AVAILABILITY OF NATURAL AND REGULATED STREAMFLOWS FOR INSTREAM USES DURING HISTORICAL DROUGHTS, LOWER NEOSHO RIVER, SOUTHEASTERN KANSAS

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CONVERSION FACTORS

Inch-pound units used in this report may be converted to metric units by using the following conversion factors:

Multiply inch-pound unit	By	To obtain metric unit
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	4,047	square meter
square mile (mi^2)	2.590	square kilometer (km^2)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
square foot per second (ft^2/s)	0.09290	square meter per second (m^2/s)
square foot per day (ft^2/d)	0.09290	square meter per day (m^2/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per day [(ft^3/s)/d]	0.02832	cubic meter per second per day [(m^3/s)/d]
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year (hm^3/yr)
foot per second (ft/s)	0.3048	meter per second (m/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
million gallons per year (Mgal/yr)	10.3699	cubic meter per day (m^3/d)
foot per foot (ft/ft)	1.0	meter per meter (m/m)

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ABSTRACT

The effects of three historical droughts on multiple-use and water-quality minimum streamflows available for instream use on the lower Neosho River were investigated. Multiple-use minimum streamflows were recommended by the Kansas Water Office, and water-quality minimum streamflows were recommended by the Kansas Department of Health and Environment. Natural streamflows that occurred during the droughts of water years 1933-36, 1953-57, and 1963 were compared to the multiple-use and water-quality minimum streamflows at the streamflow-gaging stations located near Iola and Parsons, Kansas. To simulate the effects of John Redmond Reservoir, streamflows that occurred during the three droughts at the Strawn gaging station were first routed through the reservoir using a reservoir-routing model and then routed downstream to the Iola and Parsons gages using a streamflow-routing model. The simulated regulated-condition streamflows at the Iola and Parsons streamflow-gaging stations then were compared to the multiple-use and water-quality minimum streamflows.

At the Iola gage, the regulated streamflows usually satisfied the recommended multiple-use streamflows with smaller volume deficiencies as compared to the natural streamflows. At the Parsons gage, the natural streamflows satisfied the recommended multiple-use streamflows more frequently and with smaller volume deficiencies as compared to the regulated streamflows. The larger volume deficients for the regulated streamflows were attributed to the reservoir-operating procedure in the reservoir model. At the Iola gage, the regulated streamflows satisfied the recommended water-quality streamflows more frequently as compared to the natural streamflows. At the Parsons gage, the natural streamflows satisfied the recommended water-quality streamflows more frequently but with larger volume deficiencies as compared to the regulated streamflows.

Frequency analysis made on the natural streamflows and on regulated streamflows showed that regulated streamflows reduced the number of days with low flows (less than 20 cubic feet per second) and high flows (more than 100 cubic feet per second). The reduction in days of flows of less than 20 cubic feet per second aided the achievement of both the recommended multiple-use and water-quality streamflows.

The reservoir-routing model was used to determine if the natural streamflows that occurred during the three historic droughts would maintain sufficient storage in John Redmond Reservoir that could be used to

satisfy the recommended multiple-use and water-quality streamflows at both the Iola and Parsons gages. The reservoir was assumed to be full (maximum conservation pool) before inflow began. Only during the 1950's drought was storage insufficient to maintain the multiple-use streamflows at the Parsons gage. The additional storage needed was estimated to be 15,400 acre-feet.

INTRODUCTION

Minimum streamflows have been recommended for the lower Neosho River from John Redmond Reservoir to Parsons, southeastern Kansas, by the Kansas Water Office to satisfy multiple instream uses and by the Kansas Department of Health and Environment to satisfy water-quality needs. This study, conducted in cooperation with the Kansas Water Office, evaluates the amount of additional flow needed to maintain these minimum streamflows during times of drought and the effect of reservoir regulation on the recommended minimum streamflows during times of drought.

The minimum streamflows, recommended by the Kansas Water Office, were derived from flow recommendations made by the Kansas Department of Health and Environment, the Kansas Fish and Game Commission, and the Division of Water Resources of the Kansas State Board of Agriculture (Kansas Water Office, 1983). The Kansas Water Office minimum multiple-use streamflows accounted for water-quality requirements, fishery habitat requirements, existing water appropriations, and the frequency of occurrence of the minimum streamflows for the lower Neosho River based on historic streamflow records. These minimum streamflows will be referred to as the multiple-use streamflows for the remainder of the report.

The minimum streamflows recommended by the Kansas Department of Health and Environment were based on the U.S. Environmental Protection Agency stream-quality model results. The model calculated necessary streamflows required to maintain a dissolved-oxygen concentration of 5 mg/L (milligrams per liter)(Roesner and others, 1977), given ambient water temperature and wastewater effluents projected to the year 2000 (M. K. Butler, Kansas Department of Health and Environment, written commun., 1981). These minimum streamflows will be referred to as the water-quality streamflows for the remainder of this report. The two sets of minimum streamflow recommendations for the streamflow-gaging stations on the lower Neosho River near Iola and Parsons are listed in table 1.

Purpose and Scope

The purpose of this investigation was to compare the observed (natural) streamflows of the lower Neosho River during historical droughts with the multiple-use and water-quality minimum streamflows recommended by the Kansas Water Office and the Kansas Department of Health and Environment, to determine the effects of reservoir regulation on these comparisons, and, if appropriate, to estimate the amount of additional reservoir storage needed to achieve these streamflows during the drought periods.

Table 1.--Multiple-use and water-quality minimum streamflows for the streamflow-gaging stations near Iola and Parsons

Multiple-use minimum streamflows (Kansas Water Office), in cubic feet per second and acre-feet per day (in parenthesis)			Water-quality minimum streamflows (Kansas Department of Health and Environment), in cubic feet per second and acre-feet per day (in parenthesis)	
Month	Iola	Parsons	Iola	Parsons
Jan.	40 (79)	50 (99)	6 (12)	10 (20)
Feb.	40 (79)	50 (99)	6 (12)	10 (20)
March	40 (79)	50 (99)	8 (16)	15 (30)
April	40 (79)	50 (99)	12 (24)	20 (40)
May	40 (79)	50 (99)	18 (36)	30 (59)
June	40 (79)	50 (99)	24 (48)	35 (69)
July	40 (79)	50 (99)	30 (59)	45 (89)
Aug.	40 (79)	50 (99)	30 (59)	45 (89)
Sept.	40 (79)	50 (99)	24 (48)	30 (59)
Oct.	40 (79)	50 (99)	16 (32)	25 (50)
Nov.	40 (79)	50 (99)	8 (16)	15 (30)
Dec.	40 (79)	50 (99)	6 (12)	10 (20)

The scope of the investigation included examination of daily streamflow data for the lower Neosho River during three historical droughts (water years 1933-36, 1953-57, 1963), regression analysis to simulate streamflows during periods of no streamflow record, and hydrologic-model analysis to simulate the effects of John Redmond Reservoir on the streamflows below the reservoir. This report compares natural and regulated streamflows to the multiple-use and water-quality minimum streamflows at the streamflow-gaging stations near Iola and Parsons, Kansas, and determines if the multiple-use and water-quality streamflows are met by the natural and regulated streamflows. The report also presents estimates of additional reservoir storage needed to achieve the minimum streamflows when required.

Description of Study Area

The study area and the location of streamflow-gaging stations within the area are shown in figure 1. The study area is the lower Neosho River, between John Redmond Reservoir and the Parsons streamflow gage, a distance of 142 river miles. John Redmond Reservoir is located northwest of Burlington in southeastern Kansas. The drainage area for the reservoir is 3,015 mi^2. Water-level elevation for the top of the conservation pool is 1,039 ft (above sea level), with a storage capacity of 71,300 acre-ft. The minimum storage maintained is 505 acre-ft at a pool elevation of 1,020 ft.

Four streamflow-gaging stations have operated in the study area: Neosho River at Strawn (07182400), Neosho River at Burlington (07182510), Neosho River near Iola (07183000), and Neosho River near Parsons (07183500). The Strawn gage operated from 1949 to June 1963 when John Redmond Reservoir was completed. The Burlington gage has been in operation since 1961, the Iola gage since 1917, and the Parsons gage since 1921.

To facilitate modeling procedures, the study area was divided into two reaches and one subreach (fig. 1). The upper reach is from the Strawn gage to the Iola gage, and the lower reach is from the Iola gage to the Parsons gage. The subreach is from the reservoir outlet to the Iola gage. Drainage area, river length, and channel slopes for the study area are provided in table 2.

APPROACH

Observed daily streamflow records on file with the U.S. Geological Survey (Lawrence, Kans.) for the Strawn, Iola, and Parsons gages were used in this investigation. Historical droughts of water years 1933-36, 1953-57, and 1963 were used for analysis. The severity of the three historical droughts is indicated by the annual precipitation for eastern Kansas and western Missouri shown in figure 2. Except for 1935 and 1957, the annual precipitation that occurred during the three drought periods was less than the mean annual precipitation of 38.5 inches. Periods of zero flow occurred at the Strawn gage during 1954-57, at the Iola gage during 1936, and at the Parsons gage during 1934, 1936, and 1955-57.

John Redmond Reservoir was completed in 1963 and began storage in August 1963. This storage only had a partial impact on downstream flows during August and September of the 1963 water year (October 1, 1962, to September 30, 1963).

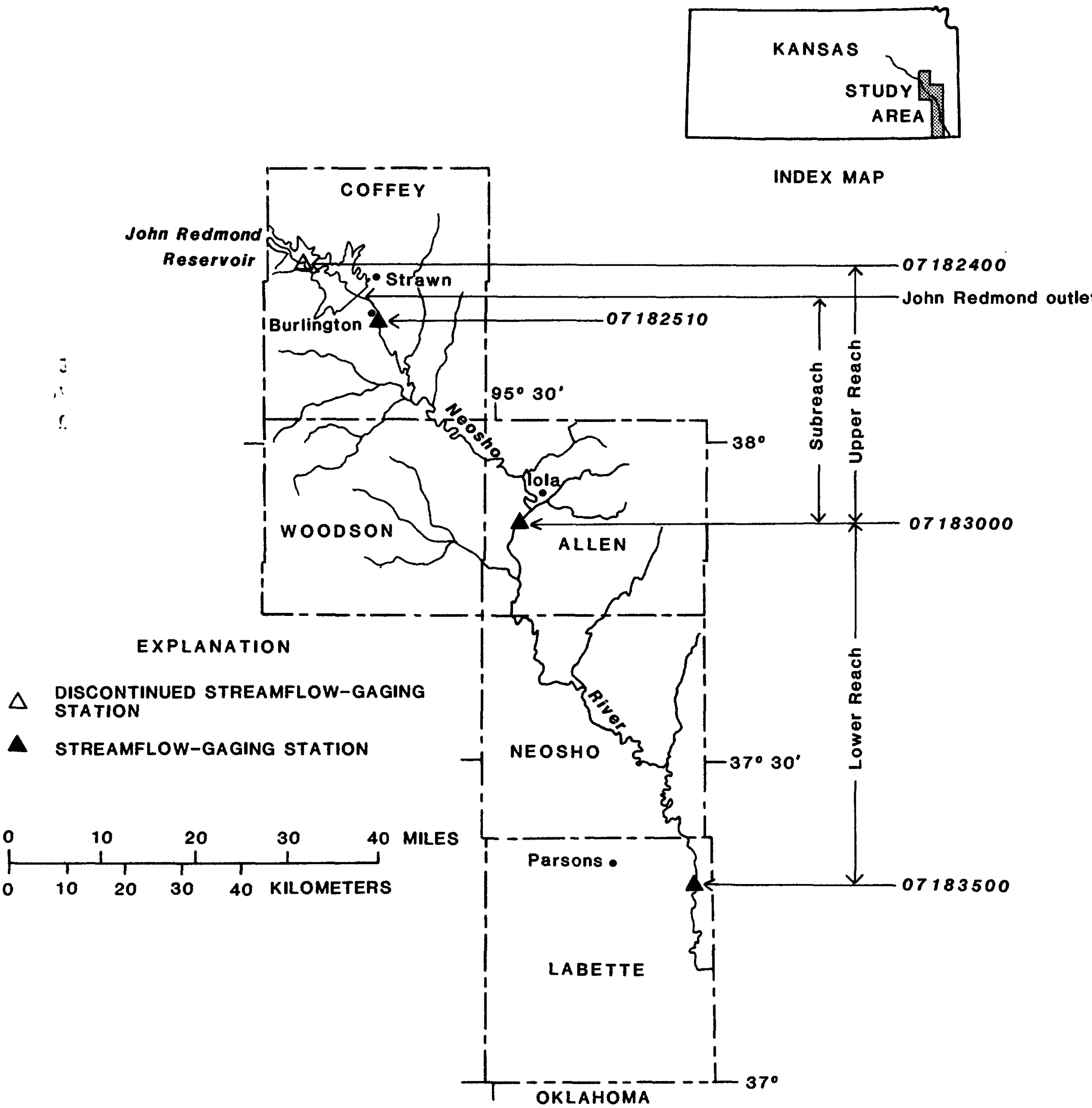

Figure 1.--Location of reaches and streamflow-gaging stations within study area.

Estimates of Missing Streamflow Records

The 1930's drought and the 1963 drought occurred outside the Strawn period of record. Estimates of inflow to John Redmond Reservoir at the

Strawn gage were needed for the 1933-36 drought and the last three months of the 1963 water year. Multiple-regression analysis based on 5,020 observed daily-streamflow values was used to investigate the feasibility of estimating Strawn daily streamflows from long-term flow records at gaging stations in the vicinity.

Table 2.--Drainage areas upstream from gages and length and slope of reaches for study area

Reach name	Total drainage area (square miles)	Length of reach (river miles)	Slope of reach (feet per feet)
Upper reach (Strawn to Iola gages)	3,818	69.1	0.00026
Subreach (John Redmond outlet to Iola gage)	---	56.3	---
Lower reach (Iola to Parsons gages)	4,905	86.0	.00023

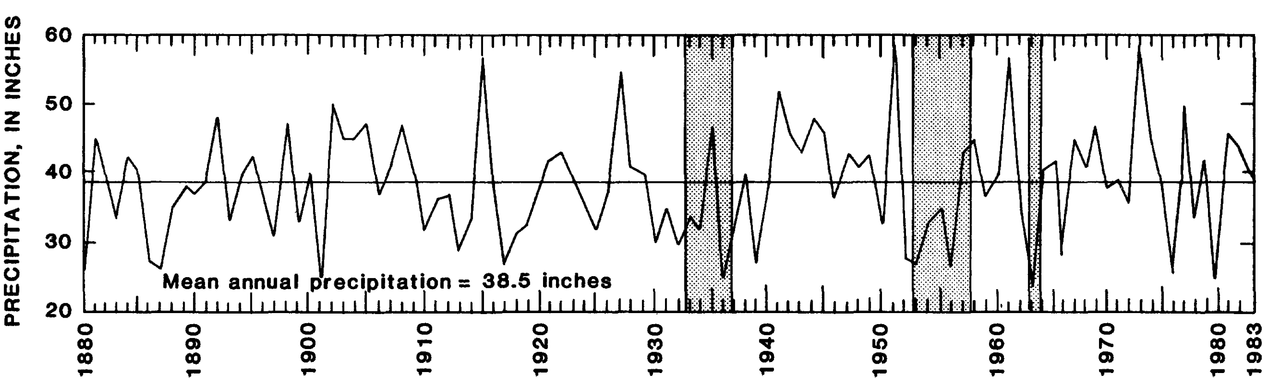

Figure 2.--Annual precipitation for eastern Kansas and western Missouri and the three historical droughts (shaded areas) investigated (C. A. Perry, U.S. Geological Survey, written commun., 1984).

Estimates of Strawn streamflow based on the Iola streamflow alone were as accurate as those based on Iola and other stations. The following equation was used:

$$\hat{Q}_s = 0.75\ Q_i \qquad (1)$$

where

$\hat{Q}_s$ is the estimated streamflow at the Strawn gage, in cubic feet per second; and

Q_i is daily mean streamflow at Iola, in cubic feet per second adjusted by 1 day.

The coefficient of determination for equation 1 is 0.925, indicating relatively good accuracy of the estimates in relation to the large variability of the Strawn daily streamflows. The standard error of estimate for equation 1 is 1,577 ft^3/s. This error of estimate is not representative for low flows; flows of less than 400 ft^3/s, with an average of 311 ft^3/s, have a root-mean-square error of estimate of 252 ft^3/s. Observed and estimated streamflow at Strawn for the first 6 months of the 1954 water year are shown in figure 3.

Reservoir-Routing Model

A simple input-output reservoir-routing model provided by the Kansas Water Office was used to mathematically route the Strawn daily streamflows through John Redmond Reservoir. The streamflows were those that occurred during the three historical droughts.

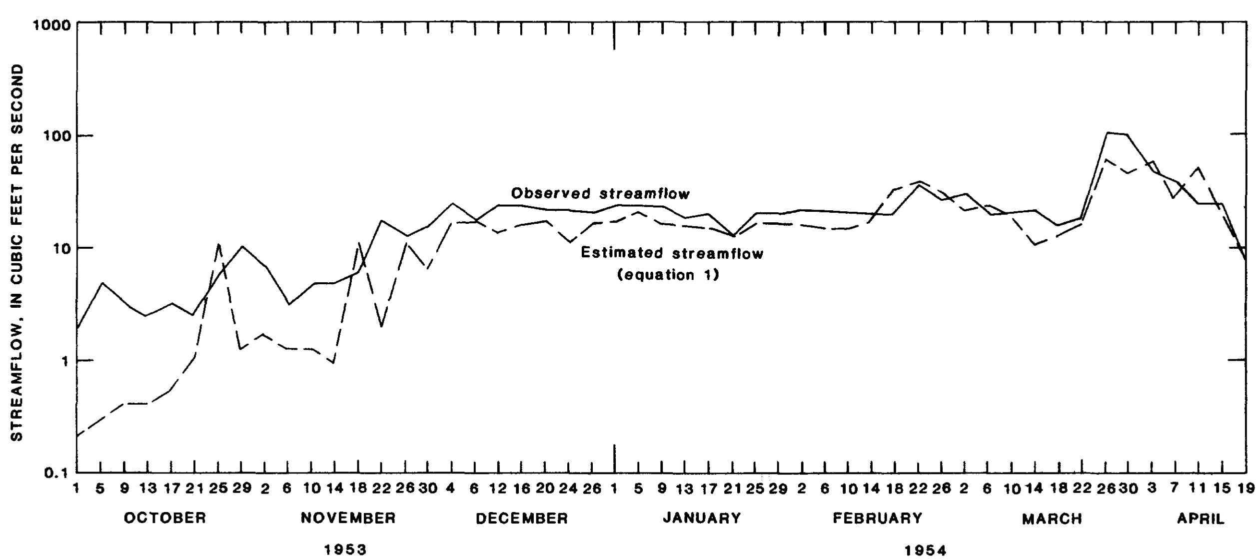

Figure 3.--Comparison of observed and estimated mean daily streamflows at the Strawn gage, October 1, 1953, to April 19, 1954.

Observed and estimated daily streamflows occurring at the Strawn gage during the three historical droughts were used as inflow to the reservoir-routing model. Daily pan evaporation at the John Redmond Dam weather station was used to estimate losses due to evaporation. The model adjusts the pan evaporation with a pan coefficient to represent reservoir evaporation. Pan evaporation rates that occurred during the drought of 1963 (National Oceanic and Atmospheric Administration, 1964) were used to estimate reservoir evaporation for all three droughts.

Daily precipitation accumulations also were used in the model. Precipitation that occurred during the droughts at Burlington, Kans., were obtained from National Oceanic and Atmospheric Administration reports for the years under study. Elevation- and area-storage values for John Redmond Reservoir also were required. Storage values used in the model are listed in table 3.

Table 3.--Elevation- and area-storage values used in reservoir-routing model

Elevation (feet)	Surface area (acres)[1]	Capacity (acre-feet)[1]
1,008	0	0
1,020	107.4	505
1,023	591	1,451
1,025	1,141	3,167
1,027	1,784	6,089
1,029	2,788	10,517
1,030	3,338	13,576
1,033	5,790	27,038
1,037	8,122	54,164
1,039	9,292	71,284
1,041	10,463	90,745
1,044	12,084	124,525
1,050	16,023	209,603
1,056	20,451	319,495
1,062	25,560	458,087
1,067	30,899	598,982
1,072	36,045	765,563
1,076	40,633	918,206
1,080	45,574	1,089,926

[1] Values based on sediment survey by the U.S. Corps of Engineers, Tulsa District, Tulsa, Okla., computed in 1974.

The reservoir-routing model mathematically simulated reservoir outflow. The outflow routine of the model reflected a simplified operating procedure for John Redmond Reservoir. The initial pool elevation was 1,039 ft (maximum conservation pool). When the pool elevation was maintained between the maximum conservation pool (1,039 ft) and the minimum conservation pool (1,020 ft), low-flow, water-quality releases for John Redmond Reservoir were made from the reservoir. These releases are listed in table 4. If the pool elevation decreased below 1,020 ft, no releases were made from the reservoir. A simplified flood-operation procedure also was used in the model. If the pool elevation increased to greater than 1,039 ft but did not exceed 1,044 ft (flood pool), the outflow equaled the inflow or the low-flow water-quality release, whichever was larger. If the pool elevation exceeded 1,044 ft, a maximum release rate of 12,000 ft^3/s was used as the outflow from the reservoir.

John Redmond Reservoir has 9,672 Mgal/yr (approximately 30,000 acre-ft) of usable water-supply storage. The average annual yield from that storage through the 2-percent-chance drought yield from water-quality storage was calculated to be 26.5 Mgal/d (41 ft^3/s). Wolf Creek powerplant has a contract to purchase all of the 41 ft^3/s of water-supply yield. The diversion for withdrawing the water is immediately below the reservoir dam. A constant withdrawal of 41 ft^3/s was made from the reservoir using the reservoir-routing model to account for the diversion of the water-supply storage. This operation assumed constant use of the contracted water by the powerplant as long as the storage was available. The operation also assumed complete capture of 41 ft^3/s by the diversion. The model determined the availability of this water supply (41 ft^3/s).

Table 4.--Low-flow water-quality releases for John Redmond Reservoir used in the reservoir-routing model

[Values are given in cubic feet per second and acre-feet per day (in parenthesis)]

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
21	21	21	24	30	39	48	48	36	24	21	21
(42)	(42)	(42)	(48)	(59)	(77)	(95)	(95)	(71)	(48)	(42)	(42)

Streamflow-Routing Model

The outflows calculated by the reservoir model were used in the streamflow-routing model. These flows then were routed downstream from the reservoir outlet to the Iola and Parsons gages. The streamflow-routing model used for this investigation simulates the discharge at the downstream end of a reach as a function of the discharge at the upstream end (Doyle and others, 1983). An inflow discharge from an upstream location can be routed to some defined downstream location to produce outflow. Application of the model involves calibration, verification, and streamflow simulation.

The model routes streamflow by a unit-response, convolution flow-routing technique. A diffusion-analogy method with multiple linearization was used to determine the unit response of a flow wave. The unit-response function defines the percentage of an upstream discharge that will arrive at the downstream end of the reach during the initial unit time (daily) and each successive unit time (Doyle and others, 1983). The advantage of using the multiple-linearization technique is that it allows a range of wave-celerity (wave speed) and wave-dispersion values for a corresponding range of streamflow discharges. The model selects an optimum number of response functions and divides the inflow appropriately, based on the range of wave-celerity and dispersion values.

The model does not take into account gains or losses from irrigation, domestic or municipal water use, evapotranspiration, base-flow contributions from ground-water discharge, or stream-aquifer interaction. Flow ratios can be developed and applied to the simulated streamflows within the model, or estimates can be made of these variables and applied to the simulated streamflows externally from the model.

Data Requirements

Data required to use the streamflow-routing model include the following: (1) Daily (or hourly) streamflow discharges, (2) river-channel hydraulic characteristics, and (3) streamflow characteristics (wave celerity and dispersion). Flow from ungaged intervening drainage also should be considered.

Selection of streamflow discharges for model calibration and verification involved screening historic streamflows for the study area. Periods of low to medium flows were of special interest since the streamflows to be simulated were under drought conditions. Daily streamflows ranging from 34 ft^3/s to 344,000 ft^3/s for the study reaches were used.

The river-channel hydraulic characteristics required for each reach are length, average channel slope, and average channel width at the water surface. Reach length and elevations for computation of channel slope were obtained from surface-water records for Kansas (U.S. Geological Survey, 1963). A channel-width and discharge relation was developed for each reach from discharge measurements. The relationships between channel width and discharge at the Iola and Parsons gages are illustrated in figures 4 and 5, respectively.

Streamflow characteristics required in the model are: (1) wave celerity (C_0) and wave dispersion (K_0). Wave celerity and dispersion were determined for varying discharges for the upper and lower reaches. The following equation was used to determine initial wave-celerity (C_0) values (Doyle and others, 1983):

$$C_o = \frac{1}{W_0} \frac{dQ_0}{dY_0} \qquad (2)$$

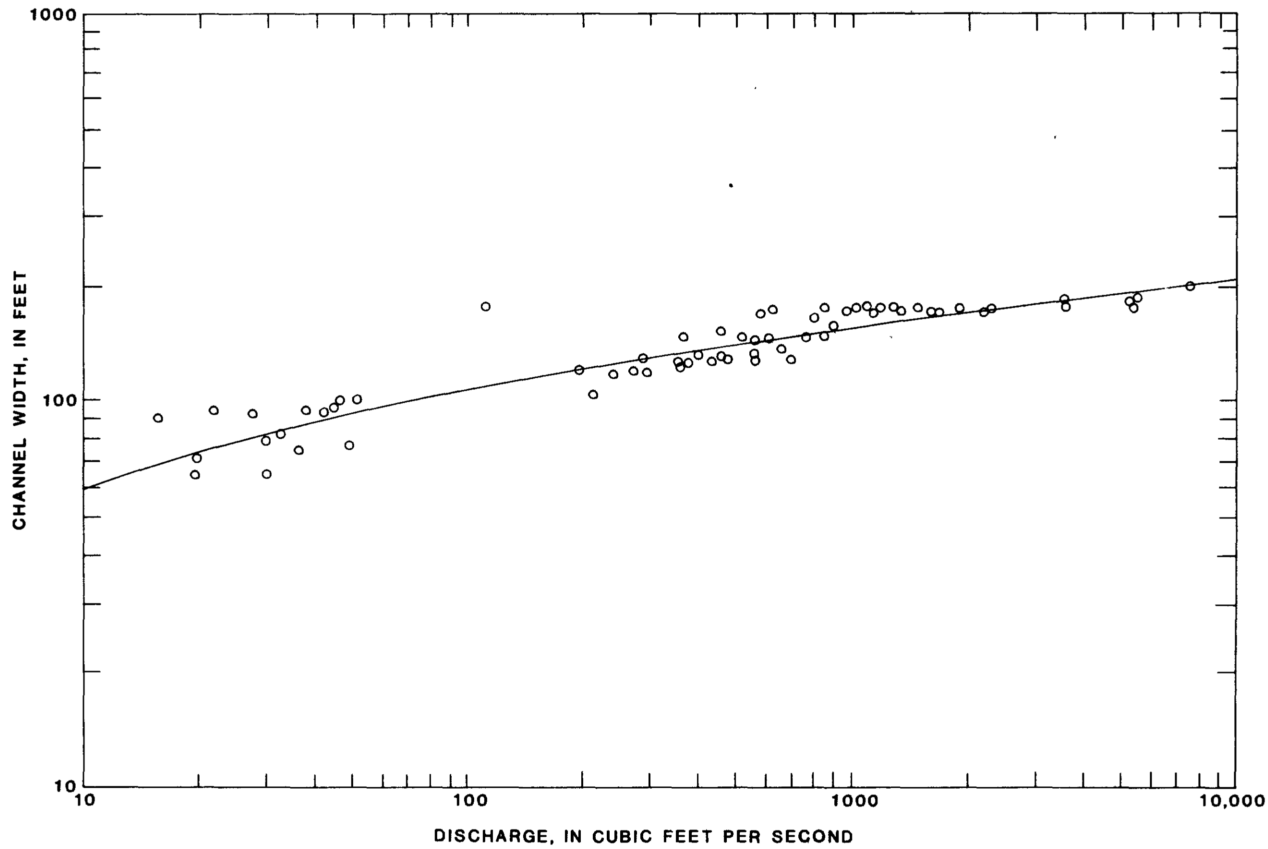

Figure 4.--Relationship between channel width and discharge for Neosho River near Iola (07183000), 1932-62.

where $\frac{dQ_0}{dY_0}$ is the slope of the rating curve (stage-discharge relation) at Q_0 (the average stream discharge through the reach), and W_0 is the average channel width at Q_0 for a particular study reach. The wave celerity determines the speed of the flow wave. A large C_0 value defines a flow wave that will arrive sooner than one resulting from a small C_0 value.

The following equation was used to determine initial wave-dispersion (K_0) values (Doyle and others, 1983):

$$K_0 = \frac{Q_0}{2 S_0 W_0} , \qquad (3)$$

where

Q_0 = average stream discharge through the reach, in cubic feet per second;
S_0 = average bed slope, in feet per feet; and
W_0 = average channel width at the water surface for discharge Q_0, in feet, for a particular study reach.

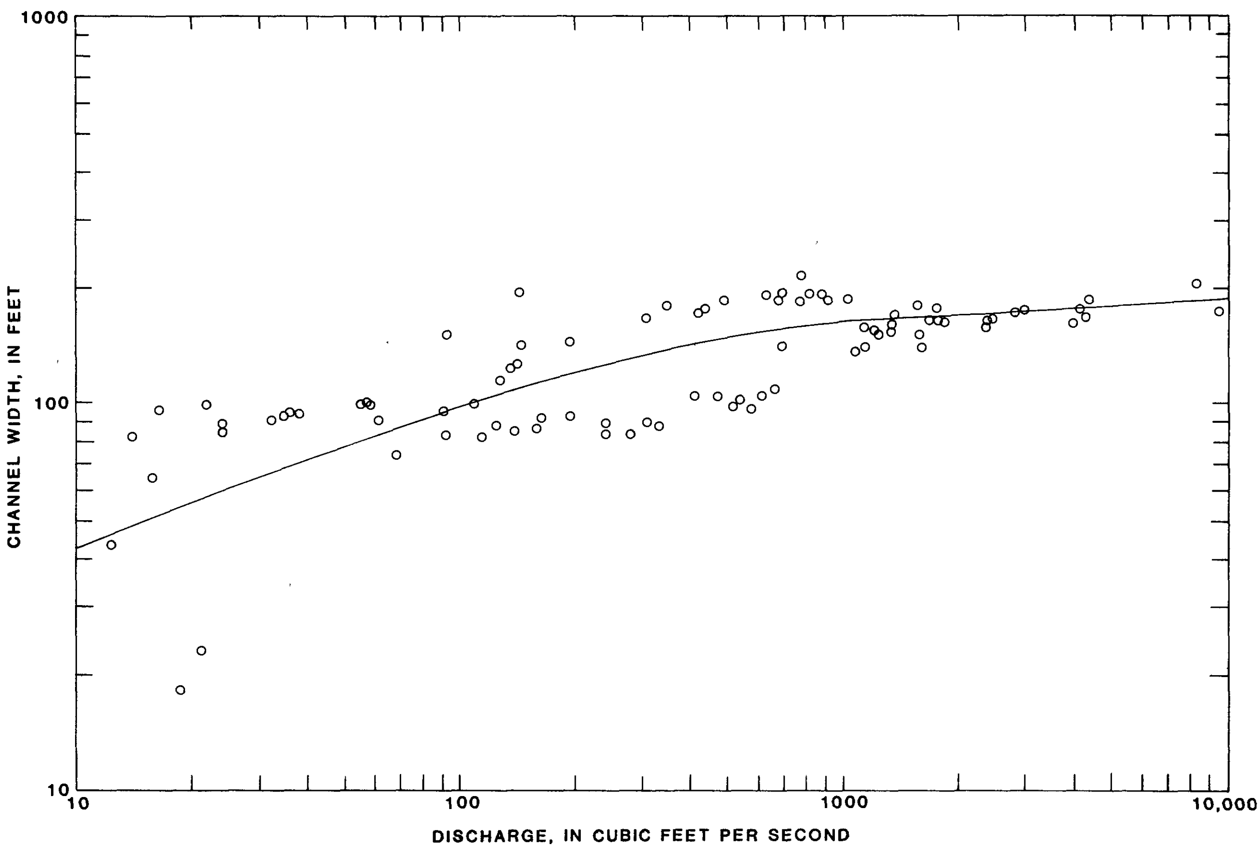

Figure 5.--Relationship between channel width and discharge for Neosho River near Parsons (07183500), 1950-62.

Wave dispersion determines the spread of the flow wave. A large K_0 value defines a discharge hydrograph that is more flat and spread out than one resulting from a small K_0 value. Wave-celerity and dispersion values are listed in table 5 and represent the final model-calibration values.

Flow ratios based on the drainage area were used for model calibration and verification to account for streamflow from intervening drainage. The method used to estimate intervening flow followed the recommendations by Doyle and others (1983).

Streamflow-Model Calibration and Verification

Model calibration was accomplished by using data values of streamflow discharges, river-channel hydraulic characteristics, streamflow characteristics, and flow ratios. Daily flows during water years 1959 to 1962 at the Strawn, Iola, and Parsons gages were used to calibrate the model. Streamflow discharge from an upstream gage was routed only to the next downstream gage. The routed streamflow discharge was then compared to the observed streamflow discharge at that gage. A "best fit" between observed and simulated streamflow at the downstream gages was obtained by varying the wave celerity, wave dispersion, and flow ratios. The period of record

Table 5.--Values of wave celerity (C_0) and wave dispersion (K_0) for selected discharges as determined from calibration of streamflow-routing model for upper and lower reaches

Upper reach			Lower reach		
Discharge (cubic feet per second)	Wave celerity (feet per second)	Wave dispersion (square feet per second)	Discharge (cubic feet per second)	Wave celerity (feet per second)	Wave dispersion (square feet per second)
10	1.42	300	10	1.30	506
50	1.87	1,023	50	1.42	1,412
200	4.14	2,380	200	3.01	3,240
500	4.16	5,790	500	5.08	6,895
1,000	6.42	10,525	1,000	5.66	12,400
2,000	6.87	16,781	2,000	7.09	24,200
5,000	8.19	35,550	5,000	7.43	57,250
10,000	8.21	41,000	10,000	8.00	105,100

and range of discharge and volume of error between the observed and simulated streamflow discharges are shown in table 6. Observed and simulated discharge hydrographs at the Iola and Parsons gages from October 7 to November 17, 1960, are shown in figures 6 and 7, respectively.

Table 6.--Period of record and range of daily discharge used in streamflow-model calibration and volume error between observed and simulated discharges

Reach name	Period of record (water years)	Range in daily discharge (cubic feet per second)	Volume error (percent)
Upper reach (Strawn to Iola gages)	1959	88 - 17,800	16
	1960	82 - 16,800	-1.9
	1961	187 - 41,100	-9.5
	1962	167 - 21,200	-3.9
Lower reach (Iola to Parsons gages)	1959	103 - 15,000	.02
	1960	101 - 19,400	-9.7
	1961	226 - 41,300	-10
	1962	182 - 25,400	-4.0

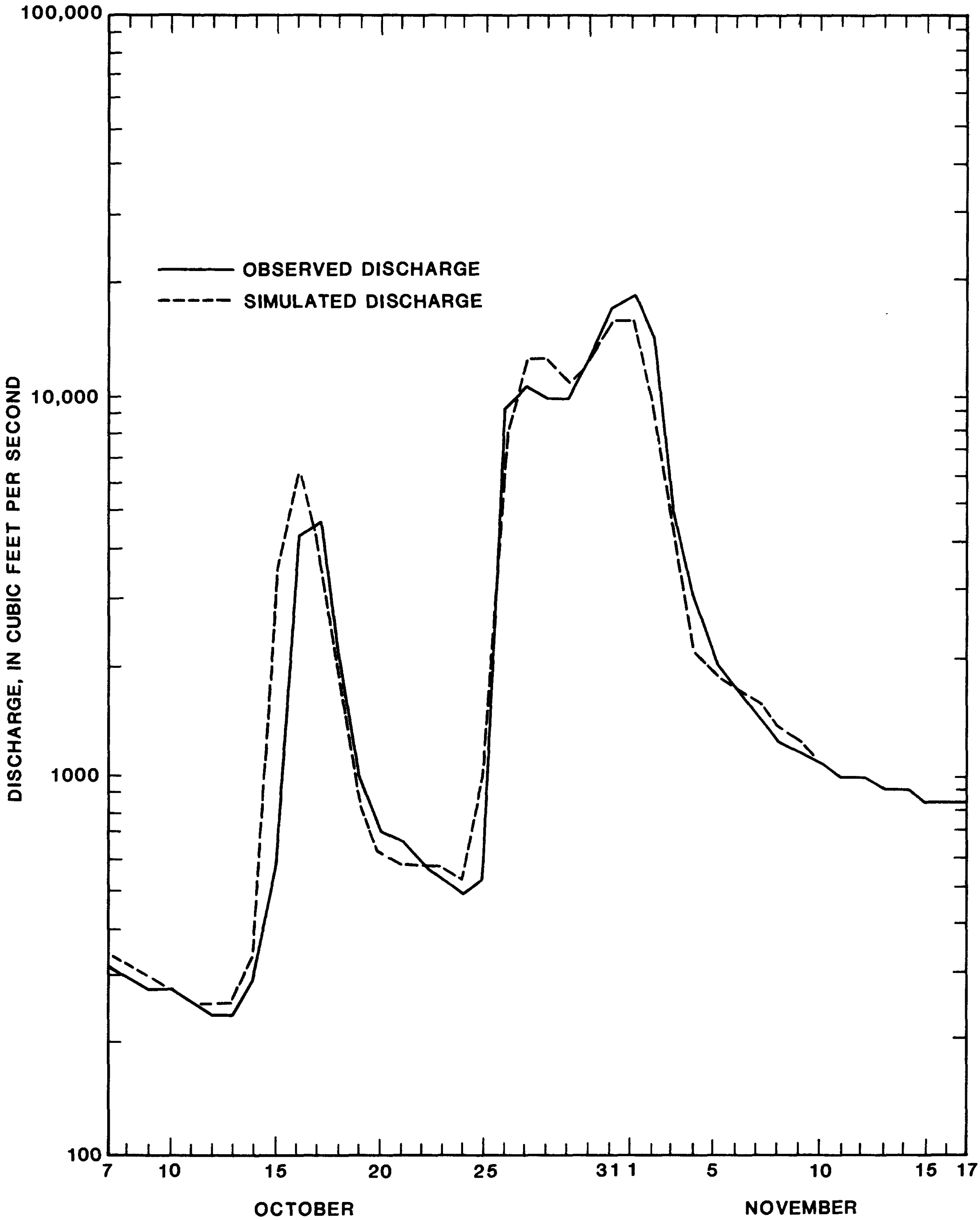

Figure 6.--Observed and simulated discharges at the Iola gage for calibration period, October 7 to November 17, 1960.

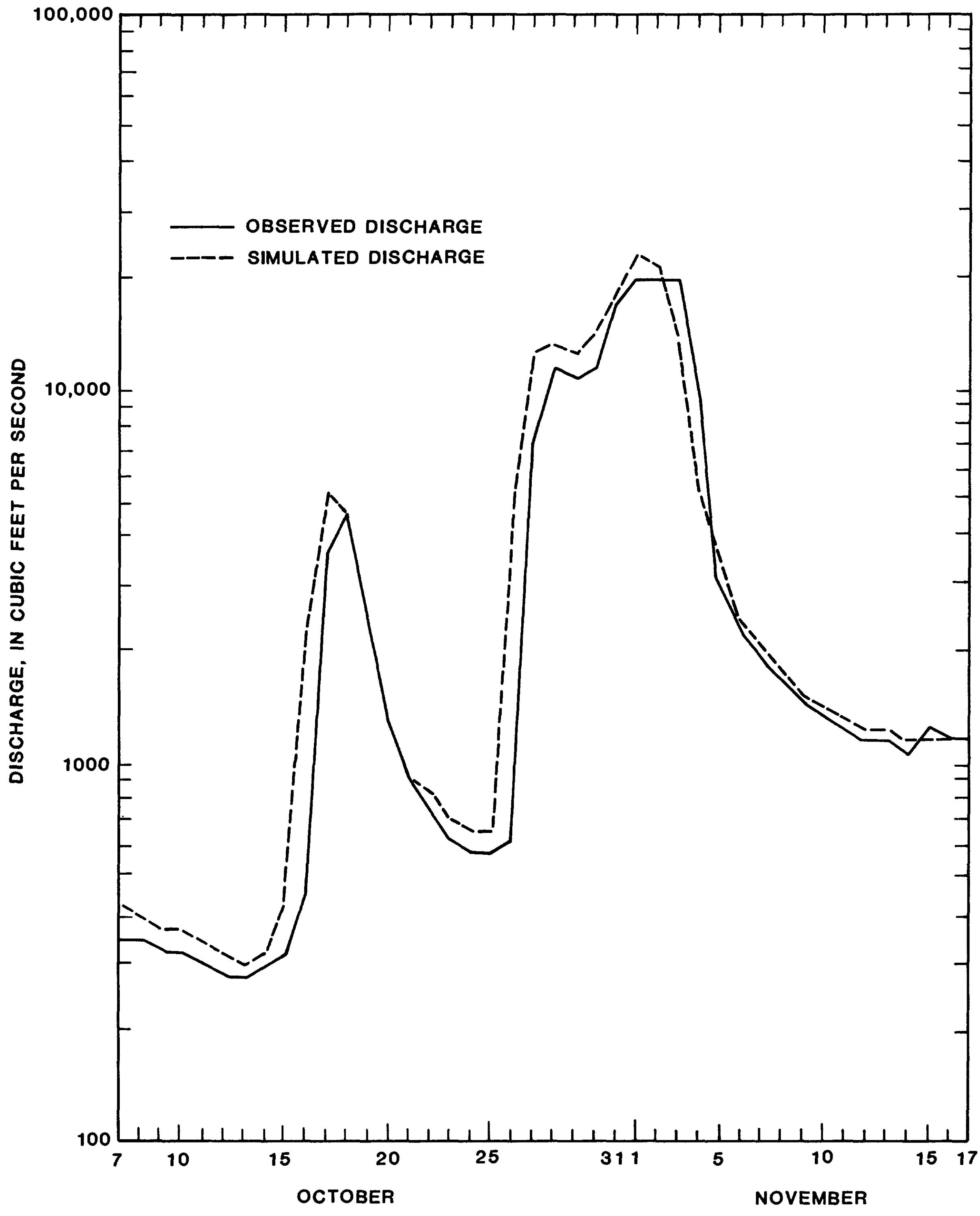

Figure 7.--Observed and simulated discharges at the Parsons gage for calibration period, October 7 to November 17, 1960.

After adjustments during the calibration process, the volume error of the simulated streamflow discharge ranged from -9.5 to 16 percent of the observed discharge at the Iola gage and -10 to 0.02 percent at the Parsons gage (table 6). Based on the errors and visual observation of streamflow hydrographs, the overall accuracy of the calibrated model was considered fair to good.

Observed streamflow discharges for water years 1950 to 1952 were used to verify the calibrated model. During this verification phase, wave celerity, wave dispersion, and flow ratios were held constant at the values determined by the calibration. As shown in table 7, the volume error between observed and simulated streamflow discharges ranged from -7.9 to 0.3 percent at the Iola gage and from -9.6 to 3.8 percent at the Parsons gage. Observed and simulated discharge hydrographs for model verification at the Iola and Parsons gages from October 12 to November 19, 1949, and October 22 to November 28, 1949, are shown in figures 8 and 9, respectively. The errors and visual comparison of the observed and the simulated discharge hydrographs indicated that reliable flow simulations could be made using the calibrated model.

Application of Model

Observed (and estimated, as needed) streamflows at the Strawn gage during the three historical droughts were routed through John Redmond Reservoir using the reservoir-routing model. The regulated outflows from the reservoir, less the 41 ft^3/s withdrawal for the Wolf Creek powerplant, were used in the streamflow-routing model. The regulated flows for each drought were routed downstream to the Iola and Parsons gages. The regulated streamflow at the Iola and Parsons gages were a function of the reservoir-outflow routine in the reservoir-routing model. The regulated outflow was routed downstream and adjusted to account for seasonal variations in base flow and evapotranspiration. Regulated streamflows at Iola and Parsons were then compared to the multiple-use, water-quality, and natural streamflows.

Base-flow contributions due to ground-water discharge below the reservoir to Parsons had to be considered for the discharge simulations of the regulated streamflows. This additional flow was considered to be minimal since the simulation period was during drought conditions. Losses to evapotranspiration also had to be considered for the simulations. Two methods were used to account for base flow and evapotranspiration: (1) An internal method that used ratios which were applied to the simulated streamflow internally in the model, and (2) an external method that used estimated values for base flow and evapotranspiration and applied to the simulated streamflow externally from the model after simulations were made.

The first accounting method used available historic base-flow data that occurred during drought conditions (1930's and 1950's) to develop base-flow ratios for the model simulations. These ratios were developed using yearly

Table 7.--Period of record and range of daily discharge used in streamflow-model verification and volume error between observed and simulated discharges

Reach name	Period of record (water year)	Range in daily discharge (cubic feet per second)	Volume error (percent)
Upper reach (Strawn to Iola gages)	1950	74 - 17,500	-7.9
	1951	100 - 274,000	-3.4
	1952	42 - 13,100	.3
Lower reach (Iola to Parsons gages)	1950	83 - 18,800	3.8
	1951	112 - 344,000	2.4
	1952	34 - 15,000	-9.6

total and seasonal base flows and were obtained from Busby and Armentrout (1965). Evapotranspiration ratios were also calculated to account for seasonal evapotranspiration losses during the simulations using available pan-evaporation data from John Redmond Dam during the 1963 drought. Evapotranspiration rates were developed using yearly total and seasonal total pan-evaporation data which were obtained from the National Oceanic and Atmospheric Administration (1964). Composite ratios, consisting of base-flow and evapotranspiration ratios, were applied internally in the model. Since the periods of simulations represented dry conditions, flow from intervening drainage was considered to be minimal or nonexistent.

The second accounting method estimated base-flow contributions and evapotranspiration losses using the same available drought data as used in the first method. The routed simulated flow was adjusted externally from the model by adding the estimated base-flow and subtracting the estimated evapotranspiration calculations (according to seasonal fluctuations) from the final simulated flow. This external method of accounting for base flow and evapotranspiration was used in the final simulations. Results between the two methods of accounting for base flow and evapotranspiration were not significantly different.

The only streamflow diversion accounted for in the investigation during the model simulations was the diversion to Wolf Creek powerplant (41 ft^3/s). That diversion was withdrawn from the reservoir using the reservoir-routing model. Other diversions during model simulations for water appropriations were not accounted for in the study area because of uncertainty in pumping rates and duration due to variations in municipal, industrial, and irrigation demands. However, the regulated (simulated) streamflow could be compared to the water rights within a reach to determine the extent of satisfying the authorized diversion rates of those rights. Water-appropriation rights in use before 1964 were authorized to divert 17 and 62 ft^3/s

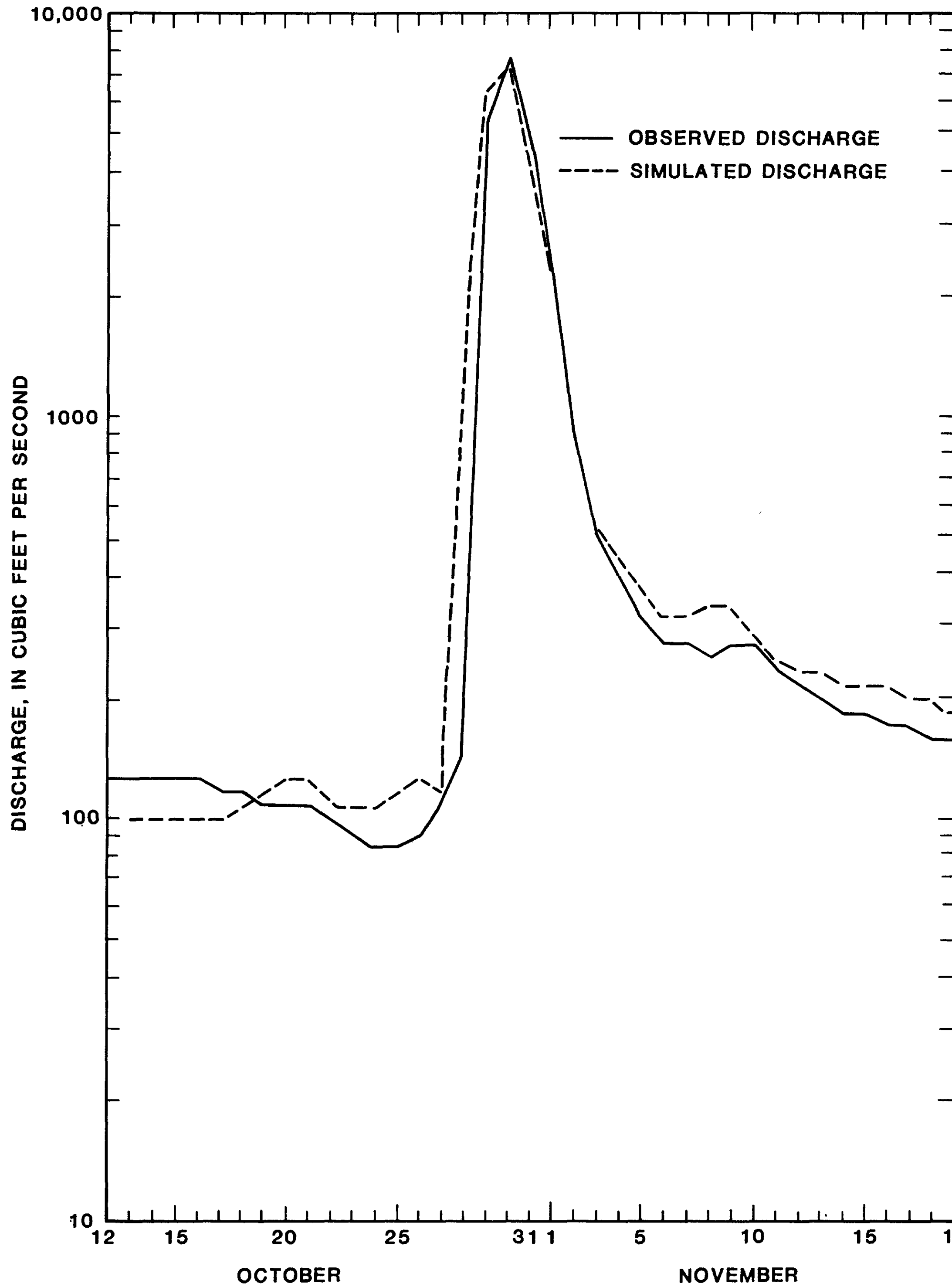

Figure 8.--Observed and simulated discharges at the Iola gage for verification period, October 12 to November 19, 1949.

within the upper and lower reaches, respectively. The authorized quantity of diverted water was 11,310 acre-ft/yr. Water-appropriation rights in use through December 1983 (including those used before 1964) were authorized to divert 71 and 168 ft^3/s within the two respective reaches. The authorized quantity of diverted water was 20,331 acre-ft/yr. These water-rights data were obtained from the Division of Water Resources, Kansas State Board of Agriculture.

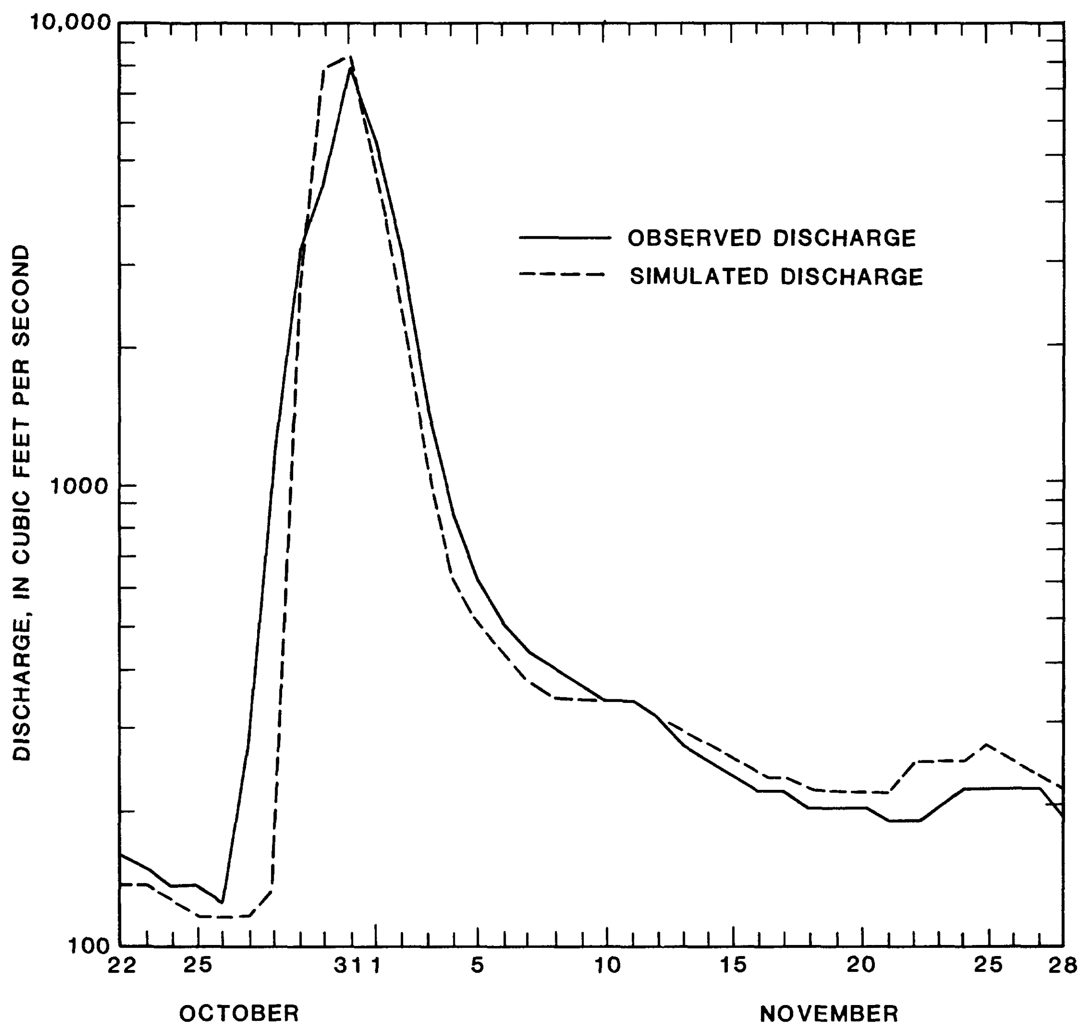

Figure 9.--Observed and simulated discharges at the Parsons gage for verification period, October 22 to November 28, 1949.

NATURAL AND REGULATED STREAMFLOWS

Streamflows During Natural Conditions

The natural, unregulated streamflows during the droughts of the 1930's, 1950's, and 1963 at the Iola and Parsons gages were compared to the multiple-use and water-quality minimum streamflows recommended by the Kansas Water Office and the Kansas Department of Health and Environment to determine the likelihood of achieving these recommended flows. The natural streamflows represented the conditions prior to regulation by John Redmond Reservoir. No diversion for Wolf Creek powerplant was considered because it was not in existence. Tables 12-19 at the back of this report (pages 31-37) show the number of days of deficient flow and the amount of streamflow deficiency for each month within each drought year. The days of deficient flow refer to the times that the recommended minimum streamflows (both multiple-use and water-quality) were not met by the natural streamflows occurring during the three historical droughts. The amount of streamflow deficiency refers to the volume of natural streamflow occurring during the three historical droughts that did not meet the recommended minimum streamflows. Tables 12-15 are the results for the multiple-use streamflows. Tables 16-19 are the results for the water-quality streamflows.

Meeting Multiple-Use Streamflow Demands

The recommended multiple-use streamflows (table 1) were not met at the Iola gage 23 percent of the time during the 1930's drought. Days of meeting the multiple-use streamflows ranged from 350 days during 1933 to 180 days during 1934 (table 12). Days of deficient flow during 1936 were approximately one-half the number during 1934, although the streamflow deficiency for 1936 was 6,289 acre-ft (table 13), which was close in magnitude to 1934 (6,661 acre-ft). The largest streamflow deficiency occurred during 1934 (6,661 acre-ft). At the Parsons gage, the multiple-use streamflows were not met 21 percent of the time for the entire 4-year drought (table 14). The largest streamflow deficiency occurred during 1934 (4,654 acre-ft, table 15).

Multiple-use streamflows at the Iola gage were not met 55 percent of the time during the 1950's drought. At least 100 days of deficient flow occurred at the Iola gage each year, with 1954 (260 days) and 1956 (265 days) having the most deficiencies. Streamflow deficiency at the Iola gage was most critical during 1954, 1956, and 1957. At the Parsons gage, streamflows were not met 53 percent of the time during the drought. The largest streamflow deficiency at the Parsons gage occurred during 1954 (11,058 acre-ft). Streamflow deficiencies were less than at the Iola gage despite the larger multiple-use streamflows due to tributary inflow between the two gages.

During the 1963 water year, multiple-use streamflows at the Iola and Parsons gages were not met 4 percent and 5 percent of the time, respectively. September 1963 was the only period of deficient streamflows and was a time of regulation by John Redmond Reservoir. Streamflow deficiencies at the Iola gage (901 acre-ft) were larger than at Parsons (654 acre-ft) during the 1963 water year.

Meeting Water-Quality Streamflow Demands

The water-quality streamflows recommended by the Kansas Department of Health and Environment were lower than the multiple-use streamflows (table 1). Therefore, the occurrence of deficient flows was much less for the water-quality streamflows. The water-quality streamflows were not met 11 percent of the time for the 1930's drought. During 1934 and 1936 at the Iola gage (table 16), water-quality streamflows were not met 70 and 85 days, respectively. Streamflow deficiencies for these 2 years were 2,666 acre-ft for 1934 and 4,029 acre-ft for 1936 (table 17). The water-quality streamflows at the Parsons gage were not met 13 percent of the time during the 1930's drought (table 18). The largest streamflow deficiency during the 1930's drought at the Parsons gage occurred during 1936 (2,964 acre-ft).

The water-quality streamflows at the Iola gage for water years 1953-57 were not met 32 percent of the time. Streamflow deficiency was most critical during 1954 (4,575 acre-ft). Flows were not met at the Parsons gage 42 percent of the time during the 1950's drought. At least 100 days of deficient flows occurred each year, and streamflow deficiencies ranged from 4,479 acre-ft during 1954 to 2,037 acre-ft during 1955.

Water-quality streamflows during the 1963 water year were not met 4 percent of the time for both the Iola and Parsons gages. Only 14 days of streamflows at the Iola gage and 15 days at the Parsons gage were not met. Deficient flows were 414 acre-ft at the Iola gage and 628 acre-ft at the Parsons gage during September, the only month when the flows were deficient.

Streamflows During Regulated Conditions

Regulated streamflows (resulting from reservoir-model simulations) were routed downstream to the Iola and Parsons gages using the streamflow-routing model. The routed streamflows at the Iola and Parsons gages reflect the reservoir-operating procedures used in the reservoir model, which incorporated the low-flow water-quality releases from John Redmond Reservoir (table 4). The regulated streamflows resulting from the reservoir- and streamflow-routing models were compared to the multiple-use and water-quality streamflows (table 1) recommended by the Kansas Water Office and the Kansas Department of Health and Environment at the Iola and Parsons gages. The results indicate that the reservoir-operating procedures do not permit the multiple-use or the water-quality streamflows to be met 100 percent of the time at the Iola and Parsons gages.

The regulated streamflows reflect the effects of a water diversion (41 ft^3/s) from the reservoir for Wolf Creek powerplant. Tables 20-27 at the back of this report (pages 38-42) show the days of deficient streamflows and the corresponding amount of deficient flow needed to maintain the recommended minimum streamflows for each month within each drought year simulated under regulated conditions. The days of deficient streamflow provided a monthly estimate of the duration that the streamflows were not met during the droughts. The days of deficient flow refer to the times that the recommended minimum streamflows (both multiple-use and water-quality) were not met by the regulated streamflows that were simulated by the reservoir- and streamflow-routing models using Strawn streamflows from the three historical droughts. The amount of streamflow deficiency refers to the volume of regulated streamflow occurring during the three historical droughts that did not meet the recommended minimum streamflows based on the low-flow water-quality releases released from John Redmond Reservoir (table 4). Tables 20-23 show the results for the multiple-use streamflows at the Iola and Parsons gages. Tables 24-27 show the results for the water-quality streamflows at the Iola and Parsons gages.

Meeting Multiple-Use Streamflow Demands

Under regulated conditions, the low-flow water-quality releases from John Redmond Reservoir did not allow the multiple-use streamflows recommended by the Kansas Water Office to be met at the Iola gage 53 percent of the time during water years 1933-36 (table 20). Streamflow deficiency ranged from 134 days during 1936 to 245 days during 1934 at the Iola gage. The largest streamflow deficiency occurred during 1934 (7,812 acre-ft) at the Iola gage, while the smallest deficiency occurred during 1936 (3,305 acre-ft). At the Parsons gage (table 22), the multiple-use streamflows were not met 70 percent of the time during the 1930's drought. Streamflow deficiency at the Parsons gage ranged from 193 days during 1935 to 309 days during 1934. The largest streamflow deficiency occurred during 1933 (13,726 acre-ft) and 1934 (13,889 acre-ft) (table 23).

For the 1950's drought, the multiple-use streamflows were not met at the Iola gage 75 percent of the time. Streamflow deficiency ranged from 235 days during 1957 to 304 days during 1954 and 1955. The largest streamflow deficiency occurred during 1954 (9,614 acre-ft) and the smallest during 1953 (7,153 acre-ft). At the Parsons gage, the multiple-use streamflows were not met 90 percent of the time during the 1950's drought. Streamflow deficiencies ranged from 261 days during 1957 to 365 days during 1954 and 1955. The largest streamflow deficiency occurred during 1955 (17,400 acre-ft), and the smallest deficiency occurred during 1953 (13,238 acre-ft).

For the 1963 drought, the multiple-use streamflows were not met at the Iola gage 19 percent of the time and 35 percent at the Parsons gage. There were 68 days of deficient flow at the Iola gage and 126 days at the Parsons gage. The amount of deficient flow at the Iola gage was 1,457 acre-ft and 3,793 acre-ft at the Parsons gage.

The above results indicated more days and amounts of deficient streamflow at the Parsons gage than at the Iola gage for regulated conditions. This can be attributed to the larger recommended multiple-use streamflows at the Parsons gage.

Meeting Water-Quality Streamflow Demands

Under regulated conditions, the low-flow water-quality releases (reservoir-operating procedures) from John Redmond Reservoir failed to meet the water-quality streamflows recommended by the Kansas Department of Health and Environment at the Iola gage only during the 1956 water year. Streamflow deficiency occurred for only 5 days (64 acre-ft) during 1956 (tables 24 and 25). At the Parsons gage, the flows were not met 32 percent of the time for the 1930's drought (table 26). The largest streamflow deficiency occurred during 1936 (596 acre-ft), and the smallest deficiency occurred during 1935 (267 acre-ft). For the 1950's drought, the water-quality streamflows were not met 41 percent of the time. Streamflow deficiencies ranged from 63 days during 1957 to 184 days during 1954 and 1955. The largest streamflow deficiency occurred during 1955 (1,124 acre-ft), and the smallest deficiency occurred during 1957 (272 acre-ft). During the 1963 drought, the water-quality streamflows were not met 18 percent of the time, and the amount of deficient flow was 177 acre-ft.

Comparison of Natural and Regulated Streamflows

Comparison of the natural streamflows (observed streamflows) to regulated streamflows (simulated streamflows) showed that the multiple-use streamflows (table 1) at the Iola and Parsons gages were met more frequently by the natural streamflows than by the low-flow water-quality releases (table 4) from John Redmond Reservoir. There were only 5 years (1936, 1954-57) where the streamflow deficiencies at the Iola gage were less for the regulated streamflows than for the natural streamflows. The low-flow water-quality releases from John Redmond Reservoir (table 4) did permit the regulated streamflows to meet the water-quality streamflow recommendations (table 1) at Iola more often than did the natural streamflows. At the Iola gage, the regulated streamflows satisfied the water-quality streamflows all of the time except for the 1956 water year, when only 5 days were deficient in streamflow. At the Parsons gage, the number of deficient days were usually more for the regulated streamflows as compared to the natural streamflows, but the streamflow deficiencies were usually less. A larger percentage of the multiple-use and water-quality streamflows were met by the regulated conditions at Iola as compared to the natural conditions, as indicated in tables 12-27. The natural flows compared to the regulated flows at the Iola and Parsons gages from October 1 to November 30, 1953, are shown in figures 10 and 11.

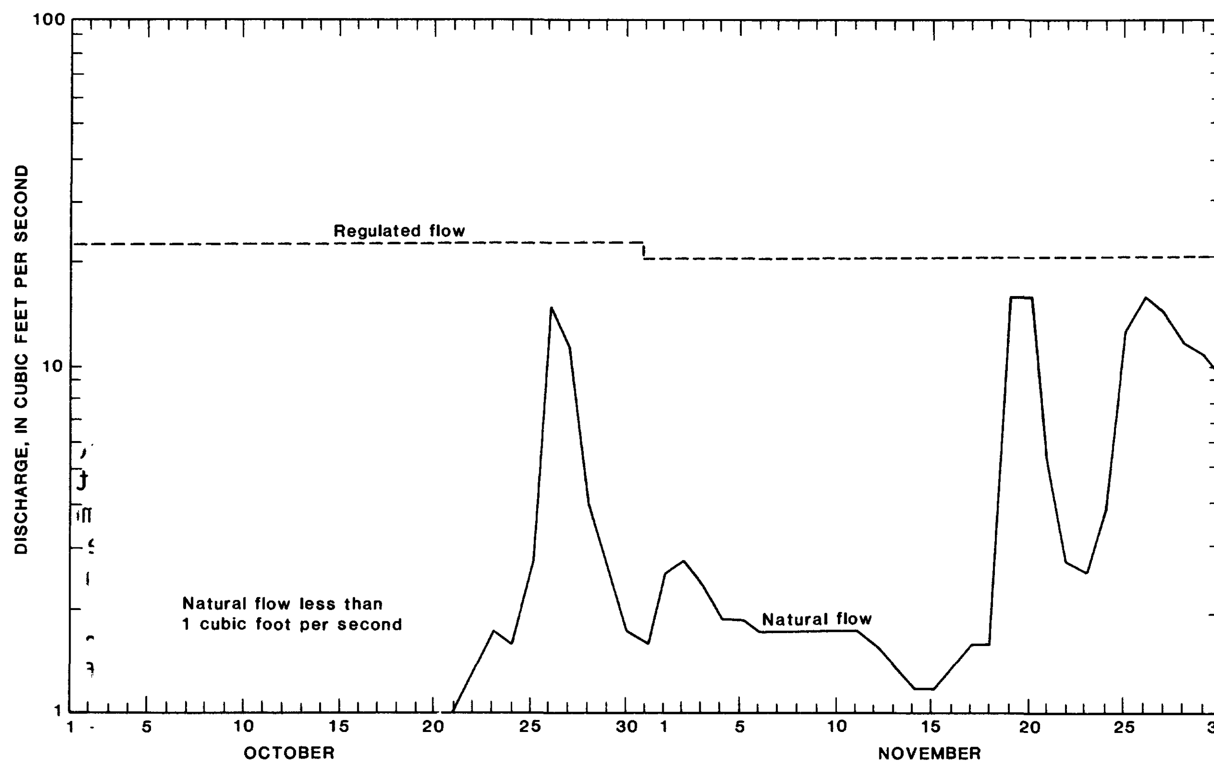

Figure 10.--Comparison of natural and regulated flows at the Iola gage, October 1 to November 30, 1953.

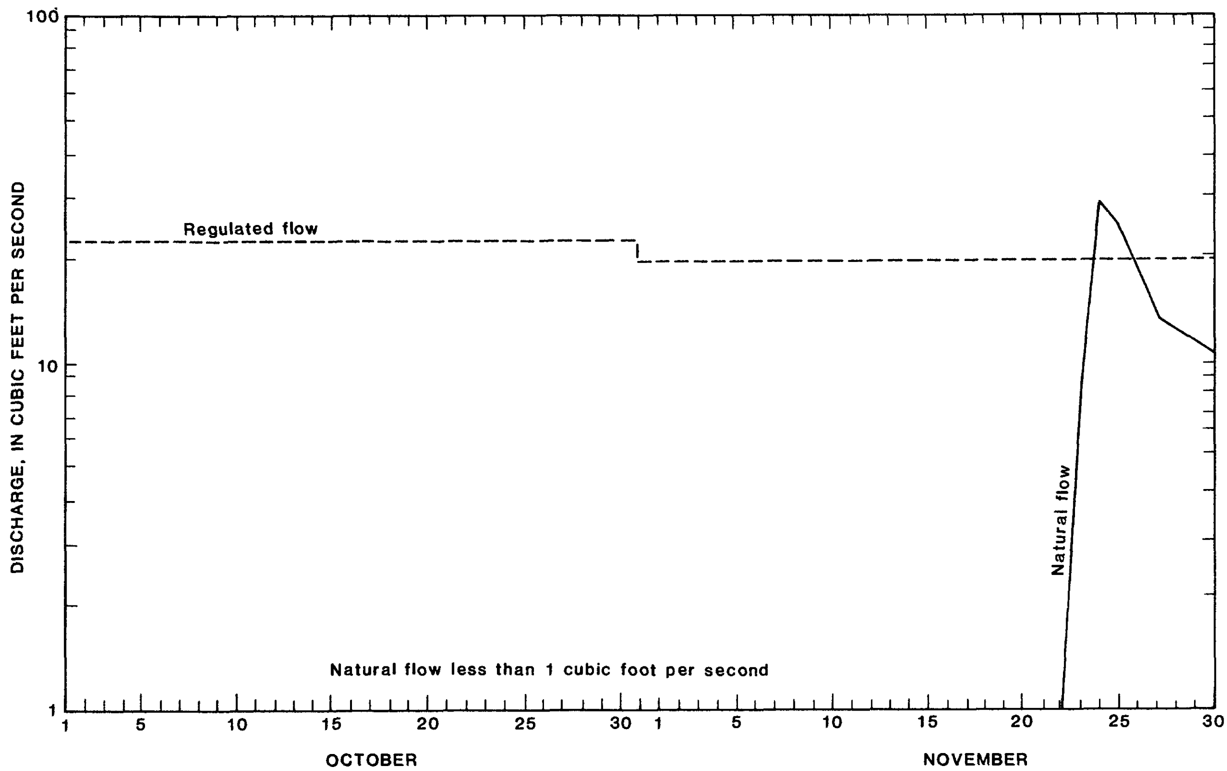

Figure 11.--Comparison of natural and regulated flows at the Parsons gage, October 1 to November 30, 1953.

A frequency analysis was performed on natural and regulated streamflow data at the Iola and Parsons gages. The results of this analysis are shown in tables 8-11. The analysis shows that regulation reduced the number of days of streamflow with less than 20 ft^3/s and with flows of more than 100 ft^3/s. Streamflow is distributed more evenly between 30 ft^3/s and 100 ft^3/s under regulated conditions than under natural conditions. The analysis shows that regulated streamflow conditions enhance and sustain flows greater than 20 ft^3/s during low-flow conditions at Iola and Parsons. This enhancement of streamflows of greater than 20 ft^3/s allowed the water-quality streamflows to be met more often at Iola.

The reservoir-routing model was used to determine the additional quantity of storage in John Redmond Reservoir that would be needed to satisfy the recommended multiple-use and water-quality streamflows at the Iola and Parsons gages during the three historical droughts. The model was modified by changing only the low-flow water-quality releases in the outflow routine to the multiple-use streamflows and then to the water-quality streamflows for both the Iola and Parsons gages.

The natural streamflows that occurred during the three historical droughts at the Strawn gage were used as inflow to the reservoir. Evaporation, precipitation, and the withdrawal of 41 ft^3/s for Wolf Creek powerplant were accounted for in the model. As with the reservoir-model simulations using the low-flow water-quality releases, the initial reservoir pool elevation was 1,039 ft (maximum conservation pool). The same reservoir-outflow operating procedure was used. During model operation, if the pool elevation decreased below the elevation of 1,020 ft (minimum conservation pool), the storage was considered to be insufficient to supply the recommended streamflows. If necessary, subsequent model simulations were made with an increased initial pool elevation and corresponding storage capacity. These were increased until sufficient storage was available to satisfy the multiple-use and water-quality streamflows at the Iola and Parsons gages. The difference between the increase in the final storage and the initial storage was considered to be the additional storage needed.

Table 8.--Frequency analysis of natural streamflows at the Iola gage

	Range of discharge (cubic feet per second)									
	0	<5	<10	<20	<30	<40	<50	<60	<100	≥100
Water year	Days of flow									
1933	0	0	0	0	4	15	37	80	222	143
1934	0	30	39	60	103	185	211	234	287	78
1935	0	0	0	0	18	34	46	63	141	224
1936	30	65	73	80	89	96	100	103	142	224
TOTAL	30	95	112	140	214	330	394	480	792	669
1953	0	19	31	61	78	101	113	126	243	122
1954	0	100	117	170	245	260	274	283	308	57
1955	0	53	95	130	166	178	196	205	236	129
1956	1	52	140	200	234	265	274	282	307	59
1957	0	172	174	182	185	192	199	208	218	147
TOTAL	1	396	557	743	908	996	1,056	1,104	1,312	514
1963	0	3	8	14	15	16	18	25	56	309
GRAND TOTAL	31	494	677	897	1,137	1,342	1,468	1,609	2,160	1,492

At the Iola gage, the streamflow occurring during all three droughts was sufficient to maintain the necessary reservoir storage needed to satisfy both the multiple-use and water-quality streamflows. At the Parsons gage, streamflow occurring during the three droughts was sufficient to provide the necessary reservoir storage needed to satisfy only the water-quality streamflows. An additional 15,400 acre-ft of reservoir storage was needed to satisfy the multiple-use streamflows at the Parsons gage during the 1950's drought.

During the three historical droughts, the multiple-use and water-quality streamflows were achieved less often under regulated conditions, indicating that streamflow during the three droughts on the lower Neosho River is primarily a function of the reservoir-operating procedures as defined by the outflow routine of the reservoir model. Under the operating procedures of the reservoir model, inflow would be held, while the designated low-flow water-quality release dictated the outflow. Thus on occasion, a significant inflow, which satisfied the multiple-use and water-quality streamflows under natural conditions, was held by the reservoir, while a relatively smaller outflow was conveyed down the lower Neosho.

Table 9.--Frequency analysis of natural streamflows at the Parsons gage

	Range of discharge (cubic feet per second)									
	0	<5	<10	<20	<30	<40	<50	<60	<100	≥100
Water year	Days of flow									
1933	0	0	0	0	14	28	55	76	176	189
1934	18	46	50	84	106	135	150	171	231	134
1935	0	0	0	0	0	2	14	20	42	323
1936	49	55	64	76	86	89	91	94	131	235
TOTAL	67	101	114	160	206	254	310	361	580	881
1953	0	22	55	88	104	115	121	129	245	120
1954	0	130	136	243	255	263	271	281	293	72
1955	1	60	71	97	103	107	109	115	143	222
1956	7	115	160	202	238	256	261	265	285	81
1957	174	185	189	200	203	210	212	215	224	141
TOTAL	182	512	611	830	903	951	974	1,005	1,190	636
1963	0	5	10	13	15	17	18	22	52	313
GRAND TOTAL	249	618	735	1,003	1,124	1,222	1,302	1,388	1,822	1,830

Table 10.-- Frequency analysis of regulated streamflows at the Iola gage

Water year	Range of discharge (cubic feet per second) 0	<5	<10	<20	<30	<40	<50	<60	<100	≥100
	Days of flow									
1933	0	0	0	0	202	238	301	303	308	57
1934	0	0	0	0	192	245	309	313	328	37
1935	0	0	0	0	154	158	193	195	239	126
1936	0	0	0	0	77	134	195	197	217	149
TOTAL	0	0	0	0	625	775	998	1,008	1,092	369
1953	0	0	0	0	184	239	300	300	326	39
1954	0	0	0	61	243	304	365	365	365	0
1955	0	0	0	61	243	304	365	365	365	0
1956	0	0	1	6	226	285	347	349	351	15
1957	0	0	0	61	207	235	261	261	265	100
TOTAL	0	0	1	189	1,103	1,367	1,638	1,640	1,672	154
1963	0	0	0	6	24	68	126	126	126	239
GRAND TOTAL	0	0	1	195	1,752	2,210	2,762	2,774	2,890	762

It should be noted that John Redmond Reservoir operating procedures and policy may vary under certain circumstances. Deviations from the low-flow release pattern, especially by passing inflows through John Redmond Reservoir for use by downstream water appropriations, could achieve multiple-use and water-quality streamflows to a greater extent than the results of this study indicate. Nonetheless, even during those periods when the multiple-use and water-quality streamflows were met less often, the magnitude of the flow deficiency usually was reduced, except for the multiple-use streamflows at the Parsons gage. For example, the days that the multiple-use streamflows were not met at the Iola gage during 1954 increased from 260 without regulation (table 12) to 304 with regulation (table 20). The amount of streamflow deficiency during 1954, however, decreased from 14,088 acre-ft (table 13) to 9,614 acre-ft (table 21).

The low-flow-augmentation capabilities of the reservoir are especially apparent during a severe drought, such as 1956 at the Iola gage. The water-quality streamflows during 1956 under natural conditions were unmet for 90 days (table 16), and the total streamflow deficiency was 3,679 acre-ft (table 17). Under regulation, only 5 days occurred when flow was less than the water-quality streamflow (table 24), and the total streamflow deficiency was only 64 acre-ft (table 25).

Table 11.--Frequency analysis of regulated streamflows at the Parsons gage

Water year	Range of discharge (cubic feet per second)									
	0	<5	<10	<20	<30	<40	<50	<60	<100	≥100
	Days of flow									
1933	0	0	0	20	202	238	301	303	308	57
1934	0	0	0	75	192	245	309	313	328	37
1935	0	0	0	0	154	158	193	195	240	125
1936	0	0	0	30	77	134	195	197	217	149
TOTAL	0	0	0	125	625	775	998	1,008	1,093	368
1953	0	0	0	12	184	239	300	300	326	39
1954	0	0	0	91	243	304	365	365	365	0
1955	0	0	0	91	243	304	365	365	365	0
1956	0	0	1	96	225	285	348	349	351	15
1957	0	0	0	61	212	235	261	261	265	100
TOTAL	0	0	1	351	1,107	1,367	1,639	1,640	1,672	154
1963	0	0	0	6	37	75	126	126	126	239
GRAND TOTAL	0	0	1	482	1,769	2,217	2,763	2,774	2,891	761

The influence of John Redmond Reservoir on downstream flows decreases as the distance below the reservoir increases, primarily because of the intervening inflow from unregulated drainage basins below the reservoir. The diversion of water for municipal, industrial, and irrigation uses also will affect the achievement of the multiple-use and water-quality streamflows.

SUMMARY

The effects of three historical droughts on multiple-use and water-quality minimum streamflows on the lower Neosho River in southeastern Kansas were investigated. Recommendations for multiple-use minimum streamflows were made by the Kansas Water Office. The Kansas Department of Health and Environment recommended the water-quality minimum streamflows. A natural condition using observed streamflows (and estimated flows when needed) and a regulated condition using simulated streamflows were compared to the multiple-use and water-quality streamflows at the Iola and Parsons streamflow-gaging stations.

The effect that John Redmond Reservoir would have had on the streamflows occurring during the historical droughts of the 1930's, 1950's, and 1963 was calculated using observed and estimated flows at the Strawn gaging station as inflow to a reservoir model. A diversion of 41 ft^3/s was withdrawn from the reservoir to account for usage by the Wolf Creek powerplant. The computed regulated outflow from the reservoir then was used in a streamflow model and routed to the Iola and Parsons streamflow-gaging stations. Comparisons of natural and regulated streamflows with the multiple-use and water-quality recommended minimum streamflows show the following:

1. Natural streamflows at the Iola gage did not meet the multiple-use streamflows 23, 55, and 4 percent of the time for the 1930's, 1950's, and 1963 droughts, respectively. The largest streamflow deficiencies occurred during 1954, 1956, and 1957, at the Iola gage. At the Parsons gage, the multiple-use streamflows were not met 21, 53, and 5 percent of the time during the three droughts, respectively. The largest deficiencies also occurred during 1954, 1956, and 1957 at the Parsons gage.

2. Natural streamflows at the Iola gage did not meet the water-quality streamflow recommendations 11, 32, and 4 percent of the time during the 1930's, 1950's, and 1963 droughts, respectively. Streamflow deficiencies were most critical during the 1954 water year (4,575 acre-ft) at the Iola gage. At the Parsons gage, the water-quality streamflows were not met 13, 42, and 4 percent of the time for each respective drought. Streamflow deficiencies also were most critical during the 1954 water year (4,479 acre-ft).

3. Regulated streamflows at the Iola gage did not meet the multiple-use streamflow recommendations 53, 75, and 19 percent of the time for the 1930's, 1950's, and 1963 droughts, respectively. The largest streamflow deficiency for all three droughts occurred during 1954 (9,614 acre-ft). At the Parsons gage, the multiple-use streamflows were not met 70, 90, and 35 percent of the time for each respective drought. The largest streamflow deficiency for all three droughts occurred during 1955 (17,400 acre-ft).

4. Regulated streamflows at the Iola gage met the water-quality streamflow recommendations all of the time except for the 1956 water year when only 5 days had deficient streamflow. At the Parsons gage, the water-quality streamflows were not met 32, 41, and 18 percent of the time for the three respective droughts. The largest streamflow deficiency for all three droughts occurred during 1955 (1,124 acre-ft).

5. At the Iola gage, the regulated streamflows usually satisfied the recommended multiple-use streamflows with smaller volume deficiencies as compared to the natural streamflows. At the Parsons gage, the natural streamflows satisfied the recommended multiple-use streamflows more frequently and with smaller volume deficiencies as compared to the regulated streamflows. The larger volume deficients for the regulated streamflows were attributed to the reservoir-operating procedure in the reservoir model. At the Iola gage, the regulated streamflows satisfied the recommended water-quality streamflows more frequently as compared to the natural streamflows. At the Parsons gage, the natural streamflows satisfied the recommended water-quality streamflows more frequently but with larger volume deficiencies as compared to the regulated streamflows.

Achievement of the multiple-use streamflows and water-quality streamflows on the lower Neosho River is largely dependent on the flow-release procedures from John Redmond Reservoir. Intervening tributary inflow may provide potential flow supplements to the reservoir releases made from John Redmond Reservoir. Existing water appropriations could cause potential streamflow depletion from the reservoir releases made from John Redmond Reservoir.

Frequency analysis of the natural and regulated flows indicate that regulation sustains flow during low-flow periods. The regulated condition reduced the number of days with flow of less than 20 ft^3/s and with flows of more than 100 ft^3/s. The number of days of flow were distributed predominantly between 30 ft^3/s and 100 ft^3/s for the regulated condition, which indicates a greater opportunity of meeting the recommended streamflows.

The reservoir-routing model was used to determine if the natural streamflows that occurred during the three historical droughts would maintain sufficient storage in John Redmond Reservoir to satisfy the recommended multiple-use and water-quality streamflows at both the Iola and Parsons gages. The reservoir was assumed to be full (maximum conservation pool) before inflow began. Only the streamflow occurring during the 1950's drought was insufficient to supply enough storage capacity to maintain the multiple-use streamflows at the Parsons gage. The additional storage needed was estimated to be 15,400 acre-ft.

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Table 12.--Days of deficient streamflow during natural conditions for multiple-use streamflows at the Iola gage

Water year	Days of deficient streamflow[1] for indicated month of water year												Annual total	Maximum number of consecutive days of deficient flows during water year
	O	N	D	J	F	M	A	M	J	J	A	S		
1933	3	1	0	0	0	0	0	0	2	3	6	0	15	4
1934	4	30	23	21	28	1	0	2	1	24	31	20	185	68
1935	21	12	0	0	0	0	1	0	0	0	0	0	34	23
1936	0	0	0	0	0	0	0	0	10	29	31	26	96	85
1953	30	0	0	0	0	0	0	0	2	9	31	29	101	43
1954	31	30	31	31	20	24	9	0	0	30	24	30	260	141
1955	18	28	31	22	5	4	0	14	0	11	24	21	178	62
1956	8	30	31	31	29	31	11	5	9	27	23	30	265	164
1957	31	30	31	31	28	26	0	0	0	0	7	8	192	176
1963	0	0	0	0	0	0	0	0	0	0	0	16	16	16

[1] Multiple-use streamflows recommended by the Kansas Water Office are given in table 1.

Table 13.--Amount of deficient streamflow during natural conditions for multiple-use streamflows at the Iola gage

Water year	Amount of deficient streamflow[1] (acre-feet) for indicated month of water year												Annual total
	O	N	D	J	F	M	A	M	J	J	A	S	
1933	85	28	0	0	0	0	0	0	4	14	73	0	204
1934	44	797	553	315	555	20	0	30	4	843	2,120	1,380	6,661
1935	446	282	0	0	0	0	18	0	0	0	0	0	746
1936	0	0	0	0	0	0	0	0	409	1,500	2,390	1,990	6,289
1953	748	0	0	0	0	0	0	0	8	280	1,640	1,880	4,556
1954	2,350	2,070	1,240	1,130	712	811	325	0	0	1,810	1,330	2,310	14,088
1955	1,200	1,760	2,030	899	173	58	0	377	0	417	1,260	1,560	9,734
1956	248	1,670	1,950	1,760	758	1,760	378	83	256	1,610	1,540	2,340	14,353
1957	2,450	2,350	2,370	2,380	2,040	1,840	0	0	0	0	270	240	13,940
1963	0	0	0	0	0	0	0	0	0	0	0	901	901

1 Multiple-use streamflows recommended by the Kansas Water Office are given in table 1.

Table 14.--Days of deficient streamflow during natural conditions for multiple-use streamflows at the Parsons gage

Water year	Days of deficient streamflow[1] for indicated month of water year												Annual total	Maximum number of consecutive days of deficient flows during water year
	O	N	D	J	F	M	A	M	J	J	A	S		
1933	8	14	0	0	0	0	0	0	9	13	11	0	55	17
1934	3	28	19	0	22	3	0	0	0	29	31	15	150	73
1935	0	6	0	0	0	0	0	0	0	0	8	0	14	8
1936	0	0	0	0	0	0	0	0	8	28	31	24	91	83
1953	31	16	0	0	0	0	0	0	6	7	31	30	121	68
1954	31	30	31	31	25	31	4	0	0	28	31	29	271	142
1955	4	18	28	0	0	0	0	6	0	5	26	22	109	46
1956	8	30	31	31	29	31	14	8	3	23	23	30	261	165
1957	31	30	31	31	28	29	1	0	0	0	9	22	212	174
1963	0	0	0	0	0	0	0	0	0	0	0	18	18	18

1 Multiple-use streamflows recommended by the Kansas Water Office are given in table 1.

Table 15.--Amount of deficient streamflow during natural conditions for multiple-use streamflows at the Parsons gage

Water year	Amount of deficient streamflow[1] (acre-feet) for indicated month of water year												Annual total
	O	N	D	J	F	M	A	M	J	J	A	S	
1933	66	149	0	0	0	0	0	0	87	200	242	0	744
1934	25	657	600	0	314	28	0	0	0	943	1,420	667	4,654
1935	0	31	0	0	0	0	0	0	0	0	72	0	103
1936	0	0	0	0	0	0	0	0	174	995	1,550	1,120	3,839
1953	934	577	0	0	0	0	0	0	59	140	1,200	1,350	4,260
1954	1,540	1,370	1,120	1,090	763	937	18	0	0	1,220	1,550	1,450	11,058
1955	139	630	1,290	0	0	0	0	157	0	148	1,070	1,080	4,514
1956	190	1,300	1,410	1,310	705	1,270	433	219	47	840	994	1,470	10,188
1957	1,550	1,500	1,550	1,550	1,400	1,370	5	0	0	0	223	822	9,970
1963	0	0	0	0	0	0	0	0	0	0	0	654	654

1 Multiple-use streamflows recommended by the Kansas Water Office are given in table 1.

Table 16.--Days of deficient streamflow during natural conditions for water-quality streamflows at the Iola gage

Water year	Days of deficient streamflow[1/] for indicated month of water year												Annual total	Maximum number of consecutive days of deficient flows during water year
	O	N	D	J	F	M	A	M	J	J	A	S		
1933	0	0	0	0	0	0	0	0	0	0	1	0	1	1
1934	0	0	0	0	0	0	0	0	0	20	31	19	70	65
1935	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1936	0	0	0	0	0	0	0	0	6	23	31	25	85	78
1953	4	0	0	0	0	0	0	0	0	7	31	26	68	40
1954	31	22	0	0	0	0	0	0	0	28	23	30	134	49
1955	16	19	22	0	0	0	0	1	0	8	23	21	110	38
1956	0	3	0	0	0	3	4	0	3	25	22	30	90	40
1957	31	30	31	31	26	23	0	0	0	0	5	3	180	137
1963	0	0	0	0	0	0	0	0	0	0	0	14	14	14

1 Water-quality streamflows recommended by the Kansas Department of Health and Environment are given in table 1.

Table 17.--Amount of deficient streamflow during natural conditions for water-quality streamflows at the Iola gage

Water year	Amount of deficient streamflow[1] (acre-feet) for indicated month of water year												Annual total
	O	N	D	J	F	M	A	M	J	J	A	S	
1933	0	0	0	0	0	0	0	0	0	0	4	0	4
1934	0	0	0	0	0	0	0	0	0	395	1,500	771	2,666
1935	0	0	0	0	0	0	0	0	0	0	0	0	0
1936	0	0	0	0	0	0	0	0	121	958	1,780	1,170	4,029
1953	32	0	0	0	0	0	0	0	0	127	1,030	1,010	2,199
1954	874	258	0	0	0	0	0	0	0	1,230	863	1,350	4,575
1955	375	103	51	0	0	0	0	2	0	230	790	889	2,440
1956	0	6	0	0	0	4	27	0	52	1,100	1,100	1,390	3,679
1957	971	445	283	287	201	271	0	0	0	0	147	87	2,692
1963	0	0	0	0	0	0	0	0	0	0	0	414	414

1 Water-quality streamflows recommended by the Kansas Department of Health and Environment are given in table 1.

Table 18.--Days of deficient streamflow during natural conditions for water-quality streamflows at the Parsons gage

Water year	Days of deficient streamflow[1] for indicated month of water year												Annual total	Maximum number of consecutive days of deficient flows during water year
	O	N	D	J	F	M	A	M	J	J	A	S		
1933	0	0	0	0	0	0	0	0	2	9	10	0	21	10
1934	0	0	0	0	0	0	0	0	0	29	31	13	73	73
1935	0	0	0	0	0	0	0	0	0	0	7	0	7	5
1936	0	0	0	0	0	0	0	0	6	27	31	24	88	82
1953	23	9	0	0	0	0	0	0	1	7	31	30	101	68
1954	31	27	0	0	0	12	0	0	0	28	31	29	158	88
1955	3	14	27	0	0	0	0	4	0	5	26	22	101	41
1956	5	29	31	23	0	24	7	7	2	23	22	30	203	83
1957	31	30	31	31	28	27	0	0	0	0	8	18	204	174
1963	0	0	0	0	0	0	0	0	0	0	0	15	15	15

Table 19.--Amount of deficient streamflow during natural conditions for water-quality streamflows at the Parsons gage

Water year	Amount of deficient streamflow[1] (acre-feet) for indicated month of water year												Annual total
	O	N	D	J	F	M	A	M	J	J	A	S	
1933	0	0	0	0	0	0	0	0	3	143	187	0	333
1934	0	0	0	0	0	0	0	0	0	798	1,270	389	2,457
1935	0	0	0	0	0	0	0	0	0	0	32	0	32
1936	0	0	0	0	0	0	0	0	72	856	1,400	636	2,964
1953	235	85	0	0	0	0	0	0	3	105	1,050	750	2,228
1954	770	344	0	0	0	29	0	0	0	1,080	1,390	866	4,479
1955	55	58	175	0	0	0	0	47	0	123	940	639	2,037
1956	27	250	174	96	0	210	91	64	8	725	881	873	3,399
1957	775	450	310	310	280	382	0	0	0	0	181	386	3,074
1963	0	0	0	0	0	0	0	0	0	0	0	628	628

1 Water-quality streamflows recommended by the Kansas Department of Health and Environment are given in table 1.

Table 20.--Days of deficient streamflow during regulated conditions for multiple-use streamflows at the Iola gage

Water year	Days of deficient streamflow[1] for indicated month of water year												Annual total	Maximum number of consecutive days of deficient flows during water year
	O	N	D	J	F	M	A	M	J	J	A	S		
1933	31	30	31	31	28	31	20	0	20	0	1	15	238	202
1934	20	30	31	31	28	31	14	7	22	0	1	30	245	167
1935	31	25	4	16	7	28	30	13	2	0	1	1	158	61
1936	0	0	0	0	15	16	30	16	26	1	0	30	134	42
1953	31	30	31	31	18	8	12	23	24	0	1	30	239	134
1954	31	30	31	31	28	31	30	31	30	0	1	30	304	273
1955	31	30	31	31	28	31	30	31	30	0	1	30	304	273
1956	16	30	31	31	29	31	30	28	29	2	0	29	286	208
1957	31	30	31	31	28	31	25	5	0	0	1	22	235	207
1963	1	2	4	2	4	1	10	13	0	0	1	30	68	31

Table 21.--Amount of deficient streamflow during regulated conditions for multiple-use streamflows at the Iola gage

Water year	Amount of deficient streamflow[1] (acre-feet) for indicated month of water year												Annual total
	O	N	D	J	F	M	A	M	J	J	A	S	
1933	1,021	1,160	1,199	1,125	1,016	1,119	750	0	155	0	15	229	7,789
1934	674	1,184	1,224	1,150	1,039	1,144	533	183	183	0	16	482	7,812
1935	1,027	972	156	578	253	1,005	970	266	5	0	13	13	5,258
1936	0	0	0	0	512	546	1,121	424	206	8	0	488	3,305
1953	1,021	1,160	1,199	1,113	646	287	452	593	190	0	16	476	7,153
1954	1,058	1,196	1,236	1,162	1,050	1,156	1,160	830	268	0	16	482	9,614
1955	1,058	1,196	1,236	1,144	1,033	1,138	1,148	818	256	0	16	482	9,525
1956	590	1,178	1,224	1,168	1,055	1,168	1,165	779	348	19	0	472	9,166
1957	1,064	1,202	1,242	1,168	1,055	1,163	719	84	0	0	13	292	8,002
1963	34	80	160	75	151	38	288	219	0	0	13	399	1,457

[1] Multiple-use streamflows recommended by the Kansas Water Office are given in table 1.

Table 22.--Days of deficient streamflow during regulated conditions for multiple-use streamflows at the Parsons gage

Water year	Days of deficient streamflow[1/] for indicated month of water year												Annual total	Maximum number of consecutive days of deficient flows during water year
	O	N	D	J	F	M	A	M	J	J	A	S		
1933	31	30	31	31	28	31	20	0	20	31	31	17	301	202
1934	23	30	31	31	28	31	14	7	22	31	31	30	309	167
1935	31	25	4	16	7	28	30	13	2	5	31	1	193	61
1936	0	0	0	15	16	30	16	26	31	31	31	30	226	118
1953	31	30	31	31	18	8	12	23	24	31	31	30	300	134
1954	31	30	31	31	28	31	30	31	30	31	31	30	365	365
1955	31	30	31	31	28	31	30	31	30	31	31	30	365	365
1956	17	30	31	31	29	31	30	28	30	31	31	30	349	209
1957	31	30	31	31	28	31	25	5	0	1	26	22	261	207
1963	1	2	4	2	4	1	10	13	7	21	31	30	126	70

1 Multiple-use streamflows recommended by the Kansas Water Office are given in table 1.

Table 23.--Amount of deficient streamflow during regulated conditions for multiple-use streamflows at the Parsons gage

Water year	Amount of deficient streamflow[1] (acre-feet) for indicated month of water year												Annual total
	O	N	D	J	F	M	A	M	J	J	A	S	
1933	1,666	1,785	1,845	1,740	1,572	1,734	1,210	0	615	461	485	613	13,726
1934	1,116	1,809	1,869	1,740	1,572	1,734	855	344	689	480	503	1,178	13,889
1935	1,636	1,463	234	895	392	1,560	1,666	567	52	62	411	36	8,974
1936	0	0	0	0	809	863	1,808	793	804	501	486	1,184	7,248
1953	1,666	1,785	1,845	1,734	1,007	447	728	1,122	743	480	503	1,178	13,238
1954	1,703	1,821	1,882	1,777	1,605	1,771	1,851	1,543	958	486	510	1,184	17,091
1955	1,861	1,922	1,992	1,765	1,594	1,765	1,839	1,543	964	497	480	1,178	17,400
1956	876	1,809	1,869	1,777	1,605	1,777	1,846	1,411	1,009	502	486	1,184	16,151
1957	1,709	1,827	1,888	1,783	1,611	1,777	1,294	199	0	13	354	803	13,258
1963	55	122	244	115	230	58	518	518	154	267	417	1,095	3,793

1 Multiple-use streamflows recommended by the Kansas Water Office are given in table 1.

Table 24.--Days of deficient streamflow during regulated conditions for water-quality streamflows at the Iola gage

Water year	Days of deficient streamflow[1/] for indicated month of water year												Annual total	Maximum number of consecutive days of deficient flows during water year
	O	N	D	J	F	M	A	M	J	J	A	S		
1933	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1934	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1935	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1936	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1953	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1956	4	0	0	0	0	0	0	0	1	0	0	0	5	3
1957	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1963	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 25.--Amount of deficient streamflow during regulated conditions for water-quality streamflows at the Iola gage

Water year	Amount of deficient streamflow[1/] (acre-feet) for indicated month of water year												Annual total
	O	N	D	J	F	M	A	M	J	J	A	S	
1933	0	0	0	0	0	0	0	0	0	0	0	0	0
1934	0	0	0	0	0	0	0	0	0	0	0	0	0
1935	0	0	0	0	0	0	0	0	0	0	0	0	0
1936	0	0	0	0	0	0	0	0	0	0	0	0	0
1953	0	0	0	0	0	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	0	0	0	0	0	0	0
1956	39	0	0	0	0	0	0	0	25	0	0	0	64
1957	0	0	0	0	0	0	0	0	0	0	0	0	0
1963	0	0	0	0	0	0	0	0	0	0	0	0	0

[1] Water-quality streamflows recommended by the Kansas Department of Health and Environment are given in table 1.

Table 26.--Days of deficient streamflow during regulated conditions for water-quality streamflows at the Parsons gage

Water year	Days of deficient streamflow[1/] for indicated month of water year O	N	D	J	F	M	A	M	J	J	A	S	Annual total	Maximum number of consecutive days of deficient flows during water year
1933	31	0	0	0	0	0	20	0	20	31	31	0	133	82
1934	20	0	0	0	0	0	14	7	22	31	31	0	125	68
1935	31	0	0	0	0	0	0	13	0	5	31	0	80	36
1936	0	0	0	0	0	0	29	16	26	31	31	0	133	88
1953	31	0	0	0	0	0	12	23	24	31	31	0	152	86
1954	31	0	0	0	0	0	30	31	30	31	31	0	184	153
1955	31	0	0	0	0	0	30	31	30	31	31	0	184	153
1956	13	10	0	0	0	0	29	28	29	31	31	0	171	90
1957	31	0	0	0	0	0	0	5	0	1	26	0	63	31
1963	1	0	0	0	0	0	0	13	0	21	31	0	66	40

Table 27.--Amount of deficient streamflow during regulated conditions for water-quality streamflows at the Parsons gage

Water year	Amount of deficient streamflow[1/] (acre-feet) for indicated month of water year O	N	D	J	F	M	A	M	J	J	A	S	Annual total
1933	129	0	0	0	0	0	20	0	20	154	178	0	501
1934	99	0	0	0	0	0	22	67	35	172	196	0	591
1935	98	0	0	0	0	0	0	52	0	13	104	0	267
1936	0	0	0	0	0	0	35	158	31	194	178	0	596
1953	129	0	0	0	0	0	14	210	29	172	196	0	750
1954	166	0	0	0	0	0	65	314	65	178	202	0	990
1955	324	0	0	0	0	0	54	313	71	190	172	0	1,124
1956	125	0	0	0	0	0	69	301	134	195	178	0	1,002
1957	172	0	0	0	0	0	0	1	0	3	96	0	272
1963	6	0	0	0	0	0	0	3	0	58	110	0	177

1 Water-quality streamflows recommended by the Kansas Department of Health and Environment are given in table 1.