TRANSIT LOSSES AND TRAVELTIMES FOR WATER-SUPPLY RELEASES FROM MARION LAKE DURING DROUGHT CONDITIONS, COTTONWOOD RIVER, EAST-CENTRAL KANSAS

By P. R. Jordan and R. J. Hart

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 85-4263

Prepared in cooperation with the

KANSAS WATER OFFICE

Lawrence, Kansas

1985

UNITED STATES DEPARTMENT OF THE INTERIOR

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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 of Units (SI) are listed below, along with appropriate abbreviations:

Multiply inch-pound unit	By	To obtain SI unit
inch	[1]25.4	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 second	0.3048	meter per second
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
cubic foot per second per mile [(ft^3/s)/mi]	0.01760	cubic meter per second per kilometer
gallon per minute (gal/min)	0.06309	liter per second

[1] Exact conversion factor.

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ABSTRACT

Proper management of the water supplies of Marion Lake, east-central Kansas, requires a knowledge of the transit losses and traveltimes associated with reservoir releases to downstream users along the Cottonwood River. To obtain this knowledge applicable to drought conditions, the U.S. Geological Survey, in cooperation with the Kansas Water Office, studied the Cottonwood River from Marion Lake to its confluence with the Neosho River near Emporia, a distance of about 127 river miles.

A streamflow-routing model was used to calculate the transit losses and traveltimes. Channel and aquifer characteristics, the model-control parameters, were estimated from available data and then verified to the extent possible by comparing model-simulated streamflow to observed streamflow at streamflow-gaging stations. Transit losses and traveltimes for varying reservoir-release rates and durations then were simulated for two different antecedent-streamflow (drought) conditions.

For the severe-drought antecedent-streamflow condition, it was assumed that only the downstream water-use requirement would be released from the reservoir. For a less-severe-drought antecedent-streamflow condition, it was assumed that any releases from Marion Lake for water-supply use downstream would be in addition to a nominal dry-weather release of 5 cubic feet per second. Water-supply release rates of 10 and 25 cubic feet per second for the severe-drought condition and 5, 10, and 25 cubic feet per second for the less-severe-drought condition were simulated for periods of 28 and 183 days commencing on July 1.

Transit losses for the severe-drought condition for all reservoir-release rates and durations ranged from 12 to 78 percent of the maximum downstream flow rate and from 27 to 91 percent of the total volume of reservoir storage released. For the less-severe-drought condition, transit losses ranged from 7 to 29 percent of the maximum downstream flow rate and from 10 to 48 percent of the total volume of release. Generally, transit losses of both rates and volumes were greatest for the severe-drought antecedent condition. The 183-day releases had larger total transit losses, but losses on a percentage basis were less than the losses for the 28-day release period for both antecedent-streamflow conditions. The transit losses considered included only water lost to evaporation and to bank storage, which did not return to the river within 30 days from the end of the release.

Traveltimes from Marion Lake to first response at the confluence with the Neosho River ranged from 2.8 to 3.5 days and had little or no variation between the various release rates and durations. Traveltimes to full response (80 percent of the maximum downstream flow rate), however, showed considerable variation. For the release of 5 cubic feet per second during less-severe-drought conditions, base flow exceeded 80 percent of the maximum flow rate near the confluence; the traveltime to full response was undefined for those simulations. For the releases of 10 and 25 cubic feet per second during the same drought condition, traveltimes to full response ranged from 4.4 to 6.5 days. For releases of 10 and 25 cubic feet per second during severe-drought conditions, traveltimes to full response near the confluence with the Neosho River ranged from 8.3 to 93 days. The longest traveltimes to full response were for the 183-day releases.

Results of calculations of transit losses and traveltimes are subject to errors from estimates of channel and aquifer characteristics that could not be fully verified. Possible errors in estimates of channel properties had no effect on simulated transit losses, but errors in estimates of wave celerity may have had moderate effect on simulated traveltimes to first response. Errors in estimates of aquifer transmissivity and storage coefficient may have had moderate effect on the simulated transit losses but no effect on the simulated traveltimes. Possible errors in the estimates of aquifer-boundary conditions would have had little effect on simulation results. Possible errors in the estimate of the evaporation pan-to-river coefficient would have had a moderate effect on the simulated transit losses but would have had no effect on the simulated traveltimes.

INTRODUCTION

The demand for water supplies has increased in the Neosho River basin, of which the Cottonwood River is a part, due to population growth, increasing irrigation, and industrial expansion. Water supplies from State-owned storage are available in Council Grove Lake on the upper Neosho River and in Marion Lake on the upper Cottonwood River. According to Kansas water law, this available State-owned water must be purchased at the release point (reservoir outlet) and not at the point of diversion. Therefore, State agencies and water purchasers need to know what part of the water purchased will be lost during transit in the channel and the period of time required for the released water to travel from the reservoir to the point of diversion.

Purchasers and the Kansas Water Office, as the State's agent in contracts for sale of the water, need information on transit losses and traveltimes to enable them to make sound decisions. Also, the Division of Water Resources of the Kansas State Board of Agriculture needs such information for the administration and protection of water-supply releases. A recent report by Carswell and Hart (1985) has described the transit losses and traveltimes for the Neosho River from Council Grove Lake to Iola, Kansas (downstream from John Redmond Reservoir). Similar information is needed for the Cottonwood River downstream from Marion Lake.

Purpose and Scope

The purpose of this report is to present the results of a study, conducted by the U.S. Geological Survey in cooperation with the Kansas Water Office, to acquire knowledge of the transit losses and traveltimes of water-supply releases from Marion Lake downstream to the confluence with the Neosho River, a distance of about 127 miles. These transit losses and traveltimes were simulated for severe and less-severe drought conditions and for varying reservoir-release rates and durations.

In general, transit loss is that part of a water wave, such as a flood wave or reservoir release, that does not reach a specified downstream point within a specified time. The scope of this report covers transit losses and traveltimes of reservoir releases from water-supply storage only; releases to evacuate flood storage are excluded. The specific traveltimes determined for this report were the time to first response and the time to 80 percent of maximum downstream flow rate. The investigation included limited data collection for measurement of channel cross sections and streamflow gains and losses during one period of low flow. Previously completed data collection and reports served as background information and for estimation of channel and aquifer characteristics. A streamflow-routing model was used to simulate transit losses and traveltimes in the study area for selected conditions.

Description of Study Area

The Cottonwood River flows across Marion, Chase, and Lyon Counties to its confluence with the Neosho River a few miles upstream from John Redmond Reservoir in eastern Lyon County, southeast of Emporia (fig. 1). Mean annual precipitation ranges from 32 inches in western Marion County to 37 inches in eastern Lyon County. Mean annual runoff ranges from 4 inches in western Marion County to 8 inches in eastern Lyon County (Carswell, 1982, fig. 12). Length of the Cottonwood River from Marion Dam to its confluence with the Neosho River is about 127 river miles. The slope of the river decreases from about 3.5 ft/mi in eastern Marion County to about 1.5 ft/mi in Lyon County. Low dams on the river at Cedar Point, Cottonwood Falls, and Emporia create pools about 2 to 5 miles long.

The alluvial valley adjoining the Cottonwood River from Marion Dam downstream to its confluence with the Neosho River ranges from 0.5 to 2.3 miles in width, the widest point being near Emporia. The alluvial deposits in Marion County have a maximum thickness of about 20 feet and are predominantly silt and fine sand but include some lenses of coarse sand and gravel (Byrne and others, 1959, p. 86). Stream-laid deposits of gravel, sand, silt, and clay as much as 55 or 60 feet in thickness occupy the valley of the Cottonwood River in Chase County. The coarser material, in deposits generally from about 3- to 18-feet thick, commonly is found in the lower parts of the accumulations (Moore and others, 1951, p. 6). Alluvium of the Cottonwood River valley in Lyon County consists of gravel, sand, silt, and clay, together with occasional cobbles and boulders. The maximum accumulations are 40- to 50-feet thick. The coarse fraction, in the basal part of the alluvium, contains considerable amounts of well-rounded quartz sand derived from sandstones in the headwaters area of the river (O'Connor and others, 1953, p. 6).

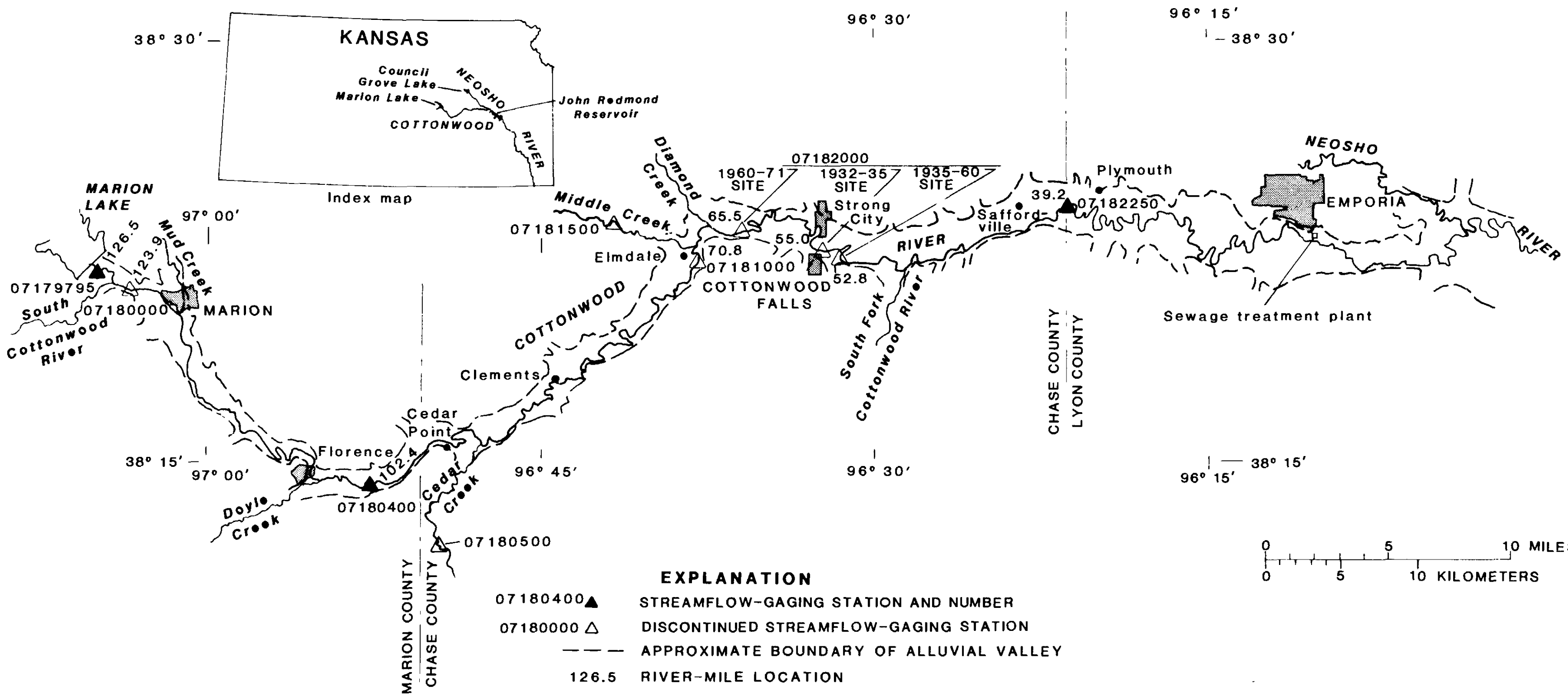

Figure 1.--Location of study area, streamflow-gaging stations, and boundary of alluvial valley.

Marion Lake began storage in 1968 and is used for flood- and water-quality control, water supply, recreation, and fish and wildlife conservation. Inflow to the lake is from a drainage area of 200 mi^2. Storage for water-quality control and water supply is 83,000 acre-feet. Scheduled minimum outflows vary seasonally and range from 1 to 13 ft^3/s.

Diversions from the Cottonwood River are for irrigation and part of the water supply for Emporia. Wells in the alluvial aquifer underlying the flood plain supply Cedar Point, Strong City, Cottonwood Falls, and Thunderbird Estates, a development midway between Emporia and Plymouth.

Cottonwood River flows were gaged from 1922 to 1932 at Elmdale (station 07181000), from 1938 to 1968 near Marion (station 07180000), and from 1932 to 1971 at three locations at or near Cottonwood Falls (all designated as station 07182000 "at Cottonwood Falls," although the most recent site is 3.5 miles northwest of Cottonwood Falls). Current (1985) streamflow-gaging stations are below Marion Lake (station 07179795) since 1968, near Florence (station 07180400) since 1961, and near Plymouth (station 07182250) since 1963.

Two tributaries to the Cottonwood River have been gaged. Middle Creek was gaged near Elmdale from 1939 to 1950 (station 07181500, drainage area 92 mi^2). Cedar Creek has been gaged near Cedar Point since 1939 (station 07180500, drainage area 110 mi^2). Both creeks have had long periods of zero flow during several years. Other tributaries to the Cottonwood River are of similar size or smaller, so all tributaries are assumed not to contribute flow to the river during drought periods.

STREAMFLOW LOSSES AND GAINS DURING TRANSIT

Sources of streamflow losses and gains during transit are withdrawal by water-right holders, evapotranspiration, return flows from municipal treatment-plant effluents, and streamflow-aquifer interaction. The study area of the Cottonwood River, from Marion Dam to its confluence with the Neosho River, was divided into reaches to better define these losses and gains and to aid in model analysis. The reaches were delineated by selected sites used in a series of low-flow measurements (described subsequently). Several of the sites are at current (1985) or discontinued streamflow-gaging stations.

Withdrawal by Water-Right Holders

Information supplied by the Division of Water Resources of the Kansas State Board of Agriculture indicates, as of September 1984, that numerous water-right permits have been issued to withdraw water from the main-stem Cottonwood River. These permits give the holder the right to withdraw natural flow from the river. During model simulations, natural-flow withdrawals were assumed not to be taken from modeled reservoir releases. Wells at Cedar Point, Strong City, Cottonwood Falls, and Thunderbird Estates were included in the streamflow-routing model, and their appropriate pumping rates for use in the simulations were estimated from information supplied by the Division of Water Resources (written commun., 1984).

Evapotranspiration

Evapotranspiration comprises both evaporation from water surfaces and transpiration from plants (evaporation of water released through the pores of plants). The water for transpiration is drawn up by roots from the soil or from the capillary fringe of the aquifer. Transpiration may be an important transit loss during the growing season (May through October) but not during the winter months. It was assumed in this study that during drought conditions, small changes in river-surface elevation resulting from reservoir releases would not change the rate of transpiration. Therefore, transit losses due to transpiration were not included in the streamflow-routing model.

To estimate river-surface evaporation, data from the Class-A evaporation pan at the Marion Dam weather station were used. The largest amount of evaporation measured or estimated for each month during 1976-83 (table 1) was used in the model because the simulations were intended to represent drought conditions. 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 (Farnsworth and others, 1982). These estimates were used in the streamflow-routing model simulations to calculate evaporation losses during reservoir releases. Evaporation calculations were adjusted to account for changes in river-surface width because the width varied with the rate of streamflow.

Table 1.--*Selected evaporation data from Class-A evaporation pan at Marion Dam, 1976-83*

[Measured data are from National Oceanic and Atmospheric Administration, 1976, 1980, 1983]

Month	Year of largest evaporation	Evaporation from pan	
		Monthly total (inches)	Average (inches per day)
July	1980	17.71	0.571
August	1976	12.77	.412
September	1983	8.68	.289
October	1980	5.62	.181
November	1980	[1] 3.1	[1] .10
December	--	[2] 1.5	[2] .05
January	--	[2] 0.6	[2] .02

[1] Partly estimated.
[2] Estimated.

Return Flows of Used Water

The principal source of return flows to the Cottonwood River is sewage-treatment plant effluent. Treatment plants are operated by the cities of Marion, Florence, Cottonwood Falls, and Emporia, and by Iowa Beef Processors at Emporia. Rates of return flow were estimated from information supplied by the Division of Environment of the Kansas Department of Health and Environment (written commun., 1984) for July 31 and August 1, 1984, which correspond to the dates of low-flow measurements made to aid in estimating channel and aquifer hydraulic characteristics. On these dates the only treatment-plant effluents reaching the river were those from the city of Emporia, where return flow enters the river at mile 12.5. This flow had been withdrawn from the Neosho River, and based on the information received, the rate of return flow to the Cottonwood River was 6 ft^3/s.

Return flows also are possible as a result of over-irrigation of crops. However, because a shortage of water for irrigation was assumed during the drought periods simulated, return flows from irrigation were not included in the model.

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 water in the alluvium causes water to move into the aquifer or decreases the amount of water moving from the aquifer into the stream; conversely, 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 an increase in flow, such as a reservoir release. The temporary storage in the aquifer adjacent to the stream is called bank storage, and the flow to or from the bank storage is called bank-storage flow.

During average or wetter years, the hydraulic head in the aquifer is higher than the river during dry weather, and the aquifer supplies the river with a steady base flow. The severe-drought conditions simulated in this report assume that the aquifer has been draining to the river during 2 or more years of drought and is no longer supplying significant flow to the river. The less-severe-drought conditions are those that existed during October 1964, when the aquifer had been drained only partially during 3 to 4 months of drought and was increasing the river flow by about 0.1 $(ft^3/s)/mi$ between the Marion (07180000) and Plymouth (07182250) streamflow-gaging stations.

Specific data on stream-aquifer interactions were not available for the Cottonwood River. The streamflow-routing model calculated the interactions based on one-dimensional equations describing ground-water flow and estimated hydraulic characteristics of the stream-aquifer system.

Gain-loss Investigation, July 31 - August 1, 1984

During July 31 and August 1, 1984, a streamflow gain-loss investigation was conducted in the study area. The purpose was to provide data to aid in estimating channel and aquifer hydraulic characteristics. The investigation was made during a period of steady low streamflow after 2 to 4 weeks of little or no precipitation and consisted of duplicated measurements for improved accuracy at 12 main-stem sites and measurements of flow or observations of no flow at 34 tributary sites (fig. 2). Data on withdrawals from the river and pumpage from the aquifer by water-right holders were supplied by the Division of Water Resources of the Kansas State Board of Agriculture, and data on return flows from treatment-plant effluents were supplied by the Division of Environment of the Kansas Department of Health and Environment. No return flows from irrigation were observed near the sites of the main-stem and tributary measurements, and return flow from irrigation was assumed to be negligible on the days of the measurements.

Results of the low-flow measurements and calculated natural gains or losses are given in table 2. The calculations show substantial gains (from the aquifer) from river mile 126.5 to mile 86.0. Small losses (evapotranspiration exceeding inflow from the aquifer) occurred from mile 86.0 to mile 65.0. Gain occurred from mile 65.0 to 52.8, followed by small losses from mile 52.8 to 13.4. A substantial gain then occurred from mile 13.4 to the last site measured, mile 2.1. These results give some indication of the areas where the aquifer may be transmissive enough to supply flow in excess of that lost to evapotranspiration. However, the short drought during summer 1984 was preceded by an unusually wet spring and early summer, making the aquifer fuller than it would have been after a long drought. The gain-loss data from the 1984 measurements must be interpreted in conjunction with other available information concerning stream-aquifer interactions.

STREAMFLOW-ROUTING MODEL

As a reservoir release or water wave moves downstream, water is temporarily stored in the bank and channel. For a reservoir release, the water that initially is stored in the bank and channel gradually returns to the river once the reservoir release has been reduced. The effects of this temporary storage are a reduction in peak discharge and an attenuation of the discharge hydrograph over distance, and possibly a delay in the apparent traveltime of the peak of the hydrograph. Losses from evaporation, ground-water withdrawals, and diversions and gains from return flows can be accounted for by using features available in a streamflow-routing model.

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 flood, reservoir release, or other water wave through the study reach (Land, 1977). The model is based on an analytical solution of the diffusion equation for an instantaneous unit input (Land, 1977, p. 3). 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 an instantaneous input (Hall and Moench, 1972; Keefer, 1974).

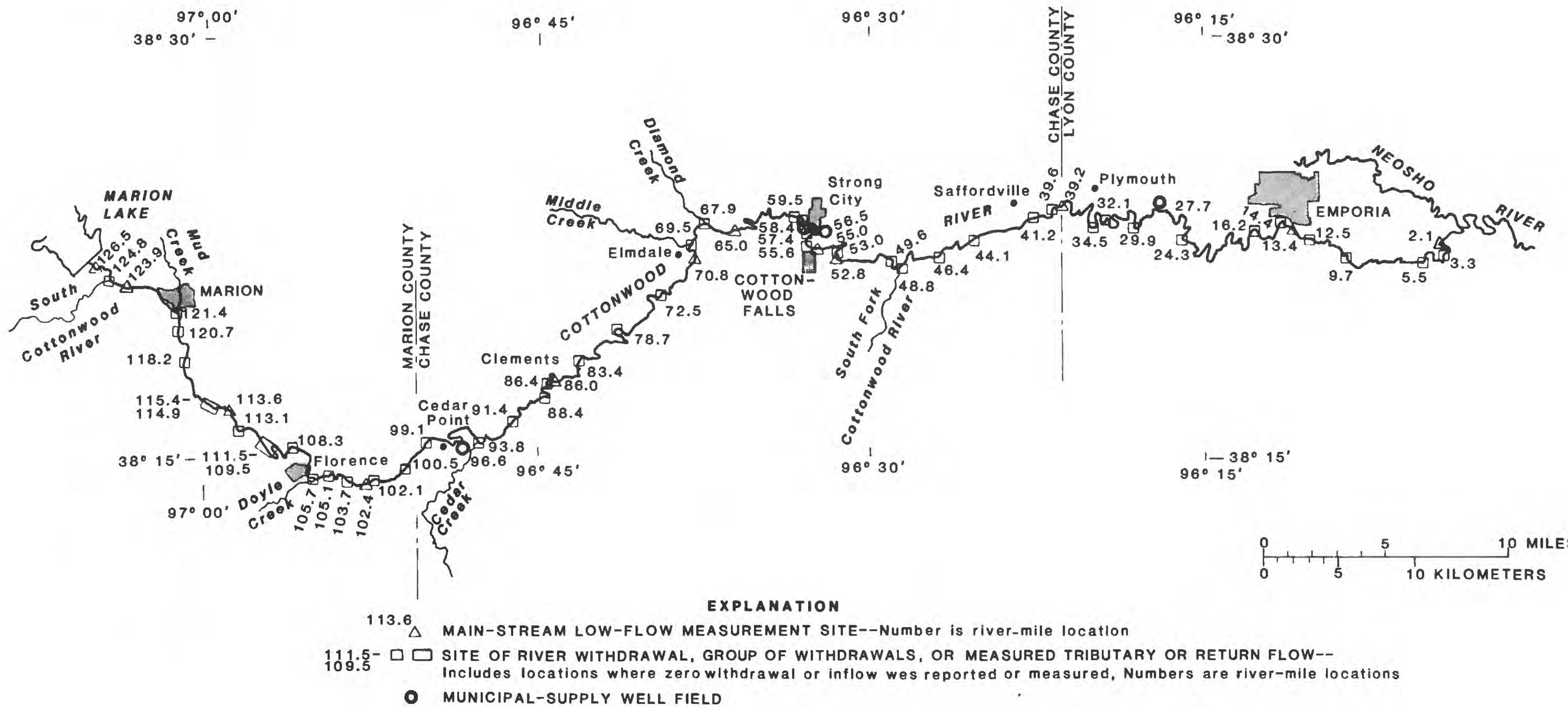

Figure 2.--Location of low-flow measurement sites, July 31-August 1, 1984, river withdrawals, and water-supply wells in alluvial aquifer.

Table 2.--*Results of gain-loss investigation, July 31-August 1, 1984*

River mile	Description	Tributary inflow (cubic feet per second)	Return flow (cubic feet per second)	Diver-sion (cubic feet per second)	Main-stem flow (cubic feet per (second)	Gain (+) or loss (-) (cubic feet per second)	Average gain (+) or loss (-) (cubic feet per second per mile)
126.5	Cottonwood River below Marion Lake	--	--	--	11.1	--	--
124.8	South Cottonwood River	3.3	--	--	--	--	--
123.9	Cottonwood River near Marion (average 2 measurements)	--	--	--	16.6	--	--
Gain, mile 126.5 to 123.9 (2.6 miles)		--	--	--	--	+2.2	+0.86
121.4	Mud Creek	5.2	--	--	--	--	--
122-121	Marion water rights and effluent	--	0	0	--	--	--
120.7	Unnamed tributary	1.2	--	--	--	--	--
118.2	Spring Branch	0.5	--	--	--	--	--
115.4-114.9	Withdrawals	--	--	-3.0	--	--	--
113.6	Cottonwood River 3 miles northwest of Florence (average 2 measurements)	--	--	--	31.4	--	--
Gain, mile 123.9 to 113.6 (10.3 miles)		--	--	--	--	+10.9	+1.1

Table 2.--*Results of gain-loss investigation, July 31-August 1, 1984*--Continued

River mile	Description	Tributary inflow (cubic feet per second)	Return flow (cubic feet per second)	Diver-sion (cubic feet per second)	Main-stem flow (cubic feet per (second)	Gain (+) or loss (-) (cubic feet per second)	Average gain (+) or loss (-) (cubic feet per second per mile)
113.3	Withdrawals	--	--	-3.5	--	--	--
113.1	Catlin Creek	1.1	--	--	--	--	--
111.5-109.5	Withdrawals	--	--	0	--	--	--
108.3	Unnamed creek (Florence water source is upstream along this creek)	0	--	--	--	--	--
105.7	Doyle Creek	9.2	--	--	--	--	--
105.7	Florence effluent	--	0	--	--	--	--
105.1	Withdrawal	--	--	0	--	--	--
103.7	Unnamed tributary	0	--	--	--	--	--
102.4	Cottonwood River near Florence (average 2 measurements)	--	--	--	48.8	--	--
Gain, mile 113.6 to 102.4 (11.2 miles)		--	--	--	--	+10.6	+0.9

Table 2.--*Results of gain-loss investigations, July 31-August 1, 1984*--Continued

River mile	Description	Tributary inflow (cubic feet per second)	Return flow (cubic feet per second)	Diversion (cubic feet per second)	Main-stem flow (cubic feet per second)	Gain (+) or loss (-) (cubic feet per second)	Average gain (+) or loss (-) (cubic feet per second per mile)
102.1	Martin Creek	0.4	--	--	--	--	--
100.5	Withdrawal	--	--	0	--	--	--
99.1	Bruno Creek	.8	--	--	--	--	--
96.6	Cedar Point wells	--	--	1/ -.02	--	--	--
93.8	Cedar Creek	8.2	--	--	--	--	--
91.4	French Creek	.05	--	--	--	--	--
88.4	Coyne Branch	.2	--	--	--	--	--
86.4	Withdrawal	--	--	-1.1	--	--	--
86.0	Cottonwood River near Clements (average 2 measurements)	--	--	--	64.3	--	--
Gain, mile 102.4 to 86.0 (16.4 miles)		--	--	--	--	+7.0	+0.4

Table 2.--*Results of gain-loss investigations, July 31-August 1, 1984*--Continued

River mile	Description	Tributary inflow (cubic feet per second)	Return flow (cubic feet per second)	Diversion (cubic feet per second)	Main-stem flow (cubic feet per (second)	Gain (+) or loss (-) (cubic feet per second)	Average gain (+) or loss (-) (cubic feet per second per mile)
83.5	Withdrawals	--	--	0	--	--	--
83.4	Silver Creek	0.8	--	--	--	--	--
78.7	Gould Creek	0	--	--	--	--	--
72.5	Withdrawal	--	--	0	--	--	--
70.8	Cottonwood River near Elmdale (average 4 measurements)	--	--	--	62.2	--	--
Loss, mile 86.0 to 70.8 (15.2 miles)		--	--	--	--	-2.9	-0.2
69.5	Middle Creek	4.8	--	--	--	--	--
67.9	Diamond Creek	9.1	--	--	--	--	--
65.0	Cottonwood River 3.5 miles west of Strong City (average 2 measurements)	--	--	--	75.7	--	--
Loss, mile 70.8 to 65.0 (5.8 miles)		--	--	--	--	-0.4	-0.07

Table 2.--*Results of gain-loss investigation, July 31-August 1, 1984*--Continued

River mile	Description	Tributary inflow (cubic feet per second)	Return flow (cubic feet per second)	Diversion (cubic feet per second)	Main-stem flow (cubic feet per (second)	Gain (+) or loss (-) (cubic feet per second)	Average gain (+) or loss (-) (cubic feet per second per mile)
59.5	Withdrawals	--	--	0	--	--	--
58.4	Fox Creek	2.1	--	--	--	--	--
58.6-56.5	Cottonwood Falls and Strong City wells	--	--	1/-1.4	--	--	--
57.4	Prather Creek	0.6	--	--	--	--	--
55.6	Spring Creek	0	--	--	--	--	--
55.5	Withdrawal	--	--	0	--	--	--
53.0	Cottonwood Falls effluent	--	0	--	--	--	--
52.9	Buck Creek	0	--	--	--	--	--
55.0 and 52.8	Cottonwood River below Cottonwood Falls (average of measurements at 2 sites)	--	--	--	92.6	--	--
Gain, mile 65.0 to 52.8 (12.2 miles)		--	--	--	--	+15.6	+1.3

Table 2.--*Results of gain-loss investigation, July 31-August 1, 1984*--Continued

River mile	Description	Tributary inflow (cubic feet per second)	Return flow (cubic feet per second)	Diver-sion (cubic feet per second)	Main-stem flow (cubic feet per (second)	Gain (+) or loss (-) (cubic feet per second)	Average gain (+) or loss (-) (cubic feet per second per mile)
49.6	Stout Run	0.1	--	--	--	--	--
48.8	South Fork Cottonwood River	4.3	--	--	--	--	--
46.4	Bloody Creek	1.4	--	--	--	--	--
44.1	Peyton Creek	0.3	--	--	--	--	--
41.2	Bull Creek	0	--	--	--	--	--
39.6	Buckeye Creek	0.3	--	--	--	--	--
39.2	Cottonwood River near Plymouth (average 2 measurements)	--	--	--	98.8	--	--
Loss, mile 52.8 to 39.2 (13.6 miles)		--	--	--	--	-0.2	-0.01
34.5	Jacob Creek	0.01	--	--	--	--	--
32.5	Withdrawal	--	--	0	--	--	--
32.1	Beaver Creek	0	--	--	--	--	--

Table 2.-- *Results of gain-loss investigation, July 31-August 1, 1984*--Continued

River mile	Description	Tributary inflow (cubic feet per second)	Return flow (cubic feet per second)	Diversion (cubic feet per second)	Main-stem flow (cubic feet per (second)	Gain (+) or loss (-) (cubic feet per second)	Average gain (+) or loss (-) (cubic feet per second per mile)
29.9	Unnamed tributary	0	--	--	--	--	--
27.7	Thunderbird Estates wells	--	--	1/0.3	--	--	--
24.3	Phenis Creek	0	--	--	--	--	--
16.5	Unnamed tributary	0	--	--	--	--	--
16.2	Emporia withdrawal	--	--	0	--	--	--
14.4	Iowa Beef Processors effluent	--	0	--	--	--	--
13.4	Cottonwood River at Emporia, K-99 (average 2 measurements)	--	--	--	98.4	--	--
Loss, mile 39.2 to 13.4 (25.8 miles)		--	--	--	--	-0.1	-0.004

Table 2.--*Results of gain-loss investigation, July 31-August 1, 1984*--Continued

River mile	Description	Tributary inflow (cubic feet per second)	Return flow (cubic feet per second)	Diversion (cubic feet per second)	Main-stem flow (cubic feet per (second)	Gain (+) or loss (-) (cubic feet per second)	Average gain (+) or loss (-) (cubic feet per second per mile)
12.5	Emporia effluent	--	2/6.0	--	--	--	--
9.7	Dry Creek	0	--	--	--	--	--
5.5	Coal Creek	0	--	--	--	--	--
3.3	Withdrawals	--	--	0	--	--	--
2.1	Cottonwood River near mouth (average 2 measurements)	--	--	--	113	--	--
Gain, mile 13.4 to 2.1 (11.3 miles)		--	--	--	--	+8.6	+0.8

1 Withdrawal wells are within 0.5 mile of river and had been pumping for several months or years; rate of pumping was assumed to result in equal rate of reduction of gain to river.

2 Includes water withdrawn from Neosho River.

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 (Glover and Balmer, 1954; Moench and others, 1974; Lucky and Livingston, 1975; Rovey, 1975). 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 (Moench and others, 1974; Land, 1977). The bank-storage discharge is combined with the streamflow-routing model results at the downstream end of each reach. If a significant change in discharge occurs due to bank storage, the stage is adjusted, and the bank-storage computations are repeated (Land, 1977).

The streamflow-routing model is capable of simulating losses from the river to the aquifer based on an analytical expression for stream depletion by wells (Glover and Balmer, 1954). However, for reduction of computations, the model treats a well less than 10 feet from the river as a direct diversion. Aquifer-boundary conditions that can be simulated are: "Case 1," semi-infinite aquifer, "Case 2," finite aquifer; and "Case 3," semi-infinite aquifer with a permeable confining bed separating the stream and aquifer.

The model requires data on streamflow rates at the upstream end, channel and aquifer hydraulic characteristics, rates of diversions, return flows, pumpage from wells, and distances of wells from the river. Channel characteristics required are length, water-wave celerity, and wave-dispersion coefficient. Aquifer characteristics required are length, transmissivity, and storage coefficient. Results of the model include tabulated and graphical hydrographs for streamflow and bank-storage discharge, traveltimes, and a summary of transit losses or gains to or from bank storage and diversions, including flow to wells and evaporation.

Determination and Estimation of Channel and Aquifer Characteristics

Channel Characteristics

Channel length has a directly proportional effect on traveltime and on the spreading of the routed streamflow (Land, 1977). Channel lengths for the Cottonwood River were determined from river mileages shown on aerial photographs in the flood-plain information report by the U.S. Army Corps of Engineers (1965). Although these mileages are not in exact agreement with U.S. Geological Survey water-data reports and the channel has shortened or lengthened in some places since 1965, the Corps of Engineers mileages provide the most consistent and convenient mileage figures for the whole study area.

Wave-dispersion coefficients and wave celerities were calculated from stream slopes, widths, and stage-discharge relations. Stream slopes were calculated from a longitudinal profile, figure 3, which was developed from U.S. Geological Survey topographic quadrangles, with a scale of 1:24,000 and a contour interval of 10 feet. Because much of the available data on stream width and stage-discharge relations are from operation of streamflow-gaging stations that were discontinued as long ago as 1932, the stream cross sections measured on July 31 and August 1, 1984, were compared with

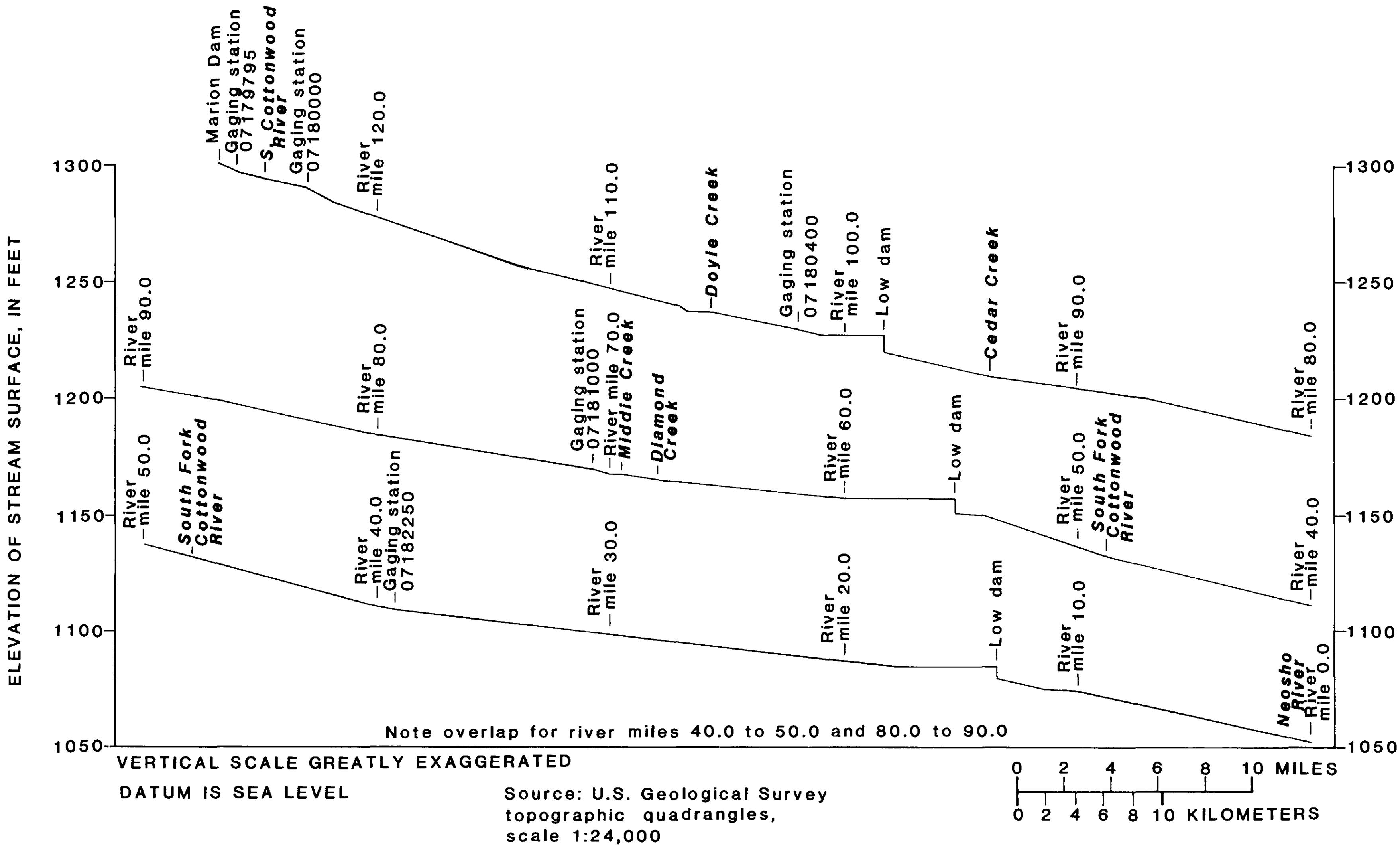

Figure 3.--Low-water profile of Cottonwood River from Marion Dam to confluence with Neosho River.

cross sections measured during the period of operation of the gaging stations (fig. 4). These comparisons show no indication of large changes affecting the width and stage-discharge relations, so the earlier data were used along with any later data available. Figure 5 shows an example of a relation between width and streamflow rate from streamflow measurements made during low and medium flow. Because hydrographers usually select narrow cross sections with adequate velocity for accurate measurement, the width-streamflow relation used for the streamflow-routing model uses the upper values of width in figure 5 to more accurately represent typical widths of the stream.

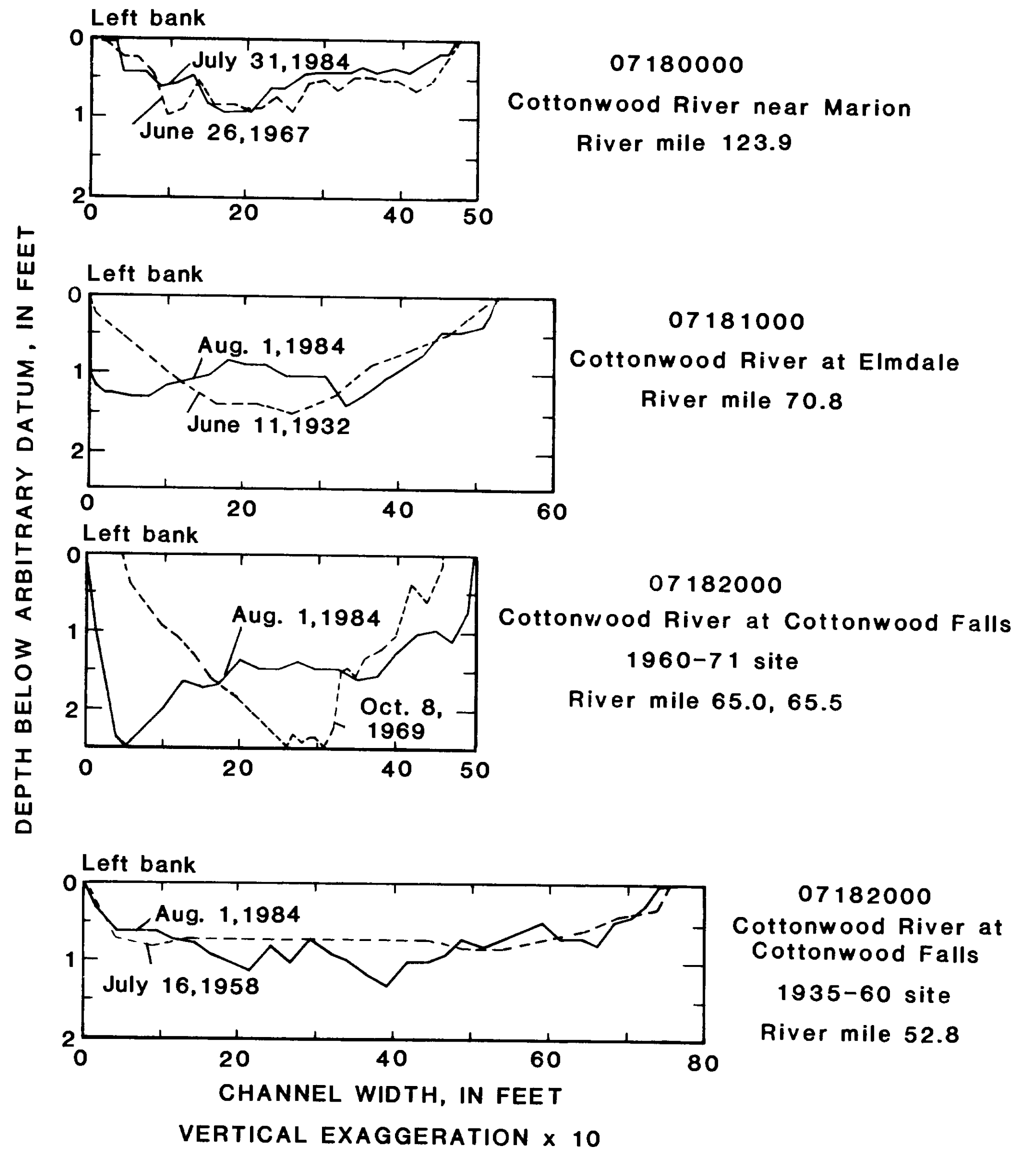

Figure 4.--Channel cross sections at sites of discontinued streamflow-gaging stations, 1984 and earlier years.

Channel characteristics must be estimated as averages for each selected reach of channel. A visual inspection by the authors during May 1984, indicated that the channel of the Cottonwood River has a consistent shape, does not have pronounced pools and riffles, and that changes along its length are gradual. The low-flow measurements made on July 31 and August 1, 1984, at locations more closely spaced than the gaging stations, show the gradual change (fig. 6) and give confidence in the estimates of the channel characteristics. For the reaches that included pools behind low dams, the pools were a small part of the length and should have had only small effects on the estimates.

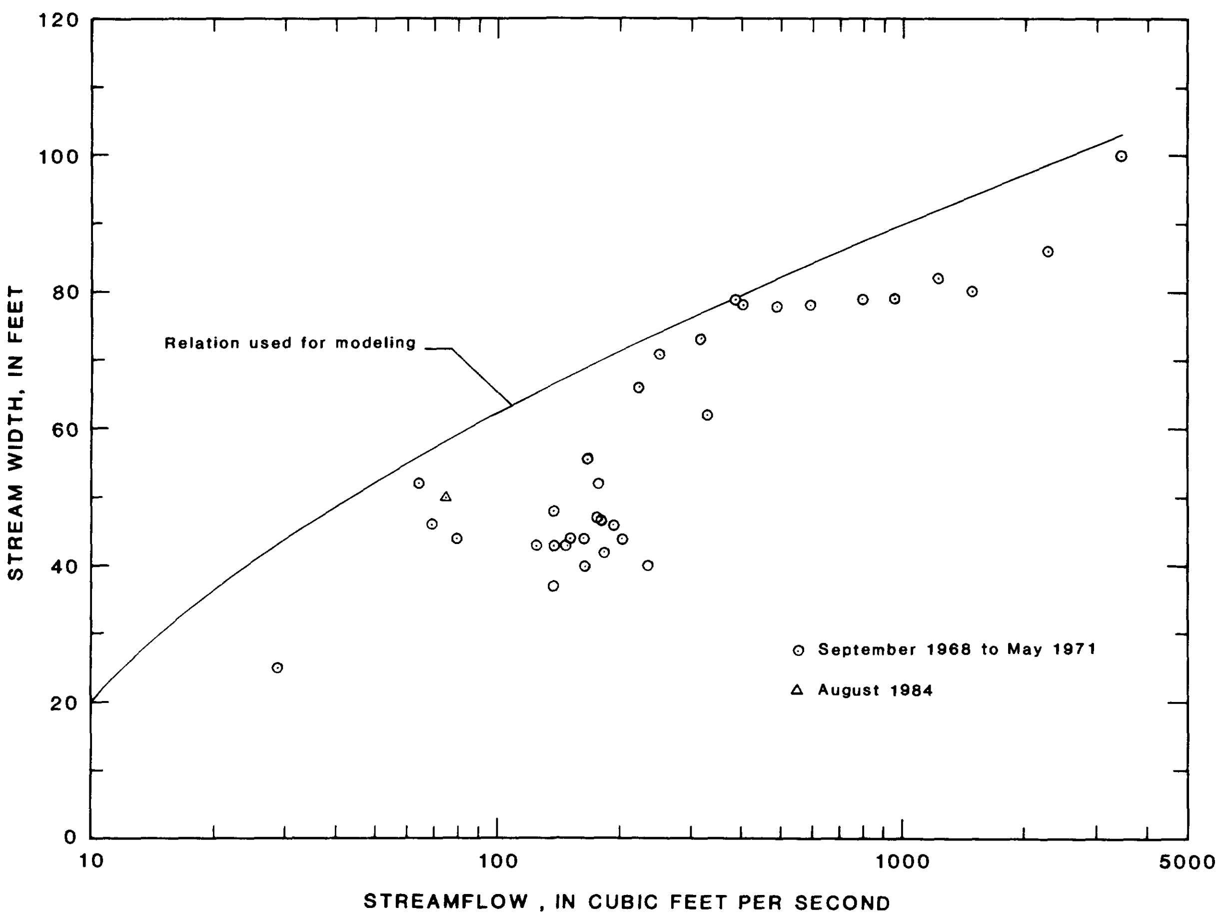

Figure 5.--Relation between stream width and streamflow, Cottonwood River gaging station 07182000, river mile 65.5.

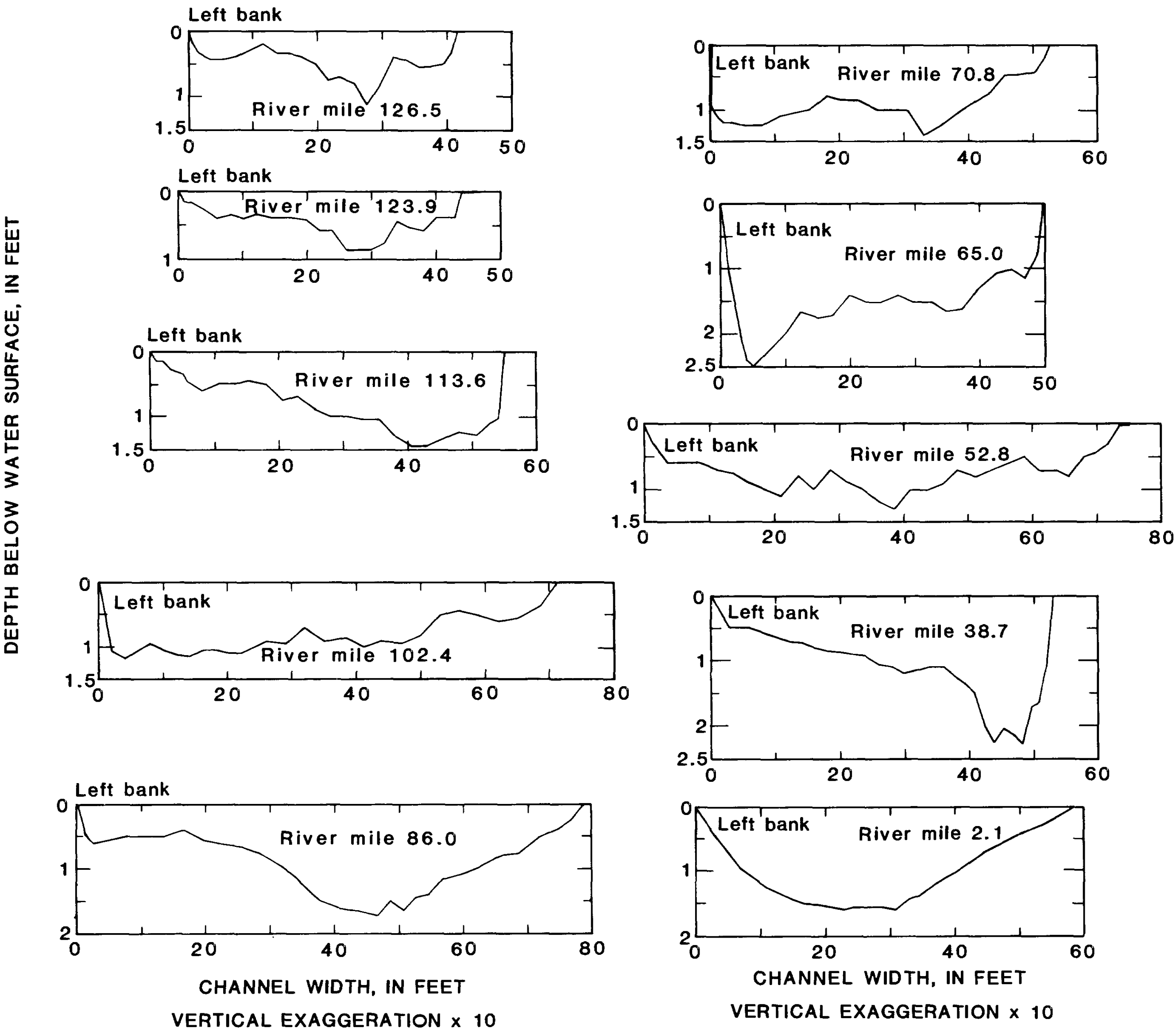

Figure 6.--Comparison of channel cross sections at sites of low-flow measurements, July 31 and August 1, 1984.

The diffusion equation uses a wave-dispersion coefficient (K_0), which controls the spreading or shape of the water wave, and also a wave-celerity (C_0) value, which controls the speed of the water wave. The relations between the wave-dispersion coefficient and streamflow discharge were developed using the following equation (modified from Keefer, 1974, p. 1053):

$$K_0 = \frac{Q_0}{2\, S_0\, W_0}, \qquad (1)$$

where K_o = wave-dispersion coefficient;

Q_o = streamflow discharge;

S_o = average stream slope; and

W_o = average channel width for a particular study reach.

Large K_o values result in hydrographs that are flatter and spread over longer times as compared to small K_o values.

The wave-celerity and streamflow-discharge relations were developed using the following equation (Land, 1977, p.3):

$$C_o = \frac{1}{W_o} \frac{dQ_o}{dY_o}, \qquad (2)$$

where $\frac{dQ_o}{dY_o}$ is the slope of the rating curve (stage-discharge relation) at

Q_o; and W_o is as previously defined.

C_o determines the traveltime of a water wave except for the effects of aquifer and channel storage. Values were determined for the dispersion coefficient and celerity for a range of discharge, as illustrated in the example in figure 7. For each simulation using the model, the dispersion coefficient and celerity for a typical discharge in each reach were used.

Aquifer Characteristics

Limited data are available on aquifer characteristics along the Cottonwood River, and time and funding constraints for this study did not permit drilling of test holes or performance of aquifer tests. The low-flow measurements on July 31 and August 1, 1984, provided some information, which was used with previously available information, for estimating aquifer characteristics. Information was obtained from Byrne and others (1959), Moore and others (1951), O'Connor and others (1953), Reed and Burnett (1985), and from drillers' logs on file with the Kansas Geological Survey, Lawrence. Some of the available data appear to be contradictory. Data on thickness of clay and silt and depth of the river channel indicate that clay occurs between the river and the sand and gravel aquifer from the upstream end of the study area to about river mile 47, except for one short length of channel. However, the 1984 low-flow measurements showed mostly gains in streamflow in this area. Available data show the channel penetrating to sand and gravel from river mile 47 to river mile 13, yet the low-flow measurements showed loss of flow in this area. This loss may be related to the increased width of the channel and flood plain providing more opportunity for evapotranspiration, therefore not necessarily contradicting the information about the aquifer.

Aquifer tests of varying reliability indicated transmissivities of about 300 to 3,000 ft^2/d (Reed and Burnett, 1985, and data on file with the Kansas Geological Survey, Lawrence). The larger transmissivities were

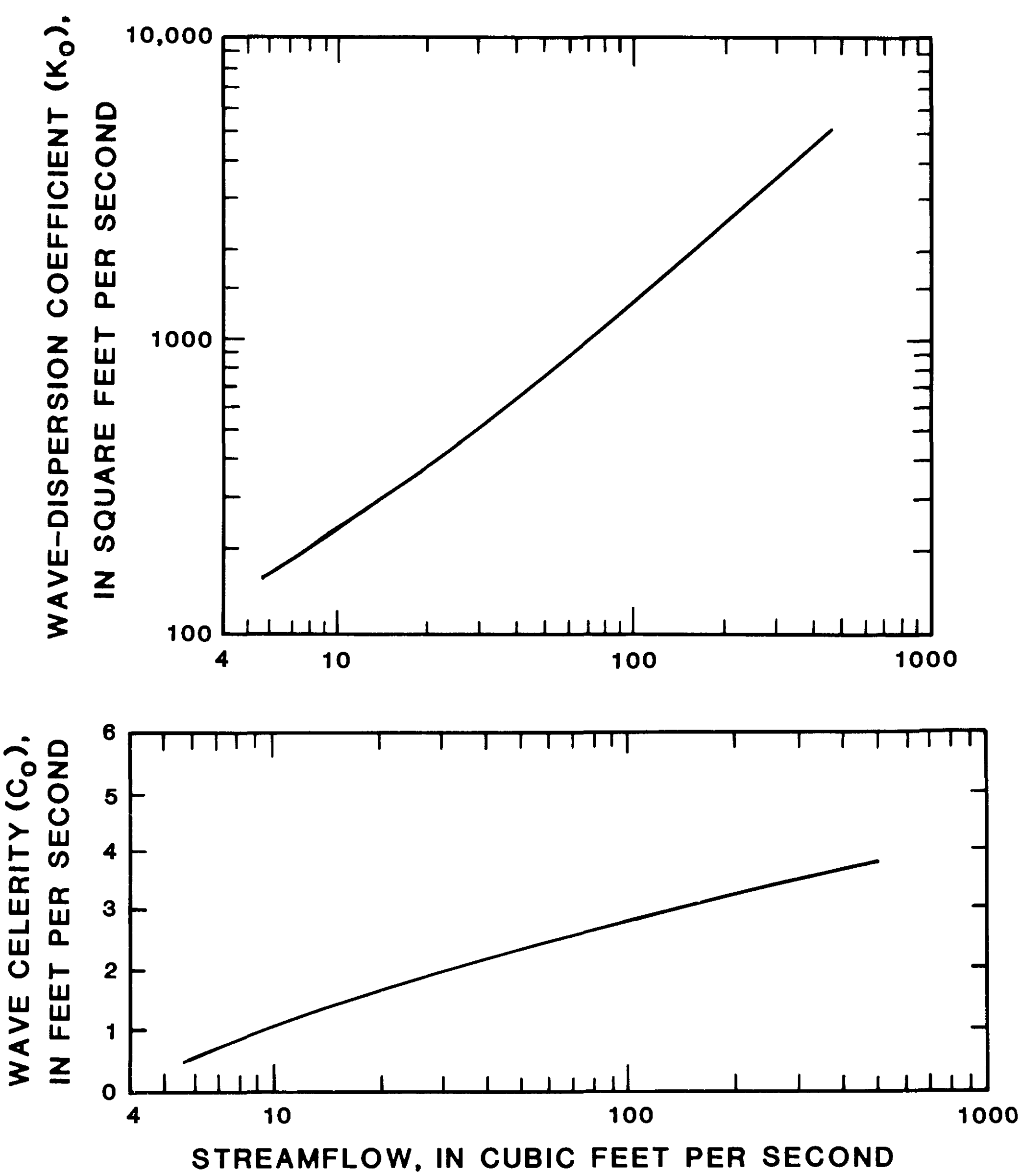

Figure 7.--Relations between wave-dispersion coefficient (K_0) and streamflow, and wave celerity (C_0) and streamflow for gaging station 07180400 (river mile 102.4).

more than 4,000 feet from the river and may not be applicable for use in the streamflow-routing model; therefore, a smaller transmissivity of 500 ft^2/d for the whole study area was used in the model. No data are available on storage coefficients in the aquifer. Because of a lack of data to show whether the aquifer was confined or not, an intermediate value of 0.01 was used for storage coefficient for river mile 126.5 to river mile 39.2. For river mile 39.2 to river mile 2.1, a storage coefficient of 0.10 was used [consistent with the channel penetrating gravel and with the value used by Carswell and Hart (1985) for the Neosho River model]. Available data on the aquifer in the Cottonwood River valley were inadequate to determine specific boundary conditions; therefore, the same boundary conditions were used for this study as were used for the Neosho River (Carswell and Hart, 1985). A semi-infinite aquifer (identified as Case 1 in the model) without a confining bed separating the stream from the aquifer with a flat initial water table was assumed in the ground-water analysis. For the modeling of the Cottonwood River, as shown later in this report, the choice of boundary condition had little effect on the results.

Measured and estimated channel and aquifer characteristics are shown in table 3.

Table 3.--*Measured and estimated channel and aquifer characteristics used in streamflow-routing model*

Reach (River miles)	Channel length[1] (miles)	Aquifer characteristic			
		Length[1] (miles)	Average width[1] (feet)	Transmissivity[2] (square feet per day)	Storage coefficient[2] (dimensionless)
126.5 - 123.9 (station 07180000)	2.6	1.5	3,600	500	0.01
123.9 - 113.0	10.9	6.0	4,800	500	.01
113.0 - 102.4 (station 07180400)	10.6	8.0	3,200	500	.01
102.4 - 86.0	16.4	9.0	4,900	500	.01
86.0 - 65.5 (station 07182000, 1960-71 site)	20.5	11.5	7,100	500	.01
65.5 - 39.2 (station 07182250)	26.3	14.9	7,900	500	.01
39.2 - 19.0	20.2	7.0	10,800	500	.10
19.0 - 2.1	16.9	8.8	9,200	500	.10

1 Measured.

2 Estimated.

Sensitivity of Calibration or Verification to Variations in Estimates of Channel and Aquifer Characteristics

Information to aid in model calibration or verification can be obtained from data on the sensitivity of the model to variations in estimates of channel or aquifer characteristics. A percentage change of either transmissivity or storage-coefficient values has the same effect. The principal effect of transmissivity and storage coefficient is on bank-storage flows, whereas traveltime is affected only slightly. Changes in bank-storage flows are directly proportional to changes in alluvial-valley length. A change in channel length has a direct proportional effect on traveltime and corresponding attenuation of the downstream hydrograph. The wave-dispersion coefficient primarily affects the shape of the downstream hydrograph and has only a minor effect on traveltime. Wave celerity primarily affects traveltime. Results of a sensitivity analysis by Land (1977) are given in table 4 and were used as general guidance during the calibration and verification of the model; effects of errors in the values used for the Cottonwood River are discussed in a subsequent section of this report.

The foregoing information on sensitivity shows that, for calibration or verification of model estimates of channel and aquifer characteristics, wave celerity should be judged from modeled results for traveltime, and wave-dispersion coefficient should be judged by the shape of the modeled downstream hydrograph. Transmissivity and storage coefficient should be judged from bank-storage flows; however, bank-storage flows have not been measured for this study, and the best available data for judging transmissivity and storage coefficient is the volume of streamflow. The sensitivity results in table 4 do not indicate the magnitude of errors in results for applications in which evaporation or depletion by wells is significant. Available periods of flow for model calibration or verification are only a few days in length; therefore, evaporation would have insignificant effect. Channel and alluvial-valley lengths can be measured accurately (table 3), so would contribute little error.

Calibration and Verification of Estimated Channel and Aquifer Characteristics

Only a limited amount of data are available for use in calibrating or verifying the estimates of channel and aquifer characteristics. Calibration or verification can be attempted by using observed flow data at pairs of streamflow-gaging stations. Ideally, to be suitable for calibration or verification, periods of observed flow should reflect steady base flow at both stations before an increase in flow at the upstream station. Increases in flow should be neither too small to show an effect at the downstream station nor too large to be applicable to the range of flows for which the model will be used. Also, no tributary inflow should occur between the two gaging stations during the period. Numerous suitable periods of flow would be necessary in order to determine the level of accuracy of the individual estimates, but computations for a few periods of flow can be used to check for large inaccuracy or bias in the estimates.

Table 4.--*Results of sensitivity analyses for selected channel or aquifer characteristics and stream-aquifer boundary conditions*

[Modified from Land, 1977]

Characteristic or boundary condition	Volume to bank storage (acre-feet)			Peak of flow to bank storage (cubic feet per second)			Traveltime (hours)		
	Change (percent)			Change (percent)			Change (percent)		
	-50	0	+50	-50	0	+50	-50	0	+50
Channel characteristics:									
Wave-dispersion coefficient: 1,000 square feet per second	290	290	290	67	67	66	9.8	9.4	9.4
Wave celerity: 2.0 feet per second	286	290	296	50	67	75	17.6	9.4	6.5
Aquifer characteristics:									
Transmissivity: 4,760 square feet per day	204	290	353	48	67	81	9.4	9.4	9.4
Storage coefficient: 0.15	[1]204	290	[1]353	81	67	48	9.4	9.4	9.4
Stream-aquifer boundary conditions:									
Case 1: Stream fully penetrates semi-infinite aquifer	---	290	---	--	67	--	---	9.4	---
Case 2: Finite aquifer, width 2,000 feet	290	290	290	67	67	67	9.4	9.4	9.4
Case 3: Semi-infinite aquifer, permeable confining bed, retardation coefficient 100 feet	274	248	226	55	44	36	9.4	9.4	9.4

[1] Correction of erroneous value in original table found in Land (1977, table 1).

The records available for the Cottonwood River showed no ideal periods of observed flow; therefore, one or more periods approaching suitable flow conditions were selected for each pair of streamflow-gaging stations that were operated concurrently--stations 07179795 and 07180400, 07180000 and 07180400, 07180400 and 07182000, 07182000 and 07182250 (see fig. 1). Each selected upstream flow was routed through the model to the downstream gaging station using a 1-hour time step, and the simulated flow and traveltime were compared with the observed flow and traveltime. Because of the irregularity of small increases in natural flow, traveltime to 50 percent of the maximum increase was used instead of traveltime to the earliest increase in flow (first response).

Results of the calibration process are given in table 5. Plotted hydrographs were compared; an example is in figure 8. The simulation underestimated the traveltime for the first rise in streamflow in figure 8 and overestimated the traveltime for the larger streamflow of the second rise, probably because the values of wave celerity and dispersion coefficient used in the model did not vary as the streamflow varied within the simulation. A single value, corresponding to a typical streamflow rate within each hydrograph simulated, was used for wave celerity and dispersion coefficient for each simulation. Because of the probability of some tributary inflow being included in the observed downstream flows, simulated flows slightly smaller than observed flows probably are desirable results. The results appear to indicate that the estimates are reasonable and that no adjustments would improve the calibration. Therefore, the estimates are considered to be verified to the extent possible.

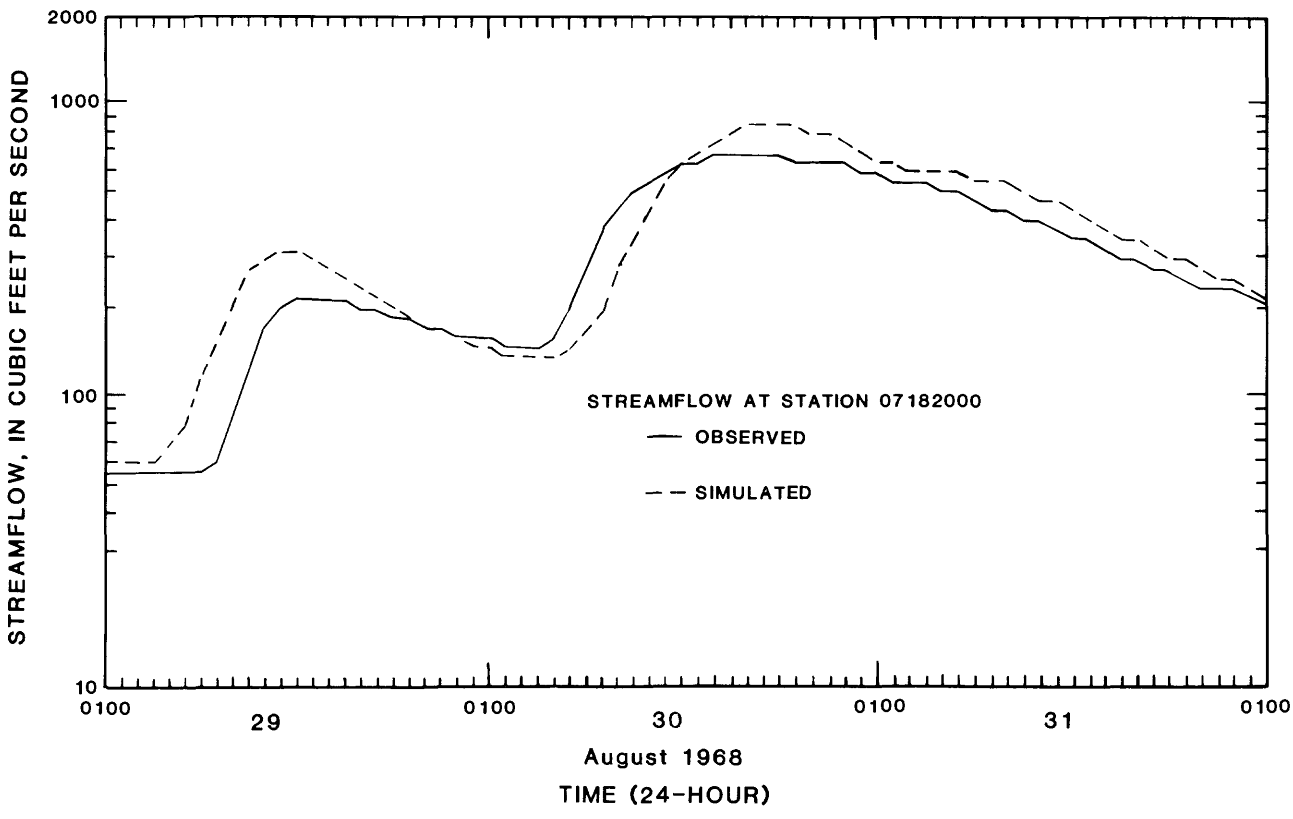

Figure 8.--Example of observed and simulated streamflow using estimated channel and aquifer characteristics from Florence (07180400, river mile 102.4) to Cottonwood Falls streamflow-gaging station (07182000, river mile 65.6), August 29-31, 1968.

Table 5.--*Observed streamflows used for calibration and verification of estimated channel and aquifer characteristics and percentage error between simulated and observed streamflow volumes and traveltimes*

Upstream and downstream streamflow-gaging stations	Period of flow	Range of observed flow at upstream station (cubic feet per second)	Percentage error of simulated streamflow volume, exclusive of base flow	Percentage error of simulated traveltime
Below Marion Lake (07179795) to Florence (07180400) (river miles 126.5 to 102.4)	November 29-December 3, 1973	13-106	+19	-27
Marion (07180000) to Florence (07180400) (river miles 123.9 to 102.4)	August 19-24, 1964	5.1-76	-21	-32
	July 26-31, 1966	3.0-99	-20	+50
	September 2-5, 1966	3.8-56	+10	-47
Florence (07180400) to Cottonwood Falls (07182000) (river miles 102.4 to 65.5)	July 24-30, 1964	16-110	-4	-24
	August 27-September 1, 1968	28-890	+10	-16
Cottonwood Falls (07182000) to Plymouth (07182250) (river miles 65.5 to 39.2)	April 11-16, 1967	47-910	-6	+17

Because of the lack of observed streamflow data downstream from the Plymouth gage (07182250), the estimates could not be calibrated or verified for the section of river downstream from river mile 39.2. Relations for wave-dispersion coefficients and wave celerity were developed for this section of river based on data from the Plymouth gage. These relations were assumed to be reasonably good estimates because the channel maintains approximately the same size and shape from river mile 39.2 to 2.1.

SIMULATION OF TRANSIT LOSSES AND TRAVELTIMES

Kansas water law provides that the quantity of water purchased from reservoir storage be the quantity released from the reservoir, rather than the quantity diverted at a downstream location for use by the purchaser. To aid in the effective management and administration of the purchased water, the streamflow-routing model was used to simulate transit losses and traveltimes in the Cottonwood River for selected reservoir releases under two antecedent-streamflow conditions. Model simulations of water-supply releases from Marion Lake were made for a severe-drought antecedent-streamflow condition such as existed during August 1956 through February 1957, after 4 years of drought, and a less-severe-drought antecedent-streamflow condition such as existed during October 1964, after a few months of drought. For other releases or antecedent conditions within the range covered in this report, interpolation can be used to estimate transit losses and traveltimes. For releases or antecedent conditions outside the range of those presented in this report, new simulations with the model would be needed. The results of simulations are subject to possible errors, which are discussed in a subsequent section of this report.

For both antecedent-streamflow conditions, it was assumed that there was no contribution of streamflow from tributaries. It was assumed also that withdrawals of natural flow by water-right holders were taken from base flow and not from the water-supply releases from reservoir storage. It was assumed that return-flow conditions were those reported at the time of the July 31-August 1, 1984, gain-loss investigation, when the only return flow was about 6 ft^3/s from the city of Emporia sewage-treatment plant (the source of that water was the Neosho River).

For the severe-drought antecedent-streamflow condition, it was assumed that there was only enough base flow to supply the depletions resulting from pumpage by wells, except downstream from the Emporia effluent. The reaches having zero flow were dry, and the ground-water level was at the level of the stream bottom. The less-severe-drought antecedent-streamflow condition assumed a nominal antecedent release rate equal to the typical dry-weather release from Marion Lake, 5 ft^3/s. Natural inflows of base flow averaging 0.1 $(ft^3/s)/mi$, as during October 1964, were assumed. However, the Emporia effluent was entered as a base flow for convenience in using the model. The smallest reservoir outflow used in the simulations was 10 ft^3/s, consisting of the 10 ft^3/s water-supply release during the severe-drought condition and 5 ft^3/s water-supply release added to 5 ft^3/s base-flow release during the less-severe-drought condition.

For both antecedent-streamflow conditions, release simulations for durations of 28 days (4 weeks) and 183 days (6 months) were made beginning with July, the month of largest evaporation. Evaporation losses due to incremental changes in river-surface width, which result from the various reservoir releases and subsequent changes in streamflow rates, were calculated using a pan-to-river coefficient of 0.7. The wells at Cedar Point, Strong City, Cottonwood Falls, and Thunderbird Estates were assumed to be pumping at the same rates as they were on July 31 and August 1, 1984 (table 2).

Transit Losses

The general definition of transit loss is that part of the streamflow 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 to evaporation and temporary bank storage from the part of the reservoir outflow that is designated as the water-supply release. For the simulations in which part of the reservoir outflow was "base flow," the base flow was included in the computations. The water-supply release added to the base flow caused an increase in river-surface width. This increase in width caused an increase in river-surface evaporation, which was accounted for in the evaporation losses. The "specified time" for the calculation of transit loss in this report extended to 30 days after the end of the release from Marion Lake. Losses were calculated for flow rate as well as for flow volume. The flow-rate loss was calculated by comparing the maximum flow rate at the specified downstream point, minus the base flow at that point, with the reservoir-release rate minus the antecedent outflow rate.

Transit losses in relation to river mileage for the severe-drought condition are shown in figure 9. Figure 10 shows the relations for the less-severe-drought condition. Figures 9 and 10 can be used to interpolate losses between locations, rates, durations, and drought conditions used in the model.

Transit losses calculated from Marion Lake to river mile 65.5 (3 road miles west of Strong City) and to river mile 2.1 near the confluence with the Neosho River for selected simulated release rates and durations are shown in table 6. Analysis of model results for transit losses of both rate and volume indicated a substantially greater loss during the severe-drought antecedent-streamflow condition. For example, for the water-supply-storage release of 10 ft^3/s for 28 days, the transit loss of flow volume to river mile 65.5 was 53 percent as contrasted with 24 percent for the less-severe-drought condition.

Releases of long duration experienced larger total but smaller percentage losses than releases of short duration for both antecedent-streamflow conditions. For the severe-drought condition and the release rate of 25 ft^3/s for 183 days, the flow-rate loss from Marion Lake to river mile 2.1 was 12 percent, and the volume loss was 27 percent, as compared with 53 percent for flow rate and 63 percent for flow volume when the release duration was 28 days. A major factor in the percentage losses is that the 28-day releases were subjected to the large evaporation rates of July and August, whereas the 183-day releases began with July evaporation but extended to the low evaporation rates of winter.

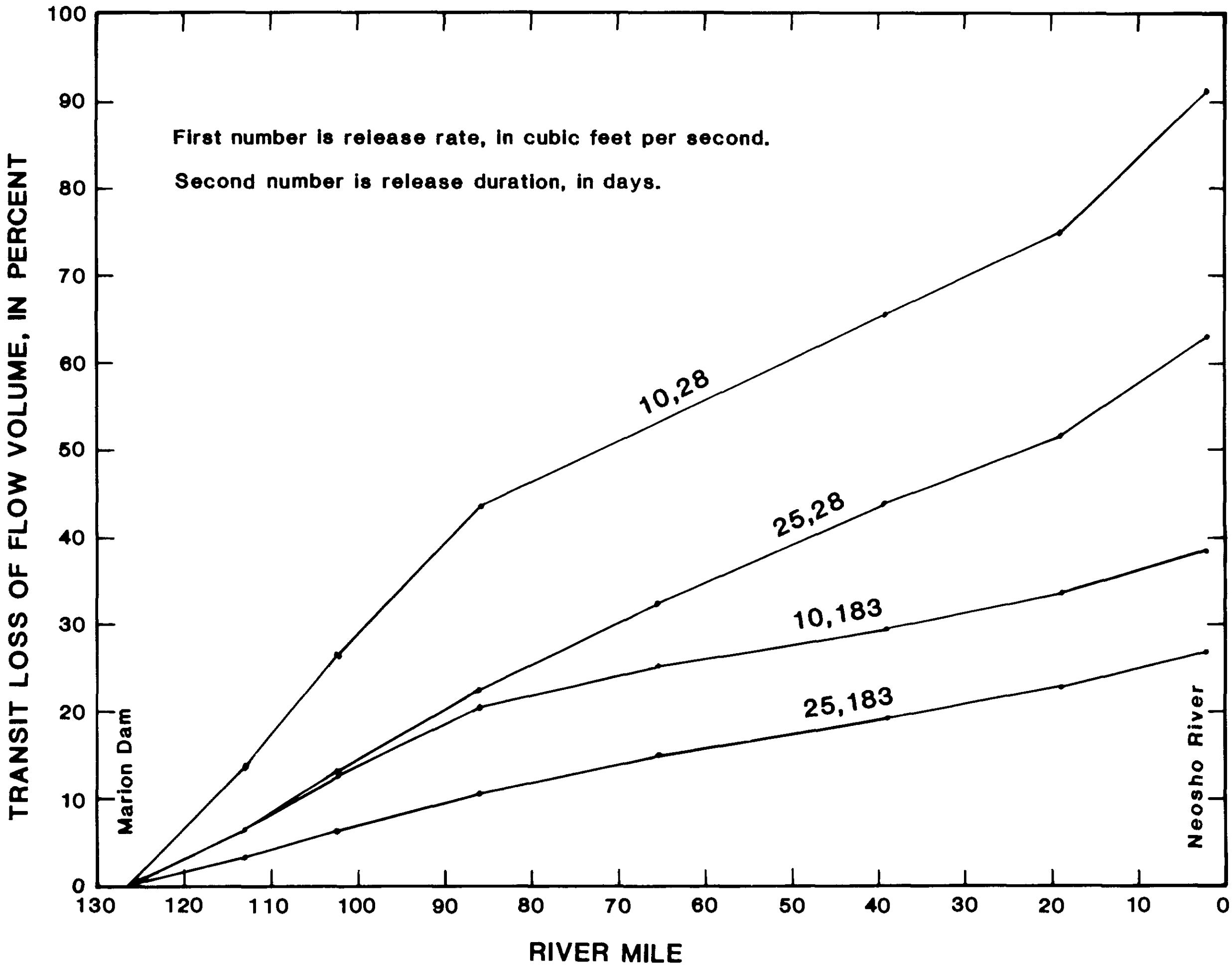

Figure 9.--Relation between transit loss and distance for selected water-supply release rates and durations during severe drought.

Model simulations for the 28-day reservoir-release duration indicate that large parts (32 to 91 percent) of the total volume of release is lost to evaporation and temporary bank storage. The volume stored temporarily in bank storage will eventually return to the river, but at a continually decreasing rate. The 30-day time period allowed at the end of reservoir-release durations during model simulations was selected for the purpose of analysis for water-management decisions although it was insufficient time for the temporary bank storage to completely return to the river. Because of the 30-day period for return of water from bank storage, the aquifer characteristics, and the large evaporation rates used in the model, the loss to evaporation substantially exceeds the loss to bank storage.

Traveltimes

Two types of traveltimes were of interest: (1) traveltime between the beginning of the water-supply release from Marion Lake and the beginning of the response at the downstream location (called "first response"), and (2) time to full response, which is defined here as the time from the beginning of the water-supply release from Marion Lake to the time when the flow rate

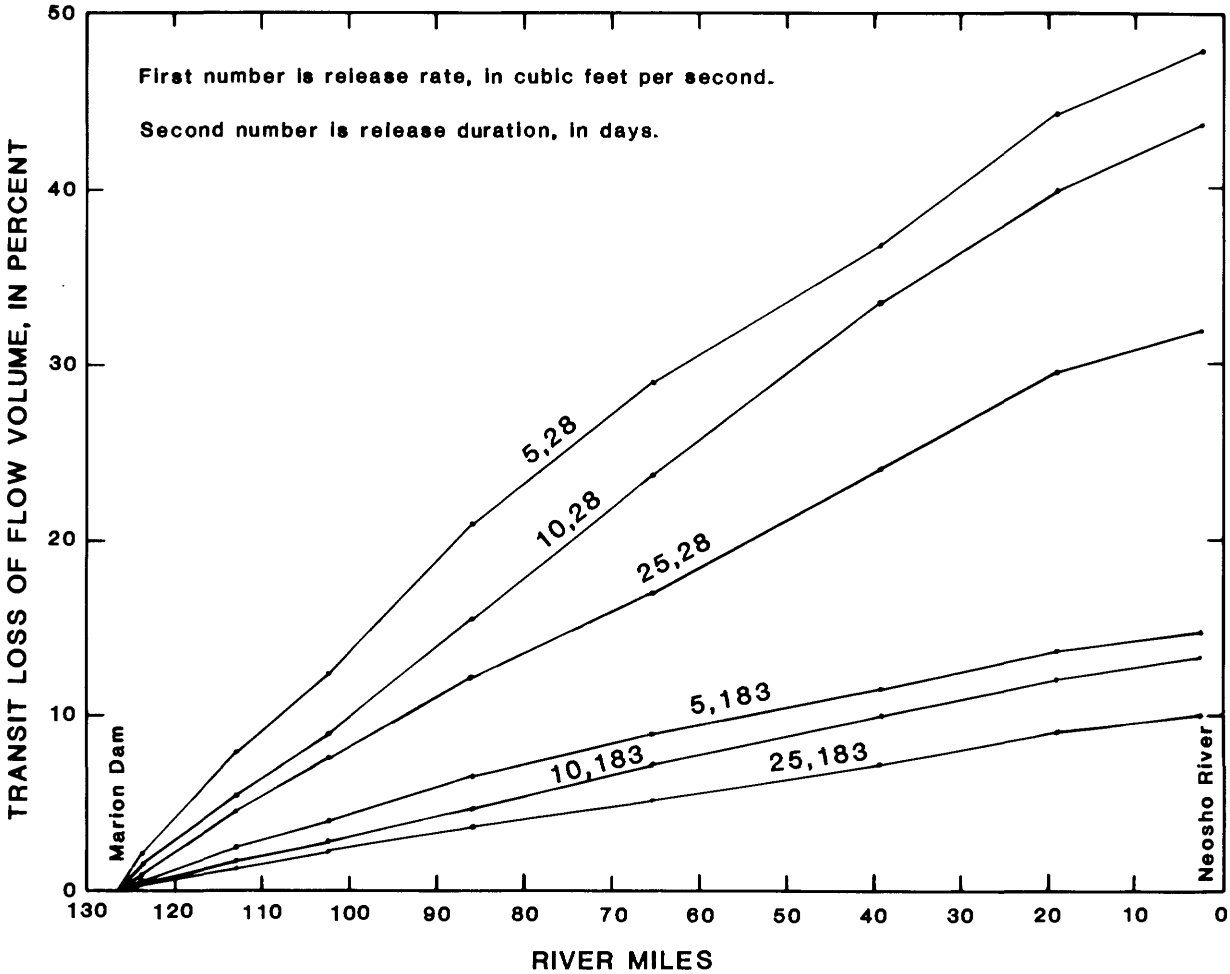

Figure 10.--Relation between transit loss and distance for selected water-supply release rates and durations during less-severe drought.

downstream attained 80 percent of the maximum flow rate. The first type is a traveltime of part of a water wave and is most affected by the wave-celerity values used in the model. The second type is not a genuine traveltime but is a value defined specifically for use in water-supply planning and management. This time is affected by the rate and duration of the release, bank storage, and the seasonal increase or decrease of evaporation rates, as well as by the wave celerity. The traveltime to "full response" is undefined when the downstream base flow exceeds 80 percent of the maximum downstream flow.

The traveltimes to first response are shown in figure 11 in relation to river mileage. The traveltimes to first response and to full response are shown for selected locations (river miles 65.5 and 2.1) in table 6. Because all streamflow rates used in the simulations were relatively small and had similar wave-celerity values, traveltimes to first response varied little with changes in release rate and antecedent-streamflow condition.

Table 6.--*Transit losses and traveltimes to selected downstream locations for water-supply releases from Marion Lake during two antecedent-streamflow conditions*

Antecedent-streamflow condition	Water-supply release: Rate (cubic feet per second)	Water-supply release: Duration (days)	Water-supply release: Volume (acre-feet)	River mile 65.5 (3 miles west of Strong City): Transit loss: Rate[1] (percent)	River mile 65.5: Transit loss: Volume[2] (percent)	River mile 65.5: Traveltime: First response[3] (days)	River mile 65.5: Traveltime: Full reponse[4] (days)	River mile 2.1 (6.5 miles east of Emporia): Transit loss: Rate[1] (percent)	River mile 2.1: Transit loss: Volume[2] (percent)	River mile 2.1: Traveltime: First response[3] (days)	River mile 2.1: Traveltime: Full response[4] (days)
				Transit loss and traveltime from Marion Lake (river mile 126.5) to indicated downstream location							
Severe drought	10	28	555	50	53	1.9	6.1	78	91	3.5	8.3
		183	3,630	7	25	1.9	93	22	38	3.5	93
	25	28	1,388	31	32	1.4	3.3	53	63	3.2	8.3
		183	9,074	4	15	1.4	36	12	27	3.2	68
Less severe drought	5	28	278	18	29	1.7	2.3	29	48	3.5	[5] --
		183	1,815	3	9	1.7	3.0	26	15	3.5	[5] --
	10	28	555	15	24	1.5	2.2	27	44	3.2	4.7
		183	3,630	2	7	1.5	3.0	15	13	3.2	5.5
	25	28	1,388	10	17	1.2	2.0	23	32	2.8	4.4
		183	9,074	1	5	1.2	3.3	7	10	2.8	6.5

1 Loss of rate is the percentage difference between the rate of release and the maximum rate at the specified river mile.
2 Loss of volume is calculated from beginning of release to 30 days after end of release.
3 First-response traveltime is the time to the earliest increase in flow at the location.
4 Full-response traveltime is the time to a rate equal to 80 percent of the maximum rate at that location.
5 Base flow exceeds 80 percent of the maximum flow.

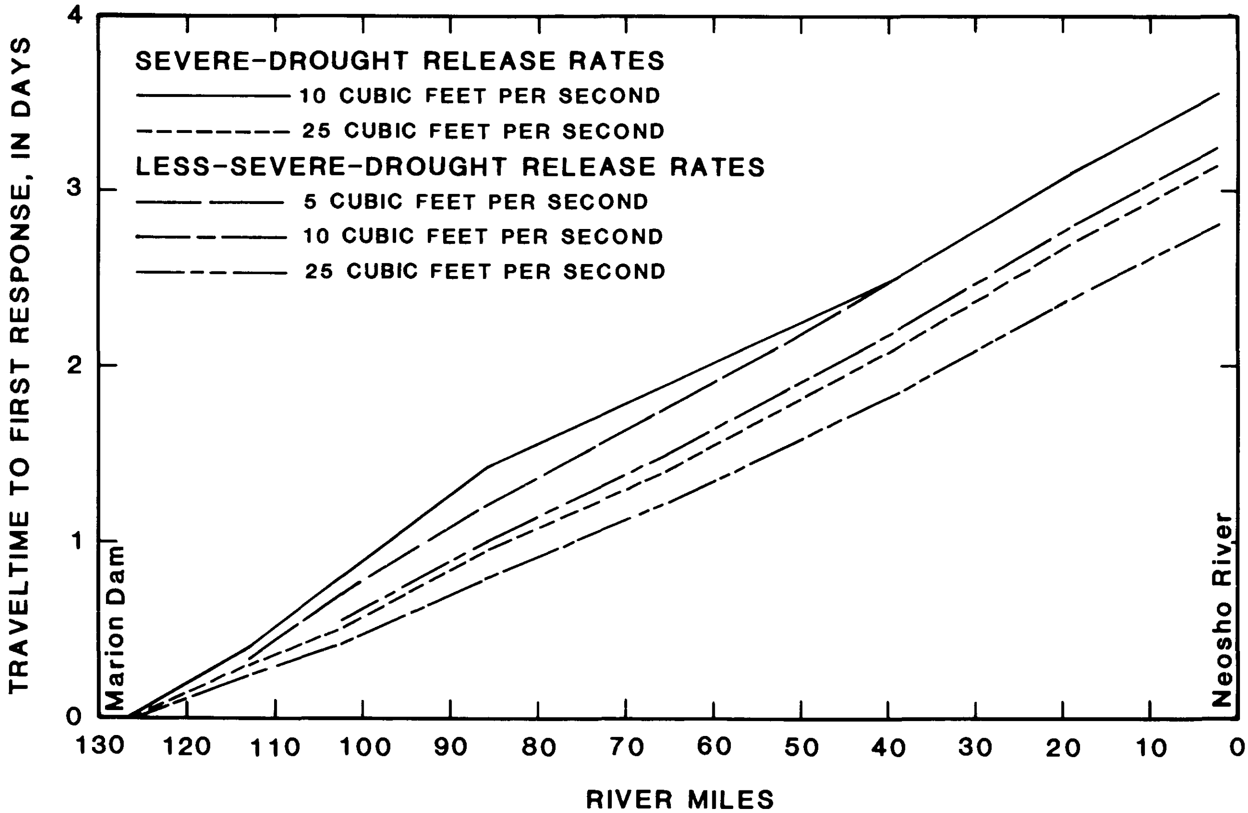

Figure 11.--Relation between traveltime to first response and distance for selected water-supply release rates and antecedent-streamflow conditions.

Times to full response varied widely. For example, the release of 25 ft^3/s for 183 days during severe-drought condition had a full-response time of 68 days, but the release of 25 ft^3/s for 28 days during the less-severe-drought condition had a full-response time of only 4.4 days. Partly because the modeled releases began in the month of greatest evaporation followed by steadily decreasing evaporation, the times to full response as defined above were long (68 and 93 days) for the 183-day releases during severe-drought conditions (table 6). If the releases had commenced during months with low evaporation (winter) rather than during months with high evaporation (summer), the longest times to full response would have been less than 10 days.

Effects of Errors on Results of Simulations

Results of calculations of transit losses and traveltimes are subject to errors from assumptions and estimates of channel and aquifer characteristics. Because the boundary conditions and values for channel and aquifer characteristics used in the simulations could not be fully verified, several computations were made to investigate the effects on the results of the simulations if the estimates used in the model were in error. Only characteristics subject to possibly significant errors were considered in these computations; those measured accurately, such as pan evaporation during months of significant evaporation, channel length, and alluvial-valley length, were not considered. However, possible errors in the coefficient for estimating river-surface evaporation from measurements of evaporation from a standard evaporation pan were considered.

The severe-drought condition was judged likely to result in the largest errors and was used in all the error computations in conjunction with a release of 10 ft^3/s, the middle of the three release rates simulated. The release duration judged likely to result in the largest errors then was used in determining the effect of errors in the estimation of each characteristic or boundary condition. For example, trial computations showed that changes in aquifer properties had larger percentage effects for the 28-day release than for the 183-day release. The percentage effect of evaporation coefficient was largest for the 28-day release. Duration of release has no effect on traveltime to first response.

Results of the error computations are given in table 7. Changes of 30 percent in the wave-dispersion coefficient and wave celerity had no effect on transit loss. Dispersion coefficients had a small effect on traveltime, but wave celerity had an effect approximately proportional to the change in the value used. Because of the large uncertainty in the estimates of aquifer properties, computations were made for extreme values of transmissivity and storage coefficient. The aquifer properties had moderate effects on transit loss but no effect on the traveltime to first response. Change in the assumed aquifer-boundary conditions had only a small effect on transit loss and no effect on traveltime.

The pan coefficient used for evaporation is subject to considerable uncertainty. A pan-to-lake coefficient of 0.7 is known to be fairly accurate (within about 10 percent) for total spring-through-fall evaporation from typical large lakes, but little is known about evaporation from river surfaces and seasonal changes in its relation to evaporation from pans. A study done for a different purpose (Delay and Seaders, 1963, p. 60-61, 75) appeared to indicate that a pan-to-river coefficient could equal and sometimes exceed 1.0 on an extremely turbulent river in Oregon. Therefore, a computation was made using a pan coefficient of 1.0. However, a coefficient of 1.0 is unrealistic for this study because the low flows in the Cottonwood River are not extremely turbulent and, during the months of significant evaporation, the water probably is cooler than a lake surface because it is derived from considerable depth in the reservoir and from the aquifer. Because of the probably cooler water, a computation also was made using a coefficient of 0.6. The change in transit loss was nearly proportional to the change in the coefficient.

The analysis on the effects of errors on model simulation also gives an indication of the kinds of further investigations or data collection needed for improving the confidence of transit-loss and traveltime simulations. The investigations or data-collection programs most needed are: (1) an investigation to study evaporation from river surfaces, and (2) data collection of alluvial aquifer characteristics, primarily transmissivity and storage coefficients. Item 1 would be important for any future transit-loss investigations, and item 2 is known to be important for the Cottonwood River. Item 2 also may be necessary for other stream-aquifer interaction investigations.

Table 7.--*Effects of errors in selected channel and aquifer characteristics on simulation results for reservoir release of 10 cubic feet per second during severe-drought conditions*

Characteristics	Transit loss through river mile 2.1, as percentage of release volume	Traveltime to first response at river mile 2.1 (days)
Channel properties (28-day release):		
Wave-dispersion coefficient:		
Reduced by 30 percent in each reach	91	3.7
150 to 800 square feet per second	1/91	1/3.5
Increased by 30 percent in each reach	91	3.4
Wave celerity:		
Reduced by 30 percent in each reach	91	4.8
1.3 to 2.1 feet per second	1/91	1/3.5
Increased by 30 percent in each reach	91	2.8
Aquifer properties (28-day release):		
Transmissivity:		
250 square feet per day	89	3.5
500 square feet per day	1/91	1/3.5
2,000 square feet per day	97	3.5
Storage coefficient (dimensionless):		
0.0001 for all reaches	76	3.5
0.01 for river miles 126.5 to 19.0; 0.10 for river miles 19.0 to 2.1	1/91	1/3.5
0.15 for all reaches	100	3.5

Table 7.--*Effects of errors in selected channel and aquifer characteristics on simulation results for reservoir release of 10 cubic feet per second during severe-drought conditions*--Continued

Characteristics	Transit loss through river mile 2.1, as percentage of release volume	Traveltime to first response at river mile 2.1 (days)
Aquifer-boundary conditions (183-day release):		
Finite aquifer, reach average width 3,200 to 10,800 feet	35	3.5
Semi-infinite aquifer	[1]38	[1]3.5
Semi-infinite aquifer with permeable confining bed, retardation coefficient 100 feet	38	3.5
Evaporation (28-day release):		
Pan coefficient = 0.6	80	3.5
Pan coefficient = 0.7	[1]91	[1]3.5
Pan coefficient = 1.0	100	3.5

[1] Result of predictive simulation (table 6).

SUMMARY

A streamflow-routing model was used to simulate the transit losses and traveltimes during drought conditions for water-supply releases from Marion Lake downstream along the Cottonwood River to its confluence with the Neosho River, east-central Kansas. The transit losses and traveltimes were determined for two antecedent-streamflow conditions, a severe-drought condition and a less-severe-drought condition. For the severe-drought condition, no antecedent release from Marion Lake and no gains from the alluvial aquifer were assumed. A nominal release of 5 ft^3/s from Marion Lake, in addition to the water-supply releases, plus downstream gains from the alluvial aquifer were assumed for the less-severe-drought condition. Transit losses and traveltimes were determined for 28-day and 183-day release periods for both antecedent conditions. Release rates were 10 and 25 ft^3/s for the severe-drought condition and 5, 10, and 25 ft^3/s for the less-severe-drought condition.

Channel and aquifer hydraulic characteristics, the model-control parameters, were measured or estimated for the study area from available data. Channel characteristics were measured or estimated using data from streamflow-gaging station records, from topographic quadrangles, a U.S. Army Corps of Engineers report (1965), and a series of low-flow measurements along the Cottonwood River and tributaries during July 31 - August 1, 1984. Aquifer characteristics were measured and estimated using data from published reports, drillers' logs, a few available aquifer tests, and also from the 1984 low-flow measurements.

The estimated characteristics were verified with the model, to the extent possible, by comparing simulated streamflow volumes and traveltimes to observed streamflow volumes and traveltimes during selected periods of changing flow. Transit losses and traveltimes for varying reservoir-release rates and durations then were simulated for two different antecedent-drought conditions.

For the severe-drought antecedent-streamflow condition, it was assumed that only the downstream water-use requirement would be released from the reservoir. For a less-severe-drought antecedent-streamflow condition, it was assumed that any releases from Marion Lake for water-supply use downstream would be in addition to a nominal dry-weather release of 5 ft^3/s. Water-supply release rates of 10 and 25 ft^3/s for the severe-drought condition and 5, 10, and 25 ft^3/s for the less-severe-drought condition were simulated for periods of 28 and 183 days commencing on July 1.

Transit losses for the severe-drought condition for all reservoir-release rates and durations ranged from 12 to 78 percent of the maximum downstream flow rate and from 27 to 91 percent of the total volume of reservoir storage released. For the less-severe-drought condition, transit losses ranged from 7 to 29 percent of the maximum downstream flow rate and from 10 to 48 percent of the total volume of release. Generally, transit losses of both rates and volumes were greatest for the severe-drought antecedent condition. The 183-day releases had larger total transit losses, but losses on a percentage basis were less than the losses for the 28-day release period for both antecedent-streamflow conditions. The transit losses considered included only water lost to evaporation and to bank

storage, which did not return to the river within 30 days from the end of the release.

Traveltimes from Marion Lake to first response at the mouth of Cottonwood River ranged from 2.8 to 3.5 days and had little or no variation between the various release rates and durations. Traveltimes to full response (80 percent of the maximum downstream flow rate), however, showed considerable variation. For the release of 5 ft^3/s during less-severe-drought conditions, base flow exceeded 80 percent of the maximum flow rate near the confluence with the Neosho River; the traveltime to full response was undefined for those simulations. For the releases of 10 and 25 ft^3/s during the same drought condition, traveltimes to full response ranged from 4.4 to 6.5 days. For releases of 10 and 25 ft^3/s during severe-drought conditions, traveltimes to full response near the confluence with the Neosho River ranged from 8.3 to 93 days. The longest traveltimes to full response were for the 183-day releases.

Results of calculations of transit losses and traveltimes are subject to errors from estimates of channel and aquifer characteristics that could not be fully verified. Possible errors in estimates of channel properties had no effect on simulated transit losses, but errors in estimates of wave celerity may have had moderate effect on simulated traveltimes to first response. Errors in estimates of aquifer transmissivity and storage coefficient may have had moderate effect on the simulated transit losses but no effect on the simulated traveltimes to first response. Possible errors in estimates of aquifer-boundary conditions would have had little effect on the simulation results. Possible errors in the estimate of the evaporation pan-to-river coefficient would have had a moderate effect on the simulated transit losses but would have had no effect on the simulated traveltimes to first response. Seasonal changes in evaporation can have a large effect on the traveltime to full response for a 183-day release.

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