HYDROLOGIC INVESTIGATION OF THE CIMARRON RIVER

OKLAHOMA WATER RESOURCES BOARD

HYDROLOGIC INVESTIGATION
OF THE
CIMARRON RIVER

Technical Report

91-1

Prepared by the
U.S. Army Corps of Engineers
Southwestern Division
Tulsa District

for the

STREAM WATER DIVISION
Oklahoma Water Resources Board

July 1991

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HYDROLOGIC INVESTIGATION OF THE CIMARRON RIVER

INTRODUCTION

The hydrologic investigation of the Cimarron River was conducted by the Tulsa District, Corps of Engineers for the Oklahoma Water Resources Board (OWRB) under the authority of Section 22 of the Water Resources Development Act of 1974 (Public Law 93-251). Section 22 establishes a program of cooperative assistance to states in preparation of comprehensive plans for water resources development, utilization and conservation.

To accurately determine water appropriations within stream basins, Oklahoma statutes (Title 82, O.S. Supp. 1981, Sec. 105.12) require a hydrologic appraisal be conducted to determine availability of water within the basin. This data is used by the OWRB to determine the impact of a proposed withdrawal on existing users, to determine area-of-origin needs for cases where water is proposed to be transported outside the stream system and to determine water available for appropriation on either a regular or a seasonal basis.

This report presents the results of the Cimarron River Basin hydrologic appraisal. The appraisal's objective was to determine the source, extent and dependability of water in the stream system. Basic data (irrigation requirements; monthly municipal and industrial water consumption; and precipitation, evaporation and streamflow) required for planning, designing, constructing and operating reservoirs are provided in this report.

BASIN DESCRIPTION

The Cimarron River, a right-bank tributary of the Arkansas River, originates in Union County, New Mexico, near both the Colorado-New Mexico and Oklahoma-New Mexico State lines. The river flows southeasterly 698 miles through Colorado, Kansas and Oklahoma to its terminus in Keystone Lake. The lake is located on the Arkansas River about 15 miles west of Tulsa, Oklahoma. The Cimarron River Basin is bounded on the north by the upper Arkansas River Basin and on the south by the North Canadian River Basin. The Cimarron River Basin contains a drainage area of about 18,927 square miles (mi^2) with only 14,000 mi^2 contributing to flows. The basin is about 550 miles long and has an average width of 40 miles.

From its source in northeastern New Mexico, the stream is also known as the "Dry" Cimarron River to distinguish it from another Cimarron River in New Mexico that is a tributary of the South Canadian River. The quality as well as the quantity of water in the river varies considerably from the source to Lake Keystone. The Cimarron River is the largest contributor of naturally mineralized water to the Arkansas River. In New Mexico and Colorado, the quality of surface water is satisfactory for most purposes, but the supply is limited. In Kansas and Oklahoma, the surface water is of poor quality, particularly on the main stem, but in large quantities. The poor quality water is caused primarily by mineral deposits, salt plains and saline springs.

The Cimarron River flows through three distinct topographical regions: (1) The headwater portion of the basin includes the mountainous and hilly plateau region of northeastern New Mexico, southeastern Colorado and the northwestern end of the Oklahoma Panhandle; (2) The High Plains region of the basin extends from the mountainous headwater area to the vicinity of Englewood, Kansas, and includes parts of southeastern Colorado, the Oklahoma Panhandle and southwestern Kansas; and (3) The lower half of the basin is located in Oklahoma. The basin elevations range from about 8,000 feet in northeastern New Mexico to about 660 feet at its confluence with the Arkansas River within Keystone Lake. All elevations referenced in this report are based on National Geodetic Vertical Datum (NGVD). The drainage basin for the Cimarron River in Oklahoma lies in portions of Alfalfa, Beaver, Blaine, Canadian, Cimarron, Creek, Garfield, Harper, Kingfisher, Lincoln, Logan, Major, Noble, Oklahoma, Pawnee, Payne, Texas, Woods and Woodward Counties.

The OWRB has divided the Cimarron River Basin in Oklahoma into the following four stream systems: (1) Stream System 2-9-1 from its mouth to the USGS Gage Number 07160000 near Guthrie including Council, Stillwater and Skelton Creeks; (2) Stream System 2-9-2 from USGS Gage Number 07160000 near Guthrie to the USGS Gage Number 07158000 near Waynoka including Cottonwood, Kingfisher, Turkey and Eagle Chief Creeks; (3) Stream System 2-9-3 from USGS Gage Number 07158000 near Waynoka to the Kansas State Line including Buffalo Creek; and (4) Stream System 2-9-4 from the Colorado State Line to the New Mexico State Line including Lake Etling and Carrizo Creeks. These stream systems are shown on Figure 1, and Table 1 contains drainage area data for the Cimarron River Basin.

TABLE 1. DRAINAGE AREA DATA FOR THE CIMARRON RIVER (Mi^2)

	Drainage Area			Mile
	Inter-vening[1]	Contri-buting	Total	Above Mouth
STREAM SYSTEM 2-9-4				
Upper limits at New Mexico - Oklahoma State line	867	867	922	597.4
Confluence with Carrizo Creek (Cr.) [tributary area, 165 mi^2]	1	1,033	1,101	596.2
USGS gage near Kenton, OK	5	1,038	1,106	594.0
Lower limits at Oklahoma - Colorado State line	1,097	2,135	NA[2]	NA

[1] Less tributary area where shown.

[2] Not available.

TABLE 1. (Cont'd)

	Drainage Area Inter-vening[3]	Contri-buting	Total	Mile Above Mouth
STREAM SYSTEM 2-9-3				
Upper limits at Kansas - Oklahoma State line, USGS gage near Mocane, OK	2,170	4,305	8,670	364.1
Oklahoma - Kansas State line	1,082	5,387	NA	NA
Kansas - Oklahoma State line	1,613	7,000	11,813	302.5
USGS gage near Buffalo, OK	191	7,191	12,004	289.1
Confluence of Buffalo Cr. (tributary area, 455 mi²)	30	7,676	12,489	280.0
Lower limits at USGS gage near Waynoka, OK	828	8,504	13,334	247.0
STREAM SYSTEM 2-9-2				
Upper limits at lower limits of Stream System 2-9-3	--	8,504	13,334	247.0
Confluence of Eagle Chief Cr. (tributary area, 480 mi²)	355	9,339	14,237	212.6
Confluence of Turkey Cr. (tributary area, 428 mi²)	1,018	10,785	15,711	161.8
Confluence of Kingfisher Cr. (tributary area, 507 mi²)	9	11,301	16,227	158.2
Confluence of Cottonwood Cr. (tributary area, 380 mi²)	283	11,964	16,890	123.0
Lower limits at USGS gage near Guthrie, OK	2	11,966	16,892	122.4
STREAM SYSTEM 2-9-1				
Upper limits at lower limits of Stream System 2-9-2	--	11,996	16,892	122.4
Confluence with Skelton Cr. (tributary area, 622 mi²)	27	12,615	17,541	115.3
USGS gage at Perkins, OK	311	12,926	17,852	87.3
Confluence with Stillwater Cr. (tributary area, 282 mi²)	130	13,338	18,264	75.9
Lower limits Mouth of Cimarron River (Mi. 540.8 Arkansas River)	663	14,001	18,927	0.0

Source of Data: U.S. Army Corps of Engineers, Drainage Area Data - Arkansas, White and Red River Basins.

[3] Less tributary area where shown.

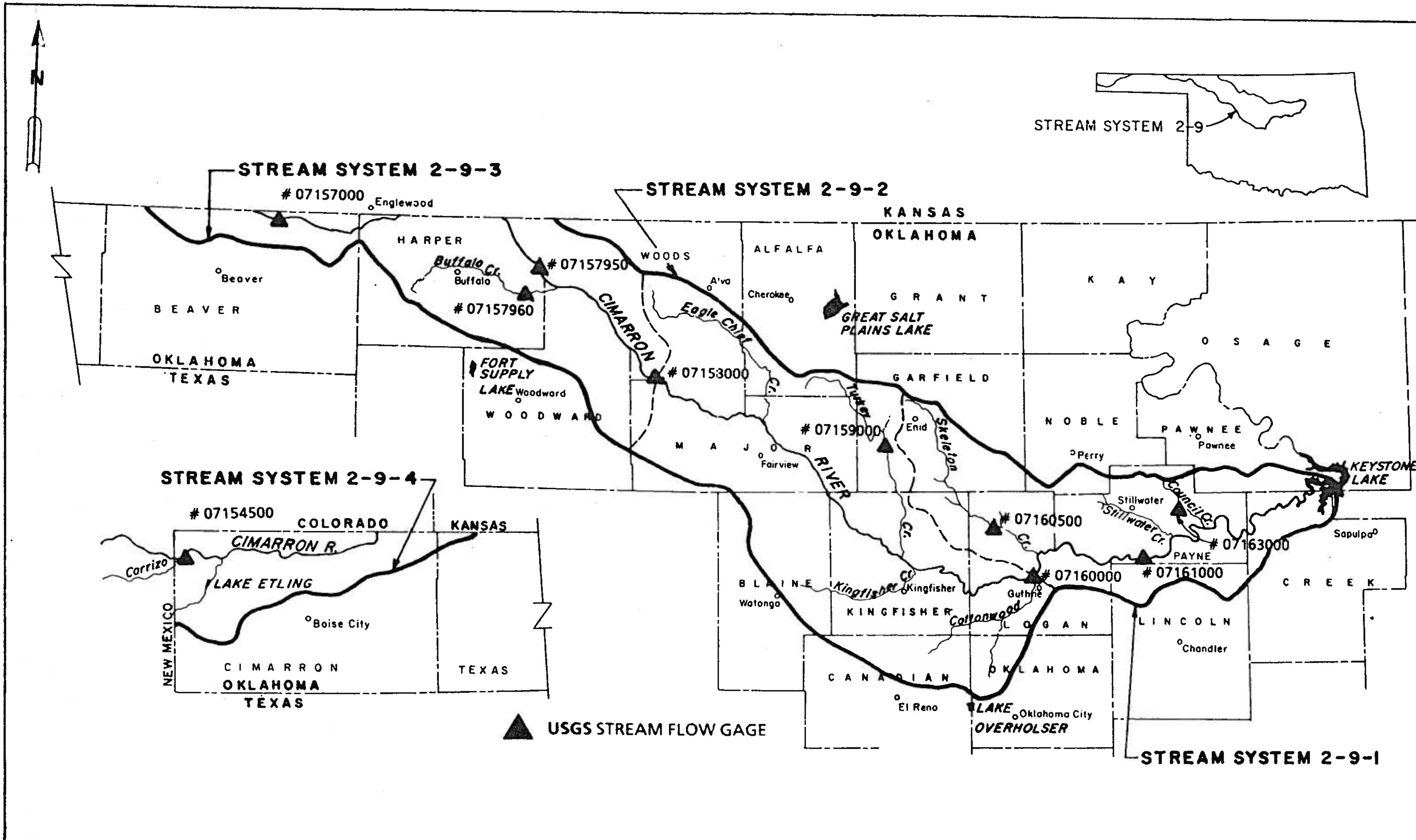


Figure 1. Stream Systems on the Cimarron River in Oklahoma

The three major ecoregions occurring within the Cimarron River Basin in Oklahoma (R. G. Bailey, 1980) are discussed below.

Source, Stream System 2-9-4 and Western Part of 2-9-3

The area from the source of the Cimarron River in northeastern New Mexico and along the river basin in the Oklahoma Panhandle is part of the Dry, Steppe, Shortgrass Prairie Province; Grama-Buffalo Grass Section. This area is characterized by rolling plains and tablelands of moderate relief with occasional valleys, canyons and buttes. Tributary streams in the mountainous areas of the source and in the hilly plateau region of Stream System 2-9-4 are short, steep and deeply entrenched.

In the western part of Stream System 2-9-3 to about Englewood, Kansas, however, the High Plains are generally flat containing many uneven low hills, intervening depressions and sand dunes. Tributaries in this region are longer, and the flood plains are narrow. The High Plains contain many broad, shallow undrained depressions varying in size from less than 100 feet to several miles in diameter. During heavy rainfalls, water drains into these depressions creating lakes or ponds.

Short grasses, such as buffalo grass, are usually bunched and sparsely distributed over the plains with sunflower and locoweed. Scattered trees and shrubs occasionally appear on the steppe and exist in all gradations of cover in semidesert and woodland formations.

Pronghorn antelope is probably the most abundant large mammal across the steppe plains, but mule and white-tailed deer are often abundant in brush cover along stream courses. The desert cottontail, prairie dogs and other small rodents are preyed upon by the coyote and several other mammalian and avian predators. Sage grouse, greater prairie chicken and sharp-tailed grouse are present in this area.

Eastern Stream System 2-9-3, 2-9-2 and Western 2-9-1

The eastern part of Stream System 2-9-3, Stream System 2-9-2 and the western part of Stream System 2-9-1 lie in the Temperate, Tall-grass Prairie Province; Bluestem-Grama Prairie Section. This region is characterized by flat and rolling plains with relief of less than 300 feet. Loess and sand deposits cover the flat to rolling hill land with well developed drainage systems. Downstream of Englewood, Kansas, the Cimarron Basin is part of the Red Hills or Cimarron Breaks physiographic province. The terrain is broken by deeply eroded ravines and valleys. The main stem floodplain is relatively flat and contains many sandy areas flanked by steep, sloping hills. Included in this area are lands heavily impregnated with natural chlorides. The lower Cimarron River Basin east of Kingfisher has more industry, a greater number of land and water improvements and a higher population density than the basin above it.

The stream system contains tall-grass and mixed grasslands. Bunch grasses are conspicuous, many taller than 6 feet, but sod-forming species dominate. Woody vegetation is rare, except on the cottonwood floodplains. Dominant plants are porcupine grass, prairie dropseed, little bluestem, side-oats grama, Junegrass, western wheatgrass, plains muhly, panic grass, match weed, broomweed, scurf-pea, sunflowers, goldenrods and ragweed. Because of the generally favorable conditions of climate and soil, most of the area is cultivated and little of this original vegetation remains.

Pronghorn antelope and coyotes are present in the area. Jackrabbits are numerous on the prairie, and cottontails are present on streams with cover. Burrowing rodents include ground squirrels, prairie dogs, pocket gophers and many smaller species. The sharp-tailed grouse, greater prairie chicken and bobwhite are present in fair numbers.

Eastern Stream System 2-9-1

The eastern part of Stream System 2-9-1 lies in the Temperate, Prairie Parkland Province; Oak and Bluestem Parkland Section. This region is gently rolling plains with mature streams, meandering within wide valleys which merge with hills covered with scrub oaks and grasses.

The cover in this region is characterized by the intermingling of prairies, groves and strips of deciduous trees. In the alteration of forest and bluestem prairies, trees generally grow near streams and on north-facing slopes of hills. Trees include elm, sycamore, bur oak, eastern cottonwood, hackberry, redbud and buckeye.

While many prairie and deciduous-forest animals inhabit the alternating prairies and forests, few forms have been identified as being peculiar to this region. Animals, birds and reptiles from the ecoregions upstream and downstream of this ecoregion merge in this stream system.

CLIMATOLOGICAL DATA

Runoff from a drainage basin is influenced by climatic factors such as precipitation, evaporation, temperature, wind velocity (direction and duration), humidity, atmospheric pressure and solar radiation. The principal climatic factors affecting runoff are precipitation and evaporation. Data regarding these factors are presented in this section of the report.

Climatic Zone

The climatic zone of the stream systems on the Cimarron River Basin in the State of Oklahoma varies from semiarid at the western boundary (New Mexico-Oklahoma State line) to subhumid at its eastern end in Lake Keystone. All parts of the basin are subject to long droughts. The average annual temperature of the basin ranges from 50 to 60 degrees Fahrenheit, west to east.

Precipitation

Data from precipitation stations at Cushing, Enid, Guthrie, Mannford, Oklahoma City, Pawnee, Perkins, Perry and Stillwater were used to estimate average annual and monthly mean precipitation for Stream System 2-9-1. Stations at Canton, El Reno, Enid, Guthrie, Helena, Kingfisher, Okeene, Oklahoma City, Watonga and Waynoka stations provided precipitation data for Stream System 2-9-2. Precipitation data from stations at Beaver, Buffalo, Freedom, Liberal (KS), Waynoka and Woodward were used to calculate precipitation data for Stream System 2-9-3. Precipitation data from stations at Boise City, Elkhart (KS) and Kenton were used for Stream System 2-9-4. Data from these stations are the observed monthly precipitation totals for varying historical periods ranging from 1925 to 1987. Missing monthly data for any station were estimated by taking the arithmetic mean of data from adjacent stations.

The rainfall data were used to determine the average precipitation over each stream system by applying the Thiessen Polygon Method. This method divides the stream system into polygons by drawing lines mid-way between adjacent stations as shown in Figure 2. Each polygon defines the sub-basin area assumed to be affected by precipitation from the indicated station. The percentage of the total stream system area defined by each polygon is a weighting factor, which multiplied by the station's monthly precipitation gives the polygon's monthly precipitation value. The monthly values for each polygon are summed to provide a monthly precipitation value for the entire stream system.

Monthly mean precipitation and annual precipitation for the stream systems on the Cimarron River Basin in Oklahoma are tabulated in Tables 2 and 3, and are graphically presented in Figures 3 and 4, respectively.

TABLE 2. MONTHLY MEAN PRECIPITATION IN INCHES FOR THE STREAM SYSTEMS ON THE CIMARRON RIVER IN OKLAHOMA, 1950-1987

	Stream Systems			
Month	2-9-1	2-9-2	2-9-3	2-9-4
January	1.00	0.74	0.49	0.34
February	1.51	1.18	0.96	0.42
March	2.36	1.92	1.68	0.91
April	2.74	2.32	2.00	1.35
May	5.39	4.96	4.22	2.44
June	4.13	3.91	3.51	2.25
July	3.32	2.67	2.87	2.93
August	2.81	2.60	2.95	2.54
September	3.80	3.21	2.46	1.60
October	3.06	2.48	1.85	0.99
November	2.08	1.64	1.26	0.62
December	1.36	1.05	0.76	0.38

U.S. Army Corps of Engineers, Tulsa District

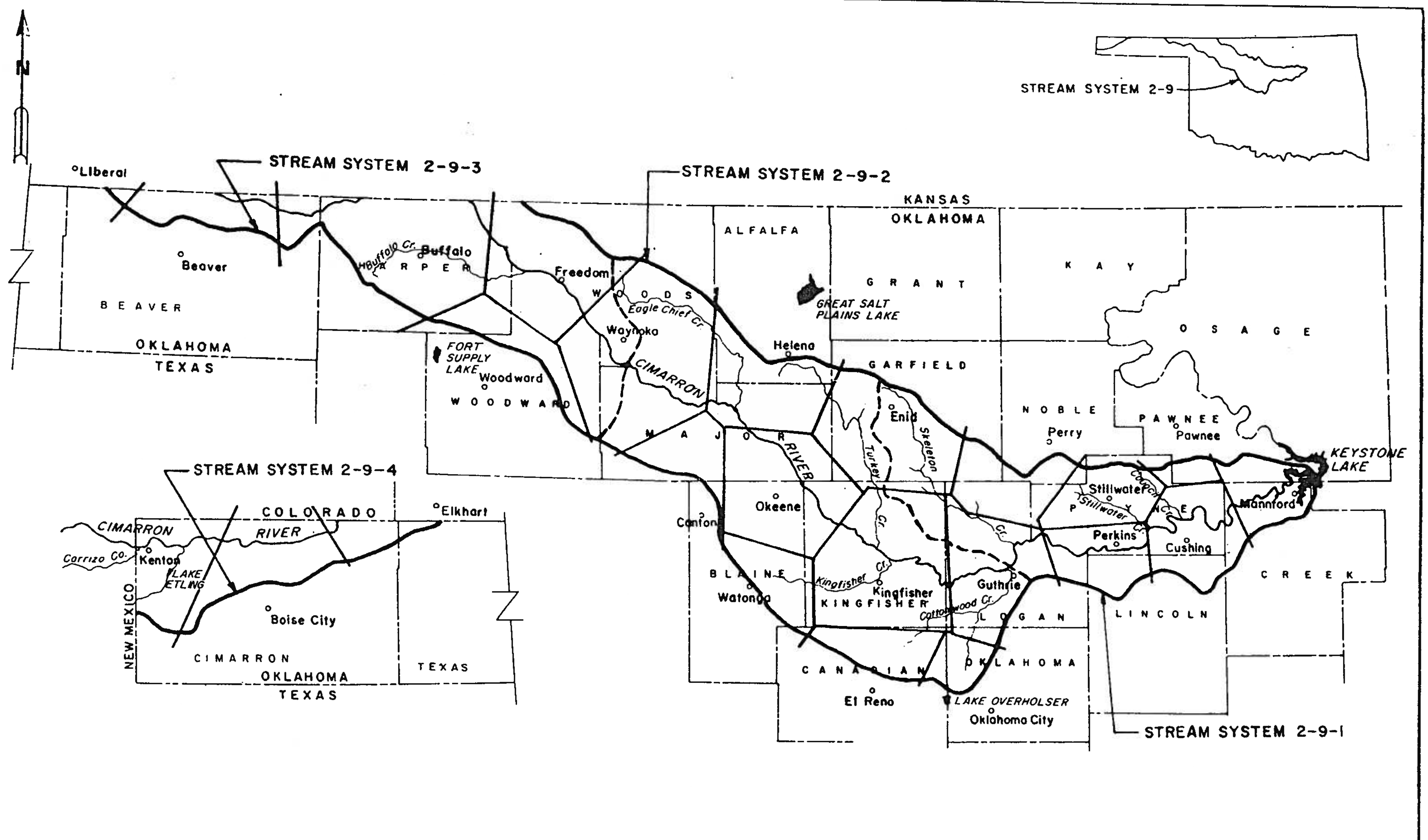


Figure 2. Thiessen Divisions of the Stream Systems on the Cimarron River in Oklahoma

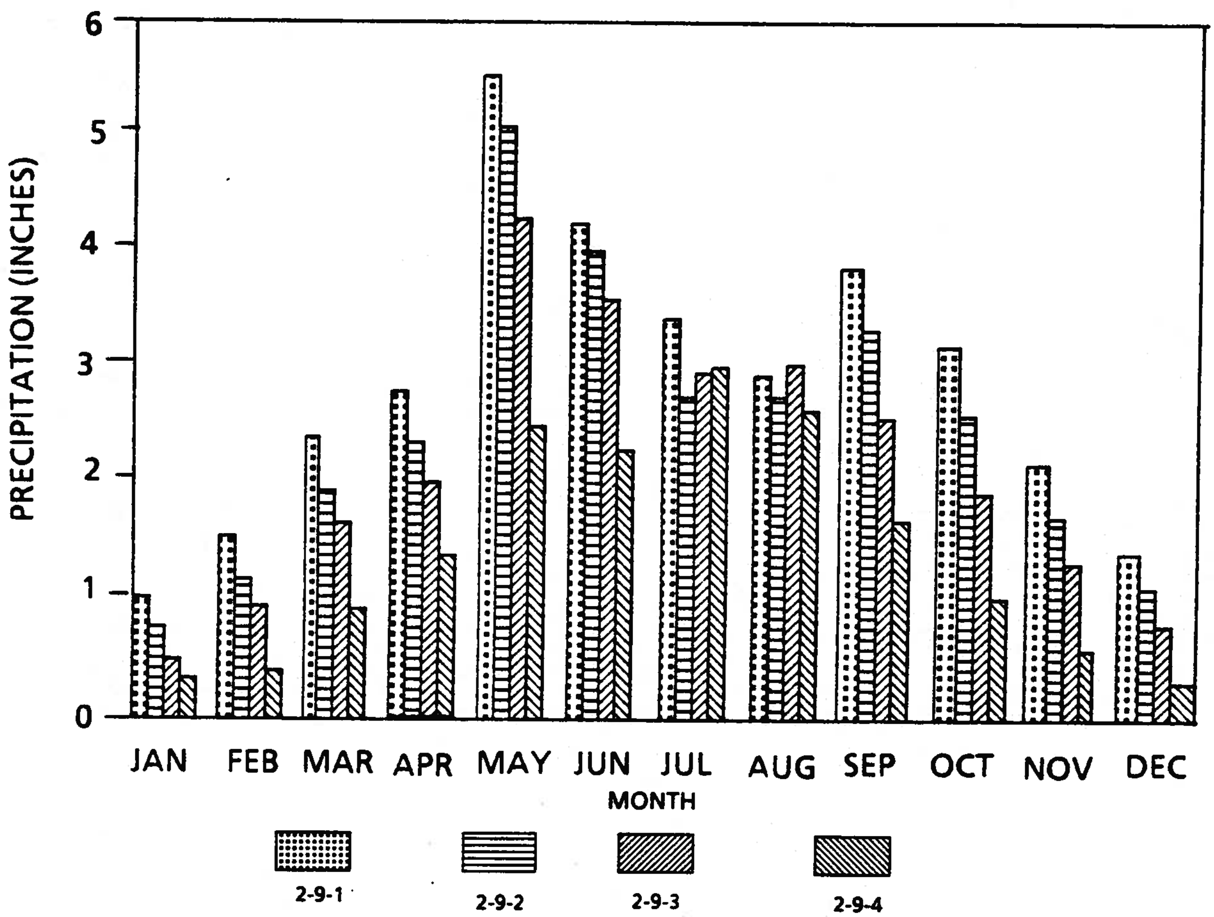
TABLE 3. ANNUAL PRECIPITATION IN INCHES FOR THE STREAM SYSTEMS ON THE CIMARRON RIVER IN OKLAHOMA, 1950-1987

Year	Stream System			
	2-9-1	2-9-2	2-9-3	2-9-4
1950	28.65	25.55	23.47	24.91
1951	36.77	30.50	30.51	17.01
1952	23.94	16.18	18.12	13.92
1953	32.34	25.13	19.25	12.25
1954	18.66	15.74	11.59	10.92
1955	29.12	30.62	19.79	11.36
1956	18.31	14.96	15.18	8.88
1957	48.98	45.44	41.84	19.34
1958	31.28	27.43	25.45	21.54
1959	47.44	34.71	29.57	16.49
1960	37.52	37.39	28.88	19.45
1961	42.82	33.95	27.28	16.83
1962	32.60	26.88	27.85	15.21
1963	29.64	25.94	19.21	11.88
1964	31.42	28.26	23.12	12.32
1965	29.25	27.80	27.05	23.82
1966	22.75	17.61	15.29	16.12
1967	33.55	28.17	21.97	14.99
1968	31.76	28.11	27.16	13.51
1969	31.11	27.12	24.40	27.70
1970	28.63	21.01	16.71	10.48
1971	33.24	27.04	25.20	20.22
1972	29.58	25.10	23.09	18.41
1973	44.46	38.28	31.74	18.22
1974	46.95	38.67	28.29	14.02
1975	37.65	29.87	21.88	14.54
1976	22.35	20.24	19.39	15.08
1977	32.96	28.48	26.30	17.40
1978	27.86	26.00	22.60	14.85
1979	33.38	31.63	32.25	19.88
1980	31.77	26.52	24.33	13.90
1981	32.21	31.61	27.53	18.00
1982	35.69	29.02	25.10	19.96
1983	35.79	32.77	28.25	14.45
1984	31.20	24.02	22.27	19.38
1985	47.56	35.02	34.30	18.54
1986	44.76	39.80	27.18	21.99
1987	40.98	37.83	36.62	19.75
MEAN	33.55	28.69	25.00	16.78
ST. DEV.	7.64	6.80	6.03	4.12

Source of Data: U.S. Department of Commerce, NOAA. Climatological Data for Oklahoma.

Pan Evaporation

The pan evaporation data presented in this report were collected from four stations to represent the changing climatic conditions across the stream systems. Data from 1957 to 1987 for the Lake Keystone Dam evaporation station are included for use in Stream System 2-9-1. For use in Stream Systems 2-9-2, data from 1952 to 1987 for the Lake Overholser Dam pan evaporation station are included. For Stream Systems 2-9-2 and 2-9-1, data from 1942 to 1987 for the Fort Supply and Great Salt Plains Dams pan evaporation stations are shown. The data are presented on a monthly mean basis in Table 4, on an annual basis in Table 5, and both are shown graphically in Figure 5.



Source of Data: U.S. Department of Commerce, NOAA. Climatological Data for Oklahoma.

FIGURE 3. Monthly Mean Precipitation for the Stream Systems on the Cimarron River in Oklahoma.

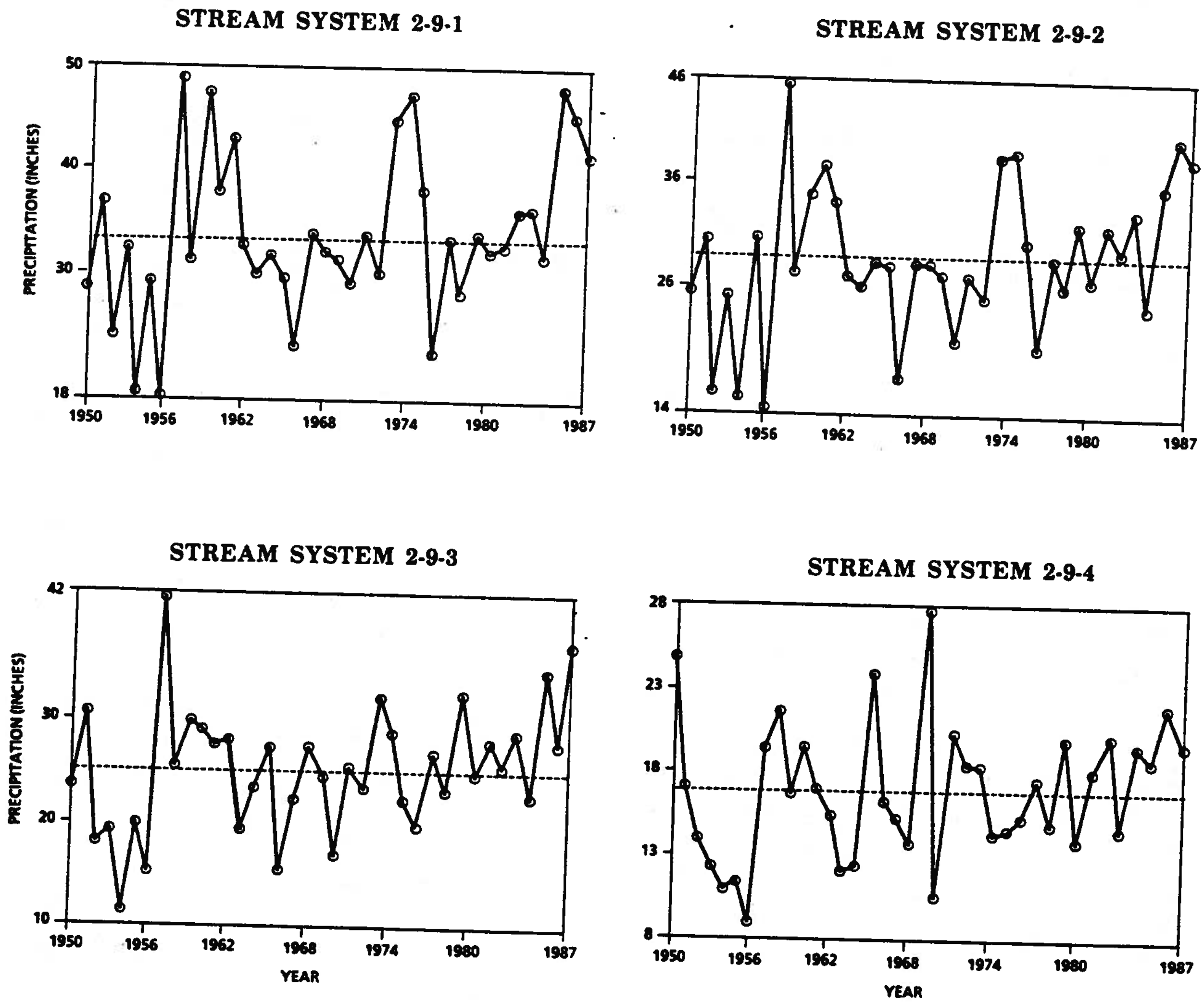


FIGURE 4. Annual Precipitation for the Stream Systems on the Cimarron River in Oklahoma.

TABLE 4. MONTHLY CLASS "A" PAN EVAPORATION IN INCHES

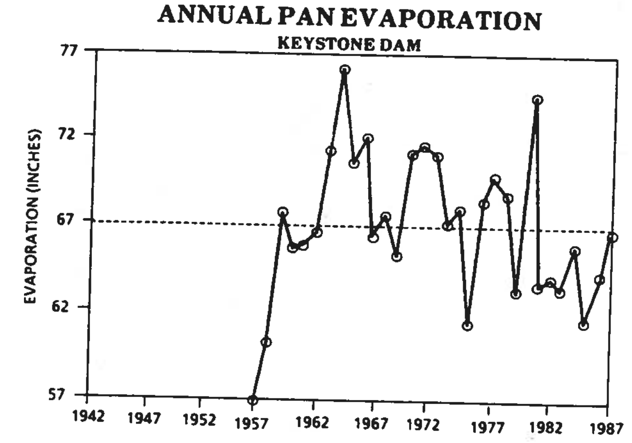
Month	Stream System 2-9-1	2-9-2	2-9-3 & - 4
January	1.92	1.92	2.67
February	2.46	2.57	3.16
March	4.64	4.99	6.06
April	6.54	6.96	8.75
May	7.49	8.19	9.68
June	8.49	9.79	11.73
July	10.12	11.42	13.10
August	9.14	10.37	12.01
September	6.42	7.49	9.15
October	4.83	5.38	6.57
November	3.00	3.07	3.92
December	1.93	1.93	2.51

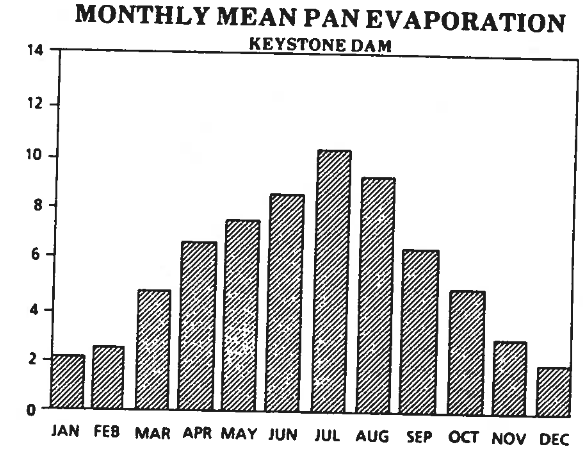
Source of Data: U.S. Department of Commerce, NOAA. Climatological Data for Oklahoma.

TABLE 5. ANNUAL CLASS "A" PAN EVAPORATION IN INCHES

Year	Stream System 2-9-1	2-9-2	2-9-3 & -4
1942	--	--	83.48
1943	--	--	89.48
1944	--	--	84.26
1945	--	--	86.14
1946	--	--	91.72
1947	--	--	91.64
1948	--	--	88.77
1949	--	--	74.58
1950	--	--	83.96
1951	--	--	81.14
1952	--	80.68	97.37
1953	--	77.61	99.27
1954	--	88.27	114.74
1955	--	75.96	101.01
1956	--	91.22	115.72
1957	57.00	58.80	79.14
1958	60.26	61.28	77.67
1959	67.76	68.66	85.68
1960	65.66	66.93	83.07
1961	65.86	69.41	83.96
1962	66.62	69.95	90.16
1963	71.21	73.21	98.91
1964	76.11	88.41	99.44
1965	70.54	78.94	86.72
1966	72.04	82.67	92.27
1967	66.28	75.29	91.78
1968	67.60	78.50	90.31
1969	65.30	72.83	84.81
1970	71.16	81.58	100.10
1971	71.55	82.53	94.88
1972	71.17	79.80	89.01
1973	67.00	76.45	83.36
1974	67.90	76.87	91.19
1975	61.48	67.35	90.36
1976	68.40	77.47	96.71
1977	69.87	74.98	90.91
1978	68.74	75.19	98.96
1979	63.49	69.05	85.55
1980	74.44	78.14	95.09
1981	63.70	68.89	86.56
1982	63.95	67.06	81.11
1983	63.41	67.86	80.37
1984	65.67	70.10	92.61
1985	61.63	63.83	71.81
1986	64.19	64.94	79.69
1987	66.51	66.06	79.36
Mean	66.98	74.08	89.58
St. Dev.	4.14	7.56	8.68

STREAM SYSTEM 2-9-1





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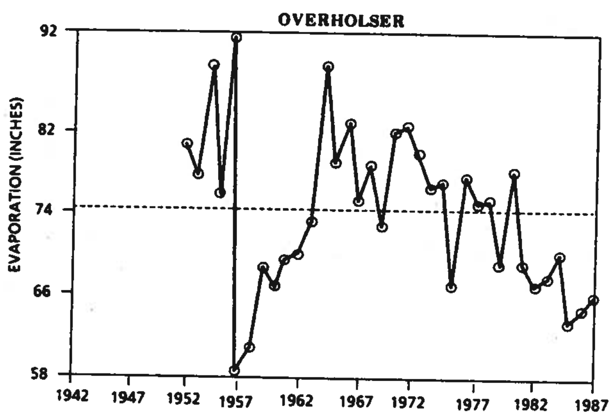
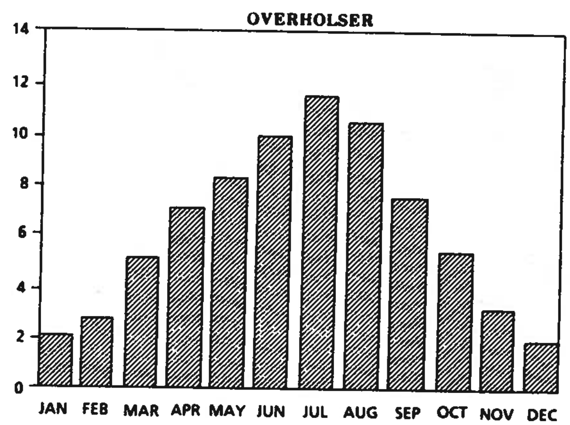
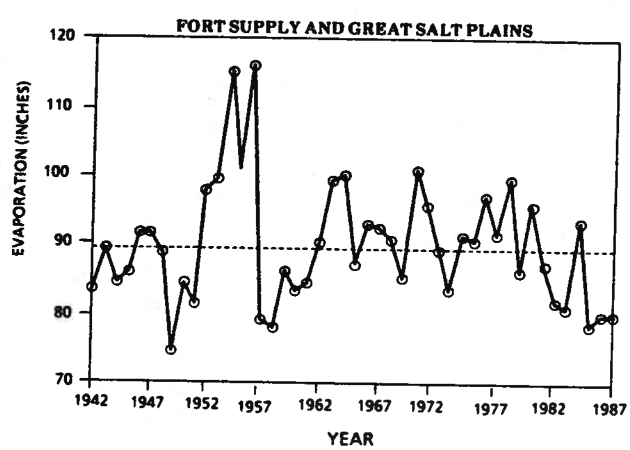
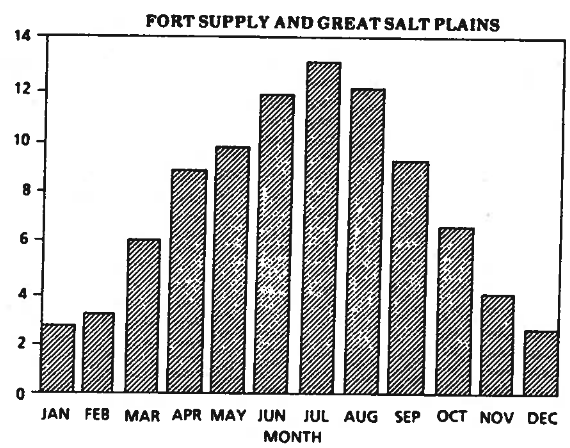




STREAM SYSTEMS 2-9-3 AND 4





Source of Data: U.S. Department of Commerce, NOAA. Climatological Data for Oklahoma.

FIGURE 5. Annual and Monthly Mean Pan Evaporation for the Stream Systems on the Cimarron River in Oklahoma.

WATER USE DISTRIBUTION

The OWRB presently defines the amount of stream water available for appropriation under a regular permit as the average annual streamflow available at least 35 percent of the time. However, water available on an average annual basis may not be available to permit holders. Water usage in Oklahoma varies from season to season, and both maximum water demand and low streamflows occur during the summer for most uses, such as irrigation, municipal and industrial.

An important tool in allocating water seasonally is a water distribution model which provides information on typical monthly usage in the basin. This monthly data can be compared to monthly streamflow hydrographs to determine the amount of water available seasonally for appropriation. Because irrigation water use data are not available on a monthly basis, water use distribution in this study was done on an annual basis. Distribution of monthly municipal and industrial use is included in this section for possible use by the report user.

Municipal and Industrial Use

Stream water use distribution data were obtained from the OWRB for Stillwater and Guthrie, Oklahoma. Data from Stillwater in 1988 and 1989 are representative of stream water use distribution in Stream System 2-9-1. Guthrie data in 1989 are used for 2-9-2. There are no municipal and industrial (M&I) stream water users in Stream Systems 2-9-3 and 2-9-4. This is insufficient data to provide generalized trends in stream water use across the stream systems of the Cimarron River in Oklahoma. However, Table 6 shows the monthly M&I water consumption and the monthly percent of annual use for the two cities.

TABLE 6. MUNICIPAL AND INDUSTRIAL WATER USE (Millions of Gallons)

	Stream System 2-9-1			Stream System 2-9-2	
Month	1988	1989	Percent of Annual	1989	Percent of Annual
January	258	143	8.9	30.0	7.4
February	226	139	8.1	30.4	7.5
March	244	189	9.6	31.3	7.8
April	291	193	10.7	33.9	8.4
May	195	145	7.5	34.6	8.6
June	232	110	7.5	32.8	8.2
July	247	159	9.0	37.9	9.4
August	272	159	9.5	35.2	8.7
September	183	157	7.5	34.4	8.5
October	192	178	8.2	33.7	8.4
November	167	134	6.6	31.9	7.9
December	152	160	6.9	37.0	9.2
TOTAL	2,659	1,866	100.0	403.1	100.0

Source of data: City Water Department Records.

It is essential to note that the water use data presented in this report are merely indicative of trends and traits in two stream systems of the Cimarron River in Oklahoma. To determine monthly water demand for particular geographical areas or communities, a more intensive and detailed study should be conducted.

Irrigation Requirements

A reasonably accurate determination of irrigation requirements is important because it aids in determining the amount of water that can be appropriated in a stream system.

A survey was made of the county containing the greatest area in each stream system to determine its prevailing crops. Crop statistics from the Oklahoma Department of Agriculture were used (ODA, 1988). In the surveyed counties, the top three crops in descending order in Payne County for Stream System 2-9-1 and in Kingfisher County for Stream System 2-9-2 were wheat, hay and oats. Wheat, hay and sorghum were the three main crops in Harper County for Stream System 2-9-3. In Cimarron County for Stream System 2-9-4, the top three crops were wheat, sorghum and hay. Barley and corn were also grown in the counties. Since alfalfa hay was the most water-intensive crop identified, irrigation requirements were based on alfalfa's water requirements so that the amount of water needed for other crops would not be underestimated.

Net irrigation requirements for normal and dry years for the following stations were used in the Stream Systems shown in Table 7: (1) 2-9-1, Goodwell; (2) 2-9-2, Woodward; (3) 2-9-3, El Reno; and (4) 2-9-4, Ponca City. The normal and dry year crop irrigation water requirements should occur 50 and 20 percent of the time, respectively (BuRec, 1986).

The normal and dry irrigation water requirements for alfalfa are: (1) 16.92 and 20.62 inches per year, respectively, in Stream System 2-9-1; (2) 20.52 and 23.88 inches per year, respectively, in Stream System 2-9-2; (3) 20.66 and 24.00 inches per year, respectively, in Stream System 2-9-3; and (4) 22.75 and 25.84 inches per year, respectively, in Stream System 2-9-4. By converting inches per year to acre-feet per acre per year, the requirements for the Stream Systems are: (1) 1.4 and 1.7 in 2-9-1; (2) 1.7 and 2.0 in 2-9-2 and 2-9-3, respectively; and (3) 1.9 and 2.0 in 2-9-4.

TABLE 7. NORMAL AND DRY IRRIGATION REQUIREMENTS FOR THE STREAM SYSTEMS ON THE CIMARRON RIVER IN OKLAHOMA (Inches)

Crop	Stream System 2-9-1 Normal	2-9-1 Dry	2-9-2 Normal	2-9-2 Dry	2-9-3 Normal	2-9-3 Dry	2-9-4 Normal	2-9-4 Dry
Alfalfa	16.92	20.62	20.52	23.88	20.66	24.00	22.75	25.84
Pasture	17.82	21.29	21.60	24.48	21.56	24.46	20.27	22.85
Corn (Grain)	13.95	16.65	17.28	19.56	17.23	19.56	17.85	20.23
Spring Wheat	--	--	12.00	14.40	--	--	--	--
Sorghum	11.22	13.43	12.72	14.28	12.69	14.45	13.55	15.48

Source of Data: U.S. Department of the Interior, Bureau of Reclamation. Technical Report on Irrigation Water Requirements, State of Oklahoma, September 1986.

STREAMFLOW

For surface water resources management, accurate measurement of streamflow data for each stream system is necessary. Streamflows for the stream systems on the Cimarron River were estimated from streamflow data measured and published by the United States Geological Survey (USGS). Flows are subject to change in the future due to changing variables such as land use, lower groundwater levels, change in climate, etc.

Stream System 2-9-4

Streamflow data from the Kenton gage was used to determine streamflows in Stream System 2-9-4. Gage 07154500 on the Cimarron River near Kenton, OK, has a total drainage area of 1,106 square miles (mi^2), but only 1,038 mi^2 contribute to streamflows. The streamflows have been recorded continuously from October 1950 to the current year.

Data from water year 1951 through water year 1985 for the gage was used to estimate streamflows: (1) at the upper limits of the stream system, the New Mexico-Oklahoma State line; (2) for Carrizo Creek at its confluence with the Cimarron River; (3) on the Cimarron River below the confluence of Carrizo Creek; (4) inflows into Lake Etling; and (5) at the lower limits of the stream system, the Oklahoma-Colorado State line. The data were used in the following formula:

$$Q = Q_k \times (A/1{,}038 \text{ mi}^2)$$

Where:

Q_k = Flows at Kenton gage.

A = Contributing drainage area in mi^2 for (1) 867, (2) 165, (3) 1,033, (4) 42 and (5) 2,135.

Average annual streamflow at the upper limits of Stream System 2-9-4 was 17.1 cubic feet per second (cfs) with a standard deviation of 17.3 cfs. Maximum average annual streamflow was 79.4 cfs, and the minimum average annual streamflow was 1.1 cfs. The average annual streamflow for the Cimarron River at the lower limits of Stream System 2-9-4 was 42.2 cfs with a standard deviation of 43.5 cfs. The maximum average annual streamflow was 195.0 cfs; the minimum, 2.7 cfs.

The monthly mean and the annual distribution of streamflows in Stream System 2-9-4 are listed in Tables 8 and 9, respectively, and are shown graphically in Figures 6 and 7.

TABLE 8. MONTHLY MEAN STREAMFLOWS FOR STREAM SYSTEM 2-9-4 (CFS)

Water Month	Upper Limit	Carrizo Creek at River	River below Carrizo C.	Gage 07154500	Inflows into L. Etling	Lower Limit
January	1.69	0.32	2.01	2.02	0.08	4.16
February	1.58	0.30	1.89	1.90	0.08	3.90
March	1.31	0.25	1.55	1.55	0.06	3.22
April	5.62	1.07	6.69	6.73	0.27	13.83
May	32.69	6.22	38.95	39.14	1.59	80.50
June	34.32	6.53	40.89	41.09	1.66	84.52
July	32.51	6.19	38.73	38.92	1.58	80.04
August	53.58	10.20	63.84	64.15	2.60	131.94
September	26.83	5.11	31.97	32.12	1.30	66.07
October	11.49	2.19	13.69	13.75	0.56	28.28
November	1.79	0.34	2.13	2.14	0.09	4.41
December	1.89	0.36	2.25	2.26	0.09	4.65

Source of Data: U.S. Geological Survey, Water Resources Data for Oklahoma.

Stream System 2-9-3

Streamflow data from one tributary and three main stem gages were used to determine streamflows for Buffalo Creek and the Cimarron River in Stream System 2-9-3.

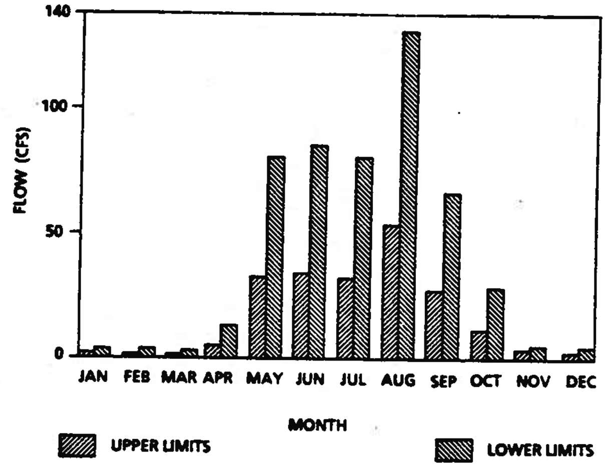
Gage 07157000 on the Cimarron River near Mocane, OK, has a total drainage area of 8,670 mi^2 of which 4,305 mi^2 contribute to flows. Flows were recorded continuously from October 1942 until September 1965 when the gage was discontinued. Its flows were used as streamflows where the river crosses the Kansas-Oklahoma State line west of the gage. These flows were also used to compute streamflows at the State line east of the gage (Q_{ok}) with the following formula:

TABLE 9. ANNUAL STREAMFLOWS FOR STREAM SYSTEM 2-9-4 (CFS)

Water Year	Upper Limit	Carrizo Creek at River	River below Carrizo C.	Kenton Gage 07154500[4]	Inflows into L. Etling	Lower Limit
1951	15.6	3.0	18.6	18.7	0.7	38.5
1952	7.8	1.5	9.2	9.3	0.4	19.1
1953	21.1	4.0	25.2	25.3	1.0	52.0
1954	24.8	4.7	29.6	29.7	1.2	61.1
1955	53.9	10.2	64.2	64.5	2.6	132.7
1956	18.7	3.6	22.3	22.4	0.9	46.1
1957	17.6	3.4	21.0	21.1	0.8	43.4
1958	20.5	3.9	24.4	24.5	1.0	50.4
1959	4.3	0.8	5.2	5.2	0.2	10.7
1960	5.1	1.0	6.1	6.1	0.2	12.5
1961	13.5	2.6	16.1	16.2	0.6	33.3
1962	3.8	0.7	4.5	4.5	0.2	9.2
1963	36.8	7.0	43.9	44.1	1.8	90.7
1964	4.1	0.8	4.9	4.9	0.2	10.1
1965	79.4	15.1	94.6	95.1	3.8	195.6
1966	51.3	9.8	61.1	61.4	2.4	126.3
1967	17.4	3.3	20.8	20.9	0.8	43.0
1968	14.5	2.7	16.9	17.0	0.7	35.0
1969	16.8	3.2	20.0	20.1	0.8	41.3
1970	2.9	0.6	3.5	3.5	0.1	7.2
1971	2.8	0.5	3.3	3.3	0.1	6.8
1972	8.9	1.7	10.6	10.7	0.4	22.0
1973	10.7	2.0	12.7	12.8	0.5	26.3
1974	4.2	0.8	5.1	5.1	0.2	10.5
1975	1.1	0.2	1.3	1.3	0.1	2.7
1976	10.0	1.9	11.9	12.0	0.5	24.7
1977	56.7	10.8	67.8	68.1	2.7	140.1
1978	21.7	4.1	25.9	26.0	1.0	53.5
1979	8.7	1.6	10.3	10.4	0.4	21.4
1980	1.2	0.2	1.4	1.4	0.1	2.9
1981	15.4	2.9	18.3	18.4	0.7	37.8
1982	10.8	2.1	12.9	13.0	0.5	26.7
1983	6.7	1.3	8.0	8.0	0.3	16.4
1984	5.8	1.1	7.0	7.0	0.7	14.4
1985	4.2	0.8	5.0	5.0	0.2	10.3
Mean	17.1	3.2	20.4	20.5	0.8	42.1
Std Dev.	17.7	3.4	21.1	21.2	0.8	43.7

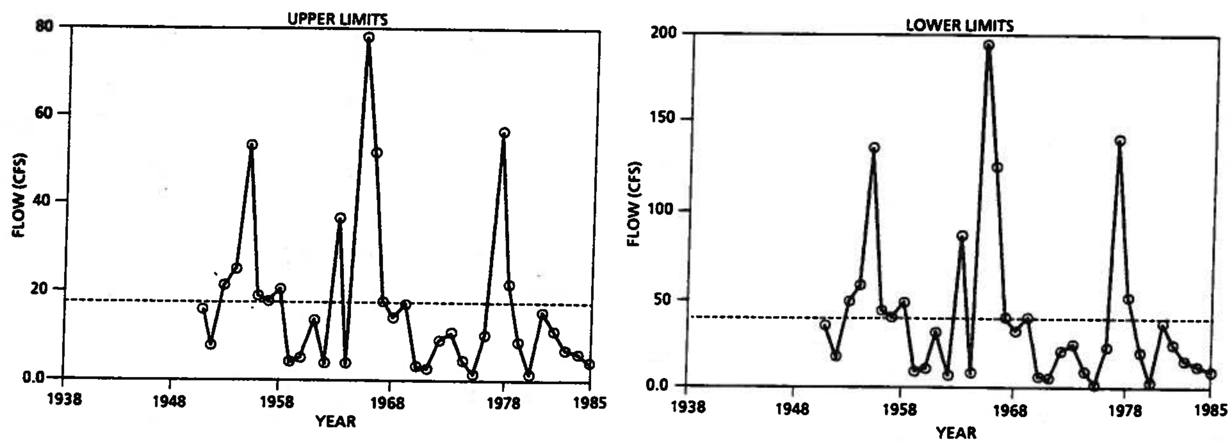
Source of Data: U.S. Geological Survey, Water Resources Data for Oklahoma.

[4] Cimarron River near Kenton, Oklahoma.



Source of Data: U.S. Geological Survey, Water Resources Data for Oklahoma.

FIGURE 6. Monthly Mean Streamflows for Stream System 2-9-4.



Source of Data: U.S. Geological Survey, Water Resources Data for Oklahoma.

FIGURE 7. Annual Streamflows for Stream System 2-9-4.

$$Q_{ok} = Q_m \times (A_{ok}/A_m)$$

Where:

Q_m = Annual or monthly mean streamflow at the Mocane gage.
A_{ok} = Contributing drainage area at the Oklahoma-Kansas State line east of the gage (see Table 1).
A_m = Contributing drainage area at the Mocane gage.

Flows from the Buffalo gage were used in a formula similar to the one above to determine streamflows for the Cimarron River at the Kansas-Oklahoma State line and below the confluence of Buffalo Creek. Gage 07157950 on the Cimarron River near Buffalo, OK, has a total drainage area of 12,004 mi^2 with only 7,191 mi^2 contributing to the gage flows recorded continuously from May 1960 to the current year.

Flows on Buffalo Creek at its confluence with the Cimarron River were determined by using flows from Gage 07157960 on Buffalo Creek near Lovedale, OK, in a formula similar to the above. The gage has a drainage area of 408 mi^2 and flows have been recorded since August 1966.

Flows from Gage 07158000 on the Cimarron River near Waynoka, OK, were used as streamflows for the lower limit of Stream System 2-9-3. The gage has a drainage area of 13,334 mi^2 of which 8,504 mi^2 contribute to gage flows. The flows have been recorded continuously since October 1937.

Average annual streamflow at the upper limits of Stream System 2-9-3 was 100 cfs with a standard deviation of 43 cfs. Maximum average annual streamflow was 200 cfs, and the minimum average annual streamflow was 57 cfs. Where the river crosses state lines, the Oklahoma-Kansas and the Kansas-Oklahoma, the average annual streamflows were 126 and 134 cfs with standard deviations of 54 and 76, respectively. Maximum average annual streamflows were 251 and 419 cfs, and minimum average annual streamflows were 71 and 41 cfs, respectively. The average annual streamflow for the Cimarron River at the lower limits of Stream System 2-9-3 was 319 cfs with a standard deviation of 253 cfs. The maximum average annual streamflow was 1,075 cfs; the minimum, 47 cfs.

The monthly mean and the annual distribution of streamflows in Stream System 2-9-3 are listed in Tables 10 and 11, respectively, and are shown graphically in Figures 8 and 9.

Stream System 2-9-2

Streamflow data from three tributary and two mainstem gages were used to determine streamflows for Eagle Chief, Turkey, Kingfisher and Cottonwood Creeks and the Cimarron River in Stream System 2-9-2.

Data from the Waynoka gage previously discussed were used as streamflows for the river at the upper limits of the stream system. The flows were also used in a formula similar to that in Stream System 2-9-3 to determine the streamflows below the confluence of Eagle Chief Creek.

TABLE 10. MONTHLY MEAN STREAMFLOWS FOR STREAM SYSTEM 2-9-3 (CFS)

Month	Upper Limit[5]	OK-KS Line	KS-OK Line	Gage 7157950[6]	Gage 7157960[7]	Buffalo Creek	Below Buffalo Creek	Lower Limit[8]
Jan	77	96	90	92	2.82	3.15	98	120
Feb	83	104	121	125	3.49	3.89	132	179
Mar	76	95	187	192	9.88	11.02	204	228
Apr	85	107	159	164	13.96	15.56	174	387
May	187	234	200	205	30.52	34.03	218	868
Jun	156	195	255	262	9.51	10.61	278	668
Jul	107	134	94	97	6.95	7.75	103	377
Aug	123	154	92	95	15.67	17.47	101	249
Sep	76	95	147	151	10.44	11.64	160	285
Oct	84	105	96	99	9.95	11.10	105	237
Nov	78	97	88	90	3.63	4.05	96	120
Dec	75	93	87	90	3.40	3.79	95	110

Source of Data: U.S. Geological Survey, Water Resources Data for Oklahoma.

[5] Gage 07157000 on the Cimarron River near Mocane, OK

[6] On the Cimarron River near Buffalo, OK

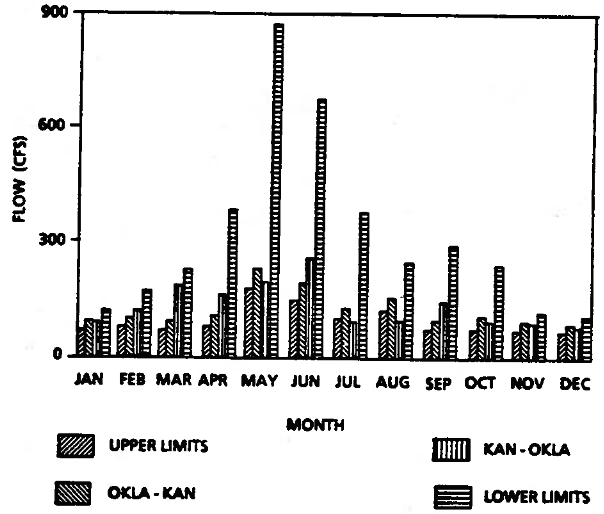
[7] On Buffalo Creek near Lovedale, OK

[8] Gage 07158000 on the Cimarron River near Waynoka, OK

TABLE 11. ANNUAL STREAMFLOWS FOR STREAM SYSTEM 2-9-3 (CFS)

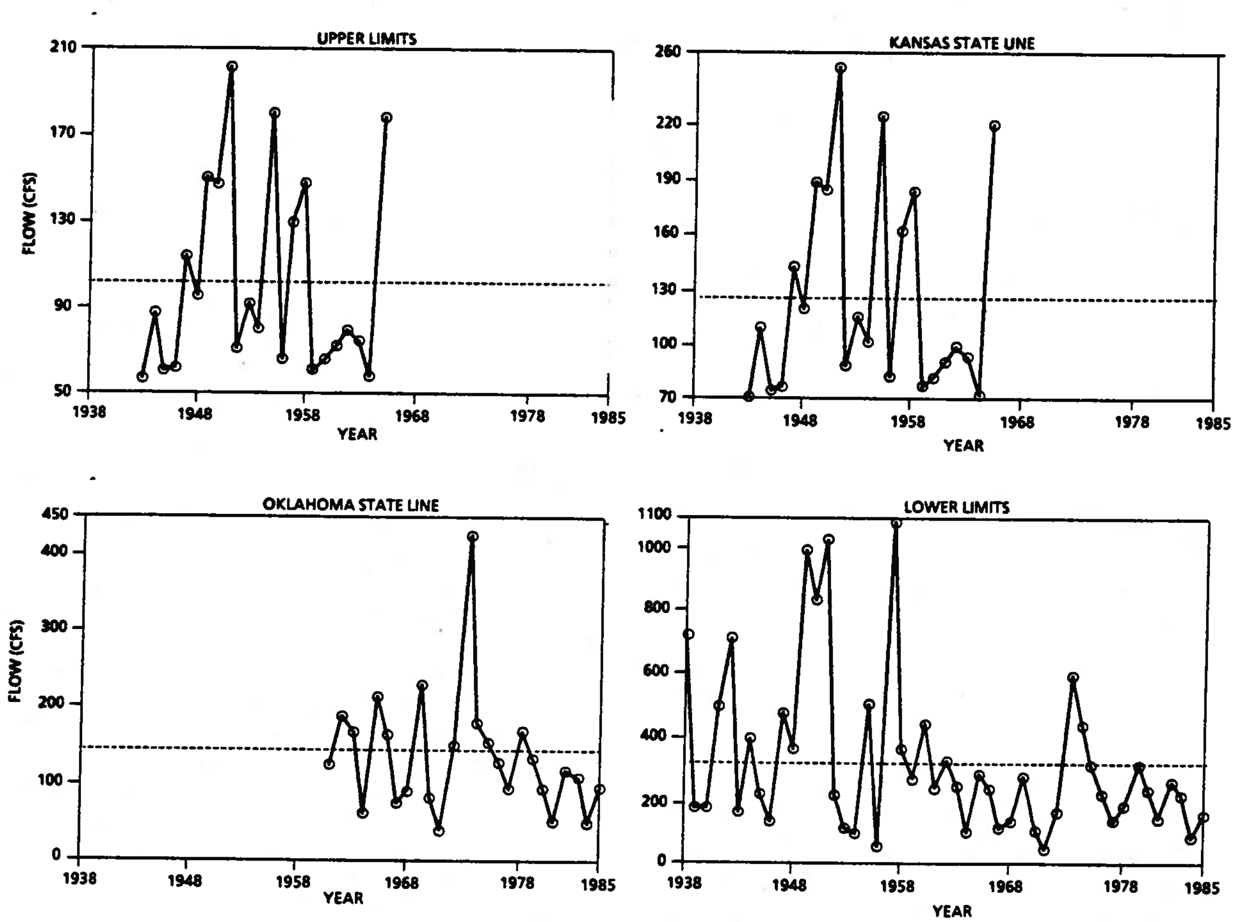
Year	Upper Limit	OK-KS Line	KS-OK Line	Gage 7157950	Gage 7157960	Buffalo Creek	Below Creek	Lower Limit
1938	--	--	--	--	--	--	--	722
1939	--	--	--	--	--	--	--	174
1940	--	--	--	--	--	--	--	176
1941	--	--	--	--	--	--	--	489
1942	--	--	--	--	--	--	--	706
1943	57	71	--	--	--	--	--	169
1944	87	109	--	--	--	--	--	397
1945	60	75	--	--	--	--	--	223
1946	62	77	--	--	--	--	--	130
1947	113	141	--	--	--	--	--	465
1948	95	118	--	--	--	--	--	354
1949	149	187	--	--	--	--	--	989
1950	145	182	--	--	--	--	--	820
1951	200	251	--	--	--	--	--	1,018
1952	71	89	--	--	--	--	--	212
1953	91	114	--	--	--	--	--	107
1954	80	100	--	--	--	--	--	94
1955	178	223	--	--	--	--	--	500
1956	66	82	--	--	--	--	--	53
1957	128	160	--	--	--	--	--	1,075
1958	145	182	--	--	--	--	--	355
1959	61	77	--	--	--	--	--	259
1960	66	82	--	--	--	--	--	428
1961	71	89	124	128	--	--	136	230
1962	78	98	187	192	--	--	205	320
1963	74	92	166	171	--	--	181	240
1964	58	73	66	67	--	--	72	90
1965	175	219	211	217	--	--	231	281
1966	--	--	161	165	--	--	176	232
1967	--	--	75	77	14	16	82	111
1968	--	--	90	92	13	15	98	132
1969	--	--	225	231	7	8	246	263
1970	--	--	82	84	1	1	90	107
1971	--	--	41	42	1	1	44	47
1972	--	--	150	154	3	3	164	157
1973	--	--	419	430	10	137	457	589
1974	--	--	178	183	35	39	194	429
1975	--	--	151	155	17	19	165	309
1976	--	--	127	130	13	14	139	214
1977	--	--	92	95	4	4	101	133
1978	--	--	167	171	3	3	182	174
1979	--	--	133	137	22	24	145	302
1980	--	--	95	98	11	12	104	224
1981	--	--	50	52	10	12	55	135
1982	--	--	115	119	8	9	126	243
1983	--	--	108	111	5	6	118	214
1984	--	--	52	53	2	2	57	81
1985	--	--	100	103	12	14	110	147
MEAN	100	126	134	138	10	11	147	319
STD DEV	43	54	76	78	8	9	83	253

Source of data: U.S. Geological Survey, Water Resources for Oklahoma.



Source of Data: U.S. Geological Survey, Water Resources Data for Oklahoma.

FIGURE 8. Monthly Mean Streamflows for Stream System 2-9-3.



Source of Data: U.S. Geological Survey, Water Resources Data for Oklahoma.

FIGURE 9. Annual Streamflows for Stream System 2-9-3.

Data from water year 1948 through water year 1970 for the Drummond gage were used to estimate streamflows at the confluences of Eagle Chief, Turkey and Kingfisher Creeks. Gage 07159000 on Turkey Creek near Drummond, OK, has a drainage area of 248 mi^2 and flows recorded continuously from October 1947 to September 1970. The 507 mi^2 drainage area of Kingfisher Creek is reduced to an effective drainage area of 420 mi^2 by 12 SCS structures controlling 87 mi^2 of drainage area.

Streamflows at the confluence of Cottonwood Creek were determined from Gage 07160500 on Skeleton Creek near Lovell, OK. The Lovell gage measures flows on 410 mi^2 of the 622 mi^2 Skeleton Creek Basin and has continuous records since October 1949. Subtracting drainage areas of 9.69, 11.4 and 12.7 mi^2 for Lake Hefner, Liberty and Guthrie Lakes, respectively, and 61 mi^2 for 16 SCS structures from 380 mi^2 leaves an effective drainage area of 285 mi^2 for the Cottonwood Creek Basin.

Flows from the Guthrie gage were used to determine streamflows for the river below the confluences of Turkey, Kingfisher and Cottonwood Creeks and were used as streamflows for the lower limits of the stream system. Gage 07160000 on the Cimarron River near Guthrie, OK, has a total drainage area of 16,892 mi^2, but only 11,966 mi^2 contribute to the gage flows. Drainage area controlled by SCS and city lakes in the Kingfisher and Cottonwood Creek Basins produces an effective drainage area of 11,784 mi^2 at the gage. The effective drainage area of the Cimarron River below the confluence of Kingfisher Creek is 11,214 mi^2 and of Cottonwood Creek, 11,782 mi^2. Streamflows at the gage have been recorded continuously from October 1937 to October 1976 and October 1983 to the current year with monthly discharge only for some months.

The average annual streamflow, standard deviation, maximum and minimum average annual streamflows at the upper limits of Stream System 2-9-2 is the same as at the lower limits of Stream System 2-9-3. Subtracting the average annual streamflow of creeks from the average annual streamflow of the Cimarron River below the confluence of the creeks leaves the following average annual streamflows in the Cimarron River: (1) 94 cfs of Eagle Chief Creek leaves 256 cfs; (2) 84 cfs of Turkey Creek leaves 723 cfs; (3) 83 cfs of Kingfisher Creek leaves 756 cfs; and (4) 81 cfs of Cottonwood Creek leaves 801 cfs. The standard deviations were not computed but could be assumed to be proportional to the standard deviations computed for the combined streamflows below the confluences. The average annual streamflow for the Cimarron River at the lower limits of Stream System 2-9-2 was 882 cfs with a standard deviation of 622 cfs. The maximum average annual streamflow was 2,485 cfs; the minimum, 190 cfs.

The monthly mean and the annual distribution of streamflows in Stream System 2-9-2 are listed in Tables 12 and 13, respectively, and are shown graphically in Figures 10 and 11.

TABLE 12. MONTHLY MEAN STREAMFLOWS FOR STREAM SYSTEM 2-9-2 (CFS)

Month	Upper Limit[9]	Eagle Chief Creek	Below Creek	Gage 07159000[10]	Turkey Creek	Below Creek	Kingfisher Creek	Below Creek	Gage 07160500[11]	Cottonwood Creek	Below Creek	Lower Limit[12]
January	120	21	132	11	19	262	18	273	30	21	286	286
February	179	43	196	22	38	405	37	421	63	44	443	443
March	228	27	250	14	24	607	24	631	107	74	663	664
April	387	79	425	41	70	1,109	69	1,153	101	70	1,212	1,212
May	868	290	953	150	259	2,079	254	2,161	372	259	2,271	2,271
June	668	258	733	133	230	1,683	225	1,750	210	146	1,838	1,839
July	377	110	414	57	98	773	96	804	101	70	845	845
August	249	86	274	44	76	495	75	514	52	36	540	540
September	285	57	313	30	51	726	50	754	110	76	793	793
October	237	80	261	42	72	776	70	806	132	92	847	847
November	120	71	132	37	63	504	62	524	83	58	551	551
December	110	12	121	6	11	266	11	277	30	21	291	291

Source of Data: U.S. Geological Survey, Water Resources Data for Oklahoma

[9] Gage 07158000 on the Cimarron River near Waynoka, OK. Also lower limit of Stream System 2-9-3.

[10] On Turkey Creek near Drummond, OK.

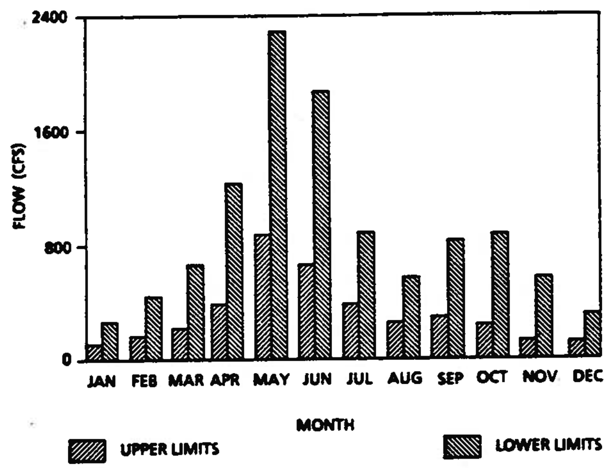
[11] On Skelton Creek at Lowell, OK.

[12] Gage 07160000 on the Cimarron River near Guthrie, OK.

TABLE 13. ANNUAL STREAMFLOWS FOR STREAM SYSTEM 2-9-2 (CFS)

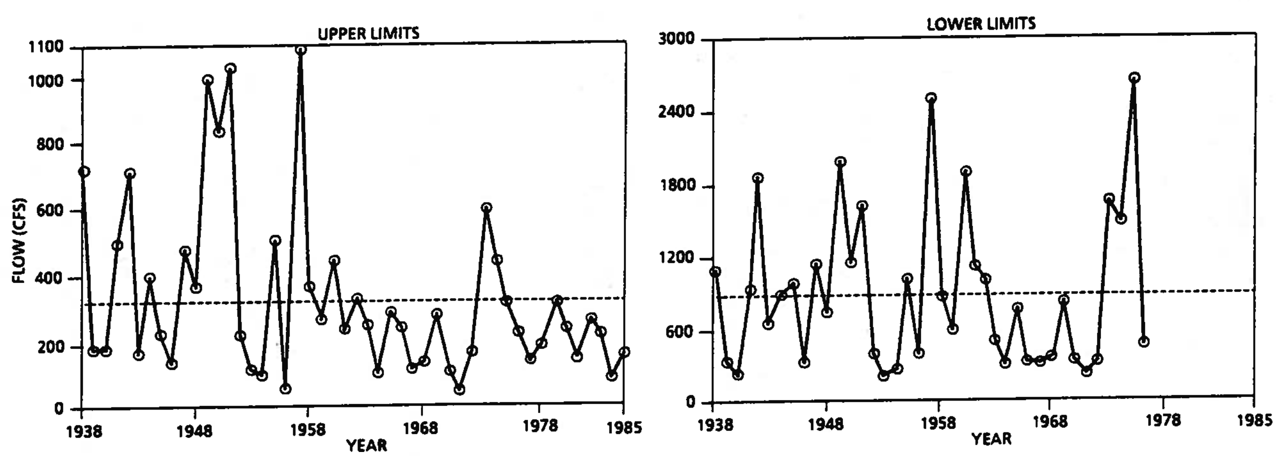
Year	Upper Limit	Eagle Chief Creek	Below Creek	Gage 07159000	Turkey Creek	Below Creek	Kingfisher Creek	Below Creek	Gage 07160500	Cottonwood Creek	Below Creek	Lower Limit
1938	722	--	793	--	--	1,002	--	1,042	--	--	1,094	1,095
1939	174	--	191	--	--	304	--	316	--	--	332	332
1940	176	--	193	--	--	223	--	232	--	--	243	243
1941	489	--	537	--	--	859	--	893	--	--	938	938
1942	706	--	776	--	--	1,687	--	1,754	--	--	1,843	1,844
1943	169	26	185	--	--	590	--	614	--	--	644	645
1944	397	257	436	--	--	801	--	833	--	--	875	876
1945	223	196	244	--	--	890	--	925	--	--	972	972
1946	130	169	142	--	--	304	--	316	--	--	332	332
1947	465	11	511	--	--	1,019	--	1,060	--	--	1,113	1,113
1948	354	13	389	14	23	663	23	689	--	--	724	724
1949	989	12	1,086	133	229	1,782	225	1,853	--	--	1,947	1,948
1950	820	119	900	101	175	1,063	172	1,106	132	92	1,162	1,162
1951	1,018	21	1,118	87	151	1,472	148	1,530	88	61	1,608	1,608
1952	212	345	233	6	10	335	10	349	18	12	366	366
1953	107	22	118	7	12	174	11	181	17	12	190	190
1954	94	27	103	6	10	234	10	243	26	18	255	255
1955	500	290	549	62	106	921	104	957	180	126	1,006	1,006
1956	53	107	59	11	19	348	18	362	64	44	380	380
1957	1,075	107	1,180	178	308	2,607	302	2,707	431	300	2,844	2,485
1958	355	63	390	11	20	781	19	812	69	48	853	853
1959	259	34	285	14	24	518	24	538	49	34	565	565
1960	428	116	470	150	259	1,697	254	1,765	314	218	1,854	1,854
1961	230	8	253	55	96	1,049	94	1,090	159	111	1,146	1,146
1962	320	35	351	55	95	961	94	999	97	68	1,050	1,050
1963	239	27	262	32	56	459	55	477	90	62	502	502
1964	90	127	99	18	30	298	30	310	57	40	326	326
1965	281	40	309	60	104	701	102	729	80	55	766	766
1966	232	--	254	4	7	309	7	321	25	18	337	337
1967	111	--	122	18	31	319	31	332	42	29	348	348
1968	132	--	144	14	24	351	24	365	54	38	384	384
1969	263	--	289	66	113	746	111	776	140	98	815	815
1970	107	--	117	21	36	316	35	329	20	14	345	345
1971	47	--	51	--	--	214	--	223	20	14	234	234
1972	157	--	172	--	--	312	--	324	33	23	341	341
1973	589	--	647	--	--	1,505	--	1,565	178	124	1,644	1,644
1974	429	--	471	--	--	1,340	--	1,393	342	238	1,464	1,464
1975	308	--	339	--	--	1,901	--	1,976	426	296	2,076	2,077
1976	214	--	235	--	--	422	--	439	44	31	462	462
1977	132	--	146	--	--	--	--	--	73	51	--	--
1978	174	--	191	--	--	--	--	--	44	31	--	--
1979	302	--	331	--	--	--	--	--	87	61	--	--
1980	224	--	246	--	--	--	--	--	211	147	--	--
1981	135	--	148	--	--	--	--	--	35	24	--	--
1982	243	--	266	--	--	--	--	--	165	114	--	--
1983	214	--	235	--	--	--	--	--	154	107	--	--
1984	81	--	88	--	--	--	--	--	115	80	--	--
1985	147	--	161	--	--	--	--	--	95	66	--	--
MEAN	319	94	350	49	84	807	83	839	116	81	882	872
STD DEV	253	95	278	49	85	570	84	592	107	75	622	595

Source of data: U.S. Geological Survey, Water Resources for Oklahoma



Source of Data: U.S. Geological Survey. Water Resources Data for Oklahoma.

FIGURE 10. Monthly Mean Streamflows for Stream System 2-9-2.



Source of Data: U.S. Geological Survey. Water Resources Data for Oklahoma.

FIGURE 11. Annual Streamflows for Stream System 2-9-2.

Stream System 2-9-1

Streamflows for and within Stream System 2-9-1 were determined from data from one tributary and two mainstem gages.

Data from the previously described Lovell gage on Skelton Creek were used to estimate streamflows at the creek's confluence. The gage on Council Creek was used to estimate streamflows at the confluence of Stillwater Creek. Gage 07163000 on Council Creek near Stillwater, OK, has a drainage area of 31 mi^2 and flows recorded continuously from March 1934 to the current year. Lake Carl Blackwell and Boomer Lake control 85 mi^2, and 29 SCS structures control 61 mi^2 of drainage area which reduces the 282 mi^2 drainage area of Stillwater Creek Basin to an effective drainage area of 136 mi^2.

Data from the Guthrie gage were used as streamflows for the river at the upper limits of the stream system and were used in a formula similar to the one in Stream System 2-9-3 to determine the streamflows below the confluence of Skelton Creek. Flows from the Perkins gage were used to determine streamflows for the river below the confluences of Stillwater Creek and inflows into Lake Keystone at the lower limit of the stream system. Gage 07161000 on the Cimarron River near Perkins, OK, has a total drainage area of 17,852 mi^2, but only 12,926 mi^2 contribute to the gage flows. This drainage area is further reduced by SCS and city lakes upstream to an effective drainage area of 12,774 mi^2 at the gage. The effective drainage areas of the Cimarron River below the confluences of Skelton and Stillwater Creeks and at Lake Keystone are 12,433, 13,010 and 13,673 mi^2, respectively. Streamflows at the gage have been recorded continuously from October 1939 to the present with monthly discharge only for some months.

The average annual streamflow, standard deviation, maximum and minimum average annual streamflows at the upper limits of Stream System 2-9-1 are the same as at the lower limits of Stream System 2-9-2. Subtracting the average annual streamflows of 176 cfs for Skelton and 50 cfs for Stillwater Creeks from the average annual streamflow of the Cimarron River leaves average annual streamflows of 754 cfs and 1,166 cfs below their confluences with the Cimarron River. The standard deviations were not computed but could be assumed to be proportional to the standard deviations computed for the combined streamflows below the confluences. The average annual inflow into Lake Keystone for the Cimarron River at the lower limits of Stream System 2-9-1 was 1,278 cfs with a standard deviation of 886 cfs. The maximum average annual streamflow was 3,889 cfs; the minimum, 250 cfs.

The monthly mean and the annual distribution of streamflows in Stream System 2-9-1 are listed in Tables 14 and 15, respectively, and are shown graphically in Figures 12 and 13.

TABLE 14. MONTHLY MEAN STREAMFLOWS FOR STREAM SYSTEM 2-9-1 (CFS)

Month	Upper Limit[13]	Skeleton Creek	Below Creek	Gage 7161000[14]	Stillwater Creek	Below Creek	Gage 7163000[15]	Lower Limit[16]
Jan	286	46	302	392	17	400	4	420
Feb	443	96	467	634	28	648	6	681
Mar	664	162	700	959	53	979	12	1,029
Apr	1,212	154	1,278	1,569	68	1,602	16	1,683
May	2,271	565	2,396	3,292	113	3,361	26	3,532
Jun	1,839	319	1,940	2,475	86	2,526	20	2,655
Jul	845	154	891	1,040	45	1,062	10	1,116
Aug	540	79	570	605	24	617	5	649
Sep	793	166	836	1,003	44	1,024	10	1,076
Oct	847	201	894	1,138	69	1,162	16	1,221
Nov	551	127	581	778	34	794	8	834
Dec	291	45	307	412	17	420	4	442

Source of Data: U.S. Geological Survey, Water Resources Data for Oklahoma.

[13] Gage 07160000 on the Cimarron River near Guthrie, OK. This is also the lower limits of Stream System 2-9-2.

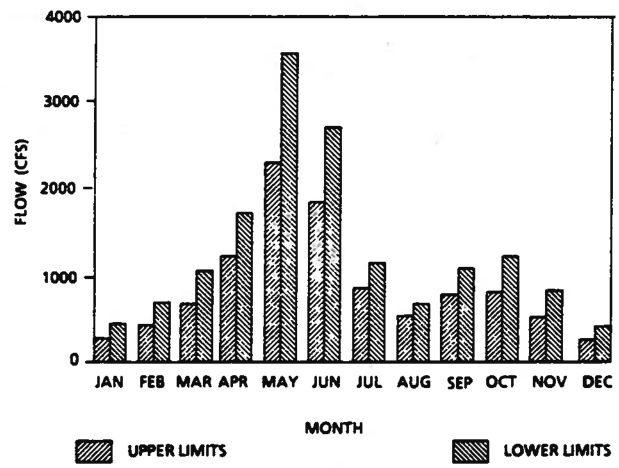
[14] On the Cimarron River at Perkins, OK.

[15] On Council Creek near Stillwater, OK.

[16] Average annual inflows into the Cimarron arm of Lake Keystone near Tulsa, OK.

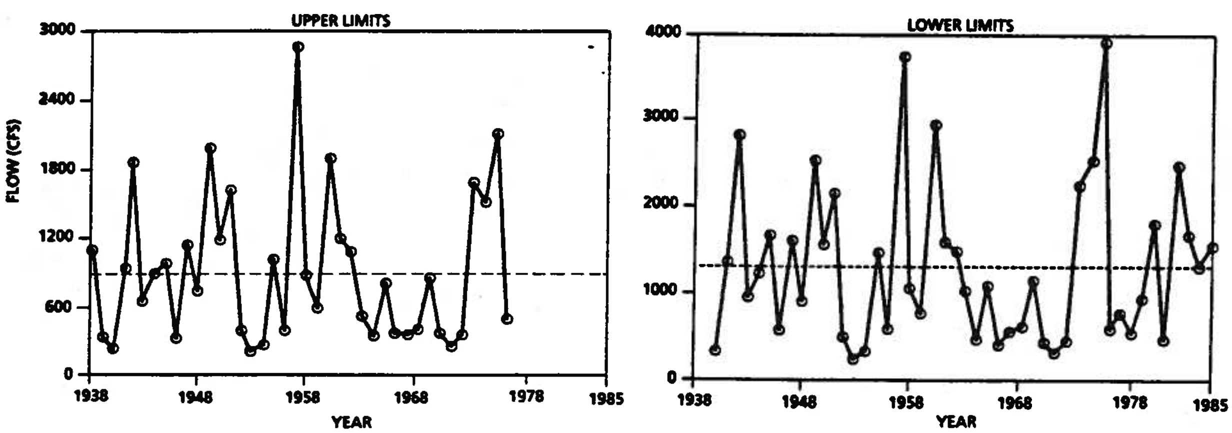
TABLE 15. ANNUAL STREAMFLOWS FOR STREAM SYSTEM 2-9-1 (CFS)

Year	Upper Limit	Skeleton Creek	Below Creek	Gage 07161000	Stillwater Creek	Below Creek	Gage 07163000	Lower Limit
1935	--	--	--	--	28	--	6	--
1936	--	--	--	--	6	--	1	--
1937	--	--	--	--	13	--	3	--
1938	1,095	--	1,155	--	43	--	10	--
1939	332	--	350	--	7	--	2	--
1940	243	--	257	306	7	313	2	329
1941	938	--	990	1,253	42	1,280	10	1,345
1942	1,844	--	1,945	2,605	203	2,659	46	2,794
1943	645	--	680	872	90	891	21	936
1944	876	--	924	1,115	72	1,138	16	1,196
1945	972	--	1,026	1,511	66	1,543	15	1,622
1946	334	--	350	521	39	532	9	559
1947	1,114	--	1,175	1,478	44	1,508	10	1,585
1948	724	--	764	821	51	838	13	881
1949	1,948	--	2,055	2,323	41	2,371	9	2,492
1950	1,162	201	1,226	1,436	45	1,466	10	1,541
1951	1,608	134	1,697	1,972	29	2,014	7	2,116
1952	366	27	387	454	33	464	8	487
1953	190	26	201	233	15	238	3	250
1954	255	39	269	304	9	310	2	326
1955	1,006	274	1,061	1,341	14	1,369	3	1,438
1956	380	97	401	537	3	548	1	576
1957	2,845	654	3,002	3,438	86	3,510	20	3,689
1958	853	105	900	951	33	971	8	1,020
1959	566	74	597	698	120	713	27	749
1960	1,854	477	1,956	2,693	212	2,749	48	2,889
1961	1,146	242	1,209	1,451	71	1,482	16	1,557
1962	1,050	148	1,108	1,349	70	1,378	16	1,448
1963	502	136	529	931	36	950	8	999
1964	326	87	344	424	12	433	3	455
1965	766	121	808	988	54	1,009	12	1,060
1966	337	38	356	371	12	379	3	398
1967	348	63	368	516	12	527	3	554
1968	384	83	405	550	47	561	11	590
1969	815	213	860	1,053	22	1,075	5	1,130
1970	345	31	364	397	19	406	4	426
1971	234	31	247	295	17	302	4	317
1972	341	50	360	438	8	947	2	470
1973	1,644	270	1,735	2,038	79	2,081	18	2,187
1974	1,464	519	1,545	2,302	70	2,350	16	2,470
1975	2,077	646	2,191	3,625	201	3,700	46	3,889
1976	462	66	487	549	8	560	2	589
1977	--	111	--	714	19	729	4	766
1978	--	68	--	525	21	536	5	563
1979	--	132	--	880	42	898	10	944
1980	--	321	--	1,657	65	1,691	15	1,778
1981	--	52	--	454	7	463	2	487
1982	--	250	--	2,263	71	2,310	16	2,427
1983	--	233	--	1,533	33	1,565	8	1,645
1984	--	174	--	1,214	52	1,239	12	1,302
1985	--	145	--	1,424	143	1,454	33	1,528
MEAN	882	176	930	1,191	50	1,216	11	1,278
STD DEV	622	163	656	826	49	844	11	886



Source of Data: U.S. Geological Survey. Water Resources Data for Oklahoma.

FIGURE 12. Monthly Mean Streamflows for Stream System 2-9-1.



Source of Data: U.S. Geological Survey. Water Resources Data for Oklahoma.

FIGURE 13. Annual Streamflows for Stream System 2-9-1.

MAJOR LAKES IN THE CIMARRON RIVER BASIN

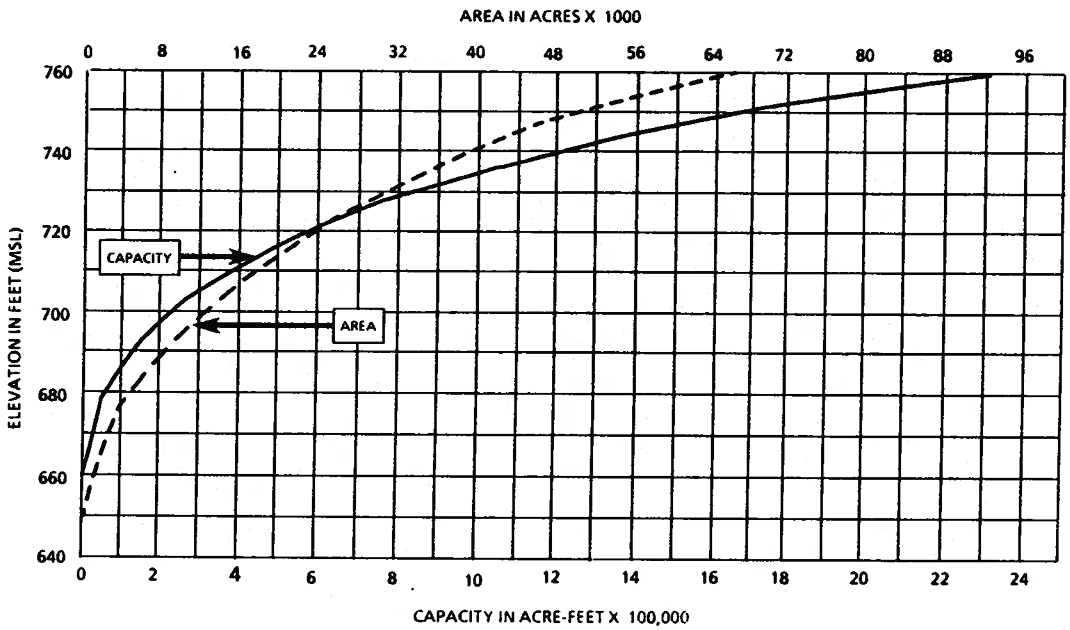
The stream systems on the Cimarron River contain only one major lake in addition to the city and SCS lakes already mentioned. The major reservoir is Keystone Lake at the lower limits of Stream System 2-9-1. The lake was placed in flood control operation in 1964 by the Corps of Engineers on the Arkansas River just below the mouth of the Cimarron River. Pertinent data for Keystone Lake are shown in Table 16, and its area-capacity curves are included as Figure 14.

TABLE 16. PERTINENT DATA FOR KEYSTONE LAKE IN STREAM SYSTEM 2-9-1

Purposes - Flood Control, water supply, hydropower, navigation and fish and wildlife

Drainage Area (square miles)	74,506 [17]
Flood Control Storage (acre-feet)	1,180,000
Power Storage (acre-feet)	296,700 [18]
Water Supply Yield (acre-feet/year)	22,400

Source of Data: U.S. Army Corps of Engineers, Tulsa District and Oklahoma Water Resources Board.



Source of Data: U.S. Army Corps of Engineers, Tulsa District.[19]

FIGURE 14. Area-Capacity Curves for Keystone Lake.

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[17] Contributing basin area is only 22,351 mi^2.

[18] Includes 20,000 acre-feet for water supply (20 mgd yield).

[19] Based on 1977 Sediment Survey, approved February 1982.

APPROPRIATED WATER

Appropriative categories for the stream systems are public water supply, power generation, irrigation, industrial, mining, recreation and fish and wildlife. Table 17 lists the total amounts of water appropriated in Stream Systems 2-9-1, 2-9-2, 2-9-3 and 2-9-4.

TABLE 17. STREAM WATER APPROPRIATED BY PURPOSE, ACRE-FEET PER YEAR

	Stream System			
Purpose	2-9-1	2-9-2	2-9-3	2-9-4
Public Water Supply	12,305	3,341	-	-
Irrigation	9,576	17,733	12,092	4,568
Industrial	5,481	718	-	-
Power Generation	1,165	-	-	-
Recreation, Fish and Wildlife	10,352	1,695	95	665
Agriculture (non-irrigation)	10	136	1	-
Mining	354	315	42	-
Commercial	-	458	10	-
Totals	39,243	24,396	12,240	5,233

Source of Data: Oklahoma Water Resources Board.

Irrigation and public water supply are the two largest users with recreation and fish and wildlife next in the stream systems on the Cimarron River in Oklahoma. Current appropriations for the Cimarron River Basin in Oklahoma show 54.3 percent allocated for irrigation, 19.3 percent for public water supply, 15.8 percent for recreation and fish and wildlife, 7.6 percent for industrial, 1.4 percent for hydropower, and 1.6 percent for mining, commercial and non-irrigational agriculture.

UNAPPROPRIATED WATER

Determining the amount of unappropriated water available in Stream Systems 2-9-4, 2-9-3, 2-9-2 and 2-9-1 is the main objective of this study. The criteria for determining the availability of water for appropriation is stated in "OWRB Rules, Regulations and Modes of Procedures, 1982":

> "As a general guide and criteria and absent evidence to the contrary, it shall be presumed that unappropriated water which is available, on an average annual basis, less than thirty-five (35) percent of the time is not and will not be deemed to constitute water available for appropriation through a 'regular' permit. Additionally and where deemed appropriate, the Board may issue regular permits allowing the taking of water based on streamflow or elevation."

The OWRB criteria for determining the percentage of availability of unappropriated water is accomplished by dividing the number of years that the selected average annual flow is equalled or exceeded by the total number of years in the period of record.

The data needed for this determination includes: streamflows, evaporation rates and amounts of appropriated water in each stream system, and the yield for the major reservoir in the region. These data combined with past records of reported water use are usually employed in the following equation to compute unappropriated water in each stream system:

$$Y_u = X_{sf} - (X_{ly} + X_{ev}) - X_{aw}$$

Where:

Y_u = Amount of unappropriated water.

X_{sf} = Amount of average annual streamflow available 35% or more of the time.

X_{ly} = Total of yield in each lake in the appropriate stream system.

X_{ev} = Annual evaporation loss with pool at top of conservation pool for lakes in the stream system.

X_{aw} = Amount of appropriated water used in the stream.

Specific assumptions were made for each stream system; therefore, not all of the above variables were included in the calculations. These assumptions were predicted on factors such as whether or not lakes are in the stream system, the location of the lake in the stream system, the length of time a lake has been in operation, and the amount of appropriated water utilized annually. The annual evaporation loss should be used only if evaporation was not used or was not known to have been used in the determination of the yield from the lake.

According to the terms of most water permits, the portion of appropriated water not used within a seven-year period would become available to other prospective users. To determine the amount of unappropriated water in this study, it was assumed that all the appropriated water is being used.

Stream System 2-9-4

All the assumptions stated above involve intra-state variables affecting the amount of unappropriated water. However, Stream System 2-9-4 has streamflow augmented by flows from drainage areas in New Mexico, Colorado and Kansas. See Figure 1. Oklahoma has no agreement with New Mexico and Colorado, but does have a compact with Kansas. For this study, the Kansas-Oklahoma Compact gives the State of Kansas free and unrestricted use of the water of the Cimarron River Basin within Kansas.

The average annual flow at the upper limit is 17.1 cfs and is exceeded 12 out of 35 years or 34 percent of the time (see Table 9). A flow of 16.8 cfs is exceeded 37 percent of the time.

The average annual inflow for the lower limit is 42.2 cfs. An inflow of 41.3 cfs is available 13 out of 35 years of record or 37 percent of the time (see Table 9). To determine the water available for appropriation, the following calculations were made:

$$41.3 \text{ cfs} - 16.8 \text{ cfs} = 24.5 \text{ cfs}$$

The total lower limit drainage area for Stream System 2-9-4 in Oklahoma is 782 mi^2. The total drainage area at the lower limit of Stream System 2-9-4, including Oklahoma, Kansas, Colorado and New Mexico, is 2,135 mi^2. The amount of 24.5 must be modified by the drainage area ratio:

$$[(782 \text{ mi}^2/(2{,}135 \text{ mi}^2\text{-}867 \text{ mi}^2)](24.5 \text{ cfs}) = 15.1 \text{ cfs}$$

The 15.1 cfs is converted to 10,932 AF/Yr.

Lake Etling's yield was estimated based on a drainage area ratio for a similar lake under construction near Spearman, Texas (7.8 mgd yield for 594 mi^2 drainage area)[20]. Based on a drainage area of 42 mi^2, Lake Etling's yield is determined from the following equation:

$$(42 \text{ mi}^2/594 \text{ mi}^2)(7.8 \text{ mgd}) = 0.55 \text{ mgd or } 615 \text{ AF/Yr.}$$

Table 17 shows that the total amount of appropriated water (X_{aw}) in Stream System 2-9-4 is 5,233 AF/Yr. Because the amounts of appropriated water at the locations within Stream System 2-9-4 are not available, the amounts of unappropriated water at various locations within the stream system could not be determined. Therefore, the amount of unappropriated water for Stream System 2-9-4 is determined from the equation below:

$$Y_u = 10{,}932 \text{ AF/Yr} - 615 \text{ AF/Yr} - 5{,}233 \text{ AF/Yr} = 5{,}084 \text{ AF/Yr}$$

[20] Canadian River Basin, Palo Duro Creek, Texas, Interim Survey Report and Environmental Impact Statement, March 1984.

Stream System 2-9-3

The contributing drainage areas for Stream System 2-9-3 lie partly in Kansas. Water available for appropriation for Oklahoma from the Oklahoma portions of the drainage areas were determined by computing the average annual streamflows at the following locations:

Kansas-Oklahoma State Line - Drainage area = 150 mi^2
Oklahoma-Kansas State Line - Drainage Area = 276 mi^2
Kansas-Oklahoma State Line - Drainage Area = 139 mi^2

Only the drainage area in Oklahoma contributes to streamflows to be appropriated by the State of Oklahoma. The average annual streamflow (X_{sf}) must be reduced by the ratio of the total drainage area of Stream System 2-9-3 to the contributing drainage area of the Cimarron River for each substream system. The following computations were made to determine the unappropriated water.

Average Annual Streamflow for Oklahoma at Upper Limits at Kansas-Oklahoma State Line, contributing drainage area from Stream System 2-9-3 = 150 mi^2

See Table 1
Contributing drainage area - Upper Limits at Kansas-Oklahoma State Line, USGS Gage near Mocane, OK - Stream System 2-9-3 = 4,305 mi^2

See Table 1
Contributing drainage Area - Lower Limits at Oklahoma-Colorado State Line, Stream System 2-9-4 = 2,135 mi^2

From previous discussion for Stream System 2-9-4
X_{sf}, Lower Limit = 41.3 cfs

See Table 11
X_{sf}, Stream System 2-9-3, Upper Limit = 100 cfs

Then,

$$X_{sf},\text{(KS-OK Line)} = [150\ mi^2/(4{,}305\ mi^2 - 2{,}135\ mi^2)]\ (100\ cfs - 41.3\ cfs) = 4.06\ cfs$$

Average Annual Streamflow for OK-KS State Line, contributing drainage area from Stream System 2-9-3 = 276 mi^2

See Table 1
Contributing drainage Area - OK-KS Line, Stream System 2-9-3 = 5,387 mi^2

See Table 1
Contributing drainage area - Upper Limits at KS-OK State Line, USGS Gage near Mocane, OK - Stream System 2-9-3 = 4,305 mi^2

See Table 11
X_{sf}, OK-KS State Line = 126 cfs

See Table 11
X_{sf}, Upper Limit = 100 cfs

Then,

X_{sf}(OK-KS Line) = [276 mi^2/(5,387 mi^2 - 4,305 mi^2)] (126 cfs - 100 cfs) = 6.63 cfs

Average Annual Streamflow for KS-OK State Line, contributing Drainage Area from Stream System 2-9-3 = 139 mi^2

See Table 1
Contributing drainage Area - KS-OK Line, Stream System 2-9-3, = 7,000 mi^2

See Table 1
Contributing drainage Area - OK-KS Line, Stream System 2-9-3, = 5,387 mi^2

See Table 11
X_{sf}, KS-OK State Line = 134 cfs

See Table 11
X_{sf}, OK-KS State Line = 126 cfs

Then,

X_{sf} (KS-OK Line) = (139 mi^2/(7,000 mi^2 - 5,387 mi^2)) (134 cfs - 126 cfs) = 0.69 cfs

Average Annual Streamflow for the Lower Limit, Stream System 2-9-3

The average flow at the Lower Limit is 319 cfs and was available 16 out of 48 years of record, or 33 percent of the time. See Table 11. A flow of 309 cfs was available 17 out 48 years of record, or 35 percent of the time.

Again, streamflow originating outside of Oklahoma is assumed to not be available for appropriation in Oklahoma. There are 50 mi^2 of drainage in Kansas between the KS-OK State Lines and the Lower Limit. Therefore, the average annual streamflow (X_{sf}) must be reduced. Computations for the reduction is as follows.

For flow originating in Kansas:

Table 1, Drainage Areas KS-OK State Line = 7,000 mi^2
Table 1, Drainage Area Buffalo Gage = 7,191 mi^2
Table 11, X_{sf} KS-OK State Line = 134 cfs
Table 11, X_{sf} Buffalo GAge = 138 cfs

$$[50 \text{ mi}^2/(7{,}191 \text{ mi}^2 - 7{,}000 \text{ mi}^2)](138 \text{ cfs} - 134 \text{ cfs}) = 1.05 \text{ cfs}$$

Then, water available for appropriation, X_{sf}, for Stream System 2-9-3 is:

$$X_{sf} = 309 \text{ cfs} - 134 \text{ cfs} - 1.05 \text{ cfs} = 173.95 \text{ cfs}$$

Total X_{sf} = 4.06 cfs + 6.63 cfs + 0.69 cfs + 173.95 cfs = 185.33 cfs.

Converted to Acre-Feet per Year

$$X_{sf} = (185.33 \text{ cfs})(723.98 \text{ AF/Yr/cfs}) = 134{,}175 \text{ AF/Yr}$$

The amount of appropriated water in the stream (X_{aw}) is 12,240 AF/YR (see Table 17). Then, the unappropriated water at the Lower Limit of Stream System 2-9-3 is:

$$Y_u = 134{,}175 \text{ AF/YR} - 12{,}240 \text{ AF/Yr} = 121{,}935 \text{ AF/Yr}$$

Stream System 2-9-2

The average annual flow at the upper limit of Stream System 2-9-2 is 319 cfs (see Table 13). However, this flow is only exceeded 33 percent of the time. A flow of 309 cfs is available 17 out of 48 times, or 35 percent of the time. For the lower limit, the average annual flow is 882 cfs and is available 16 out 39 times, or 41 percent of the time.

Then, (X_{sf}), the amount of average annual streamflow available for appropriation from Stream System 2-9-2, is:

$$X_{sf} = 882 \text{ cfs} - 309 \text{ cfs} = 573 \text{ cfs}$$

Converted to Acre-Feet per Year:

$$X_{sf} = (573 \text{ cfs})(723.98 \text{ AF/Yr/cfs}) = 414{,}841 \text{ AF/Yr}$$

Table 17 shows the amount of appropriated water in the stream (X_{aw}) for Stream System 2-9-2 is 24,396 AF/Yr.

Therefore, (Y_u), the amount of unappropriated water for Stream System 2-9-2, is:

$$Y_u = 414{,}841 \text{ AF/Yr} - 24{,}396 \text{ AF/Yr} = 390{,}445 \text{ AF/Yr}$$

Stream System 2-9-1

Table 15 shows that average annual flow at the upper limit of Stream System 2-9-1 is 882 cfs and was available 16 out of 39 years of record, or 41 percent of the time.

For the lower limit, the average annual flow is 1,278 cfs and is available 20 out of 46 times, or 43 percent of the time.

Then, (X_{sf}), the amount of average annual streamflow available for appropriation from Stream System 2-9-1, is:

$$X_{sf} = 1{,}278 \text{ cfs} - 882 \text{ cfs} = 396 \text{ cfs}$$

Converted to Acre-Feet per Year:

$$X_{sf} = (396 \text{ cfs})(723.98 \text{ AF/Yr/cfs}) = 286{,}696 \text{ AF/Yr}$$

The total yield of Keystone Lake, attributed to the Cimarron River, was determined by reducing the total yield of Keystone Lake by a factor determined by dividing the average inflow into the Cimarron Arm of Keystone by the average annual flow into Keystone Lake. The average annual inflow into the Cimarron Arm of Keystone is shown as the Lower Limit in Table 15. See also Table 14, Footnote 15. The flow is 1,278 cfs. Average annual inflow into Keystone Lake is 7,158 cfs[21]. Thus:

$$\text{Factor} = 1{,}278/7{,}158 = 0.1785$$

Total water supply yield of Keystone Lake is 22,400 AF/Yr (see Table 16).

Then X_{1y} is:

$$(0.1785)(22{,}400 \text{ AF/Yr}) = 4{,}000 \text{ AF/Yr}$$

Therefore, 4,000 AF/Yr is the total annual flow into Keystone Lake reserved for water supply storage and unavailable for appropriation.

The amount of appropriated water in the stream (X_{sw}) is 39,243 AF/Yr (see Table 17).

Therefore, (Y_u) the amount of unappropriated water for Stream System 2-9-1 is:

$$Y_u = 286{,}696 \text{ AF/Yr} - 4{,}000 \text{ AF/Yr} - 39{,}243 \text{ AF/Yr} = 243{,}453 \text{ AF/Yr}$$

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[21] Keystone Lake, Arkansas River, Oklahoma, Water Control Manual, November 1989.

SUMMARY

The primary objective of this investigation was to provide data to facilitate management of the state's stream water resources in the stream systems of the Cimarron River in Oklahoma. Table 18 summarizes the results.

TABLE 18. SUMMARY OF RESULTS

	Stream System			
	2-9-4	2-9-3	2-9-2	2-9-1
Drainage Area (mi^2) (contributing from Oklahoma)	782	2,019	3,492	2,005
Annual Average Precipitation (inches)	16.78	25.00	28.69	33.55
Annual Average Pan Evaporation (inches)	89.58	89.58	74.08	66.98
Average Annual Streamflow (cfs)	42.2	319	882	1,278
Appropriated Streamflow (AF/Yr)	5,233	12,240	24,396	39,243
Unappropriated Water (AF/Yr)	5,084	121,935	390,445	243,453

CONCLUSIONS

This study has determined that the amount of water which is unappropriated in the Cimarron River is that water which originates annually within Stream System 2-9-4, 2-9-3, 2-9-2 and 2-9-1 less the water already appropriated in the stream system. The study has taken into account land uses and farming practices and has assessed past and current water uses of the basin. It is desirable that appraisal-level hydrologic studies be conducted from time to time to maintain the accuracy of the data, and that monthly water use distribution, especially for irrigation, be given additional attention so that permits based on a seasonal availability of water can be determined and granted.

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*U.S.GPO:1991-561-050/40036