HYDROLOGIC INVESTIGATION OF THE BLUE RIVER BASIN, OKLAHOMA

Prepared by

U.S. DEPARTMENT OF INTERIOR
BUREAU OF RECLAMATION
GREAT PLAINS REGION
BILLINGS, MONTANA

In cooperation with

THE OKLAHOMA WATER RESOURCES BOARD

APRIL 1991

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Technical Report
91-2

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CHAPTER I-HYDROLOGY

INTRODUCTION

This study is a hydrologic appraisal of the Blue River basin. Its purpose is to provide a compilation of information for use by the Oklahoma Water Resources Board (OWRB) in determining the stream water available within the basin for further appropriation and use. This is a first-phase study that resulted in a conservative estimate of water availability. Future detailed studies will be completed by OWRB to further analyze water availability by tributary. This study has been conducted through the Bureau of Reclamation's (Reclamation) Technical Assistance to States program, Reclamation's Denver Office, under an agreement with the Great Plains Regional Office in Billings, Montana, in cooperation with OWRB. Generalized climatic and hydrologic information is provided to help determine the quantity, quality, and dependability of water in the Blue River stream system.

At Reclamation's request, a hydrologic data evaluation of the Blue River basin on ground-water/surface water relationships was conducted by U.S. Geological Survey (USGS) in Oklahoma City, Oklahoma. This report is included in attachment C. Streamflow data used were obtained from a computer data base of the USGS, Water Resources Division. Evaporation and precipitation data used were collected by the National Oceanic and Atmospheric Administration (NOAA) Cooperative Program, and additional precipitation data used were compiled by the Oklahoma Climatologic Survey (CLIMOS). Reservoir and water use information and stream and ground-water appropriation information was provided by the Stream Water Division of the OWRB. This report also contains the results from the innovative application of Harvard University's Synagraphic Mapping System (SYMAP), which was used to generate Blue River basin precipitation, evaporation, and runoff isopleths.

SYMAP is a computer mapping program that takes input data and creates contour maps using a standard line printer as its output device. To use SYMAP, data packages must be established. The first package is the outline of the geographic area (in this application, the Blue River study area). The second package establishes data points using the X-Y coordinate system (0,0). The third package contains the data values associated with each data point. The fourth package instructs the program to make a map using different electives. SYMAP brings these packages and electives together to produce a contour map.

Reclamation's computer program SWE-176 was used to compute area-weighted values for the Blue River basin from contour maps produced by SYMAP. Each print location on the contour map has numerical value computed by SYMAP. These values are stored on SYMVU tape. By segregating the values into ranges (i.e., the range might equal the contour intervals), SWE-176 calculates an average value for each range and also counts the total number of print locations for each range or contour as well as for the total map. For each range, a percentage of the map can then be calculated. This percentage, multiplied by the average value for the range, is the area-weighted value for that range or contour. The sum of these weighted values is the area-weighted value for the entire Blue River basin. Long-term, continuous gauging stations are not required for specific watersheds since SYMAP can use data from numerous water data collection stations and then interpolate values where no actual data exist. As a result, OWRB can make informed administrative decisions on the amount of water usually available within the Blue River basin.

BASIN DESCRIPTION

The Blue River basin is located in southeastern Oklahoma (see figure A-1, attachment A). The Blue River originates in the Arbuckle Mountain region near the town of Roff, Oklahoma, and flows 150 river miles in a general southeasterly direction until it enters the Red River about 56 river miles below Denison Dam. The basin drains an area of about 676 square miles and is about 80 miles long with a maximum width of about 14 miles in the vicinity of Durant, Oklahoma. The Blue River channel is lined with timber and small brush; nearly half of the flood plain area is covered with timber. Below the vicinity of the Bryan-Johnston County boundary, the stream channel has an average width of about 180 feet, with banks averaging about 20 feet in height. The streambed slope decreases from an average of about 9 feet per mile in the headwaters to about 2 feet per mile near the mouth of the river (Oklahoma Planning and Resources Board [OPRB], 1954).

The geologic formations of the headwaters area are mainly of Upper Cambrian and Lower Ordovician ages, with some rocks of Pennsylvanian age in the extreme northern part of the basin. The rocks were subject to intensive folding and faulting associated with major uplift of the area during early to late Pennsylvanian time. In the central part of the basin (from about 4 miles north of the town of Fillmore to a point about 2 miles north of Durant) the geological outcrops are of Lower Cretaceous age. They include the Washita Division, Goodland Limestone, and the Trinity Group. The lower portion of the basin below Durant has outcrops of the Woodbine Formation, quaternary, and alluvial river deposits (OPRB, 1954).

The two principal aquifers underlying the basin are the Arbuckle-Simpson Aquifer, with outcroppings in the upper part of the basin, and the Antlers Aquifer, with outcroppings in the lower part of the basin. Figure A-14, attachment A, shows the major aquifers in the Blue River basin.

CLIMATOLOGICAL DATA

SYMAP analyses were used to generate isopleths from mean evaporation and precipitation data as shown in table A-1 and table A-4 in attachment A. The data presented was obtained from NOAA. Most available data from continuous measuring stations were used as input to SYMAP when periods of record were similar and when there were no unexplained anomalies in the data. Several SYMAP runs were used for climatological data to demonstrate the most logical interpretations.

Pan Evaporation

Monthly mean class A pan evaporation rates are shown in table A-1, attachment A. The range of available evaporation data used was from 1953-1979 at Grapevine and Lavon Dams in Texas to 1938-1982 for Denison, Hugo, Atoka, Wister, Eufaula Dams, and Chickasha Experimental Station in Oklahoma. A SYMAP run based on data from table A-1 shows an average annual pan evaporation of 75.52 inches in the Blue River basin (figure A-2, attachment A). As shown in tables A-2 and A-3 in attachment A, several months of data were not collected at some of the evaporation pans. Where there were sufficient records to obtain a monthly average, the actual monthly averages were computed to obtain the average yearly evaporation. No adjustments were made for missing data when a valid monthly average was obtained from collected monthly data. Pan evaporation information considers rainfall and, thus, is a true measure of actual evaporation.

Precipitation

Average annual precipitation increases from west to east (figure A-3, attachment A) and within the study area is greatest at the confluence of the Red River.

Area rainfall is usually highest in April, May, and September and lowest during December, January, and February (table A-4 in attachment A and figure 1). The Blue River basin area weighted average rainfall is 39.1 inches per year, ranging from about 37 inches in the upper drainage area to more than 42 inches at the confluence of the Red River (figure A-3, attachment A).

DETERMINATION OF IRRIGATION WATER REQUIREMENTS

The Bureau of Reclamation's technical report on irrigation requirements, published in September 1986, was used to determine the maximum amount of stream water per acre per year for appropriation for each crop. To determine the present-day cropping pattern, a survey was conducted in the counties within the Blue River basin. Table 1 contains crop statistics from *Oklahoma County Statistics*, published by the Oklahoma Department of Agriculture. Consumptive use for the major crops was examined in determining their respective water requirements.

Table 1.--Principal crops
(1984 crop acreage)

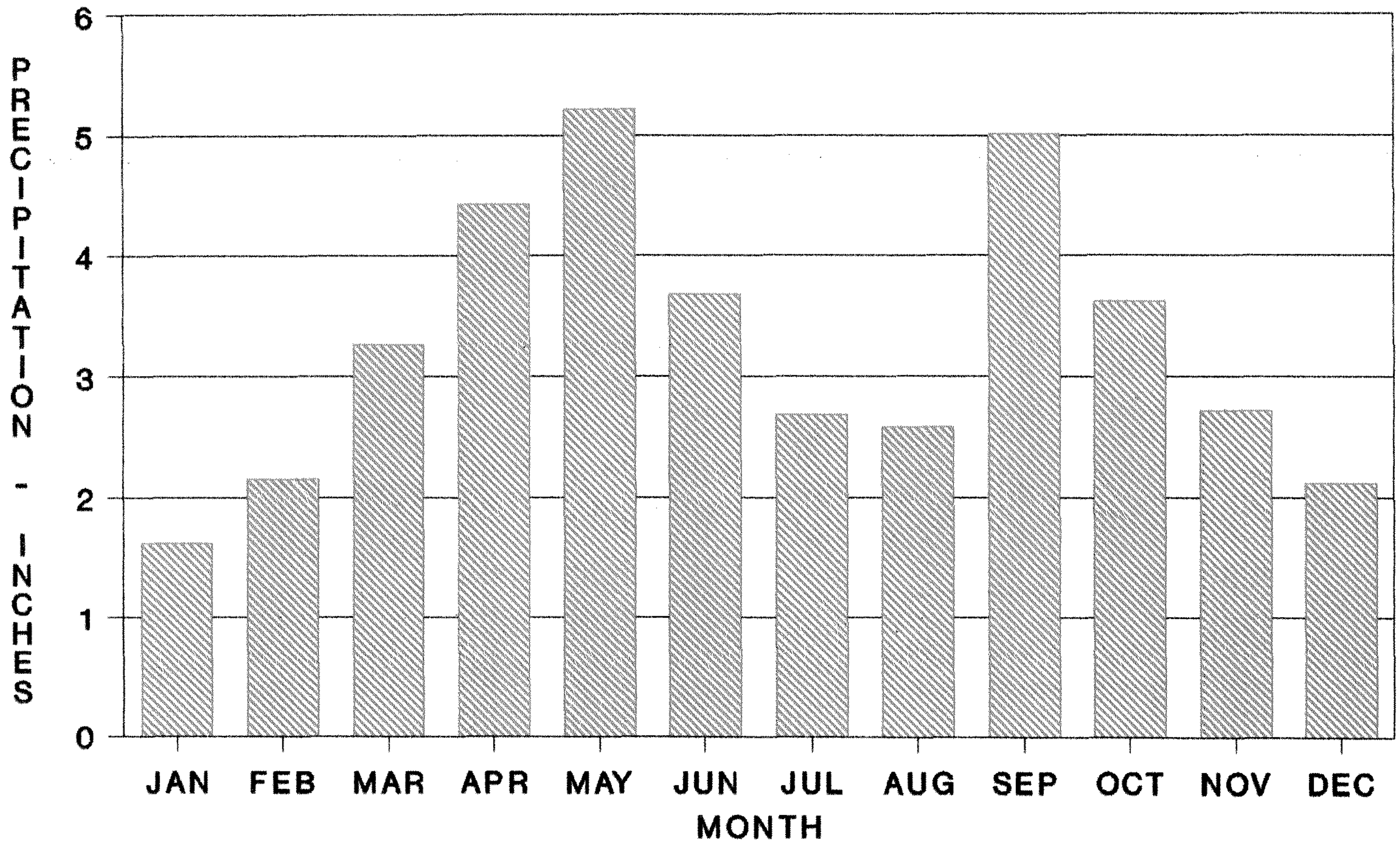
	County		
Crops	Pontotoc	Johnston	Bryan
Other hay (pasture)	16,000	17,000	32,000
Wheat	2,000	3,500	16,000
Soybeans	---	---	5,500
Alfalfa	2,400	1,000	3,200
Sorghum	---	---	2,500
Corn	---	500	1,900
Cotton	---	---	650
Oats	1,500	1,500	5,500
Peanuts	---	2,900	11,500

--- No acreage listed.

FIGURE 1

SYMAP WEIGHTED AVERAGE PRECIP (1951-80)

BLUE RIVER BASIN



Diversion requirements were calculated from irrigation efficiency coefficients published by the SCS. The SCS-predicted "high" management conveyance efficiency (transporting water to the farmland) is 99 percent, whereas "high" management farm efficiency (application to the crops) is only 70 percent. However, the 1983 *Reported Water Use of Oklahoma* lists most of the area's surface water delivery systems as either center pivot or other type sprinklers. Only 20 percent of the systems rely on gravity; i.e., furrow or flooding. The average onfarm irrigation water application efficiency was estimated as 80 percent. For gravity systems, efficiency was estimated as 65 percent and for sprinklers as 85 percent. Also, the SCS estimates irrigation return flows as 13 to 21 percent for the region. Since most of the study area farm delivery systems are sprinklers, the average irrigation return flow was estimated as 15 percent. Table 2 presents estimates of crop consumptive use, crop irrigation requirements, and diversion requirements. As shown in table 2, alfalfa and pasture have the highest water consumption, while peanuts consume the least of the 10 rated crops (U.S. Department of Agriculture [USDA] 1976 and 1974, revised 1980).

Table 2.--Consumptive use, crop irrigation and diversion requirements (inches per year)

Ardmore, Oklahoma

	Requirements		
Crop	Consumptive use	Crop irrigation	Diversion
Alfalfa	46.8	18.5	23.1
Pasture	39.8	16.5	20.6
Cotton	27.6	11.8	14.8
Corn	31.2	14.0	17.5
Sorghum	27.3	11.8	14.8
Spring wheat	---	14.5	18.1
Peanuts	19.0	11.5	14.4
Vegetables	---	11.0	13.8
Corn silage	23.6	9.8	12.2
Soybeans	23.8	8.6	10.8

--- Information not available.

NOTE: Diversion requirements equal to crop requirements plus conveyance and onfarm losses. No allocation is made for irrigation return flow.

Information on crop consumption use was obtained from the State of Oklahoma SCS data for Ardmore, Oklahoma. Irrigation requirements were calculated through SYMAP and are contained in a 1986 Bureau of Reclamation report on crop irrigation requirements for the State of Oklahoma.

According to the OWRB's *Reported Water Use in 1983*, most surface irrigation water (2,344 acre-feet) in Bryan County was used for peanuts. Irrigation of corn (685 acre-feet of water) is the dominant surface use in Johnston County. Pontotoc County diverted

332 acre-feet of water for pasture in 1983. Table 3 contains the ground water and surface water used for crop irrigation in all of Pontotoc, Johnston, and Bryan Counties.

Table 3.--1983 crop water use (acre-feet)

	County					
	Pontotoc		Johnston		Bryan	
Crop	Ground	Stream	Ground	Stream	Ground	Stream
Alfalfa	160	281	80	120	173	781
Corn						
Grain	0	0	72	678	0	650
Silage	0	21	0	7	0	0
Pasture	28	332	138	380	38	505
Peanuts	432	0	322	447	435	2344
Wheat	3	48	53	0	0	47
Grains	0	23	0	47	0	21
Sorghum						
Grain	50	20	0	43	53	124
Forage	5	30	0	15	0	117
Other crops	4	90	98	68	0	587
Horticulture	0	0	0	35	0	56
Soybeans	0	0	0	69	50	118
Not specified	0	0	0	17	0	0

Source: Oklahoma Water Resources Board reported water use in 1983.

Total irrigation demands in south-central Oklahoma are relatively less than in most other regions of the State. Stream water use is more prevalent than ground-water use for irrigation in the area. At present, the OWRB reports that 7,114 acre-feet per year of surface water and 4,986 acre-feet per year of ground water is appropriated from the Blue River basin for irrigation in Oklahoma.

GROUND WATER

The June 1989 Reclamation report, *Ground Water Assessment of the East Central and Southeast Oklahoma Water Supply Study Areas* states, "The Arbuckle-Simpson Groups, in the upper part of the basin, can produce large quantities of water; yields of 200 to 500 gallons per minute (gal/min) are common. In places, wells as deep as 250 feet yield less than 1 gal/min and have a very slow recovery. Flow occurs primarily through fractures, joints and solution channels (Harp, et al., 1985)." The average saturated thickness of the aquifer is about 3,500 feet in the outcrop area; presently, the maximum well depth is 2,500 feet. The Arbuckle Group consists of several thousand feet of limestone and dolomite (5,000 to 6,000 feet thick) that have relatively high permeability, resulting from fractures, joints, and solution channels formed in the rock. The Simpson Group consists of fine-grained, loosely-cemented and friable sandstone which yields water to wells freely. The Oklahoma State Health Department (OSHD) (1982) notes declining water tables over a number of years in the Arbuckle Group. The USGS (1985) states, "...there is no large-scale pumpage from this aquifer and that the water levels in the confined Arbuckle-Simpson Aquifer vary considerably, generally in response to annual variations in recharge...." The aquifer provides base flow to streams from springs in the outcrop area.

There is a hydraulic connection between streams draining the outcrop area and the aquifer; therefore, a change in ground-water pumping may affect streamflow. Streams in the area derive a significant portion of their base flow from the Arbuckle-Simpson Aquifer. Fairchild (1984) states the base flow of the streams that receive discharges from the aquifer accounts for approximately 60 percent of the total annual runoff from the Arbuckle-Simpson outcrop area.

The Antlers Aquifer, in the lower part of the basin, is believed to be equivalent to the upper part of the Trinity Group as recognized in Texas (Hart and Davis, 1981). Currently, the aquifer is not used to its full potential, but water use is expected to increase in the future. The aquifer is composed of fine-grained, unconsolidated, friable sand interbedded with silt and clay. The aquifer is primarily a highly lenticular sequence of fine sands and silt-clay layers with a general southward dip and downdip thickening. The best yields from the Antlers Aquifer occur where the aquifer is 70 percent sand or greater (Hart and Davis, 1981). Figure A-14, attachment A, shows the major aquifers in the Blue River basin.

Recharge rates in the Antlers Aquifer are estimated to be approximately 6 inches per year, about 15 percent of the average annual precipitation of 42 inches. The total annual recharge to the aquifer from precipitation is an estimated 480,000 acre-feet of water (Hart and Davis, 1981).

For more information on the ground water/surface water relationship refer to the *Hydrologic Data Evaluation of Blue River basin - South-Central Oklahoma* report in attachment C.

STREAMFLOW ESTIMATES

Two methods were used to estimate runoff for the Blue River basin in Oklahoma; a description of these methods follows.

Method 1 used two USGS gauging stations (Blue River near Blue, Oklahoma [07332500], and Blue River at Milburn, Oklahoma [07332400]) for estimating runoff. Drainage area adjustments were made to account for the ungauged intervening area downstream of the Blue gauge to the confluence of the Red River. Method 1 used the adjusted average annual flow for the entire Blue River basin and compared it to the ranking of the annual flow likely to occur 35 percent of the time. OWRB's basis for appropriating stream water requires the determination of what annual flow will occur 35 percent of all years. This policy is discussed later in this section. Adjusted average annual flow is defined as gauged flow or historical surface runoff, adjusted for any reservoir or lake reregulation that originates in a subbasin. For this study, annual flow records were not adjusted for historic streamflow diversions. This approach results in a conservative estimate of additional water availability for appropriation. Future studies will be performed by OWRB to analyze tributaries; at that time, the flow records will be adjusted for the effects of streamflow diversions.

Method 2 depends on the application of SYMAP. SYMAP utilized adjusted average annual flows and the annual adjusted flows that occur 35 percent of all years from 13 USGS gauging stations and from reservoirs adjacent to and in the Blue River basin, SYMAP computed an average annual runoff value for 10 different areas in the region (table A-5, attachment A). The geographic centers (centroids) of these areas were then computed from USGS hydrologic unit maps. The centroids and their corresponding average annual and 35-percentile acre-feet per year (acre-ft/yr) runoff values were input to the SYMAP program to generate predicted acre-feet per square mile (acre-feet/mi^2) values. SYMAP, through interpolation, calculated the probable runoff within the subbasin areas of the Blue River basin (figures A-4 and A-5 and table A-5 in attachment A). Figure A-4 presents a contour map of adjusted annual runoff, and figure A-5 presents a contour map of adjusted 35-percentile runoff. Using figures A-4 and A-5, the acre-foot per square mile runoff can be interpolated for a specific location.

SYMAP was used for the hydrologic investigation of the Little River in southeast Oklahoma, and some of the data used in that study is used in this study. Similar applications of SYMAP were made for Reclamation planning studies in southeast and east-central Oklahoma. These studies used SYMAP for interpolating preliminary yield estimates of potential reservoirs.

The weighted average annual adjusted runoff predicted by SYMAP and using computer program SWE-176 for the Blue River basin is 462 acre-feet/mi^2 (table A-5, attachment A). In the Blue River basin, the average annual runoff varies from about 425 acre-feet/mi^2 in the central part of the basin to more than 500 acre-feet/mi^2 in the upper and lower part of the basin (figure A-4, attachment A). The weighted 35 percentile for the Blue River basin is 471 acre-feet/mi^2. Figure A-5 in attachment A shows the adjusted 35-percentile runoff varies from less than 400 acre-feet/mi^2 in the central part of the basin to more than 475 acre-feet/mi^2 in the upper end and 600 acre-feet/mi^2 in the lower end of the basin. The variation could be attributed to the fact that the upper part of the basin above Milburn gauge is in the Arbuckle-Simpson Aquifer and has a significant amount of ground-water seepage that contributes water to the Blue River. No significant streamflow regulation or diversion withdrawals from the river occur above the Milburn gauging station. Table A-9 in attachment A shows diversions above the Blue gauging station by the State Fish Hatchery, the Rural Water District (formerly called the Blue River Valley Improvement Authority), and the city of Durant, Oklahoma. These streamflow depletions can be a major factor in the decrease in runoff in the central part of the basin.

Streamflow Availability

To determine the availability of stream annual flows, it is appropriate to use historical long-term streamflow records of an individual stream at a gauging point, as was done for method 1. However, to determine annual flows for subbasins and the main stem of the river at locations other than the gauging station locations, method 2 is considered more appropriate and should be used to determine the water available for ungauged subbasins.

The OWRB rules and regulations for determining the availability of water were used in this investigation to determine the quantity of stream water available for appropriation in the Blue River basin.

To determine the availability of water by "regular" permit, this investigation uses the long-term average annual flows of the river system estimated using method 1 and annual flow for method 2. After ranking all measured annual flows, the actual annual flow is compared to the rank of all recorded flows (table A-10, attachment A). If the probability is that the long-term average annual flow for the period of study will occur at least 35 percent of the time, then the long-term average annual flow is used to determine the quantity of water that may be available for appropriation. According to OWRB rules and regulations, "As a general guide and criteria and absent evidence to the contrary, it shall be presumed that unappropriated water which is only available, on an average annual basis, less than 35 percent of the time is not and will not be deemed to constitute water available for the appropriation through a 'regular' permit...." Even though water may not be available by regular permit, the OWRB may issue seasonal "term" or provisional temporary permits for appropriations.

The equation used to determine probability of occurrence is:

$$P_x \geq \frac{M}{N+1} 100$$

Where M = rank, M = 1 for the largest and M = n for the smallest average annual flow.

N = total number of measured annual flows.

P = probability of occurrence in percent.

x = average annual flow.

Method 1 is based on water year period of record 1937-84 for the gauging station at the Blue River at Blue, Oklahoma. The drainage area above the gauge is 476 square miles, and the area below the gauge to the river's confluence with the Red River is 200 square miles. The drainage basin of the Blue River is, then, 676 square miles. The flows of the Blue River at the confluence are estimated by adjusting the gauged flow data by a factor of 1.42, the drainage area ratio of the area above the gauge and the total basin area. For the Blue River basin, the long-term average annual runoff is 303,676 (213,856 x 1.42) acre-feet per year and the annual flow with a 35-percent probability of occurrence is 290,063 (204,269 x 1.42) acre-feet per year (table A-10, attachment A). Method 2 (SYMAP) estimates the long-term average annual runoff as 312,312 acre-feet per year and the annual flow with a 35-percent probability of occurrence as 318,396 acre-feet per year. There is a 2.8 percent difference in the two methods for the average annual runoff and a 9.8 percent difference for the 35-percentile. The difference for the 35 percentile should be applied when using the SYMAP adjusted 35-percentile-runoff in figure A-5, attachment A.

Method 2 can similarly be used for determining available flow for any subbasin or tributary within the SYMAP grid. Hydrologic judgement must be used when applying SYMAP. Only reference gauge stations with similar periods of coinciding record and similar drainage areas should be used. Likewise, caution should be exercised when using SYMAP to estimate surface runoff from a very small drainage area (i.e., less than 100 mi^2) when most reference gauging stations have considerably greater drainage areas. However, SYMAP should still give a better estimate of runoff than traditional adjustments. If there is a known area ratio multiplier of smaller-to-larger drainage area runoff, then either method 1 or 2 may be improved by using the appropriate multipliers.

Although average annual flows are used to determine available water, the quantity of stream water available for direct stream diversion depends on annual, seasonal, and daily variations. Seasonal trends in streamflow in the study area are shown by the median flow at Blue River gauging stations near Blue, Oklahoma, and at Milburn, Oklahoma (figure A-6, attachment A). The flow responds rapidly to significant rainfall events and is typically high during the early spring, when frontal storms commonly move into Oklahoma. The flow then declines during June and July, reaching base-flow levels by July or August. The flow increases during the fall and winter in response to increased rainfall. Figure 2 demonstrates the seasonal relationship of the basin precipitation with the discharge at Blue River gauging stations near Blue, Oklahoma, and at Milburn, Oklahoma. Base-flow recession curves for the Blue River at Milburn show that the base flow does not drop below about 15 ft^3 (figure 14, attachment C and table A-8, attachment A) and remains relatively sustained during the winter and summer. This reflects a large ground-water supply from the Arbuckle Aquifer which underlies the Blue River watershed (Fairchild et al., 1982). Blue River at Milburn gauging station low flow (10 percentile) is about 20 ft^3/s in August and at the Blue gauging station is about 4 ft^3/s in September (table A-8, attachment A).

OKLAHOMA APPROPRIATED WATER

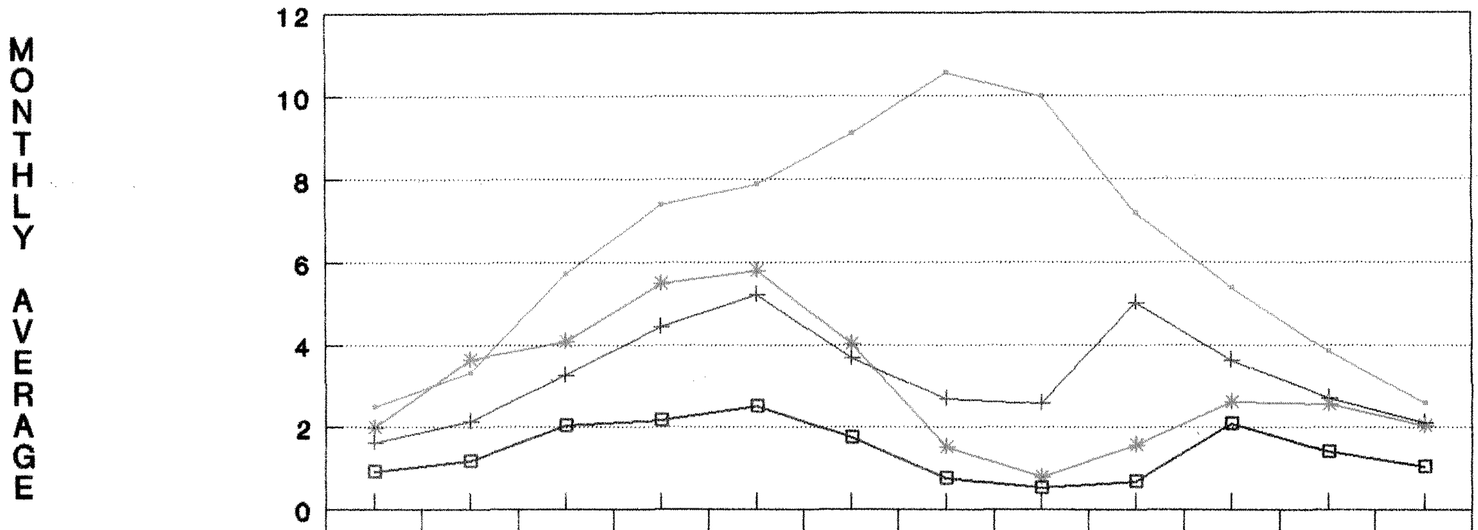
Table A-9, attachment A, shows the surface water permits in the Blue River basin. The allocated water above the Milburn gauge and below the Blue gauge are about the same; 3,147 acre-feet and 3,082 acre-feet, respectively. The combined allocations above the Blue gauge and below the Milburn gauge total 21,777 acre-feet, about 80 percent of the total surface water allocated in the basin. Table 4 shows a summary of water appropriated in the Blue River basin.

Table 4.--Oklahoma appropriated water from the Blue River basin

Purpose	Surface water		Ground water	
	Acre-feet	Percent	Acre-feet	Percent
Irrigation	7,114	25.4	4,986	11.0
Public water supply	13,435	48.0	34,940	77.2
Industrial	12	0.1	4,342	9.6
Power	0	0.0	0	0.0
Mining	0	0.0	50	0.1
Commercial	30	0.1	4	0.1
Recreation, fish, and wildlife	6,445	23.0	240	0.5
Agriculture (nonirrigation)	970	3.4	700	1.5
Total	28,006	100.0	45,262	100.0

Source: Oklahoma Water Resources Board (Memorandum dated May 4, 1990).

FIGURE 2
MONTHLY EVAP, PRECIP, AND DISCHARGE
BLUE RIVER BASIN



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EVAP (IN)	2.47	3.31	5.72	7.37	7.86	9.1	10.55	9.98	7.16	5.38	3.83	2.58
PRECIP (IN)	1.62	2.15	3.27	4.42	5.22	3.68	2.68	2.58	5.01	3.62	2.72	2.12
BLUE (100 CFS)	1.98	3.63	4.08	5.48	5.79	4.02	1.52	0.78	1.57	2.6	2.57	2.04
MILBURN (100 CFS)	0.91	1.19	2.04	2.17	2.5	1.76	0.76	0.52	0.69	2.08	1.4	1.04

MONTH

EVAP (IN) — PRECIP (IN)
BLUE (100 CFS) — MILBURN (100 CFS)

MAJOR LAKES

The Blue River Lake is an off-stream storage reservoir which stores diverted water from the Blue River and supplies water via a pipeline to the Rural Water District No. 2, formerly Blue River Improvement Authority. This lake is located in the NE quarter of Section 8, Township 6 South, Range 9 East, Bryan County, Oklahoma. The State Fish Hatchery near Armstrong, Oklahoma, diverts water from the Blue River Dam located in the NE quarter of Section 3, Township 6 South, Range 9 East, Bryan County. Table 5 shows reservoir data for the Blue River Lake.

Table 5.--Physical data for Blue River Lake

Item	Blue River Lake
Drainage area (square miles)	1.15
Surface area (acres)	40
Normal surface area (acres)	18
Top of dam elevation (feet)	665
Emergency spillway crest elevation (feet)	660
Principal spillway crest elevation (feet)	650
Maximum storage (acre-feet)	475
Normal storage (acre-feet)	190
Appropriated water (acre-feet/yr)	300

Data Source: Deltech Consulting Engineers and Land Surveyors, Madill, Oklahoma, letter to Reclamation dated August 15, 1985.

MUNICIPAL WATER USE

The city of Durant, Oklahoma, diverts water, via a pumping plant, from the Blue River. The following is an annual summary of water used:

Year	Million gallons per year	Million gallons per month
1985	972.4	81.0
1986	869.7	72.5
1987	815.5	68.0
1988	824.4	68.7
1989	790.5	65.9

Source: Telephone contact (April 27, 1990) with C.O. Reese, Manager of Durant Municipal Water Works.

The Rural Water District No. 2, formerly the Blue River Improvement Authority, diverts water from the Blue River via a pipeline to Rolling Wood Hills Lake (Blue River Lake) or directly to its water treatment plant. An average of 16-18 million gallons of water is used per month (telephone conversation, April 27, 1990).

The State Fish Hatchery has a diversion dam on the Blue River near Armstrong, Oklahoma, to divert water for its operation. The hatchery has a 6,445 acre-feet per year vested water right.

UNAPPROPRIATED WATER

Oklahoma law requires that in order to maintain a permittee's water right, the appropriated water must be put to beneficial use.

Therefore, it was assumed for this analysis that all appropriated water is being put to beneficial use and is unavailable to other potential users. The amount of water available for appropriation is determined by the difference of the total water available for appropriation and the existing water appropriations.

As discussed previously, two hydrologic methods were used to estimate the quantity of total water available; the following tabulation illustrates the comparison of these two methods for the entire Blue River basin.

Estimated runoff at the confluence of the Red River
(acre-feet per year)

Average annual		35-percentile annual	
Method 1	SYMAP (method 2)	Method 1	SYMAP (method 2)
303,676	312,312	290,063	318,396

As can be seen in the above table, method 1 shows less flow than method 2. The method 1 flow with a 35-percent probability of occurrence is less than the long-term average annual flow of the period of study. This lesser flow (35-percentile annual) is then used in determining water available for additional appropriation.

As shown in previous table 4, the existing appropriated surface water of the entire Blue River basin is 28,006 acre-feet per year. The amount of water available for appropriation is about 262,000 (290,000 - 28,000) acre-feet per year. OWRB does not recognize instream flow requirements. By using historical streamflow records to estimate surface runoff, the reductions in streamflow by historical water use in the basin, within a user's vested water right, have been included in the analysis. But, because a complete record of all river diversions in the basin is not available, it is not known to what extent a user's full allotment is being made. For this analysis then, and because vested water rights are subtracted from the 35-percentile runoff, the 262,000 acre-feet per year is considered a conservative estimate of the surface runoff available for appropriation. Although not included in this analysis, there exists a Red River Interstate Compact Agreement (approved by the Red River Compact Commission, May 12, 1978) on the Red River below Denison Dam.

HYDROLOGY SUMMARY

As previously noted, the purpose of this report is to determine if stream water is available for appropriation within the Blue River basin. The amount of water available for appropriation is about

262,000 acre-feet per year. This study demonstrates that water is available for appropriation by use of both the traditional and SYMAP techniques of runoff estimation. Since long-term gauging records of streamflows are available in the Blue River basin, both techniques of determining average annual runoff are reliable. As shown in previous figure 2, runoff in the area is at, or near, its annual minimum during July, August, and September. Lower runoff values are caused by lower rainfall rates and comparatively high evaporation during the summer months. During March, April, and May, the runoff and rainfall are at the annual maximum for the year. Although monthly diversions are not available, it is assumed that diversions are also at maximum rates during the summer months, further depleting stream waters. Annual diversions are available from OWRB.

CHAPTER II—WATER QUALITY

INTRODUCTION

As noted earlier in the report, the Blue River flows from its origin in the Arbuckle Mountains southeasterly to the Red River. As the river flows to the Red River, it undergoes changes in its stream dynamics. Past the city of Durant, Oklahoma, the Blue River changes from a mountain stream to a bottomland-type stream with hardwoods. The changes in the stream hydrology are reflected in the river's water quality. In the upper portions of the basin, the river is a high quality stream. In the vicinity of the Bryan-Johnston County line, the river becomes a more turbid, slower moving, meandering stream. The river presently supports wetlands and associated terrestrial and aquatic habitat.

The Blue River has been designated water quality management segment No. 410600 by the State of Oklahoma. The river is subdivided into three reaches: (1) from mouth to State Highway 48A bridge, (2) upstream from State Highway 48A bridge to State Highway 7 bridge 7, and (3) upstream from State Highway 7 bridge. The three subdivisions of the Blue River are shown in figure B-1, attachment B.

Reaches 2 and 3 have been designated "High Quality Waters" (HQW)(OWRB 1989). Water bodies designated HQW possess existing water quality which exceeds that necessary to support propagation of fishes, shellfishes, wildlife, and recreation as in the State's Anti-Degradation Policy Statement. An HQW designation prohibits any new point source discharge(s) or alteration of existing point source discharge(s) which would increase the concentration or increase the pollutant loadings of any constituent in the receiving water.

The chemical characteristics of water in the upper Blue River basin vary seasonally and have lower mineral concentrations during rainy seasons than during dry seasons. Flows in the stream, during dry seasons, are primarily derived from ground-water discharges to the stream (base flow).

The Blue River originates in the limestone ($CaCO_3$), dolomite [$CaMg(CO_3)_2$], and sandstone formations of the Arbuckle Mountains in south-central Oklahoma. The Blue River is sustained throughout the year by spring flow from the Arbuckle-Simpson Aquifer at its head waters. The origin of the Blue River significantly contributes to the chemical composition of water in the upper portions of the Blue River basin. Fairchild, et al., (1983) state that the quality of water from the springs that feed the Blue River and base flows in the upper Blue River is similar to that of ground water.

Most of the dissolved solids in ground water originate from solution of the porous media (i.e., rocks) through which the water has moved. The concentration of dissolved solids in the water depends on the physical and chemical characteristics of the original water, the solubility of the rocks, and the length of time water is in contact with the rocks.

Approximately two-thirds of the Arbuckle-Simpson Aquifer consists of limestone and dolomite (Fairchild, et al., 1983). Ground flow is presumed to be through interconnected fractures and solution channels. The ground water becomes a calcium-magnesium bicarbonate type which eventually discharges to the Blue River.

Portions of the Blue River were included in a 1982 National Park Service (NPS) National Rivers Inventory of Free Flowing Streams and have been studied for State scenic river status. Flood plains with wetlands exist along the lower reaches of the Blue River and support diverse aquatic and terrestrial life. A U.S. Fish and Wildlife Service (FWS) 1986 survey indicated that protecting the quality of the Blue River was a high priority (Reclamation 1989b).

EVALUATION OF WATER

This section summarizes existing water quality data on the Blue River. Environmental Protection Agency (EPA) data base, STORET, was used to search for water quality data on the Blue River. The data obtained and used were collected by the USGS and the OSHD.

Sampling stations included Connerville, Milburn, Armstrong, and Blue (see figure B-1, attachment B). The water is used for municipal, industrial, irrigation, fishery, and recreational purposes. Results obtained were compared to criteria established by the EPA (1990) and the OWRB (1989).

Data for the Stiff diagrams were taken from the USGS stations on the Blue River near Connerville, Oklahoma (No. 07332390), at Milburn, Oklahoma (No. 07332400), and near Blue, Oklahoma (No. 07332500). Data from the OSHD (station No. 10600D3X4Z12) near Armstrong, Oklahoma, were also used. The data used were the mean values from the entire period of record for each station. The diagrams are for general comparison only since the concentrations of the constituents can vary greatly from the mean with each individual sample.

Available data have been summarized in tabular form (table B-1, attachment B) and in Stiff's ion concentration diagrams. The *National Primary and Secondary Drinking Water Standards* are shown in table B-2, attachment B.

A review of the available water quality data for the Blue River basin indicates that the water quality can be described as good; it has a low salt level, is suitable for irrigation, and is suitable, with treatment, for municipal and industrial purposes. Selected water quality parameters are shown in tables B-3 and B-4, attachment B.

Municipal and Industrial Use

Samples of water collected from 12 perennial springs in the Arbuckle Mountain area indicate that the water is a calcium bicarbonate [$Ca(HCO_3)_2$] type. The average dissolved solids are 328 milligrams per liter (mg/L); the average hardness is 336 mg/L (Fairchild, 1984). These values reflect a good quality hard water. It may be seen that most of the bicarbonate (HCO_3^{-1}) and carbonate (CO^{-2}) ions are associated with calcium (Ca^{+2}) and magnesium (Mg^{+2}) ions (figures B-2 and B-3, attachment B). It may be assumed that the springs contribute to the hardness of the Blue River.

While hard water is suitable for human consumption, the cations Ca^{+2} and Mg^{+2} tend to precipitate soap and cause scale formation in water distribution systems and hot water heaters. The OWRB (1984) states that when hardness exceeds 180 mg/L in water for household uses, treatment for its removal is generally desirable.

Both total iron and manganese concentrations near Armstrong and near Blue are higher than the secondary maximum contaminant levels (SMCL) for drinking water; SMCL are unenforceable limits which are typically determined by public acceptance. Iron and manganese can stain bathroom fixtures, stain clothing, and impart an objectionable taste to drinking water. The State of Oklahoma has no criteria for the levels of iron and manganese in raw water supplies (OWRB, 1989). However, these constituents can be controlled by water treatment normally used in the area.

Existing data indicate that no violations in fecal coliforms or fecal coliform-fecal strep ratios have occurred.

With conventional treatment, the water should be suitable for industrial and municipal use. Hardness reduction with iron and manganese removal may be desirable.

Recreational Use

The Blue River is used for primary body contact recreation. Data for fecal coliform counts would apply to the use of the water for primary body contact recreation in which ingestion of the water is a possibility or secondary body contact recreation in which ingestion of water is not anticipated. The OSHD indicates that this data complies with EPA standards. The water, then, is suitable for recreational purposes.

Irrigation Use

Characteristics of water important for irrigation are salt concentration, proportion of sodium (Na) to other ions, concentration of boron, and specific conductivity. The nonadjusted sodium adsorption ratio (SAR) relates sodium to the concentration of other ions.

$$SAR = \frac{Na^{+}}{\left[\frac{(Ca^{+2} + Mg^{+2})}{2}\right]^{1/2}}$$

The calculated SAR values for the Blue River water are low (table B-3).

The specific conductivity values are moderate, indicating that a moderate amount of leaching may be required; therefore, plants with a moderate salt tolerance are recommended.

The highest boron concentration found from the Blue River was 0.18 mg/L near Blue, Oklahoma, which indicates no problem for boron sensitive crops.

The basic crops produced in the area, alfalfa, sorghum, soybeans, and wheat, grow well under the conditions described.

Fishery Use

Water for fishery use has established criteria for dissolved oxygen (DO), temperature, pH, oil and grease, and diversity of aquatic organisms. Permissible DO and temperature values vary with seasons.

Existing DO and temperature data are summarized in table B-4, attachment B. Above Milburn, the stream is a smallmouth bass and trout fishery; from Milburn to the mouth of the river it is a warm water fishery.

Oklahoma's 1989 *Section 319 Report* indicates that the Oklahoma Department of Wildlife Conservation has investigated a number of fish kills below State Highway 7 bridge. Often, the fish kills are associated with excess algal growth in the river. The algal growth appears to be caused by excess nutrients in the water from poultry wastes.

Table B-4, attachment B, reveals that the DO criteria were violated near Blue, Oklahoma, (0.2 mg/L). This value is thought to be associated with waste from a fat rendering and sausage plant formerly located on a tributary to the Blue River near Durant, Oklahoma, (personal communication, 1990). The problems with the plant wastes appear to be corrected. The maximum desirable pH is 9.0; the minimum pH is 6.5. Table B-4, attachment B, reveals that the Blue River satisfies the criteria. Oil and grease data were not available. Temperature data do not reveal seasonal variations or whether heat was added to the river to elevate its temperature by 5° F at any time. The ground-water origin of the river probably keeps water temperatures relatively constant in the upper reaches of the basin.

WATER QUALITY SUMMARY

There were some increases in sodium, chlorine, and sulfate concentrations in the water near Armstrong and Blue, Oklahoma, which could be attributed to agricultural return flows in those sites. Examination of the available data indicated that heavy metals, inorganic and organic residues, both regulated, were detected. Their concentrations, however, were much below the maximum permissible limits. The Blue River water did not appear to have any problem with toxic heavy metals and organic residues in fish. More monitoring of organics and radionuclides needs to be done.

The entire river, including the upper reaches (above Milburn, Oklahoma), shows increased suspended solids during high flows, probably due to streambank or soil erosion. The stream, however, at normal flows seems to have sufficient velocity to handle the additional load without increased siltation problems. Nutrients transported with the sediment may be the primary concern. A major concern in the lower segments seems to be increased algal growth which has resulted in oxygen deprivation and consequent fish kills. In the past, wastes thought to be released from a fat rendering and sausage plant placed a large oxygen demand on the river. There has been a marked improvement in the water, presumably after waste pretreatment by the plant.

CHAPTER III—CONCLUSIONS

The amount of additional water available for appropriation through regular State permit is about 262,000 acre-feet per year.

The hydrologic investigation shows that, with the spring water flow and artesian well flow from ground-water sources, the Blue River has a sustained base flow during the year.

Presently, the water is suitable for municipal, industrial, agricultural, recreational, and fishery purposes.

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ATTACHMENT A—HYDROLOGIC DATA

(Tables and Figures)

TABLE A-1
CLASS 'A' PAN EVAPORATION
BLUE RIVER AREA

UNITS=INCHES

MONTH	GRAPEVINE DAM 3691 (53-79)	LAVON DAM 5094 (53-79)	DENISON DAM 2394 (40-79)	HUGO DAM (38-70)	ATOKA DAM 0394 (70-82)	WISTER DAM 9724 (48-79)	EUFAULA DAM (57-82)	CHICKASHA EXP STA 1750 (53-79)	AREA AVERAGE	SYMAP BASIN WEIGHTED AVERAGE
JAN	3.17	2.83	2.71	2.35	2.24	2.52	1.95	2.90	2.58	2.47
FEB	3.97	4.03	3.53	3.18	3.08	2.65	2.77	3.86	3.38	3.31
MAR	6.56	6.25	5.86	5.31	5.61	4.73	5.08	6.48	5.74	5.72
APR	7.51	7.35	7.15	6.69	7.65	5.89	6.42	7.69	7.04	7.37
MAY	8.70	7.23	7.88	7.94	7.74	6.38	7.13	9.38	7.80	7.86
JUN	10.65	10.28	9.90	8.81	8.24	7.78	8.36	11.27	9.41	9.10
JUL	12.29	11.54	10.88	9.62	10.30	8.46	9.71	11.79	10.57	10.55
AUG	11.42	10.58	10.26	9.38	9.78	7.67	8.87	10.33	9.79	9.98
SEP	8.31	8.05	7.22	7.14	7.10	5.79	6.31	7.45	7.17	7.16
OCT	6.48	6.33	5.63	5.27	5.14	4.35	5.07	5.56	5.48	5.38
NOV	4.17	4.13	3.92	3.32	3.80	2.93	3.20	3.89	3.67	3.83
DEC	3.24	3.05	2.61	2.46	2.59	2.27	2.23	2.40	2.61	2.58
TOTAL	86.47	81.65	77.55	71.47	73.27	61.42	67.10	83.00	75.24	75.52
AVERAGE	7.21	6.80	6.46	5.96	6.11	5.12	5.59	6.92	6.27	6.29

NOTE: Hugo, Atoka and Eufaula Dam evaporation are from the Hydrologic investigation of the Little River dated March, 1987.
NOAA station index number and period of record are listed under the station name.

Table A-2
CLASS A PAN EVAPORATION
ATOKA DAM, OKLAHOMA

UNITS=INCHES

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1970	1.99	2.97	3.86	6.51	8.06	8.68	9.68	11.84	8.52	4.40	3.95	3.10	73.56
1971	2.75	3.40	7.19	8.32	7.79	9.50	11.06	7.02	6.47	4.40	4.19	2.73	74.82
1972	2.30	3.46	7.84	9.43	8.45	8.97	11.81	11.03	7.09	5.49	3.63	2.24	81.74
1973	1.63	2.41	5.05	----------	8.21	8.60	8.33	10.19	5.23	4.62	3.32	2.76	#####
1974	2.22	5.32	6.80	8.97	8.78	9.32	11.82	8.32	4.73	4.78	3.64	2.14	76.74
1975	3.25	2.99	4.99	----------	7.18	7.90	9.14	9.05	8.54	6.25	4.61	2.18	#####
1976	2.79	4.98	5.53	7.49	6.59	7.13	8.65	10.67	6.34	5.06	----------	2.41	#####
1977	1.72	3.20	5.56	----------	7.40	7.18	8.97	11.14	9.00	6.65	4.64	3.68	#####
1978	2.00	1.49	5.57	8.02	7.83	7.84	13.44	10.84	7.64	6.80	3.93	3.19	78.59
1979	1.92	2.04	5.30	6.71	8.42	8.11	8.86	6.99	6.28	3.11	----------	2.67	#####
1980	2.00	2.00	5.09	7.45	7.68	8.93	11.86	12.11	8.97	5.77	----------	2.01	#####
1981	2.26	2.82	4.53	5.99	6.43	7.83	9.96	8.15	6.38	4.64	3.10	1.98	64.07
1982	----------	----------	----------	----------	----------	7.09	----------	----------	7.05	4.91	2.97	----------	#####
TOTAL	26.83	36.98	67.31	68.89	92.82	107.08	123.58	117.35	92.24	66.88	37.98	31.09	
AVERAGE	2.24	3.08	5.61	7.65	7.74	8.24	10.30	9.78	7.10	5.14	3.80	2.59	73.27

Table A-3

CLASS A PAN EVAPORATION

EUFAULA DAM, OKLAHOMA

UNITS=INCHES

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1957	----------	----------	----------	----------	7.11	8.15	9.55	8.64	6.58	3.52	2.68	2.89	#####
1958	1.56	2.23	2.89	5.77	6.34	9.18	8.11	7.61	5.50	3.64	3.34	1.79	57.96
1959	----------	2.30	6.52	6.65	6.08	6.42	6.64	8.46	6.54	4.08	2.63	1.74	#####
1960	1.46	2.44	----------	6.04	7.38	7.90	9.63	7.04	6.01	4.50	3.11	1.80	#####
1961	2.10	1.65	5.43	5.38	6.12	6.08	----------	6.61	4.93	4.17	2.35	----------	#####
1962	----------	3.88	----------	----------	----------	----------	7.84	----------	----------	5.50	2.36	2.20	#####
1963	----------	----------	6.27	7.09	7.03	9.13	11.66	9.56	7.29	7.01	3.95	----------	#####
1964	----------	----------	4.35	7.17	7.55	7.28	11.26	9.13	5.12	3.79	2.44	2.47	#####
1965	2.61	2.78	3.30	7.08	7.49	8.84	9.93	10.42	7.61	5.60	3.65	2.55	71.86
1966	1.57	2.27	6.46	6.39	7.65	10.09	10.01	7.53	5.69	6.00	4.63	2.21	70.50
1967	----------	----------	6.59	6.20	7.73	8.34	8.25	8.64	4.86	6.16	3.16	2.08	#####
1968	1.57	2.74	4.68	6.77	6.56	8.37	8.79	8.73	6.97	5.98	3.04	----------	#####
1969	2.70	2.61	4.87	5.82	7.46	9.10	10.66	10.15	7.02	5.68	3.17	2.33	71.57
1970	----------	3.03	2.97	6.37	7.90	8.72	10.28	10.24	6.48	3.63	3.23	----------	#####
1971	----------	2.95	5.50	6.71	7.70	8.73	9.44	6.90	6.40	4.58	3.78	1.75	#####
1972	1.96	----------	6.00	6.89	7.00	9.45	9.87	9.13	6.43	4.05	2.21	----------	#####
1973	1.99	----------	4.33	4.63	7.42	6.60	8.95	9.26	5.77	5.44	3.62	2.96	#####
1974	----------	4.19	----------	8.10	7.93	8.80	11.72	8.65	5.13	4.82	----------	----------	#####
1975	----------	----------	----------	6.16	9.21	9.35	10.20	9.08	6.04	6.40	3.98	----------	#####
1976	----------	----------	5.52	6.34	6.71	8.91	8.66	9.48	5.72	4.35	----------	----------	#####
1977	----------	----------	5.98	6.69	6.62	9.35	9.68	7.52	5.88	4.38	3.25	----------	#####
1978	----------	----------	----------	6.61	6.83	8.84	11.60	9.95	7.30	6.64	3.54	----------	#####
1979	----------	----------	----------	6.20	7.15	7.64	8.32	9.22	6.78	7.24	3.58	----------	#####
1980	----------	----------	5.30	7.10	6.98	9.20	12.36	14.04	8.87	5.96	----------	----------	#####
1981	----------	----------	4.75	6.19	5.85	7.73	9.64	6.91	6.07	3.90	2.60	----------	#####
1982	----------	----------	4.81	5.63	6.49	6.75	----------	8.74	6.83	4.77	----------	----------	#####
TOTAL	17.52	33.27	96.52	153.98	178.29	208.95	233.05	221.64	157.82	131.79	70.30	26.77	
AVERAGE	1.95	2.77	5.08	6.42	7.13	8.36	9.71	8.87	6.31	5.07	3.20	2.23	67.10

TABLE A-4
MEAN MONTHLY PRECIPITATION
NOAA NORMALS (1951-80)
BLUE RIVER AREA

UNITS=INCHES

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
LINDSAY, OK	1.13	1.42	2.26	3.31	6.28	3.41	2.61	2.31	3.80	3.07	2.08	1.47	33.15
MARLOW, OK	0.90	1.20	2.00	2.68	6.01	3.82	2.57	2.42	3.66	2.95	1.95	1.36	31.52
PAULS VALLEY, OK	1.31	1.47	2.30	3.50	5.46	3.37	2.33	2.32	3.67	3.57	2.17	1.71	33.18
DUNCAN, OK	0.98	1.21	2.14	2.71	5.62	3.46	2.33	2.35	3.65	2.95	1.90	1.35	30.65
WAURIKA, OK	1.13	1.30	1.94	2.96	4.85	3.25	2.28	2.55	3.40	2.69	1.93	1.48	29.76
WICHITA FALLS,TX	0.93	1.00	1.82	2.99	4.34	2.85	2.00	2.14	3.41	2.61	1.42	1.22	26.73
RINGGOLD, TX	1.20	1.35	1.98	3.16	4.13	2.77	1.88	1.92	3.44	2.52	1.77	1.41	27.53
HEALDTON, OK	1.34	1.35	2.46	3.45	4.85	3.71	2.37	2.30	4.09	3.12	2.04	1.61	32.69
FORESTBURG, TX	1.48	1.46	2.17	3.50	4.03	2.98	2.15	1.97	4.19	3.23	2.17	1.51	30.84
MUENSTER, TX	1.66	1.80	2.62	3.68	4.65	3.00	2.19	2.18	4.32	3.22	2.34	1.71	33.37
DENTON, TX	1.55	2.00	2.63	4.13	4.71	3.04	2.12	2.04	4.14	3.03	2.21	1.93	33.53
VALLEY VIEW, TX	1.63	1.97	2.75	3.89	4.56	3.40	2.23	2.16	4.34	3.07	2.44	1.75	34.19
GAINSVILLE, TX	1.65	1.95	2.74	3.40	4.34	3.24	2.15	2.23	4.25	3.18	2.19	1.67	32.99
MARIETTA, OK	1.48	1.77	2.75	3.80	4.55	3.63	2.14	2.58	3.99	3.03	2.46	1.70	33.88
ARDMORE, OK	1.35	1.66	2.95	3.87	4.64	3.27	2.30	2.53	3.93	3.40	2.24	1.71	33.85
DALLAS, TX	1.82	2.11	2.93	4.45	4.40	2.77	2.02	2.16	3.59	3.36	2.38	2.17	34.16
GUNTER, TX	1.57	2.05	2.83	4.56	5.23	3.51	2.17	2.25	4.32	3.10	2.42	2.09	36.10
MCKINNEY, TX	1.88	2.33	3.03	4.46	5.02	3.20	2.61	2.19	4.52	2.88	2.64	2.12	36.88
DENISON DAM, TX	1.60	2.17	3.07	4.18	4.55	3.37	2.36	2.51	5.08	3.06	2.51	2.01	36.47
KINGSTON, OK	1.71	2.26	3.16	4.10	5.04	3.62	2.33	2.49	4.67	3.64	2.53	2.01	37.56
MADILL, OK	1.69	2.12	3.01	4.51	5.10	3.85	2.28	2.43	4.60	3.57	2.46	1.97	37.59
TISHMINGO, OK	1.53	2.05	3.17	4.61	4.88	3.46	2.70	2.52	4.87	3.63	2.49	2.08	37.99
TRENTON, TX	1.89	2.58	3.26	4.58	5.04	3.47	2.68	2.12	4.77	3.11	2.83	2.62	38.95
BONHAM, TX	2.06	2.67	3.58	4.77	5.07	4.08	2.90	2.33	4.83	3.50	2.99	2.77	41.55
DURANT, OK	1.74	2.25	3.27	4.54	5.00	3.72	2.54	2.47	5.61	3.47	2.80	2.18	39.59
PONTOTOC, OK	1.33	1.93	3.29	4.09	5.73	3.55	2.89	2.71	4.12	3.78	2.59	1.87	37.88
HONEY GROVE, TX	2.27	2.54	3.61	4.70	5.05	4.51	2.98	2.30	4.76	3.63	3.39	2.90	42.64
PARIS, TX	2.31	2.96	3.71	4.80	5.14	3.87	3.54	2.94	5.01	3.95	3.39	3.35	44.97
HUGO, OK	2.22	2.77	3.80	4.72	5.66	4.52	3.05	3.44	5.15	3.94	3.26	3.08	45.61
ANTLERS, OK	2.20	2.75	3.57	5.11	5.94	3.97	3.17	3.23	5.27	3.91	3.18	3.02	45.32
COALGATE, OK	1.63	2.16	3.89	4.96	5.19	3.84	2.96	2.74	5.04	3.93	2.89	2.19	41.42
ADA, OK	1.36	1.88	2.90	3.77	5.63	3.73	2.69	3.09	4.01	3.92	2.55	1.94	37.47
MCALESTER, OK	1.62	2.26	3.85	4.54	5.62	3.66	3.41	3.25	4.96	3.90	3.07	2.38	42.52
CALVIN, OK	1.40	1.90	3.38	4.43	5.82	4.53	3.55	2.58	4.32	3.71	2.69	1.96	40.27
EUFAULA, OK	1.53	2.07	3.97	4.68	5.48	4.12	3.65	2.73	4.20	3.41	2.96	2.44	41.24
HOLDENVILLE, OK	1.34	1.68	2.98	4.37	5.60	3.83	3.46	2.66	4.00	3.54	2.40	1.83	37.69
KONAWA, OK	1.33	1.65	2.89	4.12	6.10	3.72	2.53	2.46	4.12	3.59	2.34	1.86	36.71
OKLAHOMA CITY, OK	0.96	1.29	2.07	2.91	5.50	3.87	3.04	2.40	3.41	2.71	1.53	1.20	30.89
NORMAN, OK	1.13	1.33	2.33	3.30	5.89	3.62	3.23	2.56	3.73	2.63	2.04	1.35	33.14
PURCELL, OK	1.07	1.34	2.37	3.37	6.02	3.59	3.00	2.42	3.97	3.18	2.06	1.46	33.85
CHICKASHA, OK	0.90	1.21	1.94	2.84	5.12	3.09	2.52	2.52	3.48	2.71	1.55	1.08	28.96
AVERAGE	1.51	1.88	2.86	3.96	5.17	3.57	2.63	2.48	4.26	3.30	2.42	1.94	35.98
BASIN SYMAP WEIGHTED AVERAGE	1.62	2.15	3.27	4.42	5.22	3.68	2.68	2.58	5.01	3.62	2.72	2.12	39.10

TABLE A-5
ADJUSTED ANNUAL FLOWS
BLUE RIVER AREA

CENTROID SUBBASIN NAME	PERIOD OF RECORD	DRAINAGE AREA (SQ MI)	AVERAGE ANNUAL DISCHARGE (CFS)	AVERAGE ANNUAL RUNOFF (AF)	AVERAGE ANNUAL RUNOFF (AF/SQ MI)	35-PERCENTILE ANNUAL DISCHARGE (CFS)	35-PERCENTILE ANNUAL RUNOFF (AF)	35-PERCENTILE ANNUAL RUNOFF (AF/SQ MI)
PAULS VALLEY	37-84	543	273.2	197811	364	251.0	181715	335
DICKSON	28-84	1872	684.6	495611	265	846.2	612628	327
DENISON DAM	23-84	1736	733.0	530633	306	754.6	546324	315
MILBURN	65-84	203	136.1	98530	485	137.1	99229	489
BLUE	36-84	273	159.1	115170	422	140.4	101635	372
ARTHUR CITY	44-84	2281	1612.2	1167180	512	1976.1	1430583	627
SANDERS, TX	67-84	175	140.4	101663	581	170.0	123077	703
CLEAR BOGGY	42-84	720	479.3	347000	482	484.8	350994	487
MUDDY BOGGY	37-84	1000	794.8	575377	575	922.2	667626	668
MCGEE CREEK	56-84	86.6	89.7	64940	750	95.0	68778	794
METHOD 2 BASIN SYMAP WEIGHTED AVERAGE		676	431.4	312312	462	439.8	318396	471
METHOD 1	37-84	676	419.5	303676	449	400.7	290063	429

Flows adjusted by extension of period of record, additions or deletions of drainage areas, and/or reservoir storage within the watershed. Listed period of record was sometimes extended. Other non-listed watersheds not used in SYMAP were also utilized to calculate subbasin runoff. Flows for Arthur City, Sanders, Muddy Boggy, and McGee Creek are from the Hydrologic Investigation of the Little River Basin dated May, 1987.

Period of record is water year ending September 30.

TABLE A-6
MONTHLY MEAN FLOWS
BLUE RIVER AT MILBURN, OK

UNIT=CFS

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	AF/YR
1966	35.6	112.6	47.4	102.7	70.5	37.2	31.2	114.5	43.0	33.2	28.2	26.0	682.2	40856
1967	24.9	23.7	23.3	408.2	141.4	302.4	79.0	43.6	126.7	74.5	89.8	83.5	1421.0	85390
1968	237.2	139.9	347.9	246.2	649.0	284.9	148.5	98.1	61.5	55.7	99.4	122.1	2490.3	150920
1969	99.8	224.1	245.7	300.8	612.7	166.8	90.6	63.9	52.7	303.5	72.6	100.8	2333.9	140999
1970	108.5	95.6	181.5	236.4	133.0	165.7	56.8	39.3	137.8	920.6	132.9	89.4	2297.6	139370
1971	85.5	76.1	54.8	53.4	47.5	58.9	31.6	44.2	35.2	92.3	52.1	308.7	940.4	56972
1972	106.4	73.6	57.8	71.3	82.1	43.0	38.2	34.8	31.4	125.8	146.0	57.2	867.6	52329
1973	133.3	216.6	615.1	787.2	265.1	591.7	101.8	55.4	230.3	232.7	966.6	226.1	4422.0	265493
1974	125.3	133.1	108.7	159.0	163.2	138.9	52.9	48.1	182.6	310.3	330.5	137.1	1889.7	113795
1975	147.6	326.0	437.5	296.3	288.2	157.6	107.4	61.4	51.4	44.8	51.9	60.9	2031.1	121846
1976	52.6	49.4	114.5	409.9	112.5	66.3	46.2	36.1	33.4	38.7	37.3	49.6	1046.7	62977
1977	57.6	84.8	377.9	142.3	144.1	72.0	50.9	43.8	45.7	35.2	48.0	33.1	1135.3	68694
1978	33.1	70.1	127.4	132.3	213.8	160.1	57.9	40.3	36.8	31.0	38.2	32.4	973.4	58709
1979	36.6	44.3	234.0	122.9	147.8	191.6	58.4	44.9	35.1	33.3	31.0	31.1	1011.0	61144
1980	31.7	29.6	26.9	29.3	189.4	41.5	20.4	16.9	70.3	60.2	38.7	84.5	639.3	38778
1981	40.0	53.0	96.7	49.3	146.0	132.5	174.4	50.6	45.6	1328.5	217.2	120.0	2453.7	149680
1982	161.8	226.5	153.6	99.9	699.1	429.6	137.5	76.5	51.8	43.7	47.1	50.5	2177.6	131303
1983	59.0	172.1	90.0	83.6	592.9	168.8	97.0	46.8	41.6	48.6	56.6	51.6	1508.8	91053
1984	49.0	51.2	141.3	131.4	74.9	48.4	39.2	24.8	23.5	139.9	135.5	217.7	1076.6	65225
1985	188.4	185.6	605.5	469.2	220.7	266.6	93.4	47.9	38.1	204.8	177.6	202.9	2700.8	163071
AVERAGE	90.7	119.4	204.4	216.6	249.7	176.2	75.7	51.6	68.7	207.9	139.9	104.3	1704.9	
AF	5577	6631	12568	12887	15354	10485	4653	3173	4089	12781	8322	6411		102930

TABLE A-7
MONTHLY MEAN FLOW
BLUE RIVER NEAR BLUE, OK

UNIT=CFS

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	AF/YR
1937	568.7	144.7	232.0	348.0	70.7	90.9	21.2	100.0	16.0	60.0	45.0	100.9	1798.0	108705
1938	452.4	2156.4	787.6	447.8	182.1	291.0	72.2	40.5	37.6	20.0	15.0	30.4	4532.7	264313
1939	29.6	67.5	65.6	192.9	33.2	24.2	28.7	8.5	4.0	4.4	11.3	17.8	487.7	29126
1940	18.1	45.9	22.8	438.6	1010.8	684.0	440.2	94.9	45.6	30.1	150.6	264.2	3245.8	196688
1941	269.7	369.2	164.7	993.2	536.0	363.7	76.7	91.8	47.8	995.7	507.1	220.4	4636.0	279069
1942	155.9	197.6	187.8	2923.8	612.7	939.0	179.1	120.7	90.8	80.0	465.3	156.2	6108.9	365665
1943	84.5	80.1	208.7	574.3	1558.5	607.5	73.6	33.0	46.5	41.4	52.2	89.9	3450.3	209133
1944	95.0	884.9	626.5	248.4	1206.0	209.2	68.4	41.8	44.0	100.7	98.6	231.7	3855.2	230596
1945	153.4	1460.3	3089.4	2110.9	515.5	2510.2	764.5	320.7	395.3	543.1	174.0	116.9	12154.1	728340
1946	429.4	1311.9	402.0	307.1	364.4	424.3	112.2	141.8	96.0	40.7	1128.7	1271.1	6029.5	359054
1947	197.4	118.4	197.6	888.6	843.6	232.6	101.7	56.9	43.9	33.6	44.6	263.6	3022.6	182750
1948	207.0	508.2	237.5	94.9	761.7	325.0	528.0	71.4	41.0	35.8	36.2	38.6	2885.2	173400
1949	156.3	341.8	273.2	160.3	641.1	374.4	73.6	45.4	138.0	209.6	57.1	68.2	2538.9	152634
1950	436.8	694.1	109.7	192.9	1391.9	288.0	780.1	754.9	314.3	122.1	113.5	105.8	5304.3	320225
1951	101.0	305.6	190.5	113.8	92.3	1016.3	119.0	41.8	44.1	70.8	112.9	59.0	2266.9	135014
1952	54.8	59.2	164.5	897.3	145.2	48.4	31.0	20.7	19.4	19.2	43.8	33.2	1536.7	92129
1953	28.2	33.4	179.6	521.2	342.9	95.5	757.9	131.8	134.5	65.0	82.0	113.7	2485.7	150990
1954	126.2	60.6	43.3	151.4	1189.1	159.9	36.8	24.6	26.7	229.8	33.9	165.1	2247.4	137091
1955	133.6	216.7	233.3	146.5	291.2	45.1	147.7	21.5	140.4	29.4	25.3	26.4	1457.1	87595
1956	26.2	69.9	32.1	51.5	64.8	39.6	5.2	0.9	0.4	4.6	15.9	37.3	348.6	20805
1957	27.4	113.9	238.3	2373.8	2200.3	1448.9	140.1	70.8	1501.4	131.4	1185.9	261.7	9694.0	582451
1958	517.5	214.5	588.1	378.7	1285.2	121.1	71.3	43.5	38.2	30.3	35.7	35.7	3359.9	204185
1959	34.9	35.4	98.2	221.2	117.9	88.7	176.1	37.3	89.3	479.1	75.3	315.7	1768.9	107614
1960	421.7	371.6	377.1	125.6	432.3	106.9	132.8	70.5	60.8	161.9	58.7	370.7	2690.6	162535
1961	177.9	292.0	339.6	221.1	199.0	94.4	72.2	28.7	63.0	180.8	511.6	317.7	2498.3	150109
1962	144.8	124.5	161.5	273.6	78.1	967.5	83.1	48.8	179.1	506.0	672.0	291.0	3529.9	212151
1963	128.2	91.4	213.1	220.5	81.8	42.6	30.3	19.7	17.8	13.5	20.3	29.2	908.4	54715
1964	27.6	34.2	163.8	229.1	145.8	314.7	26.0	52.4	320.3	52.1	474.7	130.7	1971.5	118357
1965	126.6	343.6	122.1	114.8	263.6	70.8	33.1	25.1	52.2	24.7	59.8	30.4	1266.9	75266
1966	40.0	665.5	86.3	788.7	328.2	43.4	26.6	99.6	92.8	31.8	33.5	30.8	2267.3	133547
1967	26.2	27.0	27.9	987.4	265.0	610.2	118.4	46.5	478.4	101.3	136.9	178.6	3003.8	180142
1968	849.4	263.7	1169.2	1014.9	1712.6	686.8	238.3	109.8	201.4	112.6	317.5	331.5	7007.6	424912
1969	410.7	742.3	757.4	803.8	1684.3	271.8	86.8	57.4	50.0	434.2	83.6	237.0	5619.3	338709
1970	172.1	286.9	467.0	583.3	354.3	335.6	58.8	38.6	273.0	1025.6	174.1	107.0	3876.2	233925
1971	144.5	145.9	109.0	94.6	160.4	84.4	33.0	88.0	197.4	526.4	168.0	1383.8	3135.4	190842
1972	166.9	114.4	76.3	164.3	250.7	53.4	32.9	24.7	51.7	492.8	665.1	101.0	2194.4	132391
1973	365.0	593.1	1365.4	1792.1	651.4	1103.4	146.7	87.3	854.1	656.4	1245.0	531.9	9391.8	564036
1974	252.6	272.4	197.3	217.7	368.8	286.6	57.0	84.5	677.8	522.8	1371.0	275.8	4584.3	275185
1975	366.7	851.1	1073.1	548.6	541.0	549.4	170.0	104.1	92.9	52.3	75.8	114.4	4539.4	271544
1976	68.9	63.5	196.2	1024.5	386.9	182.5	82.6	33.3	34.9	44.5	48.3	66.7	2232.9	134356
1977	103.5	187.0	1348.7	292.1	303.7	81.5	52.5	57.0	170.6	31.9	65.1	35.1	2728.8	165472
1978	38.9	214.1	321.1	234.9	296.4	305.6	51.2	31.9	31.6	25.3	53.2	32.8	1637.0	98142
1979	116.6	273.7	803.5	349.7	792.5	363.4	104.2	50.1	34.0	34.9	35.6	33.6	2992.0	180790
1980	42.5	98.6	33.7	53.3	201.0	174.7	7.2	1.5	222.5	177.5	57.2	221.2	1291.0	77787
1981	48.8	99.4	366.3	65.5	278.5	443.7	560.1	58.3	58.1	3613.4	853.6	252.7	6698.4	408463
1982	581.9	858.3	305.0	179.4	1800.9	884.3	188.0	138.5	55.0	43.6	140.5	159.6	5335.1	320441
1983	82.0	572.7	226.1	157.4	758.8	498.4	106.6	53.4	35.8	46.4	62.6	56.5	2656.5	158441
1984	59.6	65.0	251.8	167.2	196.8	43.4	26.5	36.1	21.5	299.8	449.9	469.7	2087.2	126598
1985	416.6	649.9	1083.8	1351.0	382.3	661.1	124.8	51.2	29.8	158.7	233.5	194.7	5337.5	319805
AVERAGE	197.6	363.1	408.5	547.6	579.0	401.8	152.1	77.8	157.4	260.2	256.7	204.2	3606.0	
AF	12153	20166	25117	32582	35605	23907	9355	4784	9364	15998	15272	12559		216862

TABLE A-8
STATISTICAL FLOW ANALYSIS

BLUE RIVER AT MILBURN, OK (1966-85)

UNIT=CFS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MINIMUM	24.9	23.7	23.3	29.3	47.5	37.2	20.4	16.9	23.5	31.0	28.2	26.0
MEAN	90.7	119.4	204.4	216.6	249.7	176.2	75.7	51.6	68.7	207.9	139.9	104.3
MAXIMUM	237.2	326.0	615.1	787.2	699.1	591.7	174.4	114.5	230.3	1328.5	966.6	308.7
Percentile:												
10th (Low)	27.8	25.6	25.2	29.0	42.5	34.8	26.8	20.4	22.3	28.7	29.2	27.7
50th (Median)	68.5	76.4	97.7	101.0	104.0	94.1	58.7	44.6	40.7	44.2	50.4	59.3
90th (High)	177.0	315.0	677.0	603.0	758.0	520.0	154.0	85.2	135.0	375.0	286.0	220.0

DURATION TABLE OF DAILY MEAN FLOW FOR PERIOD OF RECORD (1966-86)

PERCENTAGE OF OCCURRENCES LESS-EQUAL THE VALUE

Percent	5	10	15	20	30	40	50	60	70	80	90	95
Value	27	30	33	37	44	51	63	81	102	134	214	349

BLUE RIVER NR BLUE, OK (1937-85)

UNIT=CFS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MINIMUM	18.1	27.0	22.8	51.5	33.2	24.2	5.2	0.9	0.4	4.4	11.3	17.8
MEAN	197.6	363.1	408.5	547.6	579.0	401.8	152.1	77.8	157.4	260.2	256.7	204.2
MAXIMUM	849.4	2156.4	3089.4	2923.8	2200.3	2510.2	780.1	754.9	1501.4	3613.4	1371.0	1383.8
Percentile:												
10th (Low)	22.9	29.2	29.2	35.2	41.8	29.6	14.1	6.1	3.8	14.0	17.8	23.0
50th (Median)	91.2	114.0	129.0	146.0	172.0	121.0	66.0	44.8	39.6	45.4	57.2	76.0
90th (High)	664.0	1350.0	1800.0	2720.0	2840.0	1760.0	398.0	199.0	553.0	890.0	772.0	714.0

DURATION TABLE OF DAILY MEAN FLOW FOR PERIOD OF RECORD (1966-86)

PERCENTAGE OF OCCURRENCES LESS-EQUAL THE VALUE

Percent	5	10	15	20	30	40	50	60	70	80	90	95
Value	25	30	34	40	51	65	86	113	166	252	537	1262

Percentile relate to the frequency of occurrence. The 50th percentile is the median and approximates the value that has the highest probability of occurence. The median is the middle value in a distribution, above and below which lie an equal number of values. Ten percent of the values fall below the 10th percentile, and 90 percent of the values fall below the 90th percentile. Eighty percent of the values fall between the 10th and 90th percentiles

TABLE A-9
SURFACE WATER PERMITS IN THE BLUE RIVER BASIN

PERMIT #	DIRECT RIVER DIVERSIONS	PURPOSE	ALLOCATED ACRE-FEET (CALENDAR YEAR)
400031B	*	Irrigation	50
640622	*	Irrigation	60
720063	*	Irrigation	30
730092	*	Irrigation	40
770026	*	Irrigation	18
770043	*	Irrigation	80
780104	*	Irrigation	129
780167	*	Irrigation	2
800101	*	Irrigation	70
800185	*	Irrigation	250
810082	*	Irrigation	320
810172	*	Irrigation	160
850013	*	Agriculture	970
880025	*	Irrigation	320
400031A		Irrigation	137
670320		Commercial	25
740166		Irrigation	34
790088		Irrigation	360
810039		Irrigation	80
710362		Industrial	12
Above Milburn Gauge			3147
360076	*	State Fish Hatchery	6445
400050	*	PWS, City of Durant	1842
520335	*	Irrigation	106
700137	*	Irrigation	160
710554	*	PWS, City of Durant	4500
740002	*	Irrigation	260
740296	*	Irrigation	7
770025	*	PWS, Rural Water District	639
780140	*	PWS, City of Durant	6000
800190	*	Irrigation	56
710296	*	Irrigation	200
720441	*	Irrigation	90
730119	*	Irrigation	5
770002	*	Irrigation	8
800180	*	Irrigation	320
810101	*	Irrigation	240
640009		Irrigation	160
641000		Irrigation	14
660587		Irrigation	66
710289		Irrigation	10
790054		PWS, Rural Water District	300
810043		Irrigation	122
850046		Irrigation	40
860030		Irrigation	50
710002		Irrigation	90
710217		Irrigation	47
Above Blue Gauge			21777

TABLE A-9 (continued)
SURFACE WATER PERMITS IN THE BLUE RIVER BASIN

PERMIT #	DIRECT RIVER DIVERSIONS	PURPOSE	ALLOCATED ACRE-FEET (CALENDAR YEAR)
530330	*	Irrigation	800
540463	*	Irrigation	67
630204	*	Irrigation	360
650156	*	Irrigation	163
660144	*	Irrigation	34
710226	*	Irrigation	45
710253	*	Irrigation	25
760088	*	PWS, Rural Water District	154
780166	*	Irrigation	35
800130	*	Irrigation	1000
720154		Irrigation	194
720166		Irrigation	50
730014		Irrigation	65
740379		Irrigation	50
810022		Irrigation	35
890047		Commercial	5
Above confluence of Red River			3082
BASIN TOTAL			28006

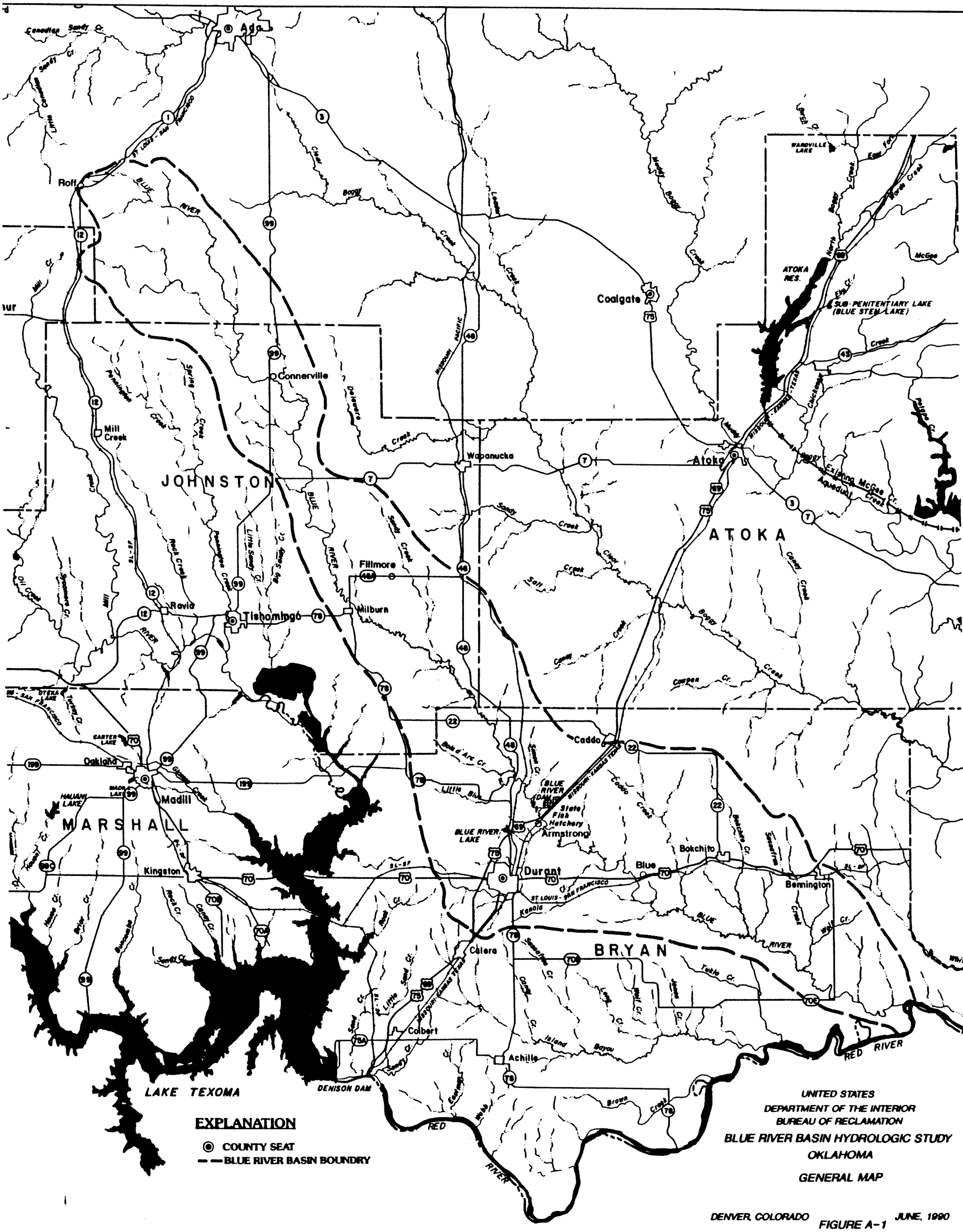
SUMMARY OF SURFACE WATER PERMITS FROM BLUE RIVER BASIN

Irrigation	7114
Public Water Supply	
City of Durant	12342
Rural Water District	1093
Industrial	12
Commercial	30
State Fish Hatchery	6445
Agriculture (nonirrigation)	970
TOTAL	28006

Data Source: Oklahoma Water Resources Board (May, 1990)

TABLE A-10
BLUE RIVER NR. BLUE, OK
ANNUAL MEAN VALUE AND RANKING (CFS)
WATER YEAR ENDING SEPTEMBER 30

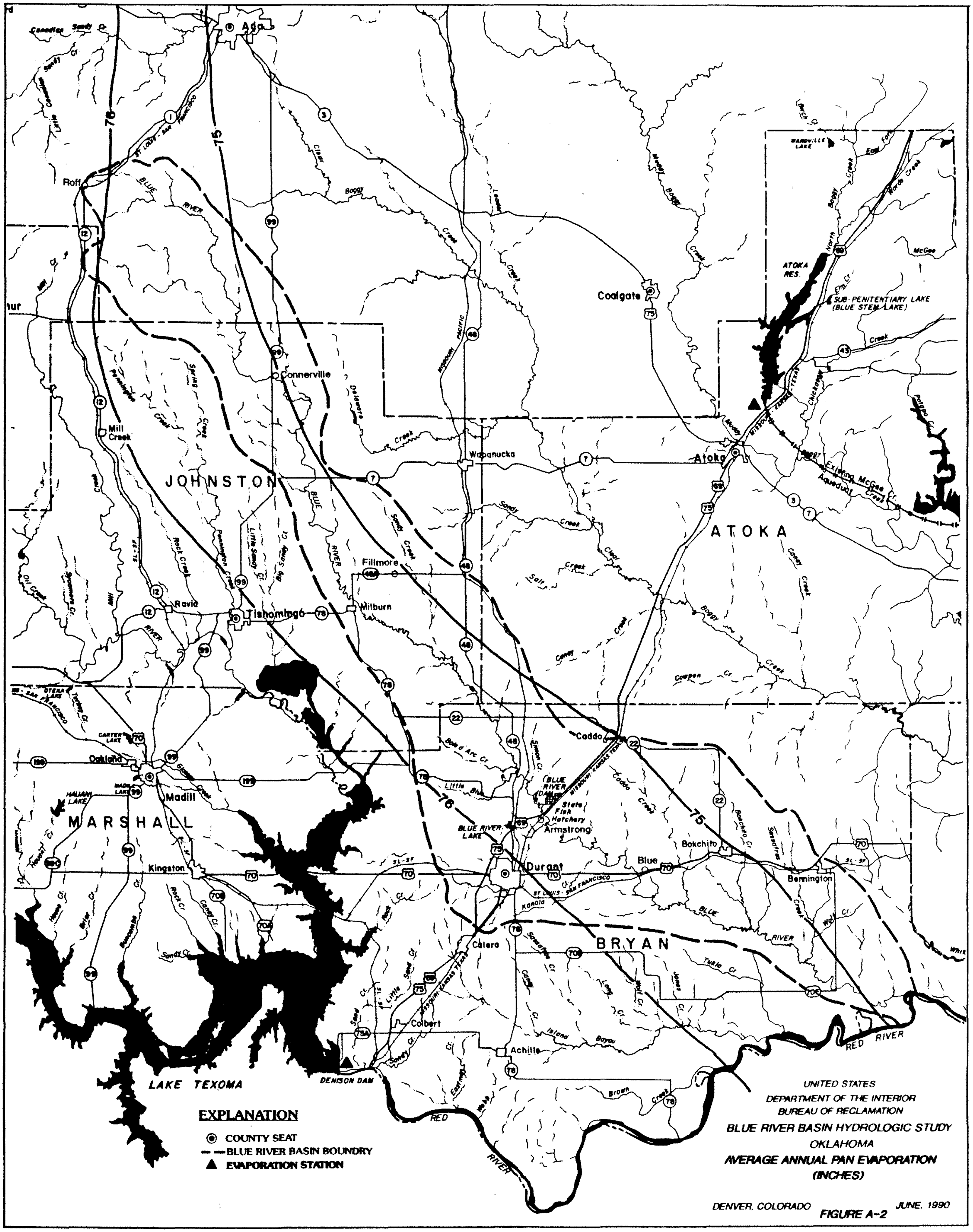
YEAR	ANNUAL MEAN (CFS)	RANKING	ANNUAL TOTAL (AF)	RATIO BELOW GAUGE (1.42)
1937	177.53	972.03	703730	
1938	376.93	812.32	588102	
1939	42.93	680.96	493001	
1940	236.60	678.56	491264	
1941	277.88	591.77	428430	
1942	591.77	557.33	403496	
1943	331.73	535.21	387478	
1944	299.22	467.78	338662	
1945	972.03	441.90	319930	
1946	362.13	427.69	309641	
1947	427.69	404.35	292740	
1948	259.81	402.85	291655	
1949	191.84	376.93	272893	
1950	441.90	362.13	262172	
1951	194.88	331.73	240163	
1952	139.30	299.22	216630	
1953	194.68	277.88	201179	
1954	174.95	276.49	200172	
1955	150.51	259.81	188098	
1956	30.78	254.52	184270	
1957	678.56	253.43	183481	
1958	404.35	250.28	181195	
1959	83.50	248.46	179883	
1960	248.46	236.60	171294	
1961	173.01	233.77	169247	
1962	254.52	230.94	167194	
1963	193.19	221.88	160640	
1964	114.03	204.25	147870	
1965	148.91	198.05	143386	
1966	185.98	194.88	141093	
1967	221.88	194.68	140946	
1968	557.33	193.19	139868	
1969	467.78	192.20	139151	
1970	276.49	191.84	138887	
1971	198.05	185.98	134648	
1972	253.43	177.53	128531	
1973	680.96	174.95	126661	
1974	402.85	173.01	125256	
1975	535.21	150.51	108968	
1976	192.20	148.91	107810	
1977	230.94	139.30	100847	
1978	137.29	137.29	99397	
1979	250.28	114.03	82553	
1980	77.69	86.36	62523	
1981	204.25	83.50	60451	
1982	812.32	77.69	56244	
1983	233.77	42.93	31078	
1984	86.36	30.78	22286	
AVERAGE	295.39		213856	303676
35%	282.15		204270	290063



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BLUE RIVER BASIN HYDROLOGIC STUDY
OKLAHOMA
GENERAL MAP

DENVER, COLORADO — JUNE, 1990

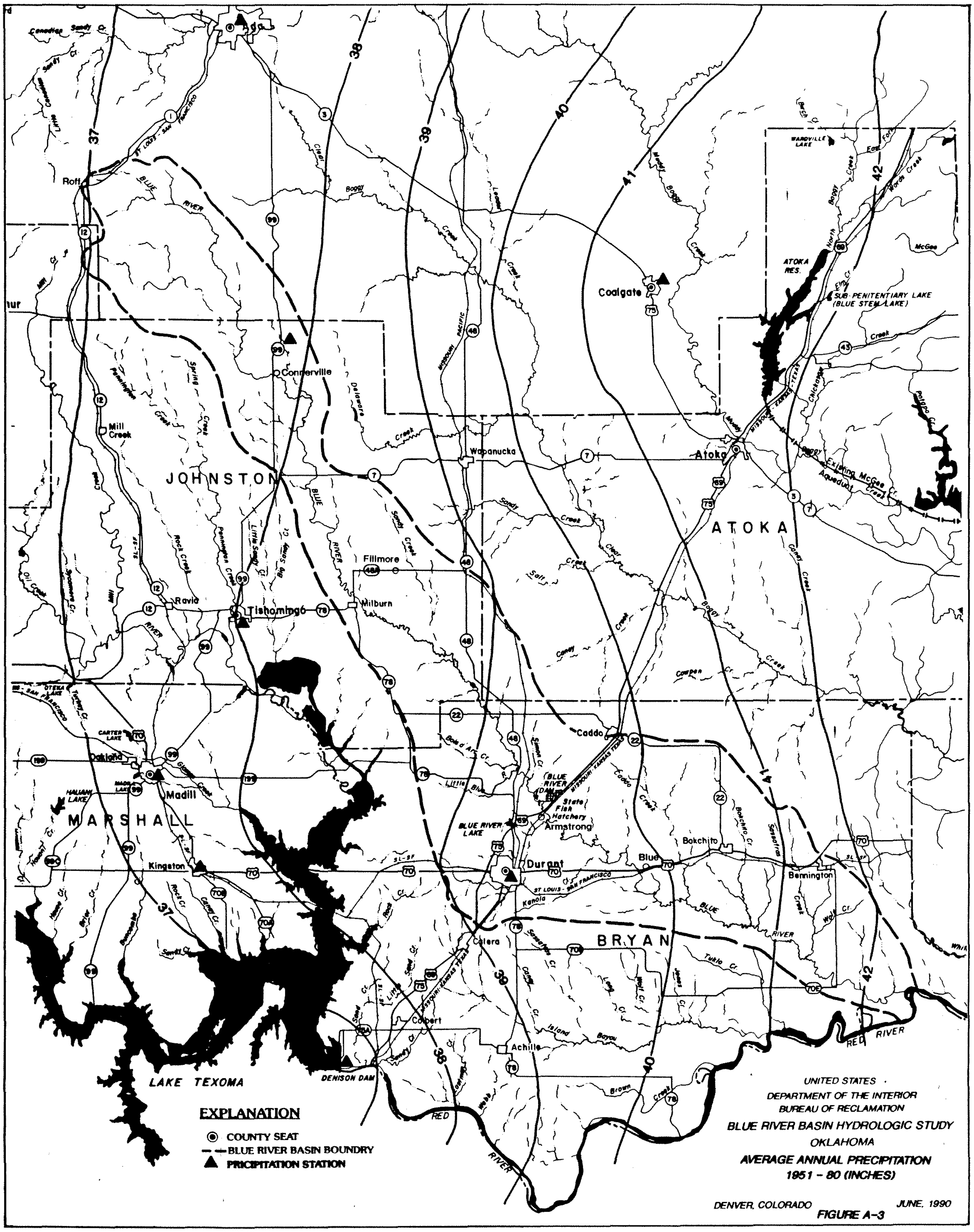
FIGURE A-1



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BLUE RIVER BASIN HYDROLOGIC STUDY
OKLAHOMA
AVERAGE ANNUAL PAN EVAPORATION (INCHES)

DENVER, COLORADO JUNE, 1990

FIGURE A-2



EXPLANATION

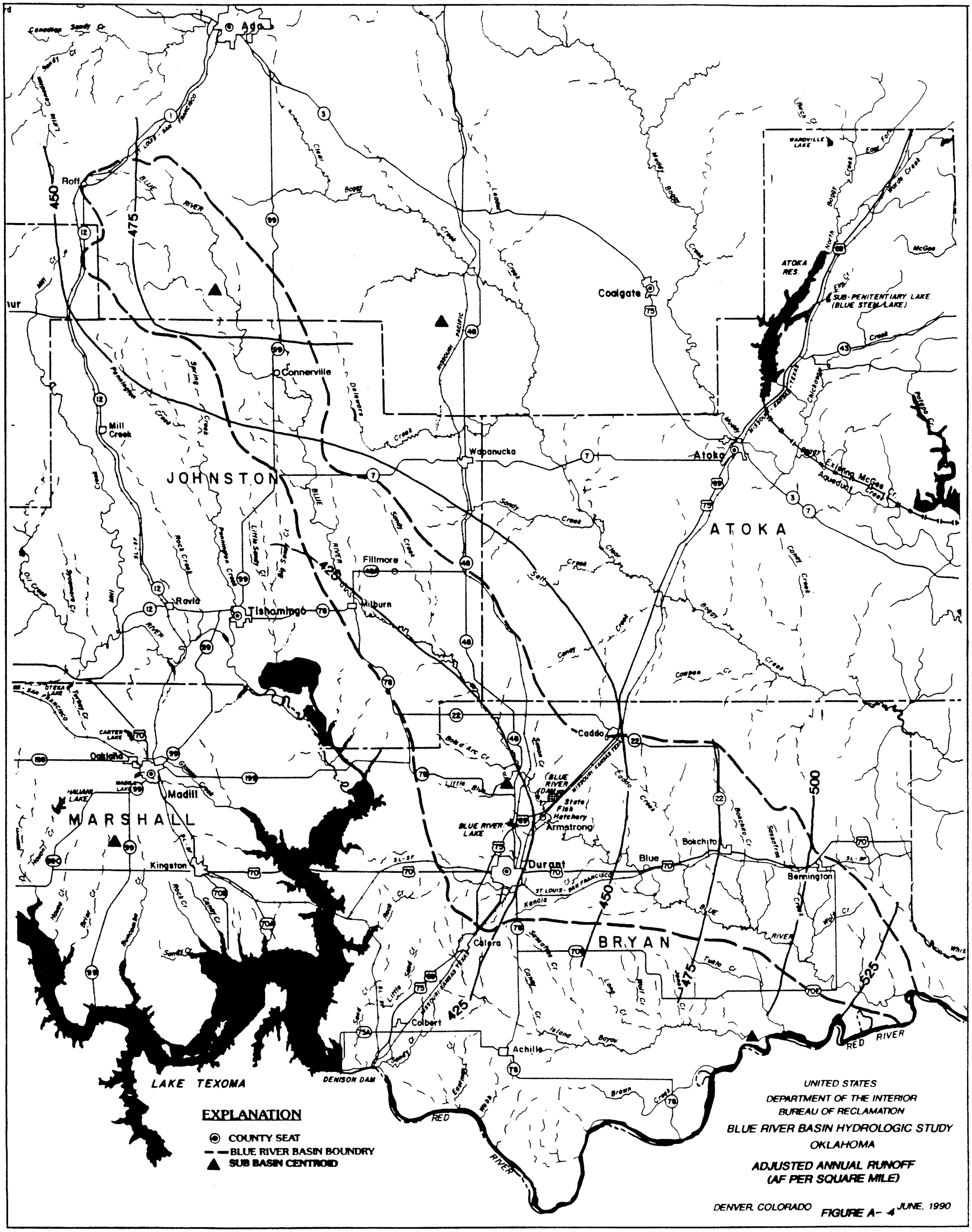
- COUNTY SEAT
- BLUE RIVER BASIN BOUNDRY
- PRICIPITATION STATION

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BLUE RIVER BASIN HYDROLOGIC STUDY
OKLAHOMA

AVERAGE ANNUAL PRECIPITATION 1951 - 80 (INCHES)

DENVER, COLORADO JUNE, 1990

FIGURE A-3



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BLUE RIVER BASIN HYDROLOGIC STUDY
OKLAHOMA

ADJUSTED ANNUAL RUNOFF
(AF PER SQUARE MILE)

DENVER, COLORADO FIGURE A- 4 JUNE, 1990

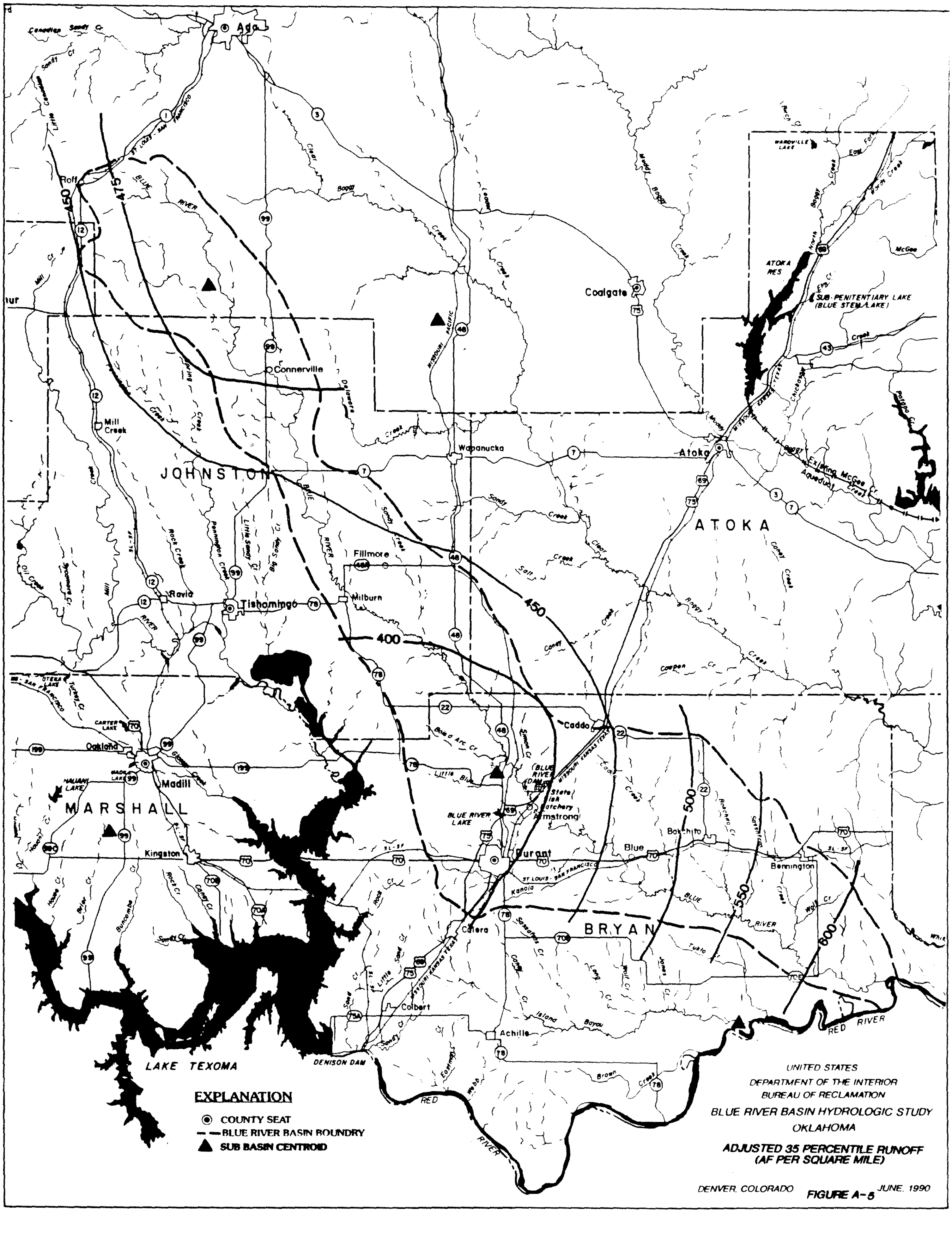
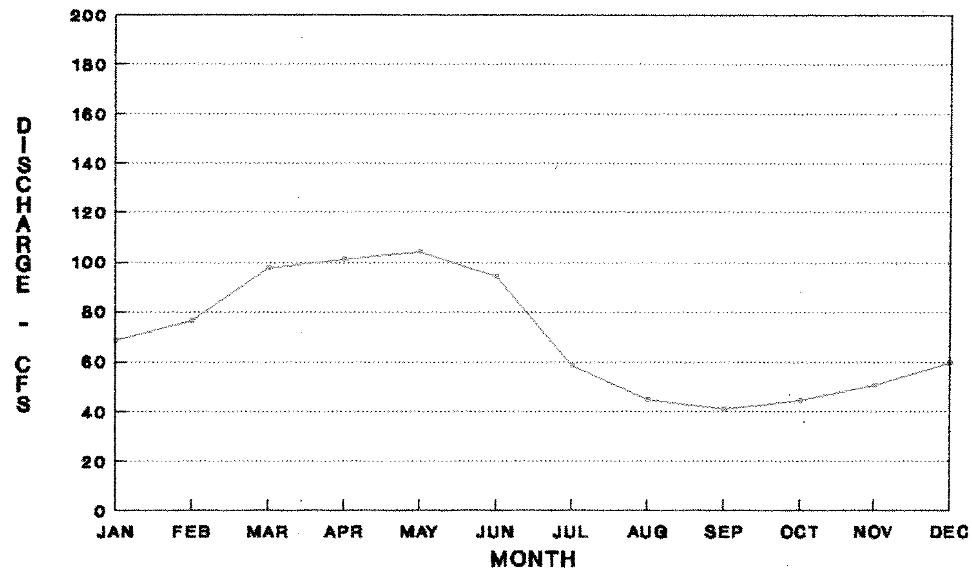

EXPLANATION
COUNTY SEAT
BLUE RIVER BASIN BOUNDRY
SUB BASIN CENTROID
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BLUE RIVER BASIN HYDROLOGIC STUDY
OKLAHOMA
ADJUSTED 35 PERCENTILE RUNOFF
(AF PER SQUARE MILE)
DENVER, COLORADO
JUNE, 1990
FIGURE A-5
JOHNSTON
ATOKA
MARSHALL
BRYAN
LAKE TEXOMA
RED RIVER
DENISON DAM
Ada
Roff
Coalgate
Connerville
Mill Creek
Wapanucka
Atoka
Fillmore
Milburn
Ravia
Tishomingo
Oakland
Madill
Kingston
Caddo
Armstrong
Durant
Bokchito
Blue
Bennington
Calera
Colbert
Achille
BLUE RIVER LAKE
ATOKA RES
SUB-PENITENTIARY LAKE
(BLUE STEM LAKE)
450
475
400
500
550
600

Figure A-6

MONTHLY MEDIAN DISCHARGE (1965-85)
BLUE RIVER AT MILBURN, OKLAHOMA



MONTHLY MEDIAN DISCHARGE (1937-85)
BLUE RIVER NEAR BLUE, OKLAHOMA

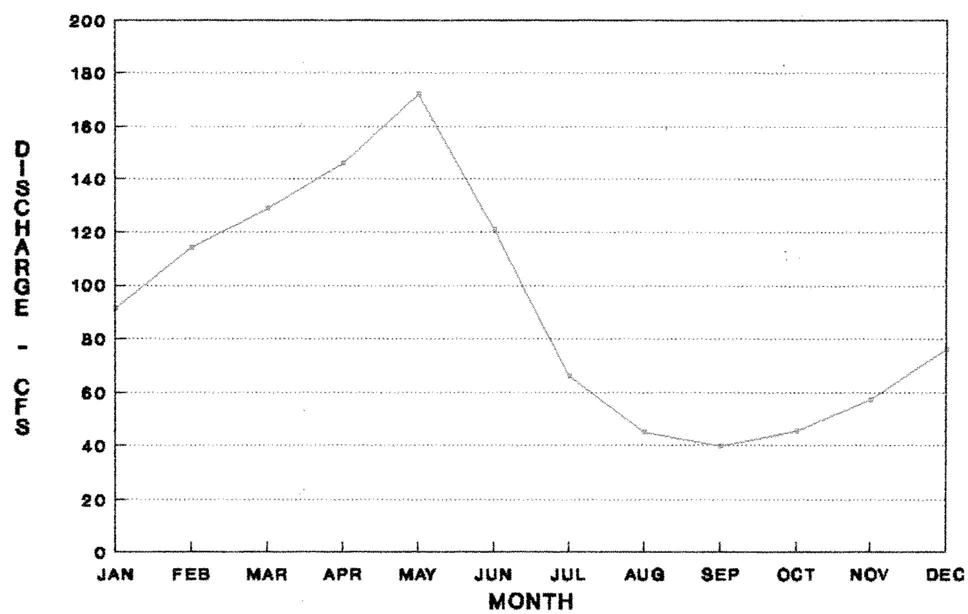
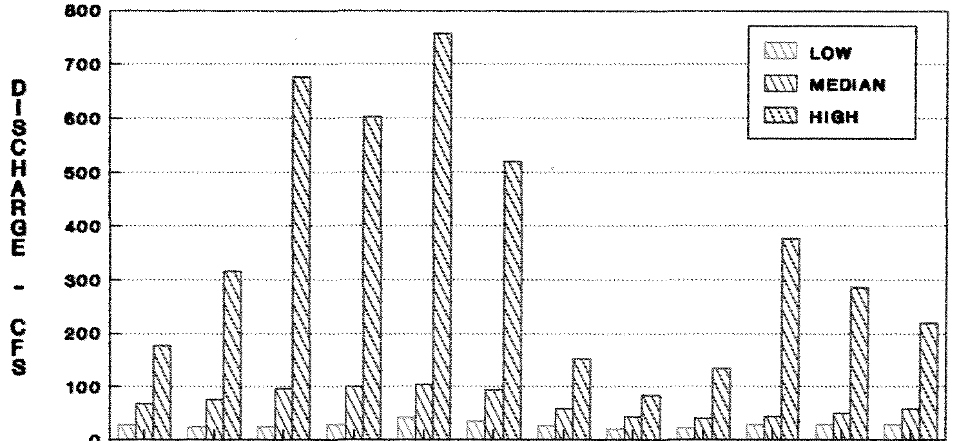


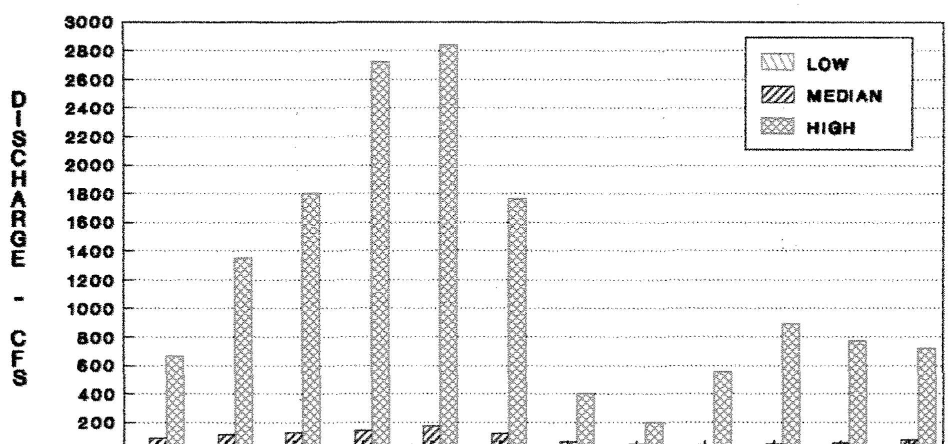
Figure A-7
MONTHLY DISCHARGE (1965-85)
BLUE RIVER AT MILBURN, OKLAHOMA



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
LOW	27.8	25.6	25.2	29	42.5	34.8	26.8	20.4	22.3	28.7	29.2	27.7
MEDIAN	68.5	76.4	97.7	101	104	94.1	58.7	44.6	40.7	44.2	50.4	59.3
HIGH	177	315	677	603	758	520	154	85.2	135	375	286	220

MONTH

MONTHLY DISCHARGE (1937-85)
BLUE RIVER NEAR BLUE, OKLAHOMA

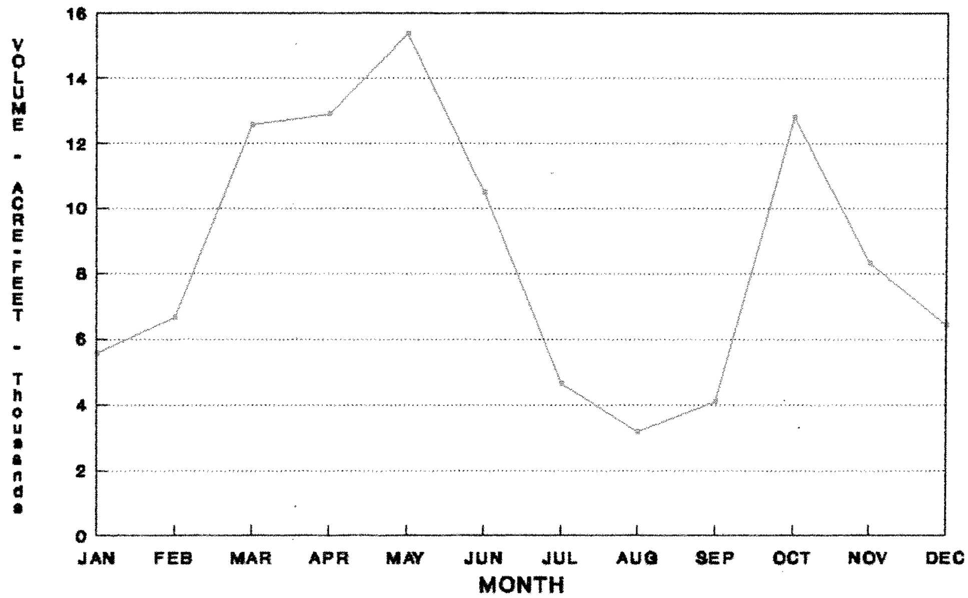


	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
LOW	22.9	29.2	29.2	35.2	41.8	29.6	14.1	6.1	3.8	14	17.8	23
MEDIAN	91.2	114	129	146	172	121	66	44.8	39.6	45.4	57.2	76
HIGH	664	1350	1800	2720	2840	1760	398	199	553	890	772	714

MONTH

Figure A-8

AVERAGE MONTHLY VOLUME (1966-85)
BLUE RIVER AT MILBURN, OKLAHOMA



AVERAGE MONTHLY VOLUME (1937-85)
BLUE RIVER NEAR BLUE, OKLAHOMA

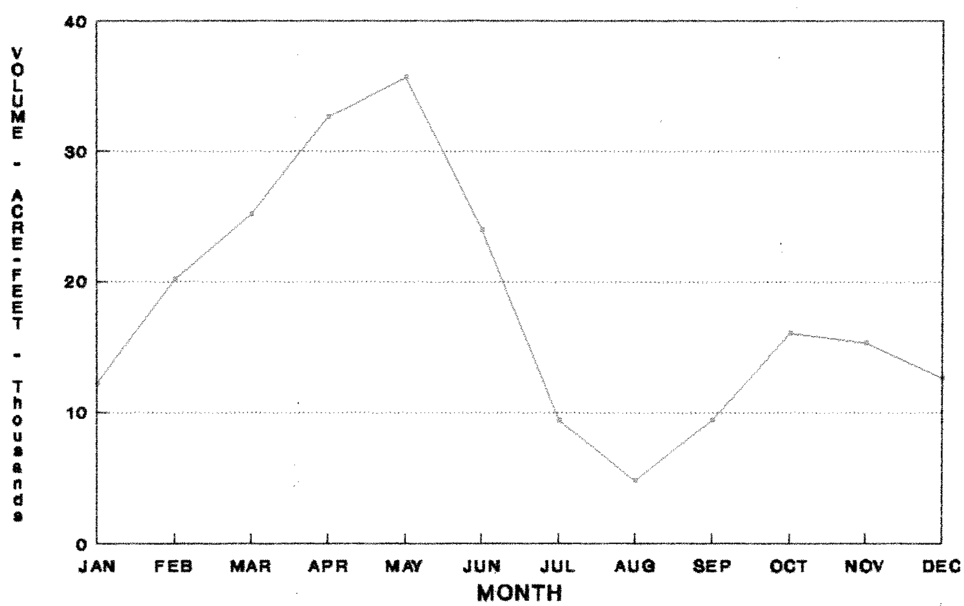
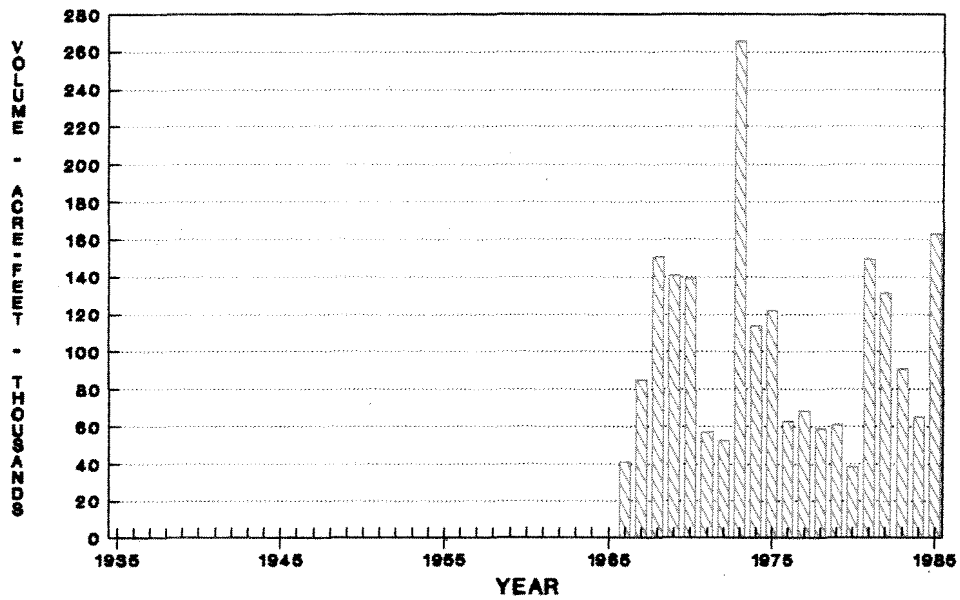


Figure A-9

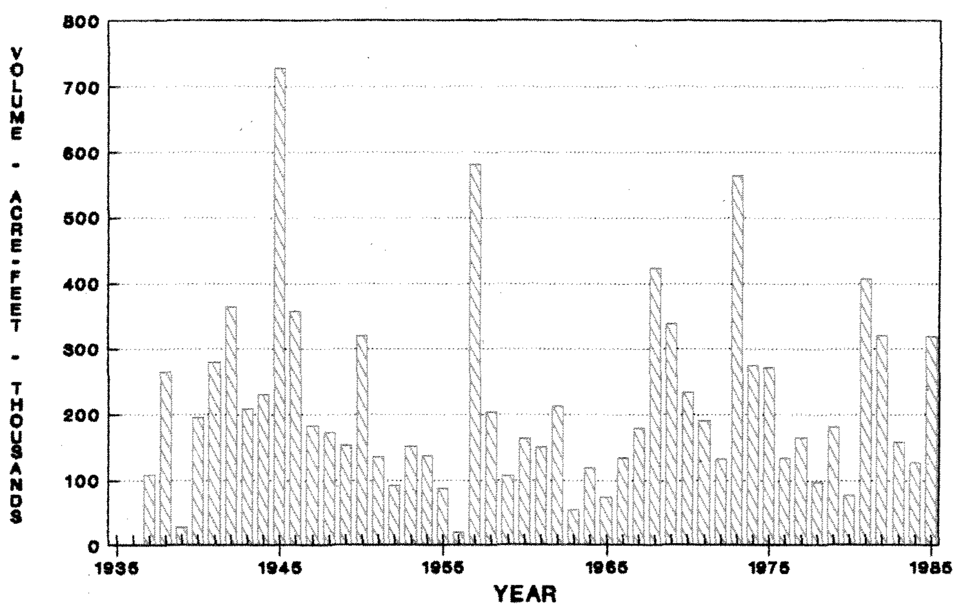
AVERAGE ANNUAL VOLUME (1966-85)

BLUE RIVER AT MILBURN, OKLAHOMA



AVERAGE ANNUAL VOLUME (1937-85)

BLUE RIVER NEAR BLUE, OKLAHOMA



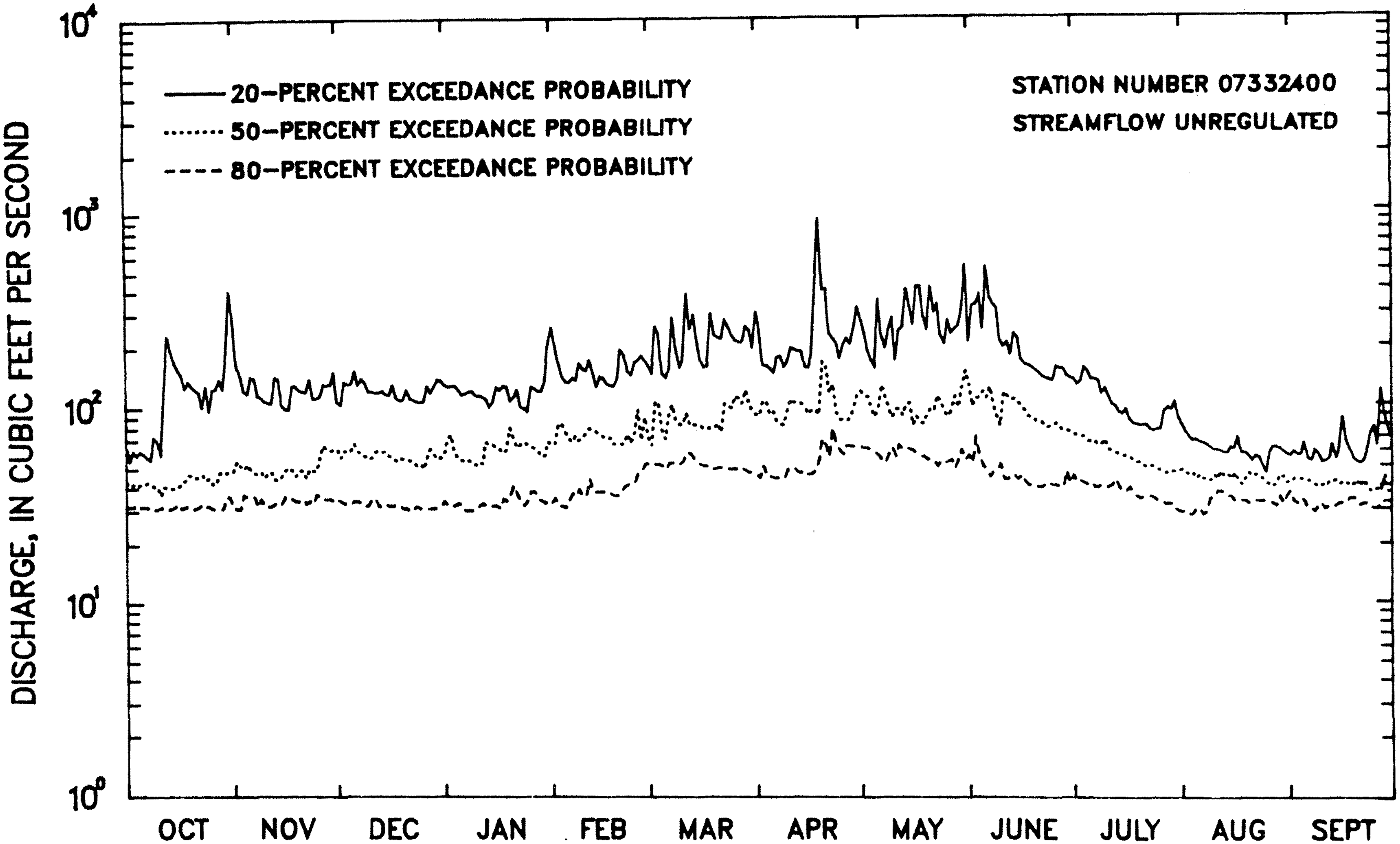


Figure A-10.--Duration hydrographs of daily discharge values for Blue River at Milburn, Oklahoma, water years 1966-1984 (streamflow unregulated).

Data Source: Heiman. D.C.. and Tortorelli. R.L. 1988

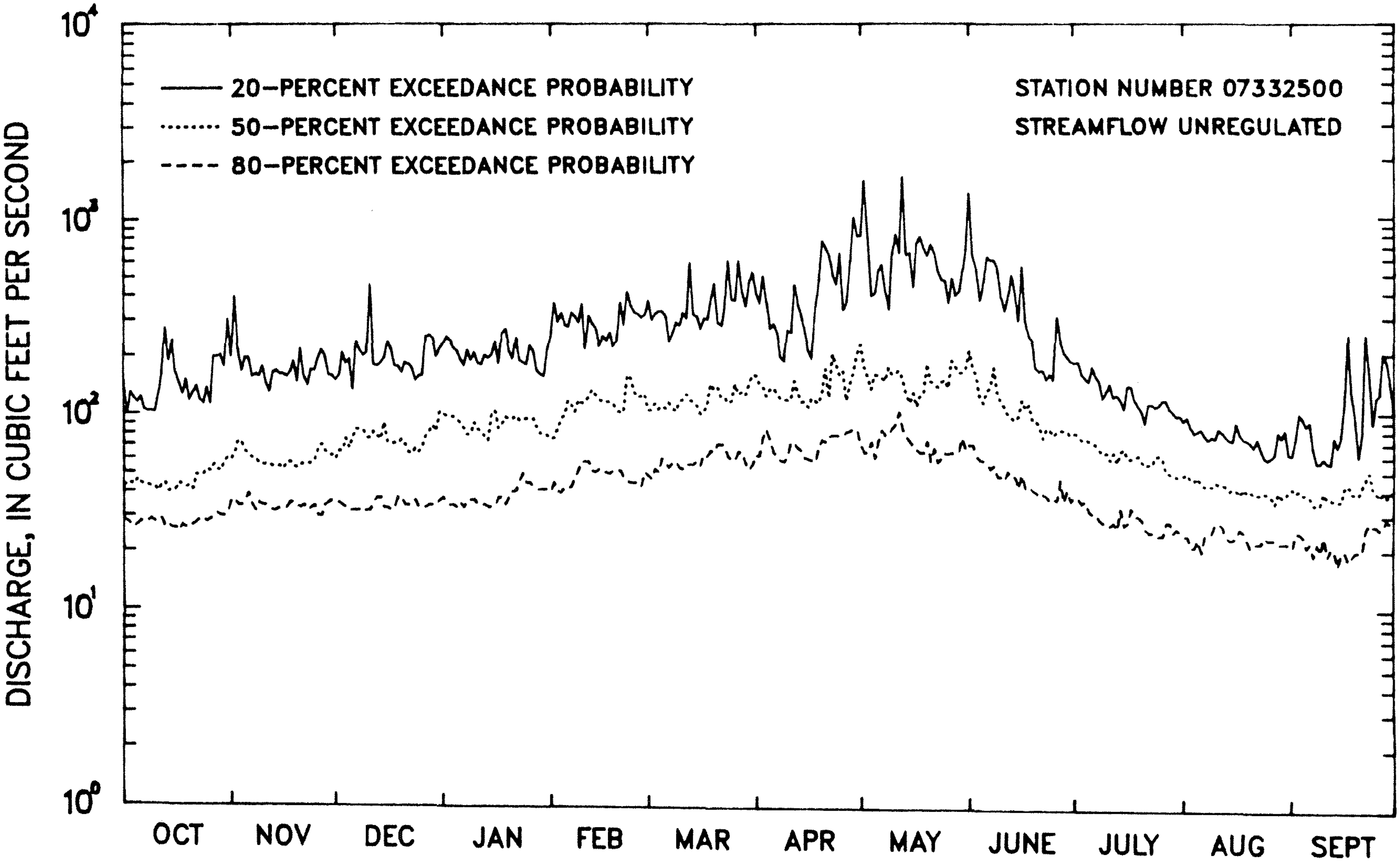


Figure A-11.--Duration hydrographs of daily discharge values for Blue River near Blue, Oklahoma, water years 1946-1984 (streamflow unregulated).

Data Source: Heiman. D.C.. and Tortorelli. R.L. 1988

FIGURE A-12

BLUE RIVER AT MILBURN, OK

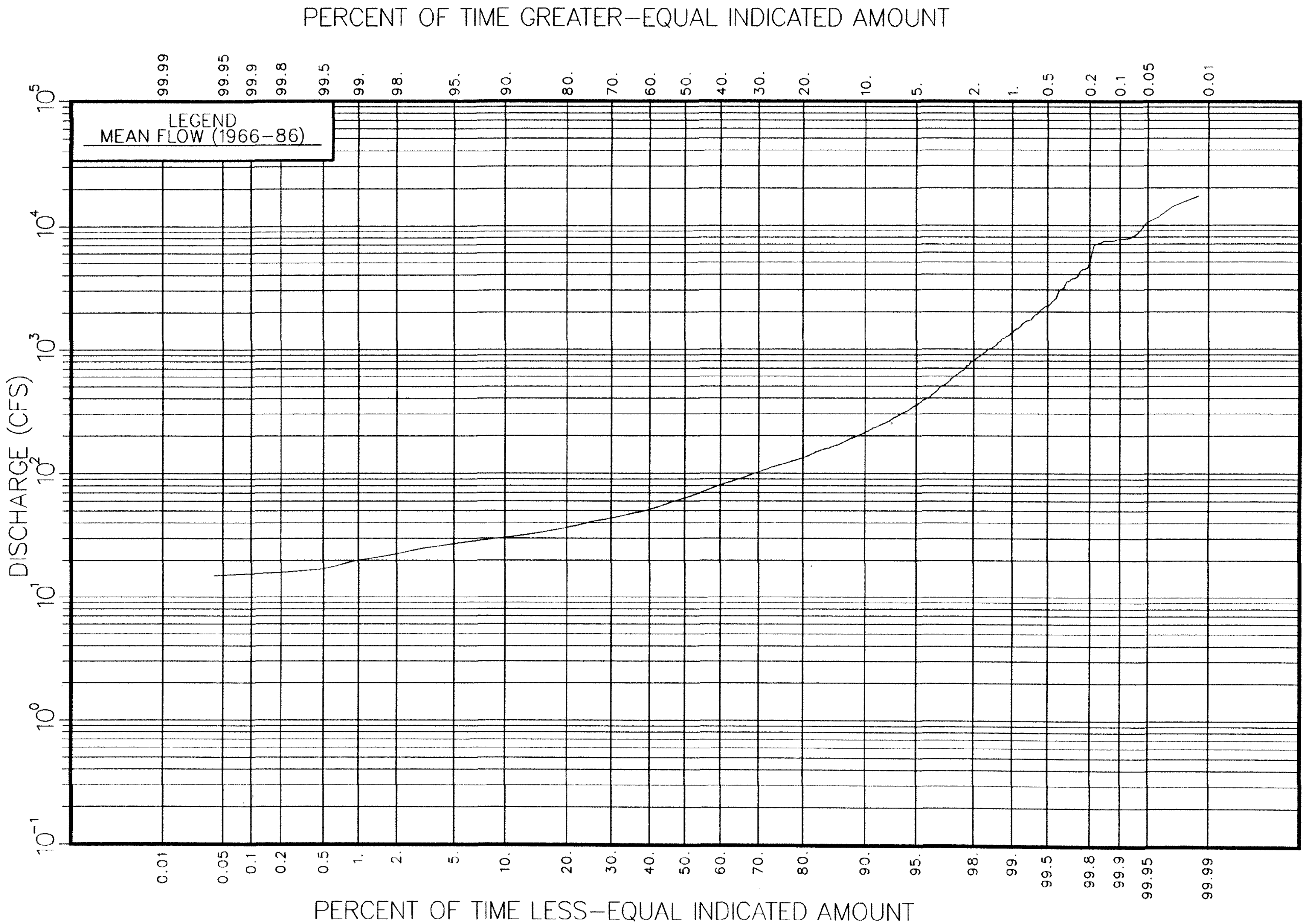
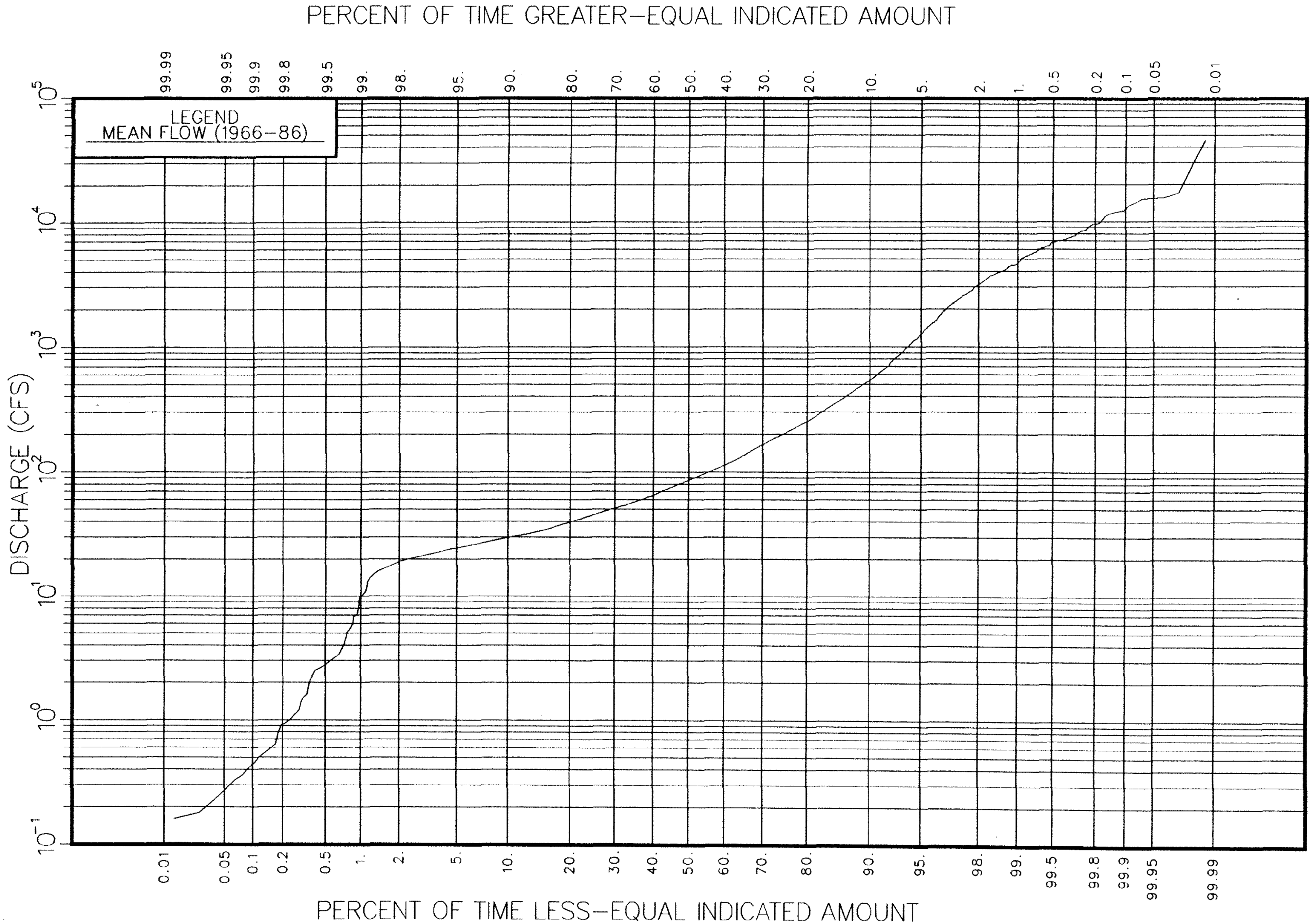
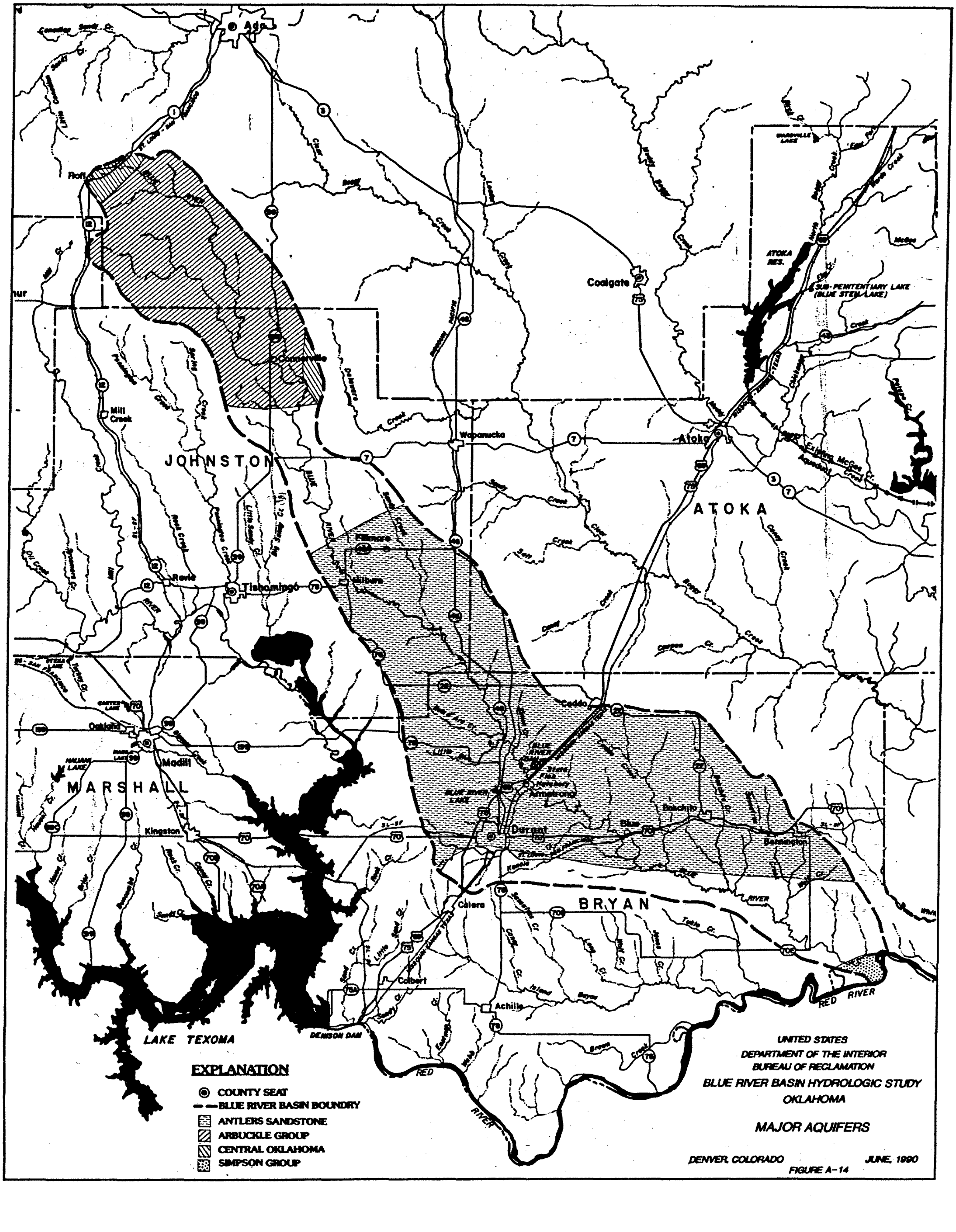


FIGURE A-13

BLUE RIVER NEAR BLUE, OK




Ada
Roff
Connerville
Coalgate
ATOKA RES.
SUB-PENITENTIARY LAKE (BLUE STEM LAKE)
Mill Creek
Wapanucka
Atoka
JOHNSTON
ATOKA
Fillmore
Ravia
Tishomingo
Milburn
Caddo
Oakland
Madill
MARSHALL
BLUE RIVER LAKE
Armstrong
Bokchito
Kingston
Durant
Blue
Bennington
Calera
BRYAN
Colbert
Achille
LAKE TEXOMA
DENISON DAM
RED RIVER
EXPLANATION
COUNTY SEAT
BLUE RIVER BASIN BOUNDRY
ANTLERS SANDSTONE
ARBUCKLE GROUP
CENTRAL OKLAHOMA
SIMPSON GROUP
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BLUE RIVER BASIN HYDROLOGIC STUDY
OKLAHOMA
MAJOR AQUIFERS
DENVER, COLORADO
JUNE, 1990
FIGURE A-14

ATTACHMENT B-WATER QUALITY DATA

(Tables and Figures)

Table B-1
State of Oklahoma's Raw Water Numerical Criteria

SUBSTANCES (Total) CRITERIA (mg/L)	NUMERICAL
Inorganic Elements:	
Arsenic	0.10
Barium	1.00
Cadmium	0.020
Chromium	0.050
Copper	1.000
Cyanide	0.200
Fluoride (at 90° F)	4.0
Lead	0.100
Mercury	0.002
Nitrates (as N)	10.000
Selenium	0.010
Silver	0.050
Zinc	5.000
Organic Elements:	
Benzidine	0.001
Detergents (total)	0.200
Methylene blue active substances	0.500
Phthalate esters (except butylbenzyl)	0.003
Butylbenzyl	0.150
2,4-D	0.100
2,4,5-TP Silvex	0.010
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.100
Toxaphene	0.005

Table B-2

National Primary Drinking Water Regulations

SUBSTANCE		
Arsenic	0.05	mg/L
Barium	1.0	mg/L
Benzene	0.005	mg/L
Beta particle and photon radioactivity	4	mrem (annual dose equivalent)
Cadmium	0.010	mg/L
Carbon Tetrachloride	0.005	mg/L
Chromium	0.05	mg/L
Coliform bacteria	<0.01	mg/L
2,4-D	0.1	mg/L
para-Dichlorobenzene	0.075	mg/L
1,2-Dichloroethane	0.005	mg/L
1,1-Dichloroethylene	0.007	mg/L
Endrin	0.0002	mg/L
Fluoride	4	mg/L
Gross alpha particle activity	15	pCi/L
Lead		0.05
mg/L		
Lindane	0.004	mg/L
Mercury	0.002	mg/L
Methoxychlor	0.1	mg/L
Nitrate (as N)	10	mg/L
Radium-226 + Radium-228	5	pCi/L
Selenium	0.01	mg/L
Silver	0.05	mg/L
Toxaphene	0.0005	mg/L
2,4,5-TP Silvex	0.01	mg/L
1,1,1-Trichloroethane	0.2	mg/L
Trichloroethylene	0.005	mg/L
Trihalomethanes (the sum of the concentrations of bromodichloromethane, (bromoform) and trichloromethane (chloroform)	0.10	mg/L
Turbidity	1	Tu (up to 5 Tu)

Corrosion Monitoring and Distribution System Composition
Sodium Monitoring and Reporting

NATIONAL SECONDARY DRINKING WATER REGULATIONS

Chloride	250	mg/L
Color	15	color units
Copper	1	mg/L
Corrosivity		non-corrosive
Fluoride	2	mg/L
Foaming Agents	0.5	mg/L
Iron		0.3
mg/L		
Manganese	0.05	mg/L
Odor		3
threshold odor number		
pH		6.5 - 8.5
Sulfate	250	mg/L
TDS		500
mg/L		
Zinc		5
mg/L		

Abbreviations: mg/L = milligrams per liter
Tu = nephelometric turbidity units
mrem = millirem
pCi/L = picoCuries per liter

Table B-3.--Basic Dissolved Solids Data

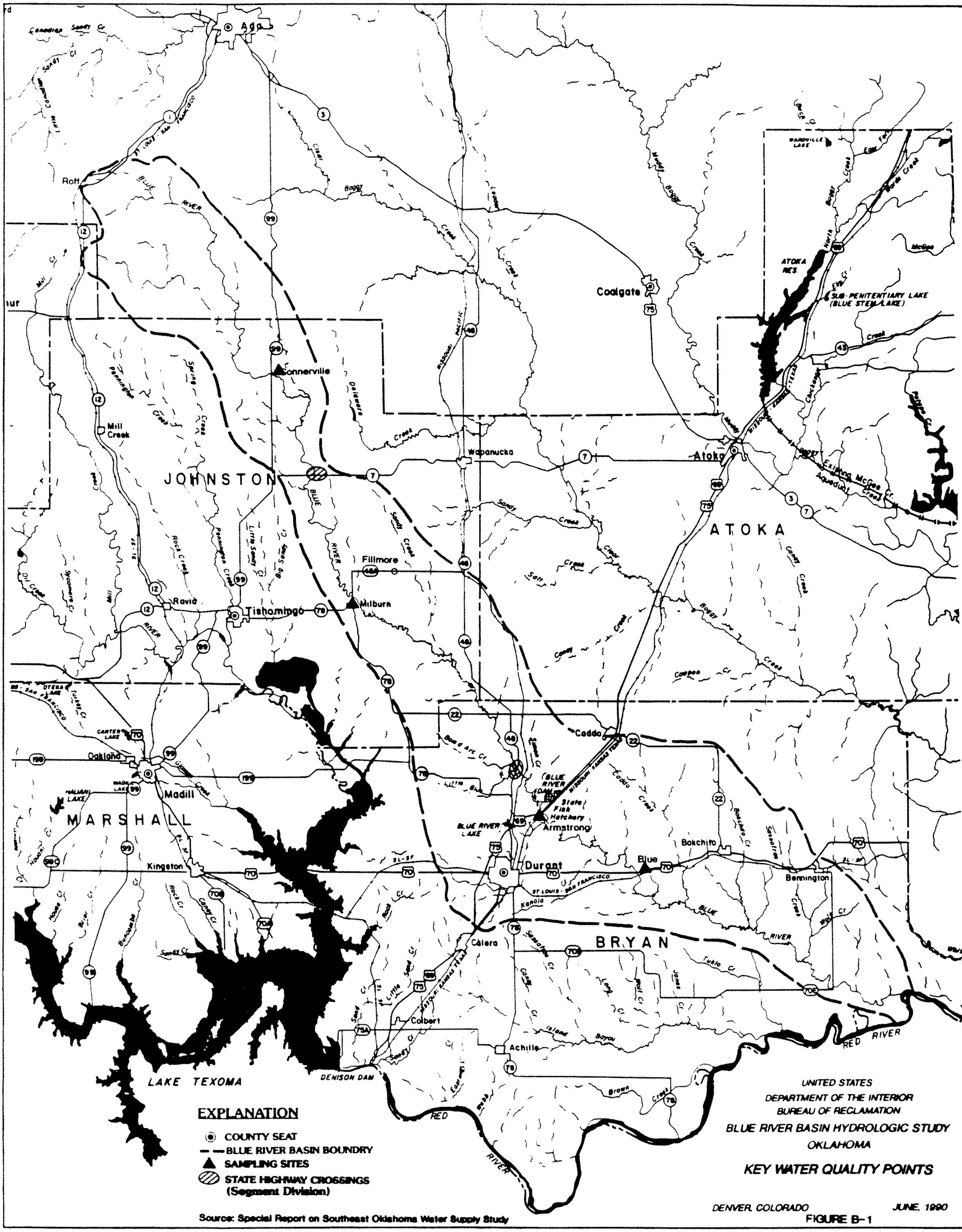
Sites	Station #	Date	# Samples	Average Conduc-tivity µmhos/cm.	# Samples	Sodium Adsorption Ratio (SAR)	# Samples	Na (mg/L)	# Samples	% Na	# Samples	Cl (mg/L)	# Samples	Ca^{+2} (mg/L)	# Samples	Mg^{+2} (mg/L)	# Samples	HCO_3^{-1} (mg/L)	# Samples	CO_3 (mg/L)
At Connerville	USGS 7332350	pre 1963	50	501.68	48	.10	48	3.25	38	2.18	50	3.9	45	56.87	45	37.89	50	328.66	50	1.24
Near Connerville	USGS 7332390	10/21/71	1	540.00	1	.10	1	2.7	1	2.0	1	2.83	1	63.00	1	38.00	1	370.00	1	0.00
Near Connerville	OSHD 1060221	7/85 - 7/89	8	636.25	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
At Milburn	USGS 7332400	pre 1963	NA	NA	11	0.14	11	4.24	9	2.25	11	6.01	11	22.09	11	34.00	11	213.64	11	6.18
		8/56 - 8/87	27	454.22	NA	NA	NA	NA	NA	NA	NA		NA		NA	NA	NA	NA	NA	NA
Near Armstrong	OSHD 10600D3X4Z12	pre 1978	7	412.86	NA	NA	5	8.00	NA	NA	22	15.9	8	44.07	11	26.37	3	274.33	3	3.33
At Armstrong	USGS 7332450	pre 1978	8	418.75	NA	NA	4	9.25	NA	NA	8	10.3	8	44.07	8	25.00	NA	NA	NA	NA
Near Blue	OSHD 10600F4X5Z29	1975 - 8/89	142	405.08	NA	NA	NA	NA	NA	NA	NA	NA	75	52.78	75	52.78	NA	NA	NA	NA
Near Blue	OSHD 10600F4X5Z29	1954 - 1976	NA	NA	167	0.27	166	8.79	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Near Blue	OSHD 10600F4X5Z29	pre 1956	NA	NA	NA	NA	NA	NA	8	9.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Near Blue	OSHD 10600F4X5Z29	1954 - 1980	NA	NA	NA	NA	NA	NA	NA	NA	220	15.6	37	54.25	37	25.14	NA	NA	NA	NA
Near Blue	USGS 7332500	11/54 - 9/63	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	165	227	165	5.06
Near Blue	USGS 7332500	11/54 - 9/80	218	407.86	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NA = not available.

Table B-4.—Selected Water Quality Parameters
Blue River Water Quality

	Station #	Date	# Samples	pH	# Samples	Temp (°C)	# Samples	DO (mg/L)	# Samples	Total Hardness (mg/L)
At Connerville	USGS 7332350	pre-1963	50	6.9 - 8.5	40	6.1 - 29.1	NA		50	287.26
Near Connerville	USGS 7332390	10/21/77	1	8.00	1	17.5	NA		1	310.00
Near Connerville	OSHD 10602Z1	79-7/89	8	7.5 - 8.0	8	15.0 - 23.0	8	6.5 - 11.4	NA	NA
At Milburn	USGS 7332400	8/56 - 8/87	27	7.0 - 8.8	25	3.9 - 31.5	NA		NA	
At Milburn	USGS 7332400	12/75	NA		NA		1	12.2	NA	
At Milburn	USGS 7332400	8/56 - 3/60	NA		NA		NA		11	195.27
Near Armstrong	OSHD 1060003X 4Z12	1972-1977	NA		19	3.0 - 29.1	15	7.0 - 19.0	NA	
	" "	12/63 - 1977	24	7.4 - 9.0	NA		NA		11	225.91
At Armstrong	USGS 7332450	10/76 - 5/77	8	7.6 - 8.5	8	3.0 - 23.5	8	7.7 - 14.2	8	219.88
Near Blue	OSHD 10600F4-X5Z29	59 - 89	294	6.7 - 8.8	144	0.1 - 32	133	0.2 - 14.8	75	233
	USGS 7332500	11/54 - 80	213	7.2 - 8.9	115	0 - 35.0	44	3.9 - 14.8	203	210.10

Na = not available.



UNITED STATES
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BUREAU OF RECLAMATION
BLUE RIVER BASIN HYDROLOGIC STUDY
OKLAHOMA

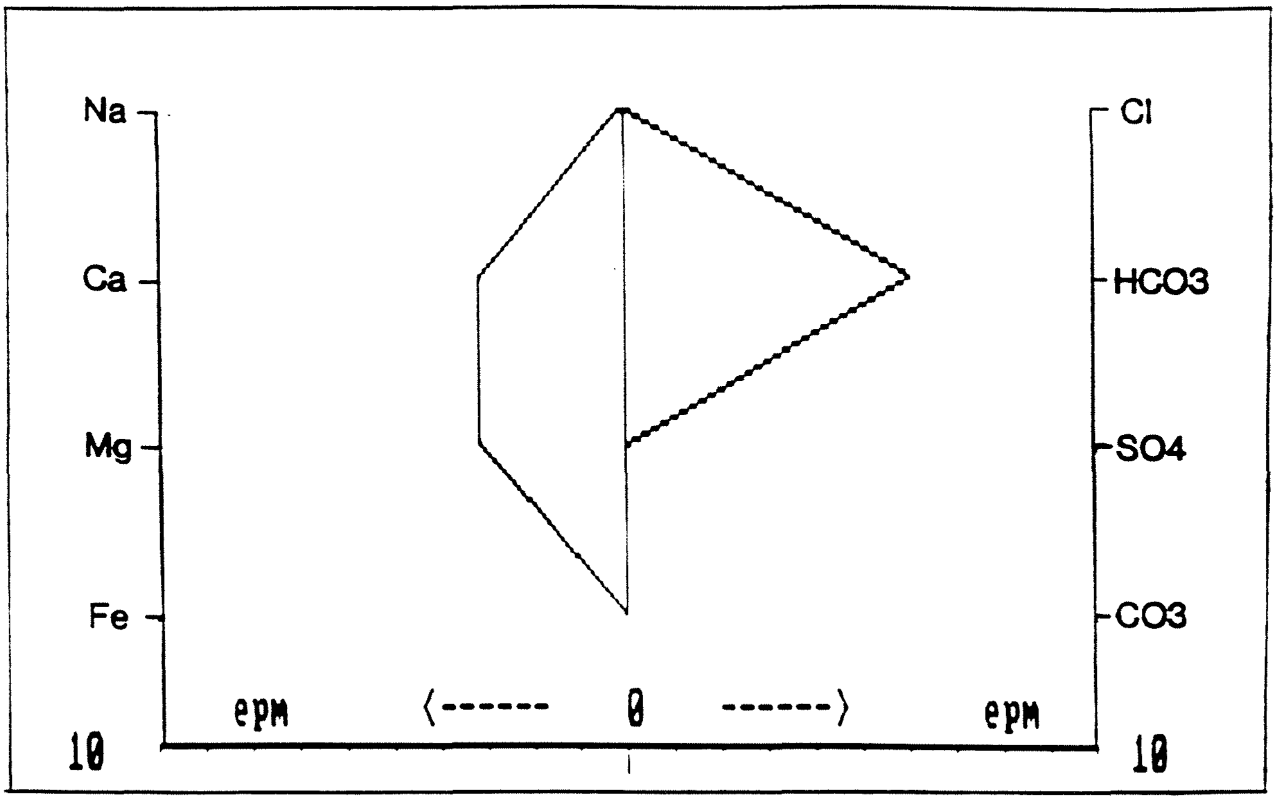
KEY WATER QUALITY POINTS

DENVER, COLORADO JUNE, 1990

FIGURE B-1

Source: Special Report on Southeast Oklahoma Water Supply Study

MILBURN, OKLAHOMA



CONNERVILLE, OKLAHOMA

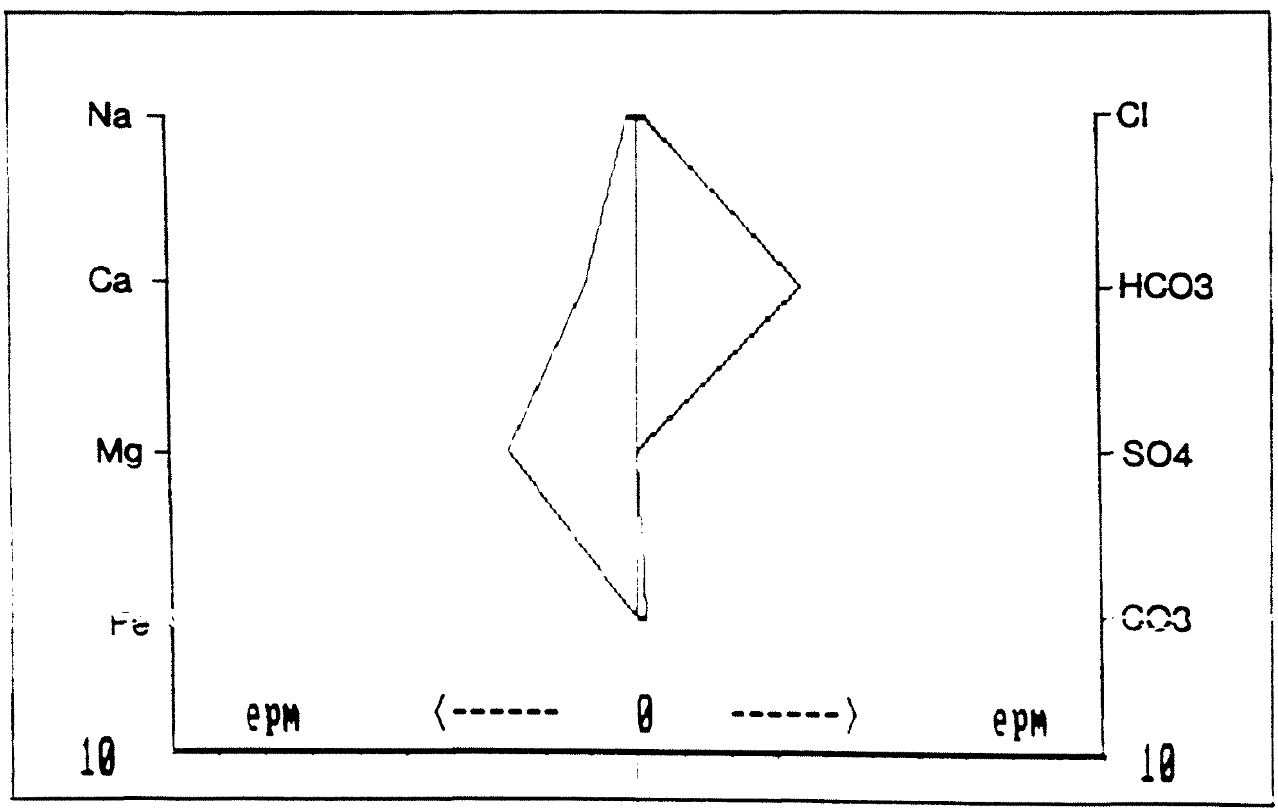
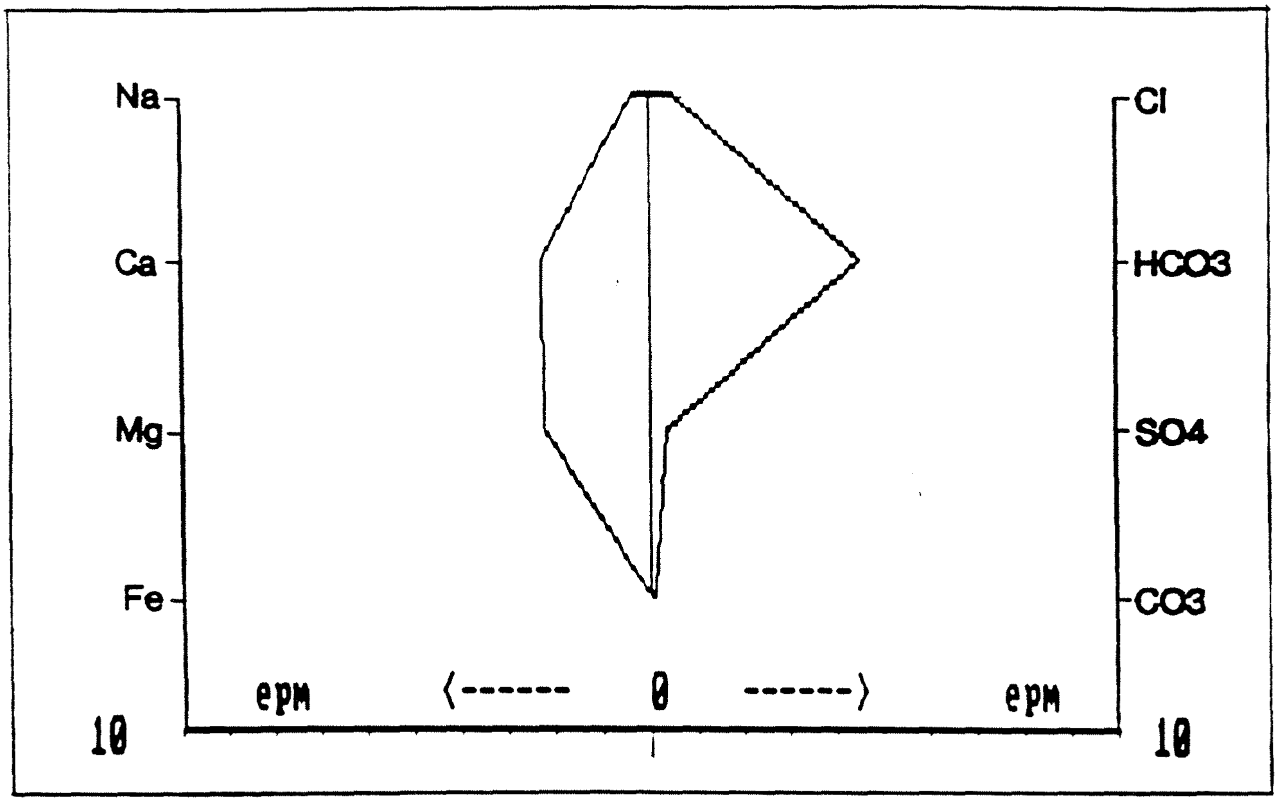


FIGURE B-2

ARMSTRONG, OKLAHOMA



BLUE, OKLAHOMA

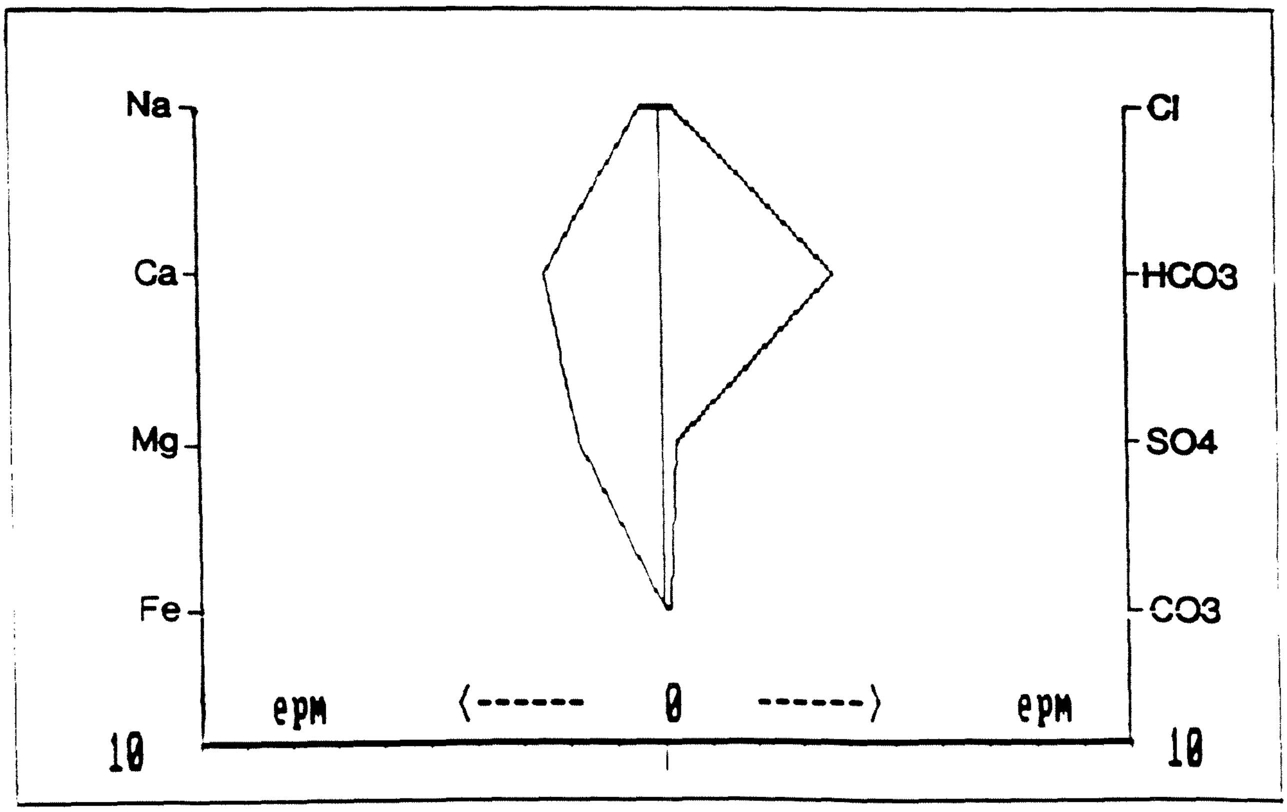


FIGURE B-3

ATTACHMENT C—HYDROLOGIC DATA EVALUATION OF BLUE RIVER BASIN - SOUTH-CENTRAL OKLAHOMA

HYDROLOGIC DATA EVALUATION

OF

BLUE RIVER BASIN - SOUTH-CENTRAL OKLAHOMA

Prepared by

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
OKLAHOMA CITY, OKLAHOMA

Prepared for and in cooperation with

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SOUTHWEST REGION
AMARILLO, TEXAS

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HYDROLOGIC DATA EVALUATION

OF

BLUE RIVER BASIN, SOUTH-CENTRAL OKLAHOMA

GROUND-WATER/SURFACE-WATER RELATIONSHIPS

By

Ronald L. Hanson

The Blue River Basin in southeastern Oklahoma drains an area of about 676 square miles (mi^2) (see figure 1 from a report by Hanson, 1987). The basin is about 80 miles long and has a maximum width of about 14 miles in the vicinity of Durant, Oklahoma. The Blue River rises in the Arbuckle Mountain region near the town of Roff, and flows 150 river miles in a general southeasterly direction to enter the Red River, about 56 miles below Denison Dam. The Blue River channel is lined with timber and small brush, and nearly half of the flood-plain area is covered with timber. Below the vicinity of the Bryan-Johnston County boundary, the stream channel has an average width of about 180 feet, with banks averaging about 20 feet in height. The streambed slope decreases from an average of about 9 feet per mile in the headwaters to about 2 feet per mile near the mouth of the river (Oklahoma Planning and Resources Board [OPRB], 1954).

The geologic formations of the headwaters area are mainly of Upper Cambrian and Lower Ordovician ages with some rocks of Pennsylvanian age in the extreme northern part of the basin. In the central part of the basin the geological outcrops are of Lower Cretaceous age. They include the Washita Division, Goodland Limestone and the Trinity Group. The lower portion of the basin below Durant has outcrops of the Woodbine Formation, and alluvial along the river (OPRB 1954).

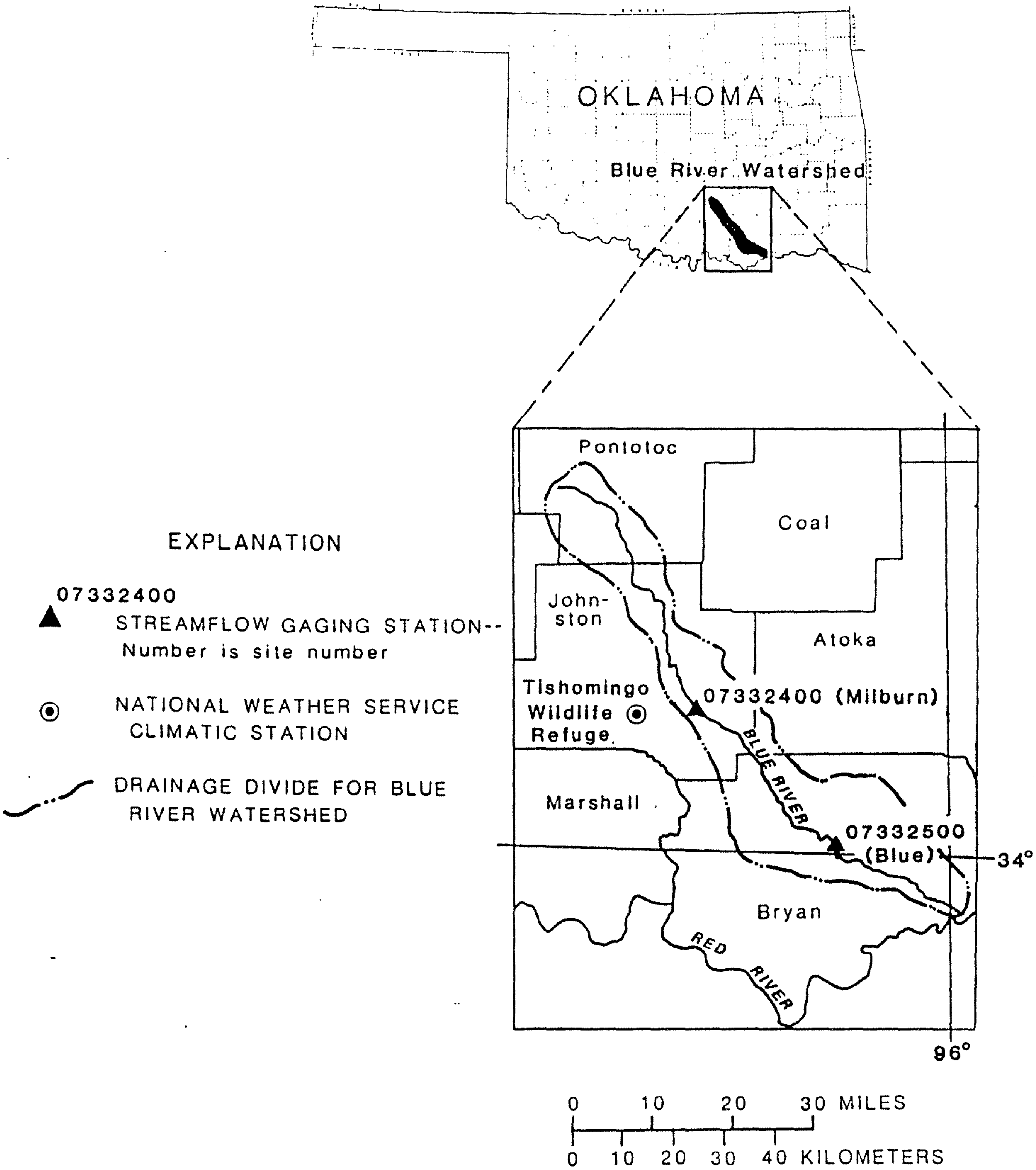

Figure 1.--Location of Blue River watershed, Blue River gaging stations, and National Weather Service climatic station at Tishomingo Wildlife Refuge, Oklahoma.
(From Hanson, 1987 ... in press)

The two principal aquifers underlying the basin are the Arbuckle-Simpson Aquifer which crops out in the upper part of the basin and the Antlers Aquifer which crops out in the lower part of the basin. The Antlers Aquifer, which consists of sandstone with included beds of silt, clay, and shale, crops out across the Blue River drainage basin in the southeastern corner of Johnston County. At about the southern boundary of Johnston County, the aquifer dips southward under younger less permeable rocks. Thus, south of the outcrop the Antlers may be characterized as a confined aquifer. A report by Hart and Davis (1981) describes the hydrologic characteristics of the Antlers Aquifer and includes several illustrations showing the location of the Blue River Basin with respect to the aquifer.

Plate 1 of Hart and Davis (1981) shows that ground water in the outcrop area is generally less than 100 feet below land surface and commonly is less than 50 feet below land surface. Hart and Davis indicate that the Antlers has an average saturated thickness of 250 feet of water containing less than 1,000 milligrams per liter (mg/L) dissolved solids. The results of aquifer tests reported in their study indicate that the transmissivity of the Antlers Aquifer ranges from 390 to 2,560 square feet per day (ft^2/d) and averages about 1,480 ft^2/d. The storage coefficient of the aquifer is reported to range from 0.00013 to 0.0010 and averages 0.0005 (dimensionless). The specific capacity ranges from 3.2 to 11.1 gallons per minute per foot. Hart and Davis report that large-capacity wells tapping the aquifer commonly yield from 100 to 500 gallons per minute (gal/min). However, plate 1 of their report shows that wells located within the Blue River Basin generally yield less than 100 gal/min.

A potentiometric map of the Antlers Aquifer based on 1975 ground-water level data (figure 8 of Hart and Davis 1981) shows that the potentiometric coutours are influenced by the Blue River where the river flows over the aquifer. Hart and Davis state that the streams crossing the aquifer are incised into the water table along some reaches, thus indicating a hydraulic connection between the aquifer and the river.

The Arbuckle-Simpson Aquifer, which outcrops in the Blue River watershed over the entire basin above the Blue River near Connerville gauging station (station number 07332390), is a freshwater aquifer consisting of limestone, dolomite, and sandstone. Fairchild, Hanson, and Davis (1982) report that the average saturated thickness of this aquifer is about 3,500 feet in the outcrop area. Their study shows that recharge to the aquifer is about 4.7 inches per year based on estimates of total average annual base flow from streams that drain the area. Figure 2 from their report shows the location of the Blue River in the Arbuckle-Simpson outcrop area. The Fairchild, Hanson, and Davis study used several different methods of analysis to derive estimates of storage coefficient (S) and transmissivity (T) of the Arbuckle-Simpson Aquifer. Their analyses give a wide range of values for these aquifer characteristics but values of S=0.008 and T=15,000 ft^2/d are considered to be representative for this predominantly carbonate aquifer. Yields from selected wells in the aquifer in Pontotoc County--which includes most of the aquifer in the upper Blue River Basin--range from about 35 to 1,900 gal/min.

Fairchild, Hanson, and Davis report that evapotranspiration for this region of Oklahoma is about 31 inches per year or 80 percent of the average annual precipitation. The remaining 20 percent of precipitation discharges from the area as streamflow. This streamflow includes 4.6 inches per year as base flow and 3.0 inches per year as direct surface runoff. Base flow, which primarily

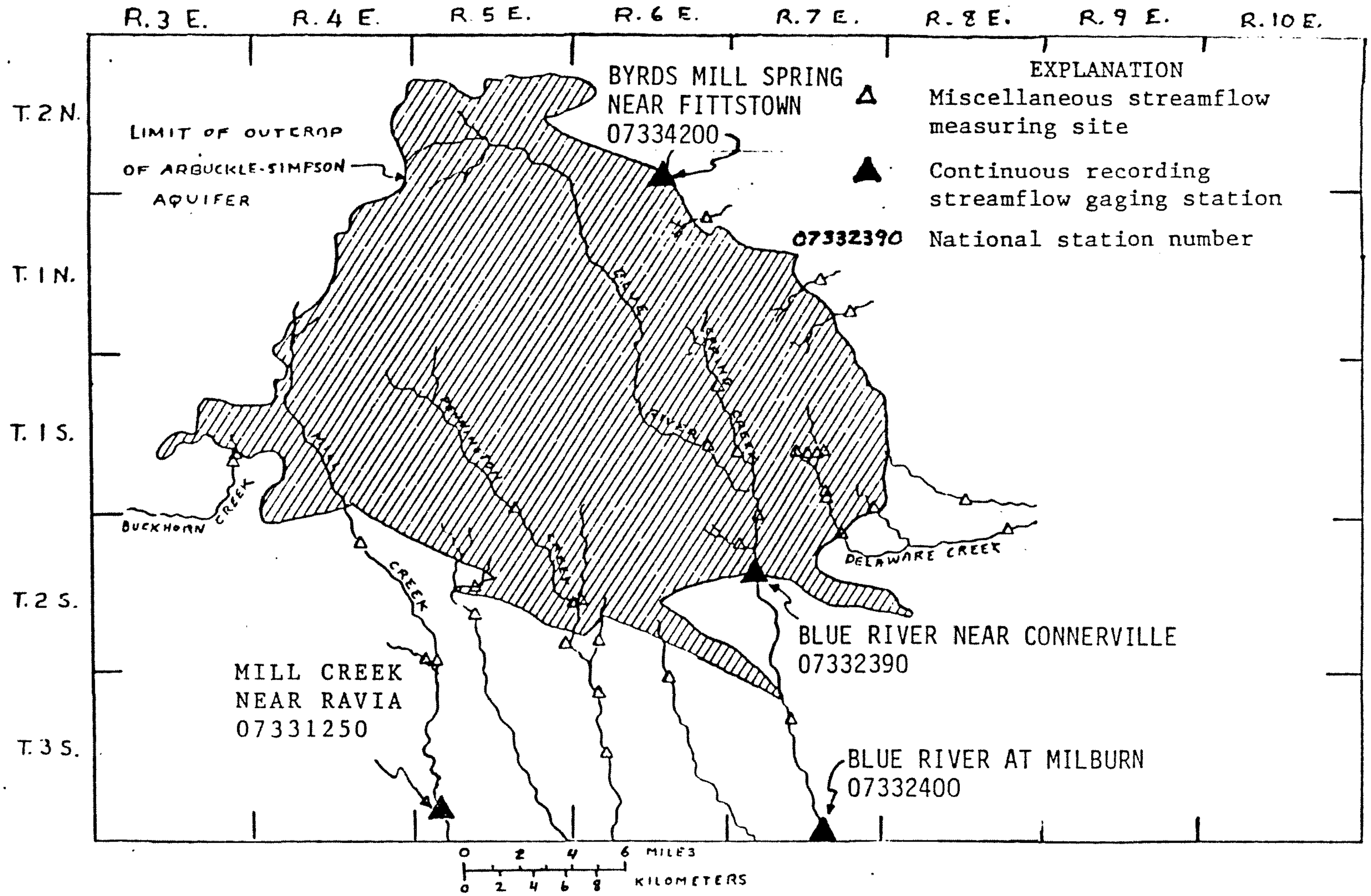

Figure 2.--Location of streamflow measuring sites in the eastern part of the study area.
(From Fairchild, Hanson, and Davis, 1982)

represents ground-water discharge from the Arbuckle-Simpson outcrop area, averages about 12 percent of the average annual precipitation.

The Fairchild, Hanson, and Davis report shows that a fairly close relation exists between the monthly mean flows of the Blue River at Milburn and the monthly mean flows 15.2 miles upstream at the Connerville stream-gauging site. Figure 3 of the report indicates that flows at the two sites are about equal when the river is flowing in the range of 30 to 40 cubic feet per second (ft^3/s). However the river is a gaining stream between the two sites when flow at the Connerville gauge exceeds about 40 ft^3/s.

Seasonal trends in streamflow of Blue River are illustrated in figure 4 of the Fairchild, Hanson, and Davis report. The flow responds quickly to significant rainfall and is typically high during the early spring. The flow generally declines during June and July, reaching base-flow levels by July or August. Drawn under the streamflow hydrograph in figure 4 is an estimate of the base flow for water years 1977-79. Their evaluation indicates that base flow at the Connerville site is about 72 percent of the average annual runoff.

Figure 5 of the Fairchild, Hanson, and Davis report shows the duration curve of mean daily flow for Blue River at Milburn and indicates the percentage of time a given daily flow can be expected to be equaled or exceeded during the year. The curve, which was defined from the period 1966-79, shows that 10 percent of the time flow equaled or exceeded 220 ft^3/s and 90 percent of the time flow equaled or exceeded 30 ft^3/s. The flat slope of the duration curve at the lower end indicates that base flow, which primarily represents ground-water discharge from the Arbuckle-Simpson Aquifer, aproaches a minimum mean daily flow of about 20 ft^3/s at the Milburn gauge.

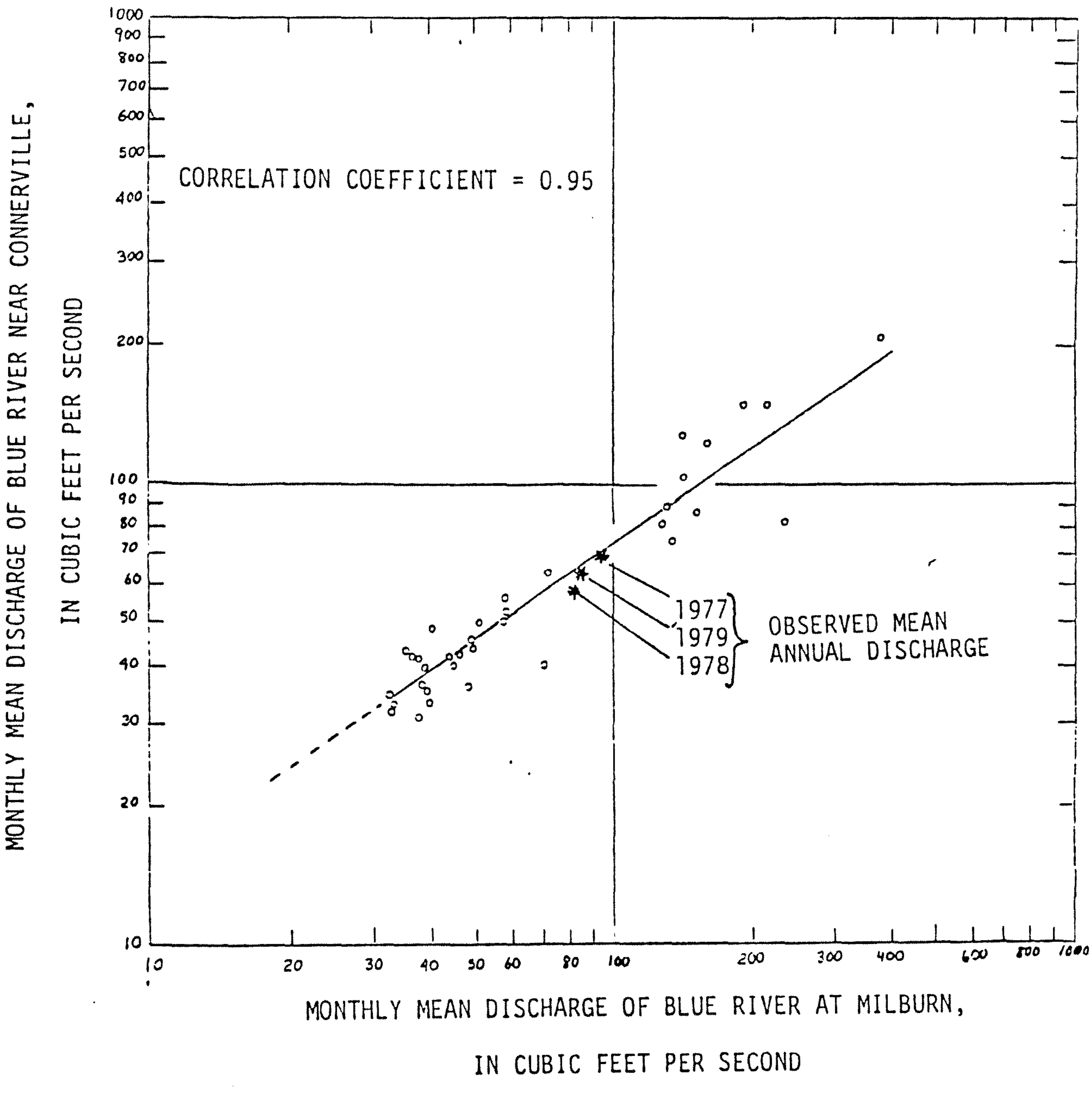

Figure 3 .--Relation between the monthly mean discharge in Blue River at Milburn and Blue River near Connerville, water years 1977-79

(From Fairchild, Hanson, and Davis, 1982)

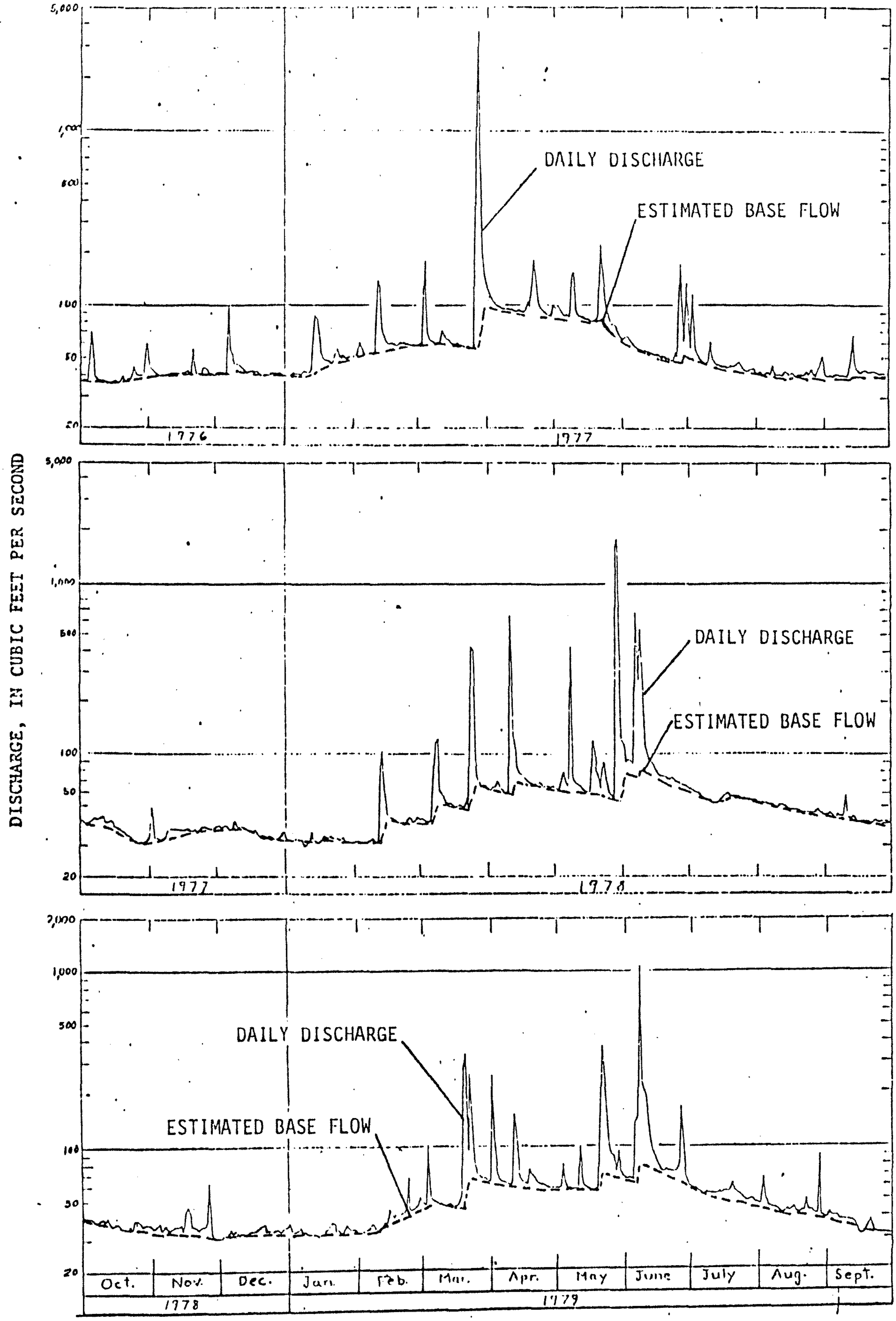

Figure 4. --Hydrograph of daily discharge of Blue River near Connerville for water years 1977-79 and estimated base flow under the total hydrograph. (From Fairchild, Hanson, and Davis, 1982)

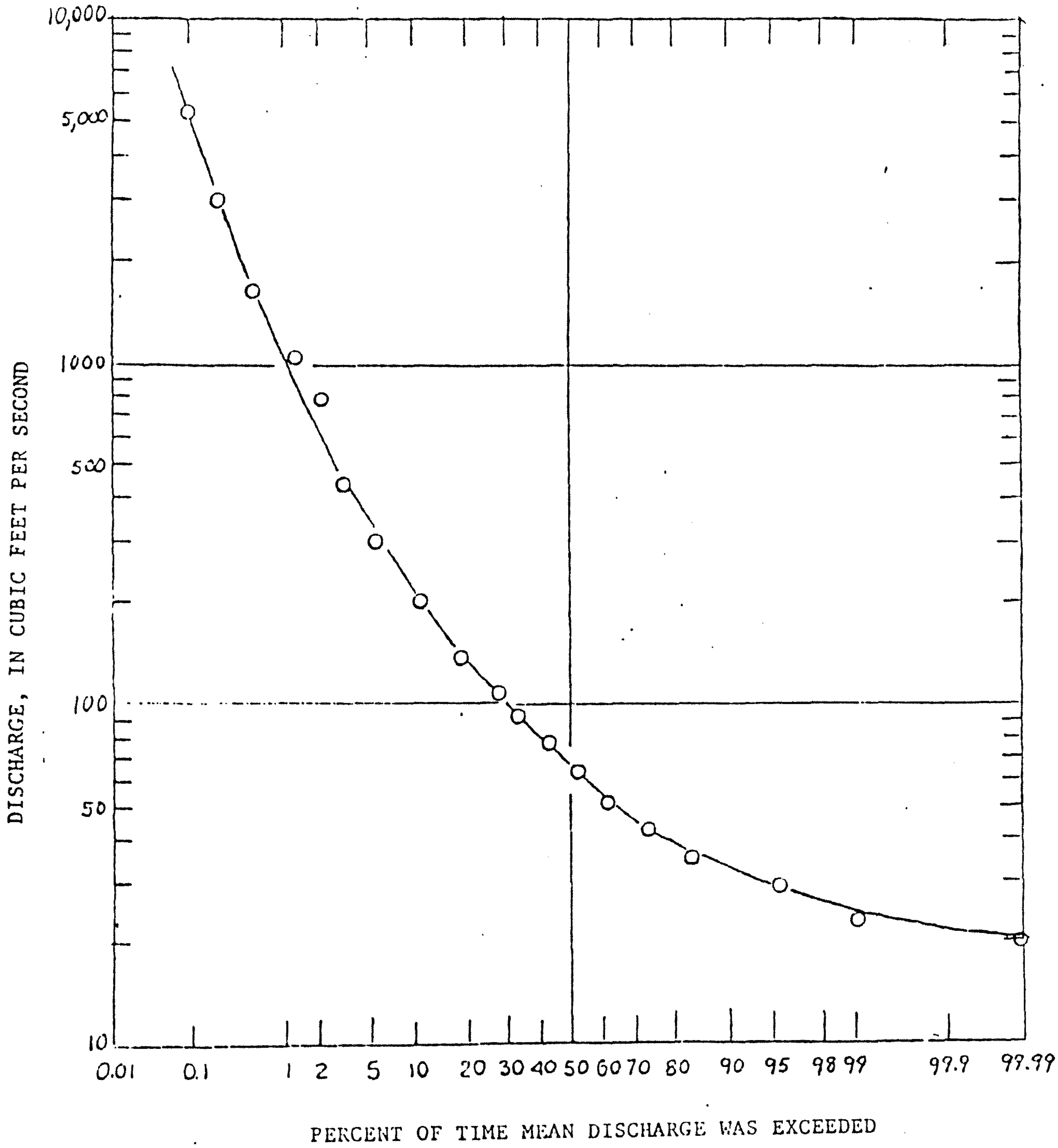

Figure 5.--Duration curve of mean daily flow, Blue River at Milburn, 1966-79.

(From Fairchild, Hanson, and Davis, 1982)

In the Fairchild, Hanson, and Davis report low-flow frequency characteristics of the Blue River were evaluated also. Figure 6 of the report shows both the summer and winter 7-day low-flow frequency curves for the Blue River at Milburn for water years 1966-79. The summer curve is computed from the lowest mean discharge for 7 consecutive days during the July to September period of each of the water years. The winter curve is computed from the lowest mean discharge for 7 consecutive days during the November to February period. These curves indicate that, on the average, the summer flow for the Blue River at Milburn will be equal to or less than 37 ft^3/s for 7 consecutive days once every 2 years and less than 27 ft^3/s for 7 consecutive days once every 20 years. Similarly, the winter low-flow frequency curve shows that the 7-day 2-year low flow is 50 ft^3/s and the 7-day 20-year low flow is 22 ft^3/s. The intersection of the curves at the recurrence interval of 5 years indicates that winter low flows fall below the summer low flows only once every 5 years on the average. The asymptotic trend of the summer curve suggests that 7-day summer low flows at the Milburn site are sustained at about 25 ft^3/s. Table 1 from the report summarizes the summer and winter 7-day low flows at recurrence intervals of 2, 10, and 20 years for both the Milburn and Connerville sites.

Numerous springs discharge water from the Arbuckle-Simpson Aquifer. Most of these springs are gravity springs, occurring where the potentiometric surface intersects the land surface. Some of the springs are "wet weather" seeps that discharge only during a short time after the rainy season. Fairchild, Hanson, and Davis indicate that these seeps flow where the water table is perched, and that they go dry when the perched water table recedes below the spring outlet. Figure 7 from the report shows the general location of the springs discharging from this aquifer. Table 2 gives a listing of these springs, showing their locations, date of measurement, and discharge.

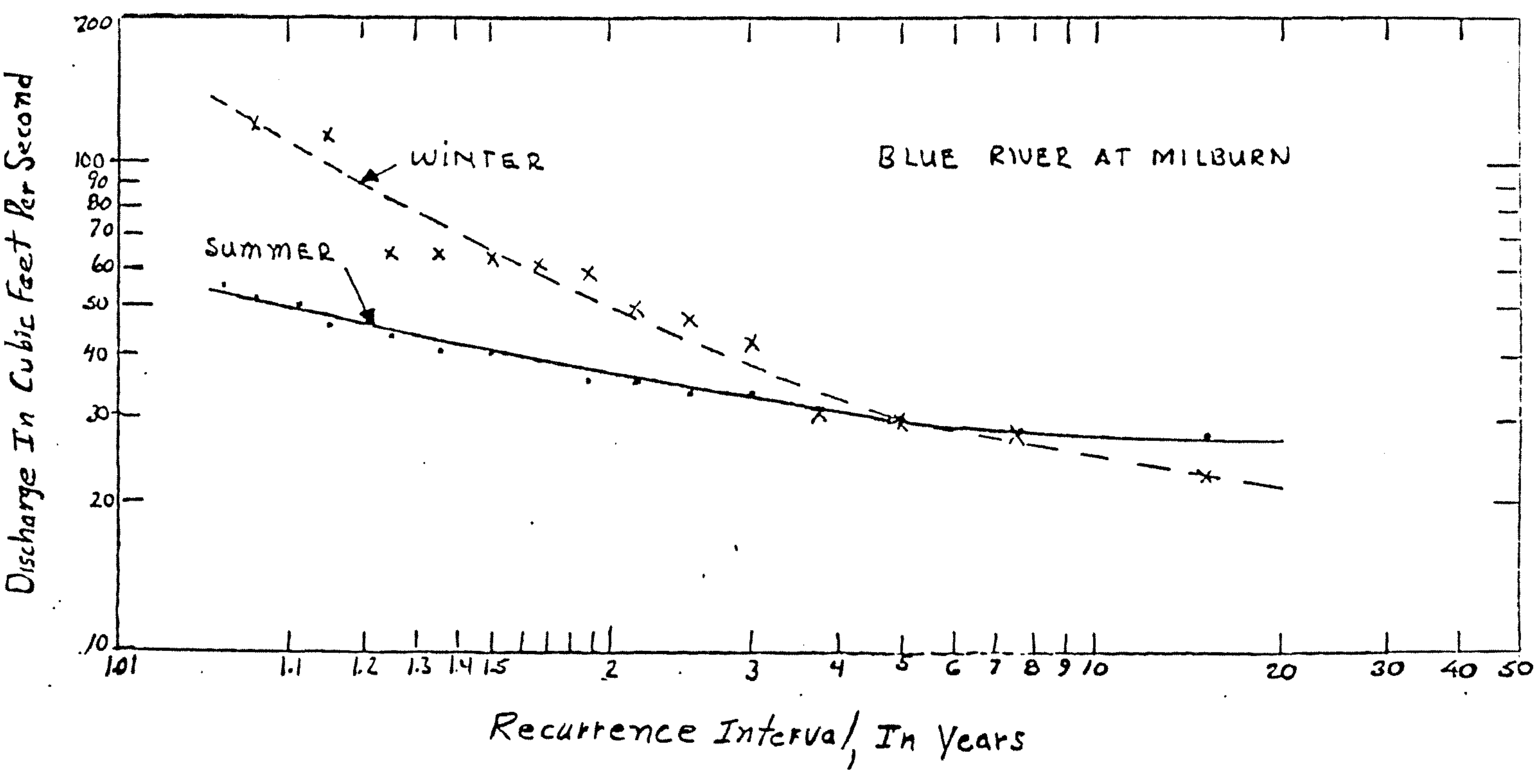

Figure 6.--Summer and winter 7-day low-flow frequency curves for Blue River at Milburn, 1966-79.

(From Fairchild, Hanson, and Davis, 1982)

Table 1.--Summer and winter 7-day low flows at recurrence intervals of 2, 10, and 20 years for Blue River at Milburn and 2 and 10 years for Blue River near Connerville

(From Fairchild, Hanson, and Davis, 1982)

Station	Period of record (water years)	Summer Recurrence interval (years)			Winter Recurrence interval (years)		
		2	10	20	2	10	20
		Seasonal 7-day low flows (cubic feet per second)					
Blue River at Milburn	1966-79	37	28	27	50	25	22
Blue River near Connerville	1977-79	40	35	--	45	25	--

Table 2

SPRINGS IN THE BLUE RIVER BASIN

LOCATION NUMBER	LATITUDE (DEGREES)	LONGITUDE (DEGREES)	COUNTY	DATE DISCHARGE MEASURED	DISCHARGE (GPM)
01N-07E-30 CDD 1	343114	0963531	123	01-25-77	202
01S-06E-12 BAD 1	342918	0963740	069	02-07-77	22.0
01S-06E-12 BDD 1	342908	0963737	069	01-07-77	660
01S-06E-21 ADB 1	342732	0964023	069	11-17-76	673
01S-06E-22 BC 1	342738	0964014	069	11-18-76	583
01S-06E-22 BC 2	342724	0964002	069	11-18-76	449
01S-06E-22 BC 4	342727	0964013	069	11-18-76	269
01S-06E-22 BCA 3	342729	0964000	069	11-18-76	.00
01S-06E-24 CAD 1	342712	0963741	069	03-08-77	1800
				05-26-77	1390
01S-06E-24 CBB 1	342718	0963804	069	02-04-77	449
				05-26-77	426
01S-07E-20 CDA 2	342702	0963545	069	02-10-77	4.00
01S-07E-32 ACB 1	342548	0963527	069	02-08-77	4.00
02N-05E-16 DBC 1	343830	0964658	123	--	--
02S-06E-01 BDC 1	342444	0963753	069	01-06-77	4.00
02S-07E-07 BAB 1	342414	0963647	069	11-04-77	157
02S-07E-18 AAC 1	342312	0963613	069	01-04-77	45.0
02S-07E-32 CDC 1	341958	0963543	069	01-03-77	135

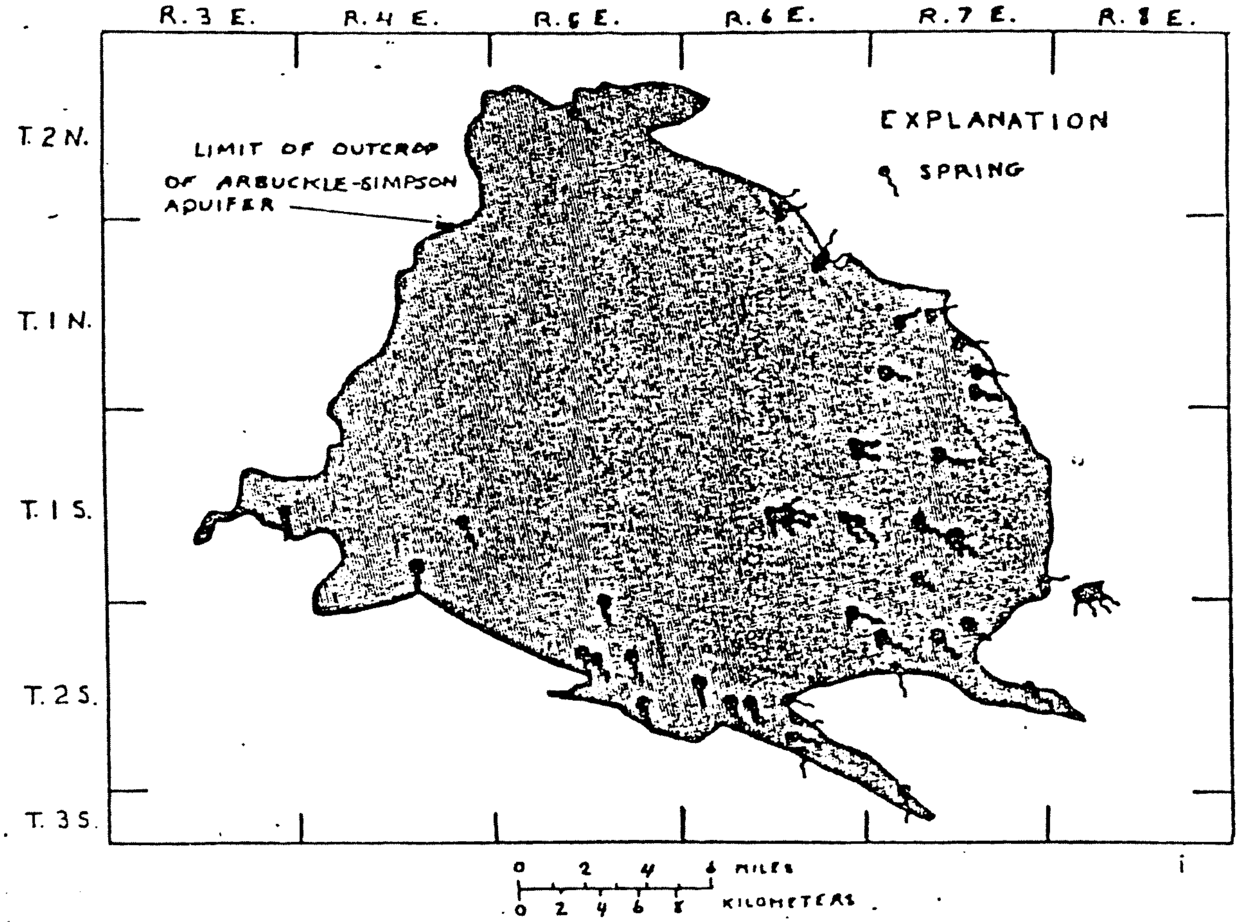

Figure 7.--Location of springs in the eastern part of the Arbuckle Mountains.

(From Fairchild, Hanson and Davis, 1982)

Observed ground-water levels in selected wells in the Arbuckle-Simpson Aquifer appear to correlate closely with base flow in the Blue River. In fact the aquifer is considered to be hydraulically connected to the stream because of: (1) relatively shallow ground-water levels in the basin (commonly less than 100 feet below land surface); (2) extensive faulting and jointing of the Arbuckle and Simpson Groups; and (3) the numerous flowing springs in topographically low areas. Figure 8 of the Fairchild, Hanson, and Davis report shows the average of water levels in five wells located within the Blue River drainage basin plotted against the corresponding base flow of the Blue River near Connerville gauge. The graph shows that during the study period seasonal ground-water levels and corresponding seasonal base flow from the Blue River were higher during the summer than during the winter.

The base flow component of steamflow in unregulated basins such as the Blue River Basin is generally a good indicator of water availability in the basin. Base flow is essentially discharge to the stream from ground-water sources. In a report by Hanson (1987, in press) the streamflow-gauging station Blue River at Milburn (station number 07332400 on figure 2, page 5) was used to illustrate the technique for applying base flow to evaluate the drought characteristics of south-central Oklahoma. The Milburn station, which was established October 1, 1965, has a drainage area of 203 mi^2 and flow is sustained throughout the year by numerous springs in the basin. No significant regulation or withdrawals from the river occur upstream from the gauging station.

Several characteristics of base flow for the Blue River are discussed in Hanson's report. For example, the minimum daily flow measured at the Milburn site during the 16-year period of record (1966-81) was 15 ft^3/s on August 22,

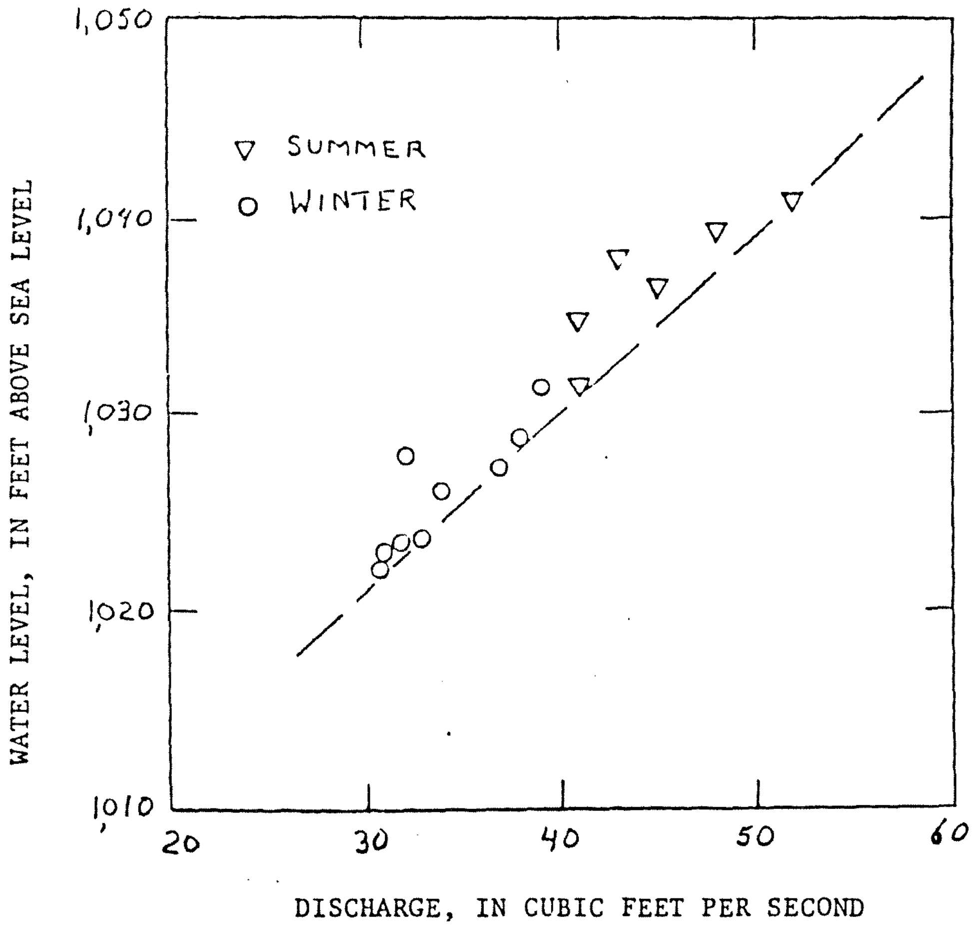

Figure 8.--Relation between average of water level in five observation wells in Blue River basin and base flow of Blue River near Connerville. (From Fairchild, Hanson, and Davis, 1982)

24, 25, and September 1, 1980. Also, the 16-year streamflow record at the Milburn station was compared with the longer streamflow record of 45 years (1937-81) at a downstream gauge, Blue River near Blue, Oklahoma (station number 07332500) shown in figure 2, page 5.

Hanson found that the annual discharges at the Blue River near Blue gauging station correlate closely with those for the Blue River at Milburn for most years during the common period of record 1966-81. The graphs of annual (calendar year) average discharge for both the Milburn and Blue stations for their respective periods of record (figure 9 of Hanson's report), indicate that 3 relatively dry years occurred during the 16-year common period of record (1966-81)--1966, 1978, and, in particular, 1980. The graph for the Blue River near Blue also indicates that annual discharge, and possibly seasonal base flows, were lower in 1939 and 1956 than were recorded during the subsequent common period of record.

Hanson also compared annual precipitation in the Blue River watershed with annual discharge of the Blue River. Figure 10 from his report shows a graph of annual precipitation for 79 years of record (1903-81) at the National Weather Service climatic station at the Tishomingo Wildlife Refuge located 12 miles west of the Milburn gauge. This graph indicates that the 45-year period (1937-81) which is common to the streamflow record at the Blue River near Blue station includes the relatively significant dry years of the late 1930's, mid-1950's, mid-1960's, and the late 1970's. Only the prolonged period of deficient precipitation (1909-12) was dryer than the 45-year period of streamflow recorded at the Blue gauging station. Also, the graph suggests that the prolonged period of significantly below-normal precipitation during 1976-78 and 1980 may compare with the prominent drought of the late 1930's.

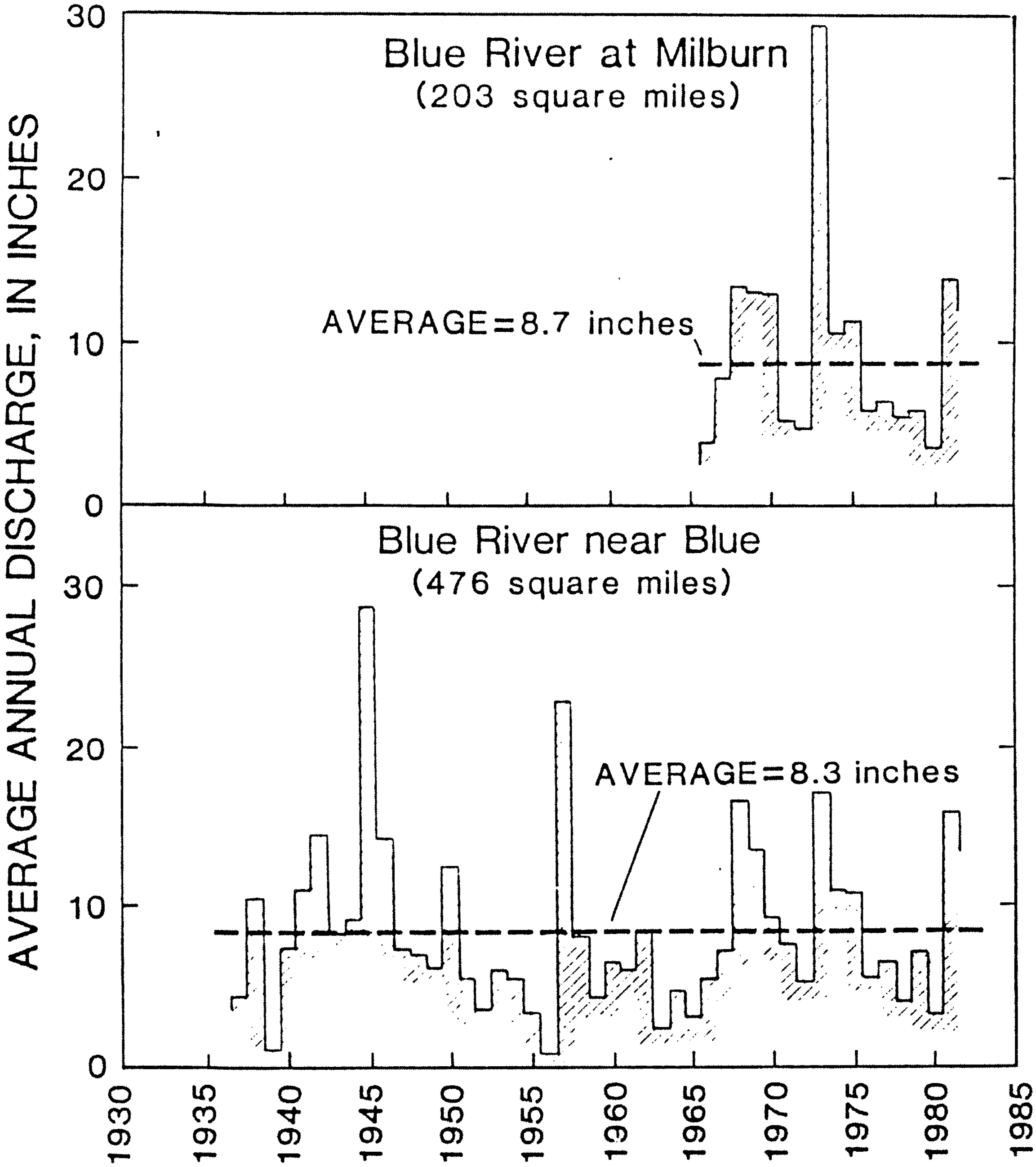

Figure 9.--Average calendar year discharges for Blue River at Milburn, Oklahoma gaging station (1966-81) and Blue River near Blue, Oklahoma gaging station (1937-81).

(From Hanson, 1987..... in press)

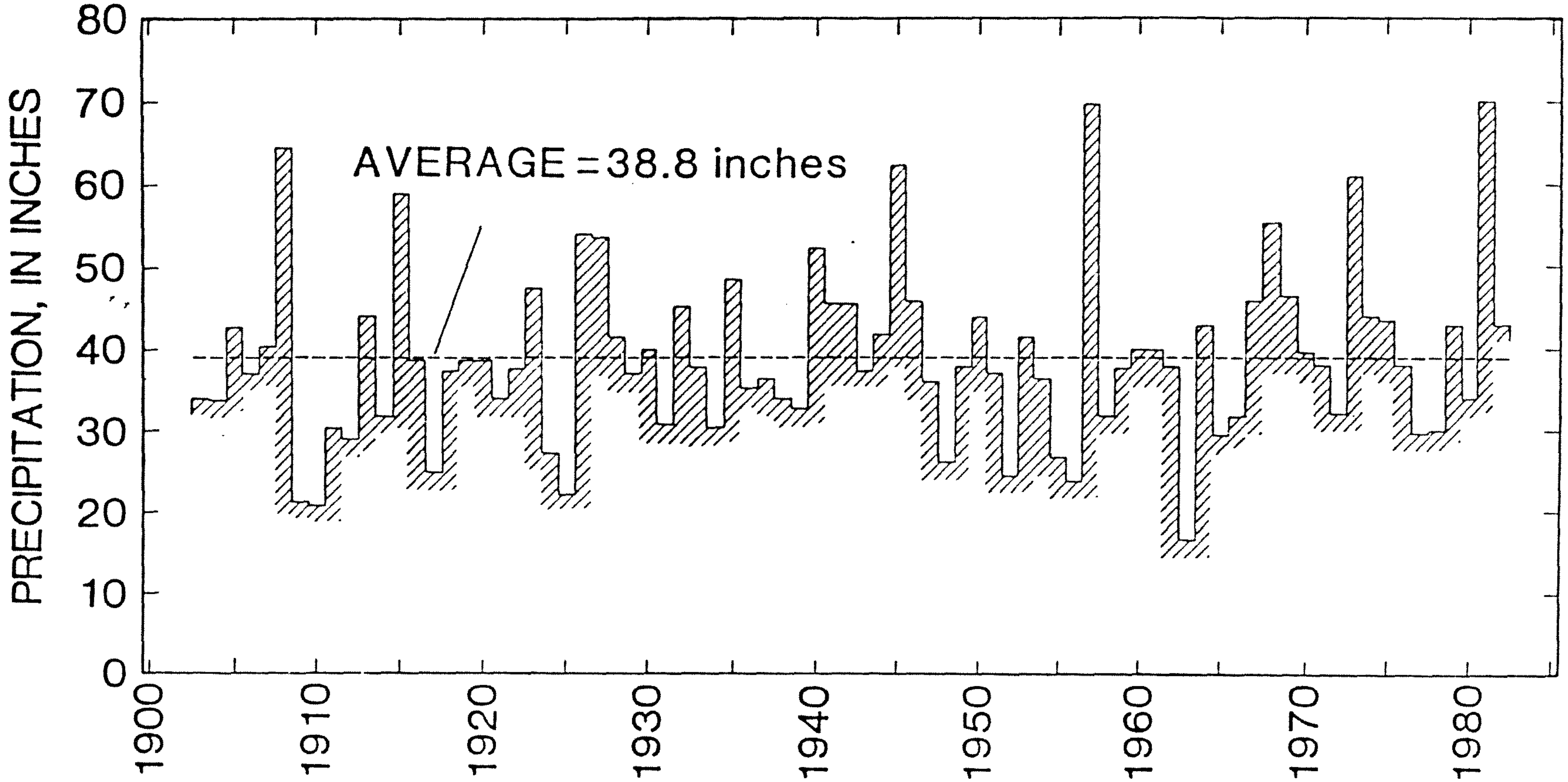

Figure 10.--Annual calendar year precipitation for National Weather Service climatic station at Tishomingo Wildlife Refuge, Oklahoma, 1903-81.

(From Hanson, 1987 .... in press)

Daily flow-duration hydrographs, which define the frequency characteristics of daily flows, provide an indication of the seasonal variation in minimum flows and may approximate base-flow conditions for some periods during the year. Hanson included in his report the daily flow-duration hydrographs for the Blue River at Milburn, Oklahoma, for water years 1970-78 (figure 11 from his report), which give the daily discharge for 3 percentage levels of exceedance--20, 50, and 100 percent. The lower hydrograph, which defines daily flows that were exceeded 100 percent of the time, reflects the low-flow characteristics of the stream. This hydrograph shows, for example, that the minimum flow observed on October 1, during 1970-78, was 29 ft^3/s and that this value was equaled or exceeded 100 percent of the time for all October 1's during the 9-year period. The smooth curve drawn through the troughs of this hydrograph approximates the minimum low flows of record but may not always reflect base flow, particularly during the spring and early summer months when streamflow may never recede to base-flow levels. An update of the daily flow-duration hydrographs for the Blue River gauging stations at the Blue and Milburn sites is in preparation. These hydrographs and other information describing the flow characteristics at these two sites will be published in the near future by Heimann and Tortorelli (see selected references).

Work by several investigators (Barnes 1939; Riggs 1963; Rorabaugh 1964) has shown that when the streamflow recession following a runoff event approaches a straight line on a semilog plot, the flow is considered to be derived entirely from ground-water discharge. An idealized streamflow hydrograph with straight-line base flow recession segments delineated on the lower end of selected hydrograph recessions is shown in figure 12. In each instance, base flow is

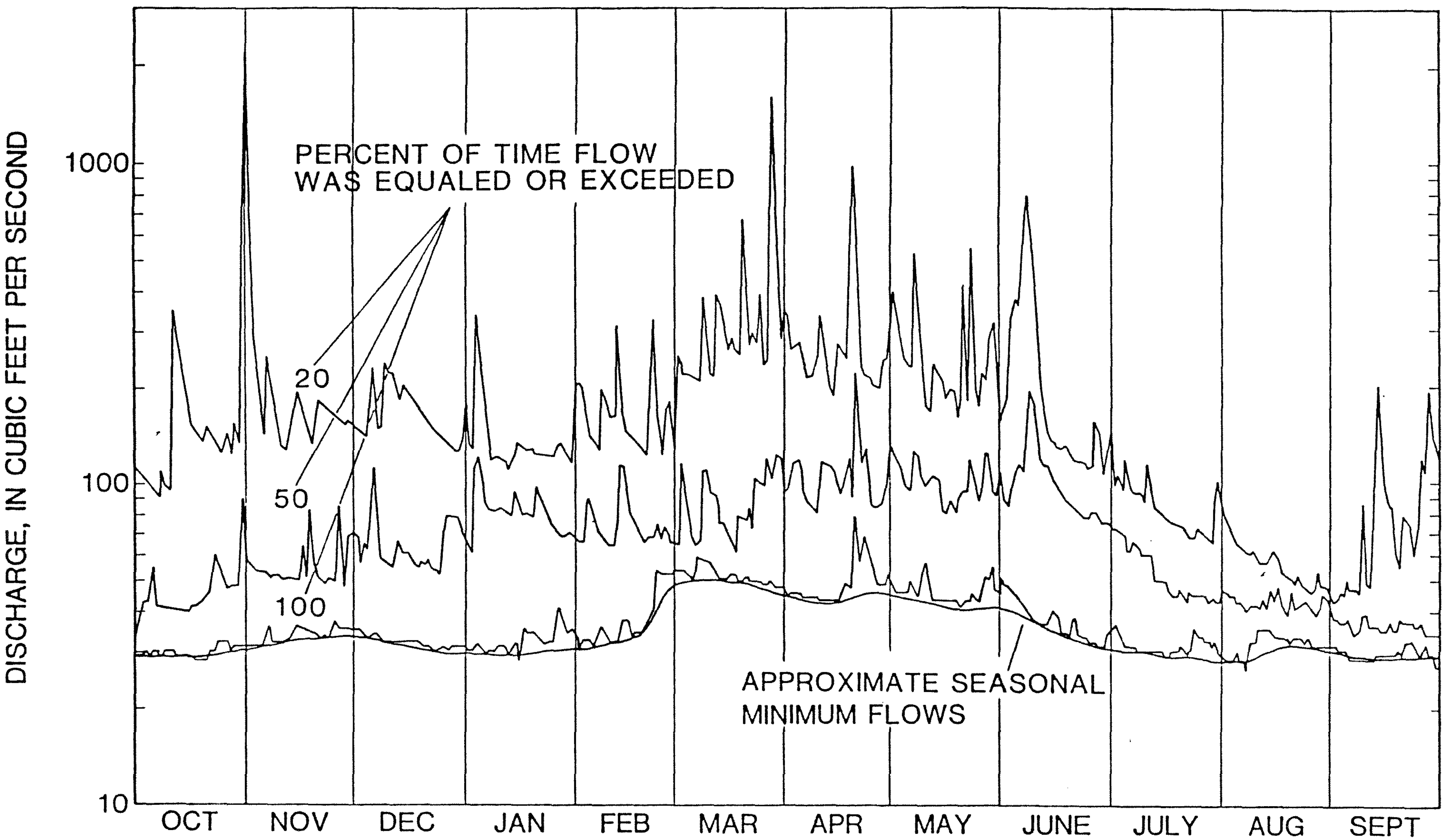

Figure 11.--Daily flow-duration hydrographs for Blue River at Milburn, Oklahoma for 20, 50, and 100 percent exceedance levels and approximate seasonal minimum flows (1970-78). (From Hanson, 1987 ... in pres

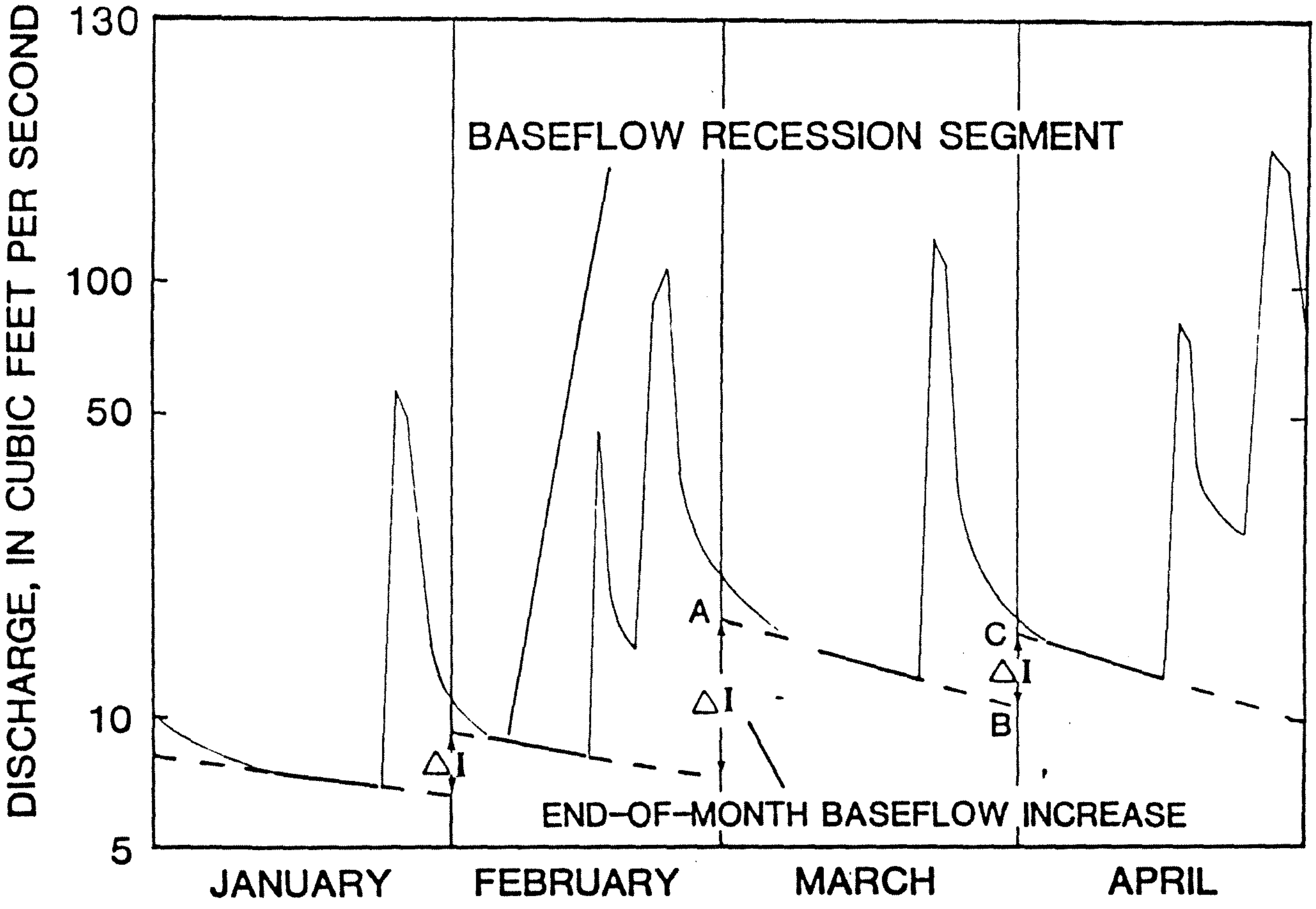

Figure 12.--Typical streamflow hydrograph showing baseflow recession segments and end-of-month baseflow increase, ΔI. For the month of March, 'A' defines beginning-month baseflow, 'B' defines end-of-month assured baseflow, and 'C' defines end-of-month adjusted baseflow.

(From Hanson, 1987 ... in press)

considered to occur only after surface runoff, bank storage, and channel storage following a storm event have been depleted and the recession approximates linearity.

The first step in defining a base flow recession curve was to select 10-day linear base flow recession segments from all appropriate hydrograph recessions observed during the 16-year period of record. A logarithmic plot of the beginning-day base flow value versus the base flow value 10 days later was then prepared for each month from January through September as described by Riggs (1963). Examples of these 10-day base flow relations are illustrated in figure 13 for January and July for the Blue River at Milburn station. These relations were determined for each month and then used to construct--by 10-day increments--the family of continuous base flow recession curves for the 9-month period, January through September, as shown in figure 14.

For example, the recession curve in figure 14 which begins on January 1 with 150 ft^3/s was drawn by first entering at 150 ft^3/s on the abscissa axis of the 10-day base flow relations in figure 7, moving up to the January relation and across to the ordinate axis to obtain the January 10 base flow of 125 ft^3/s. Then the January 10 value of 125 ft^3/s was entered on the abscissa axis to obtain the January 20 value of 106 ft^3/s. Similarly, the January 20 value of 106 ft^3/s was entered on the abscissa axis to obtain the January 30 value of 93 ft^3/s, thus defining the recession curve for January. Continuation of this curve through February and all subsequent months to September 30 was determined in a similar manner using the appropriate 10-day base flow relation for each month.

Because each of these 9-month base flow recession curves are derived from linear segments, which represent period of no rainfall and thus represent only

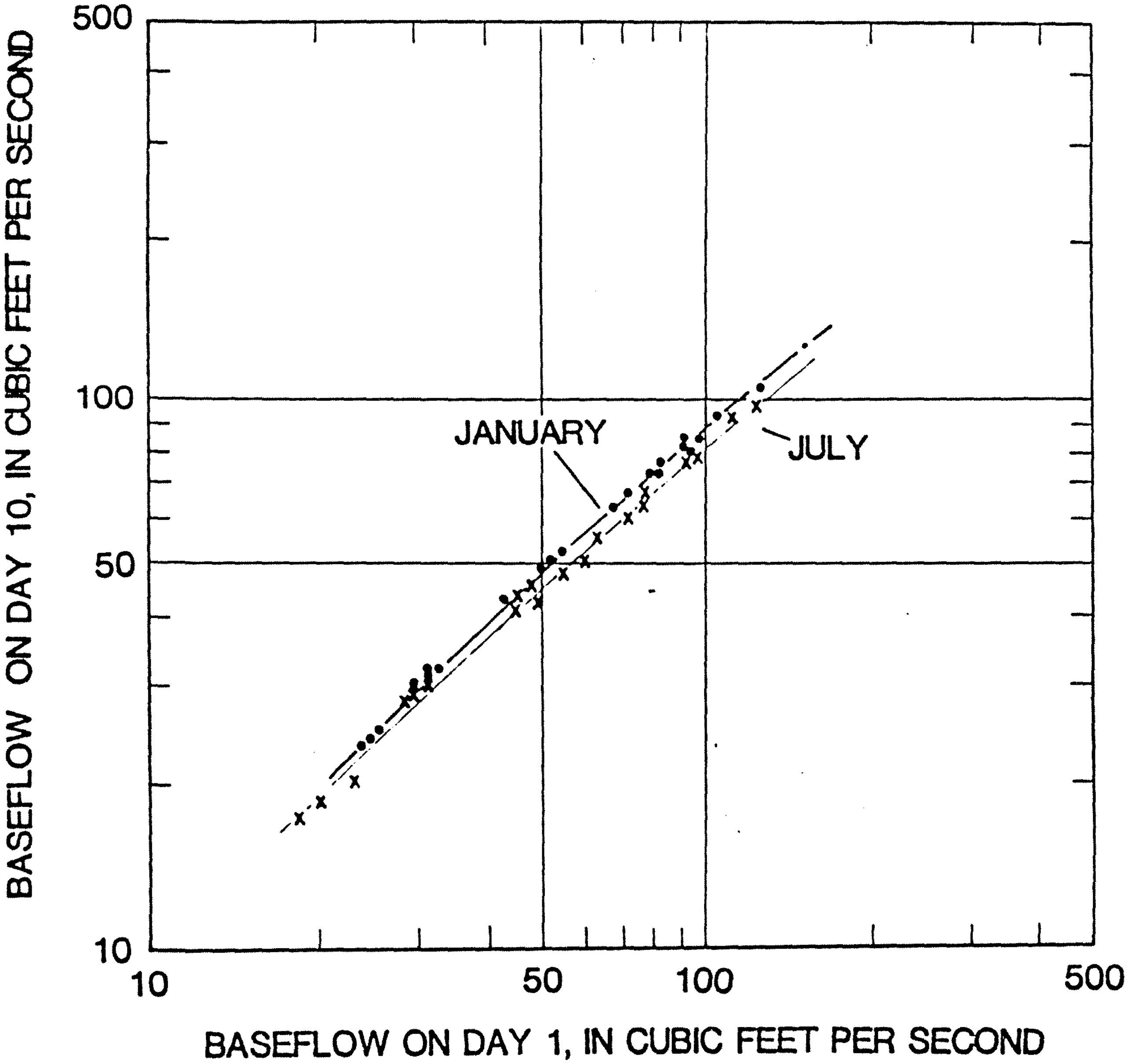

Figure 13.—Relation between baseflow on day 1 and baseflow 10 days later for January and July, Blue River at Milburn, Oklahoma, 1966–81.

(From Hanson, 1987 ... in press)

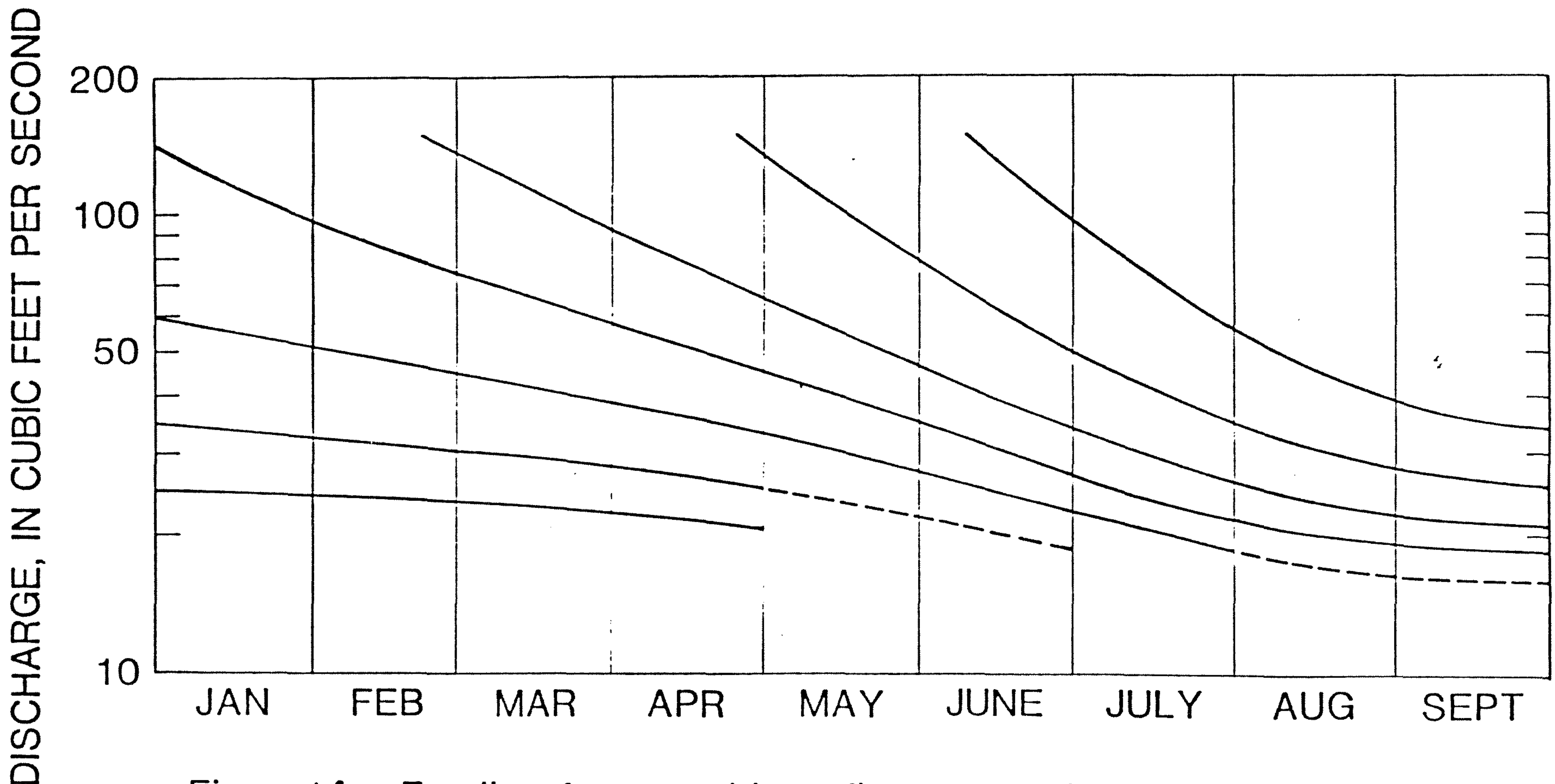

Figure 14.--Family of assured baseflow recession curves, Blue River at Milburn, Oklahoma.

(From Hanson, 1987 ... in press)

ground-water discharge to the stream, the curves are considered to approximate the minimum flow that would occur throughout the 9-month period. These curves are, therefore, referred to in this report as "assured" base flow recession curves. The lower dashed portions of these assured curves indicate that no base flow data have been recorded at these levels for the periods shown. Estimates for these periods are based on downward projections of the appropriate 10-day relations for each month.

One may expect that these base flow recession curves, derived from 10-day linear sigments, also would be linear throughout the 9-month period. However, several hydrologic factors affect the shape of these curves. First, some of the base flow segments may include discharge into the stream from delayed or prolonged bank and channel storage which will define a slightly steeper recession rate than the rate defined solely from ground-water discharge. In fact, the selection of representative linear base flow segments from the streamflow hydrograph can be a particular problem during the spring because of intermittent rainfall limiting the duration of the base flow recession. The slope of the recession curve will also be relatively steep as shallow perched ground water is depleted. In addition, summer recession slopes are typically steeper than winter slopes because of the increased transpiration by riparian vegetation during the summer. The effect of evapotranspiration on the recession hydrograph is shown in figure 13 by the displacement of the July base flow relation to the right of the January relation. The effect of evapotranspiration also is shown in figure 14 by steeper recession slopes during the summer than during the winter, for a given discharge level.

Finally, these recession curves show that base flow for the Blue River does not drop below about 15 ft^3/s and remains relatively sustained during the winter and summer months. This reflects a large ground-water supply from the Arbuckle Aquifer which underlies the Blue River watershed (Fairchild et al. 1982).

It is important to emphasize that these base flow recession curves are a composite of many 10-day base flow segments--some of which are influenced by runoff from delayed storage or depletion from evapotranspiration--and that the curves are only an approximation of ground-water discharge. Their use, however, in defining assured base flow is appropriate as long as these constraints are recognized and the curves are used, in a consistent manner, to make projections of assured base flow only for the period in which the curves have been defined.

A measure of the reliability of these derived recession curves for making projections of assured base flow for several months into the future is difficult in regions where rainfall commonly interrupts the streamflow recession during the spring and summer months. An indication of their reliability can be shown, however, by comparing the recession curves with a period of record low streamflow.

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