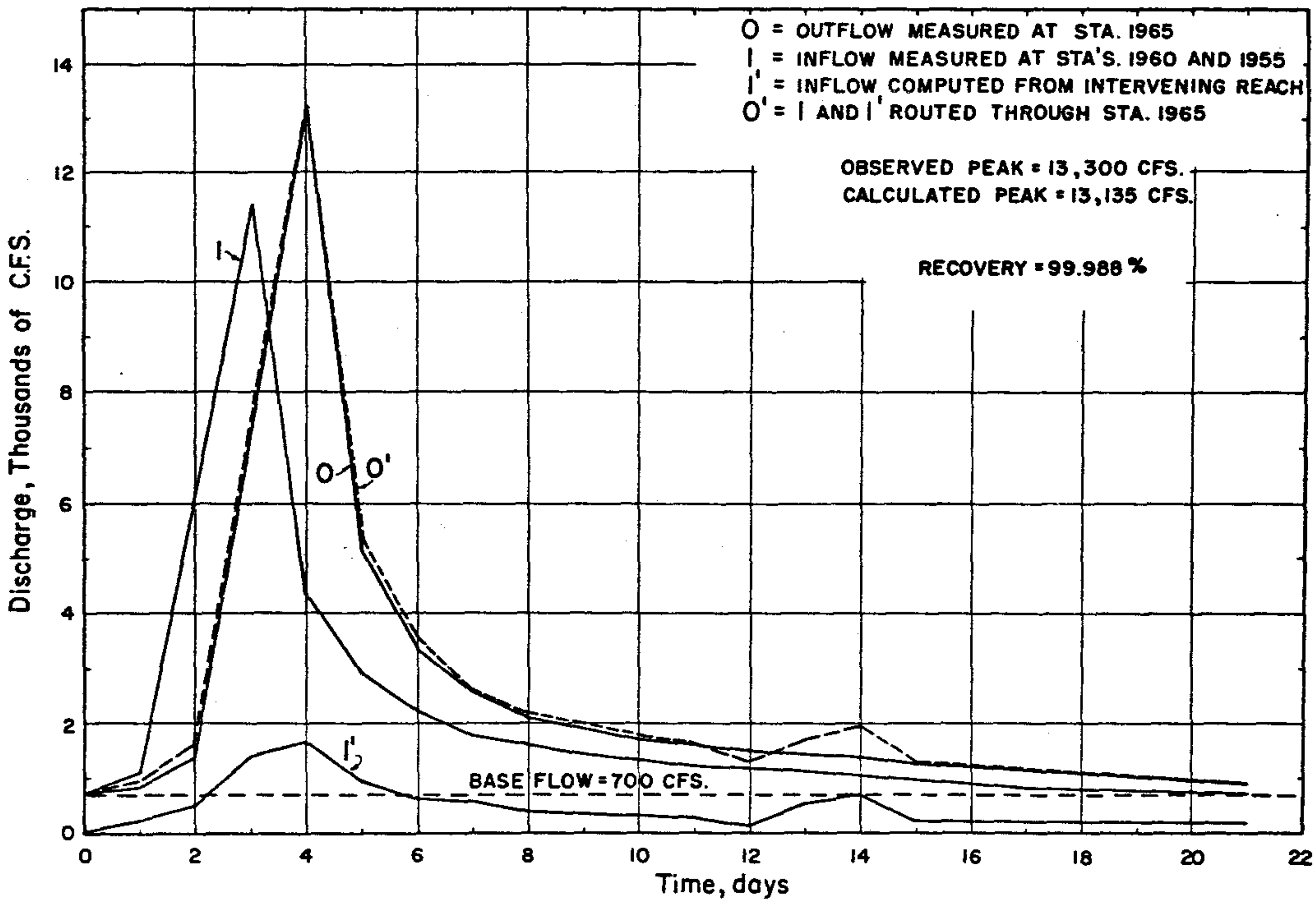


Fig. 7
Routing from Sta 1955 & 1960 to Sta 1965

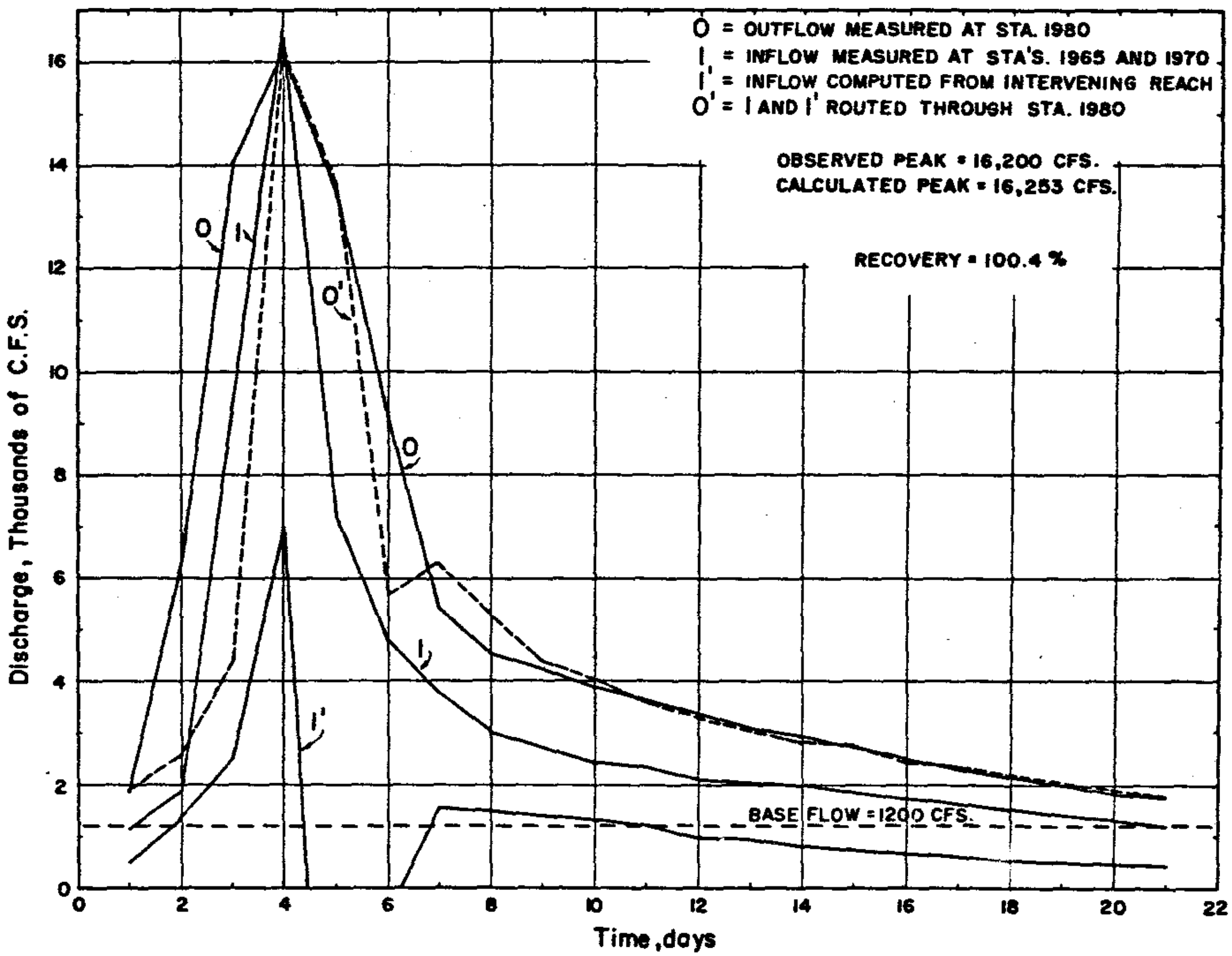


Fig. 8 Routing from Sta 1965 & 1970 to Sta 1980

Prior to 1952

The flood of May 3, 1954, had an estimated peak at station 1980 of 22,158 cfs; however, the actual flow recorded was 270 cfs, a dampening factor of 0.99. On the other hand, the flood of July 26, 1960, had an estimated peak at station 1980 of 33,330 cfs and an actual flow of 9,240 cfs, yielding a dampening factor of 0.72. Table 15 contains information on the reservior effect with respect to floods of varying magnitude.

Table -15-

Dampening Effect of Tenkiller Ferry Reservior

on Selected Floods

Flood	Routed Peak Station 1980 cfs	Actual Flow Station 1980 cfs	Dampening Factor
June 15, 1961	3,699	3,540	.04
May 4, 1958	12,679	12,400	.02
May 3, 1954	22,158	280	0.99
July 26, 1960	33,330	9,240	0.72

It is to be noted that the channel capacity at station 1980 is approximately 16,000 cfs.

C. SPAVINAW CREEK SUBBASIN

1. Description

A map showing the location of the Spavinaw Creek Subbasin in relation to Oklahoma and Arkansas is presented in Figure 10.

Spavinaw Creek originates in northestern Arkansas and flows westward into Oklahoma. The major tributaries draining into Spavinaw Creek are Beauty Creek and Cloud Creek. Near the confluence with Beauty Creek, Spavinaw Creek flows in a westerly direction into Eucha (Upper Spavinaw)Reservior. About three miles after leaving Eucha Reservior, Spavinaw Creek flows into Spavinaw Lake. Spavinaw Lake drains into Lake Hudson location on the Grand (Neosho) River. From Lake Hudson, the Grand River flows through the Fort Gibson Reservoir to the Arkansas River.

The entire drainage area of the Spavinaw Creek Subbasin is 400 square miles. Approximately 64 percent of the drainage area lies in Oklahoma and the remaining 36 precent lies in Arkansas.

There is only one gaging station, station 7-1912, hereafter called station 12, located on Spavinaw Creek. This station is located near Sycamore, Oklahoma, and is about two miles from the Oklahoma-Arkansas line. The drainage area above the station is 133 square miles and the period of record for the station is from October, 1961 to present.

2. Synthesis of Missing Data for Station 7-1912 - Synthesis of Mean Monthly Flows

The selection of the method for synthesizing the missing data was complicated by the short period of record available for station 12 for comparison with the flow records of adjacent gaging stations. Because of this short period of record, it was difficult to establish trends or patterns common to the gaging stations that would permit using correlation methods for synthesis of the missing flow data for the base period (1935-1965). It is also to be noted that, judging by adjacent stations, the period 1962-1965 was a very dry period and it represents one of the critical droughts encountered during the period of record.

The flow data for station 12 for the years of record available were compared with the flow data of stations 7-1890, 7-1910 at Big Cabin Creek, Oklahoma, 7-1920 at Pryor Creek, Oklahoma, 7-1950 at Osage Creek, Arkansas, and 7-1960 at Flint Creek, Oklahoma, (hereafter called station 90, station 10, station 20, station 50, and station 60 respectively). The mean monthly flows for these stations were plotted on the same graph as compared to the flows of station 12. A study of this graph showed that the flow data of station 50 and station 60 compare favorably with the pattern of flows of station 12. The flow data of station 90, station 10, and station 20 did not follow the same general pattern as station 12. This was suspected since station 10 and station 20 are located far enough west of station 12 so as to fall in a significantly different rainfall-intensity area; moreover, station 90 has a drainage area of 848 square miles as compared to 133 square miles for station 12. Station 10 and station 20 have drainage areas of 466 square miles and 229 square miles respectively, and these areas are significantly larger than the drainage area of station 12.

The following two factors are offered as to why the flow patters of station 50 and station 60 are similar to that of station 12:

1. The drainage areas of station 50 and station 60 are 129 square miles and 110 square miles respectively, and thus are comparable in size to the drainage area of station 12 which is 133 square miles.
2. The drainage areas of station 50 and station 60 are adjacent to area of station 12 and all of the areas are in the same rainfall-intensity area. Also, since the areas are adjacent, the land slopes and land cover and probably the runoff is similar for these three areas.

Synthesis of Station 12 from Station 60 and Station 60

For station 50 flow data were available for the period October, 1951 - September 1965 while for station 60 flow data were available for the period October 1955 - September, 1965. For the years of the base period prior to these data, the missing flow data for station 50 and station 60 were synthesized from station 7-1965.

Period of October, 1955 - September, 1960

For flows less than 250 cfs (the channel capacity) the mean monthly flows for station 12 were computed as the average of the flow of station 50 times the ratio of drainage areas of station 12 to station 50 and the flow of station 60 times the ratio of the drainage areas of station 12 to station 60. The ratio of the drainage areas of station 12 to station 50 is 1.03 and the ratio for station 12 and station 60 is 1.21. Thus, Q12 = (Q50)(1.03) + (Q60)(1.21) /2, where the Q's are the flows of the respective stations.

For flows greater than 250 cfs (high flows and flood flows) a study of the flows for the overlapping period showed that the flow data for station 12 could be determined using the flow data of station 50 along rather than station 50 and station 60 together. Thus, the flows greater than 250 cfs, the flows of station 12 was computed as the flow of station 50 times the drainage area ratio of station 12 to station 50 times the ratio of the total tributary lengths of station 50 to station 12. This equation is Q12 = (Q 50)(1.03) (50/55) or Q12 = (Q50)(0.93). The synthesized flow data for station 12 and the flow data for station 50 and station 60 are presented in the Appendix.

Period of October, 1951 - September, 1955

For this period no flow data were available for station 60 but flow data were available for station 50. Therefore, the missing data for station 12 for this period were synthesized from flow data of station 50. For flows less than 250 cfs the flows for station 12 were computed as the flow of station 50 times the drainage area ratio of station 12 to station 50 or, Q12 = (Q50)(1.03). The same procedure as described in the preceding paragraph was used to compute the flow when the flow was greater than 250 cfs. The synthesized flow data for station 12 and the flow data for station 50 are presented in the Appendix.

Period of October, 1935 - September, 1950

The synthesized data of station 60 were used to compute the mean monthly flows for station 12 for this period. Comparing the mean monthly flows for station 12 and station 60 for the years of overlapping records, October, 1960 - September, 1965. It was found that the flows of station 60 were usually greater than the flows of station 12. However, the difference in flows of station 12 and station 60 was not constant, but varied from month to month throughout the year. Therefore, it was decided that the missing flow data should be synthesized on a monthly basis instead of using the same multiplying factor for the entire year. To determine the multiplying factor for each month, the average of the ratios of the mean monthly flows of station 12 to station 60 was found at each month for the overlapping period of record. The multiplying factor is then: Average of Sum (Q12/Q60) for years 1960 - 1965.

These values for the corresponding months are:

Month	Multiplying Factor
October	0.74
November	0.68
December	0.65
January	0.66
February	0.69
March	0.85
April	0.85
May	0.88
June	0.95
July	1.12
August	0.51
September	0.66

Thus, the mean monthly flows for station 12 were computed as the mean monthly flow of station 60 times the appropriate multiplying factor.

3. Flood Studies on Spavinaw Creek

A study of flood flows of stations 1912, 1950, and 1960 was made to attempt to define a method of synthesizing the missing flood flows for station 1912 for the base period (1938 - 1965). For the overlapping period of record, the mean daily flood flows of station 1912 were compared with the mean daily flood flows of stations 1950 and 1960. The ratios of mean daily flows of station 1912 to station 1950 and station 1912 to station 1960 were studied for all floods occurring during the overlapping period of record. These ratios were very erratic and varied greatly, and it was decided that these ratios in themselves could not be used for synthesizing the missing flood flows for station 1912. Next these flood flow ratios were compared with the average ratios of the mean monthly flows for station 1912 to 1950 and station 1912 to station 1960 for the overlapping period of record. Again no apparent correlations was found in these comparisions to use for synthesizing the missing flood flows for station 1912. Another method of attempting to relate watershed areas to the flood flow ratios proved fruitless.

The inability to develop a feasible method of synthesizing the missing flood flows for station 1912 from stations 1950 and 1960 was probably due in part to the short period of overlapping flow data available (1960 - 1965, 6 years). Another important factor was that during this period, the rainfall in this study area was substantially below normal for all of the years of record. Only four floods occurred during the six year period, and at least two of these floods were rather small.

Because of these considerations the missing flood flows for station 1912 were not synthesized for the base period. This should not cause undue concern since it is not expected that the Spavinaw Creek subbasin would have a significant influence on the hydrology of that protion of the Arkansas River basin under study. The Spavinaw Creek subbasin is the smallest subbasin in the study area; and the flow from the subbasin drains through two reservoirs in the subbasin itself, empties into Lake Hudson on the Grand (Neosho) River, from Lake Hudson down the Grand River through the Fort Gibson Reservoir and on to the Arkansas River. By the time the flows from the Spavinaw Creek subbasin traverse this route any characteristics attributable to the subbasin itself will have been diminished and any direct contribution due to the subbasin would probably be insignificant.

However, due to the proximity of location of both station 1912 and station 1960, it is reasonable to assume that flood flows at both stations are similar.

Flood flows for station 1960 had been determined in the Illinois River basin study, thus there is no reason to repeat this procedure for the Spavinaw Creek.

4. Mass Curves

Mass curves were plotted for the actual and synthesized mean monthly flows of the Spavinaw Creek. A hypothetical demand curve was exerted on the system to illustrate the degree of severity of different droughts and to establish the capacity needed for a reservoir if such similar droughts are to reoccur in the future. The results of this study are shown in figure 11.

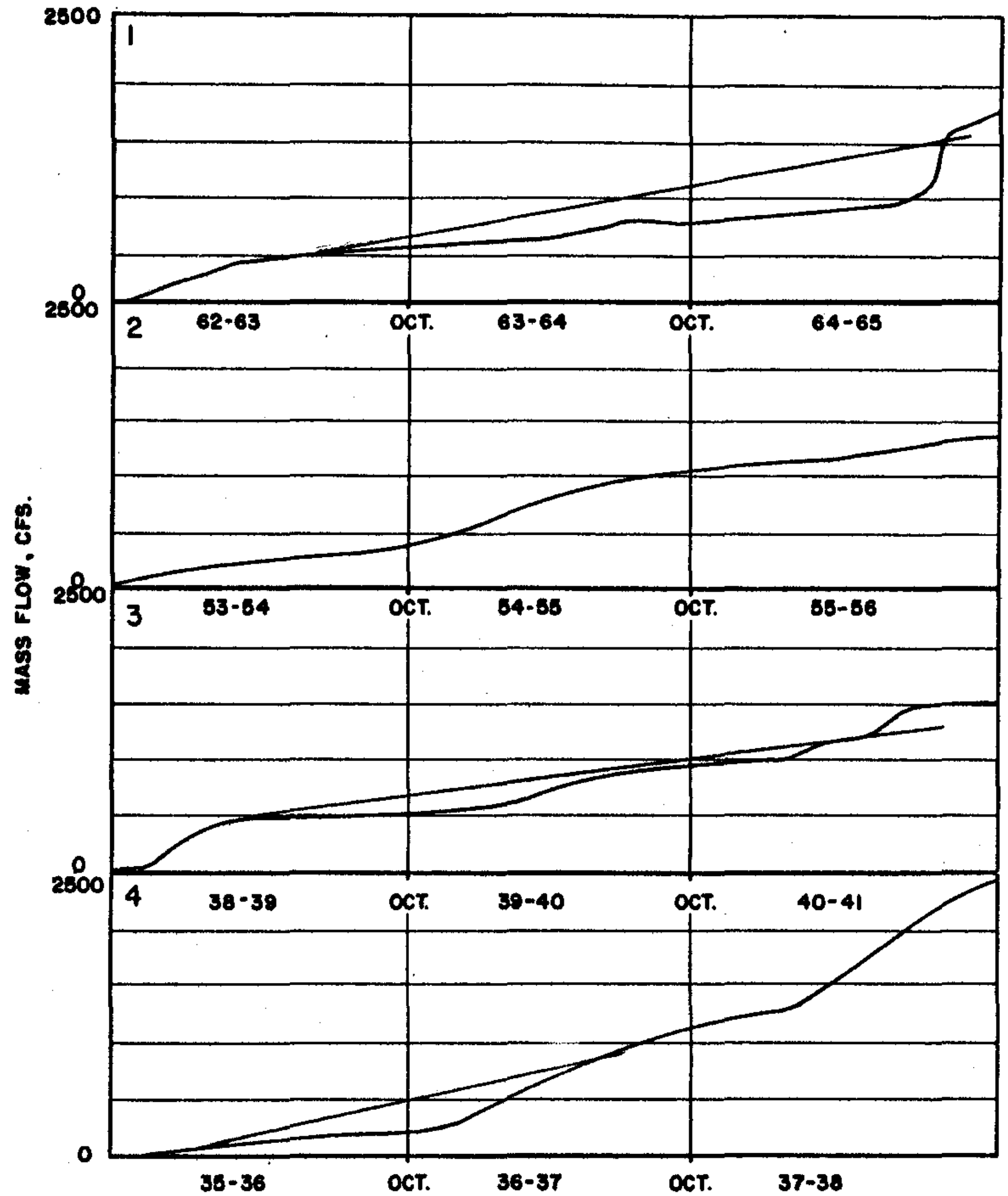


Fig. 11. Mass Curves on Spavinaw Creek

D. LEE CREEK

1. Description

Lee Creek subbasin originates in northwestern Arkansas as Fall Creek and Mountain Creek. Fall Creek and Mountain Creek drain the northern portion of the subbasin and join to form the Lee Creek a few miles east of the Arkansas-Oklahoma State Line. Lee Creek proceeds into Oklahoma and joins with another creek draining the western portion of the subbasin. The general direction of the flow in Lee Creek is southerly and it joins the Arkansas River near Van Buren, Arkansas. A detailed map of Lee Creek is shown in Figure 12. The entire drainage area of Lee Creek is approximately 450 square miles, of which 45 percent is in Oklahoma and the rest is in Arkansas.

The gaging stations on Lee Creek are station 2495 located on Cove Creek, Arkansas. The drainage area tributary to this station is 36.9 square miles, and the period of record extends from May, 1950 to the present.

Another gaging station on Lee Creek is station 2500 located on Lee Creek at the state line border. The drainage area tributary to this station is 430 square miles, and the period of record covers the years 1930 - 1937 and 1950 to the present.

Table -16-

Gaging Stations on Lee Creek

Station No.	Location	Dr. Area	Period of Records
7-2495	Cove Creek, Arkansas	36.9	May, 50-Sept., 65
7-2500	Lee Creek, Van Buren, Arkansas	430	Sept. 30-June, 37 Oct., 50-Sept., 65

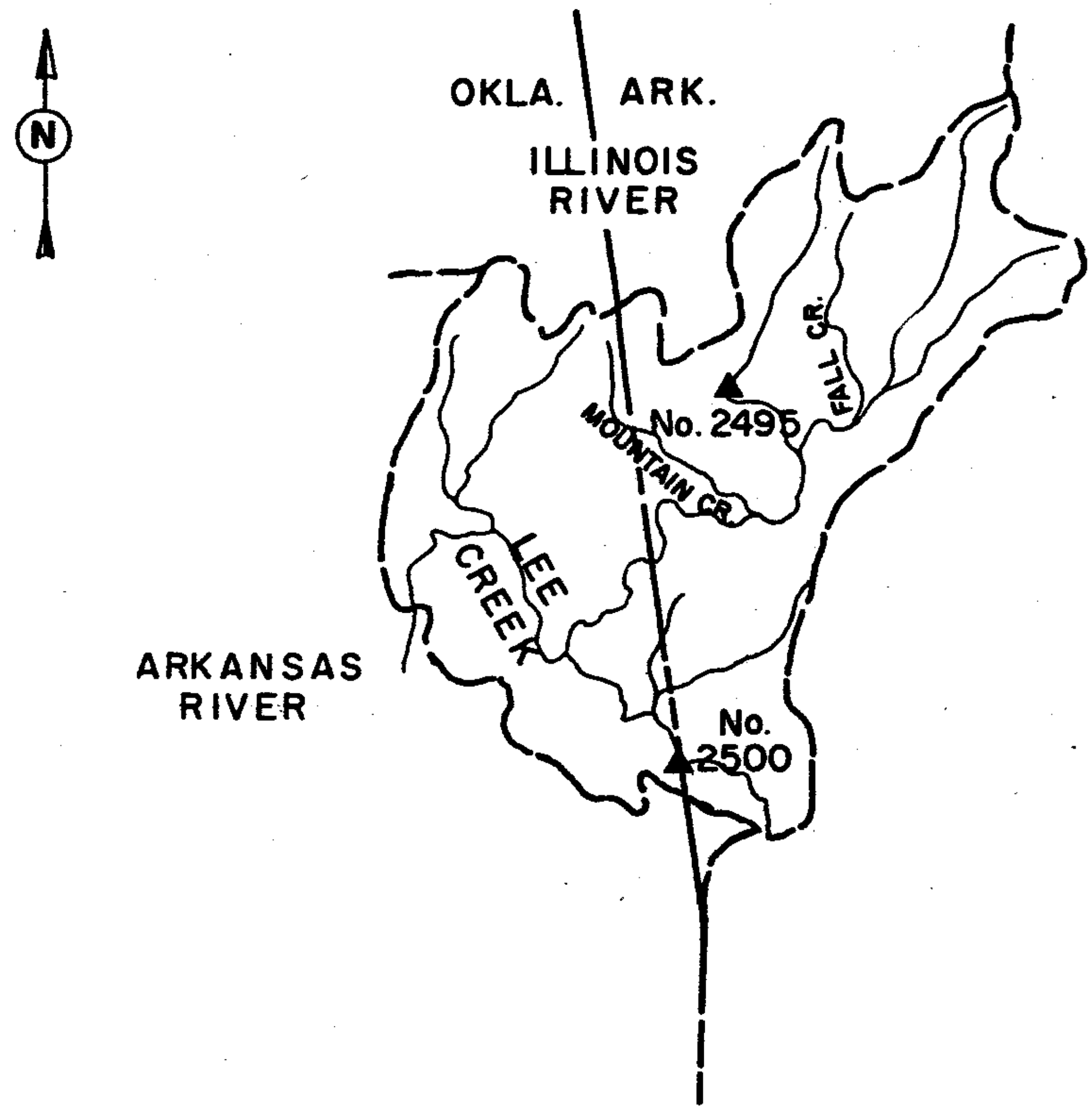


Fig 12

HYDROLOGY OF ARKANSAS RIVER
—LEE CREEK—
SCHOOL OF CIVIL ENGINEERING
OKLAHOMA STATE UNIVERSITY

2. Synthesis of Missing Data - Mean Monthly Flow

The missing flows at station 2500 cover the period of June, 1937 to September, 1950. Surrounding stations in adjacent basins to the Lee Creek are:

1. Station 2455 on Sallisaw Creek, having a drainage area of 181.0 square miles and records covering the period October, 1942 to the present.

2. Station 2515 on Frog Bayou, having a drainage area of 217.0 square miles and records covering the period May, 1950 to the present.

3. Station 2520 on Mulberry River, having a drainage area of 372.0 square miles and records covering the period May, 1930 to the present.

Station 2515 was dismissed from further consideration due to lack of actual records covering the selected base period and due to the fact that its tributary area is approximately one-half of the tributary area of station 2500.

When cross correlating the flows of station 2500 to station 2455 during the period of overlapping record the lack of good and acceptable correlation was evident as illustrated by a standard deviation exceeding 50 percent in dry months. This was possibly due to the noncompatibility of tributary areas since the tributary area of station 2500 is more than $2\frac{1}{2}$ times the tributary area of station 2455. It is also to be noted that the period of record at station 2455 does not cover the entire selected base period and thus station 2455 was dismissed from further consideration.

Station 2520 has records covering the selected base period, and its tributary area is 0.87 of the tributary area of station 2500.

Mean monthly flow records of station 2500 were correlated to flows of station 2520 over the period of overlapping record. Table 17 shows the results of the correlation.

Table -17-

Cross Correlation of Mean Monthly Flows

Station $\frac{2500}{2520}$ D. A. $\frac{427}{372}$

	Ratio			Ratio	
October	0.99	.85	April	0.88	.35
November	0.69	.37	May	1.02	.37
December	0.65	.36	June	1.35	.70
January	0.68	.30	July	1.40	.98
February	0.76	.30	August	1.23	.72
March	0.74	.26	September	.97	.57

From this correlation it is obvious that the runoff of station 2500 during the months November to April is less than that of station 2520 in the corresponding period in spite of the drainage area of station 2500 being larger than that of station 2520. It is felt that this is due to the fact that station 2520 is located about 25 miles to the east of station 2500 and is thus falling in a bigger rainfall intensity area causing higher runoff results.

The correlation factors were incorporated in a computer program, similar to the program developed for the Illinois River study, and using the actual data of station 2520 covering the years 1938 to 1950, the missing data of station 2500 were synthesized.

3. Flood Flows

Floods occurring during years 1950 to 1965 have been arranged in a maximum annual series. The magnitude of the mean flood was 13,390 cfs, and the standard deviation was 9600 cfs. Table 18 shows the maximum annual series floods.

Table -18-

Maximum Annual Series Floods

Water Year	Flood, cfs	Water Year	Flood, cfs
50 - 51	13,200	58 - 59	11,400
51 - 52	9,600	59 - 60	36,200
52 - 53	9.510	60 - 61	19,500
53 - 54	8,280	61 - 62	7,910
54 - 55	10,600	62 - 63	4,010
55 - 56	5,860	63 - 64	11,600
56 - 57	33,000	63 - 64	5,330
57 - 58	17,900		

This series shows that the highest flood of 36,200 cfs has a return period of 16 years. Checking these floods by using the mean flood, the standard deviation and Gumbel's coefficient, the 15 year flood has a peak of 33,690 cfs and the 20 year flood has a peak of 36,570 cfs.

Analyzing the floods of station 2500, using the partial duration series, the flood of one year return period was 9510 cfs. Table 19 shows floods and their return periods using the partial duration series.

Table -19-

Floods on Station 2500 - Partial Duration Series

Date	Flood Peak cfs	Return Period years
March 18, 1953	9,510	1.0
March 5, 1959	11,400	2.0
May 5, 1961	19,500	4.0
April 3, 1957	33,000	8.0
May 6, 1960	36,200	16.0

Floods occurring on station 2520 were then arranged in a maximum annual series covering the period of 1938 - 1935. This series resulted in a mean flood of 10,600 cfs and a standard deviation of 5,825 cfs. Using Gumbel's factors in conjunction with the mean flood and standard deviation of this series, the 25 year flood has a peak of 25,900 cfs, the 30 year flood has a peak of 27,100, and the actual 28 year flood from the series has a peak of 26,500. These results are in very close agreement.

Analyzing these floods, using the partial duration series, the one year flood was 9,260 cfs. Table 20 shows the flood peaks and return periods as derived by the partial duration series.

Table -20-

Flood Peaks and Return Periods, Station 2520

Date	Flood Peak dfs	Return Period Years
May 6, 1960	9,260	1.0
January 4, 1950	12,500	2.0
May 10, 1943	18,000	4.0
June 10, 1945	21,300	7.0
January 24, 1949	26,300	14.0
April 15, 1948	26,500	28.0

Synthesis of Flood During Missing Period of Record on Station 2500

Floods occurring during the period of overlapping records (1950 - 1965) were compared. In flood comparison the daily flows are utilized, and it was found that the peak of the flood occurred approximately one day earlier at station 2500 than at station 2520. Since station 2520 is 25 miles to the east of station 2500 and since the normal storm systems move easterly on this basin, the delay in registering the flood peak at station 2520 could be understood. A sample of the floods compared, their peaks and data of occurrence are shown in Table 21.

Table -21-

Sample of Floods Compared of Stations 2500 and 2520

Date	Peak 2500	Peak 2520
February 12-28, 1951	13,200	14,500
March 9-20, 1951	2,110	1,120
April 19-25, 1951	1,990	2,560
March 9-15, 1952	6,090	8,590
April 9-19, 1952	9,600	9,240
May 22-26, 1952	3,980	4,990
February 18-24, 1955	10,600	9,380
April 2-11, 1957	33,000	13,400
June 8-17, 1957	11,000	7,020

The graphical comparison of most of these floods was favorable as shown in Figure 13.

For flood durations in excess of five days, the ratio of flood flows at station 2500 to station 2520 was more or less 0.8. Ratios of floods of less than five days duration varied greatly and no general pattern could be established.

This criteria was then used to synthesize daily flood flows for station 2500 from records of station 2520 during the years 1938 to 1950. The floods synthesized during this period are given in Table 22, and the results are presented in the Appendix.

Table -22-

Floods Synthesized for Station 2500 - 1938 to 1950

Date	Peak 2520	Date	Peak 2520	Date	Peak 2520
Feb.20, 39	4,560	Apr.9, 44	6,260	Jan.1, 48	9,210
Apr.17, 39	8,300	June 13, 44	8,220	Feb.27, 48	6,300
Apr.11, 40	5,740	Feb.21, 45	21,800	Jan.24, 49	26,300
Apr.29, 40	5,200	Mar.19, 45	15,200	May 1, 49	19,200
Dec.16, 40	2,010	Mar.30, 45	26,500	Jan. 4, 50	4,980
Jan.24, 41	4,490	Apr.15, 45	26,500	Jan. 4. 50	12,500
Oct.31, 41	9,810	May 16, 45	8,620	Feb.12, 50	11,700
Apr. 8, 42	8,240	June 10, 45	21,300	May 11, 50	12,800
Apr.12,43	3,600	Feb.13, 46	11,900	July 23, 50	4,400
May 10, 43	18,000	May 25, 46	11,000	Aug. 6, 50	4,050
Feb.28, 44	4,030	Dec.12, 46	15,300	Sep.16, 50	4,940
Mar.16, 44	5,510	May 20, 47	9,490		

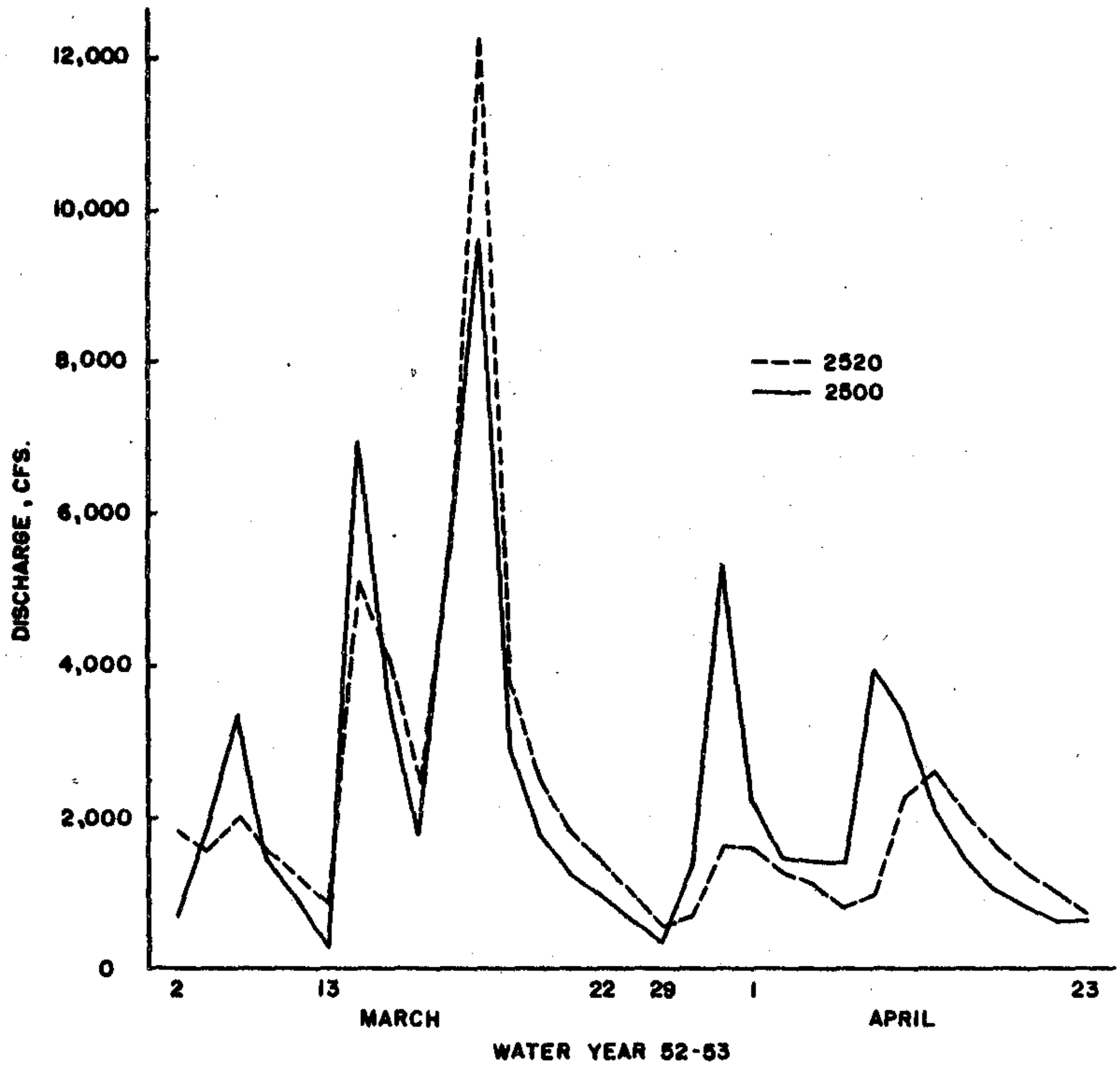


Fig 13. Flood Hydrograph Comparison

4. Mass Curves

The actual records of Lee Creek are used to compare and evaluate the droughts that occurred in the 1930's with droughts of more recent dates and to assess which droughts were of a more severe nature.

Mass curves were plotted for the mean monthly flows covering the period 1930 to 1965 and a hypothetical demand was exerted on this basin to establish the period of most severe drought during the entire record. The mass curves are shown in Figure 14, and it could be shown that the drought of June, 1953 - May, 1954 was the most severe during the period of record.

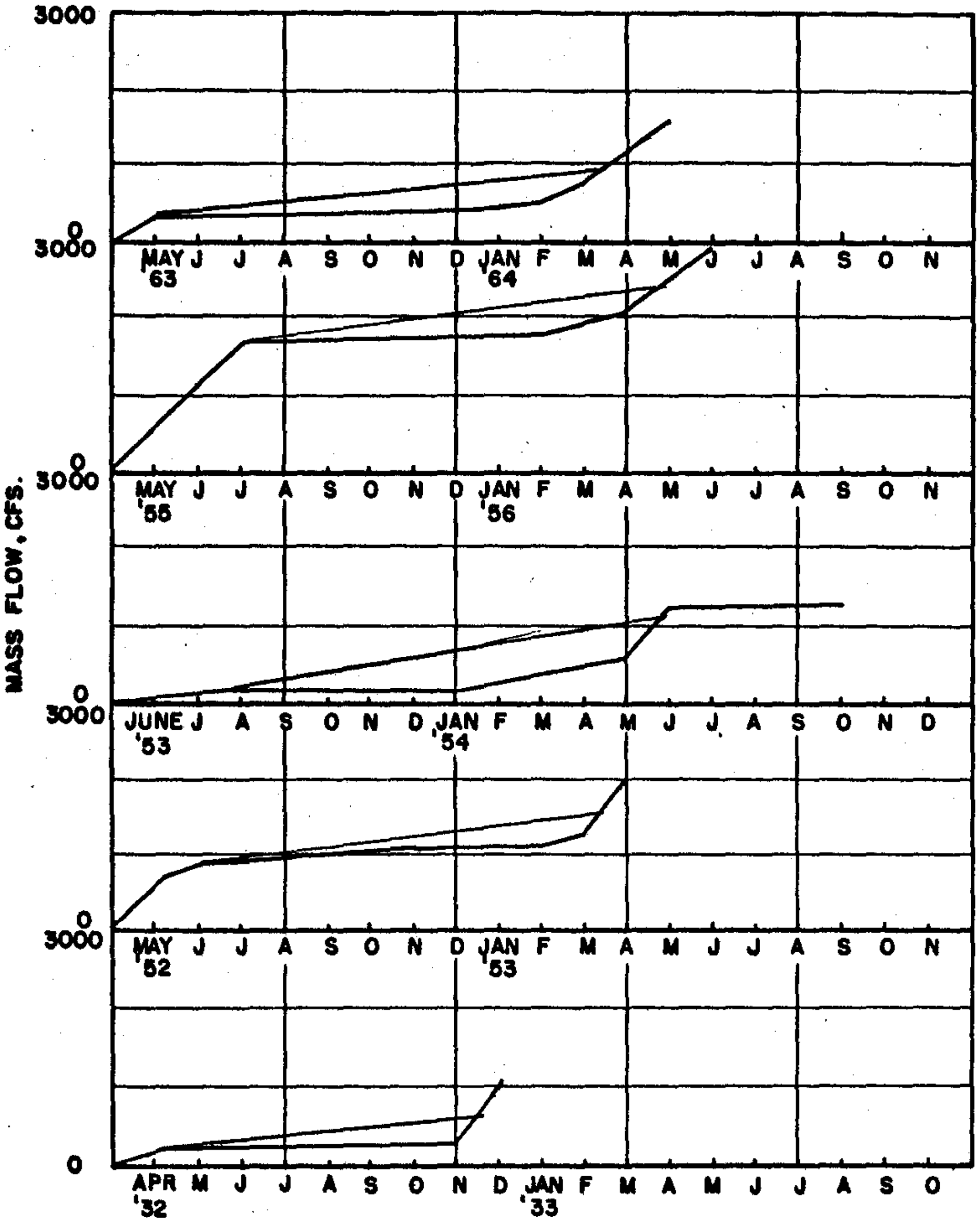


Fig 14. Mass Curves on Lee Creek

E. POTEAU RIVER SUBBASIN

1. Description

The Poteau River originates in Western Arkansas, flows westward crossing the Oklahoma - Arkansas line and continues in a westerly direction to its junction with the Fourche Maline. The river turns abruptly and flows in a northeasterly direction to its confluence with the Arkansas River at Fort Smith, Arkansas. The Poteau River is approximately triangular in shape (Figure 15) and has a tributary area of 1,888 square miles. The drainage area is generally mountainous and varies from elevation 460 feet to 2,250 feet above MSL. The stream slope varies from 25 feet/mile in the upper reaches to 0.3 feet/mile in the lower reaches. The tributaries to the Poteau River are the Fourche Maline with a drainage area of 411 square miles, and the James Fork with a drainage area of 201 square miles.

The Poteau River falls in a rainfall intensity area of roughly 44.0 inches/year distributed more or less uniformly during the year with an average minimum rainfall of 2.68 inches in December and an average maximum of 5.59 inches in May.

2. Gaging Stations

The gaging stations located on the Poteau River and its tributaries, their numbers, locations, drainage areas, and periods of record are shown in Table 23.

Table -23-

Gaging Stations on Poteau River and Tributaries

Station Number	Location	Drainage area Sq. Mile.	Period of record
7-2470	Poteau River, Cauthron, Oklahoma	198	Feb. 39 - Sept., 65
7-2475	Fourche Maline, Red Oak, Oklahoma	121	March, 39 - Sept., 65
7-2485	Poteau River, Wister, Oklahoma	1015	May, 38 - Sept., 65

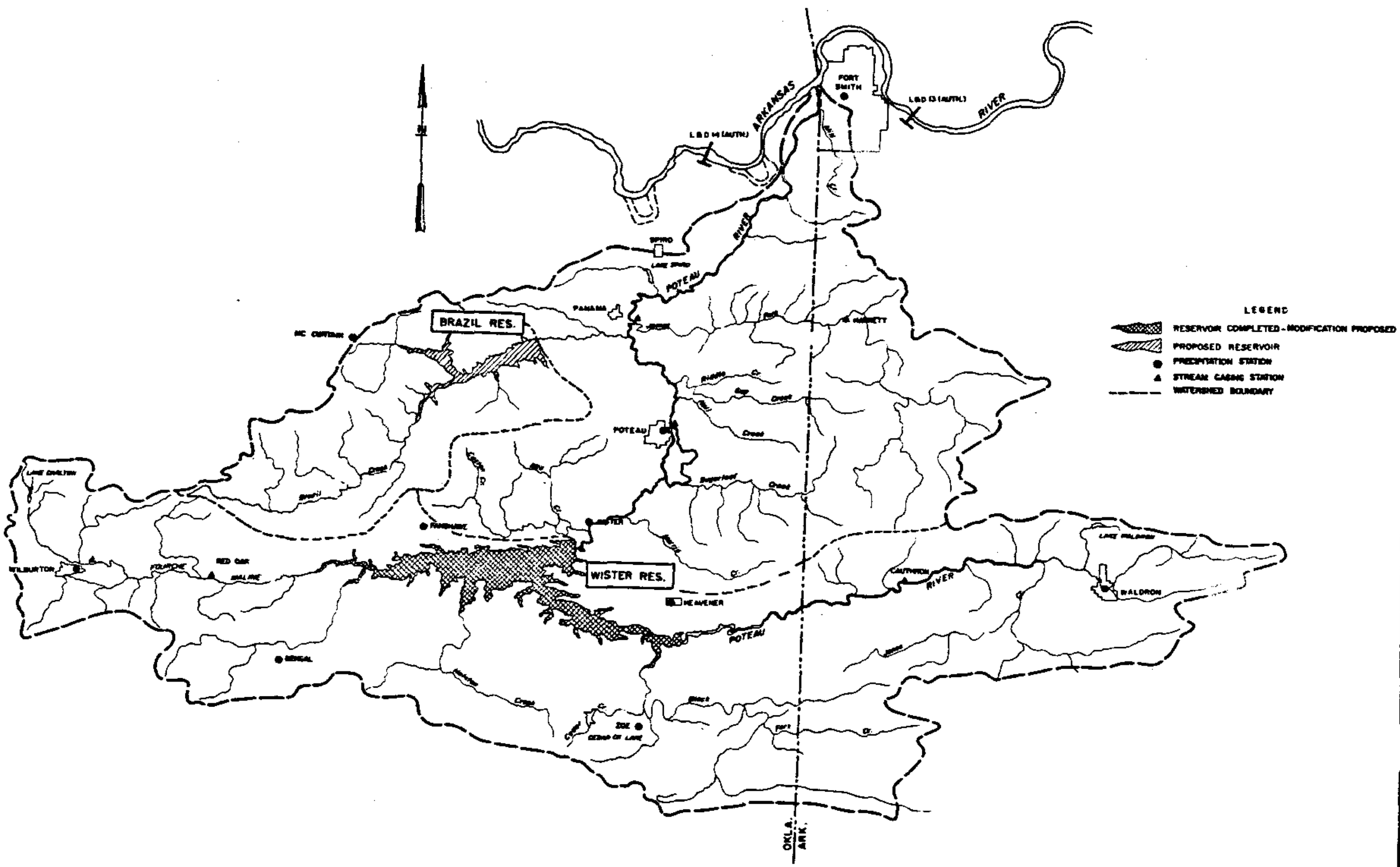

BRAZIL RES.
WISTER RES.
ARKANSAS
RIVER
POTEAU
RIVER
POTEAU
FORT SMITH
POTEAU
WALDRON
OKLA.
ARK.
LEGEND
RESERVOIR COMPLETED - MODIFICATION PROPOSED
PROPOSED RESERVOIR
PRECIPITATION STATION
STREAM GAGING STATION
WATERSHED BOUNDARY

Figure 15

The three gaging stations located in Oklahoma have records covering the selected base period for this study and thus no synthesis of missing data was necessary. However, Wister Reservoir, located immediately upstream of Station 2485, was put in operation in October, 1949, and as a result the flows registered at Station 2485 since that time are not the natural flows but rather reflect the effects of regulation and operation policies of the Wister Reservoir.

3. Flow Transformation

There exists about 11 years of natural flow records at station 2485 prior to the completion of Wister Reservoir. These records were used jointly with the corresponding 11 years at stations 2470 and 2475 to establish monthly coefficients for every month of the year by applying the continuity equation. For example:

For December, 1942, the flow at station 2485 - Q_{85} - was 2,158 cfs

the flow at station 2470 - Q_{70} - was 170 cfs

and the flow at station 2475 - Q_{75} - was 461 cfs

$$Q_{85} = K(Q_{70} + Q_{75}) \text{ or } 2158 = K(170 + 461)$$

resulting in a K value of 3.43 for December of 1942. This procedure was repeated for the entire 11 years of natural records at station 2485, resulting in a K value for each month. The mean K value for each month was averaged over the 11 years and these values are reported in Table 24.

Table -24-

K Values for Flow Transformation at Station 2485

	K		K
October	2.82	April	2.78
November	4.28	May	3.79
December	3.14	June	4.33
January	4.12	July	3.50
February	3.42	August	2.79
March	3.60	September	5.52

Using the K values, just derived, and the natural flows at stations 2470 and 2475, the most probably natural flows at station 2485 are calculated. This natural flow is the flow that would have been recorded at station 2485 had the Wister Reservoir not been built. The natural flow at station 2485 (years 1938 - 1949) plus the transformed flows (years 1949 - 1965) are presented in Table 25.

4. Mass Curves

Mass curve for the Poteau River at station 2485 covering the period of record is shown in Figure 16, after Wister Reservoir was built, the mass curve reflects the degree of regulation imposed upon the stream. Dry periods occurred in 1939 - 1940, 1948 - 1949, and 1955 - 1957.

Table -25-

Unregulated and Synthesized Flow-cfs.
Station 2485 Poteau River

Actual Flow						
1938	0	49	52	138	2736	682
1939	6939	385	260	71	30	1
	2	14	30	35	238	114
1940	1728	492	192	109	247	48
	5	326	993	1699	2479	766
1941	2151	864	402	53	29	143
	1358	2032	1154	893	1589	1709
1942	4726	1465	528	265	64	173
	25	884	2158	319	169	1221
1943	1243	6830	708	43	1	2
	190	96	308	1076	3443	3547
1944	1744	3024	1314	36	65	43
	14	71	613	374	6657	10860
1945	3661	6226	7115	790	317	1648
	1458	244	137	2876	3616	540
1946	2184	5543	2119	237	28	0
	1	4522	4687	516	146	675
1947	3585	3537	465	17	163	417
	70	159	1436	2482	3141	2564
1948	1073	1241	86	72	251	17
Synthesized						
	16	107	389	8825	3977	1998
1949	1081	1940	2173	77	0	44
	149	51	345	6662	5194	399
1950	699	4540	623	4070	1049	4675
	90	29	21	263	4370	964
1951	1103	795	2762	619	58	143
	259	2157	803	1573	506	2610
1952	6376	492	164	7	0	11
	0	2062	850	1157	742	5263
1953	6796	3664	25	689	25	5
	8	17	53	1392	694	100
1954	502	2201	25	7	0	0
	194	55	891	704	1771	3830
1955	1236	280	51	3	16	77
	59	0	0	4	1761	309
1956	192	310	17	21	0	0
	0	21	339	1462	1706	2559
1957	10784	6253	3403	21	789	1567
	56	2495	599	1470	642	3744
1958	2294	4896	1991	787	471	237
	76	1001	204	358	417	2653
1959	1731	1489	69	556	47	132
	1001	445	2329	2739	1361	1584
1960	313	10828	194	1816	318	27
	22	51	1664	887	1398	2779
1961	1134	2046	502	1956	136	320
	152	2906	1874	2381	1710	1537
1962	2037	197	225	486	33	436
	829	1134	436	374	71	1188
1963	710	280	51	3	0	0
	0	0	0	0	47	1468
1964	1436	1129	17	0	583	921
	64	1450	307	947	3129	2131
1965	604	2383	1052	101	25	1556

F. MAINSTEM, ARKANSAS RIVER

1. General

Only stations 2455 and 2465 has records less than the selected base period and thus needed synthesis of missing records. Station 2455 lacked four years of record, and it was decided not to synthesize these missing years due to the small tributary area that this station drains in comparison to other stations on the mainstem.

Station 2465 lacked ten years of record, and the missing flows were synthesized from station 2505 using the cross correlation approach. The ratios used in the synthesis and their standard deviation were excellent due to the 18 years of overlapping record and to the proximity of the drainage areas. These ratios are presented in Table 26.

Table -26-

Cross Correlation of Mean Monthly Flows

Station 2465 to 2505

Drainage Areas 147,757/150,483

Month	%		Month	%	
October	94.7	9.55	April	85.2	9.79
November	90.8	8.63	May	89.4	9.93
December	86.3	10.22	June	95.8	5.65
January	81.7	11.97	July	96.8	4.11
February	80.5	13.83	August	95.5	6.36
March	80.9	13.41	September	96.5	6.02

It is to be noticed that the ratio during the wet season (December - May) was lower than that during the dry season because most of the drainage area lies in Western Oklahoma with average rainfall much less than Eastern Oklahoma. In other words, the intervening area between the two stations (about 3,000 square miles) falls in a much higher rainfall intensity area than the rest of the drainage area, and this factor accounts for the low ratios during the wet months.

A comparison was than made of the flows at station 2465 with the summation of flows from stations 2450, 1980, and 1945 during the period of the study. It was found that the mean ratio of the sum of the flows was 94.8% of the flows at station 2465 with a standard deviation of 3.75%. This difference of about 5% would be contributed by the influent tributaries extending the mainstream between the confluence of the Canadian and Arkansas Rivers and station 2465. However, as the standard of accuracy of the records available is of the order of ∓ 5%, it was felt that little could be gained by more detailed consideration of these tributaries and accordingly synthesis was not carried out on Station 2455, for the missing record of five years at the beginning of the base period.

2. Mass Curves

Mass curves were plotted for selected gaging stations using the mean monthly flows at each station. These mass curves help to illustrate the periodicity of high flows and low flows over the period of available records.

Isolating the low flow periods and imposing a hypothetical rate of demand, either constant or variable, gives an indication of the need for storage and the volume of such needed storage. Figure 17 shows mass curve for a selected dry period on Station 2505, located near the state line on the Arkansas River.

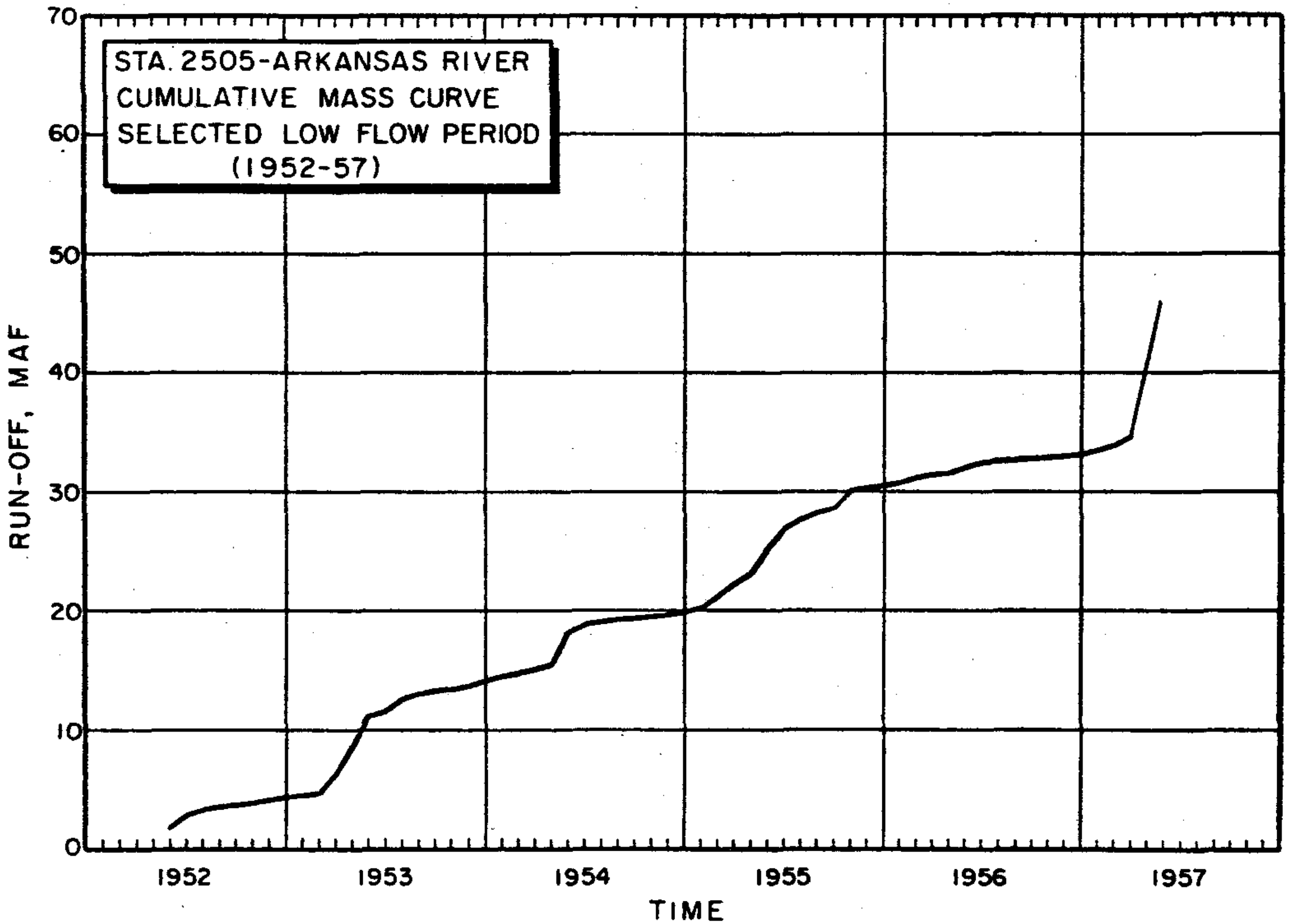


Figure 17 Mass Curve For Dry Period In 1950's

G. RESERVOIRS IN THE STUDY AREA

This section of the report is intended to deal with the reserviors within the study area as well as the reservoirs adjacent to the study area but play an important role upon the flows entering the study area due to regulation and operation policies. The reservoirs in the study area are Eucha Reservoir and Lake Hudson on the Spavinaw Creek, Webbers Fall lock and dam on the Arkansas River, Tenkiller Ferry Reservoir on the Illinois River, and Wister Reservoir on the Poteau River. Reservoirs adjacent to the study area are Fort Gibson Reservoir on the Neosho River, Oologah Reservoir on the Verdigris River, Keystone Reservoir on the Arkansas River, and Eufaula Reservoir on the Canadian River.

1. Lake Hudson

The drainage area contributing to this reservoir is 11,534 square miles. The reservoir is formed by earth dam and gated concrete spillway.

Storage began November 12, 1963, and power pool stage was reached on June 12, 1964. At the top of the taintor gates (elevation 636.0 feet above MSL) the capacity of the reservoir is 444,500 acft, at the top of the weir crest (elevation 599.0 feet) the capacity of the reservoir is 48,630 acft. The reservoir was designed for flood control and power development.

2. Fort Gibson Reservoir

The drainage area contributing to the Fort Gibson Reservoir is 12,492 square miles. The reservior is formed by a concrete-gravity and earth-fill dam. Regulated storage began

September 5, 1949. The capacity of the reservoir at elevation 582.0 (flood control pool) is 1,284,000 acft. This reservoir was designed for flood control and power development.

3. Tenkiller Ferry Reservoir

The drainage area contributing to the Tenkiller Ferry Reservoir is 1910 square miles. The reservoir is formed by an earth dam. The spillway consists of 590 feet concrete modified ogee weir controlled by ten taintor gates. Water is conducted to two hydroelectric turbines through tunnels in the abutment. Regulation started in July, 1952, and minimum power-pool stage was reached in April 9, 1953. At flood control pool (elevation 667.0 feet) the capacity of the reservoir is 1,231,000 acft. At the spillway crest (elevation 642.0) the capacity is 791,900 acft. At maximum power pool (elevation 730.0) the storage is 728,700 acft. At conservation and minimum power pool (elevation 594.5) the capacity is 283,100 acft. This reservoir was designed for flood control and power development.

4. Oologah Reservoir

The drainage area contributing to this reservoir is 4,330 square miles. The reservoir is formed by an earth dam with concrete outlet structure and emergency spillway. Regulated storage began May 15, 1963. At the crest of the uncontrolled spillway (elevation 651.0 feet) the reservoir capacity is 1,020,000 acft. At the conservation pool (elevation 608.0 feet) the capacity is 58,020 acft. There is a capacity of 9,260 acft. below elevation 592.0 feet for dead storage. This reservoir was designed for flood control and conservation.

5. Keystone Reservoir

The drainage area of Keystone Reservoir is 74,507 square miles of which 12,541 square miles is probably noncontributing. The reservoir is formed by rolled-fill earth dam. The spillway is concrete ogee weir controlled by 18 - 40 feet taintor gates. Outlet works consist of none sluices. Regulated storage began September 11, 1964. At the top of the flood control pool (elevation 754.0 feet) the reservoir capacity is 1,879,000 acft. At the top of the power pool (elevation 723.0) the capacity is 662,700 acft. At the crest of the controlled spillway (elevation 719.0 feet) the capacity is 563.000 acft. At conservation and minimum power pool (elevation 706.0 feet) the capacity is 311,800 acft. This reservoir was designed for flood control, power development and conservation.

6. Eufaula Reservoir

The drainage area of Eufaula Reservoir is 47,522 square miles of which 9700 square miles is probably noncontributing. The reservoir is formed by an earth dam having a gated, concrete, ogee type spillway weir controlled by 11 - 40 feet taintor gates. Regulated storage began February 10, 1964. At the top of the flood control pool (elevation 597.0 feet) the reservoir capacity is 3,844,000 acft. At the top of the power pool (elevation 585.0) the capacity is 2,376,000 acft. At minimum power pool level (elevation 565.0) the capacity is 897,000 acft. This reservoir was designed for flood control, sediment control, and power development.

7. <u>Wister Reservoir</u>

The drainage area contributing to Wister Reservoir is 993 square miles. The reservoir is formed by an earth dam. Regulation storage began on October 4, 1949. At the crest of the spillway (elevation 502.5 feet) the reservoir capacity is 429,600 acft. At the conservation pool (elevation 471.6) the capacity is 29,950 acft. The reservoir was designed for flood control and recreation.

H. STATE LINE FLOWS

To satisfy one of the goals of this study, namely the apportionment of flows between the states of Oklahoma and Arkansas, we have attempted to present the mean monthly flows at the state line for each subbasin for the duration of the selected base period.

For Spavinaw Creek Subbasin, the State Line flows were those flows, actual and synthesized, for station 1912. These flows are originating from Arkansas and flowing to Oklahoma.

For Illinois River Subbasin, the state line flows for the northern branch were those flows, actual and synthesized, for station 1955 plus one half the flows, actual and synthesized, for station 1960. For the southern branch, the state line flows were those flows, actual and synthesized, for station 1969. These flows also originate in Arkansas and flow to Oklahoma.

For Lee Creek Subbasin, the state line flows were considered as six-tenths of the flows, actual and synthesized, at station 2500. These flows originate in Arkansas and flow to Oklahoma.

For the Poteau River Subbasin, the state line flows were computed as 1.2 times the flow, at station 2470 as sized, at station 2494 as the northern branch. These flows originate Arkansas and flow to Oklahoma.

For the Mainstream, the state line flows were those flows recorded at station 2505. These flows are flowing from Oklahoma to Arkansas.

These mean monthly flows at the state line for the entire study area and covering the selected base period are exhibited in Appendix A.

I. FLOODS AND THEIR RETURN PERIODS IN THE STUDY AREA

Since the purpose of this study was the equitable apportionment of the waters of the Arkansas River and its tributaries between the states of Oklahoma and Arkansas, a very thorough and careful analysis of floods occurring during the selected base period was conducted, and the results of the analysis are presented in this section.

Floods at major gaging stations in the study area were arranged in a maximum annual series and their return periods were derived. These stations, their period of record and drainage areas are presented in Table 27.

Table -27-

Floods at Major Gaging Stations

Station		Drainage Area Sq. Mi.	Period of Record
1945	Arkansas River, Muskogee, Oklahoma	96,674	10/27-9/65
1965	Illinois River, Tahlequah, Oklahoma	959	4/35-9/65
1980	Illinois River, Gore, Oklahoma	1,626	4/39-9/65
2450	Canadian River, Whitefield, Oklahoma	47,576	7/38-9/65
2505	Sallisaw Creek, Sallisaw, Oklahoma	182	10/42-9/65
2500	Lee Creek, Van Buren, Arkansas	430	9/30-9/65
2505	Arkansas River, Van Buren, Arkansas	150,483	10/27-9/65

The return periods of floods at each station were derived using the formula

$$T = \frac{N + 1}{M}$$

Where T is the return period in years, N is the number of years of record, and M is the rank of the flood, with the annual flood of the highest magnitude assigned the rank 1, the second highest annual flood assigned the rank 2, and so on until each flood in the maximum annual series was ranked. Since the length of records in the study area is relatively short (between 23 and 38 years), floods of greatest magnitude at each gaging station was found to have an alarmingly short return period. This phenomenon is clearly illustrated in Table 28.

Table -28-

Flood Magnitudes and Their Return Periods on Selected Gaging Stations

Station	Flood Magnitude, cfs	Return Period, Years
1945	651,000	32
1965	90,400	30
1980	147,000	28
2450	239,000	28
2455	27,000	24
2500	36,200	36
2505	784,000	39

This approach for determining the return periods of floods based on short length of record appears to be questionable. Sound judgement and caution has to be exercised where dealing with short length of records. Table 29 shows that there is a 40 percent chance that the flood of 100 year return period will occur in any 50 years of record and a 22 percent chance that it will occur in any 25 years of record. This table also shows that there is a 36 percent chance that the 50 year return period flood will not occur in any 50 years of record. It is now apparent that the return periods of floods of great magnitude are, at least, incorrect.

The floods of great magnitudes affected the analysis in other ways as well. One of these ways was the fact that the flood at each gaging station was unstable in that it fluctuated from year to year depending on the value of the annual flood to be added to the record each year. The instability of the value of the mean annual flood

Table -29-

Probability that an Event of Given Recurrance Interval will be Equalled or Exceeded During Periods of Various Lengths[1]

PERIOD YR. / T_p, YR.	1	5	10	25	50	100
	PROBABILITY					
1	1.0	1.0	1.0	1.0	1.0	1.0
2	0.5	0.97	0.999	*	*	*
5	0.2	0.67	0.89	0.996	*	*
10	0.1	0.41	0.65	0.93	0.995	*
50	0.02	0.10	0.18	0.40	0.64	0.87
100	0.01	0.05	0.10	0.22	0.40	0.63

*Probability is unity for all practical purposes

[1]From Water - Resources Engineering by R. K. Linslay & J. B. Franzini, McGraw Hill Book Company, New York, 1964, p. 115.

affected the values of the standard deviation, the return period, as well as other statistical parameters of the gaging station.

To stabilized the value of the mean annual flood, preliminary frequency curves were plotted for each gaging station, Figure 18, and the mean annual flood was determined graphically as the flood of 2.33 year return period.

Computation of the standard deviation of floods at each gaging station was further simplified by use of the graphical mean annual flood, a stable value that does not fluctuate due to additional years added to the record.

To attempt to derive return periods for floods of great magnitude comparable to those return periods derived had the period of record been of much greater length, the return period of the flood with the greatest magnitude was calculated using the graphical mean annual flood the resulting standard deviation and an appropriate frequency factor from the theory of extreme values, Table 30. The flood with the greatest magnitude is then replaced with a flood having a return period of (N + 1) years, where N is the length of record in years. A new standard deviation is computed and the return period of the highest flood on record is computed using the graphical mean annual flood, the new standard deviation and a table of frequency factors. This concept was the back bone of a paper presented at the Forty-Ninth Annual Meeting of the American Geophysical Union, Hydrology Section, Washington, D. C., April 8 - 11, 1968. The summary of flood studies is presented in Table 31.

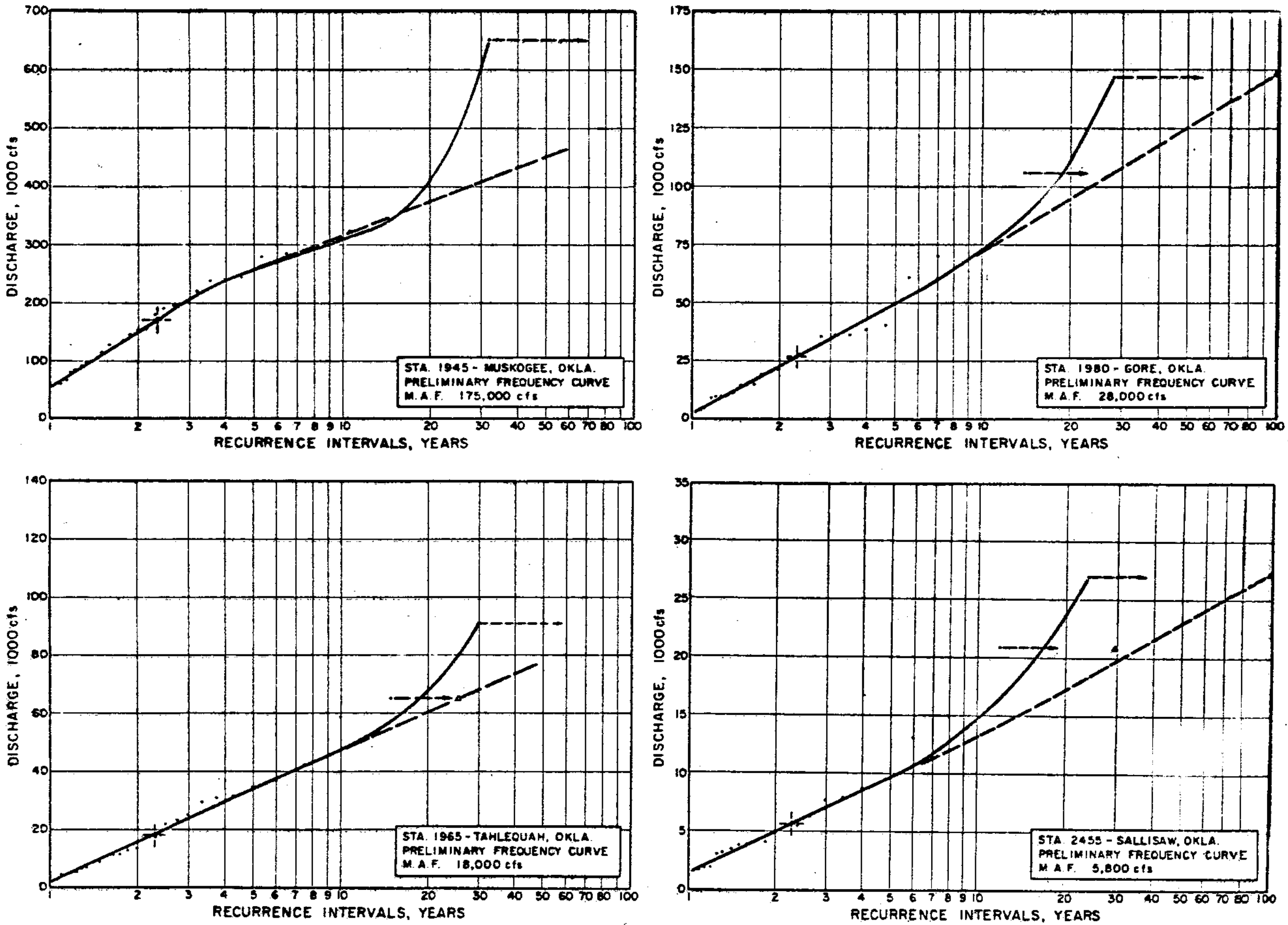


Figure 18 - Preliminary Frequency Curves

Table -30-

Frequency Factor K(T,n)

Sample size n	Return period T 5	10	15	20	25	30	50	60	75	100	1000
15	0.967	1.703	2.117	2.410	2.632	2.823	3.501	3.501	3.721	4.055	6.265
20	0.919	1.625	2.023	2.302	2.517	2.690	3.342	3.352	3.563	3.836	6.006
25	0.888	1.575	1.963	2.235	2.444	2.614	3.257	3.257	3.463	3.729	5.842
30	0.866	1.541	1.922	2.188	2.393	2.560	3.026	3.191	3.393	3.653	5.727
35	0.851	1.516	1.891	2.152	2.354	2.520	2.979	3.142	3.341	3.598	
40	0.838	1.495	1.866	2.126	2.326	2.489	2.943	3.104	3.301	3.554	5.576
45	0.829	1.478	1.847	2.104	2.303	2.464	2.913	3.078	3.268	3.520	
50	0,820	1.466	1.831	2.086	2.283	2.443	2.889	3.048	3.241	3.491	5.478
55	0.813	1.455	1.818	2.071	2.267	2.426	2.869	3.027	3.219	3.467	
60	0.807	1.446	1.806	2.059	2.253	2.411	2.852	3.008	3.200	3.446	
65	0.801	1.437	1.796	2.048	2.241	2.398	2.837	2.992	3.241	3.429	
70	0.797	1.430	1.788	2.038	2.230	2.387	2.834	2.979	3.219	3.413	5.359
75	0.692	1.423	1.780	2.029	2.220	2.377	2.812	2.967	3.155	3.400	
80	0.788	1.417	1.773	2.020	2.212	2.368	2.802	2.956	3.145	3.387	
85	0.785	1.413	1.767	2.013	2.205	2.361	2.793	2.946	3.135	3.349	
90	0.782	1.409	1.762	2.007	2.198	2.353	2.785	2.938	3.125	3.367	
95	0.780	1.405	1.757	2.002	2.193	2.347	2.777	2.930	3.116	3.357	
100	0.779	1.401	1.752	1.998	2.187	2.341	2.770	2.922	3.109	3.349	5.261

Table -31-

Results of Investigation of Maximum Floods at Gaging Stations

Gaging Stations	$\bar{X}_m$	$\bar{X}_G$	m	G	T	X	t_p	t_{pn}	X_{n+1}
1945	183,400	175,000	118,200	118,600	99,400	651,000	32	200	483,200
1965	22,800	18,000	20,800	20,820	18,680	90,400	30	190	70,820
1980	34,300	28,000	34,780	35,360	32,000	147,000	28	100	116,820
2450	93,000	86,000	69,900	70,700	72,100	239,000	28	18.3	261,000
2455	7,150	5,800	6,050	6,400	5,620	27,000	24	99	21,260
2500	13,700	12,500	8,200	8,300	8,300	36,200	36	47	34,350
2505	248,000	250,000	158,000	160,000	160,000	784,000	39	96.4	784,500

$\bar{X}_m$ = Mean annual flood derived arithmetically

$\bar{X}_G$ = Mean annual flood derived graphically

m = Resulting standard deviation using $\bar{X}_m$

G = Resulting standard deviation using $\bar{X}_G$

T = Resulting standard deviation using X_{n+1}

X = Flood having number rank

t_p = Return period of X flood using $t = \frac{n+1}{m}$

t_{pn} = New return period calculated using suggested method

X_{n+1} = Flood having a return period of (n+1) years, to replace flood of number one rank

J. DROUGHT STUDIES

1. Analysis of Low Flows

(a) Mass Curves

One of the methods used for investigating low flows is the mass curve where the cumulative flows are plotted versus the time and a hypothetical demand curve, either constant or variable, is superimposed on the mass curve to show the size of reservoir needed to assure a certain demand or to show the yield of a reservoir of a given capacity on a specific stream.

The disadvantages of the mass curve as an indicator of periods and magnitudes of drought on a given basin are numerous. The most serious disadvantage is the fact that using mass curves we can only protect against droughts of the same or smaller magnitude than had occurred during the period of record. Since the periods of record are not long enough to be hydrologically stable, it is then a certainty that droughts of larger magnitudes and longer durations will occur during the life of water resources structures built on the river basin. To achieve the goals of water appropriation based on conservation storage it is essential that the recommendations be founded on records of much greater length than the historical record at each gaging station in the basin.

(b) Duration Curves

The historical records at Stations 1965 on the Illinois River, 2500 on the Lee Creek, 2485 on the Poteau River, and 2505 on the Arkansas River were utilized to develop duration curves at these stations. The duration curves were plotted and they show the percent of time the flow is less than or equal to a stated magnitude for a given duration at each gaging station. For gaging station 2485, the selected durations were 7 days, 30 days, 6 months, and 1, 2, 3, and 5 years. For stations 1965, 2500, and 2505, the selected durations were 30 days, 6 months, 1, 2, 3, and 5 years. Sample duration curves for these gaging stations are shown in Figure 19-22. Duration curves for various durations (30 days, 6 months, 1, 2, 3, and 5 years) are included.

The levels of probabilities of low flows as indicated from the duration curves reflect the effects of the short length of the available historical record. Short periods of record, as previously indicated under flood studies, pose some basic problems, and to overcome these problems another method has to be developed that eliminates the effects of the short length of record.

The flows for seven day duration consisted of the lowest possible combination of successive daily flows averaged over the seven day period for each month of the entire record. The mean monthly flow was selected as the flow for thirty day duration.

At station 2485 the six month periods from June through November had low flows; and high flows usually occurred from December through May, however, at station 2505 the period, July through December, exhibited low flows and January through June exhibited relatively high flows.

The mean annual flow was selected as the average flow for a duration of one water year. Durations of 1, 2, 3, and 5 year periods were studied by taking successive additions of the mean annual flows that occurred in the period of record for a particular duration. In other words, there will be N - 1 flows of two year duration, N - 2 flows of three year duration, and N - 4 flows of five year duration where N is the length of the record in years at each gaging station.

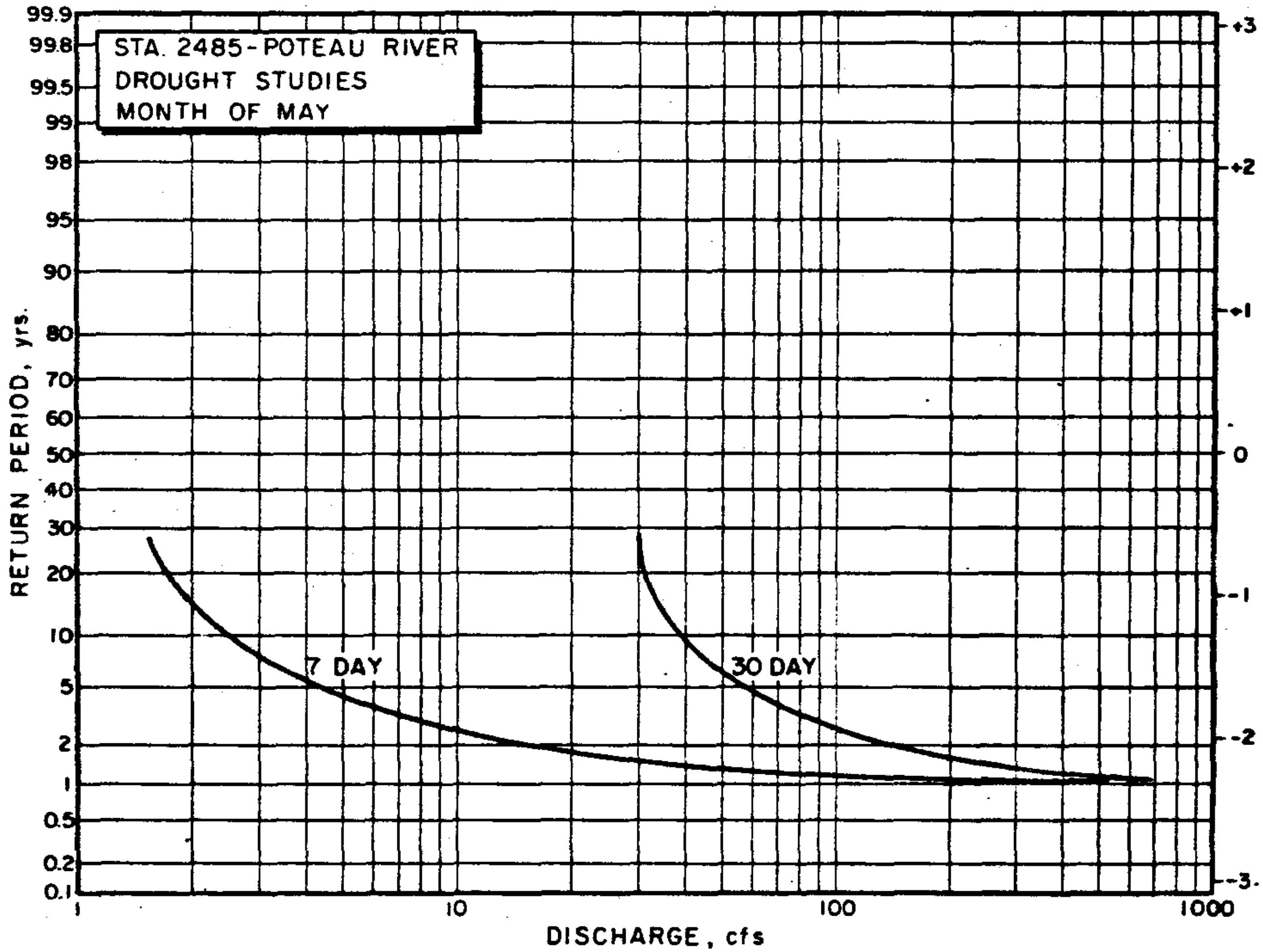


Figure 19 **7 and 30 Day Duration Curves Station 2485**

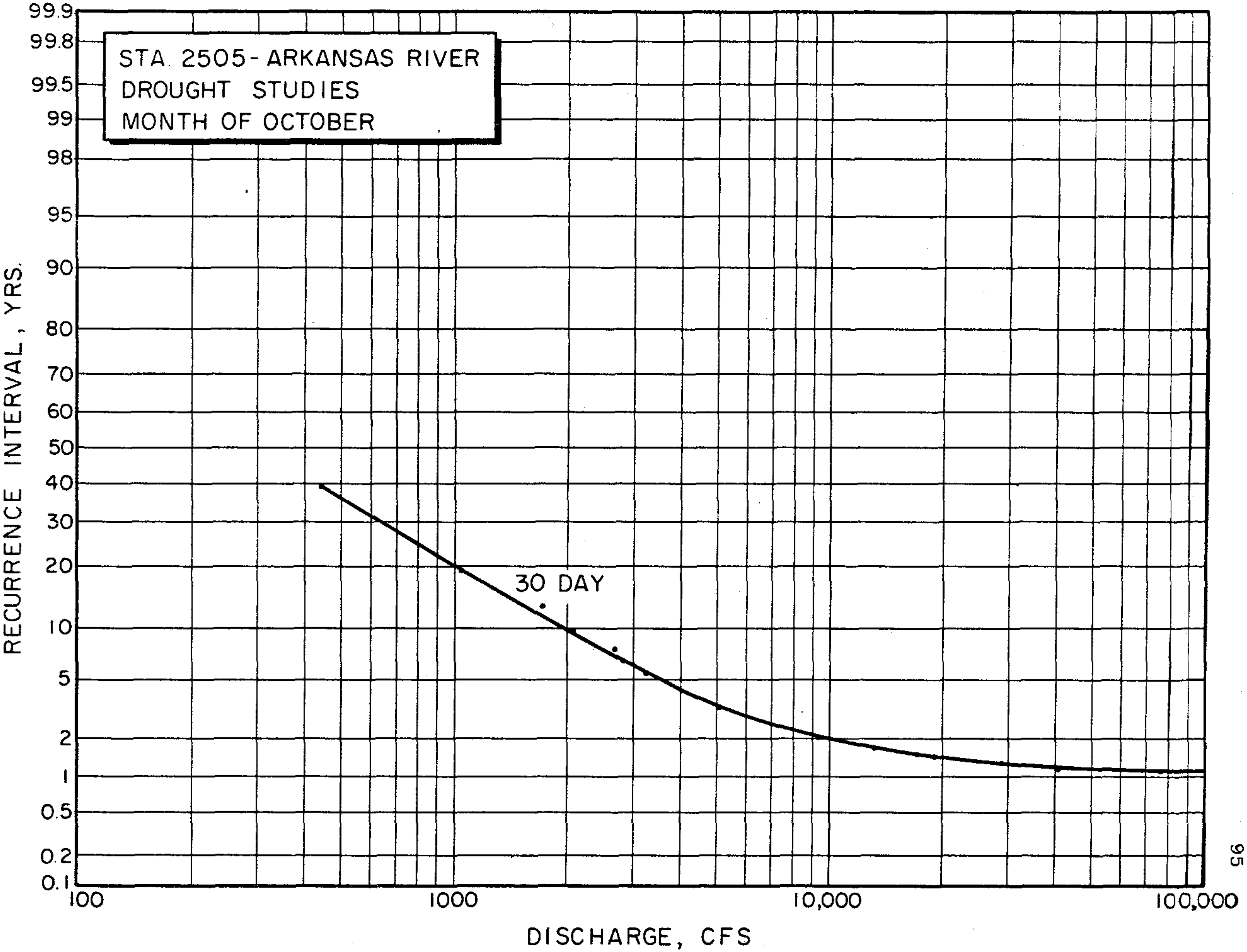
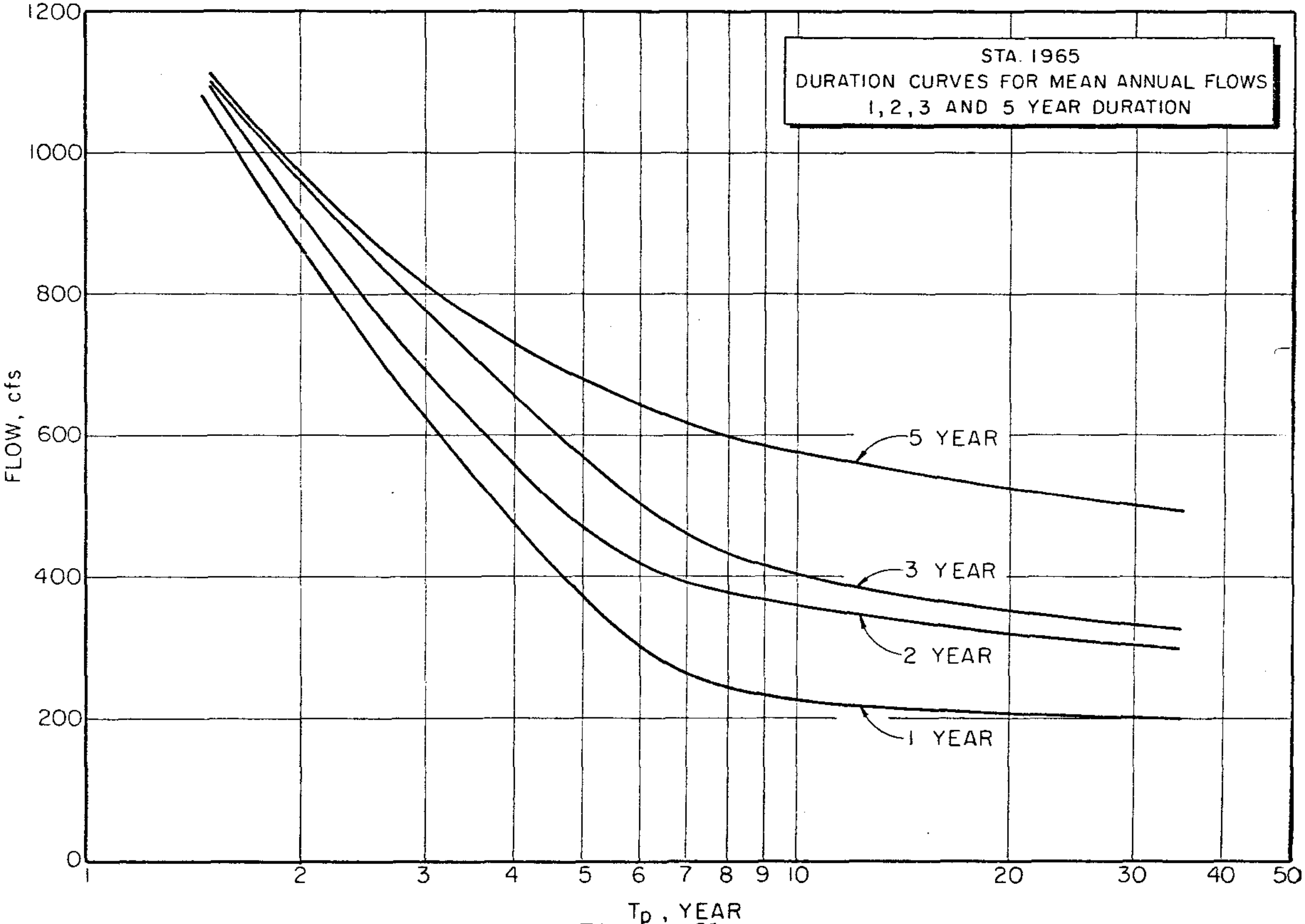
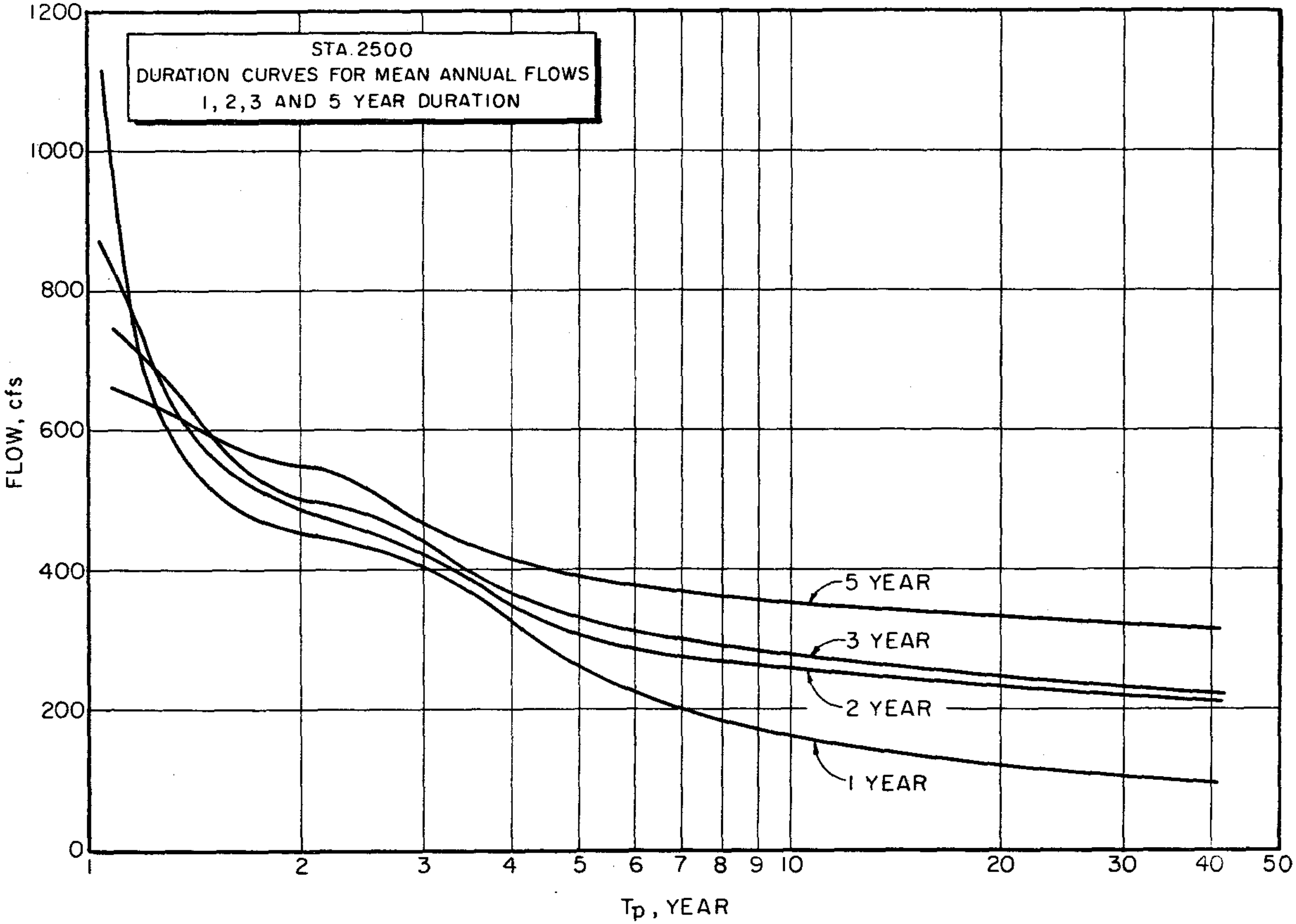

STA. 2505- ARKANSAS RIVER
DROUGHT STUDIES
MONTH OF OCTOBER
30 DAY
RECURRENCE INTERVAL, YRS.
99.9
99.8
99.5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
100
1000
10,000
100,000
DISCHARGE, CFS

Figure -20-


STA. 1965
DURATION CURVES FOR MEAN ANNUAL FLOWS
1, 2, 3 AND 5 YEAR DURATION
FLOW, cfs
1200
1000
800
600
400
200
0
1
2
3
4
5
6
7
8
9
10
20
30
40
50
Tp , YEAR
5 YEAR
3 YEAR
2 YEAR
1 YEAR
Figure -21-



STA. 2500
DURATION CURVES FOR MEAN ANNUAL FLOWS
1, 2, 3 AND 5 YEAR DURATION
FLOW, cfs
1200
1000
800
600
400
200
0
5 YEAR
3 YEAR
2 YEAR
1 YEAR
1
2
3
4
5
6
7
8
9
10
20
30
40
50
Tp, YEAR

Figure -22-

For each duration the flows are ranked lowest flow, number 1, the second lowest flow, number 2, and so on, until all flows were ranked.

The recurrence interval used in plotting the low flows was computed from the formula:

$$\text{Recurrence interval } t_p = \frac{N + 1}{M}$$

Where N = Length of record in years

M = the rank

The probability of occurrence was the percent of time the flow was less than or equal to a selected flow, and was the inverse of the recurrence interval.

The type of duration curve used in this study is a two variable plot of discharge versus recurrence interval and/or the discharge versus the probability of occurrence. The duration curves in this study were best portrayed by a smoother curve on log-normal plot.

Table -32-

Comparison of Minimum Flows From the Synthesized and Actual Flows at Station 2505 - Arkansas River

Month	Synthesized Flow - cfs Year	Synthesized Flow - cfs Min. Monthly	Actual Flow - cfs Min. Monthly	Actual Flow - cfs Min. Daily
October	478	50	492	306
November	340	40	1262	602
December	289	130	1421	695
January	395	10	1194	559
February	24	100	2328	1260
March	288	40	2401	1360
April	133	290	3185	1280
May	409	510	7450	2280
June	279	800	5553	2440
July	53	1210	1571	795
August	432	20	658	245
September	178	310	742	418

Table -33-

Comparison of Average Synthesized and Actual Flows At Station 2505 - Arkansas River

Month	Average Synthesized Flow - cfs	Average Actual Flow - cfs
October	27890	24079
November	20880	20021
December	18270	16925
January	22780	19125
February	27450	23984
March	36330	28705
April	43920	47054
May	72860	66958
June	57140	54147
July	33910	33507
August	17280	15672
September	27360	18638

Table -35-

Correlation Coefficients for Station 1965 and 2485

Pair of Months	Station 1965 Illinois River Record 30 years Correlation r	Station 2485 Poteau River Record 28 years Correlation r
October - November	0.61668	0.47915
November - December	0.75117	0.73271
December - January	0.16005	0.12252
January - February	0.23432	0.60842
February - March	0.35072	0.46080
March - April	0.57444	0.12102
April - May	0.10965	0.15528
May - June	0.49094	0.49372
June - July	0.19848	0.37537
July - August	0.39033	0.49453
August - September	0.35254	0.73223
September - October	0.15825	0.56470

The value of the correlation coefficient for the 10 percent probability level for Station 1965 is 0.3068 and that of Station 2485 is 0.3178.

(b) Testing the Model

Referring to Table 35, containing the correlation coefficients for consecutive months on both the Illinois and Poteau Rivers we find that, for Station 1965, the correlation coefficient fell below the 10 percent significance level of 0.3068 in December-January, January-February, April-May, June-July, and September-October. For Station 2485, the correlation coefficient fell below the 10 percent significance level of 0.3178 in December- January, March-April, and April-May. The drainage area tributary to Station 1965 is 959 square miles and that tributary to Station 2485 is 1,015 square miles. The terrain and slopes of both drainage areas are hilly and steep and their response to storms is extremely fast. Using monthly correlations in these cases did not yield accurate results. Checking the daily flows for the months yielding poor correlation coefficient, it was found that the daily flows were between 200 to 300 cfs for more than 20 days of the month, then the flows jumped up to more than 10,000 cfs. for about a week thus causing a falsely high mean monthly flow which in turn causes the poor correlation coefficient. As for Station 2505, the correlation coefficient at 10 percent significance level is 0.2676. All the correlation coefficients for the monthly flows exceeded this level except for February-March correlation coefficient which was 0.24779. It is easy to detect the reasons behind this marginal correlation coefficient. Since March is the start of the spring melt and since the drainage area tributary to Station 2505 is in excess of 150,000 square miles the water flowing in the Arkansas River is a result of rainstorms during March plus the snowmelt from snowstorms during the winter. If there was available a method for separating the runoff due to snowmelt from that due to rainstorms occurring in March, the correlation coefficient for February-March will have definitely been improved and fallen above the 10 percent significance level.

Based on the table showing the statistical values to be used in the model for flow generation at Station 2505, it was decided that the selected model (Markov Chain Model) as expressed earlier without modifications is suitable for generating streamflows at Station 2505. To test for the effect of the size of the drainage areas, the Markov Chain Model without modifications was tested on Station 1945, the Arkansas River at Muskogee and 1745, the Arkansas River at Tulsa having drainage areas of 96,674 and 74,615 square miles respectively and having historical records covering 39 years. Table 36 shows the correlation coefficients between successive months for both stations. The 10 percent significance level for these stations is 0.2676.

All the correlation coefficients are well above the 10 percent significance level except for the April-May coefficient. This is to be expected since May is the wettest month of the year and both stations are located in Northeast Oklahoma, a high rainfall intensity area, and the runoff is a result of severe and frequent thunderstorms of short durations.

(c) Streamflow Hydrographs

The synthesized mean annual flows for Stations 2505, 1645, and 1945 were plotted as discharge hydrographs. The historical hydrograph was superimposed upon the syntehtic hydrograph for Station 2505 resulting in a very favorable comparison of the

Table -36-

Correlation Coefficients for Station 1945 and 1645

Station	1945	1645
Number of Years	39	39
10% S. L.	.2676	.2676
Correlation Coefficient	(r)	(r)
October - November	0.54206	0.32497
November - December	0.62462	0.60224
December - January	0.44623	0.52731
January - February	0.62505	0.84778
February - March	0.35271	0.54870
March - April	0.53548	0.47315
April - May	0.19569	0.24796
May - June	0.47601	0.77489
June - July	0.31487	0.56744
July - August	0.39340	0.34982
August - September	0.33761	0.34494
September - October	0.47727	0.43947

patterns of flows. The historical hydrograph fitted the synthetic years 55 - 92, 115 - 152, 266 - 303, and 410 - 447; a further indication of the applicability of the selected model to represent the gaging stations. Now it is evident that the mathematically generated streamflows represent a hydrologically stable system, unaffected by the problems that beset short periods of record.

Analyzing the synthetic record will yield, under these conditions, better results and accurate conclusions. These ideas are the subject of a paper entitled "Duration Curves Versus Mass Curve as a Design Criteria" which was presented at the Fourth National Water Resources Conference, November 18-22, 1968 in New York City.

(d) Analysis of Synthetic Flows for Droughts

Duration curves of thirty days were not determined for the synthesized data since the monthly flows of zero magnitudes were not considered typical of the actual flows. Duration curves of six months, one, two, three, and five years were plotted and analyzed. These curves are presented in Figure 23 - 26. The five hundred years of synthesized data were divided into five one-hundred year periods was analyzed for low flows. A computer program ranked each flow, calculated its return period and probability of occurrence.

(e) Effect of Length of Record on the Model

Stations 1645 at Tulsa and 1945 at Muskogee were selected to evaluate the effect the length of available historical record on the correlation coefficient at the percent significance level. Both stations have periods of records covering the water

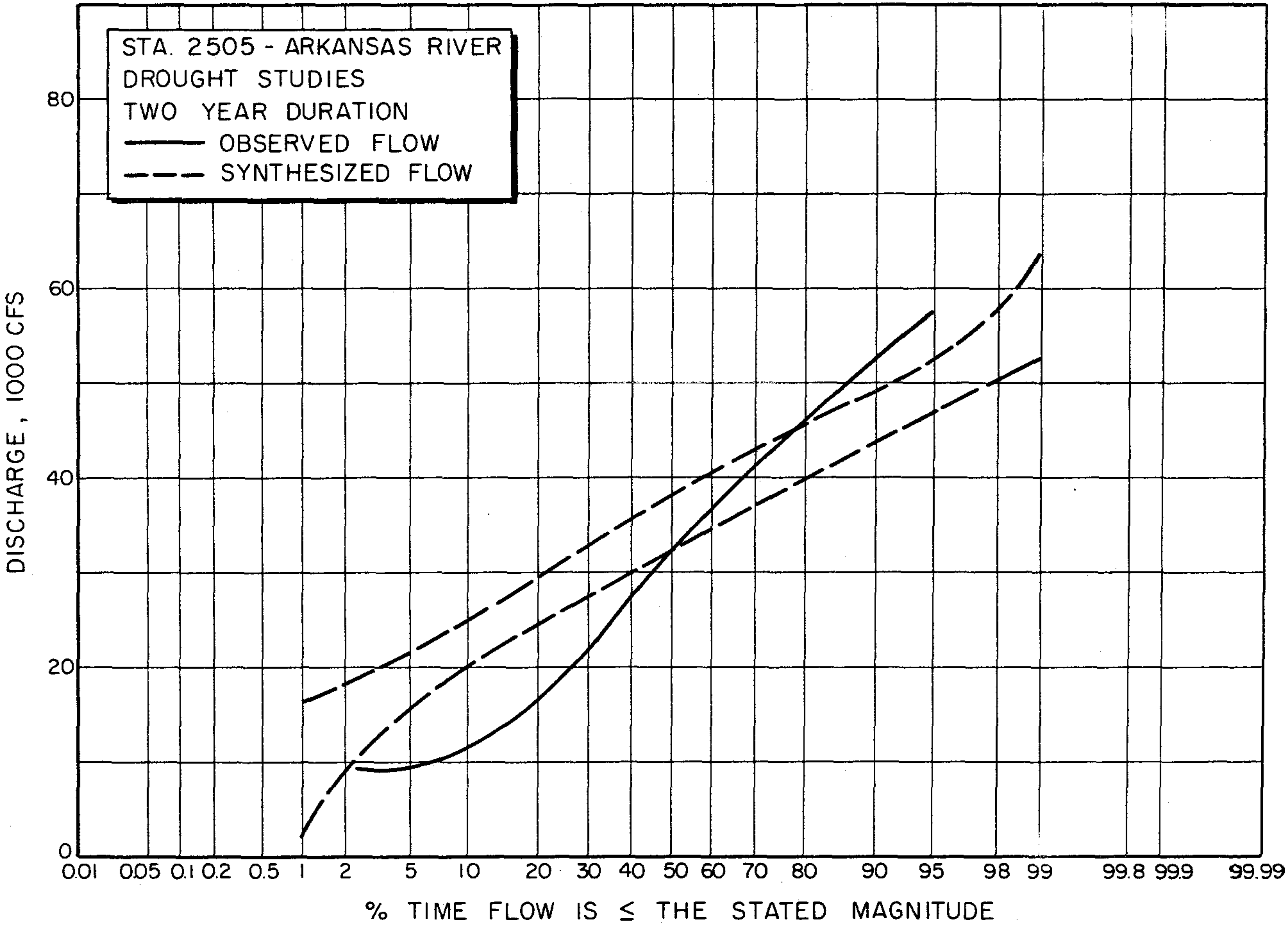

STA. 2505 - ARKANSAS RIVER
DROUGHT STUDIES
TWO YEAR DURATION
OBSERVED FLOW
SYNTHESIZED FLOW
DISCHARGE, 1000 CFS
0
20
40
60
80
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99
% TIME FLOW IS ≤ THE STATED MAGNITUDE

Figure -23-

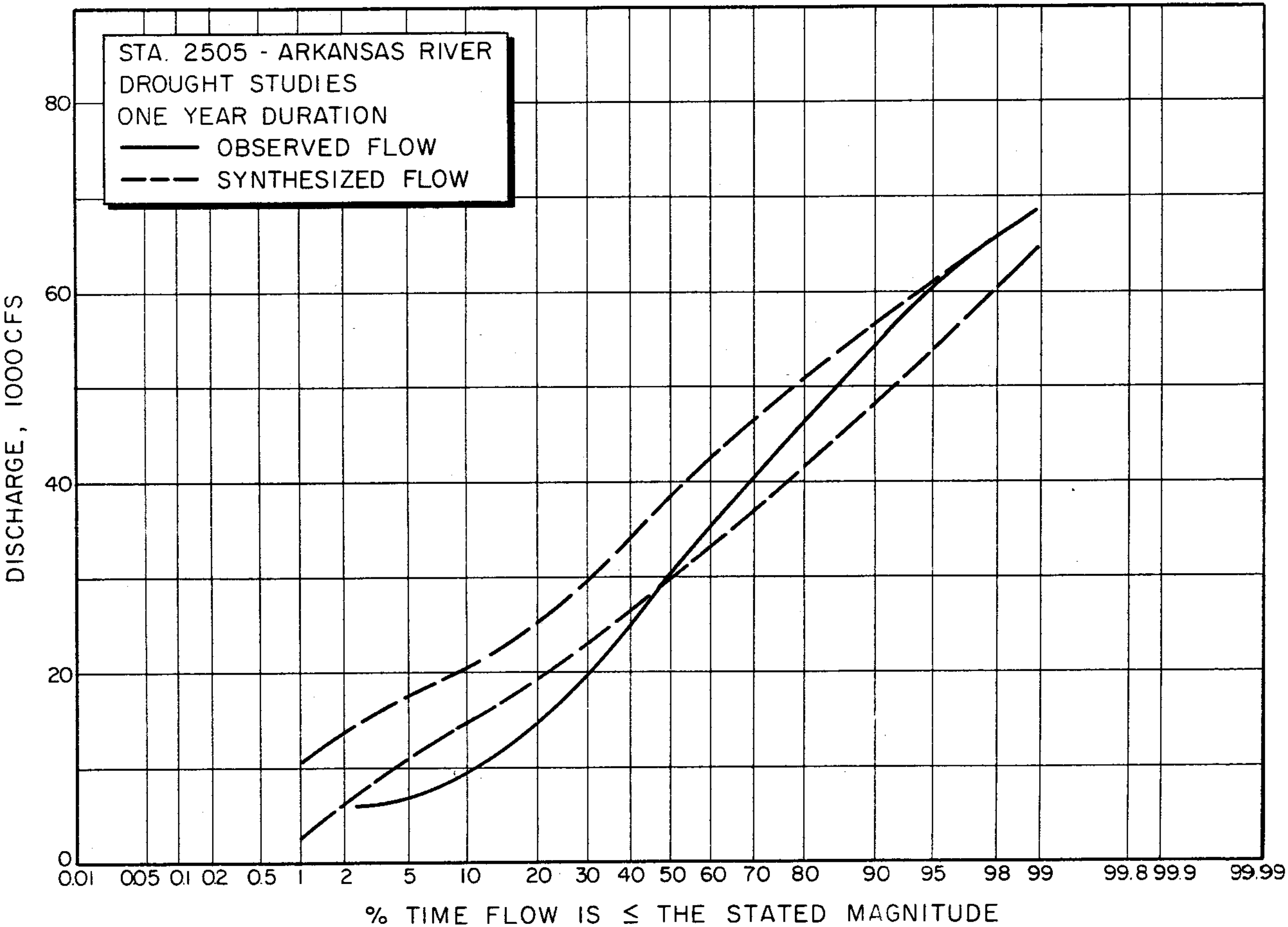

STA. 2505 - ARKANSAS RIVER
DROUGHT STUDIES
ONE YEAR DURATION
OBSERVED FLOW
SYNTHESIZED FLOW
DISCHARGE, 1000 CFS
0
20
40
60
80
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99
% TIME FLOW IS ≤ THE STATED MAGNITUDE

Figure -24-

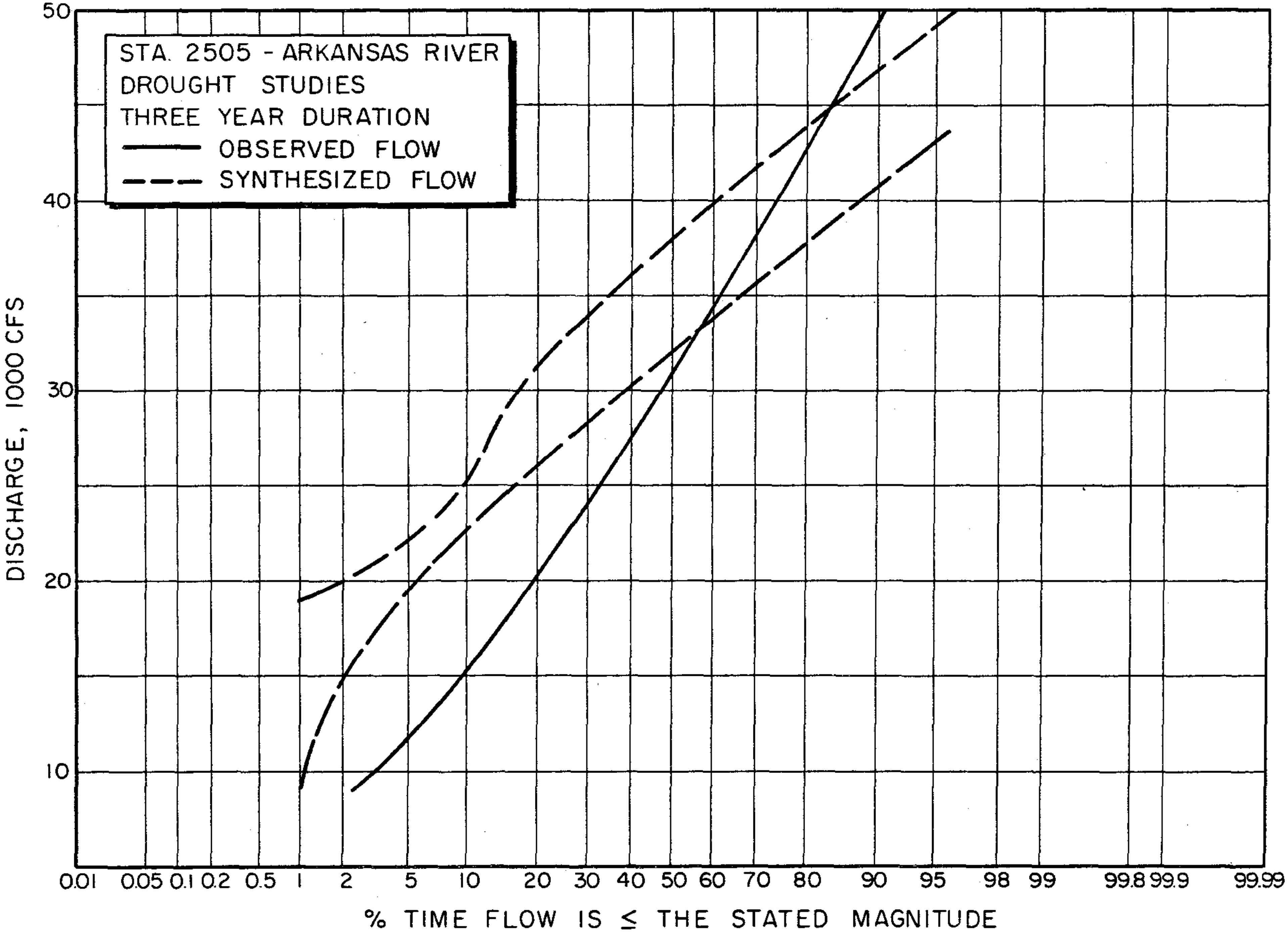

STA. 2505 - ARKANSAS RIVER
DROUGHT STUDIES
THREE YEAR DURATION
OBSERVED FLOW
SYNTHESIZED FLOW
DISCHARGE, 1000 CFS
50
40
30
20
10
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99
% TIME FLOW IS ≤ THE STATED MAGNITUDE

Figure -25-

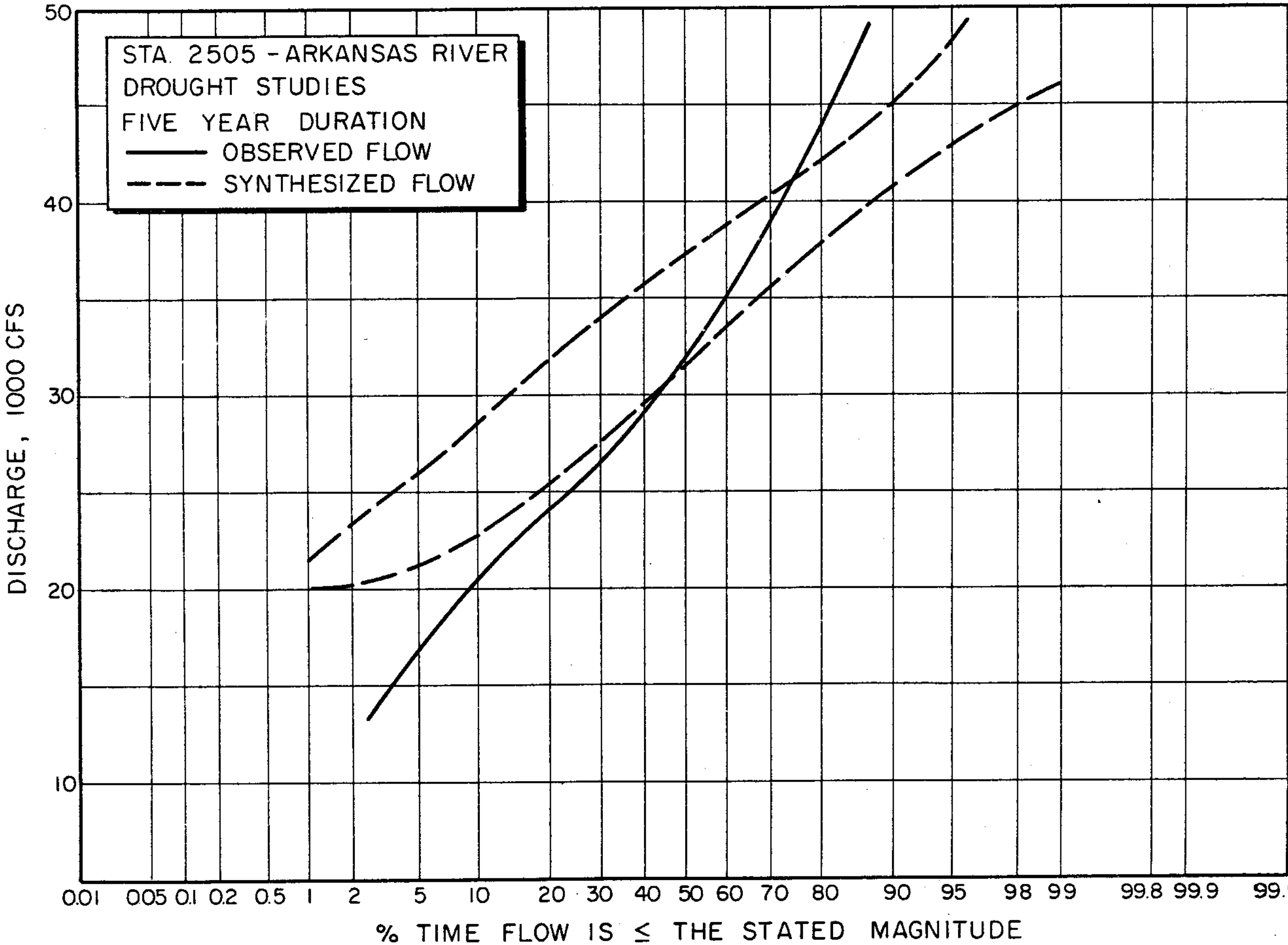

STA. 2505 - ARKANSAS RIVER
DROUGHT STUDIES
FIVE YEAR DURATION
OBSERVED FLOW
SYNTHESIZED FLOW
DISCHARGE, 1000 CFS
50
40
30
20
10
0.01
0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
% TIME FLOW IS ≤ THE STATED MAGNITUDE

Figure -26-

years 1928 up to the present time (39 water years). Correlation coefficients for consecutive months were computed for the first 15 years of the record (1928 - 1942) then we added the next 10 years of record and computed another set of correlation coefficients for 25 years of record (1928 - 1962). The last set of correlation coefficients was computed for the entire length of record of 39 years (1928 - 1966). The results of this study are shown in Table 37.

A discharge hydrograph using the mean annual flow at the two gaging stations is presented in Figure 27 and 28, and it could be seen that the components of the mathematical parameters used in the model tend to stabilized as the length of record increases. It is also evident from the correlation coefficients that a desirable period of record longer than 25 years is needed for the model to yield results within the 10 percent significance level.

Table -37-

Correlation Coefficients for Various Length of Record at Station 1645 and 1945

Station	1645				1945			
Period, Years	15	25	35	39	15	25	35	39
10% level of Significance	0.4409	0.3379	0.2831	0.2676	0.4409	0.3379	0.2831	0.2676
October-November	-.03509	.34322	.33552	.32497	.10865	.61786	.56560	.54206
November-December	.90163	.47767	.55181	.60224	.70077	.40368	.50864	.42462
December-January	.91844	.37445	.49738	.52731	.56560	.29301	.43090	.44623
January-February	.69351	.83082	.83961	.84668	.45421	.55068	.60773	.62505
February-March	.63616	.56781	.55380	.54870	.43011	.29562	.33840	.35271
March-April	.64500	.58092	.47195	.47315	.60955	.59527	.53164	.53548
April-May	.23904	.28382	.23414	.24796	.34709	.13751	.17923	.19569
May-June	.68014	.56050	.72074	.77489	.52696	.30207	.49927	.47601
June-July	.71603	.29830	.56343	.56744	.62464	.24329	.30479	.31489
July-August	.03388	.48636	.34436	.34982	.19846	.54880	.38061	.39340
August-September	.29851	.37110	.37507	.34494	.14072	.28740	.34179	.33761
September-October	.57666	.51073	.45655	.43947	.87531	.69074	.51484	.47727

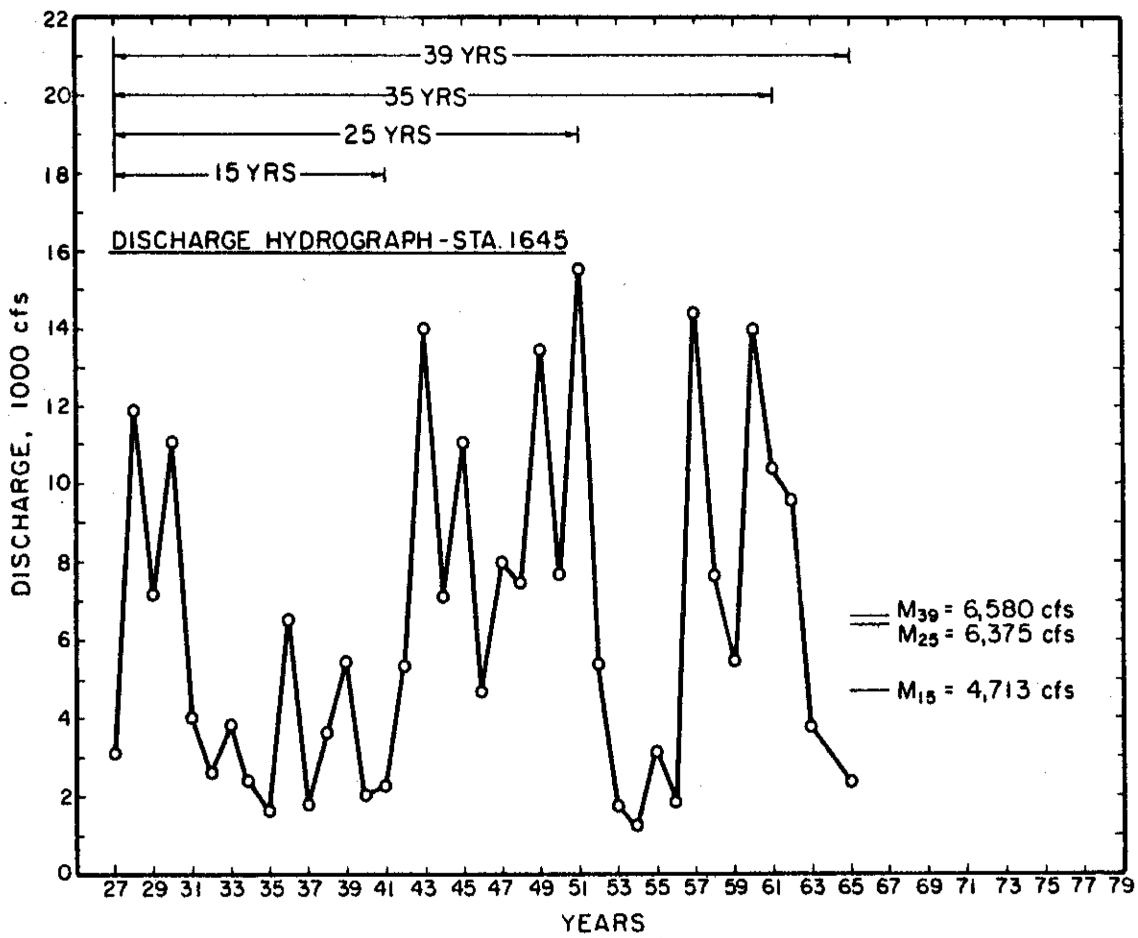


Figure 27 - Station 1645, Discharge Hydrograph

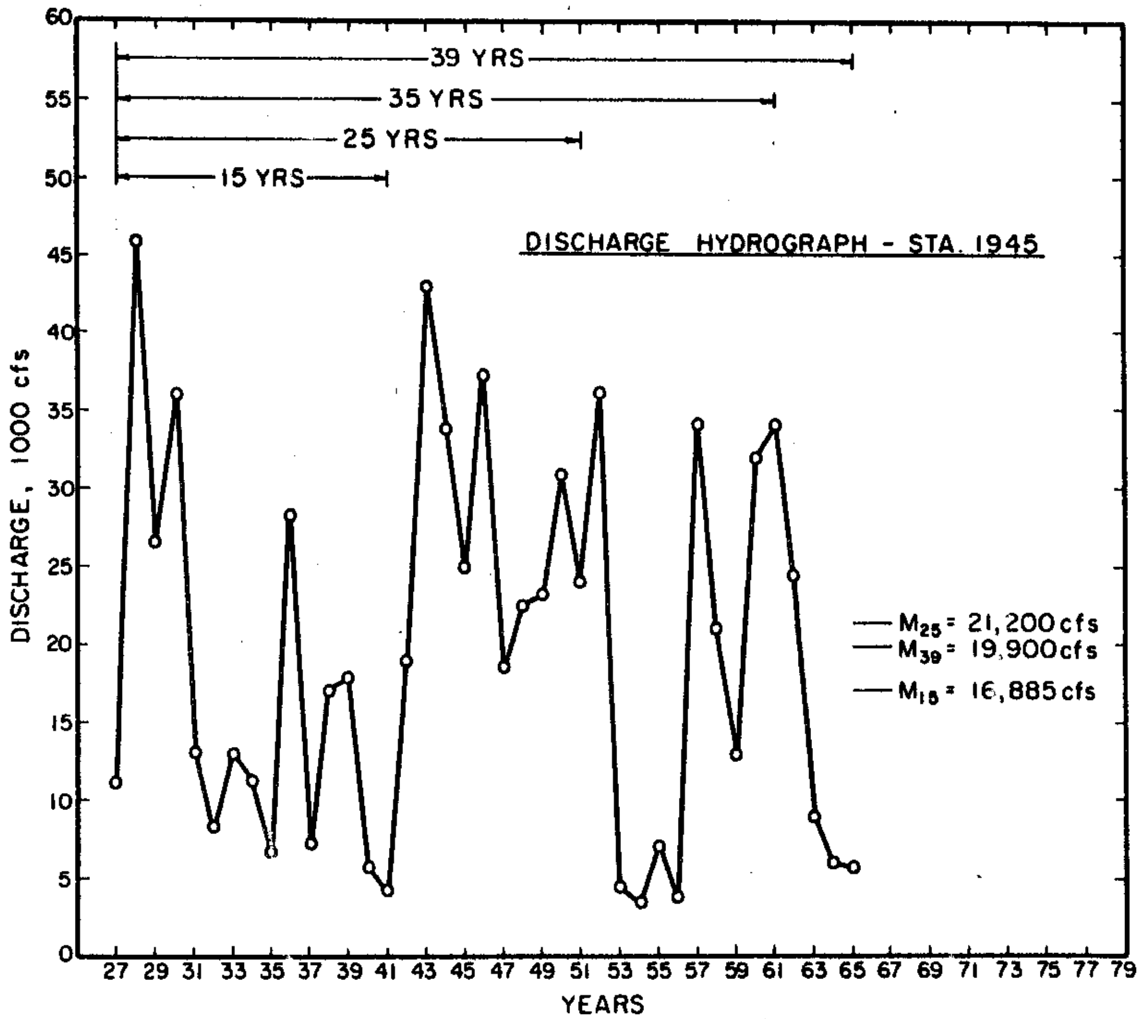


Figure 28 - Station 1945, Discharge Hydrograph

2. Linear Autoregression

In the previous studies it was found that the Thomas and Fiering Model could not be applied to basins with a small drainage area. As a result of this finding an investigation was conducted into a linear autogressive model to determine whether if could be applied in situations where insignificant correlation might limit the application of the Thomas Fiering model. Nine river basins with small contributing areas were selected from the records in the U.S.G.S. Water Supply Papers and examined to determine whether their sequences of mean monthly streamflows could be described by linear autoregression. Stations were selected for having a long continuous record where the natural streamflow had not been substantially affected by regulation abstraction or diversion. Station 7-1965 was included, but station 7-2485, which had only a short record, was excluded. Subsequently two stations with large contributing areas examined by the Thomas and Fiering model were also included for comparison. Table 38 shows the location of the stations, the period of record available, and their drainage area.

(a) Models Used

The simple first order autoregression model applicable to stationary time series has been widely referred to in the hydrological literature. The equation is of the form

$$W_t = P_1 W_{t-1} + E_t \qquad (1)$$

Where W_t is a variable at time t and E_t is a random component. The coefficient P_1 is the first order autocorrelation coefficient of the set $\{W_t\}$ defined for a general lag K by

Table -38-

Details of Gauging Stations

U. S. G. S. Station No.	Location	Area Mi.^{2}	Record Available
7-1478	Walnut River at Winfield, Kansas	1840	1921-66
7-1645	Arkansas River at Tulsa, Oklahoma	74615	1925-64*
7-1705	Verdigris River at Independence, Kansas	2892	1922-48*
7-1945	Arkansas River near Muskogee, Oklahoma	96674	1925-64*
7-1965	Illinois River near Tahlequah, Oklahoma	959	1937-66
7-3325	Blue River near Blue, Oklahoma	478	1937-77
7-3365	Kiamichi River near Belzoni, Oklahoma	1423	1926-66
7-3390	Mountain Fork River near Eagletown, Oklahoma	787	1930-66
6-8680	Saline River near Wilson, Kansas	1900	1930-63*
6-8905	Delaware River at Valley Falls, Kansas	922	1923-66
6-8915	Sakarusa River near Lawrence, Kansas	458	1930-66

*Regulation of the river basin commenced.

$$P_k = \frac{\text{cor}\left[W_t \cdot W_{t+k}\right]}{\left[\text{var}(W_t) \cdot \text{var}(W_{t+k})\right]^{\frac{1}{2}}} \tag{2}$$

and if the series is described by first order autoregression

$$P_k = P_1^{\,k} \tag{3}$$

The use of Equation (1) is limited to a set $\{W_t\}$ which, is weakly stationary. This limitation is due to the stipulation that E_t be drawn from a population with mean of zero and variance of one. Stationarity is the condition where statistical parameters of all subsets of $\{W_t\}$ do not vary, moments about the mean of the set being constant. Stationarity is normally defined to the second order, where

$$E\left[W_t\right] = \mu = \text{constant} \tag{4}$$

$$E\left[W_t \cdot W_{t+k}\right] = \mu^2 + P_k \sigma^2 \tag{5}$$

Where μ and σ^2 are respectively the mean and variance of the set $\{W_t\}$.

Only if $\{W_t\}$ is normally distributed is the set stationary to the third and higher moments. If $\{W_t\}$ is not stationary it may be made stationary to the second order by means of the transformation:

$$V_t = \frac{W_t - \mu}{\sigma} \tag{6}$$

and V_t is used in place of W_t in Equation (1) with P_1 now the first order serial correlation coefficient of $\{V_t\}$. If the series is stationary to the second order the random variable E_t may be shown to be

$$E_t = \eta_t \,(1 - P_1^2)^{\frac{1}{2}} \tag{7}$$

and the autoregression equation is then

$$\nu_t = P_1^{*}\nu_{t-1} + \eta_t(1 - P_1^2)^{\frac{1}{2}} \tag{8}$$

If $\{W_t\}$ is skewed and is made stationary only to the second order by the transformation of Equation (6), the skewness of $\{W_t\}$, which is a property of the third moment about the mean, is not transmitted to the synthetic record generated by Equation (1). However, if the normal random variable E_t is replaced by a skewed random variable the autoregressive process is stationary to the third order, and the shewness of the sample is reflected in the skewness of the synthesised record. Thomas and Fierring showed that the standardised normal random variable η_t of Equation (7) may be replaced by

$$\xi_t = \frac{2}{\gamma_\xi}\left(1 + \frac{\gamma_\xi \eta_t}{6} - \frac{\gamma_\xi^2}{36}\right) - \frac{2}{\gamma_\xi} \tag{9}$$

Where γ_ξ is the shewness of ξ_t and is relaxed to the skewness γ_w of $\{W_t\}$ by the expression

$$\gamma_\xi = \frac{(1 - P_1^3)}{(1 - P_1^3)^{3/2}} \cdot \gamma_w \tag{10}$$

If this replacement is made the autoregressive scheme is stationary to the third order and is represented by

$$\nu_t = P_1 \nu_{t-1} + \xi_t(1 - P_1^2)^{\frac{1}{2}} \tag{11}$$

The shewness γ_w is given by

$$\gamma_w = \frac{\mu_3}{\sigma^3} \tag{12}$$

Where μ_3 is the third moment about the mean

The estimate g_w of γ_w is given by

$$g_w = \frac{n^2}{(n - 1)(n - 2)} \cdot \frac{m_3}{S^3} \tag{13}$$

and is approximately

$$\sim n \left[0, \frac{6(n - 2)}{(n + 1)(n + 3)} \right]$$

Confidence limits for g_w at significance level α are then

$$C. L. (\alpha) = \mp K_\alpha \left[\frac{6(n - 2)}{(n + 1)(n + 3)} \right]^{\frac{1}{2}} \tag{14}$$

and if g_w falls within these confidence limits the hypothesis that $g_w = 0$ is accepted.

(b) Testing the Applicability of the Autoregressive Scheme

If Equation (1) describes an autoregressive scheme, the variable E_t should be independent. Thus the sequence

$$E_t = W_t - P_1 W_{t-1}$$

may be constructed, and if E_t is independent, the serial correlation coefficients P_k^1 calculated from E_t should not be significantly different from zero, a test of the independence of the variable. If the variable is normally distributed with variance one about its mean (i.E. the variable is weakly stationary) the serial correlation coefficients are approximately normally distributed with mean of -1/ (n - 1) abd varance $(n - 2)/(n - 1)^2$. Confidence limits for P_k^1 at significance level α are then

$$C. L. (\alpha) = \frac{-1 \mp K_\alpha (n - 2)^{\frac{1}{2}}}{(n - 1)} \tag{16}$$

If any P_k^1 falls outside these confidence limits the hypothesis that $P_k^1 = 0$ is rejected, the independence of E_t cannot be assumed, and the assumption that the equation represents a process of linear autoregression is not valid.

An alternative and more elegant test of the autoregressive scheme is a large sample χ^2- test. The statistic R_{k+1}, which is approximately normally distributed with mean of zero and variance of $\sigma^2 [R_1]$ is constructed from the serial correlation coefficients thus

$$R_{k+1} = P_{k+1} - 2P_1 P_{k-1} + P_1^2 P_{k-1}$$

The variance $\sigma^2 [R_1]$ is given by

$$\sigma^2 [R_1] = \frac{(1 - P_1^2)^2}{n - k}$$

and

$$\chi^2_{m-1} = \sum_{k=1}^{m} \frac{R_{k+1}}{\sigma^2 [R_1]}$$

Where m is the number of P_k used to test the significance of the scheme, is approximately distributed as χ^2 with (m - 1) degrees of freedom. The hypothesis that the autoregressive scheme is of the first order is rejected if $\chi^2_{m-1} > \chi^2(\alpha)$ the value of χ^2 at significance level α for (m - 1) degrees of freedom.

(c) Methods of Analysis

A sequence of mean monthly stream flows $\{X_t\}$, where X_t is the mean monthly flow at time t, may be considered to be a sample from a set $\{W_t\}$. The sequence has mean m, variance S^2, and skewness g_x and these are estimates of the parameters of $\{W_t\}$. The sample $\{X_t\}$ may be used in the autoregressive scheme of Equation (1), but it is rarely found to be stationary and may be standardised by means of Equation (6) thus

$$Z_t = \frac{X_t - m}{S}$$

The autoregressive scheme is then

$$Z_t = r_1 Z_{t-1} + E_t \tag{17}$$

Where r_1 is the first order serial correlation coefficient of Z_t, an estimate of P_1 in Equation (8). This equation will be referred to as Model A. The adequacy of the model can be tested by means of the tests described above.

If the series $\{X_t\}$ can be described by a first order autoregressive scheme its correlation coefficients should be described by Equation (3). Thus the serial correlations should decrease, but not disappear, as k increases. However, inspection of the correlogram, a plot of the serial correlations against the lag, produced from the hydrological sequence $\{X_t\}$ frequently shows a distinct cycle indicating that part of all of the sequence may be described by harmonics. Continuous functions of the monthly mean and monthly standard deviation, assuming a fundamental period of twelve months in the sequence, may be constructed as follows

$$m_t = m + \sum_{p=1}^{n} A_p \operatorname{Cos} \frac{2n}{12} pt + \sum_{p=1}^{n} B_p \operatorname{Sm} \frac{2}{12} pt \tag{18}$$

$$S_t = S + \sum_{p=1}^{n} C_p \operatorname{Cos} \frac{2}{12} pt + \sum_{p=1}^{n} D_p \operatorname{Sm} \frac{2}{12} pt \tag{19}$$

Where p = order of harmonic

n = maximum number of harmonics.

The constants A_p, B_p, C_p, D_p, may be defined in terms of the mean m_t and variance S_t^2 of the monthly flow in the month $\tau(\tau = 1, 2, \ldots, 12)$.

Harmonics may then be removed from X_t by means of the expression

$$Z''_t = \frac{X_t - M_t}{S_r} \tag{20}$$

The harmonics of Equations (18) and (19) have periods of 12, 6, 4, 3, etc. months, and when sufficient harmonics have been removed it may be possible to describe the residual Z_t'' by means of an autoregressive scheme of the form of Equation (3). It is not necessary to remove harmonics until the resudual is independent. Instead the residual may be examined to determine whether it can be described by a first order autoregression equation using the tests described above. First the variable Z_t'' is standardised according to Equation (6) by means of the expression

$$Z_t' = \frac{Z_t'' - m_Z}{S_Z} \tag{21}$$

where m_Z and S_Z are respectively the mean and variance of Z_t''. The autoregression equation using Z_t' is then

$$Z_t' = r_1 Z_{t-1}' + E_t \tag{22}$$

Where r_1 is the first order serial correlation coefficient of $\{Z_t'\}$. This will be referred to as Model B.

(d) Results

Each of the observed hydrological sequences of the eleven stations chosen for this study was examined to determine whether it could be described by a linear autoregressive model. Both tests of the applicability of the model, the residual correlation test, and the χ^2-test of significance were examined. Analysis of the sequences was carried out on the untransformed flows and also the natural logarithms of the flows.

(1) Tests of the Applicability of an Autoregressive Scheme

To test the proposed first order autoregressive scheme, the residual E_t was formed as in Equation (15) for both Model A and Model B. In order that the confidence limits of Equation (16) may be applied the residual should be normally distributed with varance one. The distributation of the residuals was examined by Pearson's χ^2-test and for this purpose the variables were assumed to be independent. Twenty classes were chosen for the analysis and the number of degrees of freedom was therefore seventeen. A residual was considered not to be normally distributed if the calculated value of χ^2 exceeded 27.587, the value of χ^2 at 17 degrees of freedom at the 0.05 significance level. Computed χ^2 and the standard deviations of the variables are shown in Table 39. Values of χ^2 less than the stated value are underlined, the variables in these cases being considered to be approximately normally distributed. It may be noted that in not one case was the residual distributed approximately normally with variance of one about its mean. In cases where the variance was approximately one the distribution could not be considered normal and in cases where the distribution was approximately normal, the variance differed widely from one.

Thus, the hypothesis upon which the residual correlation test using the confidence limits of Equation (16) is based was not satisfied in any of the 44 cases examined. None of the residuals was part of a series which was weakly stationary, and it was concluded therefore that the test as described by Roesner and Yevdjevach was not strictly valid for any of the stations examined

Table -39-

Distribution Parameters of E_t

	MODEL A				MODEL B			
	Untransformed		Logarithms		Untransformed		Logarithms	
Station	σ	χ^2	σ	χ^2	σ	χ^2	σ	χ^2
1478	1.000	999	0.999	28.978	-----	-------	0.758	69.270
1645	1.000	790.088	0.710	57.411	0.877	257.325	0.705	41.051
1705	0.967	810.313	0.707	<u>20.963</u>	0.983	564.368	0.807	<u>25.688</u>
1945	0.918	833.086	0.731	43.707	0.900	321.822	0.740	31.544
1965	0.930	690.972	0.744	39.942	0.935	443.173	0.814	50.192
3325	0.919	640.498	0.776	<u>27.574</u>	0.940	409.858	0.825	44.621
3365	0.952	556.861	0.812	54.866	0.981	381.383	0.924	<u>10.385</u>
3390	0.923	327.700	0.814	92.214	0.973	225.487	0.921	30.724
8680	0.879		0.760	62.828	0.966	947.152	0.759	<u>20.174</u>
8905	0.948		0.787	30.306	0.943	688.598	0.820	27.648
8915	0.927		0.678	58.806	0.948	867.293	0.774	57.722
							(27.587)	

in this study. It was decided nevertheless to attempt to apply the test in order to assess whether it would be practicable to apply it in a condition where it was valid. However, the test proved to be very cumbersome to use, as correlograms of the residual had to be examined. Often a residual was found to have a few significant correlations, and the hypothesis of the independence of the residual should be rejected in this case. However, these significant correlations could have arisen through sampling errors it was not felt to be practicable to put an arbitrary limit on the number of significant correlations observed, below which number the series could be considered independent. Furthermore, the alternative method of testing the scheme, Quenouille's χ^2-test, accepted models which the residual correlations tests rejected in this way.

The χ^2-test proved to be much more simple to apply as its computations are carried out on the serial correlations from the series $\{Z\}$ in model A, or $\{Z_t'\}$ in model B. The test is not limited by the series on which it operates as is the residual correlation test. The residuals $\{Z_t\}$ and $\{Z_t'\}$ are stationary to the second order. No reported use of the test has been found in the hydrological literature so it is not possible to compare the results presented here with other studies. However, it was found to be a very convenient test with the advantage that it could be used during execution of the model analysis. This enabled the same program to evaluate combinations of models and to select the most suitable for the station being analysed. All subsequent testings of the models was carried out with this test and the residual correlations test was not considered further.

Table -40-

Station	A		B		Q		B		C. L.
	χ^2	g_x	χ^2	g_x	χ^2	g_x	χ^2	g_x	$g_x \mp$
1478	26.480	3.2679	31.148	3.0423	30.954	-2.9868	31.490	-1.1782	0.2054
1645	------	------	------	------	------	------	27.190	-1.7637	0.2205
1705	------	------	25.252	5.1212	------	------	27.337	-1.3605	0.2643
1945	------	------	30.807	2.6618	32.886	-2.0911	18.678	-1.1937	0.2205
1965	------	------	30.506	3.4520	29.747	-1.7314	22.971	-0.6674	0.2509
3325	34.168	3.3900	27.782	3.1876	------	-------	21.246	-1.3134	0.2509
3365	------	------	23.035	2.3465	------	-------	32.849	-1.0330	0.2151
3390	------	------	25.718	1.9392	------	-------	26.927	-1.3075	0.2263
8680	------	------	------	------	------	-------	26.563	-1.1899	0.2359
8905	------	------	------	------	------	-------	------	-------	0.2078
8915	25.361	4.3671	16.189	4.1300	------	-------	------	-------	0.2263

described by four parameters: the mean, variance, coefficient of skewness, and first order serial correlation coefficient. The remainder could only be described by Model B, which required harmonic removal. However, in most cases only one, or at most two harmonics had to be removed before the residual could be described by an autoregressive scheme. These stations them required the four parameters required in Model A and four for each successive harmonic removed. All of the models required the skewed random variable ξ_t in order to produce a sequence stationary to the third moment about the mean.

The number of parameters required to describe these sequences is far less than that required by the Thomas and Fiering Model. This required at least 36 parameters: twelve monthly means, twelve monthly standard deviations and twelve significant correlations from month to month. The Thomas and Fiering model also requires a skewed random variable in place of the normal random variable γ_t if the variables upon which it operates are skewed and this skewness is to be transmitted to the synthetic record generated by the model. As the model operates upon the sets of monthly flows, a separate skewed random variable is required for each monthly set. Thus, the skewness of each set must be determined and tested for significance: Twelve monthly skewness parameters similar to γ_ξ of Equation (10) are, therefore, required. Moreover, the testing of the significance of the skewness coefficients is unreliable for the small samples sizes usually available, as was discussed above, as the distribution of the coefficient is not accurately known for small n. The linear autoregressive models, even with three or four harmonics removed, are therefore more simple and require far fewer parameters.

V. WATER QUALITY STUDIES

A. General

In the development of any water resources system, the quality of the water is as important a consideration as its quantity, since the beneficial use to which the resource may be most opportunially employed is determined in large measure by water quality. It is with this thought in mind that the water quality studies of this project were undertaken. The studies were divided into two main categories: the chemical quality and the biochemical quality. All available records were analyzed. These records were obtained mainly from the Geological Survey and the Federal Water Pollution Control Administration. No field studies were undertaken during the course of the present study. In addition to the analysis of chemical and biochemical quality of the waters under study, surveys of existing industrial and agricultural activities were conducted in order to assess contribution of these activities to the present quality of the waters and their potential contribution in the future.

B. Chemical Quality

1. Frequency Analysis

The general chemical quality of the mainstem of the Arkansas River has been well known for some time. In fact, it is quite well known that the water in the Arkansas River enters Oklahoma from Kansas under conditions of poor quality. This water deteriorates in quality as it travels through Oklahoma until it reaches the Tulsa area. This is due primarily to the inflow from the Salt Fork and the Cimarron River. After the Arkansas River passes Tulsa, flows from tributaries such as the Verdigris River, the Neosho River, and the Illinois River all contribute to the improvement of the quality of the mainstem. The Canadian River also is of better quality than the mainstem of the Arkansas. However, it is not of as high a quality as the other tributaries. The net effect of this dilution is that the quality of the water in the Arkansas River leaving the state of Oklahoma is better than that which enters the state through this water way.

The U. S. Geological Survey has for several years been analyzing samples of water at various stations in the state of Oklahoma for chemical analyses and frequency analyses. In this study it was felt justifiable to run frequency analysis on the data available from water in the mainstem of the Arkansas River, and the various tributaries to the Arkansas River before it flows into the state of Arkansas. The reason for this justification is that additional records are available since the last published frequency analysis had been made on these waters. Also it was felt that it would be of interest to make frequency analysis of various portions of this record. It was felt that there might be a possibility that the chemical quality of the waters could have changed during the period of record and that by taking various periods this would be shown. Frequency analyses were made on the following streams at the stations listed.

1. Mainstem of Arkansas River
    (a) Arkansas City - Station 1465
    (b) Ralston - Station 1525
    (c) Sand Springs - Station 1644
    (d) Van Buren - Station 2505
2. Cimarron River near Perkins - Station 1610
3. Verdigris River near Inola - Station 1786
4. Neosho River near Ft. Gibson - Station 1936
5. Illinois River near Gore - Station 1980
6. Canadian River near Nobel - Station 2291

No frequency analyses were made on Lee Creek, Spavinaw Creek, or Poteau River. The records available for these three streams are very scarce or not available at all and do not warrant frequency analysis.

The parameters analyzed included chlorides, sulfates, total hardness and dissolved solids. The frequency analysis of these various parameters at each station were derived using the formula $P = m/n+1$ where, P is the percentage of time the parameter was equal to or less than the station value; m is the rank of the parameter with the annual of the highest magnitude assigned the rank of 1. The second highest annual values is assigned the rank of 2 and so on until each parameter in the maximum annual series was ranked; n is the number of years of record. A computer program was written which ranked the parameters and then computed the frequency of the parameters. Three separate frequency analyses were made at each station. These were (1) all years of record; (2) the last ten years of record (3) the years of record ealier than the last ten years.

a. Mainstem of Arkansas River

Figures 29 through 32 show the frequency analysis for the parameters under study for stations on the mainstem of the Arkansas River. If the frequency analysis conducted here for all years of available records are compared with other frequency analysis that have been conducted, such as those that were used to set the Oklahoma Water Quality standards, it can be seen that there is very close agreement with the values obtained. The present study in most cases will show a slightly lower value than previous studies. This can be explained if one observes the last ten years of records for the parameters chlorides and dissolved solids. It can be seen that the last ten years of record provides a much lower curve than the available records previous to the last ten years. Thus, analysis that would have been made previous to this time and including less years of record would not include some of these years with better quality water yielding values greater than the present frequency curves.

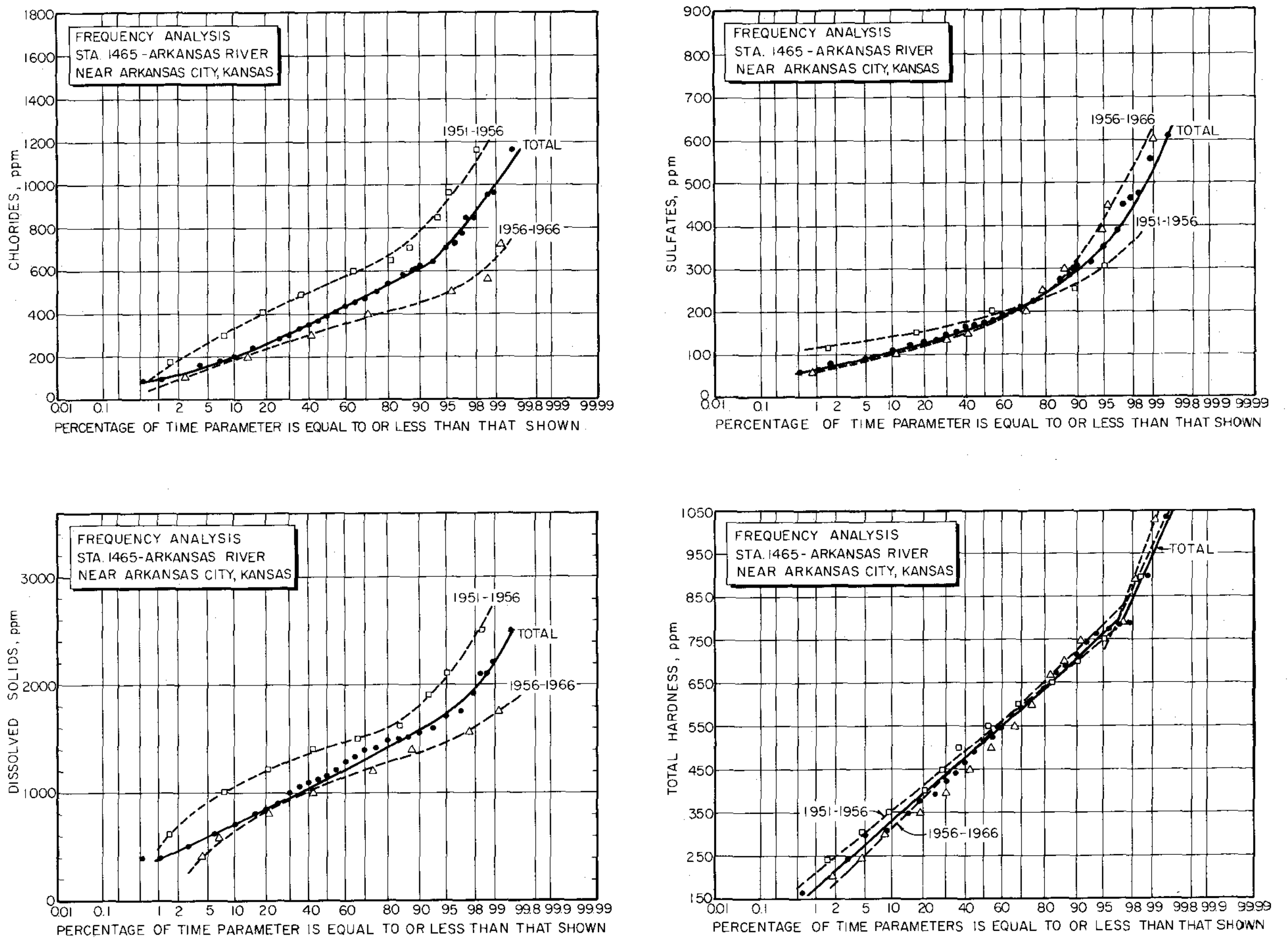


Figure -29- Frequency Curves

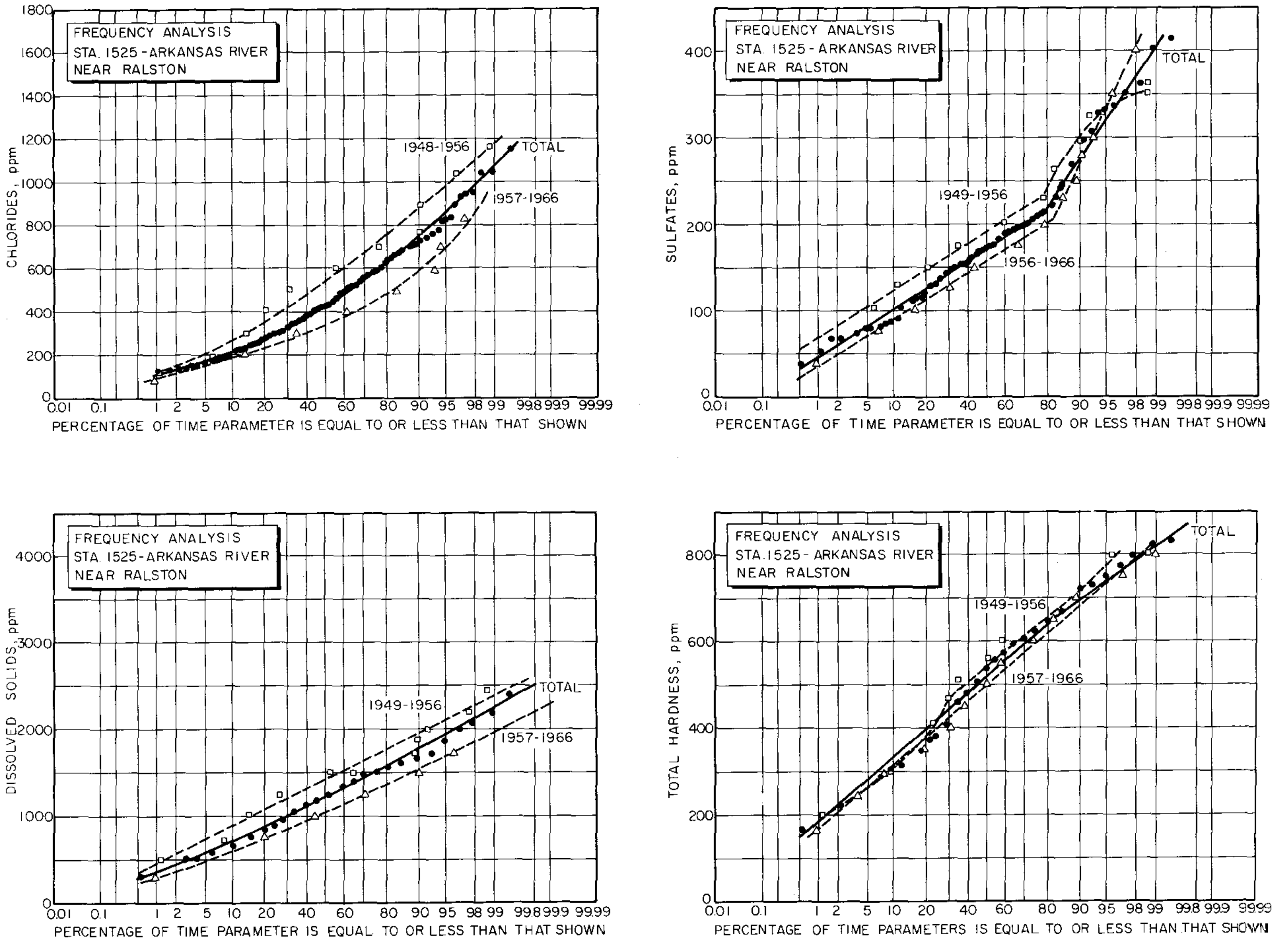


Figure -30- Frequency Curves

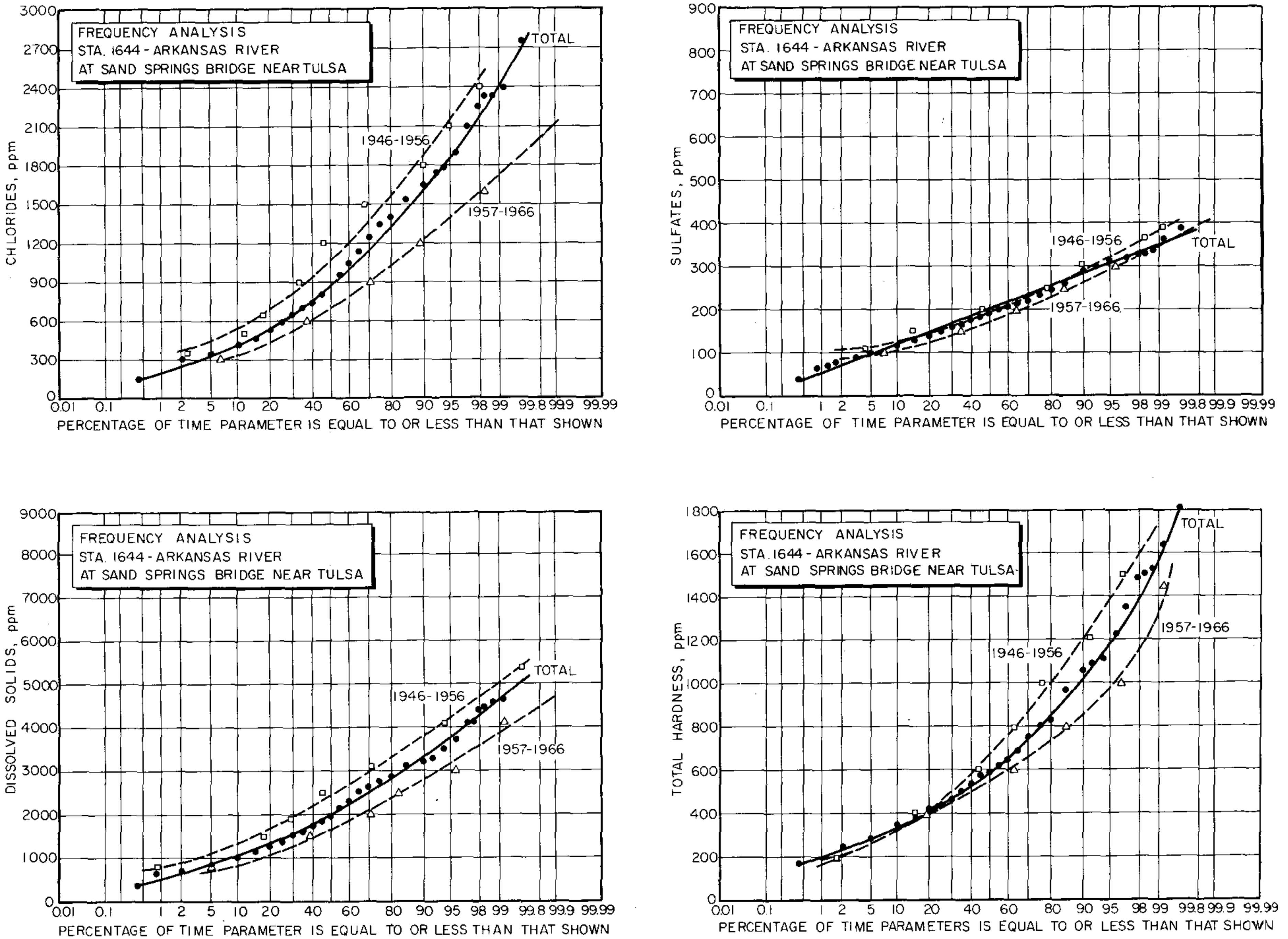


Figure -31- Frequency Curves

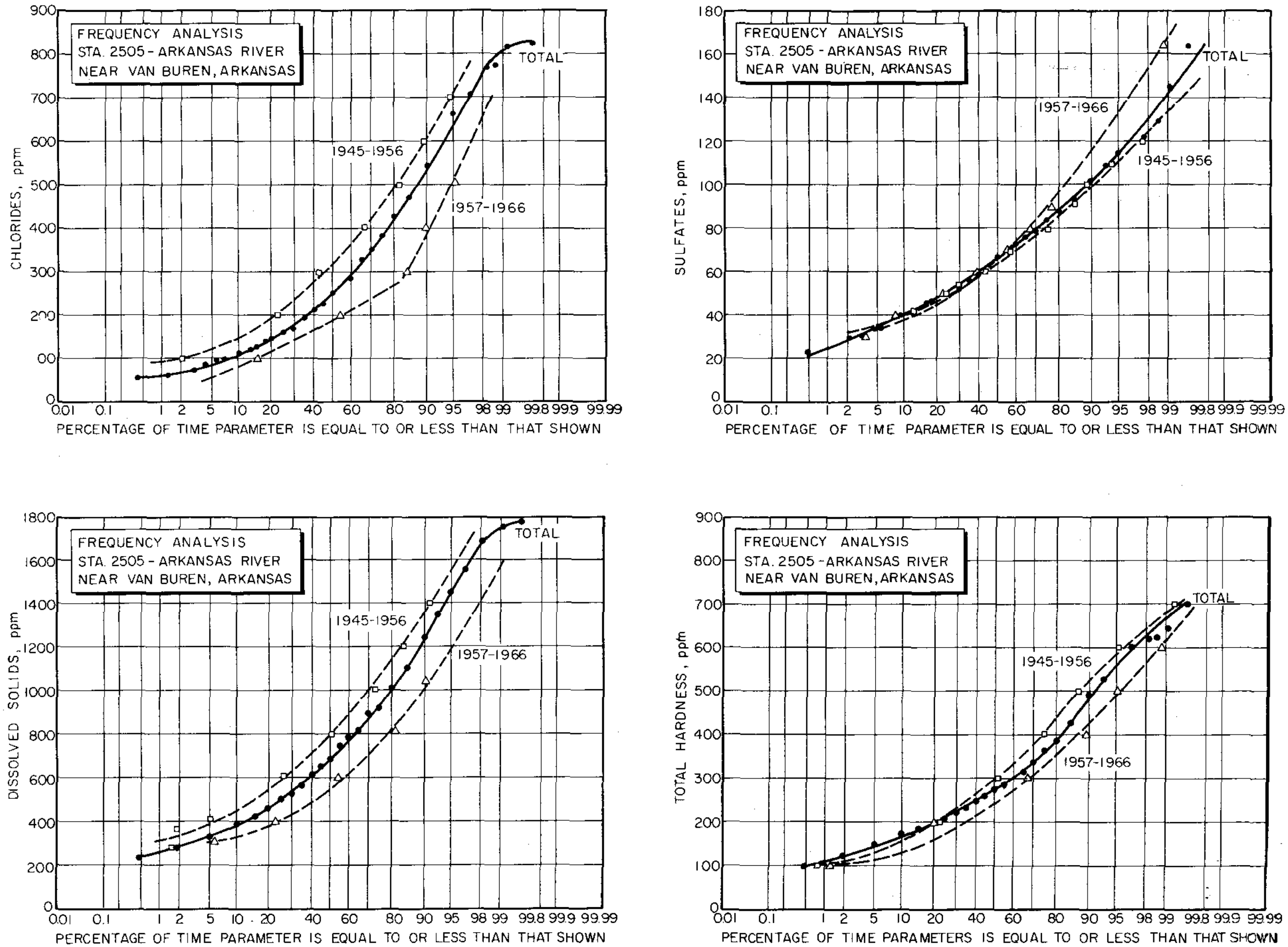


Figure -32- Frequency Curves

It is interesting to note also that in these studies, the total hardness and the sulfate concentrations do not exhibit the same trends as do the chlorides and dissolved solids. This could stem from the fact that many of the chlorides values from earlier years could have resulted from the discharge of oil field brines into the stream. It is reasonable to assume that in the last few years, a great deal of the salt water pollution from the oil fields has been corrected and therefore, the quality of the water as related to chlorides and dissolved solids should have improved. However, the concentrations of sulfates and hardness would not be a result of oil field pollution but simply a result of leaching of these chemicals from the soils. Therefore, there is essentially no difference in the frequency analyses for the three periods for total hardness and sulfates. The difference in the three periods of frequency analysis for chlorides can be seen in Table 41. These findings could have a significant ramification when considering the Oklahoma water quality standards. As mentioned previously the standards have been set based upon all years of record, however, if only the last ten years of records are considered then concentrations much less than those now set could be considered as the water quality standards for that particular parameter.

b. Tributaries to the Mainstem of the Arkansas River

Figure 33 through 37 show the frequency analysis for the tributaries to the Arkansas River. In these tributaries the chemical analysis in all streams except the Cimarron River and the Canadian River show the water to be of such quality that the

Table -41-

Duration Table of Chlorides at Various Stations on the Arkansas River

Results in mg/l	Percentage of time parameter is equal to or less than that shown						
Years	5	10	25	50	75	90	95
			Arkansas City - Station 1465				
1951-56	265	340	440	540	640	780	920
1956-66	140	190	260	330	400	450	500
all	160	200	280	400	500	610	710
			Ralston - Station 1525				
1949-56	200	270	390	540	720	880	980
1957-66	160	180	250	340	450	590	700
all	180	210	300	430	600	760	860
			Sand Springs - Station 1644				
1946-56	440	540	750	1060	1490	1860	2130
1957-66	290	330	470	700	990	1230	1400
1963-67	250	350	510	730	990	1240	1420
all	330	420	600	890	1250	1600	1850
			Van Buren, Arkansas - Station 2505				
1945-56	120	150	215	320	455	600	710
1957-66	55	80	130	190	250	400	510
all	85	110	160	250	380	530	630

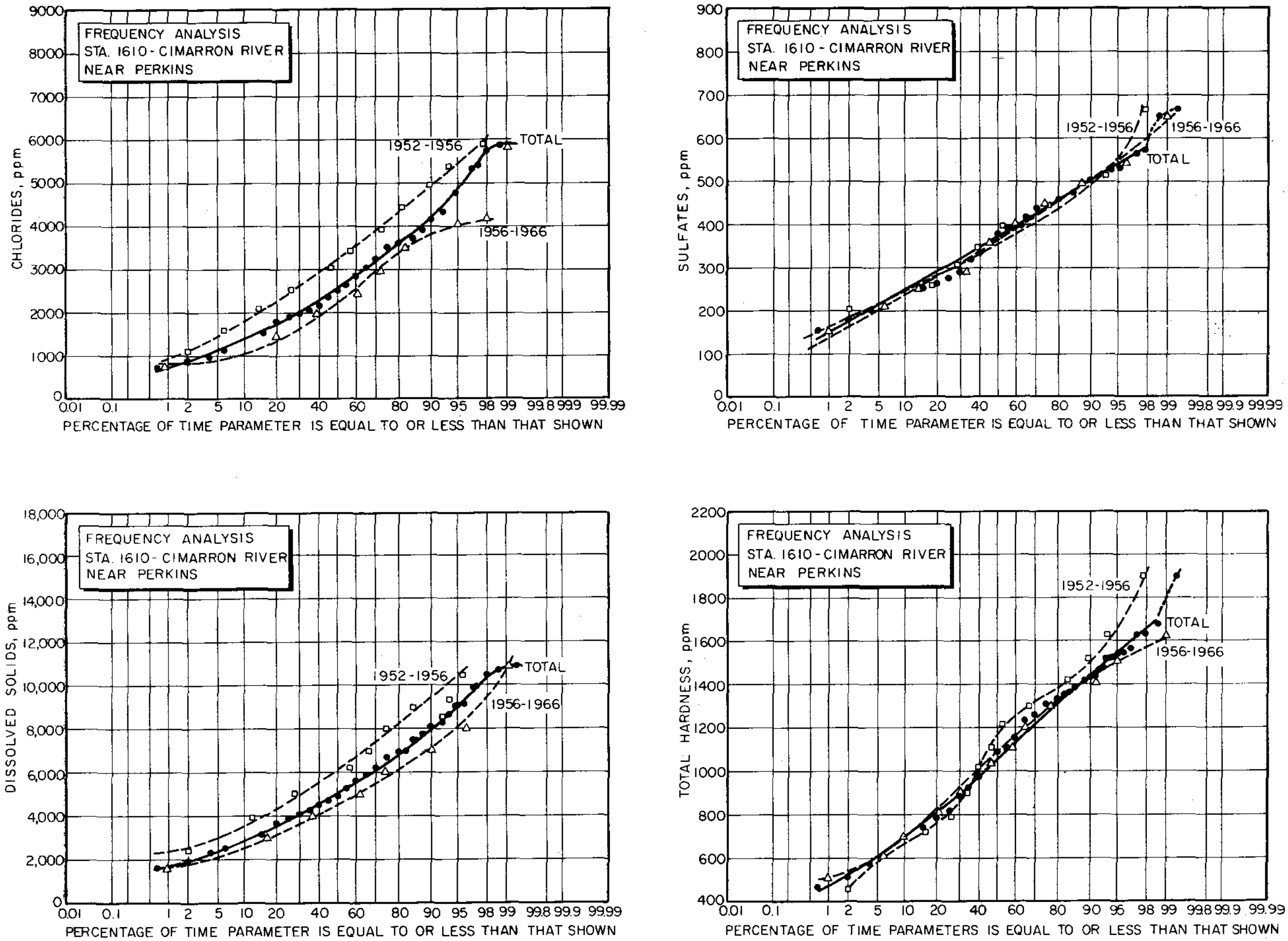


Figure -33- Frequency Curves

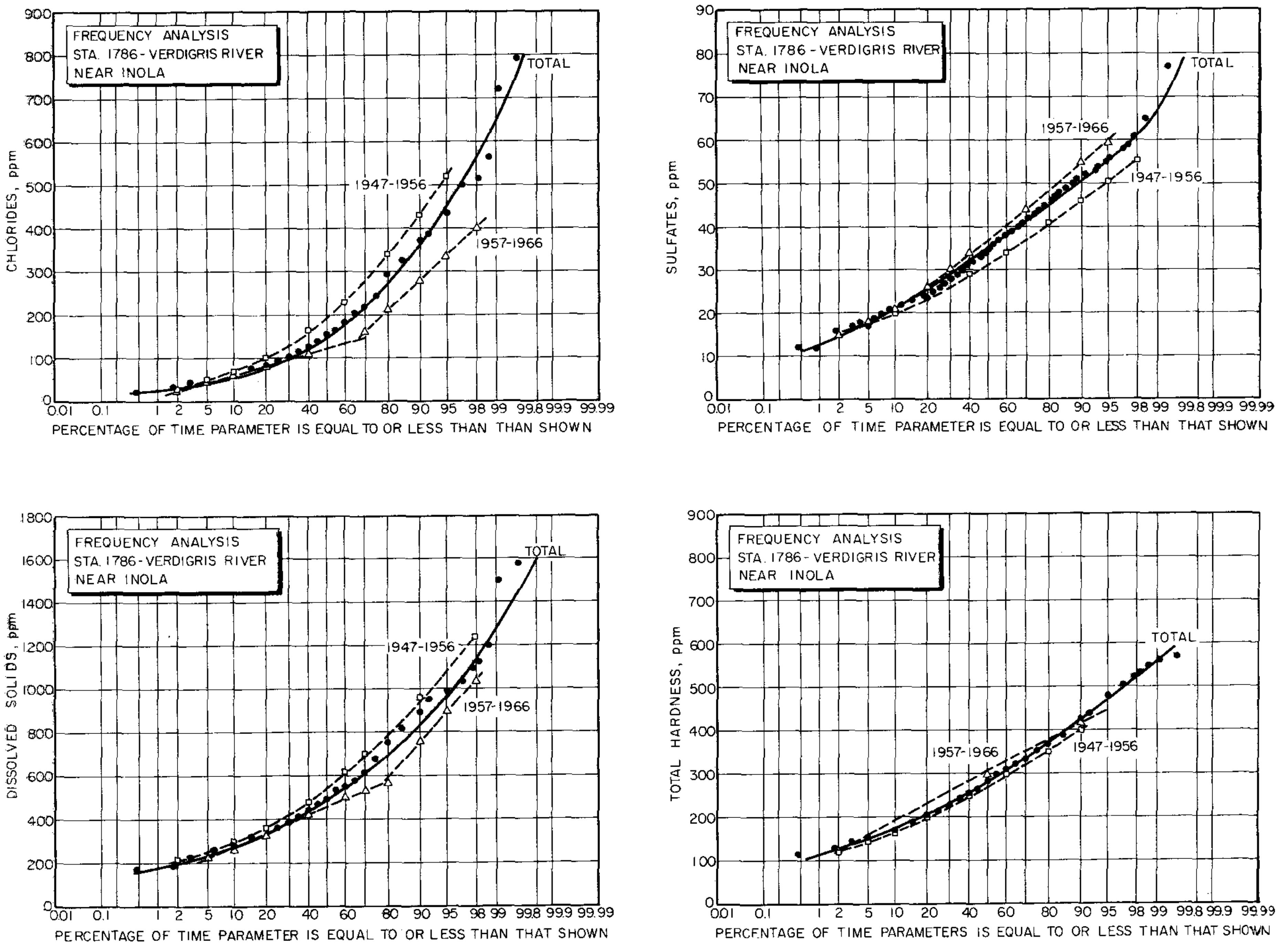


Figure -34- Frequency Curves

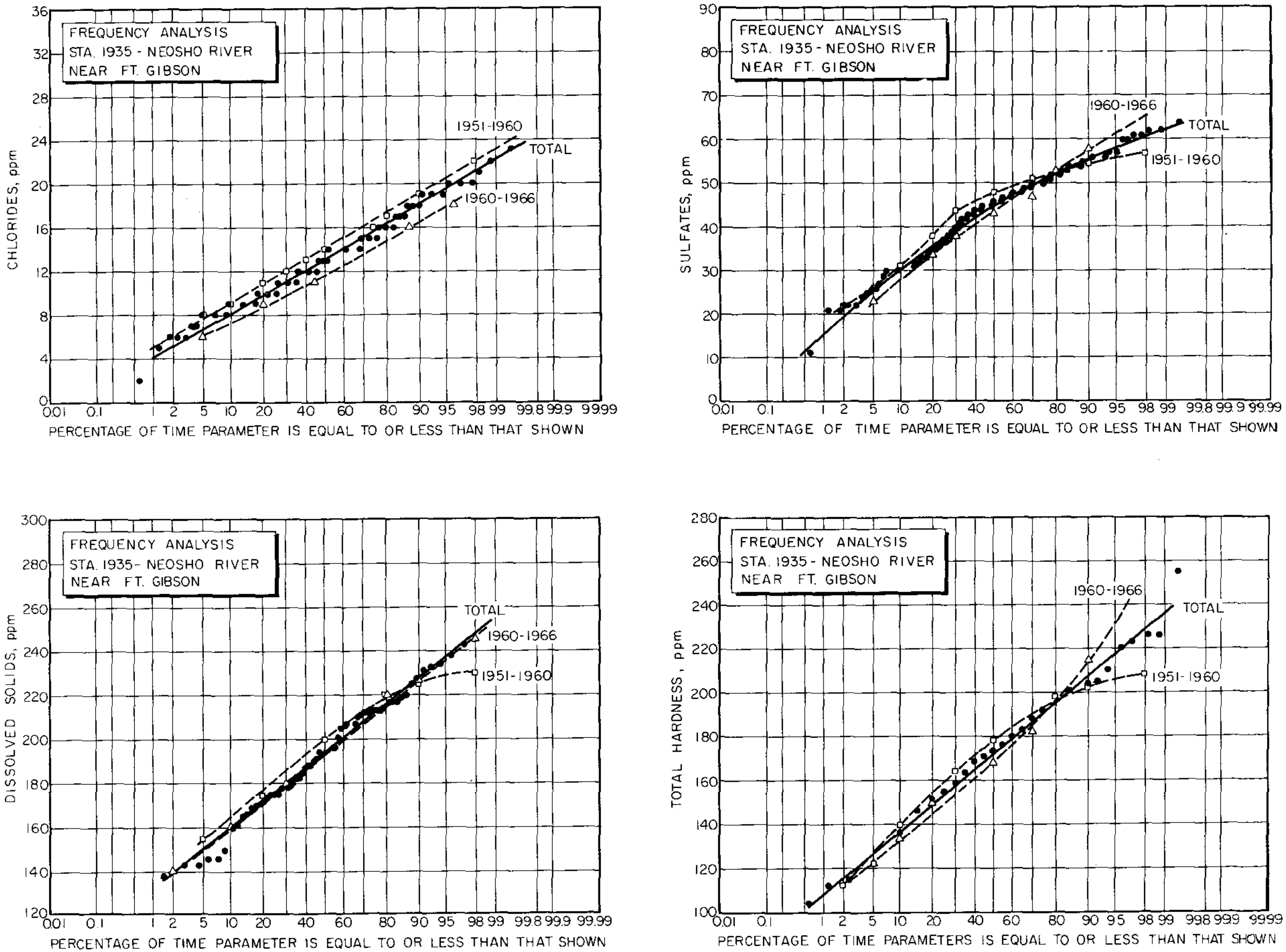


Figure -35- Frequency Curves

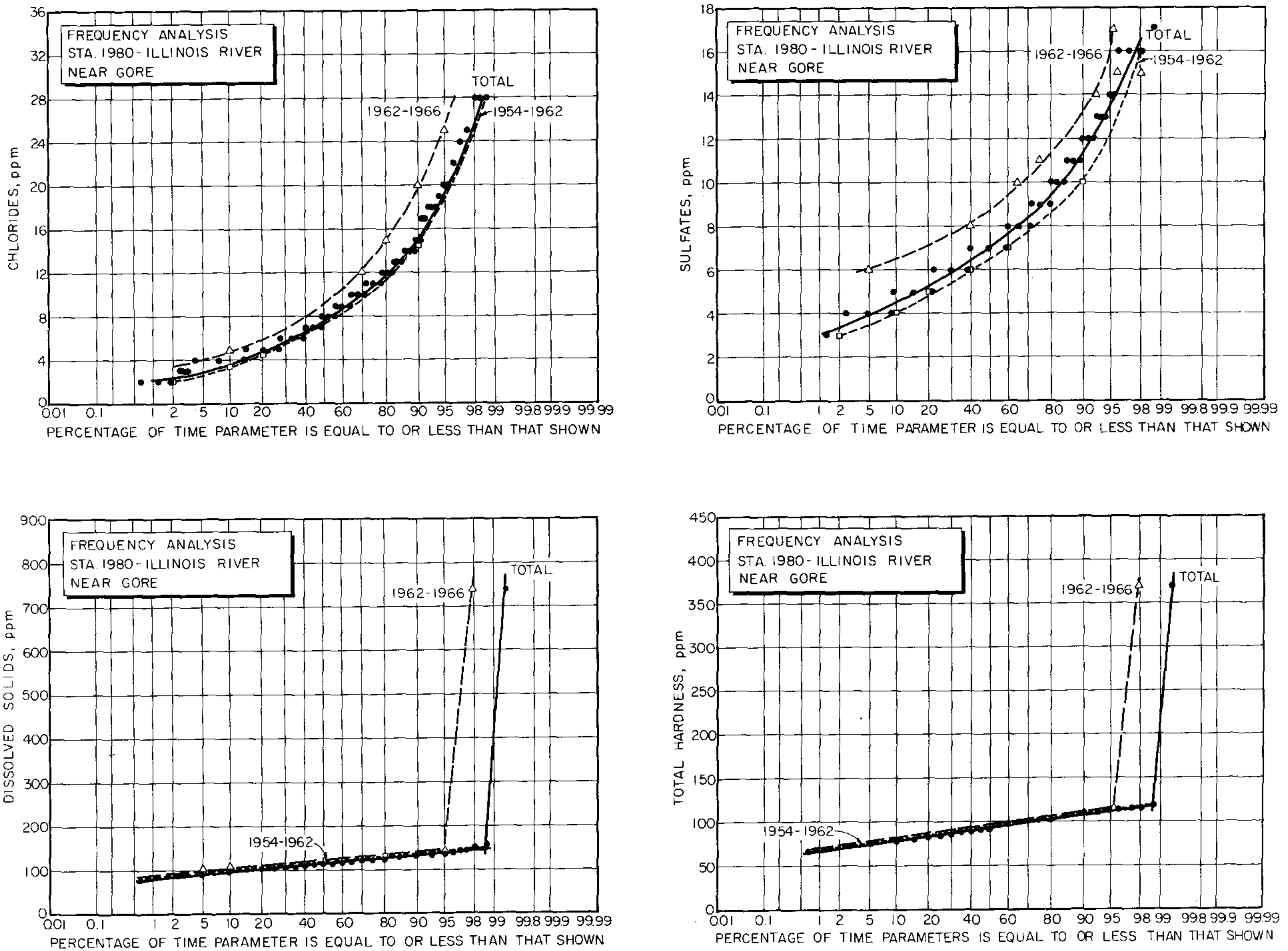
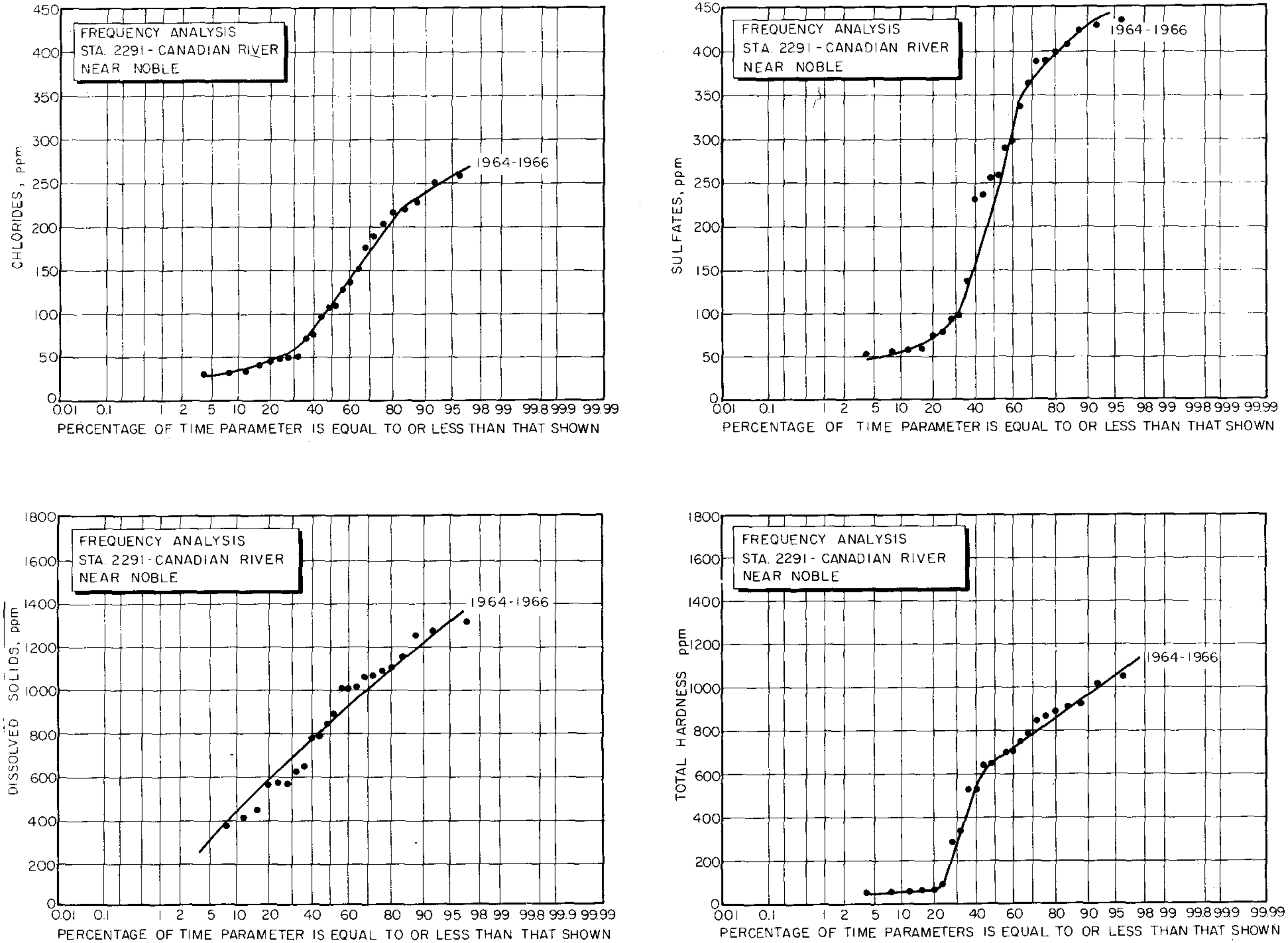


Figure -36- Frequency Curves

Figure -37- Frequency Curves



concentrations of the parameters in the study area are of no consequence, except that they do provide dilution water to the mainstem of the Arkansas. The Cimarron River, however, is a stream which has a very low quality water, and again the frequency analysis vary greatly with the various period of record. The data show that during the last ten years of record the quality of the stream has improved. This could also be due to the cleaning up of oil field brines.

2. Correlation of Stream Flow and Quality

During the course of the water quantity studies the short length of record available made it necessary to investigate the generation of synthetic streamflow data. It then seemed reasonable to see if a correlation between streamflow and water quality could be developed. If this correlation could be determined then synthetic water quality data could also be generated from the synthetic streamflow data.

In this study four regression models, in logarithmic form, were used for expressing the relationship between the different parameters of inorganic water quality and streamflow. The average monthly concentrations of chlorides, dissolved solids, hardness, and sulfates at five stations (shown in figure 38) located in the Arkansas River Basin were investigated to determine if they could be related to monthly streamflow by a regression model. Either the current monthly streamflow or the current monthly streamflow and its antecedent flow were considered as independent variables in four regression models tested. Significant tests were performed for evaluating the suitability of the model.

All data on water quality and streamflow used in this study

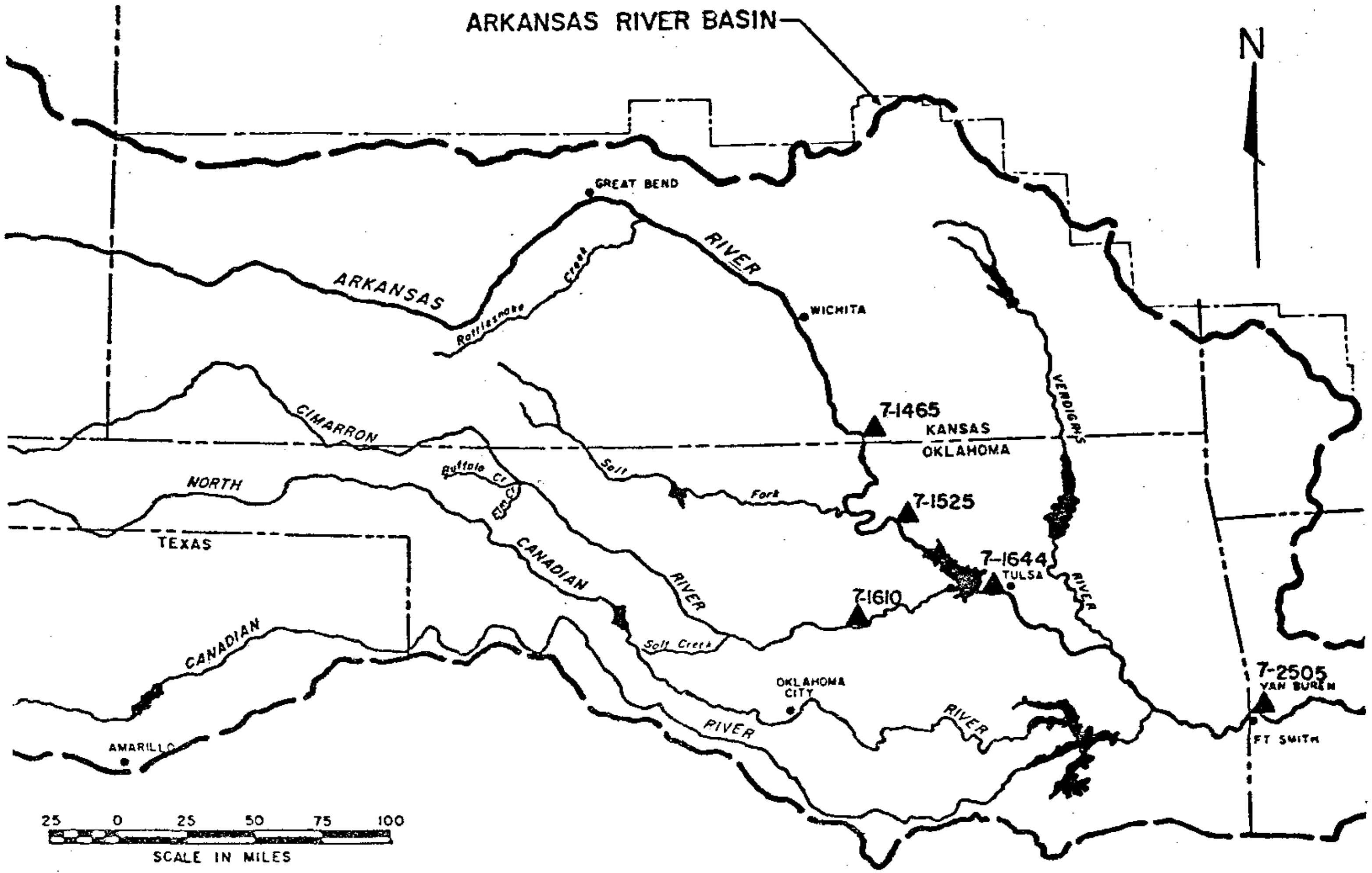


Figure 38 Location of Investigated Stations

were taken from the water-supply papers published by the Geological Survey, U. S. Department of the Interior (USGS). The data on water quality and streamflow are time-weighted averages with units in parts per million (ppm) and cubic feet per second (cfs), respectively. In this study the quality-flow relationship involved essentially unregulated streamflow.

a. Quality-Flow Relationship

Normally, changed in quality of river water are caused by the variable quality of direct surface runoff and groundwater inflow that make up the flow in the stream. During high flow conditions, the concentration of dissolved minerals in a stream is low because the principal flow component is surface runoff that hashad little time of contact with soluble mineral materials. During low-flow conditions, the concentration is high because the principal flow component is ground-water inflow which has had longer duration of contact with soluble materials.

In assessing the effect of streamflow on the change in dissolved mineral concentrations in the stream, the antecedent flow was considered in this study with the current streamflow to account for the influence of prior leaching of the soluble materials in the basin. It is possible that after being leached by prior surface runoff and ground-water flow, residual moisture conditions, amount of soluble minerals remaining, etc., can affect the degree of leaching of dissolved minerals by the succeeding surface runoff and ground-water flow.

In an attempt at expressing the monthly concentration of dissolved minerals in the stream as a function of either the current monthly streamflow or the current monthly streamflow and its antecedent flow, the regression models shown below were used:

$$\text{Model 1:} \quad \log C = a + b_1 \log Q \tag{1}$$

$$\text{Model 2:} \quad \log C = a + b_1 \log Q + b_2(\log Q)^2 \tag{2}$$

$$\text{Model 3:} \quad \log C = a + b_1 \log Q + b_3 \log Qa \tag{3}$$

$$\text{Model 4:} \quad \log C = a + b_1 \log Q + b_2 (\log Q)^2 + b_3 \log Qa \tag{4}$$

In these equations C is the monthly concentration of chlorides, dissolved solids, hardness, and sulfates, respectively, in parts per million (ppm); Q denotes the current monthly streamflow in cubic feet per second (cfs); a is the intercept; b's are regression coefficients; Qa denotes the antecedent flow index, which is:

$$(Qa)_k = \sum_{i=1}^{3} \frac{Qi}{i} \tag{5}$$

Q is the monthly flow, and i represents the number of months prior to the kth month. Model 1 is a simple linear regression. Model 3 is a multiple linear regression with two independent variables. Models 2 and 4 can be treated as multiple linear regression models by considering $(\log Q)^2$ as an independent variable.

Regression analysis in the study of quality-flow relationship is applicable mainly because this method requires neither the dependent variable nor the independent variable to follow a probability distribution. In order to improve the reliability of the results by the application of regression analysis, two steps were taken. First the statistical characteristics of the data for streamflow and water quality were checked before the analytical work was conducted. Statistically, the monthly streamflow and dissolved mineral concentrations of different months are serially correlated and non-homogenous. If these monthly averages are used, the computed standard error of estimate for a regression equation would be an average of the standard errors of the individual monthly averages. In this study the monthly averages of streamflow and water quality coming from the same month were grouped together for statistical analysis. Each set of monthly averages is approximately a set of homogenous samples taken from a population and within each set of samples each monthly average can be said to be independent of the other. Secondly, monthly averages of water quality and streamflow and other derived data was transformed into logarithmic values before the regression analysis was undertaken. A logarithmic transformation can achieve the linearization of the regression equation.

In justifying the suitability of any model it is important to examine calculated standard errors of estimate and to check results of significance tests for partial regression coefficients. The standard error of estimate (also called standard deviation of residuals) which is the standard deviation of the distribution of residuals about the regression equation is a criterion for measuring the reliability of a regression model. The significance test provide a means for determining whether the regression coefficient is significantly different from zero or not under an assigned level of significance. The statistic, t, was used in the significance test in thie study. For a linear regression with k independent variables.

$$Y = a + b_1X_1 + b_2X_2 = ... + b_kX_k$$

The addition of a new independent variable x_{k+1} will decrease the standard error of estimate if this added variable really affects the dependent variable Y. Whether this variable should be included in the regression equation can be determined by examining how much the standard error of estimate is decreased and by checking results of the significance test for partial regression coefficients. An illustration of the use of calculated standard error of estimate and the significance test for regression coefficient as criteria in justifying a model is shown in table 42. In this case, an addition of the antecedent flow index, Qa, to the original simple linear regression, $\log C = a + b_1 \log Q$, made a significant decrease in standard error of estimate (from .06811 to .5158). This fact aided by a satisfactory result of significance test for regression coefficient enables one to conclude that both the current monthly streamflow and its antecedent flow index have a significant effect on the variation of chloride concentration in the stream for that specified case.

Selection models for different months at stations investigated in this study are summarized in Table 43. Aided by the calculation of standard error of estimate, several levels of significance which include .1%, 1%, 5%, 10%, 20%, and 30% were used in the two-taled t test in making the selection of models.

Table -42-

Example of Justifying the Regression Model

Model	Intercept a	Regression Coefficient B_1	B_3	log $\bar{C}$	Standard error of estimate
1: $\log C = a + b_1 \log Q$	3.62912	-.33510**	-------	2.53608	.06811
2: $\log C = a + b_1 \log Q + b_3 \log Qa$	3.98479	0.24380**	0.19527**	2.53608	.05158

Remarks: (1) C, $\bar{C}$, Q, and Qa are chloride concentration, mean of chloride concentration, current monthly streamflow, and antecedent flow index, respectively, at station 7-1465 for calendar May.

(2) Sample size is 15.

(3) ** indicates that the regression coefficient tested is significant at 1% level.

b. Evaluation of the Regression Relationship

Normally the concentrations of dissolved minerals in a stream varies inversely with the streamflow. Because of many factors, geological, meterologic, man-made, etc., which affect the relationship between inorganic quality of river water, and streamflow, there was no common regression model found in this study. However, the four different models used in this study were shown to provide a useful means of detecting the relationship between some parameters of inorganic water quality and streamflow by the application of the regression analysis. Table 44 shows a summary of the applicability of the models for the five stations investigated. For relating chloride concentrations and streamflow in regression form, model 1 is the one which prevailed most frequently nearly 50 percent frequency (i.e. 28/60) model 3 reached next in frequency (approximately 25 percent frequency); 2 and 4 were the least applicable regression models. Concerning the relation between concentration of dissolved solids and streamflow, models 1 and 3 were applicable with a frequency of 33 percent and the suitability of models 2 and 4 was not pronounced. With respect to hardness, the regression models were applicable with a frequency of only 33 percent, model 3 was the most significant one with a frequency of occurrence of 25 percent. Concerning the concentration of sulfates it is obvious that the suitability of each model is poor.

The occurrences of a regression relationship (any of the four models) between each parameters of inorganic water quality and streamflow are compared in Table 45. The frequency of occurrence of an acceptable regression relationship was highest for chloride concentration (80 percent of the total, 100 percent for station 7-1465, 92 percent for station 7-1525 and 7-1655, 67 percent for station 7-1610, and 50 percent for station 7-2505.) The frequency of occurrence of statistically significant regression equations for dissolved solids are nearly as high as for chloride (74 percent of the total, 67 percent for stations 7-1465 and 7-1610, 92 percent for station 7-1525 and 7-1644, and 60 percent for station 7-2505). For hardness, the frequency of occurrence of a regression relationship with streamflow was low (33 percent of the total, 33 percent for station 7-1465, 25 percent for station 7-1525, 8 percent for station 7-1610, and 50 percent for stations 7-1644 and 7-2505.) The frequency of occurrence of a suitable regression model for sulfate concentration was very low (only 17 percent for station 7-1610, and 8 percent for stations 7-1644 and 7-2505.

It is seen from Table 45 that the stations idffer rather widely with respect to regression relationships for inorganic water quality and streamflow. Generally, stations 7-1465, 7-1525, and 7-1644 were better in this respect than station 7-1610 and 7-2505. For stations 7-1465, 7-1525, and 7-1644, all located in the Arkansas River upstream from Tulsa, Oklahoma, the prevalence of a regression relationship can be classified as good to fair for either chloride or dissolved solids and streamflow, but poot for either hardness or sulfates and streamflow. Station 7-1610, located in the Cimarron River, can be ranked fair in regard to prevalence of a relationship between either chloride or dissolved solids and streamflow, but poor for either hardness or sulfates and

C. Biochemical Quality

There are very little biochemical water quality data available at the present time. During the present study, all data which was available was obtained from the Department of Health, Education, and Welfare and from the U. S. Geological Survey. Study of this material has very clearly revealed a definite deficiency in biochemical data but even the small amount available did provide indication that there is a very serious problem in this area. The data from each of the sources is discussed in more detail below.

1. Data from the Department of Health, Education, and Welfare

The biochemical water quality data available from the Department of Health, Education and Welfare is shown in Figure 39 through 40. Figure 39 shows the data obtained by the agency during three different periods (years 1961 through 1963, years 1963 through 1965, and years 1964 through 1965). Data was obtained at 8 sampling stations and included only temperature and dissolved oxygen (D.O.). The lowest dissolved oxygen observed in Bird Creek (3.8 mg/l). However, the average DO at this point was 6.9 mg/l. At all other stations the lower DO observed was always greater than 4.0 mg/l. The lowest temperature was 32° F and highest temperature observed was 90° F.

During the summer of 1965 the Federal Water Pollution Control Administration undertook a comprehensive study in the Arkansas River and its tributaries. The administration is carrying out an investigation of the water quality in the Arkansas River Basin in three phases: (1) The reach extending through Keystone

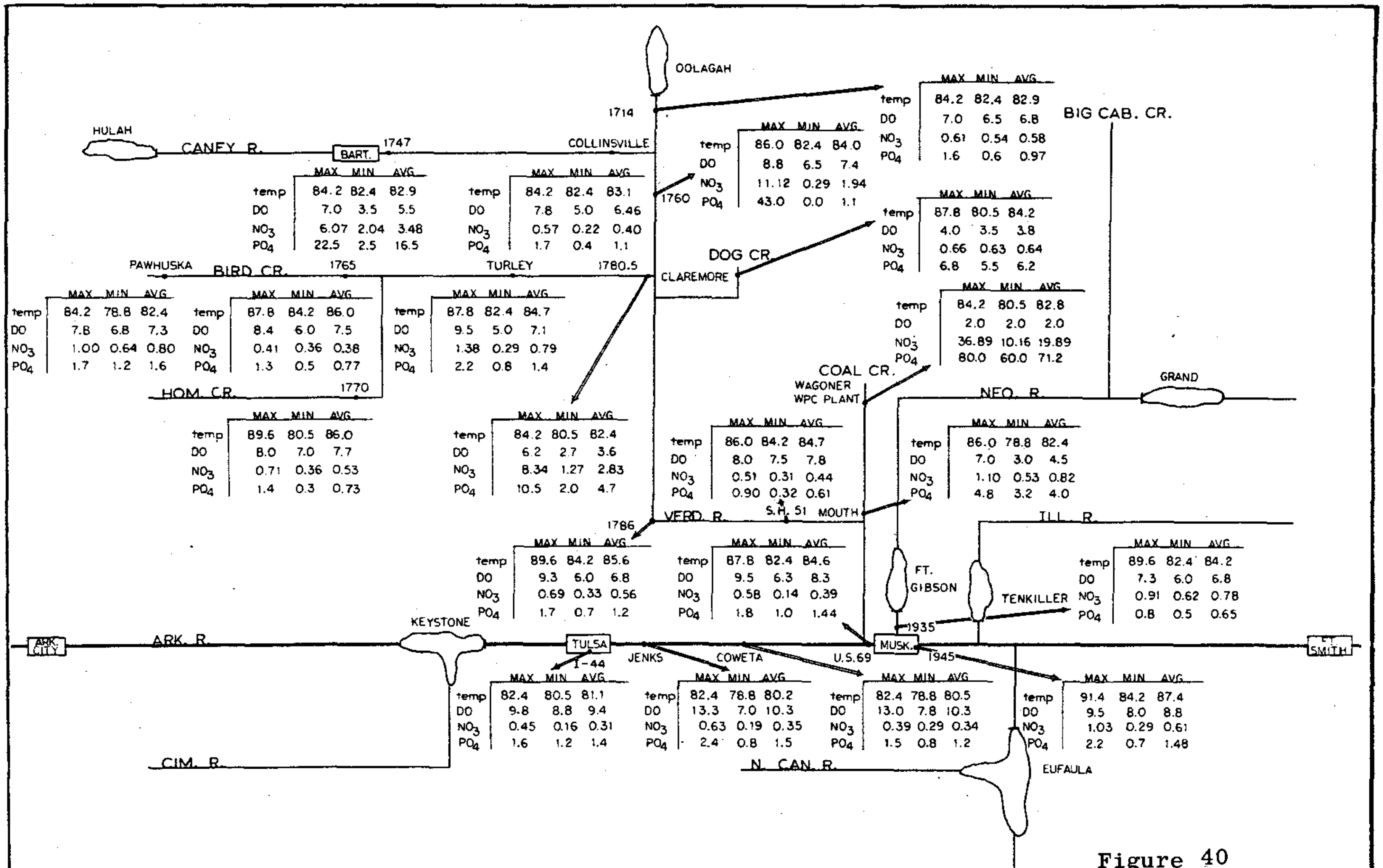


Figure 40

OKLAHOMA - ARKANSAS PLANNING STUDIES
WATER QUALITY ANALYSIS
DATA OBTAINED FROM
DEPT. OF HEALTH, EDUCATION, AND WELFARE
SUMMER 1965

Reservoir through the Tulsa area to Jenks, Oklahoma; (2) The reach extending through Tulsa to Muskogee; (3) The reach extending from Muskogee to the Arkansas Stateline. The study conducted during 1965 included only the reach extending from Tulsa to Muskogee (phase 2) and was the only data available for analysis. Sampling was conducted only during the three summer months (June, July, and August). Some stations were sampled throughout the three-month period, while others were not.

The data are summarized in Figure 40. The average temperature was in the mid 80's in all streams throughout the study area. The dissolved oxygen in the Arkansas River was at a high level; the lowest obtained being 7.0 mg/l. However, in Caney River a DO of 3.5 mg/l was observed and the lowest DO observed in the study area was 2.7 mg/l in Bird Creek. In general rather high DO level were observed throughout the study area. The nitrate concentration was rather low. The highest observed in the Arkansas River was 1.03 mg/l and highest in any of the tributaries was in the Verdigris River (11.12 mg/l). The phosphate concentration was low in the Arkansas River with the maximum observed being 2.2 mg/l. However, in the Verdigris River a maximum phosphate concentration of 43 mg/l was observed.

From this study, one might conclude that there was no serious pollution problem with regard to constitiants of biochemical significance in the Arkansas River or its tributaries. However, date from the U. S. Geological Survey presented a different picture.

2. <u>Data from U. S. Geological Survey</u>

Figure 41 shows data obtained by the Beological Survey during the years 1961 through 1963. It includes 8 sampling points for which dissolved oxygen and temperature were analyzed. The lowest dissolved oxygen observed in the Arkansas River was 4.5 mg/l and the lowest observed in the Verdigris River was 4.4 mg/l. The temperature ranged from 32° F to 95° F.

Figure 42 shows the data obtained by the U. S. Geological Survey during the year 1966 and includes analyses from 5 sampling points for nitrates and phospates. The maximum nitrate concentration observed in the Arkansas River was 4.9 mg/l and the maximum nitrate concentration observed in the Verdigris River was 19.0 mg/l. The maximum phosphate concentration observed in the Arkansas River was 1.5 mg/l and the maximum concentration in the Verdigris River was 11.0 mg/l.

The most thorough biochemical water quality sampling program yet accomplished by the U. S. Geological Survey during water year 1967. The results of these analyses are presented in Figure 43. Nitrate concentration, phosphate concentration, pH, BOD, and temperature at various stations on the Arkansas River and its tributaries are shown. The nitrate concentration varied a great deal and in most of these stream significantly high maximum nitrate concentrations were observed. The maximum nitrate concentration observed in the Arkansas River was only 9.3 mg/l, however, in the Verdigris River the maximum was 48 mg/l; in Pryor Creek, 130 mg/l; and in Caney River, 26 mg/l. It is interesting to note (see figure 43) that in general the high concentrations were observed in the

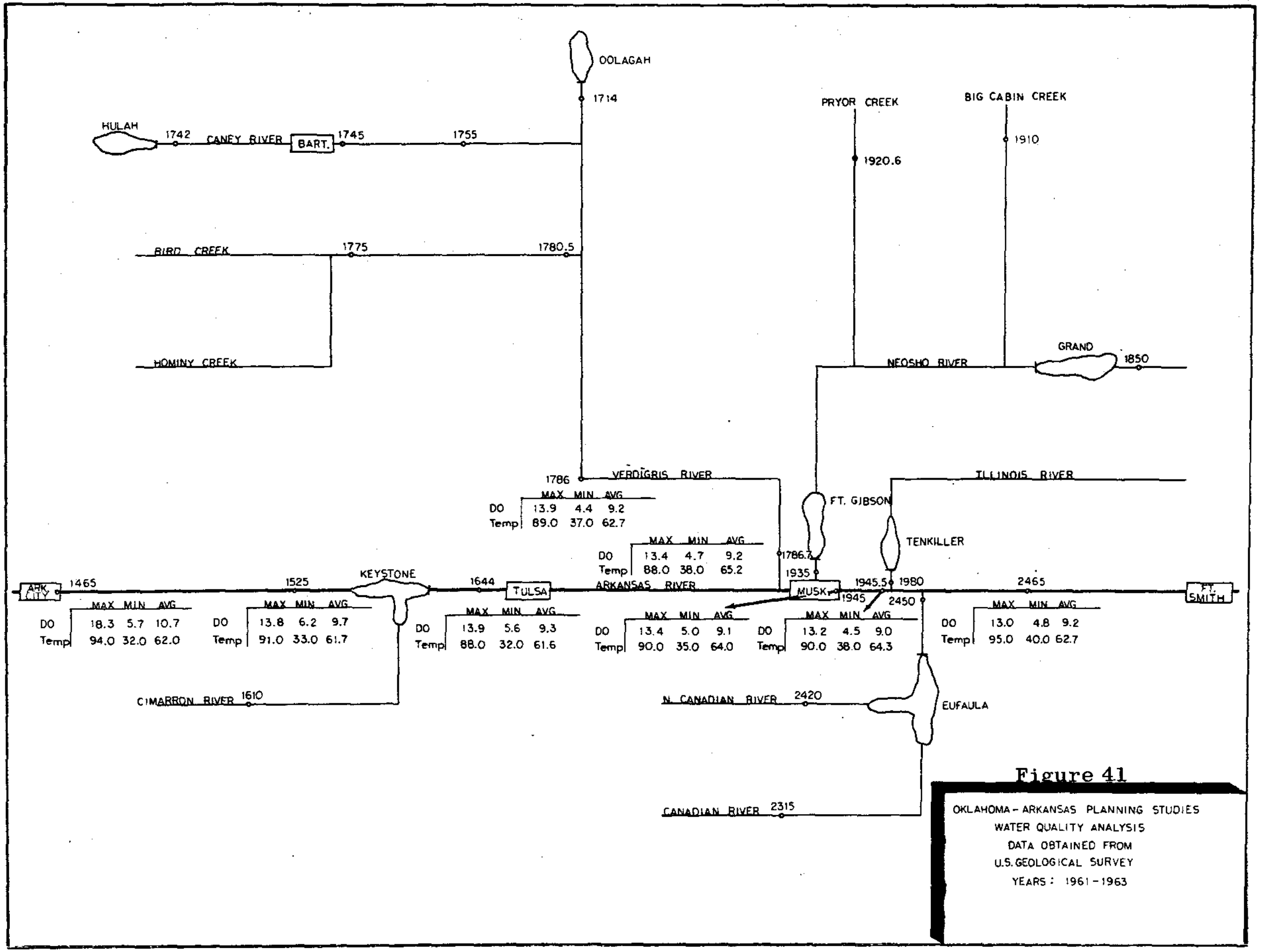


Figure 41

OKLAHOMA - ARKANSAS PLANNING STUDIES
WATER QUALITY ANALYSIS
DATA OBTAINED FROM
U.S. GEOLOGICAL SURVEY
YEARS: 1961 - 1963

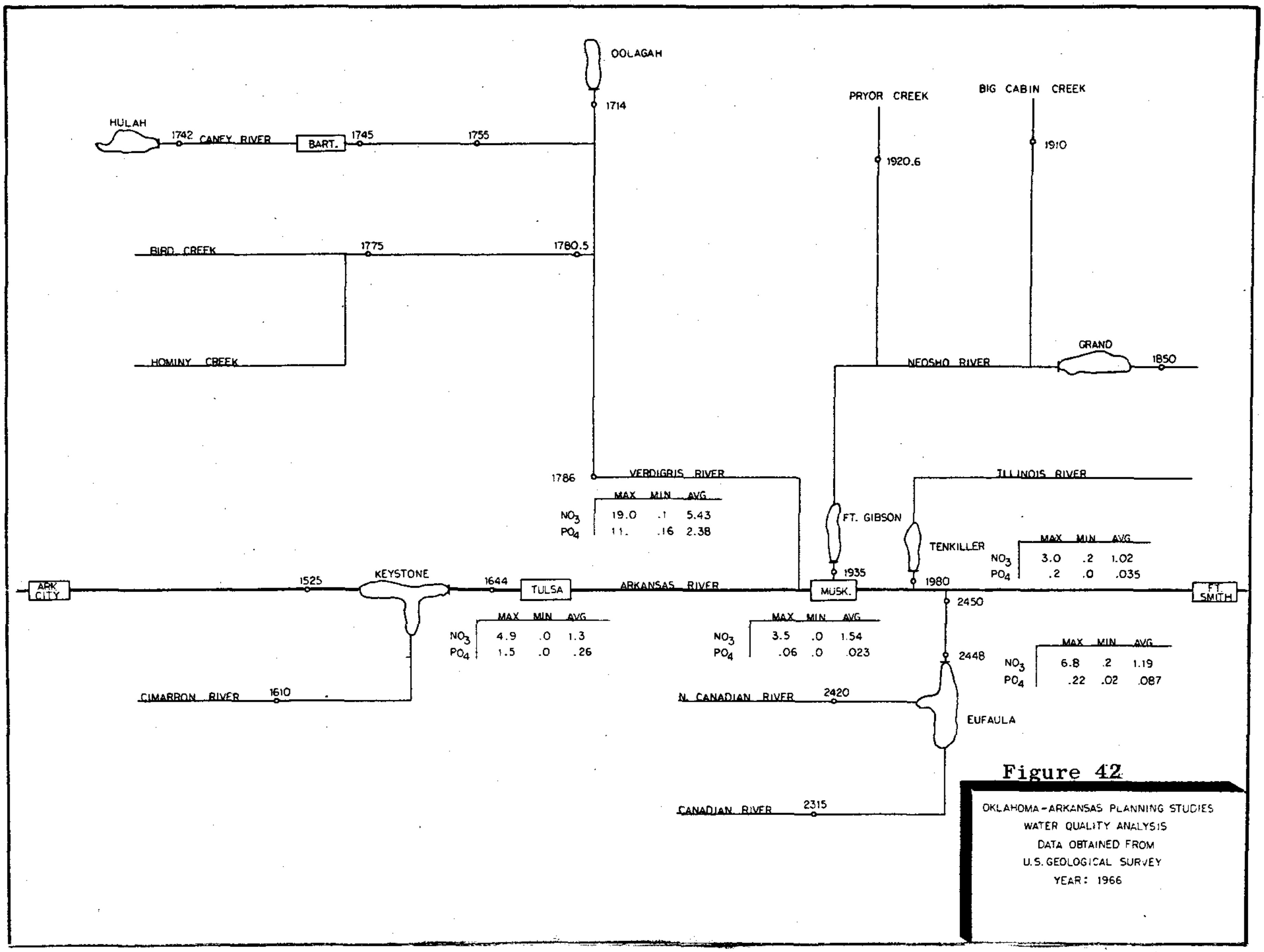


Figure 42

OKLAHOMA-ARKANSAS PLANNING STUDIES
WATER QUALITY ANALYSIS
DATA OBTAINED FROM
U.S. GEOLOGICAL SURVEY
YEAR: 1966

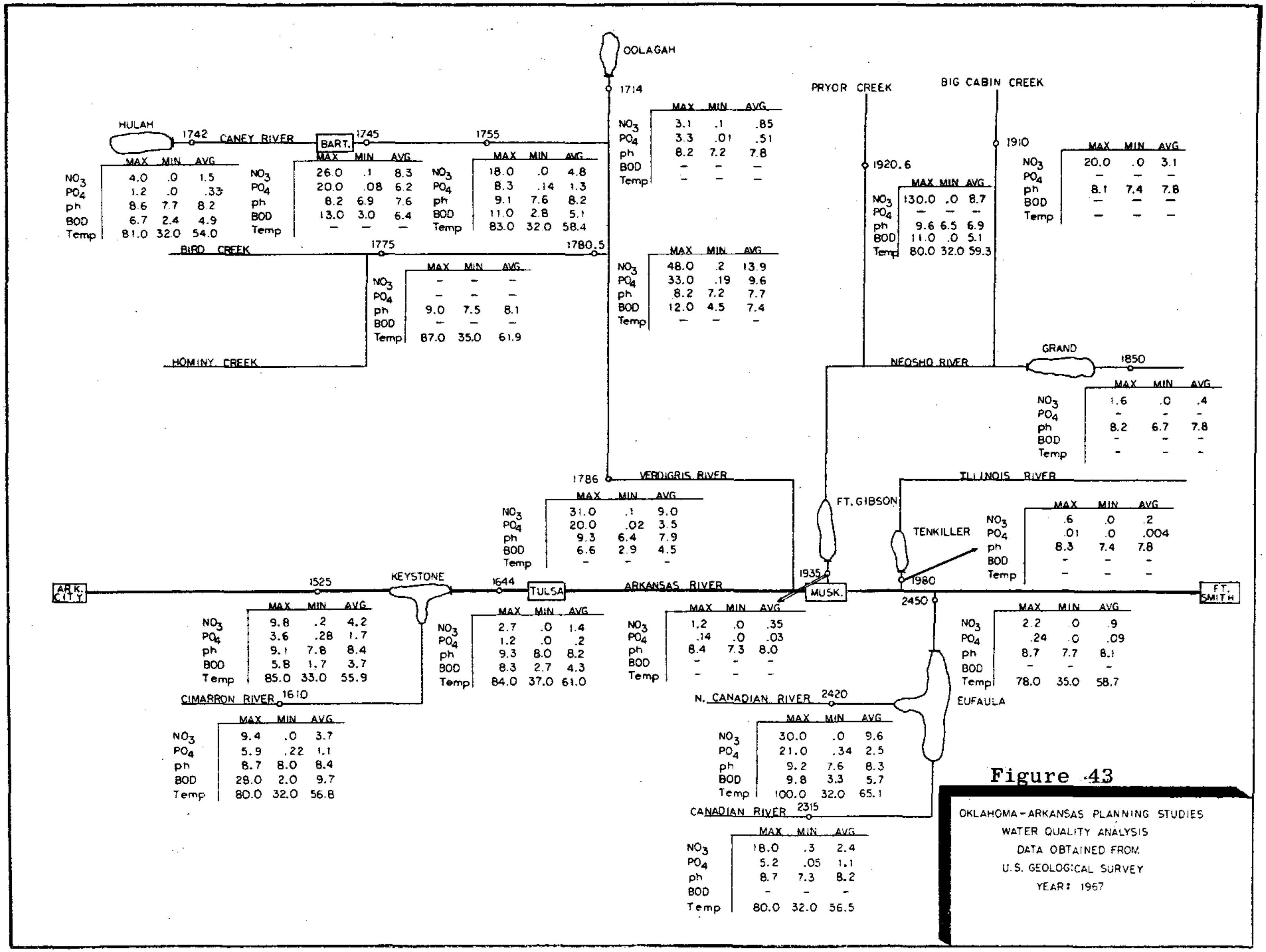


Figure 43

OKLAHOMA-ARKANSAS PLANNING STUDIES
WATER QUALITY ANALYSIS
DATA OBTAINED FROM
U.S. GEOLOGICAL SURVEY
YEAR: 1967

streams above reservoirs whereas below the reservoir the concentrations of nitrates were much lower. For example compare the data for stations 2420 and 2315 above Eufala Reservoir and station 2450 below the reservoir. Since the decrease in nitrate concentration is undoubtably accomplished by biological activity it seems wider but their pressure is enhancing urtroplication of the reservoir.

Concerning phosphate it is observed that, in the Arkansas River the maximum concentration was only 3.6 mg/l, however, in several of the tributaries the phosphate concentration reached fairly high values. In the Verdigris River a maximum of 33 mg/l was observed; Caney Creek, 20 mg/l; and the North Canadian River, 21 mg/l. In Pryor Creek, where a nitrate concentration of 130 mg/l was observed, there was no phosphate analyses available. Again, as with nitrates, the phosphate concentration below the reservoirs was much lower than that above the reservoirs.

No large variations in pH were observed. The greatest variation was in Pryor Creek in which the pH varied from a minimum of 6.5 to a maximum of 9.5, with an average of approximately 6.9. The average pH throughout the whole study area was approximately 8.0.

The highest BOD value recorded (28 mg/l) was at a station in the Cimarron River. The other stations normally showed a maximum BOD of approximately 10 mg/l.

The maximum temperature observed in the North Canadian River was 100° F, which is especially interesting since the maximum temperature observed at all other sampling points varied between 80 and 85^{o} F. The finding could indicate that some sort of thermal pollution occurred in the North Canadian River during this study year.

It is of special interest to compare the data obtained by the U. S. Geological Survey during the year 1966 with the data obtained by the Federal Water Pollution Control Administration during the summer of 1965 (i.e. data of figures 43 and 40). As mentioned earlier, data obtained by the FWPCA during the summer of 1965 indicated there was no serious problems regarding water quality characteristics pertinent to biochemical activity. However, data obtained by the U. S. Geological Survey during the year 1967, indicates some cause for concern, e.g. nitrate concentration of 130 mg/l, in Pryor Creek and a phosphate concentration of 33 mg/l in the Verdigris River. It is especially interesting to note that the maximum values obtained at these various stations generally occurred during the months of October, November, or December, not during the summer months. It is assumed that the Federal Water Pollution Control Administration made the study during the summer months in order to observe what is normally considered to be the worse conditions, when in fact, the worse conditions apparently occurred during the fall and winter months. It is especially regreatable that in many cases the data from the U. S. Geological Survey does not also include water quantity data so that a maximum amount of each consititiant could be determined. This is especially of significance when these waters are flowing into such reservoirs as Fort Gibson, Tenkiller Ferry, and others which constitute a significant portion of the water resource in eastern Oklahoma.

3. Subbasins Where no Data is Available

No biochemical water quality data were obtained for Lee Creek, Spavinaw Creek, and Poteau River. These streams have been considered to be of excellent quality and, in fact, on the basis of chemical quality data, they are of very high quality. However, there is some doubt concerning the biochemical quality of Poteau River water. In a study conducted by the Federal Water Pollution Control Administration, regarding water supply and water quality control in the Poteau River Basin, one stated objective for the development of water resources systems on the Poteau River was to provide water for dilution purposes to control the water quality of the stream. The report pointed that there were three locations in the Poteau River Basin which would require dilution water for quality control. These requirements were based on return flows (from projected municipal and industrial growth) receiving adequate treatment to remove 90% of the BOD. The three locations for which water quality control is necessary were listed as follows: (1) the Poteau River below Waldron, Arkansas; (2) the Forche Maline below Wilburton, Oklahoma; (3) and the Poteau River below Wister Reservoir. In the report it was pointed out that the biochemical quality of the river (with treated discharges from municipal and industrial operations) will not be satisfactory unless dilution water above these points is provided. In view of the projected growth in this basin and the fact that dilution water will be needed to control water quality there is an imperative need for more data on the biochemical character of the water.

D. Effect of Industrial Activity

The Directory of Manufacturers and Products, published by the Oklahoma Industrial Development and Part Department was used in this phase of the study to develop a general view of the industries located in the study area. These industries are shown in figure 44. The industries are divided into five general categories. These include petroleum products, chemical products, textiles, metal processes, and food products. Figure 44 shows the number of industries within each category at various communities throughout the study area. The importance of industrial activity in the study area can be illustrated by considering the situation at Pryor. It is recalled that in 1967 a maximum nitrate concentration of 130 mg/l was recorded in Pryor Creek. There are five chemical processing plants in Pryor, one of these is involved in fertilizer production and another in nitrogen products. It may be deduced that since the high concentration of nitrates only occurred during approximately two or three days during the year it was the result of a spill at one of these plants and therefore, the high concentration does not necessarily represent a typical or reoccurring event.

There are various other industries in the study which represent potential polluters of the streams. Also, at the present time, there is an active campaign in the state of Oklahoma to bring new industry into the state. This area of Oklahoma is especially suitable for industrial development. Several large industries have already decided to locate in the study area, for example, a large carpet manufacturing firm has decided to locate in

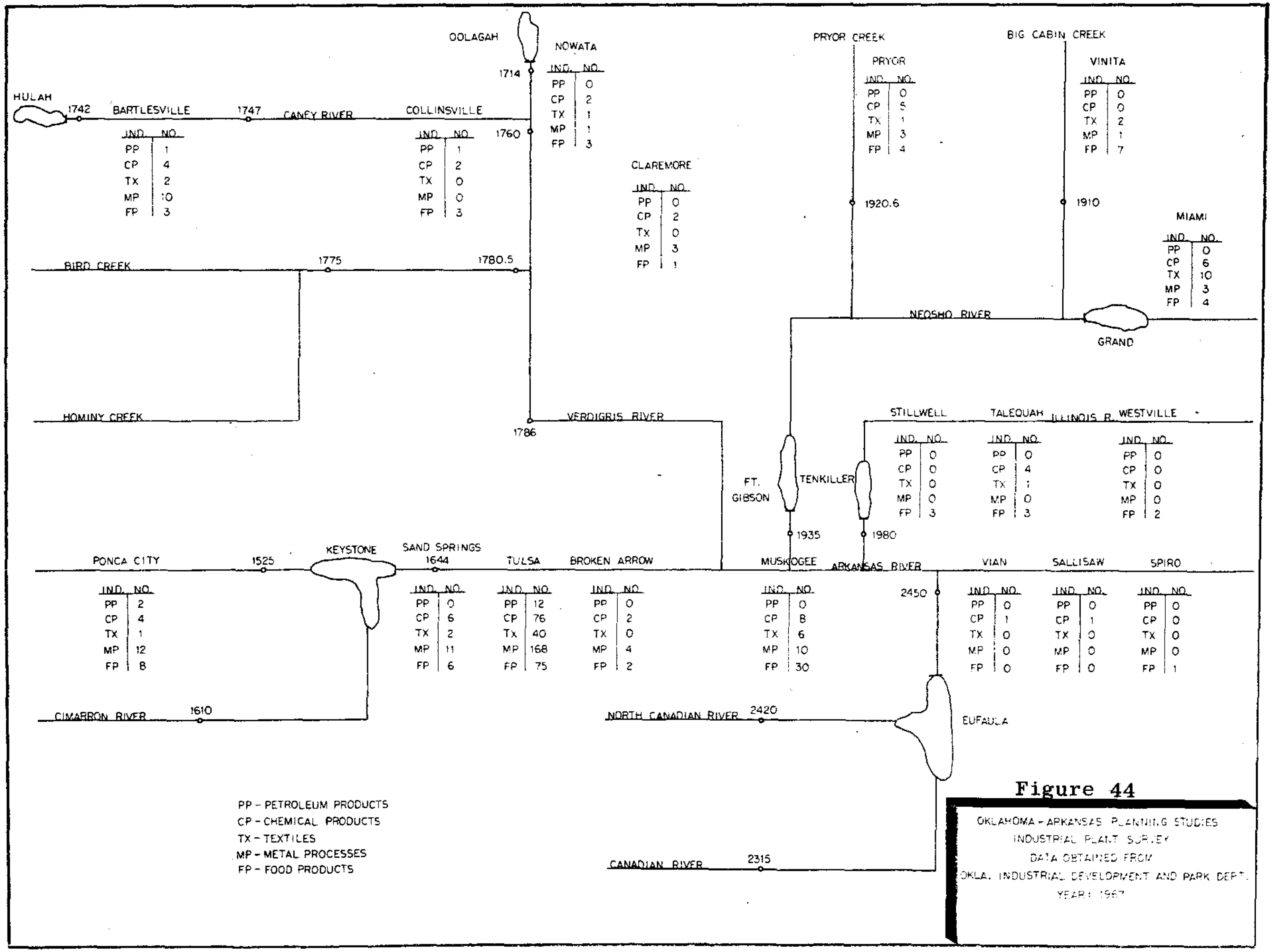


Figure 44

OKLAHOMA - ARKANSAS PLANNING STUDIES
INDUSTRIAL PLANT SURVEY
DATA OBTAINED FROM
OKLA. INDUSTRIAL DEVELOPMENT AND PARK DEPT.
YEAR: 1967

PP - PETROLEUM PRODUCTS
CP - CHEMICAL PRODUCTS
TX - TEXTILES
MP - METAL PROCESSES
FP - FOOD PRODUCTS

Wilburton on the Poteau River. It seems apparant that development of the area requires coordinated use and control of the water resource in order that industrial expansion and population growth proceed at the desired rate. In accomplishing this aim, it also seems apparant that a more comprehensive water quality monitoring system would be beneficial.

E. Effect of Agriculture

It was of interest to review the agricultural practices in the study area to determine the potential pollution of the stream due to agricultural activities.

The five watersheds of primary interest comprise all or a part of each of eleven counties in Eastern Oklahoma. The counties are identified in Table 47 with their population area, and other relevant information about the study area.

The land area of the eleven counties is about 5.9 million acres, of which 61 percent is in the watershed study area. The percent of the land that can be classfied as farm land averages 63.2 percent for the eleven counties. The population of the area that can be considered as "rural farm" varies from about 12 percent to about 28 percent for the counties and averages about 20 percent.

The population of the area has been declining for the past 20 years of so and decreased approximately 20 percent in the period from 1950 to 1960.

1. General Agriculture Information for the Area

The type of agriculture in the study has changed drastically

Table -47-

Relevant Information for the Study Area (1)

County	Population No	Area Ac.	Percent Farm %	Percent In Study area %	Cropland Ac.	Pasture Ac.	Forest and Woodland Ac.	Irrigated land Ac.
Adair	13063	364,160	53.3	100	58,410	44,393	82,370	1105
Cherokee	17762	483,840	54.7	70	58,324	72,466	125,519	918
Delaware	13198	457,600	57.7	40	103,299	57,797	94,857	448
Haskell	9121	392,960	84.8	90	75,234	149,231	100,367	33
Latimer	7738	471,680	50.0	85	19,126	96,726	110,588	7
LeFlore	29106	1,004,160	45.7	85	96,726	176,348	171,100	861
McIntosh	12371	457,600	66.6	10	69,164	173,525	53,852	310
Mayes	20073	432,640	70.1	5	110,782	138,245	46.610	0
Muskogee	61866	524,800	75.1	80	142,615	190,561	50,454	2191
Pittsburg	17419	869,760	66.5	5	68,165	357,250	140,552	35
Sequoyah	18001	446,080	70.3	100	85.975	131,361	85,844	1060
TOTAL OR AVERAGE	219,718	5,905,280	73.2	60.9	887,966	1,587,893	1,029,113	7868

in the past two or three decadeis. Up until about 1940 the farms were of a general or diversified type of corn, cotton, and oats being the predominant crops grown. Large numbers of hogs and beef cattle and a significant number of dairy cows were raised. After 1940 there was a decline in the production of corn, cotton, oats, and hogs. By 1964, acreages planted in corn, cotton, and oats were insignificant and the number of hogs had declined appreciably. Around 1950, the dairy cattle population started to decline, by 1964, their numbers were also insignificant. Data relating to the trends in agriculture of the area are presented in Table 48. Data were not available for the spaces left blank in the table. During the period 1940 to 1964, sorghum and wheat production for the area declined. However, this was not true for all of the counties. In some counties acreages in these crops decreased while in others there was an increase; the net result was a decrease in the total sorghum and wheat acreage. A relationly new crop in the area is soybeans and it is expected that the soybean acreage will increase somewhat in the near future.

The drastic reduction in corn, cotton, oat, and hog production has been offset by a large increase in the beef cattle production. In almost every county the numbers of beef cattle have increased by 100 percent ormore during the period 1940 to 1964. Thus, the agricultural emphasis has shifted from a diversified type of farming to an agricultural effort centered around beef cattle production. The efforts in this area are oriented toward the production of high quality stocker and feeder cattle.

Table -48-

Agricultural Production Trends (1), (2)

County	Year	Crops: Corn Ac.	Cotton Ac.	Hay Ac.	Oats Ac.	Sorghum Ac.	Soybean Ac.	Wheat Ac.	Livestock: Beef Cattle No.	Dairy Cows No.	Hogs No.	Sheep No.
Adair	1940											
	1950											
	1964	1,196	0	18,341	402	1,116	40	661	31,145	3,497	3,134	914
Cherokee	1940	27,900			10,500	8,700		4,180	21,100		24,000	
	1950	12,500			6,400	700		720	29,500		14,500	
	1964	699	0	19,686	483	894	47	141	40,417	3,009	3,208	415
Delaware	1940	30,400			18,600	9,100		11,000	20,300	7,800	32,600	
	1950	13,400		25,000	7,500	1,900		7,000	24,500	9,600	19,100	
	1964	2,356	0	23,895	2,201	4,156	2,249	5,415	40,417	3,009	3,208	415
Haskell	1940	38,000	20,506	11,500	10,000	8,900			18,800	6,900	10,600	
	1950	18,500	8,200	16,350	5,400	2,800			23,100	5,500	6,000	
	1964	505	197	23,068	738	763	2,611	2,296	49,146	914	2,605	688
Latimer	1940	11,800	3,700		2,900	5,900			15,100		7,800	
	1950	5,900	220	7,600		1,200			14,800		6,400	
	1964	42	20	7,948	0	196	0	0	26,223	592	1,021	163
LeFlore	1940		30,600					600	38,300		19,600	
	1950		8,000	22,500			2,933	5,150	36,500		12,100	
	1964	879	39	21,507	857	1,468	9,629	4,570	61,970	1,089	1,700	271
McIntosh	1940	56,000	47,300		11,400	7,400		500	17,900			
	1950	49,700	23,500	10,300	2,900	4,800		200	21,200			
	1964	1,792	2,967	13,514	307	7,707	4,833	985	41,205	1,047	2,752	254
Mayes	1940	40,300			39,000	11,800		20,500	29,700	10,400	28,300	4,100
	1950	25,500		28,600	18,100	7,800		5,800	36,500	12,000	17,400	1,700
	1964	3,241	264	32,243	5,143	10,571	615	7,085	59,727	5,763	4,359	977

Table -48-

(continued)

County	Year	Crops: Corn Ac.	Cotton Ac.	Hay Ac.	Oats Ac.	Sorghum Ac.	Soybean Ac.	Wheat Ac.	Livestock: Beef Cattle No.	Dairy Cows No.	Hogs No.	Sheep No.
Muskogee	1940	61,100	54,300		33,900	11,500		4,310	32,500	13,800	25,200	
	1950	57,700	34,700	23,500	11,000	5,100		4,400	39,100	13,300	19,600	
	1964	3,169	9,231	34,430	2,006	6,933	14,258	7,102	59,206	4,347	2,893	846
Pittsburg	1940	44,800	30,400		13,100	20,100		380	39,600	12,100	24,500	1,800
	1950	31,900	13,900	24,100	3,500	6,600		300	41,200	8,700	17,400	600
	1964	1,206	862	19,188	715	6,885	1,211	586	73,663	884	3,128	704
Sequoyah	1940	33,600	20,000		2,900			150	21,100	7,900	14,200	
	1950	15,400	2,160	14,200	1,100		1,330	1,000	21,500	2,200	8,000	
	1964	763	1,031	16,569	741	588	11,321	5,221	46,972	952	1,274	231

The shift to beef cattle production has resulted in increased acreages of hay and hay-type products, seeded pastures, and improved rangeland. Of the total area listed as cropland in Table 47, about one-half is used for seeded pastures and hay products. These crops include alfalfa, cereal grains, lespedize and clover-timothy-grass mixtures.

There are some vegetable, fruit, nursery and landscaping products grown in the study area. Acreages in these crops are small as a percentage of the total area, but in the value of products sold they are fairly significant since these products have a high return per acre. Also, these crops may be important as a possible pollutant source because of the chemicals used to control weeds, insects, and disease. This aspect will be discussed later in the report.

The current and probable future agricultural activity of the area should not contribute, to a significant extent, to stream pollution problems from soil erosion. Indeed, the change from a row crop type farming to nearly exclusive beef cattle production, with the accompanying increased acreages of hay, pasture, and improved rangeland, will be conducive to significant reduction in soil erosion. More conservation practices are being employed each year and this should also help to reduce soil erosion in the study area.

2. <u>Irrigation Practices</u>

Irrigation in the study area is almost non-existent since the area receives sufficient rainfall, usually, to obtain good production from the agricultural effort. In the eleven county area only 7,868 acres of land were irrigated in 1964. The acreages irrigated by county are presented in Table 47. Pasture-land and horticultural crops comprise, about equally, the major part of the land which is irrigated.

Almost all of the water used for irrigation is obtained from surface water. The amount of water applied averages about 1.5 acre-feet per acre and totaled about 11,800 ac-ft in 1965. Because of the small acreage irrigated and the minute quantity of water used there should not be any significant contribution to stream pollution from this source.

3. Soils of the Study Area

A soil map of the elven county area is present in figure 45. The map shows the land resources areas with the soil associations which occur in each area. Also, the watershed boundaries are located and the individual watersheds indentified. Table 49 gives a general description for the soil associations in each of the land resources area.

There are nine soil associations present in the eleven county area, but only four of these occur with much frequency in the study area. These are: (1) Bodine-Baxter association; (2) Hector-Pottsville association; (3) Enders-Conway-Hector association; and (4) Parson-Dennis-Bates association. In general, all of these soils are acid to slightly acid, and are moderately too strongly leached. All are deficient in phosphorus and nitrogen for best agrcultural production and most of these soils are low in potassium.

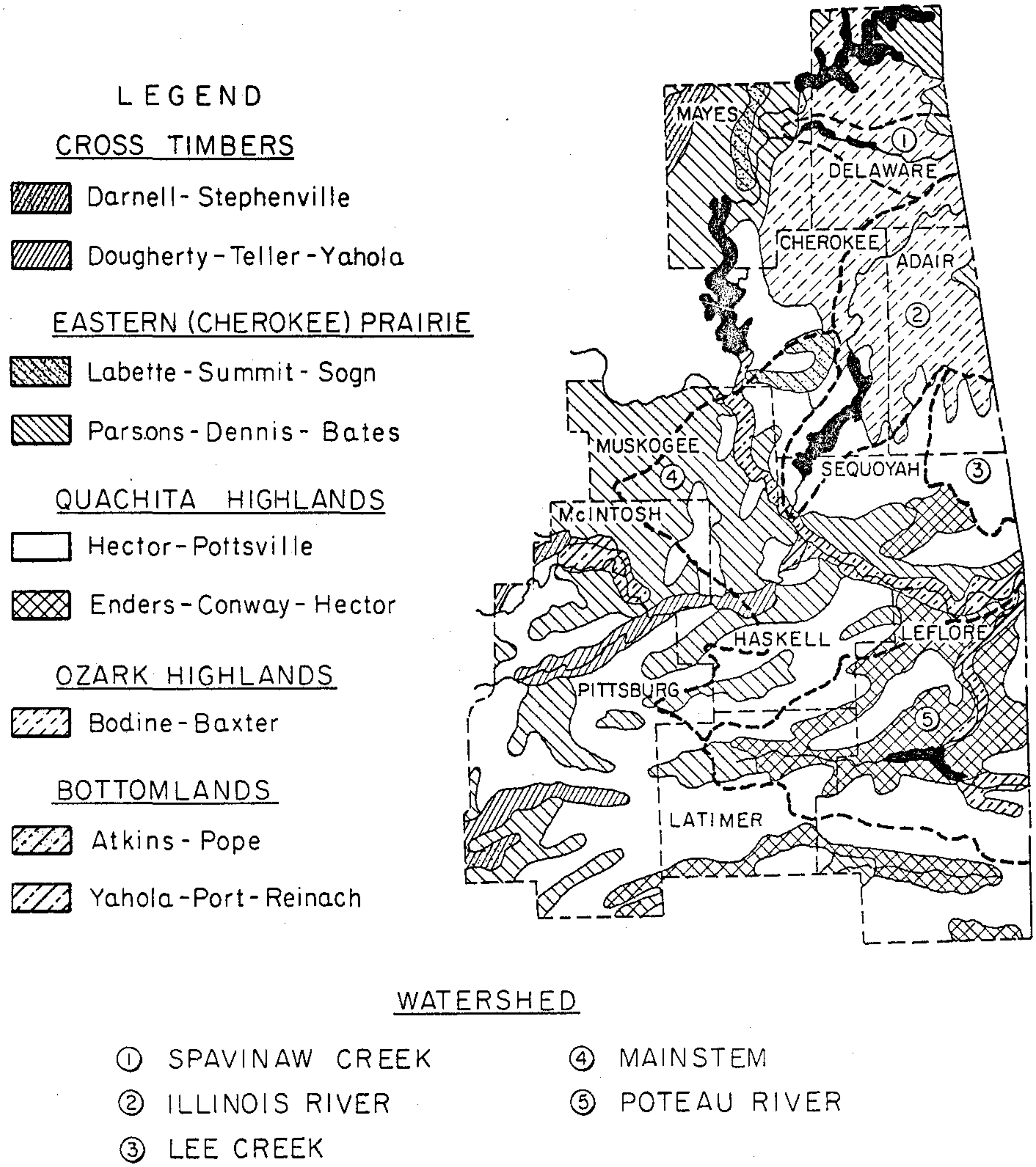

LEGEND
CROSS TIMBERS
Darnell - Stephenville
Dougherty - Teller - Yahola
EASTERN (CHEROKEE) PRAIRIE
Labette - Summit - Sogn
Parsons - Dennis - Bates
QUACHITA HIGHLANDS
Hector - Pottsville
Enders - Conway - Hector
OZARK HIGHLANDS
Bodine - Baxter
BOTTOMLANDS
Atkins - Pope
Yahola - Port - Reinach
MAYES
DELAWARE
CHEROKEE
ADAIR
MUSKOGEE
SEQUOYAH
McINTOSH
HASKELL
LEFLORE
PITTSBURG
LATIMER
WATERSHED
① SPAVINAW CREEK
② ILLINOIS RIVER
③ LEE CREEK
④ MAINSTEM
⑤ POTEAU RIVER

Figure -45-

Table -49-

General Soil Descriptions

Cross Timbers* - Red-yellow podzolic, lithosols, ligh-colored solids with reddish sobsoils on various sandy materials developed under oak-hickory forests with prairie openings (savannah).

Eastern (Cherokee) Prairies*- Brunizems plansols, lithosols Dark-colored soils mostly with clayey subsoils developed on shales, sandstones, and limestones under tall grasses.

Quachita Highlands* - Red-yellow podzolics and lithosols Light-colored acid sandy to loamy soils with heavier subsoils and shallow soils developed on sandstones and shales under oak-hickory-pine forests.

Ozark Highlands* - Red-yellow podzolics Brown and light brown silty soils with reddish clay loam subsoils on cherty limestone developed under oak-hickory-pine forests and tall grasses.

Bottomlands* = Alluvial soils Nearly level, deep sandy to clayey bottomland soils. Some area flood frequently; most flood occasionally, and some rarely. Soils are developed under lowland hardwoods which decrease in density from east to west.

*Donminant great soil group(s) of the area.

4. Fertilizer Usage

The fertilizer and lime acreages and tons applied for the eleven-county area are presented in Table 50. A total of 238,981 acres had fertilizer applied in 1964. This is only 4 percent of the total land area of the eleven counties. Equating this acreage to the agricultural acreage of the area, this represents only 6.3 percent. The acreage limed is about 1 percent of the agricultural acreage. These amounts are insignificant and are about 1 percent or less of the quantities that should be applied for good agricultural production.

The largest use of fertilizer and lime is on pastureland. Smaller amounts are used on wheat, still smaller amounts on sorghum, with lesser amounts being applied to other crops.

About 80 to 85 percent of the fertilizer used is "10-20-10" (a mixture of 10 percent nitrogen (N), 20 percent available phosphoric acid (P_2O_5), and 10 percent soluable potash (K_2O)). The next type of fertilizer most commonly used is ammonium nitrate (32.5 to 33.5 percent N). There is also a small amount of anhydrous ammonia (82 percent N) used. The lime applied comes from limestone, hydrated and burnt lime, marl, and oyster shells.

The amounts of fertilizer and lime used are so small that it is not expected that they should contribute singificantly to water pollution in the study area.

5. Agricultural Chemical Usage

A. Weed and Brush Control

There were 41,269 acres of land in the eleven counties treated for weed and brush control in 1964. This is equivalent excessive quantities is poisonous. There is one very important difference between aspirin and DDT. Small doses of aspirin daily over a long period of time will not cause serious problems. Contrasted to this, a substantial part of DDT is stored in body tissue so a cumulatire effect can be obtained. Used unwisely, DDT may be harmful to wild life. Fish are especially susceptible to DDT poisoning.

Dieldrin, another chlorinated hydrocarbon, is used on peach, apricot, and plum trees for pest control. Its use is somewhat restricted since it is poisonous to mammals, fish, and fowl. It is lethal if taken internally. It is soluable in fats, but it is practically insoluable in water. Dieldrin has a presistent residue which is unsafe for a week or more following an application. The material is known to be quite toxic to fish.

Parathian, an organo-phosphorus insecticide, is used in small amount on some vegetables. It is poisonous to mammals, fish and fowl. It is especially hazardous to beneficial insects. It has a residual action of at least 10 to 12 days. Parathion is also a contact poison and causes skin contamination.

Malathion, another organo-phosphorus material, used for insect control on pecan trees is also highly poisonous to man. However, it is easily and rapidly broken down to relatively harmless substances. Thus, under most conditions, Malathion is considered a safe and useful insecticide.

Guthion is another organo-phosphorus material that is used on apple and pear trees for insect control. It is a highly toxic compound and is almost as toxic to warm-blooded animals as Parathion. Also, it has residual effects of from 1 to 3 weeks.

Wevin or Carbaryl (1-napthyl, N-methylcarbonate) is used extensively on vegetables and fruit trees for insect control. It leaves a relatively non-toxic residue and is approved for use on edible crops up to one day before harvest. It is considered a very safe insecticide and its use is increasing appreciably.

These agricultural chemicals used for pest control are a possible source for pollution of stream. However, unless their usage is increased appreciably, there is probably no danger of their polluting the streams of the area.

APPENDIX A

STATE LINE FLOWS

STATE LINE FLOWS FOR BASE PERIOD

SPAVINAW CREEK

ARKANSAS TO OKLAHOMA

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
35-36	0	0	61	26	20	30	29	18	9	4	1	28
36-37	50	49	34	229	102	63	138	39	78	44	14	73
37-38	16	13	45	52	367	198	220	180	138	37	13	14
38-39	9	18	11	14	80	86	105	106	52	31	6	5
39-40	10	10	10	9	11	14	109	55	40	30	11	38
40-41	10	34	56	166	81	42	423	45	58	17	10	11
41-42	252	240	78	42	82	63	340	161	155	49	17	26
42-43	76	318	167	73	31	51	141	712	140	44	10	12
43-44	18	13	14	19	51	314	181	172	152	40	24	20
44-45	33	13	19	15	164	640	796	203	248	96	20	74
45-46	115	37	22	100	165	76	60	301	125	101	12	12
46-47	11	179	257	46	22	30	206	238	136	44	8	11
47-48	9	18	14	29	53	239	92	74	134	108	270	39
48-49	19	18	33	121	183	127	98	297	232	170	20	55
49-50	39	21	32	189	140	91	139	857	97	179	76	68
50-51	0	0	60	59	425	237	145	110	267	195	78	71
51-52	86	208	147	125	152	204	192	109	68	47	93	45
52-53	36	40	37	36	33	157	138	128	55	45	32	26
53-54	27	27	29	29	28	31	36	108	26	14	11	14
54-55	56	26	64	56	177	127	69	59	70	48	26	31
55-56	24	18	17	16	28	20	19	96	61	25	11	7
56-57	7	23	29	66	112	112	496	618	500	112	64	63
57-58	40	81	53	50	99	261	167	256	88	273	109	59
58-59	45	58	41	37	48	116	139	116	97	135	43	44
59-60	235	231	74	93	80	169	190	252	119	112	61	31
61-62	62	100	136	93	83	122	166	94	84	73	45	61
62-63	167	56	62	59	37	110	55	37	21	12	8	6
63-64	5	9	11	10	12	22	76	33	87	14	26	35
64-65	13	37	24	25	38	72	503	81	57	25	12	42
65-66	18	15	25	71	166	76	82	111	37	10	9	7

ILLINOIS RIVER

NORTHERN BRANCH

ARKANSAS TO OKLAHOMA

GAGING STATION 1955

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
35-36	0	0	515	252	183	217	149	124	50	26	8	205
36-37	387	448	285	2175	929	446	711	252	407	216	161	535
37-38	126	122	382	499	3318	1395	1129	1161	725	186	144	103
38-39	69	166	92	132	719	611	541	681	276	157	70	36
69-40	83	95	87	86	101	98	561	361	211	154	119	276
40-41	82	311	472	1581	734	299	2166	293	303	84	110	86
41-42	1926	2161	659	401	746	443	1738	1038	811	247	192	189
42-43	584	2863	1401	696	286	359	725	4592	738	218	106	88
43-44	139	122	118	183	465	2204	924	1113	796	200	265	146
44-45	251	120	166	144	1484	4492	4077	1315	1300	475	219	544
45-46	885	338	185	946	1497	540	308	1943	656	497	136	87
46-47	86	1611	2162	440	205	210	1057	1531	710	216	88	86
47-48	68	168	121	277	479	1682	471	481	701	535	2949	287
48-49	150	172	278	1147	1653	392	504	1915	1219	838	218	402
49-50	302	187	275	1796	1265	646	713	5525	510	884	828	496
50-51	397	200	149	228	2946	1207	520	404	653	829	209	173
51-52	238	1016	573	570	714	1149	1003	534	202	107	195	88
52-53	68	112	104	107	101	938	1152	1003	143	141	84	46
53-54	52	69	77	91	83	99	89	887	61	15	8	2
54-55	199	103	237	374	972	972	423	490	583	141	63	33
55-56	108	67	60	61	254	114	214	715	333	114	33	15
56-57	21	97	102	453	741	596	3347	3936	2021	340	329	312
57-58	175	928	289	250	626	1482	750	1371	428	1807	876	276
58-59	186	293	173	155	229	828	700	836	347	567	150	116
59-60	952	1029	321	508	384	764	549	2013	409	1526	281	118
60-61	122	113	323	185	255	540	516	4286	629	723	1172	436
61-62	450	882	1047	635	479	654	1155	507	313	217	535	343
62-63	730	347	244	255	172	232	176	198	113	91	98	57
63-64	44	66	73	65	75	184	294	323	191	51	193	255
64-65	163	225	115	376	340	487	1592	338	286	119	132	197
65-66	77	74	119	405	1381	531	769	683	196	106	150	108

GAGING STATION 1960

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
35-36	0	0	48	20	15	18	17	11	5	2	1	21
36-37	34	36	26	174	74	38	81	22	41	20	14	56
37-38	11	10	35	40	266	117	128	102	73	17	13	10
38-39	6	13	9	10	108	51	61	60	28	14	6	4
39-40	7	8	8	7	8	8	64	32	21	14	10	29
40-41	7	25	44	126	59	25	246	25	31	8	10	9
41-42	170	176	61	32	59	37	198	92	82	22	17	20
42-43	52	232	128	56	23	30	82	405	74	20	10	9
43-44	12	10	11	15	37	186	105	98	80	18	24	15
44-45	22	10	15	12	119	377	463	115	131	43	20	57
45-46	78	27	17	76	120	45	35	171	66	45	12	9
46-47	8	131	199	35	16	18	120	35	72	20	8	9
47-48	6	14	11	22	38	142	54	42	71	49	264	30
48-49	13	14	26	92	132	75	57	168	123	76	20	42
49-50	27	15	25	143	101	54	81	487	51	80	74	52
50-51	35	16	19	18	236	102	59	36	66	75	19	18
51-52	21	83	53	46	57	87	114	47	20	10	17	9
52-53	6	9	10	9	8	79	131	88	14	13	8	5
53-54	5	6	7	7	7	8	10	78	6	1	1	0
54-55	18	8	22	30	78	82	48	43	59	13	6	3
55-56	7	5	6	5	8	6	7	51	29	9	3	1
56-57	1	5	11	13	37	42	212	345	217	33	13	19
57-58	13	23	19	19	45	115	68	87	28	131	29	17
58-59	15	24	16	15	20	52	75	54	29	60	16	18
59-60	115	118	30	43	28	81	110	242	37	46	25	11
60-61	12	13	28	13	20	37	36	392	90	108	105	46
61-62	37	78	84	47	38	52	97	45	31	23	51	44
62-63	55	29	34	30	19	35	28	28	15	10	8	8
63-64	5	7	9	9	9	22	45	19	27	6	27	25
64-65	10	24	15	24	33	40	261	35	22	10	10	17

ILLINOIS RIVER

SOUTHERN BRANCH

ARKANSAS TO OKLAHOMA

GAGING STATION 1969

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
35-36	0	0	26	14	11	16	9	7	2	1	0	6
36-37	12	15	14	128	57	34	47	16	23	10	4	16
37-38	4	4	20	29	205	107	75	73	41	9	4	3
38-39	2	5	4	7	44	47	36	43	15	7	2	1
39-40	2	3	4	5	6	7	37	22	12	7	3	8
40-41	2	10	24	93	45	23	145	18	17	4	3	2
41-42	63	73	34	23	46	34	116	65	46	12	5	5
42-43	19	97	73	41	17	27	48	291	42	10	3	2
43-44	4	4	6	10	28	170	61	70	45	10	7	4
44-45	8	4	8	8	92	347	272	83	74	23	6	16
45-46	28	11	9	55	92	41	20	123	37	24	3	2
46-47	2	55	113	25	12	16	70	97	40	10	2	2
47-48	2	5	6	16	29	130	31	30	39	27	85	8
48-49	5	10	23	115	130	80	32	125	103	45	6	10
49-50	8	6	15	116	94	41	45	222	18	28	20	11
50-51	6	4	4	11	191	61	32	22	18	27	3	3
51-52	3	17	16	20	29	76	72	40	13	3	2	1
52-53	1	3	4	4	3	84	67	74	7	7	1	0
53-54	1	1	3	6	5	8	9	74	3	1	0	0
54-55	2	2	14	18	61	102	32	33	78	6	1	1
55-56	3	1	2	2	13	9	18	46	36	5	1	0
56-57	0	1	3	18	47	37	235	265	189	14	11	15
57-58	0	0	0	0	0	0	46	124	39	131	57	13
58-59	5	21	8	8	13	88	106	87	12	41	3	2
59-60	73	70	39	51	33	55	45	163	22	127	9	3
60-61	2	4	33	16	23	57	42	186	26	74	31	41
61-62	39	94	97	49	28	42	51	17	16	3	3	2
62-63	4	5	8	5	3	8	7	4	0	0	2	0
63-64	0	1	1	1	2	12	12	30	5	1	8	7
64-65	1	10	3	49	40	55	88	11	11	2	1	3
65-66	1	1	4	39	146	52	97	53	20	1	2	1

LEE CREEK

ARKANSAS TO OKLAHOMA

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
30-31	22	45	302	16	915	322	459	230	135	9	29	10
31-32	68	100	162	1280	520	229	154	31	29	13	5	1
32-33	1	11	388	411	128	348	745	1080	62	4	18	720
33-34	150	114	131	302	81	294	437	100	11	1	0	396
34-35	58	477	265	411	128	1354	535	988	2225	93	4	2
35-36	57	121	478	51	36	87	90	76	4	0	0	220
36-37	190	187	350	1026	291	282	416	163	124	0	0	0
38-39	0	12	13	55	494	360	569	584	169	196	9	0
39-40	2	18	41	58	79	67	683	260	43	15	40	16
40-41	3	64	152	357	340	112	342	116	115	14	4	21
41-42	430	257	225	137	343	228	632	700	96	12	2	5
42-43	3	216	339	102	93	251	375	1153	400	16	0	0
43-44	9	9	25	44	340	534	598	470	859	59	150	53
44-45	23	51	150	107	773	1526	1573	630	1748	76	6	95
45-46	82	68	32	483	760	428	335	849	175	20	7	0
46-47	1	675	612	116	48	134	524	819	283	83	2	4
47-48	4	27	96	265	410	505	180	271	90	60	151	10
48-49	2	15	190	1048	894	324	259	535	469	56	10	9
49-50	39	16	55	764	692	260	256	929	232	636	585	370
50-51	17	6	5	36	1212	306	287	155	300	431	14	18
51-52	63	407	186	178	214	568	763	250	46	4	10	0
52-53	0	16	30	67	70	888	863	617	15	20	5	0
53-54	0	0	9	77	59	53	48	297	10	0	0	0
54-55	99	24	320	263	615	574	295	301	201	15	6	3
55-56	2	1	2	2	91	44	232	252	127	9	0	0
56-57	0	0	13	90	493	264	1828	1758	1061	33	197	139
57-58	26	464	114	112	235	808	369	707	219	954	292	94
58-59	38	380	84	68	154	653	758	626	159	90	18	9
59-60	283	284	324	372	251	286	243	1373	104	116	24	3
60-61	3	3	107	59	106	456	336	918	59	366	71	162
61-62	134	529	543	354	185	292	343	103	32	11	24	21
62-63	106	91	130	85	26	85	225	123	14	2	3	6
63-64	0	0	2	2	24	199	486	449	30	5	23	27
64-65	8	50	25	213	296	262	659	333	72	19	5	26
65-66	3	3	17	381	923	259	751	413	86	7	1	1

POTEAU RIVER

ARKANSAS TO OKLAHOMA

NORTHERN BRANCH

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
38-39	0	0	0	0	2128	318	1928	274	82	6	0	0
39-40	16	0	8	8	82	22	480	126	28	8	224	20
40-41	0	200	272	338	598	204	368	236	278	10	18	66
41-42	906	520	368	458	382	442	824	630	192	10	24	24
42-43	14	128	226	56	28	276	240	2098	144	4	0	0
43-44	10	24	78	282	1338	688	576	840	372	6	34	10
44-45	0	70	462	170	2906	3362	47	1687	1176	80	18	218
45-46	258	70	40	854	1002	226	664	1944	198	24	0	0
46-47	0	1190	1334	118	40	154	570	482	12	0	5	56
47-48	0	34	560	708	1156	508	536	296	32	46	104	2
48-49	8	42	118	2376	1246	490	254	472	382	8	0	12
49-50	70	14	112	1876	2078	110	274	1378	212	510	536	456
50-51	38	8	4	50	1250	202	294	128	446	204	16	18
51-52	110	604	286	514	184	648	2002	154	12	0	0	0
52-53	0	790	342	386	282	1094	1674	1190	6	6	0	0
53-54	0	2	4	368	292	22	162	816	2	0	0	0
54-55	104	20	296	172	588	942	272	44	12	0	0	0
55-56	0	0	0	0	684	96	40	66	0	0	0	0
56-57	0	8	142	436	622	554	2704	1908	724	4	542	284
57-58							622	1338	544	170	32	36
58-59	12	86	62	106	90	624	350	134	72	74	20	42
59-60	272	526	596	460	398	426	84	1668	42	198	18	9
60-61	46	16	214	105	230	662	436	946	212	860	72	64
61-62	109	740	696	648	488	482	284	44	30	34	21	121
62-63	224	292	135	91	31	156	91	77	22	5	2	0
63-64	0	0	2	1	44	376	244	302	8	3	47	140
64-65	34	404	100	308	790	604	246	698	131	13	4	18
65-66	2	2	1	2	310	77	340	386	6	5	19	17

POTEAU RIVER

ARKANSAS TO OKLAHOMA
SOUTHERN BRANCH

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
38-39	---	---	---	---	1500	299	1390	183	56	5	1	0
39-40	12	1	7	7	59	22	348	85	19	6	140	17
40-41	0	140	245	282	422	192	266	157	188	8	12	53
41-42	680	364	331	383	270	415	596	421	132	8	16	20
42-43	11	90	204	48	20	260	174	1400	97	4	0	0
43-44	8	17	71	236	945	646	418	562	252	5	22	8
44-45	0	47	312	126	1820	2650	360	1175	1055	67	13	205
45-46	194	49	36	713	708	214	480	1300	134	18	1	0
46-47	1	833	1195	99	29	145	428	337	12	1	8	53
47-48	1	24	502	590	815	476	387	198	22	35	65	2
48-49	7	30	107	1980	878	461	185	316	258	7	0	10
49-50	53	11	100	1562	1468	105	199	920	144	380	336	360
50-51	29	6	5	42	884	191	214	87	300	151	11	14
51-52	83	423	257	428	131	608	1450	103	8	1	0	0
52-53	0	552	307	323	200	1027	1210	794	5	5	1	0
53-54	0	2	5	308	206	22	118	545	4	1	0	0
54-55	79	14	266	144	416	884	198	30	8	1	0	0
55-56	0	0	0	0	484	91	30	44	1	0	0	0
56-57	0	6	127	364	439	518	1954	1272	487	4	339	226
57-58	16	464	138	319	168	864	586	1110	379	-172	31	11
58-59	29	214	61	83	117	473	378	26	10	14	7	2
59-60	167	62	665	487	296	361	55	1775	16	66	5	1
60-61	2	10	456	178	371	563	255	516	114	529	54	34
61-62	22	421	456	522	415	359	209	23	41	50	12	73
62-63	144	138	74	49	16	365	65	60	13	1	0	0
63-64	0	0	0	0	14	399	174	227	2	0	24	144
64-65	19	322	105	242	890	576	146	360	240	30	6	322
65-66	31	7	4	89	692	72	549	337	4	13	5	22

ARKANSAS RIVER

OKLAHOMA TO ARKANSAS

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT
27-28	76800	16400	24600	19500	23000	26400	85500	46400	122000	44300	35900	6960
28-29	5790	34900	33100	45000	19600	33400	107000	165000	91500	48400	7760	7340
29-30	9470	6970	10200	16000	39500	8090	3960	87400	37500	5560	2550	9680
30-31	6720	6330	21400	5660	27500	18500	28800	28300	21400	8390	9670	3490
31-32	11600	34800	30200	90700	47700	14800	10200	7450	43300	40600	11600	2980
32-33	2830	1980	26500	20600	7250	24600	47600	71200	9880	4080	22500	46200
33-34	13830	11240	7445	17280	5201	10090	32570	19610	5954	1571	658	21920
34-35	17300	26320	14030	19220	11940	70870	28370	114100	231000	40200	5358	16230
35-36	13350	25390	33680	7451	4466	5803	3243	11680	18330	3135	904	15290
36-37	40770	13260	6888	46830	35530	17180	20860	14250	59340	13640	7439	17790
37-38	4467	6253	8691	12670	85890	30190	56260	75750	80940	13670	14690	7234
38-39	3325	4498	2439	3210	12010	9513	27790	26420	15760	15320	5453	1867
39-40	1042	1384	1421	1194	2328	2401	14440	15970	9965	11620	10750	17860
40-41	2096	11750	15330	36600	34740	11320	76240	43800	83340	19190	10700	39490
41-42	144400	146400	31750	16040	28660	23500	140806	74290	83880	32100	20120	42750
42-43	28950	45090	40550	29890	15820	18930	28280	302100	64380	16880	5895	3670
43-44	11710	6887	6271	10380	21400	67240	101300	91790	47200	14160	11760	12460
44-45	36510	10330	33600	13160	36350	141700	219200	75740	93440	51390	14650	29940
45-46	95570	10340	6940	47590	51610	29170	28160	71000	35420	18530	4939	6165
46-47	8910	38220	56170	9847	6294	14170	120100	116100	57930	21450	7379	6395
47-48	5042	5283	7420	11980	17630	53910	20040	25610	70350	124200	65250	9974
48-49	6138	9746	9264	41990	111700	49720	36500	128300	90030	34390	12720	17220
49-50	14020	8131	8364	32740	33060	16420	13020	89570	37000	79420	97360	68330
50-51	19230	7784	6506	7665	43750	36040	19860	73660	82980	176000	25870	51260
51-52	23710	48980	25010	18000	22660	57390	63550	30660	18500	5494	4277	3670
52-53	1720	2479	3904	3550	4388	23750	43650	39010	5353	16470	6491	3749
53-54	4428	5087	5235	7519	5362	3535	4846	47440	10360	4083	2211	861
54-55	2686	2618	4445	8897	11410	20810	13590	35050	28610	14540	5434	5883
55-56	24510	4101	3988	3044	6633	3223	3185	8915	7123	3509	2365	742
56-57	492	1262	2127	3137	11760	12300	97660	195400	218800	82410	14490	21390
57-58	7850	19510	10040	12030	13360	67860	61310	52020	37890	85540	38080	19700
58-59	8266	9547	6252	5799	9921	30180	22240	44340	19290	63090	21430	18910
59-60	164300	37580	34440	38360	39600	42970	40540	100700	46170	38400	23560	15180
60-61	11380	18620	20430	9596	13590	29490	47610	159700	52110	56430	30620	71400
61-62	46780	75140	49810	27350	30040	29200	33840	10830	41730	18430	11560	30770
62-63	32150	16410	15290	11130	6723	16370	11680	9783	7806	11640	6938	9227
63-64	3264	2302	1780	1816	2485	5130	15830	13890	21710	7301	5892	11770
64-65	3594	27490	17930	13180	10530	14610	58470	21170	48760	27530	10310	32510
65-66	15840	5626	5318	8706	21510	11780	18490	25530	13150	8059	11230	10390
MEAN	24079	20021	16925	19125	23984	28705	47054	66958	54147	33507	15672	18638

APPENDIX B

THESIS AND PAPERS COMPLETED IN CONNECTION WITH THIS PROJECT

THESIS COMPLETED IN CONNECTION WITH THIS PROJECT

Peter F. Johnson
Flood Routing on the Illinois River in Oklahoma

Lawrence E. Dunaway
Analysis of Low Flows by Statistical Methods

Kenneth L. Perry
The Effects of Historical Record Lengths on Generating Synthetic Data Using a Stochastic Model of the Markov Chain

F. T. Painter
Autocorrelation Analysis of Streamflow Sequences

Wen-Hsiung Kao
A Statistical Study of the Relationship Between Inorganic Quality of River Water and Streamflow

PAPERS COMPLETED IN CONNECTION WITH THIS PROJECT

Bechir, M. H., "Return Periods for Floods of Great Magnitudes" Presented at the Forty-Ninth Annual Meeting of the American Geophysical Union, Hydrology Section, April 8-11, 1968, Washington, D. C.

Bechir, M. H., Quintin B. Graves, and A. F. Gaudy, Jr., "Effect of Basin Morphology on Response to Flood Flows" Proceedings International Hydrology Symposium, 47, 1967.

Dunaway, Lawrence E. and M. H. Bechir, "Duration Curves Versus Mass Durve as a Design Criteria" Presented at the Fourth National Water Resources Conference, November 18-22, 1968, New York City, New York.

Kao, Wen-Hsiung and D. F. Kincannon, "Correlation of Chemical Water Quality and Streamflow in the Arkansas River", In preparation.

Patterson, Kent, "Analysis of Water Quality Data in the Arkansas River" Presented at the Twenty-Fifth Annual Med-Continent Conference of Student Chapters of the American Society of Civil Engineers, May 8-10, 1969, Stillwater, Oklahoma.