TRANSIT LOSSES AND TRAVELTIMES FOR RESERVOIR RELEASES DURING DROUGHT CONDITIONS ALONG THE NEOSHO RIVER FROM COUNCIL GROVE LAKE TO IOLA, EAST-CENTRAL KANSAS

By W. J. Carswell, Jr., and R. J. Hart

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CONVERSION FACTORS

For those readers interested in the metric system, the factors for converting inch-pound units used in this report to the International System (SI) of Units are listed below, along with appropriate abbreviations:

Multiply inch-pound units	By	To obtain SI unit
inch	25.4 1/	millimeter
foot	0.3048	meter
mile	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
acre-foot	1,233	cubic meter
foot per foot (ft/ft)	1.0000	meter per meter
foot per mile (ft/mi)	0.1894	meter per kilometer
square foot per second (ft^2/s)	0.09290	square meter per second
square foot per day (ft^2/d)	0.09290	square meter per day
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06309	liter per second
gallon per day	3.785	liter per day
million gallons per day (Mgal/d)	4.381×10^{-2}	cubic meter per second
million gallons per year (Mgal/yr)	3,785	cubic meter per year
degree Fahrenheit (°F)	2/	degree Celsius (°C)

1 Exact conversion factor.

2 °C = (°F -32)/1.8.

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ABSTRACT

Knowledge of the transit losses and water-wave traveltimes in the Neosho River for varying reservoir-release volumes and durations is necessary for proper management of water supply. To obtain this knowledge, the U.S. Geological Survey, in cooperation with the Kansas Water Office, studied two reaches along the Neosho River in east-central Kansas. The upper reach is from Council Grove Lake to John Redmond Reservoir, a distance of 83.0 river miles. The lower reach is from John Redmond Reservoir to Iola, Kansas, a distance of 56.3 river miles.

Channel and aquifer characteristics were estimated from available data and used in a streamflow-routing model. These estimated characteristics were verified using the model by comparing simulated reservoir releases to observed reservoir releases. The verified model then was used to simulate transit losses (or gains) and traveltimes for selected reservoir-release volumes and durations from Council Grove Lake to Iola. Transit losses and traveltimes were investigated for the selected reservoir releases while under a severe-drought antecedent-streamflow condition (zero base flow) and a less-severe-drought antecedent-streamflow condition (2-percent drought base flows).

The largest total transit loss from Council Grove Lake to Iola occurred during the severe-drought antecedent-streamflow condition, small reservoir-release rates, and long reservoir-release durations. The total transit loss included water that was temporarily lost to bank storage. For a severe-drought condition, transit losses ranged from 1,100 acre-feet for a release volume of 1,840 acre-feet for a duration of 50 days to 6,280 acre-feet for a release volume of 6,280 acre-feet for a duration of 365 days. For a less-severe-drought condition, transit losses ranged from 860 acre-feet to 3,234 acre-feet for the same release volumes and durations as for the severe-drought condition.

Antecedent streamflows associated with severe-drought conditions resulted in slower wave celerities and longer traveltimes than for less-severe-drought conditions. Traveltimes to beginning of response from Council Grove Lake to Iola ranged from 2.2 days for small release rates (less than 18.6 cubic feet per second) for the severe-drought condition to 2.0 days for the less-severe-drought condition. Traveltimes to full response (when the downstream discharge is equal to 80 percent of the sum of the reservoir release and base flow) ranged from 69 days for a release rate of 18.6 cubic feet per second to more than 365 days for a release rate of 8.69 cubic feet per second during the severe-drought condition. For the less-severe-drought condition, traveltimes to full response ranged from 41 days for a release rate of 18.6 cubic feet per second to 200 days for a release rate of 8.69 cubic feet per second.

INTRODUCTION

The availability of surface water and ground water for water supply in the Neosho River basin of east-central Kansas is becoming more critical. The demand for water has increased due to population growth and industrial expansion. All the water supply available for purchase from State-owned storage in John Redmond Reservoir, about 100 miles downstream from Council Grove, has been purchased. Additional State-owned water supplies on the Neosho River are available only from Council Grove Lake.

Kansas water law provides that water purchased from reservoirs be purchased at the release point and not at the point of diversion. Therefore, a potential water purchaser needs to know what portion of the water released for his use will be lost during transit in the channel from the release point to the point of diversion. To effectively manage the release of the purchased water, the period of time required for the increase in flow due to the released water to travel from the reservoir to the point of diversion also needs to be known.

Purpose and Scope

In August 1980, the U.S. Geological Survey, in cooperation with the Kansas Water Office, began a study to determine the magnitude of streamflow losses and gains during drought conditions in two reaches of the Neosho River. One reach is from the outlet of Council Grove Lake to the inlet of John Redmond Reservoir. The other reach is from the outlet of John Redmond Reservoir to the U.S. Geological Survey streamflow gage near Iola, Kansas (fig. 1).

The scope of the investigation included data collection for surface- and ground-water information. Previously completed data collection and reports were used as background information. Model analysis was used to simulate transit losses and traveltimes in the study area. In this report the term traveltimes refers to water-wave traveltimes and not water-particle traveltimes. This report discusses the results of the investigation.

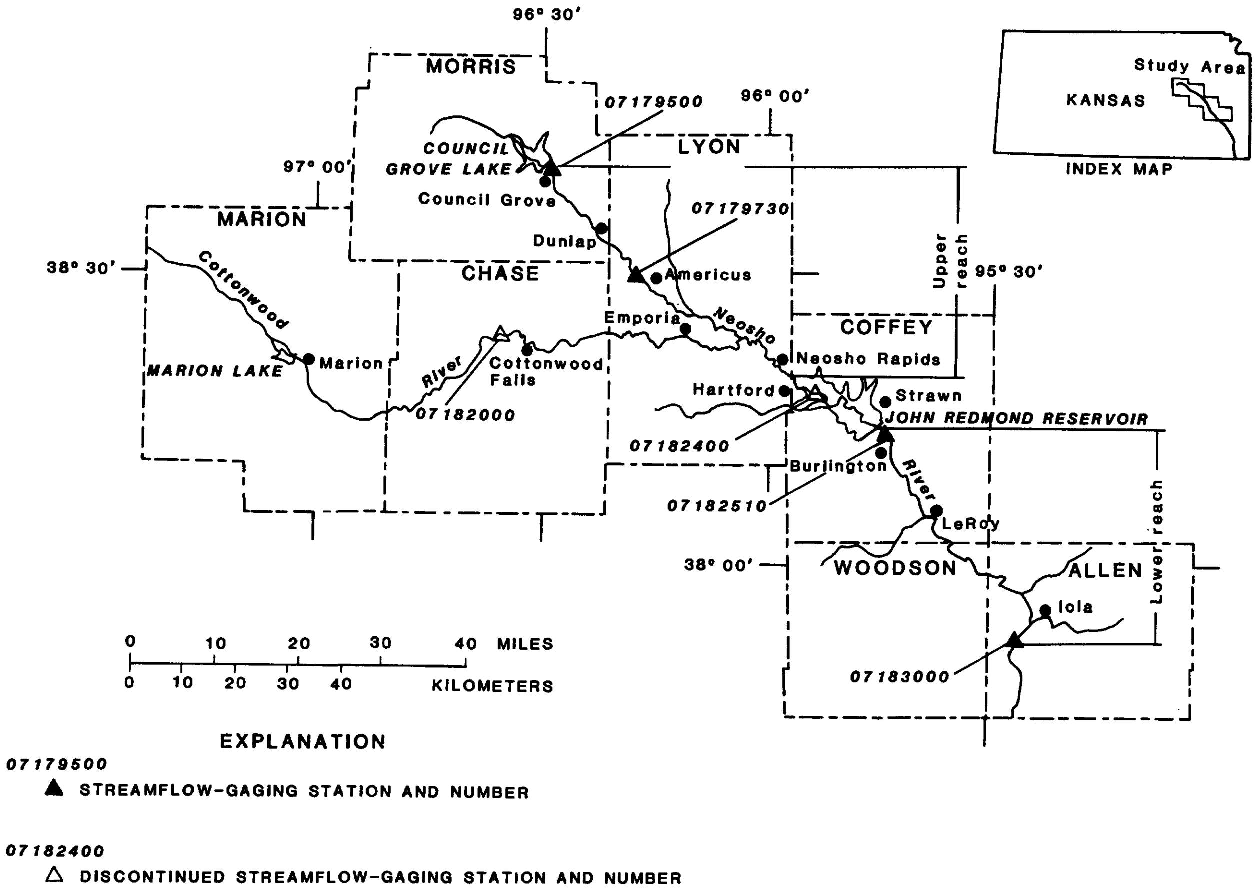

Figure 1.--Location of Neosho River, detail of study area, and streamflow-gaging stations.

Description of Study Area

The Neosho River originates in the Flint Hills Upland (Schoewe, 1949) in Morris County and flows southeasterly for more than 300 river miles in Kansas. The study area, shown in figure 1, includes approximately 165 river miles and has been divided into upper and lower reaches for ease of data handling and model analysis. The Neosho River valley downstream from Council Grove Lake to the inlet of John Redmond Reservoir (upper reach) is about 36 miles long and ranges in width from about 0.3 mile near Council Grove to about 1.6 miles near the confluence with the Cottonwood River. The valley downstream from John Redmond Reservoir to Iola (lower reach) is approximately 30 miles long and ranges in width from about 0.4 mile near Iola to about 4.5 miles near LeRoy.

The climate of the area is subhumid to humid. The principal source of precipitation in the area is from warm, moist air from the Gulf of Mexico. Precipitation and unregulated streamflows are extremely variable from year to year. Average annual precipitation in the study area is approximately 37 inches, and the average annual runoff is approximately 7 inches.

The study area lies chiefly within the Flint Hills Upland and the Osage Cuestas in the Osage Plains section of the Central Lowland Province (Schoewe, 1949). The Flint Hills are an area of outcrop of flint-bearing Permian rocks. The hilly topography is a result of differential weathering of the flint-bearing limestones and the less resistant shales. The streams in the area have deep, narrow valleys lined with outcropping rock ledges. The study area from Dunlap to Iola lies in the Osage Cuestas. The surface features include many east-facing escarpments, which trend irregularly from north-northeast to south-southwest. Between these westward-dipping hard limestone escarpments are flat to gently rolling plains.

The principal tributaries of the Neosho River in the study area are shown in figure 1. The Cottonwood River, which originates in Marion County to the west and joins the Neosho River in Lyon County, is the largest tributary in the study area (drainage area, 1,908 mi^2). All other main-stem Neosho River tributaries in the study area have drainage areas less than 200 mi^2. These smaller tributaries experience periods of no flow during moderate droughts. The streamflow-gaging station on the Cottonwood River near Cottonwood Falls (07182000) had no flow at times during 1955-57, during one of the severest droughts in recent Kansas history. The Neosho River near Iola (07183000) had no flow at times during 1936 and 1956.

Stream slopes in the vicinity of Council Grove exceed 3 ft/mi but decrease to less than 2 ft/mi in the vicinity of Emporia. Downstream from Emporia, the Neosho River channel slope averages about 1.2 ft/mi. The channel slope is controlled primarily by outcropping ledges of limestone and shale, which at low flows create a series of riffles and pools.

Alluvial deposits in the river valley consist mainly of unconsolidated stream-laid gravel, sand, silt, and clay, together with occasional cobbles and boulders. The larger stream valleys contain large amounts of chert gravel in the basal part of the alluvium in addition to considerable amounts of sand-size chert grains. Limestone and shale detritus, mollusk shells, and woody plant material locally occur with the quartz and chert sand and gravel. The material in the upper and middle parts of the alluvial deposits consists of silt and clay. The lower part is generally sandy, and the upper part is nearly free of sand (O'Connor and others, 1953; Miller, 1969).

The unconsolidated deposits near Emporia range in thickness from zero to approximately 60 feet. Wells screened in the unconsolidated deposits have been reported to yield up to 100 gal/min (Morton and Fader, 1975).

STREAMFLOW LOSSES AND GAINS

Sources of streamflow losses and gains during transit are withdrawal by water-right holders, evapotranspiration, return flows from municipal sewage effluents, and streamflow-aquifer interaction. The upper and lower reaches of the Neosho River were divided into subreaches (figs. 2 and 3) to better define these losses and gains and to aid in model analysis. The subreaches were delineated by streamflow-measuring sites located near riffles.

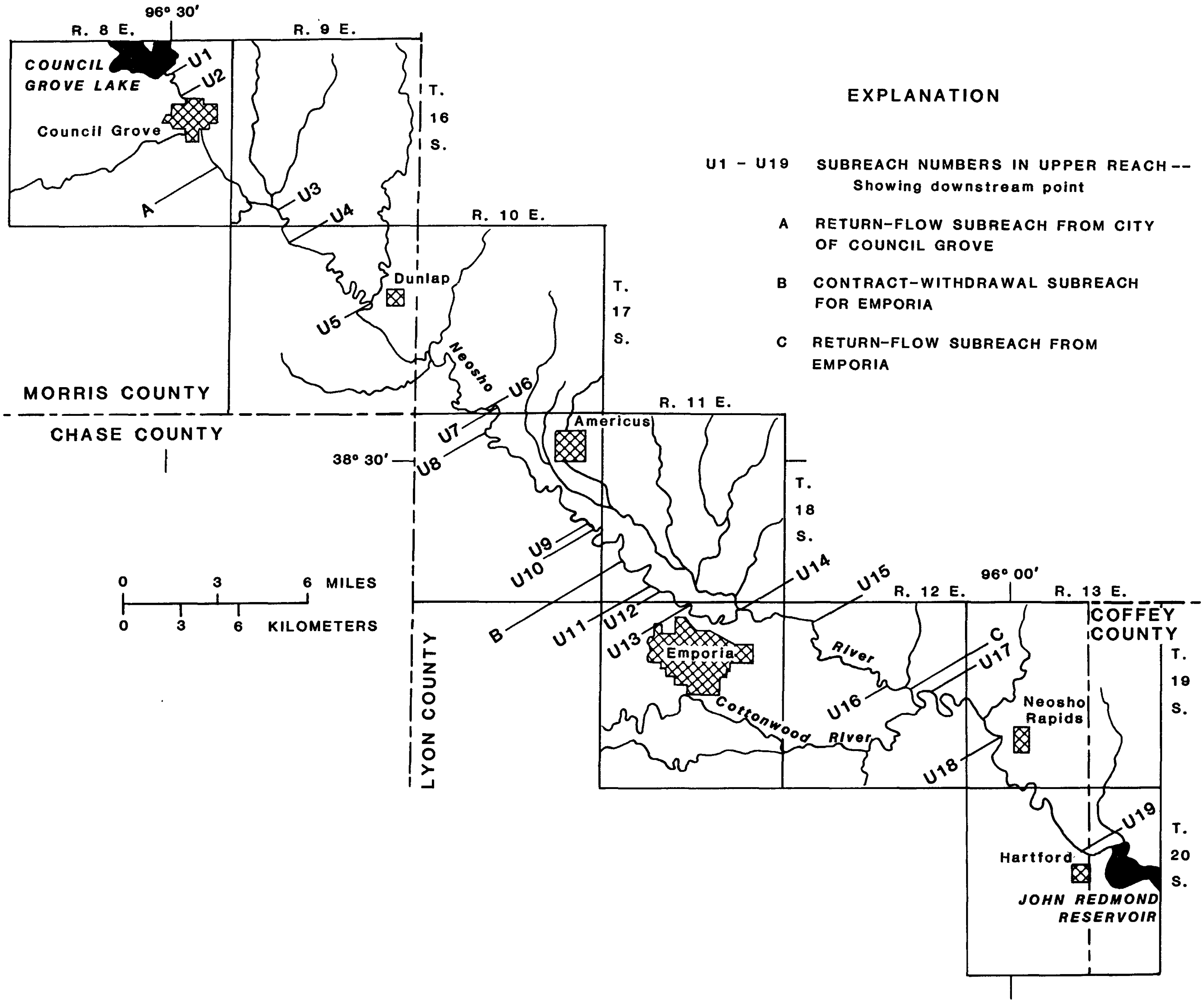

Figure 2.--Location of subreaches, contract-withdrawal points, and return flows in upper reach.

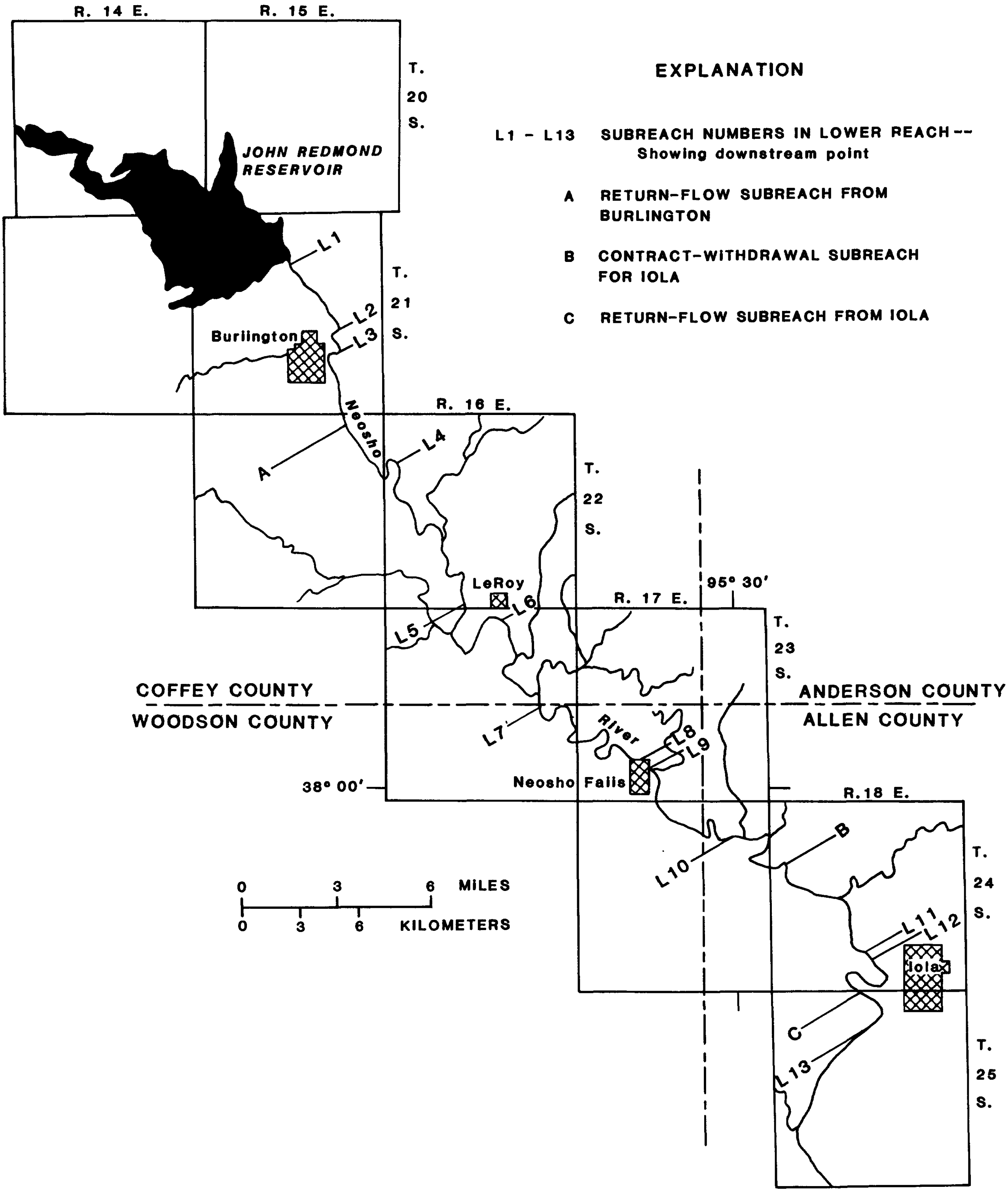

Figure 3.--Location of subreaches, contract-withdrawal points, and return flows in lower reach.

Withdrawal by Water-Right Holders

Information supplied by the Water Resources Division of the Kansas State Board of Agriculture indicates, as of December 1980, that 62 water-right permits have been issued to withdraw water from the main-stem Neosho River between Council Grove Dam and the streamflow-gaging station near Iola. Of these 62 permits, four are for vested water rights held by municipalities. A vested right is the right to continue the use of water having been appropriated for a beneficial use prior to June 28, 1945. The total authorized withdrawal rates (streamflow losses) on the main-stem Neosho River are listed in table 1, providing information as to the authorized diversions (losses) that can occur within a subreach.

Two municipalities, Emporia and Iola, have entered into purchase contracts with the State of Kansas for water from Council Grove Lake. All the water supply available in John Redmond Reservoir has been contracted for by the Kansas Gas and Electric Company. These contract-withdrawal and subreach locations are shown in figures 2 and 3.

Table 1.--Total authorized withdrawal rates by water-right holders in the study area by subreach

Subreach number[1]	River mile	Total authorized withdrawal rate[2] (gallons per minute)
U2	448.0	4,200
U4	438.4	1,200
U5	430.5	6,140
U6	418.4	5,700
U9	409.2	3,050
U11	401.3	13,600
U13	398.1	1,550
U16	384.9	1,800
U18	374.3	3,700
L1	343.6	100
L2	340.1	117,035
L3	338.4	2,200
L4	332.8	2,150
L5	325.0	1,500
L6	320.9	4,160
L8	307.5	310
L10	301.9	1,400
L11	292.1	8,050

1 "U" denotes upper reach, and "L" denotes lower reach.

2 Information supplied by the Water Resources Division of the Kansas State Board of Agriculture.

Evapotranspiration

Estimates were made for river-surface evaporation and riparian evapotranspiration (both streamflow losses) for use in model simulations. By definition, evapotransporation is the evaporation from all water, soil, snow, ice, vegetation, and other wetted surfaces plus transpiration from plants (Linsley and others, 1982). For the purpose of this study, consideration of evapotranspiration is limited to that which could directly affect transit losses; that is, from the river surface and from riparian land, which includes land that forms the banks of a stream.

To estimate river-surface evaporation within the study area, pan evaporation data for John Redmond Reservoir were used. Pan evaporation for 1980 was used since it was desirable to use a dry period of record. Because of the absence of knowledge concerning evaporation from river surfaces, the pan evaporation was adjusted using a pan coefficient of 0.70, which is often used for lake evaporation. These estimates were used in the streamflow-routing model simulations to determine evaporation losses during reservoir releases. Evaporation was adjusted for changes in river-surface width since the width varied with the rate of reservoir release.

A technique presented by Jensen (1973) was used to estimate the riparian evapotranspiration along the streambanks in the study area. An estimate of the width of the riparian land along streams was made and used for determining the riparian evapotranspiration estimates. Riparian evapotranspiration was varied during the model simulations, depending upon the season of the year.

Return Flows from Municipal Sewage Effluent

The primary source of return flows (streamflow gain) is from municipal sewage effluent. The subreach location of these return flows is shown in figures 2 and 3. Municipal sewage effluent of any significance is returned to the main-stem Neosho River by the cities of Council Grove, Burlington, and Iola. Water withdrawn by Emporia is discharged after treatment to the Cottonwood River. Also, Iowa Beef Packers discharges treated water to the Cottonwood River. Return flows also are possible as a result of overirrigation of crops. However, after inspection of several irrigated fields, irrigation return flows in the study area were considered negligible. The Kansas Gas and Electric Company diversion has no return flow.

Stream-Aquifer Interaction

If the alluvium (aquifer) and river are hydraulically connected, an interchange of water is possible. In a stream-aquifer system, a rise in stage of the stream above the level of ground water in the alluvium causes water to move into the aquifer or decreases the amount of water moving from the aquifer into the stream; a drop in the stage of the stream releases water that was stored temporarily in the aquifer. Also, ground-water inflow can be stopped or diminished by increases in hydraulic head resulting from a reservoir release or water wave. This phenomenon is called bank storage.

In an effort to better understand the stream-aquifer system, water levels in existing domestic wells located in the alluvial aquifer were evaluated. For the majority of these wells, monthly water-level altitudes were available only for March to September 1981; however, for some of the wells, monthly water-level altitudes were available from August 1980 to September 1981. A potentiometric-surface map for the alluvial aquifer (figs. 4 and 5) was developed for August 1981, in which the maximum number of wells were measured. The contours indicate that on August 11 and 12, 1981, the ground-water gradient was generally toward the river.

Well-Data-Collection Sites

In addition to the areal evaluation of the stream-aquifer system, more detailed information was obtained concerning the interchange of water in the stream-aquifer system at two locations in the study area about 2 miles downstream from Council Grove and about 1 mile downstream from Burlington (fig. 1). These more detailed data-collection sites were selected based on accessibility. At each site four observation wells were placed at varying distances from the river.

The continuous measurement of water-level response in the wells to changes in the river stage were used to determine the aquifer diffusivity in the vicinity of the well site. Diffusivity, the ratio of the transmissivity to the storage coefficient (T/S), was determined from type curves using an equation developed by Pinder and others (1969). They assumed in their paper that they had a semi-infinite aquifer, which also was assumed in this investigation for modeling purposes.

Council Grove Site

At the data-collection site near Council Grove, the three wells closest to the river (wells 1, 2, and 3) were instrumented with bubble-gage-driven digital recorder (5-minute punch intervals). The well farthest from the stream (well 4) was not instrumented. The river stage at this data-collection site was determined by using a bubble-gage-driven digital recorder (5-minute punch interval).

Periodic water-level measurements at the Council Grove data-collection site confirmed that at low river stages in the upper reach, the gradient of ground water in the alluvium was toward the river (fig. 6). The water levels shown in figure 6 for November 3, 1981, when the river stage was higher than base-flow conditions, indicate movement of water from the river to the aquifer. All other ground-water gradients shown in figure 6 are for periods during which the river stage was low, and the gradient indicates that water movement was from the aquifer to the river.

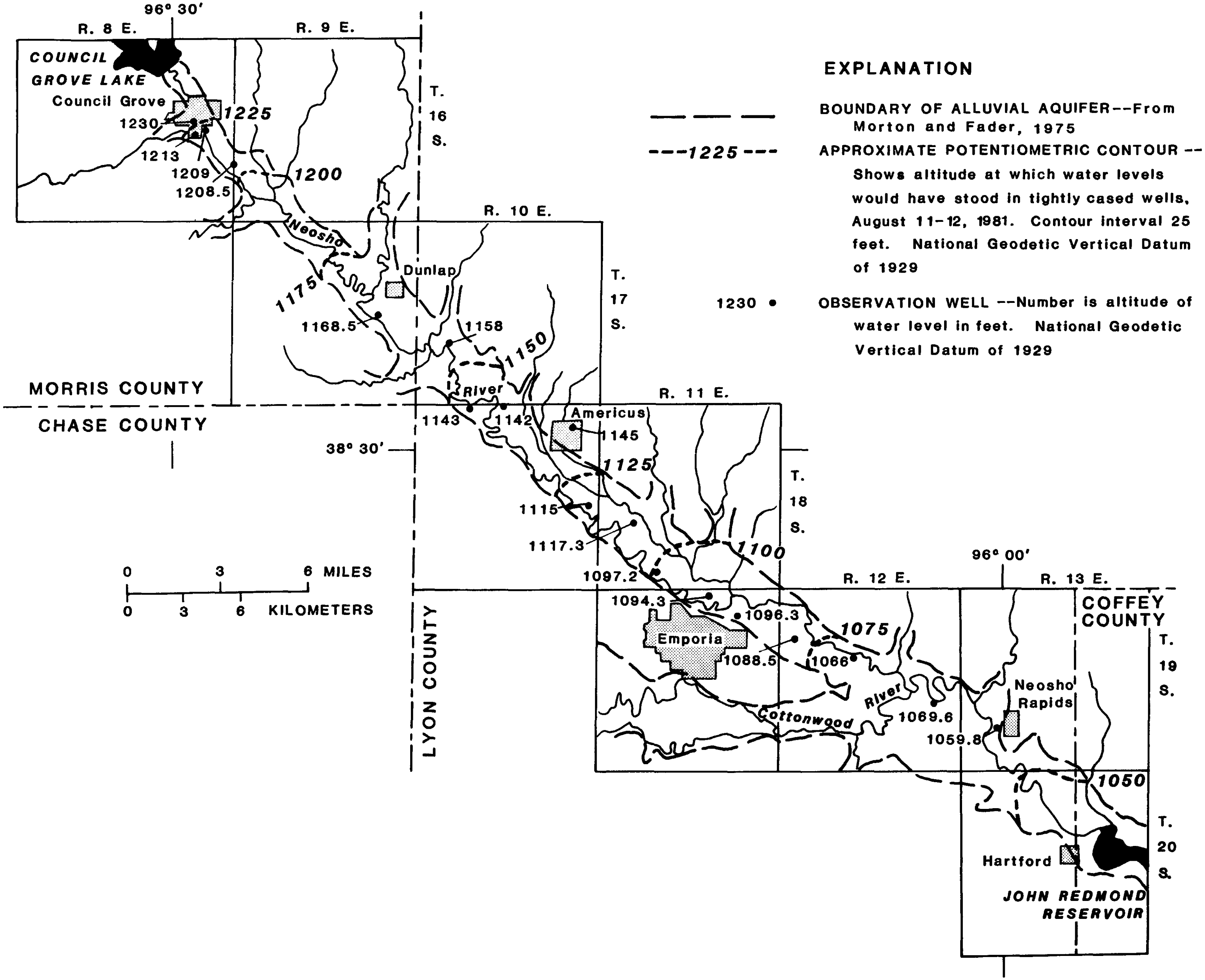

Figure 4.--Altitude of approximate potentiometric surface in alluvial aquifer, August 11-12, 1981, in upper reach.

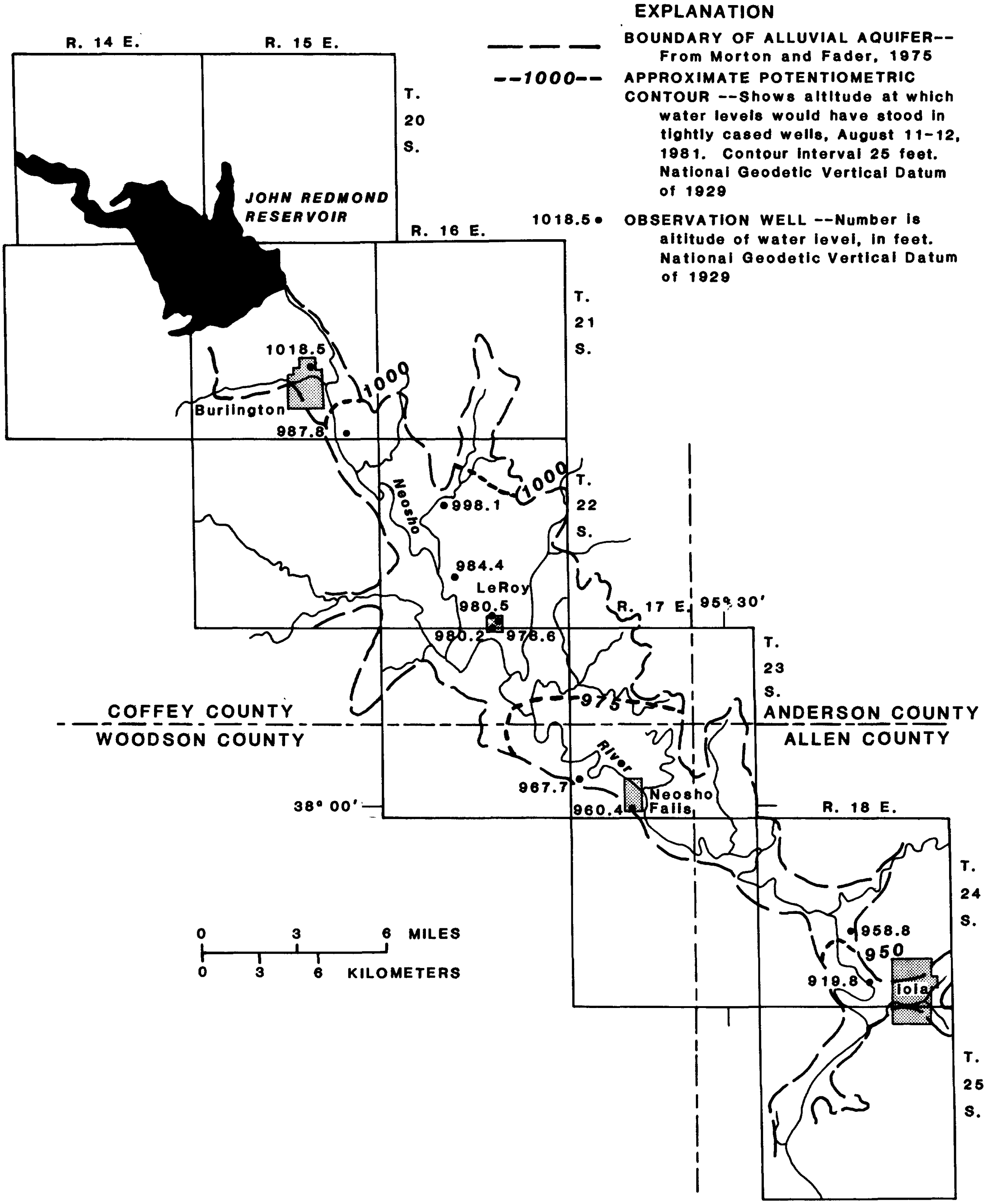

Figure 5.--Altitude of approximate potentiometric surface in alluvial aquifer, August 11-12, 1981, in lower reach.

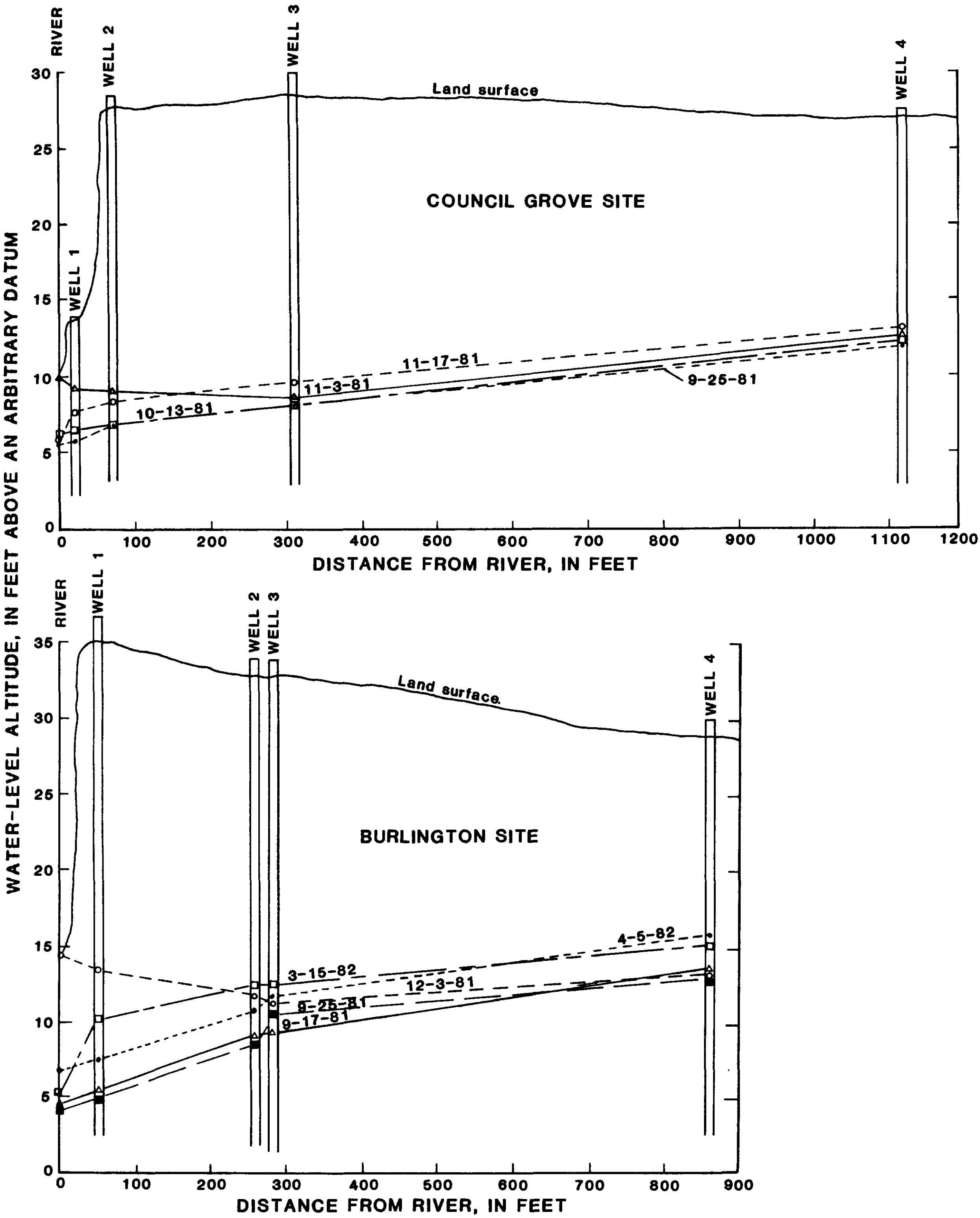

Figure 6.--Selected water levels and ground-water gradients for data-collection sites at Council Grove and Burlington.

Well 1 was used as the reference well. The change in stage in this well was used to calculate water-wave responses for observation wells 2 and 3. A diffusivity value of 6,900 ft^2/d provided the "best fit" for the observed hydraulic-head changes. An example of the observed and calculated water-wave-response values for well 2 is shown in figure 7.

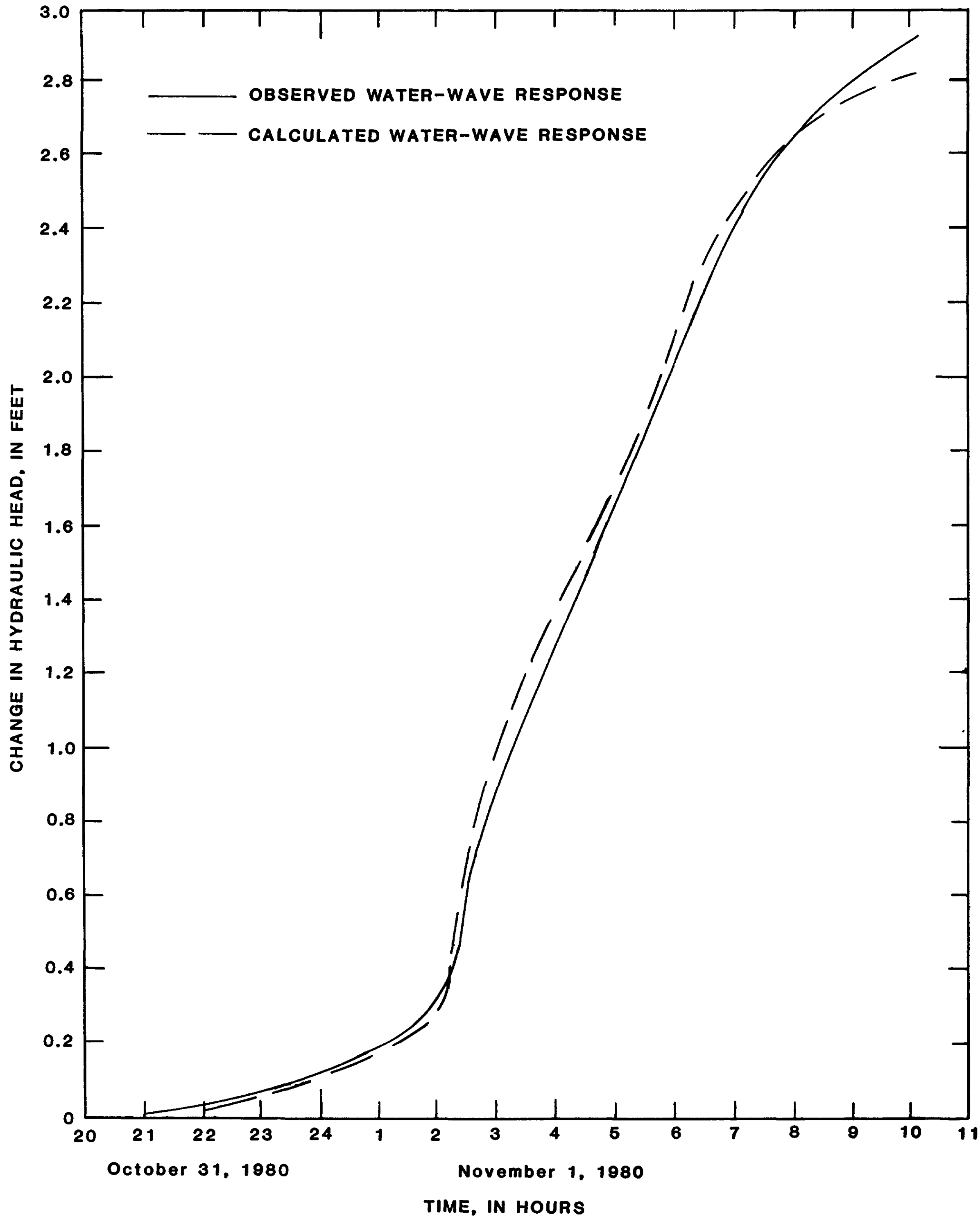

Figure 7.--Observed and calculated water-wave response for well 2 at Council Grove data-collection site.

An injection test was performed for well 3 to determine the aquifer transmissivity. Water levels in the well were monitored, and the Theis recovery method (Theis, 1935) was used to determine a transmissivity value of 350 ft^2/d. Once the diffusivity and transmissivity were known, the storage coefficient was calculated to be 0.05.

Burlington Site

At the data-collection site near Burlington, the well closest to the river (well 1) was instrumented with a bubble-gage-driven digital recorder (15-minute punch interval). Wells 2 and 3 were instrumented with bubble-gage-driven graphic recorders. Well 4 was instrumented with a float-driven graphic recorder.

As with the Council Grove data-collection site, periodic water-level measurements at the Burlington well site confirmed that at low river stages in the lower reach the alluvial ground-water gradient was toward the river (fig. 6). The water levels shown for December 3, 1981, when the river stage was higher than base-flow conditions, indicate movement of water from the river to the aquifer. All other ground-water gradients shown in figure 6 are for periods in which the river stage was low, and the gradient indicates that water movement was from the aquifer to the river. Calculation of diffusivity and injection tests were not performed at this site due to a time limitation on the project.

Gain-Loss Investigations

To determine in a general sense if the magnitude of streamflow losses or gains during low-flow periods exceeds transit losses for the main stem Neosho River, available streamflow records were examined for the Neosho River streamflow-gaging stations at Council Grove (07179500), drainage area 250 mi^2; near Americus (07179730), 622 mi^2; at Strawn (07182400), 2,933 mi^2; at Burlington (07182510), 3,015 mi^2; and near Iola (07183000), 3,818 mi^2. Minimum mean daily discharges during concurrent extended low-flow periods were plotted for adjacent streamflow-gaging stations to determine if losses in the reach exceeded the ground-water gain. The comparisons are presented in figure 8, which shows that during a few low-flow periods less water arrives at the downstream streamflow-gaging station than was present at the upstream station. The points that plot to the right of the line of equal discharge in figure 8 indicate that a net loss of water occurred in the reach between stations. The streamflow-discharge data indicate that some form of transit loss does occur in the main stem Neosho River.

During August 21-22, and November 4-5, 1980, streamflow gain-loss investigations were conducted in the study area. The investigations involved discharge measurements or observations of no flow at 21 main-stem sites and 18 tributary sites and water-level determinations for selected alluvial wells.

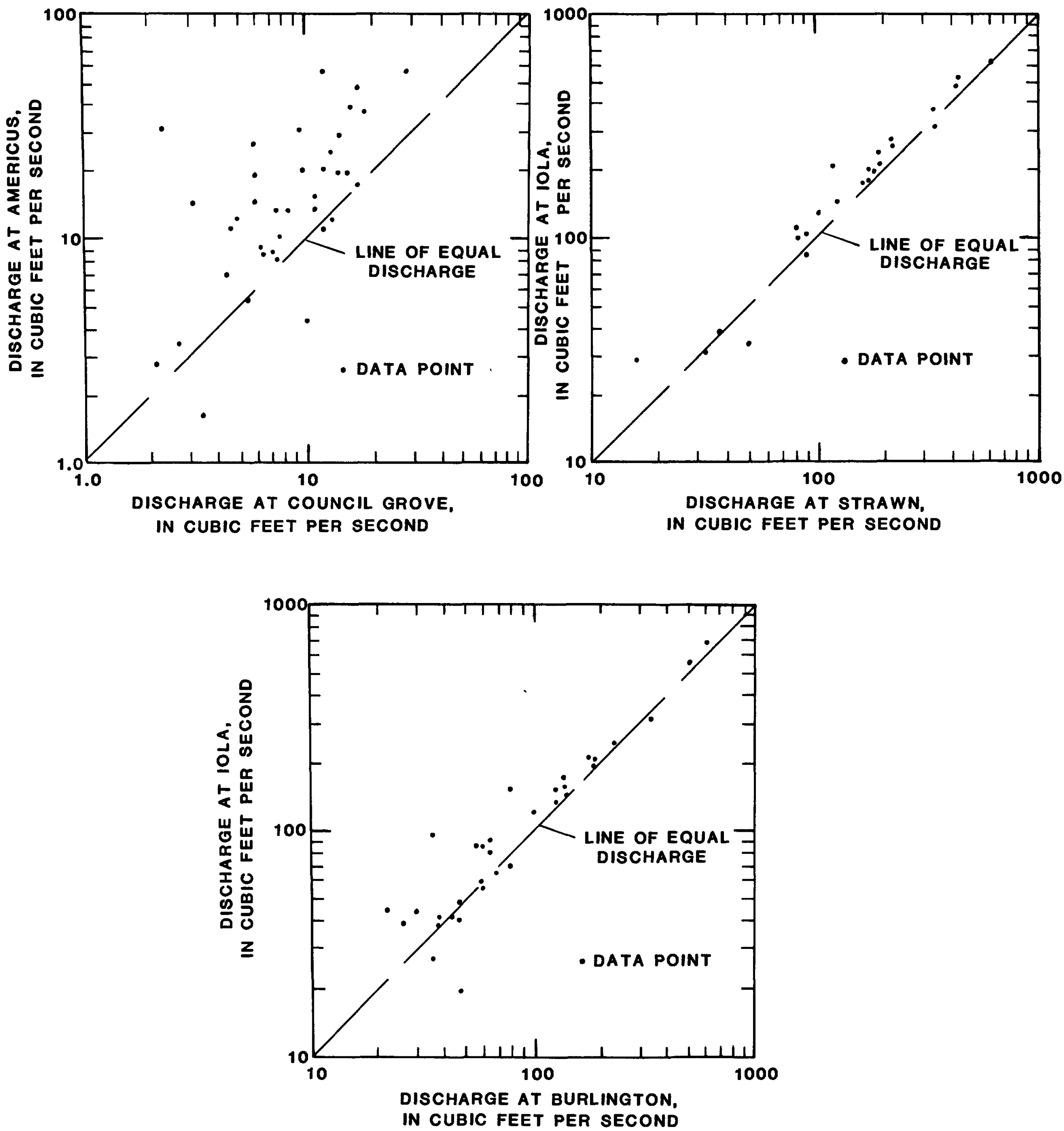

Figure 8.--Comparison of minimum mean daily discharges during concurrent low-flow periods at streamflow-gaging stations in study area.

Diversions for irrigation and water-supply purposes were examined along the study area, and adjustments were made. Amounts of withdrawals by water-right holders were obtained by contacting each right holder. From their records, an estimate was obtained of the water withdrawn in each subreach on the day in which the gain-loss measurement was made. Return-flow discharges were obtained from municipal sewage-disposal records, and along with tributary inflow, were subtracted from measured discharge to produce the main-stem Neosho River discharge adjusted for withdrawals and return flows.

August 1980 Investigation

The August 21-22, 1980, gain-loss investigation was made during a period in which river evaporation and riparian evapotranspiration were high. For the previous 4 months, April-July, the rainfall in the basin was approximately 13 inches below the 4-month average (April-July). Rainfall amounts generally totaling less than 1.5 inches occurred during August 14-18 (National Oceanic and Atmospheric Administration, 1981), and very little surface runoff occurred as a result of this rainfall. Steady-flow conditions occurred during this gain-loss investigation throughout the entire basin. Table 2 shows the results of the investigation.

Based solely on the measured discharge, the Neosho River would be considered generally a losing stream in the subreaches from U3 to U12, U14-U15, U18-U19, L6-L9, and L10-L12. This apparent water loss could result from pumping from the stream, river-surface evaporation, riparian evapotranspiration, and water moving from the stream to the aquifer. After adjustments were made to the measured discharge, all subreaches showed gains, except for subreaches U4-U10, U14-U15, U18-U19, L6-L9, and L10-L12, which remained losing subreaches.

November 1980 Investigation

The November 4-5, 1980, gain-loss investigation was made after killing frosts had occurred, which essentially reduced transpiration to zero. For the previous 4 months, July-October, rainfall in the basin was 4 to 5 inches below average. Rainfall amounts generally totaling less than 1 inch occurred during October 24-28 (National Oceanic and Atmospheric Administration, 1981). Because of the dry conditions, very little surface runoff occurred as a result of this rainfall. A steady-flow condition occurred in the upper part of the basin from Council Grove Lake to John Redmond Reservoir during this investigation. Interpretation of these data to determine natural gains and losses is more difficult than for the August gain-loss data. Table 3 shows the results of the November investigation.

The major complexity in the upper part of the basin is evident near the Americus streamflow gage (U10). Although discharge measurements defined a gain of approximately 3 ft^3/s in the reach from U8-U10, this does not represent the entire ground-water discharge but includes a release of water stored behind a low-head dam immediately upstream from the streamflow gage. Due to the lack of additional information on the exact quantity of water released, all of the main-stem increase in discharge in this reach was assumed to be water released from the low-head dam.

Table 2.--Results of the August 21-22, 1980, gain-loss investigation

Subreach[1] number	River[2] mile	Average measured discharge (cubic feet per second)	Water pumped in subreach (cubic feet per second)	Return flows (cubic feet per second)	Tributary inflow (cubic feet per second)	Adjusted discharge (cubic feet per second)	Gain or loss (cubic feet per second)	Cumulative gain/loss (cubic feet per second)
				Upper Reach				
U2	448.0	23.6	0	0	0	23.6	0	0
U3	442.0	24.4	0	0.62	0	23.8	0.2	0.2
U4	438.4	23.6	1.82	0	0	24.8	1.0	1.2
U5	430.5	21.2	2.23	0	0.02	24.6	- .2	1.0
U7	418.3	19.0	0	0	0	22.4	-2.2	-1.2
U8	416.3	18.6	0	0	0	22.0	- .4	-1.6
U10	409.1	18.1	0	0	0	21.5	- .5	-2.1
U12	401.2	6.64	12.4	0	0	22.4	.9	-1.2
U13	398.1	8.36	0	0	0	24.1	1.7	.5
U14	395.0	9.44	0	0	0	25.2	1.1	1.6
U15	389.9	8.75	0	0	0	24.5	- .7	.9
U18	374.3	61.6	1.12	0	51.4	27.2	2.7	3.6
U19	366.8	60.4	0	0	51.4	26.0	-1.2	2.4
				Lower Reach				
L3	338.4	52.7	0	0	0	52.7	0	0
L4	333.0	54.6	1.67	0.35	0	55.9	3.2	3.2
L5	325.0	54.6	0	0	0	55.9	0	3.2
L6	320.9	55.1	.15	0	0	56.6	.7	3.9
L9	307.4	53.0	.18	0	0	54.6	-2.0	1.9
L10	301.9	54.2	0	0	0	55.8	1.2	3.1
L12	292.1	45.8	3.01	0	0	50.5	-5.3	-2.2
L13	287.4	48.3	0	1.24	0	52.1	1.6	-0.6

1 "U" denotes upper reach, and "L" denotes lower reach.

2 Information obtained from the U.S. Army Corps of Engineers Flood Plain Information for the Neosho and Cottonwood Rivers (1965).

Table 3.--Results of November 4-5, 1980, gain-loss investigation

Subreach[1] number	River[2] mile	Average measured discharge (cubic feet per second)	Water pumped in subreach (cubic feet per second)	Return flows (cubic feet per second)	Tributary inflow (cubic feet per second)	Adjusted discharge (cubic feet per second)	Gain or loss (cubic feet per second)	Cumulative gain/loss (cubic feet per second)
				Upper Reach				
U1	449.7	3.20	0	0	0	3.20	0	0
U2	448.0	3.22	0	0	0	3.22	0.02	0.02
U3	442.0	3.32	0	0	0	3.32	.10	.12
U4	438.4	3.60	0	0	0	3.60	.28	.40
U5	430.5	3.30	0	0	0	3.30	-.30	.10
U8	416.3	2.73	0	0	0.03	2.70	-.60	-.50
U10	409.1	5.88	(-2.5)	0	0	3.60	.90	.40
U12	401.2	0.00	7.26	0	0	4.73	1.13	1.53
U13	398.1	.54	0	0	0	4.27	-.46	1.07
U14	395.0	.88	0	0	.05	5.59	1.32	2.39
U15	389.9	.86	0	0	0	5.54	-.05	2.34
U16	384.9	.84	0	0	0	5.52	-.02	2.32
U17	380.9	32.6	2.32	0	33.6	6.00	.48	2.80
U18	374.3	34.9	0	0	0	8.30	1.70	4.50
U19	366.8	35.7	0	0	0	9.10	.80	5.30

1 "U" denotes upper reach.

2 Information obtained from the Corps of Engineers Flood Plain Information for the Neosho and Cottonwood Rivers (1965).

In the lower part of the basin downstream from John Redmond Dam, a steady-state condition did not exist on November 5, when the discharge measurements were made. Beginning in October 1980, approximately 150 ft^3/s of water were released from John Redmond Reservoir for withdrawal immediately downstream from the dam. The released water, however, was pumped at a varying rate from the river ranging from 100-145 ft^3/s. This withdrawal was made by the Kansas Gas and Electric Company under contract with the State. Due to the nonsteady-state condition, results of the gain-loss investigation on the lower reach are not presented in table 3.

As with the August gain-loss investigation, water-right withdrawals and return flows and tributary inflow, which occurred during the November investigation, were used to adjust the main-stem measured discharges.

STREAMFLOW-ROUTING MODEL

As a reservoir release or water wave moves downstream, water is temporarily stored in the bank and channel. The water that initially is stored in the bank and channel gradually returns to the river once the flow has been reduced. The effect of this temporary storage is a reduction in peak discharge and an attenuation of the discharge hydrograph over distance.

The streamflow-routing model used for this study mathematically simulates the response of the stream-aquifer system to the stress created by the movement of a reservoir release or water wave through the study reach. The model is based on an analytical solution for the diffusion equation for an instantaneous unit input. The diffusion equation has been shown to be an approximation of the diffusion-wave model of one-dimensional streamflow routing. This type of model is called a diffusion-analogy model. The downstream hydrograph is computed by convoluting the upstream (inflow) hydrograph with the analytical solution for instantaneous input. Computation of bank storage in the model is based on an analytical solution for the one-dimensional saturated ground-water-flow equation for a sudden unit change in stage in the river. The bank-storage discharge is computed by convoluting the analytical solution of the ground-water-flow equation with the mean stage hydrograph for the reach. The bank-storage discharge is combined with the streamflow-routing model results at the downstream end of the reach. If a significant change in discharge occurs due to bank storage, the stage is adjusted, and the bank-storage computations are repeated (L. F. Land, U.S. Geological Survey, written commun., 1977). Based on data obtained from R. D. Burnett and T. B. Reed (U.S. Geological Survey, written commun., 1982), Miller (1969), Morton and Fader (1975), O'Connor and others (1953), and information obtained from the observation-well sites at Council Grove and Burlington, the boundary condition used was determined to be a semi-infinite aquifer without a confining bed separating the stream and the aquifer.

The streamflow-routing model is capable of simulating pumpage from the river based on an analytical expression for stream depletion by wells. This capability can be used also to account for losses from evapotranspiration and gains from return flows. The model assumes a flat water table at the initial time.

The model requires as input: (1) streamflow discharge, (2) channel characteristics, and (3) aquifer characteristics. Table 4 lists the selected channel and aquifer characteristics used in the model. For each subreach, output from the model produces tabulated and graphical hydrographs for upstream, downstream, and bank-storage discharges, traveltimes, and a summary of transit losses or gains to bank storage and diversions.

The streamflow-routing model was used to simulate transit losses and traveltimes for reservoir releases. Use of the model consisted of three phases: (1) determination and estimation of channel hydraulic characteristics and aquifer characteristics, (2) verification of channel and aquifer characteristics, and (3) the simulation phase.

Determination and Estimation of Channel and Aquifer Characteristics

Channel Hydraulic Characteristics

Determinations of channel length, average river-channel slope, and stage-discharge relations were made for each subreach. Initial values for wave-dispersion coefficients and celerity were estimated for each reach. Subreach lengths were obtained from the U.S. Army Corps of Engineers (1965; 1977) and from flood-insurance studies for Iola (U.S. Department of Housing and Urban Development, 1978), and Lyon County (U.S. Department of Housing and Urban Development, 1981). The channel length has a directly proportional effect on traveltime and on the spreading of the routed discharge (L. F. Land, U.S. Geological Survey, written commun., 1977). The average river-channel slope was computed on the basis of the subreach streambed-elevation change divided by the subreach length and was used to calculate wave-dispersion coefficients and celerity values. Stage-discharge relations were available at each of the gaging stations but not for the subreaches. Measurements made during the gain-loss investigations and flood-profile information (U.S. Army Corps of Engineers, 1965) were used to develop stage-discharge relations for each subreach. The accuracy of the subreach ratings due to the method of development may be a limitation of the model in this study.

A range of discharge from 10 to 2,000 ft^3/s was used to calculate initial wave-dispersion coefficients and celerity values. These values then were verified in the streamflow-routing model. The relations between the wave-dispersion coefficient and discharge were developed using the equation suggested by Keefer (1974):

$$K_o = \frac{Q_o}{2\, S_o\, W_o}, \tag{1}$$

where K_o = wave-dispersion coefficient;
Q_o = stream discharge;
S_o = average bed slope; and
W_o = average channel width for a particular study reach.

Table 4.--Selected channel and aquifer characteristics used in the streamflow-routing model

Sub-reach number	Length of subreach (river miles)	Average aquifer width (feet)	Valley length (miles)	Transmissivity (square feet per day)	Storage coefficient (dimensionless)
			Upper Reach		
U1	0.2	2,900	0	350	0.05
U2	1.8	2,900	0.4	350	.05
U3	6.0	2,900	3.5	350	.05
U4	3.6	2,900	1.8	500	.05
U5	7.9	4,500	2.7	700	.06
U6	12.1	5,300	3.6	800	.07
U7	0.1	5,300	0	800	.07
U8	2.0	5,500	.4	900	.09
U9	7.1	5,800	3.8	1,000	.10
U10	0.1	5,800	0	1,000	.10
U11	7.8	5,800	2.7	1,200	.10
U12	0.1	5,810	.1	1,400	.10
U13	3.1	5,300	1.3	1,400	.10
U14	3.1	5,300	1.0	1,600	.10
U15	5.1	5,400	2.5	1,500	.10
U16	5.0	6,100	4.4	1,500	.10
U17	4.0	8,180	1.2	2,500	.10
U18	6.6	8,450	2.6	3,000	.10
U19	7.5	6,340	4.3	3,000	.10
			Lower Reach		
L1	0.1	8,450	0.1	3,000	0.10
L2	3.5	4,100	1.9	3,000	.10
L3	1.7	3,560	1.1	3,000	.10
L4	5.4	9,500	3.5	3,000	.10
L5	8.0	19,000	4.7	3,000	.10
L6	4.1	23,800	.9	3,000	.10
L7	4.7	19,800	3.1	3,000	.10
L8	8.7	12,400	3.1	3,000	.10
L9	0.1	7,920	.1	3,000	.10
L10	5.5	9,500	3.7	3,000	.10
L11	5.4	5,300	3.5	3,000	.10
L12	0.1	4,490	.1	3,000	.10
L13	4.7	4,500	2.0	3,000	.10

A large K_0 value results in a hydrograph that is flatter and more spread-out as compared to a small K_0 value. The K_0 value primarily influences the shape of the routed discharge hydrograph. The wave celerity and discharge relations were developed using the equation also suggested by Keefer (1974):

$$C_0 = \frac{1}{W_0} \frac{dQ_0}{dY_0} , \tag{2}$$

where $\frac{dQ_0}{dY_0}$ is the slope of the rating curve (stage-discharge relation) at Q_0; and W_0 is as previously defined. Wave celerity is the speed of the water wave. Therefore, C_0 determines the traveltime except for the effects of aquifer and channel storage. Values were determined for the dispersion coefficient and celerity for each subreach for a range of discharge, and an example is presented in figure 9 for subreach U7 to U8.

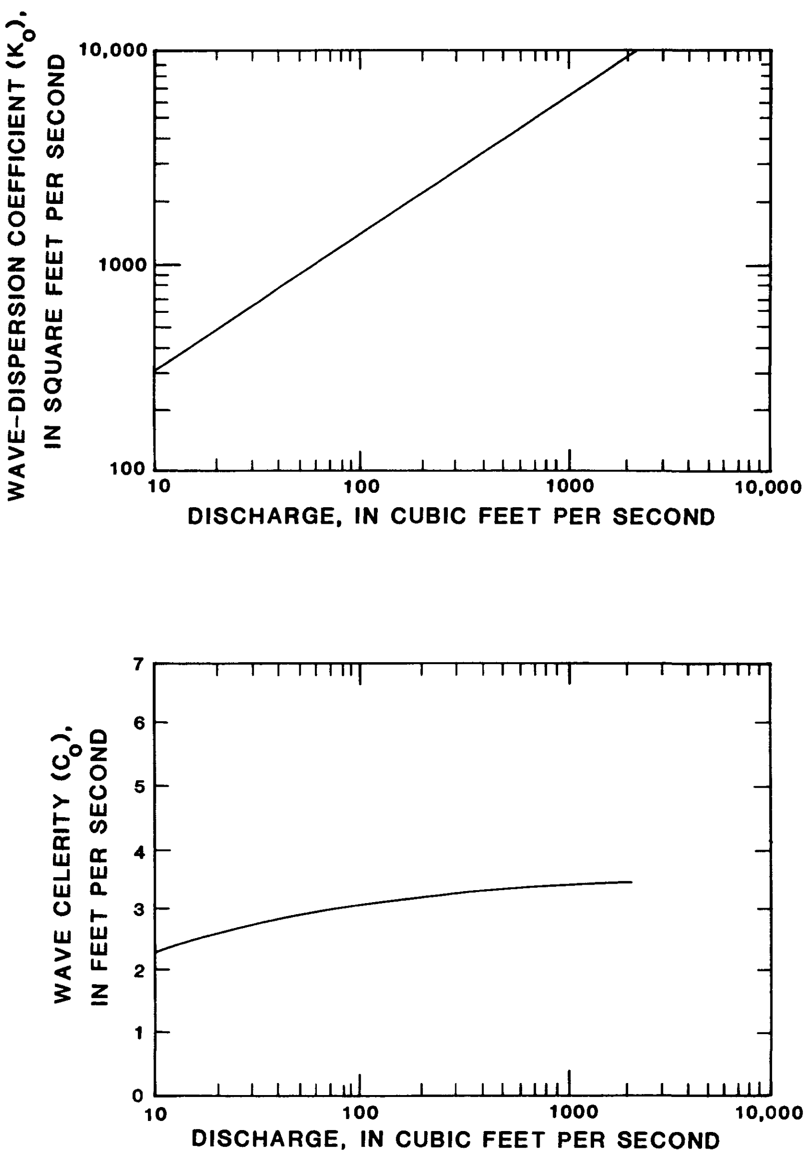

Figure 9.--Relationship between wave-dispersion coefficient (K_0) and discharge, and wave celerity (C_0) and discharge, for subreach U7 to U8.

For wave-dispersion coefficients and celerity calculations, average channel width was obtained from channel width and discharge relations developed using discharge measurements at the streamflow-gaging stations. Figure 10 shows an example of channel width and discharge relations at the Iola gaging station.

Aquifer Characteristics

The aquifer characteristics required for model input are length, width, transmissivity, and storage coefficient. Aquifer length and width values were obtained using U.S. Geological Survey topographic maps and from Morton and Fader (1975). Transmissivity and storage-coefficent values were obtained based on data from R. D. Burnett and T. B. Reed (U.S. Geological Survey, written commun., 1982), Miller (1969), Morton and Fader (1975), and O'Connor and others (1953). Transmissivity and storage coefficients primarily affect the volume to bank storage and the peak of flow to bank storage. Additional information on aquifer characteristics was obtained from the observation-well sites previously discussed. Selected channel and aquifer characteristics used in the streamflow-routing model are listed in table 4.

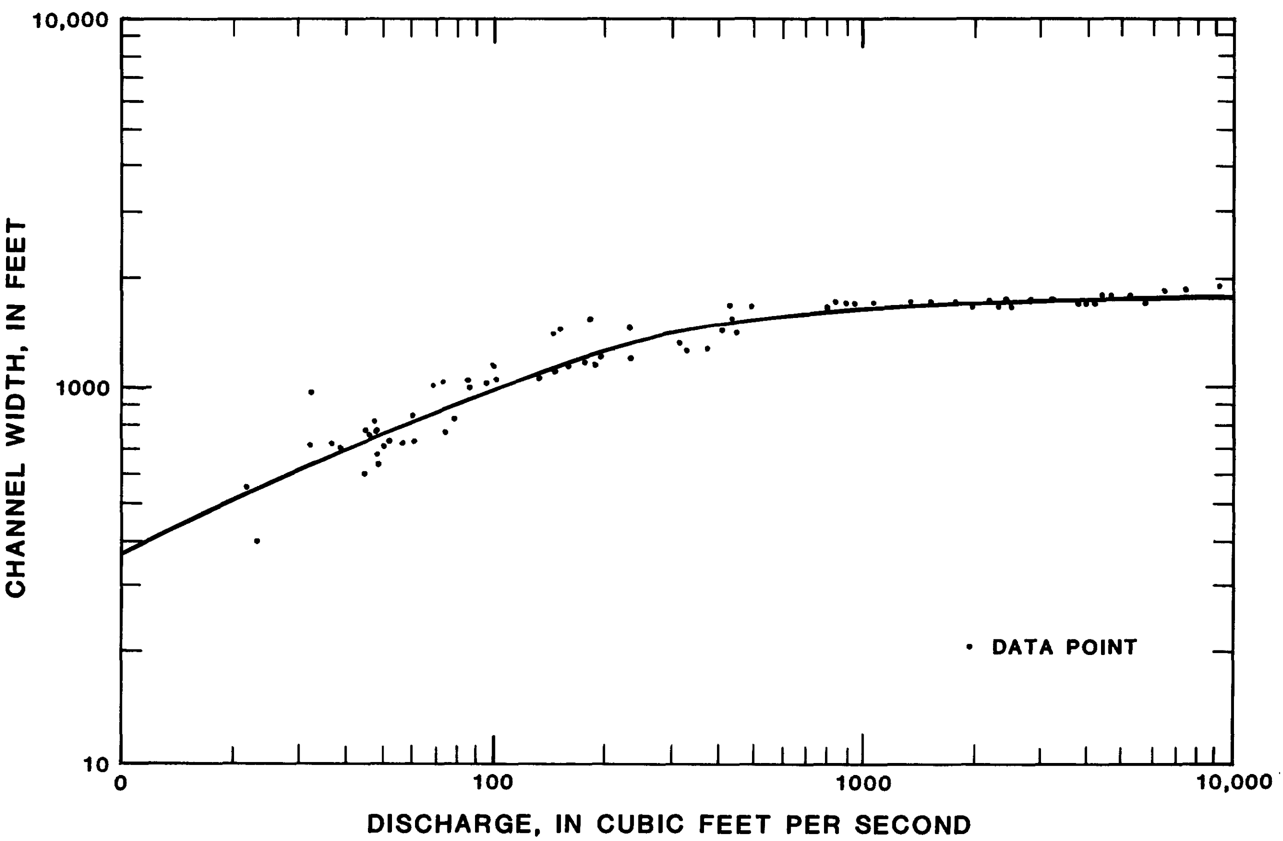

Figure 10.--Relationship between channel width and discharge for Neosho River near Iola, August 1973 - October 1980.

Model Verification of Estimated Channel and Aquifer Characteristics

The initial phase of the model verification was accomplished for selected periods of varying release rates by using values for aquifer characteristics, channel characteristics, and stage-discharge relation for each subreach as described above. Model verification was made using subreaches between the streamflow-gaging stations from Council Grove to Americus and from Burlington to Iola (table 5).

Several reservoir-release periods were selected for model verification. Reservoir releases were screened for all low- to medium-stage releases in the study area. Periods were selected in which evapotranspiration and withdrawals were assumed to be minimal, and any precipitation during the period would likely produce a small or negligible amount of runoff. To help meet these requirements, only recorded reservoir releases for the late fall and winter months were considered for verification. The available range of antecedent conditions and reservoir-release rates used in the verification did not include the range of the driest antecedent conditions and the smallest reservoir-release rates used in the model simulations. Table 5 also shows the verification periods used.

Each selected reservoir release was routed to the downstream gaging station using a 2-hour step, and the simulated discharge was compared with the observed discharge. Wave-dispersion coefficients and celerity

Table 5.--Reservoir releases used to verify the estimated channel and aquifer characteristics and percentage error between simulated and observed streamflow volumes

Upstream release point and downstream target point (upstream and downstream subreach numbers)	Percentage error between simulated and observed streamflow volumes	Period of release	Range of reservoir outflow (cubic feet per second)
Council Grove Lake (07179400)	-5	December 11-17, 1967	0.03 to 64.0
to	-13	November 23 to December 8, 1971	3.20 to 24.0
Americus (07179730) (U1 to U10)	5	December 15-28, 1977	1.60 to 608
John Redmond Reservoir (07182450)	-2	December 16-25, 1967	369 to 1,504
	-1	February 15-22, 1970	215 to 405
to Iola (07183000) (L1 to L13)	-14	February 24 to March 7, 1972	81.0 to 260

values were varied to obtain a "good fit" between observed and simulated reservoir-release discharges. Except for the subreaches below low-head dams, adjustments were not required for wave-dispersion coefficients and celerity calculated using equations 1 and 2. For the subreaches below low-head dams, model results indicated that the simulated values were inconsistent with the observed values. To obtain a good fit for these subreaches, the wavedispersion coefficients and celerity equations for the subreaches upstream from the low-head dams were modified based on the model simulations.

The following equation was used to estimate wave-dispersion coefficients (KD_0) for subreaches in which there were low-head dams (modified from Keefer, 1974):

$$KD_0 = \frac{Q_0}{2W_0\left[S\,\frac{D}{L} + SD\,\frac{(L-D)}{L}\right]}\,, \tag{3}$$

where Q_0 = stream discharge, in cubic feet per second;
W_0 = average channel width for the low-head dam subreach, in feet;
S = the water-surface slope during low flow, in foot per foot;
SD = the water-surface slope in the subreach if the dam was not present, in foot per foot;
D = the dam height above the stream profile, in feet; and
L = the length of the subreach, in miles.

The following equation was used to estimate wave celerity (CD_0) for subreaches in which there is a low-head dam (modified from Keefer, 1974):

$$CD_0 = \frac{1}{W_0}\,\frac{dQ_0}{dY_0}\,\left[0.25 + \left(0.75\,\frac{D}{L}\right)\right]\,, \tag{4}$$

where $\frac{dQ_0}{dY_0}$ is the slope of the stage-discharge relation at Q_0, and where

W_0, D, and L are as previously defined.

Equations for KD_0 and CD_0 are applicable only in subreaches for which the control feature at the downstream end is a low-head dam. These equations are applicable from approximately 1 ft^3/s to about one-half bankfull. Reservoir-release discharges considerably less than bankfull stage were used for the model simulations.

Due to the lack of gaged data downstream from the Americus gage, the model was not verified for the subreaches between the Americus gage and subreach U19, a distance of approximately 49 river miles. Relations for wave-dispersion coefficients and celerity were developed for these subreaches based on channel-hydraulic characteristics and data from the Americus and Burlington gages; the accuracy of these relations is unknown, and therefore, the accuracy of the model simulations is unknown for these subreaches.

For the verified subreaches (other than subreaches with low-head dams), adjustments were not required for wave-dispersion coefficients and celerity. Verification of inflow and outflow bank storage was not directly possible due to the lack of appropriate data. Aquifer characteristics and stage-discharge relations were not adjusted in the verification process.

Comparison of observed and simulated reservoir releases are shown in figures 11 to 14. Verifications were accomplished using a wide range of reservoir releases ranging from 0.03 to 1,500 ft^3/s. Table 5 lists the reservoir releases used to verify the estimated channel and aquifer characteristics and the percentage error between simulated and observed streamflow volumes. Figures 11 to 14 show that the shape and timing of the simulated hydrographs approximate the shape and timing of the observed hydrographs. These observations confirm that the model performs well enough to be useful for simulating transit losses and traveltimes within the range of flows and for the subreaches included in the verifications.

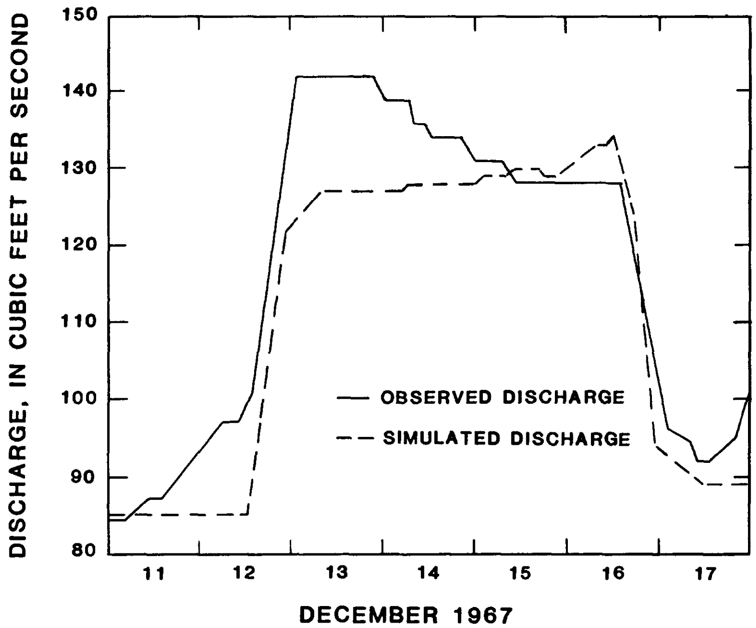

Figure 11.--Comparison of observed and simulated reservoir releases used in verifying estimated channel and aquifer characteristics at Americus streamflow-gaging station, December 11-17, 1967.

MODEL SIMULATION OF TRANSIT LOSSES AND TRAVELTIMES

Kansas water law provides that water purchased from reservoirs be based on the quantity released. Two municipalities, Emporia and Iola have water-purchase contracts within the study area. Emporia has contracted for a maximum of 1,095 Mgal/yr and a minimum of 547 Mgal/yr from Council Grove Lake. Iola has contracted for a maximum of 110 Mgal/yr and a minimum of 55 Mgal/yr, also from Council Grove Lake. Based on these contracts, model simulations were made to reflect the maximum (1,205 Mgal/yr) and minimum (602 Mgal/yr) contract-release volumes from Council Grove Lake. The release durations of these contracts ranged from 50 to 365 days depending upon the release rate. For example, for the maximum contract-release volume of 1,205 Mgal/yr, a release was made over 100 days at a rate of 12.0 Mgal/d (18.6 ft^3/s). This same contract-release volume (1,205 Mgal/yr) also was released over 365 days at a rate of 3.29 Mgal/d (5.09 ft^3/s). Other release rates and durations that reflect the contract-releases volumes from Council Grove Lake are listed in table 6.

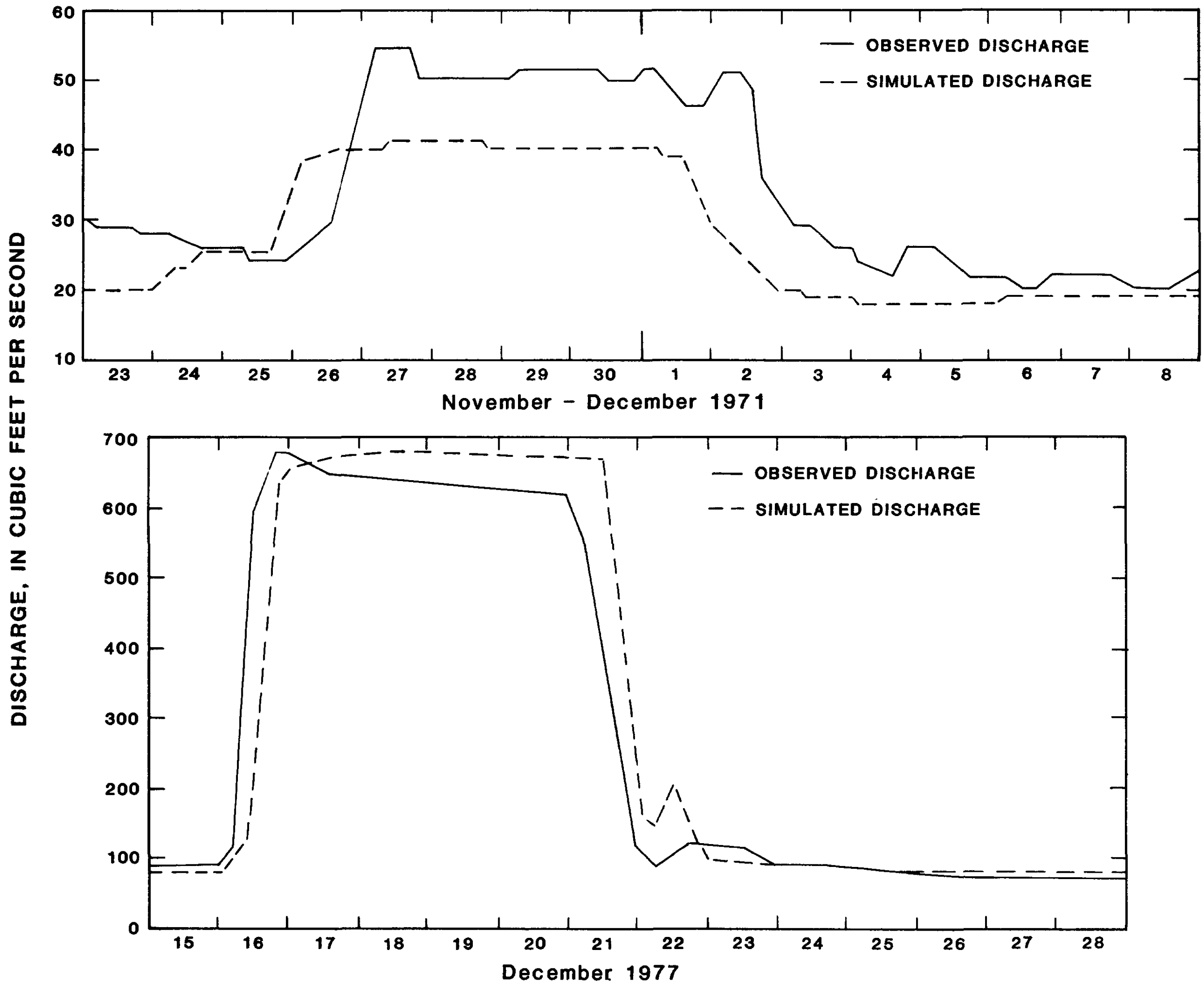

Figure 12.--Comparison of observed and simulated reservoir releases used in verifying estimated channel and aquifer characteristics at Americus streamflow-gaging station, November 23 to December 8, 1971, and December 15-28, 1977.

Further model simulations were made based on the yearly total release volume (2,051 Mgal/yr) available from water-supply storage in Council Grove Lake. For these simulations, the maximum release rate was assumed to be proportional to the maximum release volume under existing contracts. The total maximum release rate for the entire water-supply storage was approximately 20.5 Mgal/d (31.7 ft^3/s) and was released over approximately 100 days. The same quantity was released over 365 days at a rate of 5.61 Mgal/d (8.69 ft^3/s). Table 6 lists the release rates and durations for these simulations.

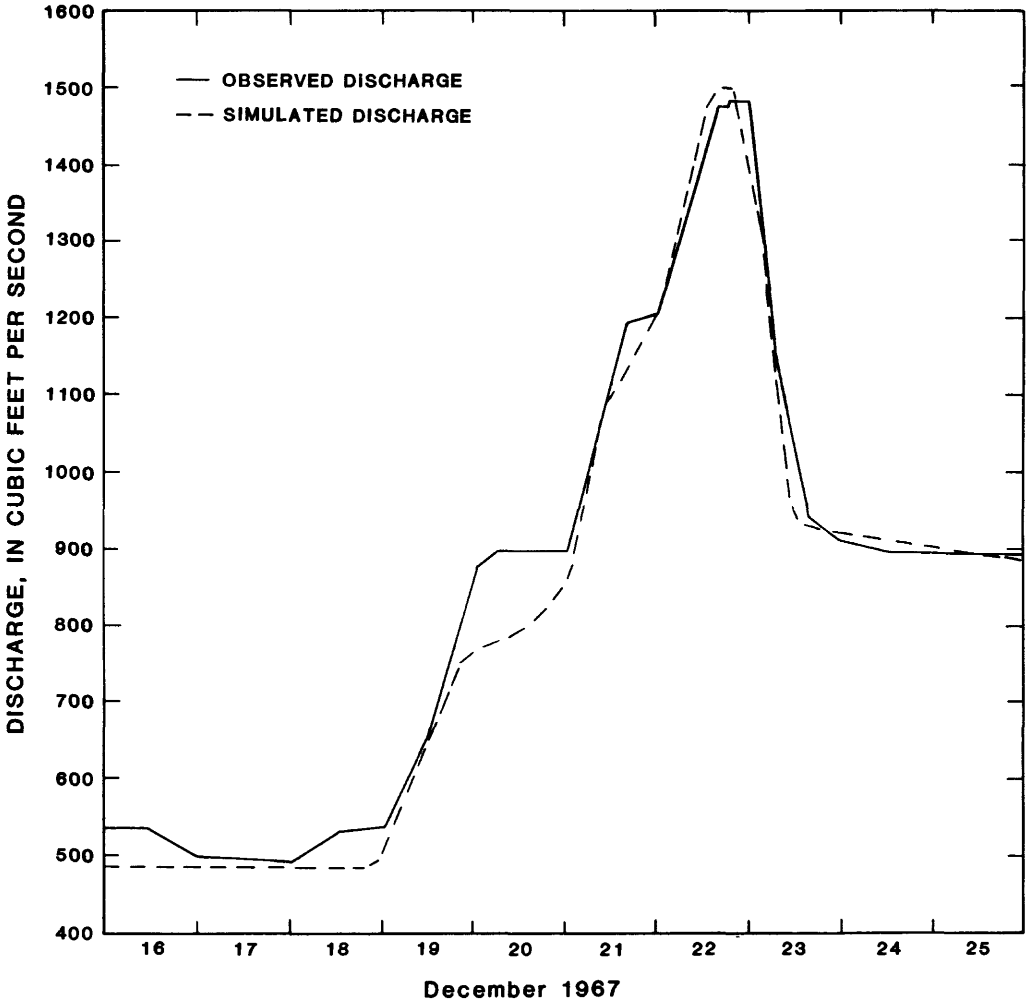

Figure 13.--Comparison of observed and simulated reservoir releases used in verifying estimated channel and aquifer characteristics at Iola streamflow-gaging station, December 16-25, 1967.

To aid in the effective management of the purchased water, the streamflow-routing model can be used to simulate transit losses and traveltimes in the Neosho River associated with reservoir releases under varying antecedent-streamflow conditions. Simulation of water-supply releases from Council Grove Lake was accomplished for a severe-drought antecedent-streamflow condition and a less-severe-drought antecedent-streamflow condition. For the severe-drought antecedent-streamflow condition, it was assumed that there was zero base flow in all subreaches. It was assumed also that there was no contribution of streamflow from the Cottonwood River, either from natural flow or from releases from Marion Lake (fig. 1).

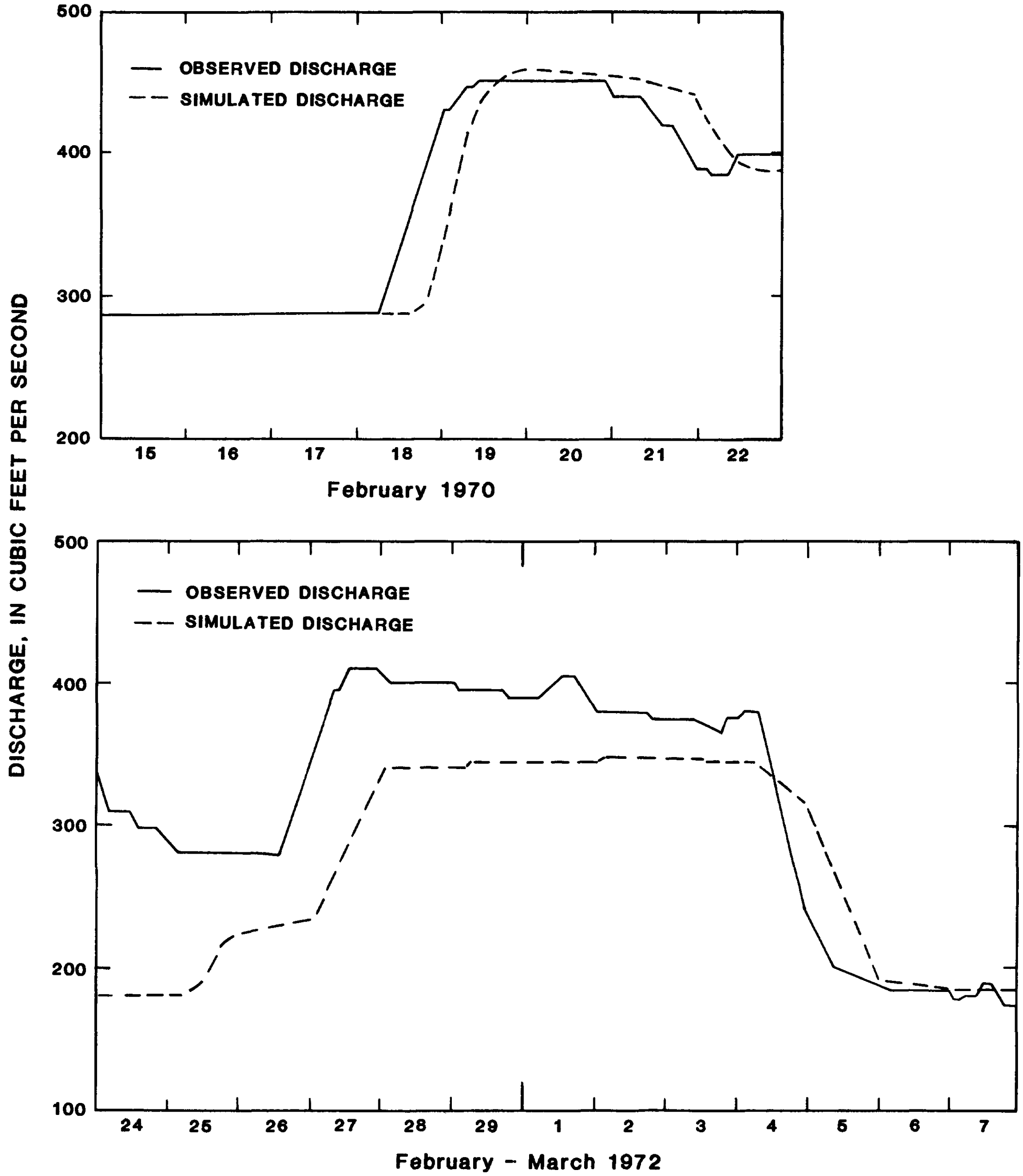

Figure 14.--Comparison of observed and simulated reservoir releases used in verifying estimated channel and aquifer characteristics at Iola streamflow-gaging station, February 15-22, 1970, and February 24 to March 7, 1972.

The less-severe-drought antecedent-streamflow condition assumed a base-flow release rate equal to the 2-percent drought yield from water-quality storage for both Council Grove Lake and John Redmond Reservoir. For Council Grove Lake, the 2-percent yield is 6.3 ft^3/s, and for John Redmond Reservoir, the yield is 32.0 ft^3/s. To account for changes in base flow within each

Table 6.--Reservoir releases from Council Grove Lake used in model simulations

Contracts for sale of water from Council Grove Lake	Release volumes (acre-feet)	Release rates[1]	Duration of release (days)
Minimum volume under contract	1,840	12.0 (18.6)	50
	1,840	3.30 (5.11)	182
Maximum volume under contract	3,680	12.0 (18.6)	100
	3,680	3.29 (5.09)	365
Total water-supply storage	6,280	20.5 (31.7)	100
	6,280	5.61 (8.69)	365

1 Upper figure is million gallons per day, and lower figure in parenthesis is cubic feet per second.

subreach, the natural gains and losses, as determined from the 1980 gain-loss investigations, were used in conjunction with river-surface evaporation rates to modify the initial 2-percent drought yields in each subreach downstream from Council Grove Lake and John Redmond Reservoir. Table 7 shows the base flows in each subreach resulting from the adjusted 2-percent drought-yield release rate for the upper and lower reaches. Streamflow from the Cottonwood River also was accounted for during the less-severe-drought condition. The 2-percent drought yield from water-supply storage for Marion Lake was used as the inflow from the Cottonwood River. This yield of 6.59 Mgal/d (10.2 ft^3/s) was treated as inflow to subreach U17 (the confluence of the Cottonwood River). It was assumed that no additional releases were made from Marion Lake.

For both antecedent-streamflow conditions, release simulations for durations of 50 to 182 days were made to coincide with the greatest mean monthly evaporation. Evaporation losses due to incremental changes in river-surface width, which result from the various reservoir releases, were determined for each subreach. A percentage of the reservoir releases from Council Grove Lake were diverted to Emporia (subreach U12) to satisfy the terms of contracts for water supply. For the maximum release volume under

Table 7.--Adjustment to initial base flows in each subreach for model simulations

Upper reach (Council Grove Lake outlet to subreach U19) Initial base flow = 6.3 cubic feet per second		Lower reach (John Redmond Reservoir outlet to subreach L13) Initial base flow = 32.0 cubic feet per second	
Subreach	Adjusted base flow (cubic feet per second)	Subreach	Adjusted base flow (cubic feet per second)
U1	6.3	L1	32.0
U2	6.3	L2	32.0
U3	6.5	L3	32.0
U4	7.5	L4	35.2
U5	7.3	L5	35.2
U6	7.3	L6	35.9
U7	5.1	L7	35.9
U8	4.7	L8	35.9
U9	4.7	L9	33.9
U10	4.2	L10	35.1
U11	4.2	L11	35.1
U12	5.1	L12	29.8
U13	6.8	L13	31.4
U14	7.9		
U15	7.9		
U16	7.2		
U17	7.2		
U18	9.9		
U19	8.7		

contract (3,680 acre-feet), 90 percent of the release was diverted to Emporia. This percentage was determined by dividing the average release rate of 3.0 Mgal/d for Emporia by the total average release rate of 3.3 Mgal/d for Emporia and Iola, and multiplying by 100. For the minimum release volume under contract (1,840 acre-feet), 83 percent of the release was diverted to Emporia. This percentage was determined by dividing the maximum release rate of 10 Mgal/d allowed under contract for Emporia by the total maximum release rate of 12 Mgal/d for Emporia and Iola, and multiplying by 100. For the total water-supply-storage release volume (6,280 acre-feet), 50 percent of the release was diverted to Emporia. This percentage was determined by dividing the maximum release rate of 10 Mgal/d allowed under contract for Emporia by the maximum release rate of

20.5 Mgal/d (the entire water-supply storage), and multiplying by 100. For all diversions to Emporia, the remaining amounts and return flows from Emporia were routed downstream to Iola. An estimate of 28 percent of the diverted reservoir releases was used to account for return flows from Emporia. This percentage was determined from withdrawal and return-flow information obtained from the city of Emporia. These return flows were included in subreach U17, the confluence of the Cottonwood River.

Diversions and return flows by water-right holders other than Emporia were not considered in the simulations due to a time constraint and also since they can vary depending upon the need. Diversion and return-flow data could be included in subsequent simulations using the model. Estimates of the effects of diversion and return flows could be made by applying them externally. These estimates would not be as realistic as including the data in the model since the diversions and return flows would directly affect the total streamflow, bank storage, traveltimes, and river-surface evapotranspiration.

Tributary inflow was considered for use in the model; however, due to the limited amount of time allowed for the investigation, only inflow from the Cottonwood River was considered for model simulations. Transit losses from evapotranspiration were treated as direct diversions from each subreach for model simulations (see section on "Evapotranspiration").

The effects of John Redmond Reservoir on the simulated reservoir releases from Council Grove Lake were not analyzed since it was beyond the scope of this study. For model simulations, the releases from Council Grove Lake were routed to subreach U19, and the downstream discharges of subreach U19 were used as the upstream discharges in the lower reach (subreach L1). John Redmond Reservoir was treated as if inflows to the reservoir immediately became outflows. A contract with the Kansas Gas and Electric Company utilizes all the water supply available from John Redmond Reservoir; therefore, no additional flow from the reservoir is available for water-supply purposes.

Transit Losses

In general, transit loss is that part of the streamflow discharge or reservoir outflow that does not reach a specified downstream point within a specified time. For the purposes of this report, transit loss is only the loss of evapotranspiration and temporary bank storage from the part of the reservoir outflow that is designated as the release to fulfill water-supply contracts with downstream users. For the simulations in which part of the reservoir outflow was "base flow," the base flow was included in the computations. The base flow caused an increase in river-surface width for the reservoir-release flows. This increase in width caused an increase in river-surface evaporation, which was accounted for in the evapotranspiration losses. The "specified time" for the calculation of transit loss in this report extends to 30 days after the end of the release from Council Grove Lake.

Table 8 shows the transit losses from Council Grove Lake to John Redmond Reservoir and from Council Grove Lake to Iola for selected simulated release volumes (table 6). Analysis of model simulations for total transit losses from Council Grove Lake to Iola indicated a substantially greater loss during the severe-drought antecedent-streamflow condition. For example, for the water-supply-storage release volume of 6,280 acre-feet for 365 days, the total transit loss was 3,046 acre-feet greater than that for the less-severe-drought antecedent-streamflow condition.

Table 8.--Total transit losses in the study area for two antecedent-streamflow conditions

			Transit losses for indicated reaches, in acre-feet	
Release volume (acre-feet)	Release rate (cubic feet per second)	Release duration (days)	Council Grove Lake to John Redmond Reservoir (River miles 449.8 to 366.8)	Council Grove Lake to Iola (River miles 449.8 to 287.4)
		Severe-drought antecedent-streamflow condition		
1,840	18.6	50	510	1,100
1,840	5.11	182	1,459	1,755
3,680	18.6	100	783	1,686
3,680	5.09	365	1,723	2,188
6,280	31.7	100	1,172	2,754
6,280	8.69	365	3,036	6,280
		Less-severe-drought antecedent-streamflow condition		
1,840	18.6	50	404	860
1,840	5.11	182	921	1,909
3,680	18.6	100	727	1,592
3,680	5.09	365	1,310	2,793
6,280	31.7	100	833	1,701
6,280	8.69	365	1,486	3,234

Small release rates of long duration experienced a greater total loss than large release rates of short duration for both antecedent-streamflow conditions. For the severe-drought condition and the maximum contract-release rate of 5.09 ft^3/s for 365 days, the total loss from Council Grove Lake to Iola was 502 acre-feet greater than that for a release rate of 18.6 ft^3/s for 100 days. For the less-severe-drought condition and the same release rates and durations, the total loss was 1,201 acre-feet greater for the smaller release rate.

For both antecedent-streamflow conditions, transit losses increased as release duration increased for any given release. For the severe-drought antecedent condition and the water-supply-storage release volume of 6,280 acre-feet for 100 days, the loss from Council Grove Lake to Iola was 2,754 acre-feet as compared to 6,280 acre-feet for the 365-day duration. For the less-severe-drought antecedent condition and a 100-day duration, the loss was 1,701 acre-feet as compared to 3,234 acre-feet for a 365-day duration.

Long reservoir-release durations (greater than 182 days) with small release rates (less than 18.6 ft^3/s) allowed the total release to be lost to evapotranspiration and temporary bank storage. However, the discharge stored in the banks of the river eventually will return to the river during the recession of the release. The 30-day time period allowed at the end of reservoir-release durations during model simulations was insufficient time for the bank-storage discharge to completely return to the river.

Table 9 shows the transit losses to temporary bank storage and evapotranspiration for selected release rates and durations (table 6). The transit loss into temporary bank storage from Council Grove Lake to Iola was less for the shorter release periods for both antecedent conditions. For the severe-drought condition and the minimum contract-release volume of 1,840 acre-feet for 50 days, the total loss to temporary bank storage was 552 acre-feet less than for the 182-day release duration. For the less-severe-drought condition and the minimum contract-release volume of 1,840 acre-feet for 50 days, the total loss was 219 acre-feet less than for the 182-day release duration.

The severe-drought antecedent-streamflow condition had a greater loss to temporary bank storage than the less-severe-drought condition. For example, for the maximum contract-release volume of 3,680 acre-feet and a release duration of 100 days, the loss to temporary bank storage was 225-acre-feet greater than that for the less-severe-drought condition. It should be noted again that most bank-storage discharge eventually will re turn to the stream during the recession of a reservoir release.

Table 9 reflects the effects of base flow during the less-severe drought. Even though the total transit loss was less for this drought condition, evapotranspiration was generally higher. This can be attributed to the increase in river-surface width, which in turn caused greater losses to river-surface evaporation. Evapotranspiration losses were greater for the longer release durations for both antecedent-streamflow conditions. For example, for the severe-drought condition and the maximum contract-release volume of 3,680 acre-feet and a duration of 365 days, the loss to evapotranspiration from Council Grove Lake to Iola was 315 acre-feet greater than for the duration of 100 days. For the less-severe-drought antecedent-streamflow condition, the loss to evapotranspiration was 934 acre-feet more for the 365-day duration than for the 100-day duration for the same release volume. Evapotranspiration generally was greater for the less-severe-drought antecedent condition since river-surface evaporation increased due to an increase in river-surface width caused by base flow.

Table 9.--Losses to temporary bank storage and to evapotranspiration during transit

Release volume (acre-feet)	Release rate (cubic feet per second	Release duration (days)	Transit losses for indicated reaches, in acre-feet: Council Grove Lake to John Redmond Reservoir (River miles 449.8 to 366.8): Temporary bank storage	Council Grove Lake to John Redmond Reservoir (River miles 449.8 to 366.8): Evapotranspiration	Council Grove Lake to Iola (River miles 449.8 to 287.4): Temporary bank storage	Council Grove Lake to Iola (River miles 449.8 to 287.4): Evapotranspiration
Severe-drought antecedent-streamflow condition						
1,840	18.6	50	248	262	628	472
1,840	5.11	182	889	570	1,180	575
3,680	18.6	100	273	510	725	961
3,680	5.09	365	772	951	912	1,276
6,280	31.7	100	621	551	1,724	1,030
6,280	8.69	365	1,978	1,058	4,250	2,030
Less-severe-drought antecedent-streamflow condition						
1,840	18.6	50	122	282	307	553
1,840	5.11	182	216	705	[1]526	[1]1,383
3,680	18.6	100	171	556	500	1,092
3,680	5.09	365	279	1,031	767	2,026
6,280	31.7	100	273	560	603	1,098
6,280	8.69	365	448	1,038	1,195	2,039

[1] Includes some loss of base flow.

Traveltimes

Traveltimes are determined based on the wave-celerity values used in the model. They are primarily affected by the antecedent-streamflow conditions. During model verification, wave-celerity values were adjusted so that simulated traveltimes would match observed traveltimes for various streamflow conditions. Two types of traveltimes were of interest: (1) traveltime to beginning of response, which is defined as the time interval between the beginning of the reservoir release from Council Grove Lake to the leading edge of the response at the downstream subreach, and (2) traveltime to full response, which is defined as the time from the beginning of the reservoir release from Council Grove Lake to the time when the downstream discharge is equal to 80 percent of the sum of the reservoir release and base flow. The approximate traveltimes to beginning of response and to full response in the study reach for the reservoir releases are shown in tables 10 and 11, respectively. The quantified effects of John Redmond Reservoir on the traveltimes in the study reach were not considered in this investigation.

Table 10.--Approximate traveltimes to beginning of response for two antecedent-streamflow conditions

			Traveltimes for indicated reaches, in days	
Release volume (acre-feet)	Release rate (cubic feet per second)	Release duration (days)	Council Grove Lake to John Redmond Reservoir (River miles 449.8 to 366.8)	Council Grove Lake to Iola (River miles 449.8 to 287.4)
		Severe-drought antecedent-streamflow condition		
1,840	18.6	50	1.4	2.2
1,840	5.11	182	1.4	2.2
3,680	18.6	100	1.4	2.2
3,680	5.09	365	1.4	2.2
6,280	31.7	100	1.2	2.0
6,280	8.69	365	1.4	2.2
		Less-severe-drought antecedent-streamflow condition		
1,840	18.6	50	1.1	1.6
1,840	5.11	182	1.4	2.0
3,680	18.6	100	1.1	1.6
3,680	5.09	365	1.4	1.9
6,280	31.7	100	1.1	1.6
6,280	8.69	365	1.4	2.0

Table 11.--Approximate traveltimes to full response for two antecedent-streamflow conditions

Release volume (acre-feet)	Release rate (cubic feet per second)	Release duration (days)	Traveltimes for indicated reaches, in days: Council Grove Lake to John Redmond Reservoir (River miles 449.8 to 366.8)	Traveltimes for indicated reaches, in days: Council Grove Lake to Iola (River miles 449.8 to 287.4)
Severe-drought antecedent-streamflow condition				
1,840	18.6	50	17	69
1,840	5.11	182	more than 182	more than 182
3,680	18.6	100	63	129
3,680	5.09	365	148	237
6,280	31.7	100	52	112
6,280	8.69	365	150	more than 365
Less-severe-drought antecedent-streamflow condition				
1,840	18.6	50	8	41
1,840	5.11	182	92	92
3,680	18.6	100	84	162
3,680	5.09	365	83	181
6,280	31.7	100	23	73
6,280	8.69	365	83	200

Wave celerities were slower, and therefore, traveltimes were generally longer for the severe-drought antecedent condition than for the less-severe-drought antecedent condition from Council Grove Lake to Iola. For a release rate of 18.6 ft^3/s of 50-day duration during the severe-drought condition, the traveltime to beginning of response from Council Grove Lake to Iola was 0.3 days longer than that during the less-severe-drought condition (table 10). For the same release rate and duration, the traveltime to full response was 28 days longer for the severe-drought condition than for the less-severe drought condition (table 11). The small release rates of 5.09 to 8.69 ft^3/s for both antecedentstreamflow conditions had a much longer traveltime to full response than did the release rates of 18.6 and 31.7 ft^3/s. This increase is due to the small rate of discharge, which results in smaller wave-celerity values. For example, during the less-severe-drought antecedent condition, for a release rate of 5.11 ft^3/s for 182 days, the traveltime to full response was 51 days longer than for the larger release rate of 18.6 ft^3/s, which was released for 50 days.

SUMMARY

The investigation of the Neosho River from Council Grove Lake to Iola, east-central Kansas, used a streamflow-routing model to simulate the transit losses or gains, and water-wave traveltimes for selected reservoir releases. The reservoir releases were made under two separate antecedent-streamflow conditions. The first antecedent condition was a severe-drought condition, with zero base flow in all subreaches in the study reach. The second antecedent condition was a less-severe-drought condition, with an initial base flow equal to the 2-percent drought yield from water-quality storage from Council Grove Lake for the upper reach and from John Redmond Reservoir for the lower reach.

Channel and aquifer characteristics for the study area were estimated using data from streamflow-gaging stations at Council Grove, Americus, Burlington, and Iola. These characteristics were verified using the streamflow-routing model by comparing simulated reservoir releases to observed releases from both Council Grove Lake and John Redmond Reservoir. The verified characterisitics were used in the model to simulate transit losses and traveltimes for selected reservoir-release volumes from Council Grove Lake while in transit to Iola. Model output for each subreach included tabulated and graphical hydrographs for upstream, downstream, and bank-storage discharges, traveltimes, and a summary of losses or gains to bank storage and diversions.

Model results indicated a greater total transit loss for a severe-drought antecedent-streamflow condition, small reservoir-release rates, and long reservoir-release durations. During the severe-drought condition and a release volume of 6,280 acre-feet for 365 days, the transit loss was 3,046 acre-feet greater than for the less-severe-drought condition. For the severe-drought condition and small release rate of 5.09 ft^3/s for 365 days, the total loss was 502 acre-feet greater than that for the larger release rate of 18.6 ft^3/s for 100 days. For the release volume of 6,280 acre-feet for 100 days during the severe-drought condition, the loss was 2,754 acre-feet as compared to 6,280 acre-feet for the 365-day duration.

Temporary losses to bank storage were less for the shorter release durations for both antecedent conditions. For example, during the severe-drought condition and a release volume of 1,840 acre-feet for 50 days, the total loss to temporary bank storage was 552 acre-feet less than for the 182-day duration. Also, the severe-drought condition had a greater loss to temporary bank storage than the less-severe-drought condition. For example, for a release volume of 3,680 acre-feet and a release duration of 100 days, the total loss to temporary bank storage was 225 acre-feet greater than for the less-severe-drought condition.

Transit losses to evapotranspiration were greater for the longer release durations for both antecedent conditions. For example, during the severe-drought condition, for a release volume of 3,680 acre-feet and a duration of 365 days, the loss to evapotranspiration was 315 acre-feet greater than for the duration of 100 days.

Traveltimes were longer for reservoir releases made during severe-drought antecedent-streamflow conditions as compared to the less-severe-drought antecedent-streamflow conditions because of the slower corresponding wave celerities. For a release rate of 18.6 ft^3/s and a 50-day duration during the severe-drought condition, the traveltime to beginning of response from Council Grove Lake to Iola was 0.3 days longer than that for the less-severe-drought antecedent condition. For the same release rate and duration, the traveltime to full response was 28 days longer than that for the less-severe-drought condition. Small release rates of long duration for both antecedent conditions had a longer traveltime to full response than large release rates of short duration.

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