EFFECTS OF RESERVOIRS ON FLOOD DISCHARGES

IN THE KANSAS AND MISSOURI RIVER BASINS 1 · 9 · 9 · 3

USGS
science for a changing world

U.S. GEOLOGICAL SURVEY CIRCULAR 1120-E

Front cover—Tuttle Creek Lake, dam, and spillway (Paul Maginness, Photographic Services, Kansas State University, Manhattan, Kansas)

Back cover—Tuttle Creek Lake spillway (lower right) and uncontrolled flow over spillway at Milford Lake (upper left)

EFFECTS OF RESERVOIRS ON FLOOD DISCHARGES IN THE KANSAS AND THE MISSOURI RIVER BASINS, 1993

By Charles A. Perry

Floods in the Upper Mississippi River Basin, 1993

U.S. GEOLOGICAL SURVEY CIRCULAR 1120-E

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

ROBERT M. HIRSCH, Acting Director

UNITED STATES GOVERNMENT PRINTING OFFICE: 1994

Free on application to the
USGS Map Distribution
Box 25286, MS 306
Denver Federal Center
Denver, CO 80225

FOREWORD

During spring and summer 1993, record flooding inundated much of the upper Mississippi River Basin. The magnitude of the damages—in terms of property, disrupted business, and personal trauma—was unmatched by any other flood disaster in United States history. Property damage alone is expected to exceed $10 billion. Damaged highways and submerged roads disrupted overland transportation throughout the flooded region. The Mississippi and the Missouri Rivers were closed to navigation before, during, and after the flooding. Millions of acres of productive farmland remained under water for weeks during the growing season. Rills and gullies in many tilled fields are the result of the severe erosion that occurred throughout the Midwestern United States farmbelt. The hydrologic effects of extended rainfall throughout the upper Midwestern United States were severe and widespread. The banks and channels of many rivers were severely eroded, and sediment was deposited over large areas of the basin's flood plain. Record flows submerged many areas that had not been affected by previous floods. Industrial and agricultural areas were inundated, which caused concern about the transport and fate of industrial chemicals, sewage effluent, and agricultural chemicals in the floodwaters. The extent and duration of the flooding caused numerous levees to fail. One failed levee on the Raccoon River in Des Moines, Iowa, led to flooding of the city's water treatment plant. As a result, the city was without drinking water for 19 days.

As the Nation's principal water-science agency, the U.S. Geological Survey (USGS) is in a unique position to provide an immediate assessment of some of the hydrological effects of the 1993 flood. The USGS maintains a hydrologic data network and conducts extensive water-resources investigations nationwide. Long-term data from this network and information on local and regional hydrology provide the basis for identifying and documenting the effects of the flooding. During the flood, the USGS provided continuous streamflow and related information to the National Weather Service (NWS), the U.S. Army Corps of Engineers, the Federal Emergency Management Agency (FEMA), and many State and local agencies as part of its role to provide basic information on the Nation's surface- and ground-water resources at thousands of locations across the United States. The NWS has used the data in forecasting floods and issuing flood warnings. The data have been used by the Corps of Engineers to operate water diversions, dams, locks, and levees. The FEMA and many State and local emergency management agencies have used USGS hydrologic data and NWS forecasts as part of the basis of their local flood-response activities. In addition, USGS hydrologists are conducting a series of investigations to document the effects of the flooding and to improve understanding of the related processes. The major initial findings from these studies will be reported in this Circular series as results become available.

U.S. Geological Survey Circular 1120, *Floods in the Upper Mississippi River Basin, 1993*, consists of individually published chapters that will document the effects of the 1993 flooding. The series includes data and findings on the magnitude and frequency of peak discharges; precipitation; water-quality characteristics, including nutrients and man-made contaminants; transport of sediment; assessment of sediment deposited on flood plains; effects of inundation on ground-water quality; flood-discharge volume; effects of reservoir storage on flood peaks; stream-channel scour at selected bridges; extent of flood-plain inundation; and documentation of geomorphologic changes.

Robert M. Hirsch

Acting Director
January 26, 1994

Contents

FIGURES

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
acre-foot (acre-ft)	0.001233	cubic hectometer

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Effects of Reservoirs on Flood Discharges in the Kansas and the Missouri River Basins, 1993

By Charles A. Perry

Abstract

The floods of 1993 were of historic magnitude as water in the Missouri and the Mississippi Rivers reached levels that exceeded many of the previous observed maximums. Although large parts of the flood plains of both rivers upstream from St. Louis, Missouri, were inundated, water levels would have been even higher had it not been for the large volume of runoff retained in flood-control reservoirs. Most of the total flood-control storage available upstream from St. Louis is located along the main stem and tributaries of the Missouri River; the largest concentration of reservoirs is located within the Kansas River Basin. The Kansas River Basin accounts for about 10 percent (60,000 square miles) of the drainage area of the Missouri River Basin, and reservoirs control streamflow from 85 percent (50,840 square miles) of the drainage area of the Kansas River Basin. Analyses of flood discharges in the Kansas River indicate that reservoirs reduced flooding along the Kansas and the lower Missouri Rivers. Results of analyses of the 1993 flooding, which include total basin rainfall, peak discharge, and total flood volume on the Kansas River, are compared with analyses of the 1951 flood, which had a similar total volume but a substantially larger peak discharge.

INTRODUCTION

Wet climatic conditions prevailed from the Pacific Northwest, through the northern one-half of the Central Plains, to the Upper Midwestern States during 1993. A multiyear drought in the western one-half of this large region was broken by average and above-average 1992–93 winter precipitation. Average to above-average precipitation in the upper Midwest during 1992 continued into spring and summer 1993 and reached accumulations during the 1993 water year (October 1, 1992–September 30, 1993) that were more than twice the normal (October–September 1961–90) precipitation (National Weather Service, 1993). As a result, flooding was severe in many rivers in the upper Mississippi River Basin (fig. 1). Flood discharges from the Mississippi and the Missouri Rivers combined for a historic peak of 1,080,000 cubic feet per second (ft^3/s) on the Mississippi River at St. Louis, Missouri, on August 1, 1993. Historic streamflow records show that this discharge was the largest since 1861 and has been exceeded only by an estimated discharge of 1,300,000 ft^3/s for the flood of 1844. Discharge for the flood of 1903, which has been estimated to be 1,019,000 ft^3/s, was slightly less than that of 1993. However, changes in the upper Mississippi River Basin, such as the construction of many flood-control reservoirs, that have been made in the last 50 years reduced the magnitude of the maximum discharge of the 1993 flood at St. Louis.

Flood-control reservoirs throughout the upper Mississippi River Basin helped reduce flooding during 1993.

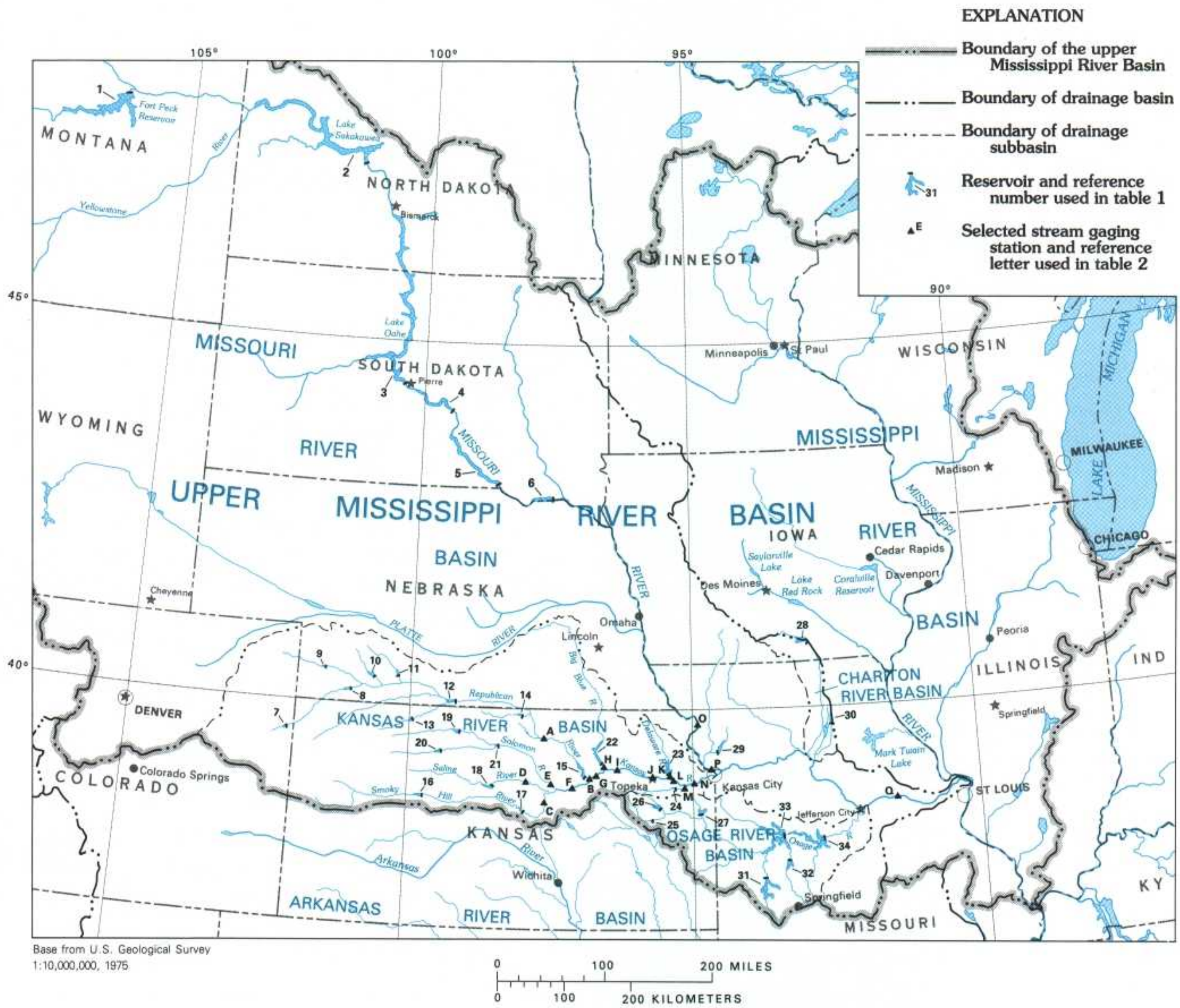

Figure 1. Locations of flood-control reservoirs and selected streamflow-gaging stations in the Missouri, the Kansas, and the upper Mississippi River Basins.

Purpose and Scope

As the principal Federal agency responsible for the collection of water-resources data, the U.S. Geological Survey (USGS) operates a network of about 7,300 continuous-record streamflow- and lake-level-gaging stations throughout the Nation. The records from selected stations on the Kansas and the Missouri Rivers form the basis for the discussion of the effects of flood-control reservoirs on the 1993 flood discharges in the upper Mississippi River Basin. Because most of the flood-control reservoirs are in the Missouri River Basin, this report focuses on this part of the upper Mississippi River Basin, with special emphasis on the Kansas River Basin.

An analysis of total flood storage in the Missouri River Basin from April 1 to August 1 and during July 1993 is provided to assess the effects of reservoirs on flood discharges downstream. A detailed analysis of the effects of reservoirs on peak discharge is provided for the Kansas River, including a comparison of the controlled flood discharges of 1993 with the uncontrolled flood discharges of 1951.

Flood-Control Reservoirs

The function of flood-control reservoirs is to store temporarily a part of the flood discharge for later release so that the flood peak downstream will be reduced. In an uncontrolled stream, the flood discharges of the tributary streams are added to the discharge in the main stem. As a result, the total flood volume increases in the downstream direction, as does the peak discharge (fig. 2*A*). In the case of the controlled stream, all or part of the flood discharge is stored in a reservoir for later release at a reduced flow rate (fig. 2*B*). Downstream from the reservoir, additional flood discharges in the tributaries enter the main stem, which add uncontrolled flood discharges to the controlled discharge. In the actual operation of a flood-control reservoir, the uncontrolled flood discharges from the drainage area downstream from a reservoir need to be considered before reservoir releases are made. If uncontrolled flood discharge from areas below the reservoir produces a flood on the main stem, then reservoir releases can be reduced to near zero discharge to minimize additional flooding downstream.

Most flood-control reservoirs in the Kansas and the Missouri River Basins are of the multipurpose type, which are used to store water for irrigation, navigation, public-water supply, and recreation. The flood-control, or flood-storage capacity, pool of a reservoir is always above the multipurpose-pool level (fig. 3). All reservoirs with provision for flood control are operated so that a minimum amount of water in the flood-control pool is maintained prior to flooding to maximize flood protection. The flood reduction potential of a reservoir is compromised if additional flood water must be stored before the previously stored water can be released.

Flood-control reservoirs are constructed with an emergency spillway to protect the dam from being overtopped, which can cause severe damage to or failure of the dam. Flow through the spillway can be uncontrolled or can be controlled by gates that regulate the releases up to a certain elevation in the reservoir. Once the water level in the reservoir rises to the top of the closed spillway gates or the sill of an uncontrolled spillway, water stored above this elevation in the reservoir is in the surcharge pool. Outflow of surcharge in the reservoir is determined by the depth of water and the geometry of the spillway or the spillway gate opening.

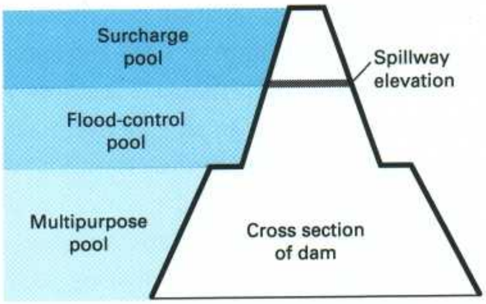

Figure 3. Typical reservoir showing locations of surcharge, flood-control, and multipurpose-pool levels.

CLIMATIC CONDITIONS

Precipitation during the 1992–93 winter, spring, and summer months (January–August) in much of the upper Mississippi River Basin generally was more than 100 to 200 percent of normal (January–August 1961–90) (National Weather Service, 1993). Some precipitation stations recorded single-month (July) accumulations of more than 600 percent of normal (July 1961–90) (Wahl and others, 1993). Persistent wet soil conditions in 1993 throughout this large region, coupled with many intense rainstorms, led to widespread flooding in the upper Mississippi River Basin.

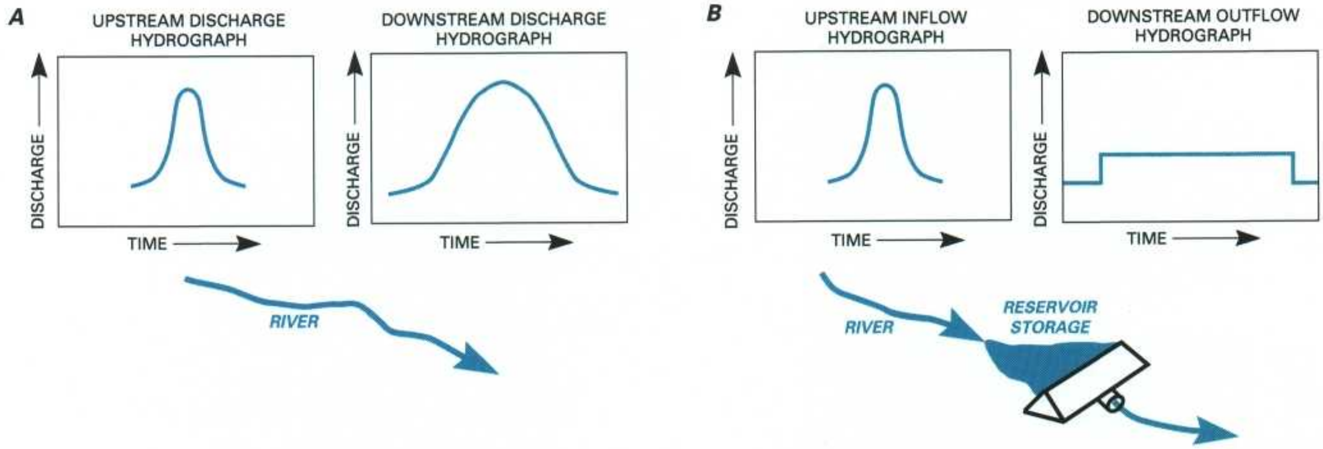

Figure 2. Hypothetical hydrographs of *(A)* an uncontrolled stream and *(B)* reservoir-regulated outflow.

As a result of average to above-average precipitation during late summer and fall 1992 in many Midwestern States, stream, ground-water, and lake levels were near normal at the beginning of 1993. During winter 1992–93, average to above-average snowpack was produced throughout much of the Northern Rocky Mountains as storms from the North Pacific Ocean drove inland; this precipitation ended a severe 6-year drought. The plentiful precipitation continued into spring and summer 1993 and spread eastward into Wisconsin and Illinois as a storm-steering jet stream anchored itself to an upper-atmospheric low-pressure trough over the Northwestern States and a strong high-pressure ridge over the Eastern States (fig. 4). West of the trough, the jet stream directed cool air from the Gulf of Alaska southeastward, while east of the trough, the jet stream pulled warm, moist air northward from the Gulf of Mexico. Under the eastern high-pressure ridge, severe drought conditions developed by midsummer.

Flash flooding was common throughout the Missouri River Basin.

Tuttle Creek Lake rose over 60 feet above multipurpose level into its surcharge pool.

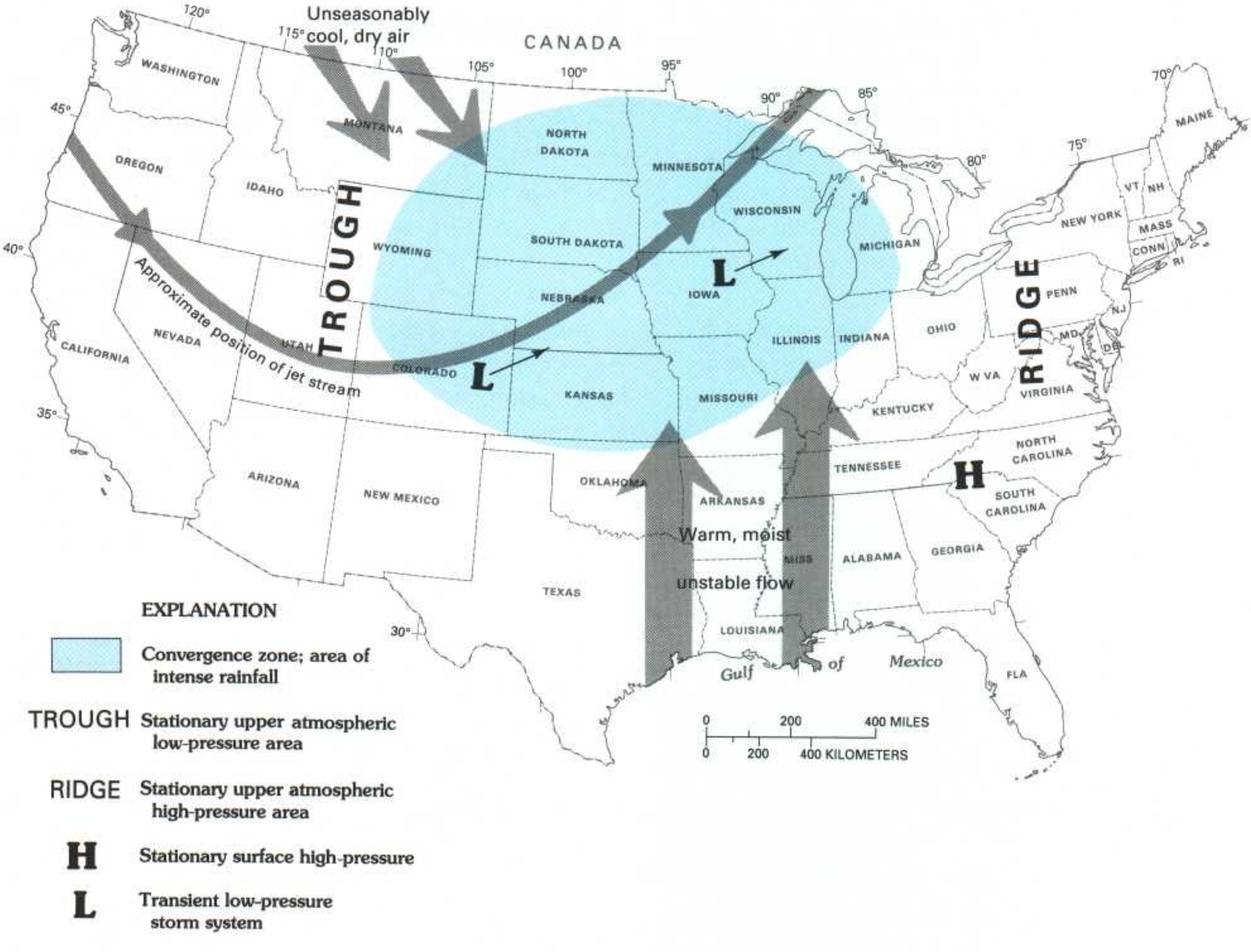

Figure 4. Persistent weather pattern responsible for the floods of 1993 (modified from Wahl and others, 1993).

As a result of the persistent position of the jet stream, very cool conditions prevailed in the northwestern part of the United States through the spring and summer months, while the southeastern part of the country was very warm. Weather on the eastern side of the trough was very active as the contrasting air masses clashed within the convergence zone. Thunderstorms that extended to heights of 60,000 feet (ft) above land surface released torrential rains somewhere in the North-Central States nearly every day during spring and summer. Individual storm rainfall totals, which sometimes exceeded 5 inches (in.), fell on already saturated soils; this commonly produced local flash floods in small streams and persistent riverine floods in much of the upper Mississippi River Basin.

The initial influx of large volumes of runoff into the small streams caused local flooding. Because many of the small streams flooded simultaneously, the larger streams also exceeded flood stages. Flood-control reservoirs on the larger streams easily contained the initial onslaught of flooding. However, as the rains continued to fall over a very large area and uncontrolled streams continued to flood, the capacity of reservoirs to store additional storm runoff was diminished. Because of little opportunity to lower the water-surface elevations of these reservoirs to their multipurpose-pool levels, water-level elevations in many reservoirs reached record highs.

FLOOD STORAGE IN AND EFFECTS OF RESERVOIRS ON FLOOD DISCHARGES, MISSOURI RIVER BASIN

Missouri River Main Stem

The six-reservoir system on the main stem of the upper Missouri River from Montana through North Dakota and South Dakota is used for power generation, storage for navigation and public-water supply, and flood control. When the 1993 water year began, the total storage content in the reservoir system was about 43,900,000 acre-feet (acre-ft). By April 1, 1993, the total system content had increased to 45,468,000 acre-ft (U.S. Army Corps of Engineers, written commun., 1993). The additional 1,568,000 acre-ft resulted from runoff produced by melting snowpack in the mountains during winter and early spring. The total increase in storage contents of the six-reservoir system from April 1 to August 1 was 10,293,000 acre-ft (table 1), which was the result of increased rainfall during this period. During July 1993 alone, reservoirs in the main-stem Missouri River stored nearly 5,369,000 acre-ft of floodwater. If this water had been released at a constant rate, then the daily average discharge of the Missouri River downstream during July would have been about 87,000 ft^3/s larger than the observed average discharge of 291,000 ft^3/s on the Missouri River at Kansas City, Missouri.

Flood storage in the Missouri River Basin reservoirs, such as the Harry S Truman Lake, reduced the average daily flow near St. Louis for July 1993 by over 211,000 ft^3/s. (U.S. Army Corps of Engineers.)

Platte River in Missouri

The Platte River in Missouri is a small tributary of the Missouri River just upstream of its confluence with the Kansas River and is controlled by the Lake Smithville reservoir. During July 1993, this reservoir stored 55,200 acre-ft of floodwater. The water level in the reservoir reached a record elevation of 874.3 ft above sea level on July 28.

Kansas River Basin

The Kansas River Basin is about 60,000 square miles (mi^2) in area, of which streamflow from 85 percent, or 50,840 mi^2, of the basin is controlled by reservoirs. Except for the main-stem Missouri River reservoir system, the Kansas River Basin is the largest basin under flood control in the Mississippi River Basin. Eighteen reservoirs (table 1), which have a total flood-control capacity of 7,390,000 acre-ft, provide flood protection within the basin and along the Missouri

Table 1. Summary of flood-control and storage characteristics for selected reservoirs in the Missouri River Basin, 1993

[Basins: Mu, upper Missouri River (above Sioux City, Iowa); P, Platte River in Missouri; K, Kansas River; O, Osage River; C, Chariton River; mi², square miles; acre-ft, acre-feet; ft, feet; - -, data unavailable; data from U.S. Corps of Engineers, Bureau of Reclamation, and U.S. Geological Survey]

Reservoir			Drainage area (mi²)	Year storage began	Multi-purpose pool (acre-ft)	Flood-control pool (acre-ft)	Surcharge pool (acre-ft)	Spillway elevation (ft above sea level)	Previous record reservoir elevation		1993 Maximum reservoir elevation		Change in storage	
Map no. (fig. 1)	Gaging station no.	Name (basin)							Ft above sea level	Date	Ft above sea level	Date	April 1 to August 1 (acre-ft)	July 1 to August 1 (acre-ft)
		Montana												
1	06131500	Fort Peck (Mu).............	57,500	1937	15,773,000	2,657,000	980,000	2,250.0	2,251.6	7/15/75	2,228.4	9/30	2,085,000	1,169,000
		North Dakota												
2	06338000	Garrison (Mu)...............	181,400	1953	18,750,000	4,250,000	- -	1,854	1,854.6	7/5/75	1,837.4	9/25	4,453,000	2,000,000
		South Dakota												
3	06439980	Oahe (Mu)....................	243,500	1958	20,140,000	2,390,000	1,100,000	1,620.0	1617.9	8/22/75	1,611.6	9/12	3,426,000	1,869,000
4	06442700	Sharpe (Mu)..................	249,300	1963	1,465,000	260,000	175,000	1,423.0	1,421.9	4/22/71	1,421.2	6/13	9,000	22,000
5	06452500	Francis Case (Mu)..........	263,500	1952	1,336,000	3,498,000	982,000	1,375.0	1,364.2	6/ 2/62	1,361.0	7/28	333,000	294,000
6	06467000	Lewis and Clark (Mu)......	279,500	1955	156,000	321,000	64,000	1,210.0	1,210.7	4/ 1/60	1,208.9	7/15	−13,000	15,000
		Colorado												
7	06826000	Bonny (K).....................	1,820	1950	41,400	128,800	- -	3,710.0	3,678.10	5/17/57	3,671.92	6/ 6	−940	−1,000
		Nebraska												
8	06829000	Swanson (K)..................	8,620	1953	116,100	137,900	107,600	2,773.0	2,757.42	8/ 2/62	2,752.29	6/14	2,160	−11,500
9	06832000	Enders (K)....................	950	1950	36,010	38,510	6,210	3,127.0	3,118.20	3/25/60	3,101.62	6/24	−1,230	−3,890
10	06837390	Hugh Butler (K)............	730	1961	31,470	54,890	76,240	2,604.9	2,584.14	9/ 8/78	2,580.63	7/30	4,210	2,520
11	06842000	Harry Strunk (K)...........	880	1949	32,230	57,080	106,690	2,386.2	2,374.10	3/23/60	2,371.40	7/28	10,220	5,220
12	06849000	Harlan Co. (K)..............	20,750	1952	319,800	509,000	46,800	1,973.5	1,955.67	4/ 6/60	1,953.62	9/8	126,300	82,800

Kansas														
13	06847950	Keith Sebelius (K)..........	683	1964	35,930	98,800	58,280	2,331.4	2,304.59	6/27/67	2,297.10	9/29	2,620	2,180
14	06853900	Lovewell (K)...............	345	1957	41,690	50,460	94,140	1,595.3	1,595.01	10/13/73	[1]1,595.37	7/22	24,400	17,500
15	06857050	Milford (K)..................	24,880	1967	415,400	673,600	291,000	1,176.2	1,170.03	10/17/73	[1]1,181.94	7/25	805,000	735,000
16	06861500	Cedar Bluff (K)............	5,530	1950	185,060	191,900	493,400	2,166.0	2,154.90	7/ 2/51	2,119.79	9/29	46,000	39,600
17	06865000	Kanopolis (K)..............	7,857	1948	55,200	356,700	69,000	1,507.0	1,506.98	7/14/51	1,505.85	7/25	246,000	233,000
18	06868100	Wilson (K)..................	1,917	1964	242,500	1,245,000	179,500	1,582.0	1,528.06	4/26/87	[1]1,548.27	8/6	388,000	388,000
19	06871700	Kirwin (K)..................	1,367	1955	99,700	214,900	198,400	1,757.3	1,732.15	6/10/61	[1]1,733.47	9/29	54,000	42,200
20	06873100	Webster (K).................	1,150	1956	76,430	184,300	140,900	1,923.7	1,899.66	6/10/61	[1]1,903.9	9/29	63,700	50,500
21	06874200	Waconda (K)...............	5,076	1969	241,400	722,300	165,000	1,488.3	1,471.32	4/27/87	[1]1,487.02	7/29	566,000	600,000
22	06886900	Tuttle Creek (K)...........	9,628	1962	388,600	1,937,000	860,100	1,136.0	1,127.90	10/18/73	[1]1,137.76	7/22	1,615,000	1,317,000
23	06890898	Perry (K)....................	1,117	1969	225,000	517,500	36,160	922.0	917.07	10/19/73	[1]920.94	7/25	443,000	437,000
24	06891478	Clinton (K)..................	367	1977	129,200	268,400	285,800	903.4	886.72	6/ 4/82	[1]887.57	7/31	84,400	88,600
25	06910997	Melvern (O)................	349	1972	154,400	258,600	507,600	1,057.0	1,049.07	6/ 2/82	1,048.31	7/29	107,000	103,000
26	06912490	Pomona (O)..................	322	1963	66,640	176,500	255,400	1,003.0	990.24	6/ 2/82	[1]992.67	7/31	91,000	90,300
27	06914995	Hillsdale (O)................	144	1981	76,270	83,570	155,800	931.0	928.49	10/20/86	826.70	7/28	55,000	55,800
Iowa														
28	06903880	Rathbun (C).................	549	1969	199,800	345,800	- -	926.0	924.46	7/22/82	[1]927.20	7/28	295,000	269,000
Missouri														
29	06821140	Smithville (P)...............	213	1981	144,600	101,800	182,200	876.2	873.17	11/16/85	[1]874.3	7/28	72,600	55,200
30	06906190	Long Branch (C)...........	109	1978	34,640	30,600	98,590	801.0	799.56	7/28/81	799.0	7/26	9,000	9,000
31	06918990	Stockton (O)................	1,160	1969	887,100	779,600	- -	892.0	885.94	4/28/73	884.5	9/29	74,000	42,000
32	06921325	Pomme de Terre (O).......	611	1960	241,500	407,200	- -	874.0	862.35	4/30/73	[1]864.6	9/27	21,000	29,000
33	06922440	Harry S Truman (O).......	11,500	1977	1,203,000	4,006,000	2,911,000	739.6	738.69	10/11/86	735.2	8/3	3,078,000	3,046,000
34	06925500	Lake of the Ozarks (O)...	14,000	1931	1,927,000	400,000	- -	660.0	665.45	5/22/43	659.92	6/17	122,000	-78,000

[1]New record elevation.

River downstream. From April 1 to August 1, 1993, the reservoir system in the Kansas River Basin stored 4,500,000 acre-ft. Of this amount, 4,027,000 acre-ft was stored during July alone. If this water had been released at a constant rate, then the average discharge of the Kansas River downstream during July would have been about 65,500 ft^3/s larger than the observed average discharge of 76,800 ft^3/s on the Kansas River at DeSoto, Kansas. About one-half of the July total of 4,027,000 acre-ft was stored in Milford and Tuttle Creek Lakes. Both lakes filled their flood-control pools and were required to store floodwater in their surcharge pools. Tuttle Creek Lake stored 97,000 acre-ft in its surcharge pool, while Milford Lake stored 207,000 acre-ft in its surcharge pool.

Chariton River Basin

The Chariton River is a tributary of the Missouri River and flows from Iowa through northern Missouri. Lake Rathbun in Iowa and Lake Longbranch in Missouri are flood-control reservoirs in the Chariton River Basin and stored 269,000 and 9,000 acre-ft, respectively, during July 1993. The water level in Lake Rathbun reached a record elevation of 927.2 ft above sea level on July 28, thus requiring the storage of 27,000 acre-ft in its surcharge pool.

Osage River Basin

Streamflow from the nearly 15,000-mi^2 Osage River Basin is almost completely controlled by Lakes Melvern, Pomona, and Hillsdale in Kansas and Lakes Stockton, Pomme de Terre, and Harry S Truman and Lake of the Ozarks at Bagnal Dam in Missouri. The reservoir system in this basin stored 3,547,000 acre-ft between April 1 and August 1, 1993; of this total, 3,289,000 acre-ft was stored during July. The effect of Lake Harry S Truman on discharge in the Osage River was significant because it stored more than 3,000,000 acre-ft during July. The storage in Lake Harry S Truman and that of the other reservoirs in the Osage River Basin system reduced the average discharge of the Osage River at its confluence with the Missouri River for the month of July by 53,500 ft^3/s.

Combined Effect of Flood-Control Reservoirs on Missouri River Discharge

As severe as the flooding was in 1993, stream and river levels could have been even higher had a system of flood-control reservoirs not been in place throughout the Missouri River Basin. About 10,300,000 acre-ft of additional water was stored in the upper Missouri River main-stem reservoirs in Montana, North Dakota, and South Dakota from April 1 to August 1, 1993. In the lower sections of the Missouri River Basin, the quantity of water stored from April 1 to August 1 in reservoirs on the Kansas River was 4,500,000 acre-ft, while reservoirs in the Platte, the Chariton, and the Osage River Basins stored 3,900,000 acre-ft. If the total 18,700,000 acre-ft stored in the system had been allowed to flow to St. Louis, then the average discharge of the Missouri River would have been 77,300 ft^3/s greater for this 4-month period. During July alone, the combined storage of about 13,000,000 acre-ft in the Missouri River Basin—5,400,000 acre-ft in the Missouri River main stem reservoirs, about 4,000,000 acre-ft in the Kansas River Basin reservoirs, and about 3,600,000 acre-ft in the reservoirs of the Platte, the Chariton, and the Osage River Basins—reduced the average discharge of the Missouri River at Hermann, Missouri, from about 587,000 ft^3/s to 376,000 ft^3/s, which is a difference of 211,000 ft^3/s.

Record Reservoir Levels

The 34 major reservoirs in the Missouri River Basin drain an area that is greater than 100 mi^2. Of these reservoirs, water levels in 13 reached historic elevations, 3 came within 1 ft of their records, and 4 exceeded their spillway elevations (table 1). Water levels in reservoirs on tributaries of the Mississippi River upstream of its confluence with the Missouri River, including Lakes Saylorville, Coralville, and Red Rock, all in Iowa, also reached record elevations.

Many reservoirs in the midwest rose to record levels in 1993.

Several reservoirs, which are located in the Arkansas River Basin just south of the Kansas River Basin, had record and near-record water-level elevations. The number of reservoirs with record water-level elevations is an indication of the magnitude and wide extent of the floods of 1993.

KANSAS RIVER FLOOD DISCHARGE ANALYSIS

The Kansas River Basin is unique within the Mississippi River Basin because streamflow from all major tributaries is controlled by reservoirs. Many of these tributaries flooded during spring and summer 1993, as well as other rivers in much of the upper Mississippi River Basin. If the reservoirs had not stored a large volume of floodwaters, then discharges on the Kansas, the Missouri, and the Mississippi Rivers would have been greater than they were. An analysis of the storage of flood volumes in the Kansas River Basin from April 1 to September 1, and specifically during July, enables a comparison of discharges at various points along the river with and without the protection of the reservoirs.

The Kansas River Basin is located in northern Kansas, southern Nebraska, and eastern Colorado. Major tributaries of the Kansas River Basin include the Big Blue, the Republican, the Saline, the Solomon, and the Smoky Hill Rivers. The Kansas River begins at the confluence of the Republican and the Smoky Hill Rivers (figs. 5, 6). Total drainage areas and drainage areas of subbasins where discharge is uncontrolled in the Kansas

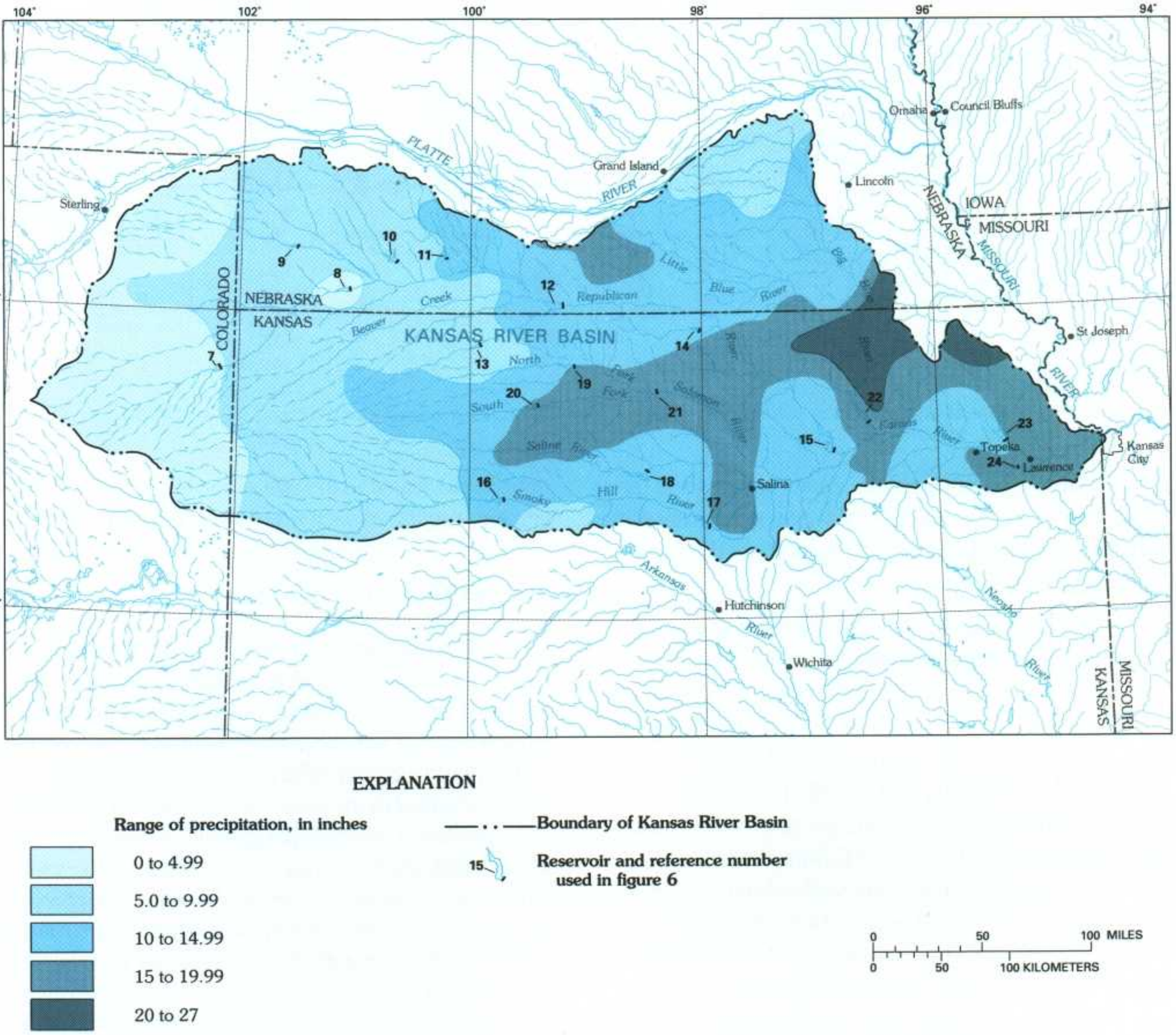

Figure 5. Areal distribution of rainfall during July 1993 and locations of reservoirs in the Kansas River Basin.

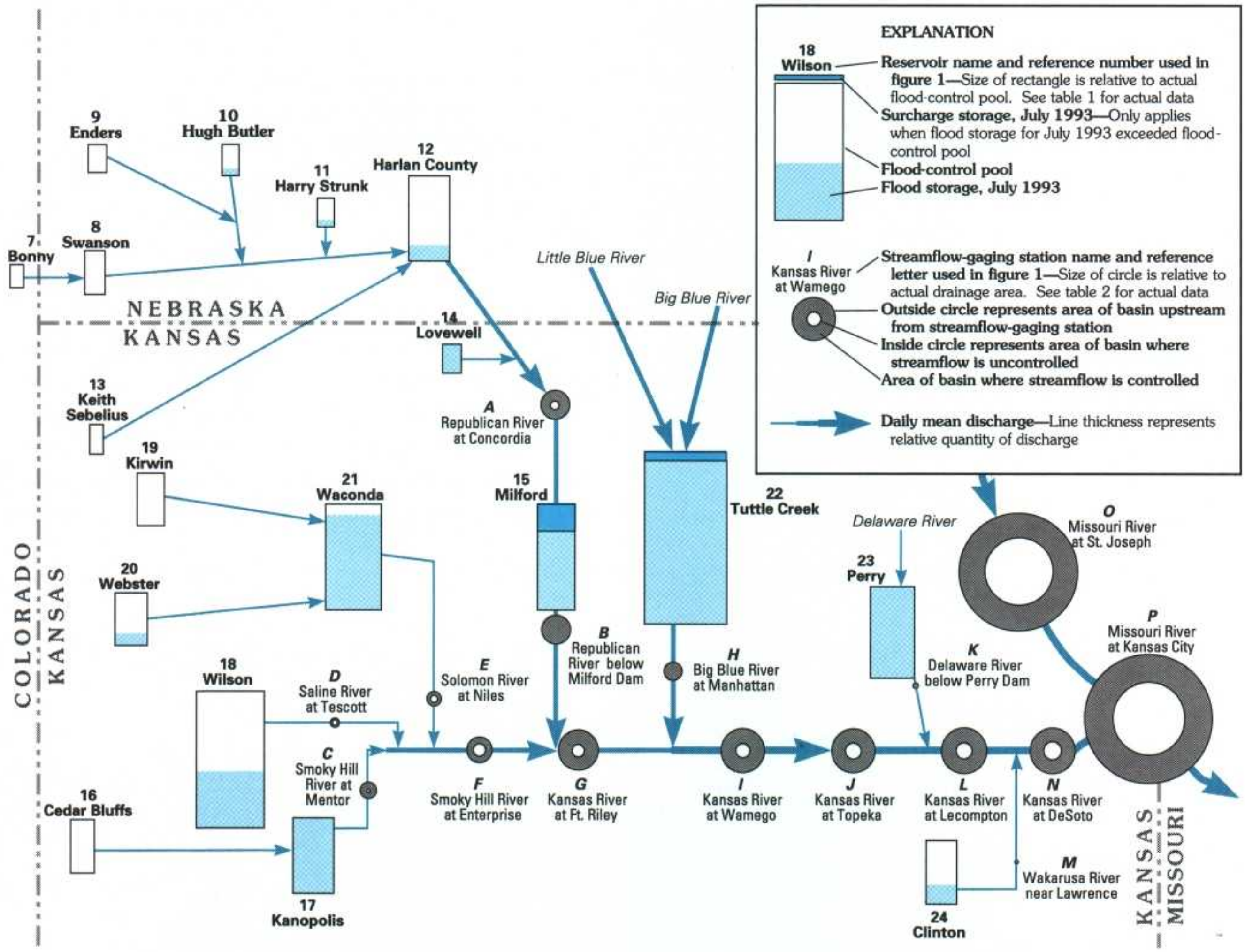

Figure 6. Flood-control storage in the Kansas River Basin reservoir system, maximum storage for July 1993.

River Basin are listed in table 2. Many streams and rivers flooded in the Kansas River Basin as significant precipitation fell during July (fig. 5) throughout the basin (National Weather Service, 1993).

The reservoirs in the Kansas River Basin were operated as part of the total Mississippi River Basin system during July 1993. The total flood-storage system in the Kansas River Basin is shown in figure 6. Most reservoirs west of the area that had 10 in. or greater precipitation (fig. 5) were able to store most of the flood discharges in their multipurpose pools. Lakes Kanopolis, Wilson, Waconda, Milford, Tuttle Creek, and Perry contained most of the pool volume. [Note: the flood-control pool and the portion filled during July 1993 for each reservoir shown in figure 6 is scaled in relation to the size of the rectangle representing a reservoir. Drainage areas (total and subareas where streamflow is uncontrolled) for selected streamflow-gaging stations are scaled to the size of the circles. The geographic location of each reservoir is shown in fig. 5.]

Kansas River Tributaries

The discharges for streams in the Kansas River Basin during July 1993 were analyzed under the condition that the reservoir system was not in place. Floodwater that was stored in a particular reservoir was routed down the river valley under high-discharge conditions and added to the observed discharge downstream. This simulation process was iterative because several streams had additional reservoirs upstream. Routing times were determined from observed high discharges before reservoir construction. The Muskingum routing method (Viessman and others, 1972) was used to allow for flood discharge storage along the river valley as the flood discharges moved downstream. Daily mean discharges were estimated for selected gaging stations in

Table 2 Flood discharge in selected streams in the Kansas and the Missouri River Basins, July 1993

[mi², square miles; ft³/s, cubic feet per second; <, less than; - -, data unavailable]

Map reference letter (fig. 1)	Gaging station number	Stream name and location	Total drainage area (mi²)	Percentage of total Kansas River Basin	Area where discharge is uncontrolled (mi²)	Percentage of basin where discharge is uncontrolled	Observed instantaneous peak discharge, July 1993		Uncontrolled instantaneous peak discharge[1]		Simulated uncontrolled maximum daily average discharge[2]	
							ft³/s	Date	ft³/s	Date	ft³/s	Date
		Kansas										
A	06856000	Republican River at Concordia.	23,560	39	2,517	11	38,500	7/23	42,400	7/23	33,800	7/23
B	06857100	Republican River below Milford Dam.	24,890	42	10	0	33,700	7/26	- -	- -	67,300	7/9
C	06866500	Smoky Hill River at Mentor.	8,358	14	501	6	10,700	7/22	30,300	7/25	29,500	7/24
D	03269500	Saline River at Tescott.....	2,820	5	903	32	10,700	7/25	52,900	7/25	45,600	7/22
E	06876900	Solomon River at Niles....	6,770	11	1,694	25	17,900	7/22	74,000	7/24	62,700	7/23
F	06877600	Smoky Hill River at Enterprise.	19,260	32	4,410	23	45,600	7/22	155,000	7/24	122,000	7/23
G	06879100	Kansas River at Ft. Riley..	44,870	75	5,130	11	87,600	7/25	200,000	7/24	189,000	7/24
H	06887000	Big Blue River near Manhattan.	9,640	16	12	0	60,000	7/26	- -	- -	107,000	7/5
I	06887500	Kansas River at Wamego..	55,280	92	5,912	11	171,000	7/26	258,000	7/25	240,000	7/25
J	06889000	Kansas River at Topeka....	56,720	95	7,352	13	166,000	7/26	261,000	7/26	245,000	7/25
K	06890900	Delaware River below Perry Dam.	1,117	2	0	0	5,000	7/26	- -	- -	28,500	7/6
L	06891000	Kansas River at Lecompton.	58,460	98	7,975	14	175,000	7/27	265,000	7/26	240,000	7/25
M	06891500	Wakarusa River near Lawrence.	425	<1	58	14	260	7/27	- -	- -	8,100	7/23
N	06892350	Kansas River at DeSoto....	59,756	100	8,904	15	172,000	7/27	266,000	7/27	252,000	7/10
		Missouri										
O	06818000	Missouri River at St. Joseph.	420,300	700	140,500	34	335,000	7/26	461,000	7/26	- -	- -
P	06893000	Missouri River at Kansas City.	485,200	808	154,900	32	541,000	7/28	713,000	7/27	- -	- -
Q	06934500	Missouri River at Hermann.	524,200	873	179,400	34	750,000	7/31	852,000	7/31	- -	- -

[1]Data supplied by the U.S. Army Corps of Engineers, Kansas City District. Values computed by use of the BENEFITS computer program.
[2]Values computed by the Muskingum routing method described in Viessman and others (1972).

the Kansas River Basin by using daily reservoir storage and observed stream discharges. The computer program BENEFITS (U.S. Army Corps of Engineers, written commun., 1993) was used to estimate the uncontrolled instantaneous peak discharge at selected gaging stations on the Kansas and the Missouri Rivers. The uncontrolled instantaneous peak discharges are compared with the observed instantaneous peak discharges and the simulated uncontrolled maximum daily mean discharges (table 2). The locations of these stations in relation to the reservoirs are shown in figures 1 and 6.

Examples of observed controlled and simulated uncontrolled daily mean discharges are shown in figures 7 to 15. Figures 7 to 9 show the streamflow contribution of each of the three major tributaries upstream of the Smoky Hill River at Enterprise, Kansas; these tributaries are the Saline, the Solomon, and the Smoky Hill Rivers. From July 22 to 25, all three tributaries had the largest simulated uncontrolled discharges, which were two to three times greater than the observed reservoir-controlled discharges. The greatest instantaneous peak discharge for each river as determined by BENEFITS also is shown in figures 7 to 10 and 13 to 15.

The combined flood discharge from the three tributaries of the Smoky Hill River at Enterprise is shown in figure 10. The addition of the simulated uncontrolled discharges would have resulted in a simulated uncontrolled maximum discharge of 122,000 ft^3/s at that location. However large, this discharge is much less than the 233,000 ft^3/s recorded during the 1951 flood (U.S. Geological Survey, 1992). Effects of multiple upstream reservoirs, controlled reservoir outflow, and uncontrolled spillway releases for the Republican River below Milford Dam are shown in figure 11. Flood storage in Lake Milford prevented a simulated uncontrolled daily average discharge of 67,300 ft^3/s in the Republican River below Milford Dam on July 9, 1993.

Kansas River Main Stem

In Kansas, the Republican and the Smoky Hill Rivers converge at Junction City to form the Kansas River. At the streamflow gage at Fort Riley, which is located 1.6 miles (mi) downstream from the juncture, an instantaneous peak discharge of 87,600 ft^3/s was recorded on July 25, 1993. Without the reservoirs in place, an uncontrolled instantaneous peak of about 200,000 ft^3/s would have occurred, and a simulated uncontrolled maximum daily average discharge would have been about 189,000 ft^3/s on July 24 (table 2).

About 20 mi downstream from the Fort Riley gage, the Kansas River receives discharge from the Big Blue River. At this confluence, the normal discharge of each river is nearly equal. The Big Blue River drains much of southeastern Nebraska and northeastern Kansas, which also was the area of greatest rainfall recorded in July (fig. 5). The storage of floodwaters in Tuttle Creek Lake reduced a potentially devastating flood of more than 107,000 ft^3/s on July 5 on the Big Blue River near Manhattan, Kansas,

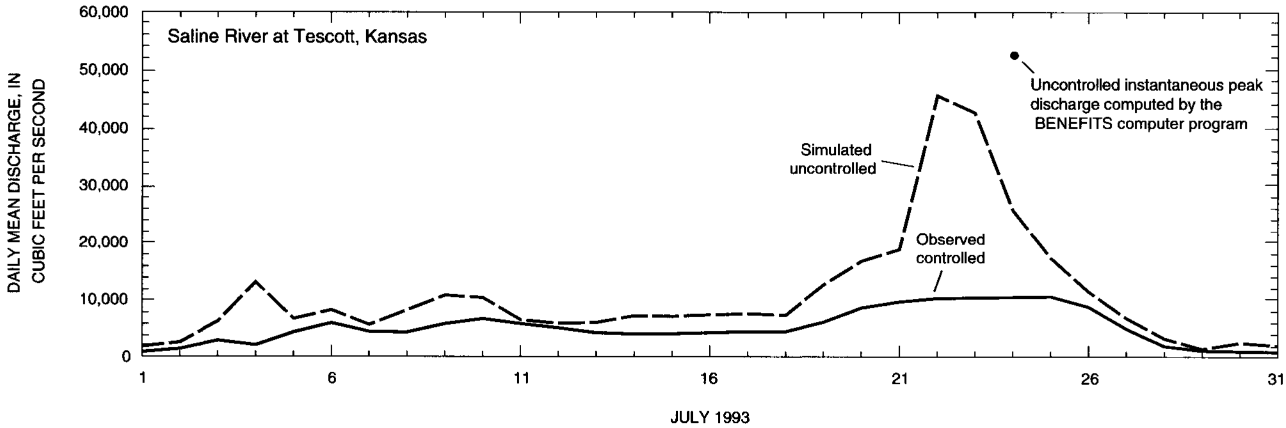

Figure 7. Observed and simulated uncontrolled discharges in the Saline River at Tescott, Kansas, July 1993.

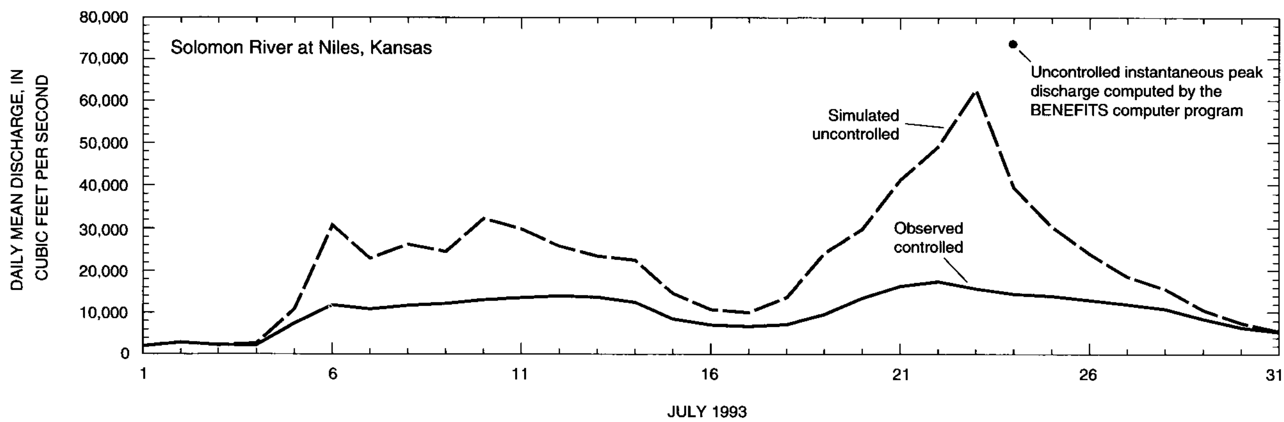

Figure 8. Observed and simulated uncontrolled discharges in the Solomon River at Niles, Kansas, July 1993.

Without the storage of Tuttle Creek Lake, the flood of 1993 on the Big Blue River near Manhattan, Kansas, would have exceeded the record flood of 1951 by more than 13,000 ft^3/s.

to a much less destructive flood of 60,000 ft^3/s on July 25 (fig. 12). At this location, the historic flood of 1951 was 93,400 ft^3/s. Without the reservoir storage, the Big Blue River near Manhattan would have overtopped the Federal levee, and flooding downstream along the Kansas River would have been much more severe.

After joining with the Big Blue River, the Kansas River meanders eastward along its broad fertile flood plain toward Kansas City, Kansas. Because only low levees have been built along the river between Manhattan and Topeka, Kansas, the protection of thousands of acres of prime agricultural land is provided by the upstream reservoirs. Tuttle Creek and Milford Lakes and other reservoirs upstream reduced the Kansas River discharges, as shown in the observed and simulated uncontrolled discharges of the Kansas River at Wamego, Kansas (fig. 13), to levels that could be contained by the low levees. Controlled floods on the Big Blue River on July 5, the Republican River on July 9, and the upper tributaries on July 22–23 caused the Kansas River to inundate only the lowest lying farmlands during 1993. The discharges in the Kansas River at Topeka (fig. 14) were contained by its levee system.

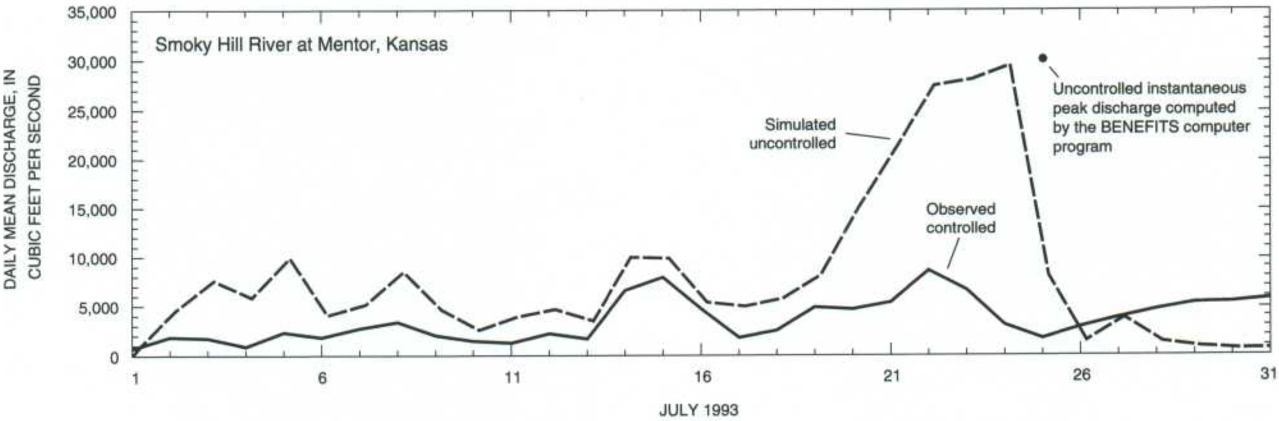

Figure 9. Observed and simulated uncontrolled discharges in the Smoky Hill River at Mentor, Kansas, July 1993.

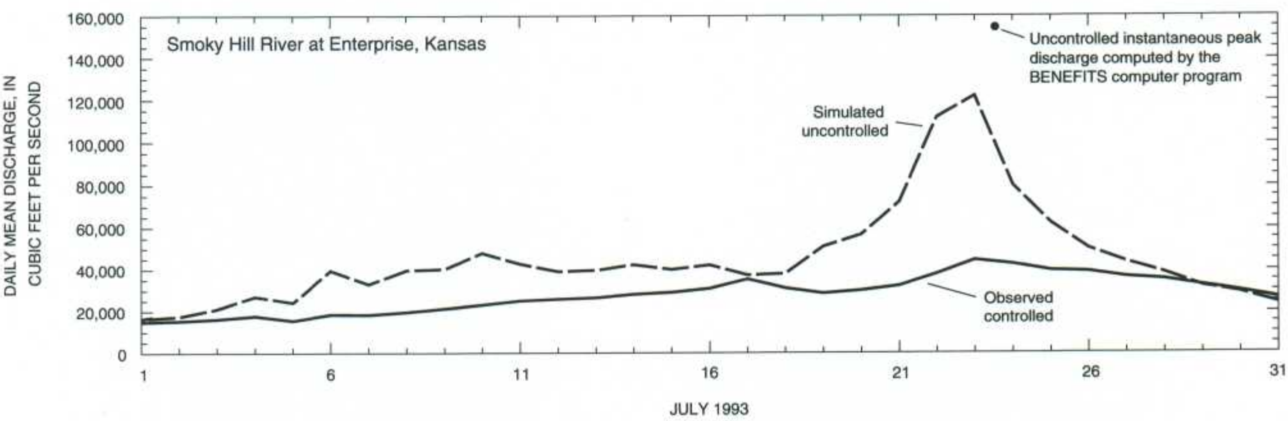

Figure 10. Observed and simulated uncontrolled discharges in the Smoky Hill River at Enterprise, Kansas, July 1993.

The streamflows from only two other tributaries to the Kansas River are controlled downstream from Wamego. Perry and Clinton Lakes control the Delaware and the Wakarusa Rivers, respectively. The water level in Perry Lake, which filled its flood-control pool on July 25, surpassed its previous high elevation in 1973 by almost 4 ft (table 1). Although the water level in Clinton Lake was at an all-time high elevation on July 31, the lake still had reserve flood storage available.

The total effect of the Kansas River Basin reservoirs can be seen in the analysis of the flood discharges on the Kansas River at DeSoto, Kansas (fig 15). The simulation of uncontrolled disharges

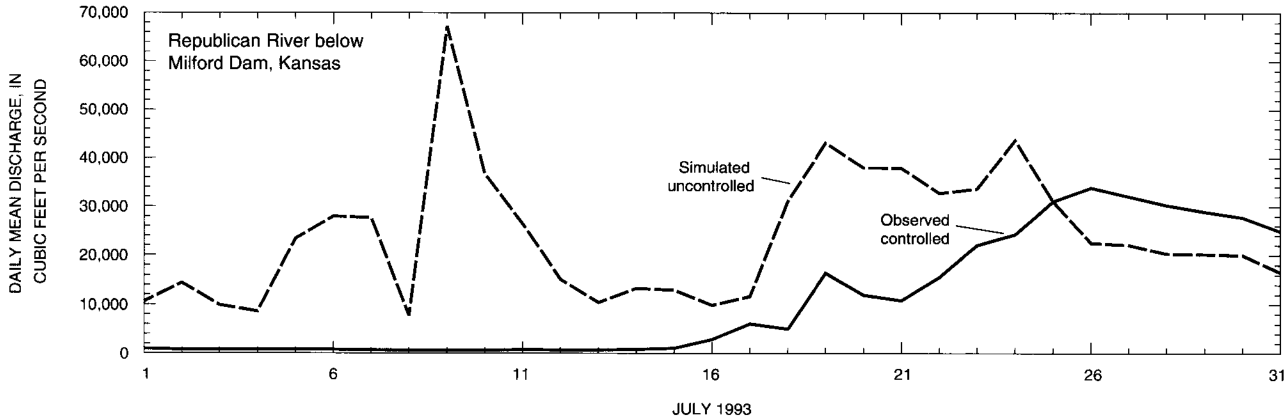

Figure 11. Observed and simulated uncontrolled discharges in the Republican River below Milford Dam, Kansas, July 1993.

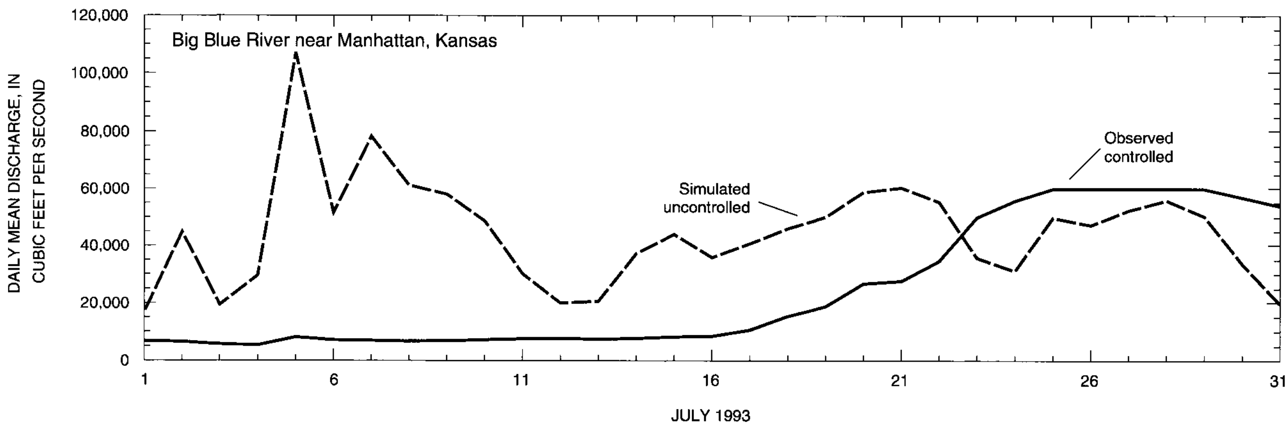

Figure 12. Observed and simulated uncontrolled discharges in the Big Blue River near Manhattan, Kansas, July 1993.

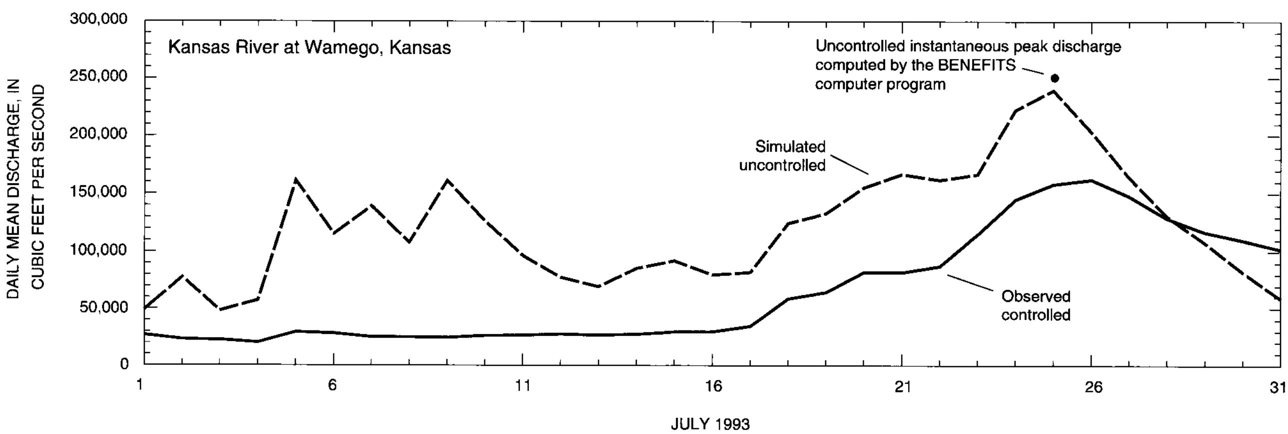

Figure 13. Observed and simulated uncontrolled discharges in the Kansas River at Wamego, Kansas, July 1993.

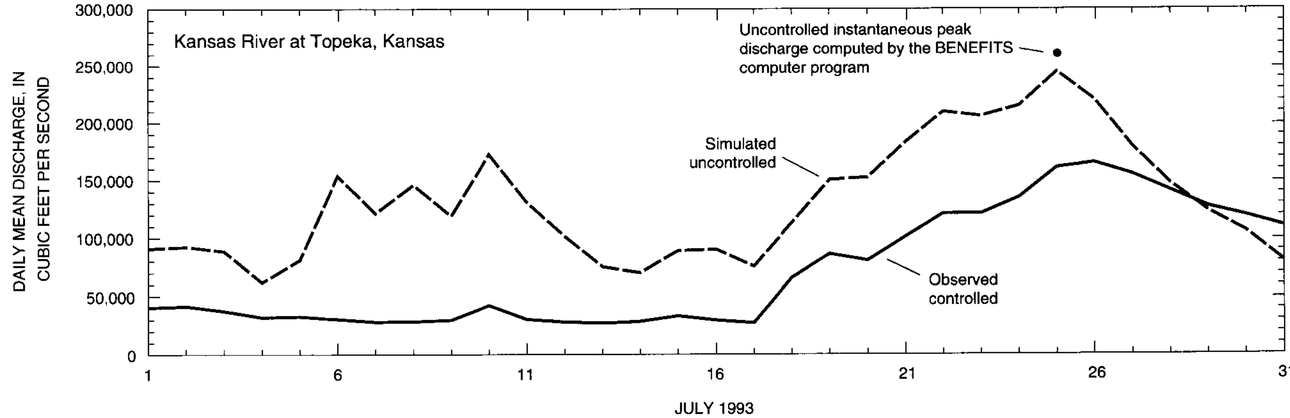

Figure 14. Observed and simulated uncontrolled discharges in the Kansas River at Topeka, Kansas, July 1993.

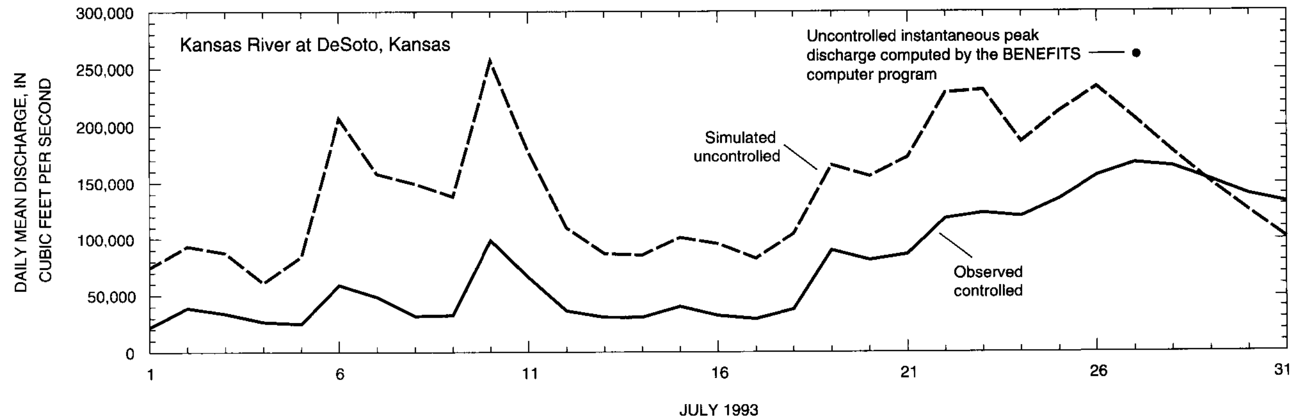

Figure 15. Observed and simulated uncontrolled discharges in the Kansas River at DeSoto, Kansas, July 1993.

resulted in the highest daily mean discharge of 252,000 ft^3/s on July 10. A secondary simulated uncontrolled discharge of 233,000 ft^3/s would have occurred on July 26. An observed instantaneous peak discharge of 172,000 ft^3/s occurred on July 27. Many other cities and hundreds of thousands of acres of farmland along the tributaries and main stem of the Kansas River benefited from the flood-control reservoirs as flood discharges were reduced by 30 to 70 percent.

All simulated uncontrolled discharges on the Kansas River would have been contained by the Federal levee system, except in Kansas City where backwater from the flooding Missouri River on July 27 might have caused the river stage to overtop the levee system there. However, without the control of reservoirs in the main-stem Missouri River, the combined uncontrolled discharges of the Kansas and the Missouri Rivers would have overtopped the Kansas City levees (Flood Insurance Administration, 1981).

Reservoir Level Maintenance

To maintain storage capacity in flood-control reservoirs, stored floodwater is released as soon as the river downstream can accept it without additional flooding, as indicated by figure 16, which shows water-level fluctuations during the 1993 water year at selected reservoirs in the Kansas River Basin. The water levels in many of the reservoirs in the Kansas River Basin at the beginning of the 1993 water year were above multipurpose-pool elevation, but all were lowered during the 1992–93 winter. However, the snowmelt and precipitation of February through May 1993 resulted in fluctuations and steadily increasing discharge in streams in the Kansas River Basin as summer approached. An example is Tuttle Creek Lake, where, beginning in February, monthly increases in storage were followed by controlled releases to lower the lake level back to multipurpose-pool elevation. At the same time, other reservoirs in the Kansas River Basin were releasing stored water, and many uncontrolled streams were flooding. This

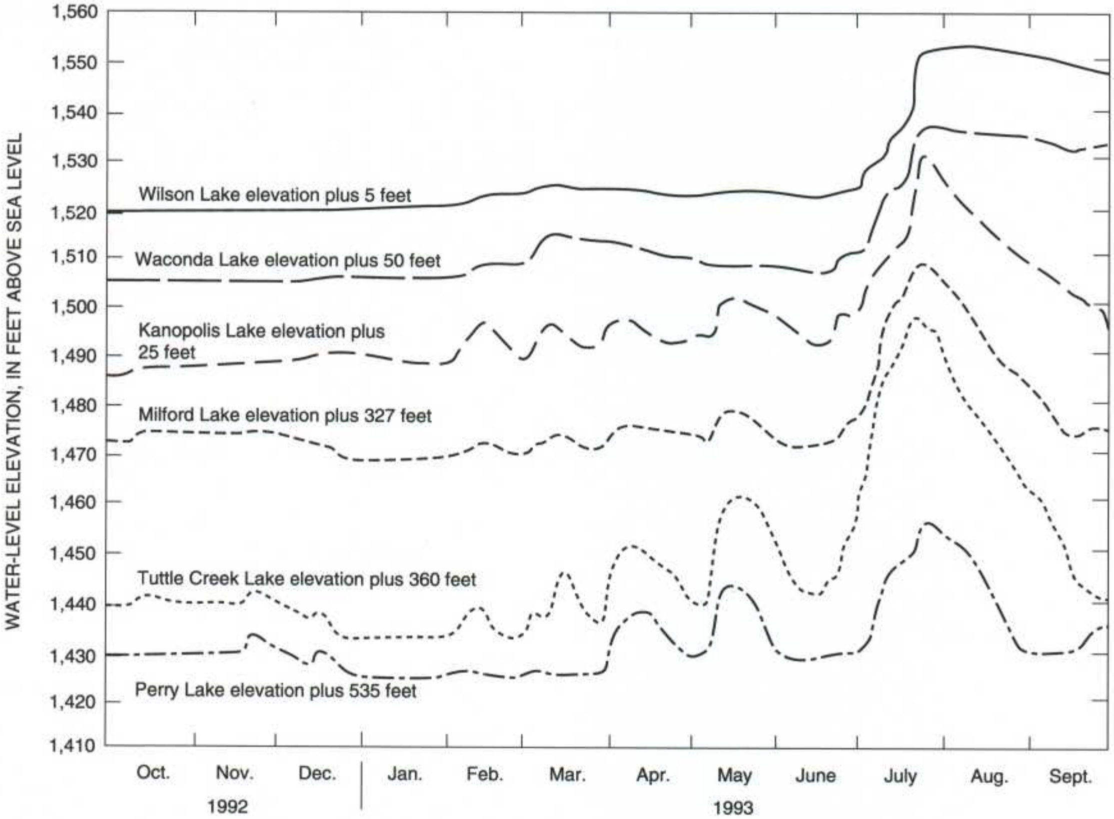

Figure 16. Water-level elevations of selected reservoirs in the Kansas River Basin, 1993 water year.

combination resulted in many streams being at bankfull capacities for extended periods of time.

This cycle of precipitation, flooding, and resulting releases of water from reservoirs was interrupted in July when intense rains fell somewhere in the basin nearly every day of the month. With most uncontrolled streams at or above flood stage and the lower Missouri and Mississippi Rivers flooding, the flood-storage capacity of the Kansas River Basin reservoir system was tested. Some floodwater was released as water levels in Tuttle Creek and Milford Lakes reached surcharge storage elevations, but the reservoir system contained most of the flooding.

Comparison of 1951 and 1993 Floods

The flood of 1951 on the Kansas River at DeSoto, which had a peak discharge of 510,000 ft^3/s, is considered to be the largest flood in the Kansas River Basin during the 20th century; all floods in the basin are compared to it. The flood of 1903 ranks second to the 1951 flood with an estimated peak discharge of 337,000 ft^3/s. Even without the reservoirs in place, the 1993 flood is estimated to be about 266,000 ft^3/s (about 50 percent of the 1951 flood), thus ranking it third. Peak discharge, however, is only one way of ranking floods; another way is to compare flood volumes. This type of ranking is usually more consistent with the longer term, widespread climatic patterns that are responsible for the flooding. Instantaneous peaks are greatly dependent on storm intensities, timing, and direction of movement,

On July 13, 1951, peak flow of 510,000 ft^3/s from the Kansas River flooded Kansas City, Kansas and Missouri. (Warner Studio, Kansas City, Missouri.)

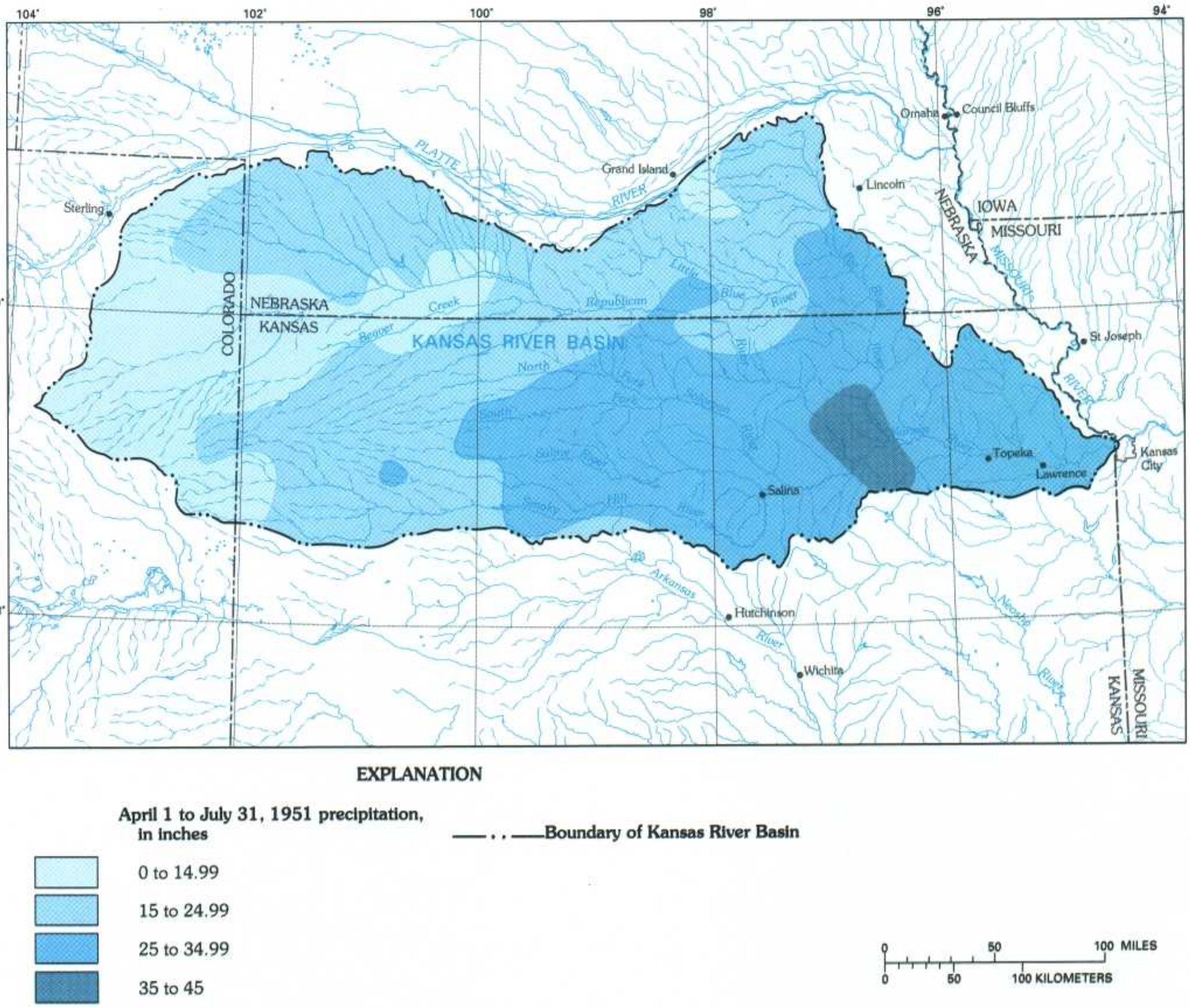

Figure 17. Total precipitation in the Kansas River Basin, April 1 to July 31, 1951.

which are critical in the development of large floods. However, total rainfall during the flooding period correlates closely with total flood volumes.

The total volumes of the floods of 1951 and 1993 are comparable because they occurred at nearly identical times of the year and the precipitation patterns also were quite similar. Figures 17 and 18 show the total rainfall for the period from April 1 to July 31, 1951 and 1993, respectively. The greatest rainfall in 1951 was in northeastern Kansas and extended southward toward east-central Kansas. The area of greatest rainfall in 1993 was farther north and extended from central Kansas into southeastern Nebraska.

Hydrographs of observed discharge during the two flood periods for the Kansas River at DeSoto shown in figure 19 are similar in some ways. Both hydrographs show a discharge increase in early May, the major flooding in July, and another increase in September. However, the observed discharges for 1993 are lower in June 1993 than those in June 1951 because water was being stored in the flood-control reservoirs. Observed discharges in August and early September 1993 are much higher than those during the same time in 1951 because stored floodwater was being released. Even though the discharges shown in figure 19 end on September 30, flows during fall 1993 remained high because of the release of about 900,000 acre-ft that had been retained in flood-control reservoirs as of October 1, 1993. The total flood volume from April 1 to September 30, 1951, was 19,500,000 acre-ft compared with 18,500,000 acre-ft for the same period in 1993 (includes the amount in flood-control pools on October 1, 1993).

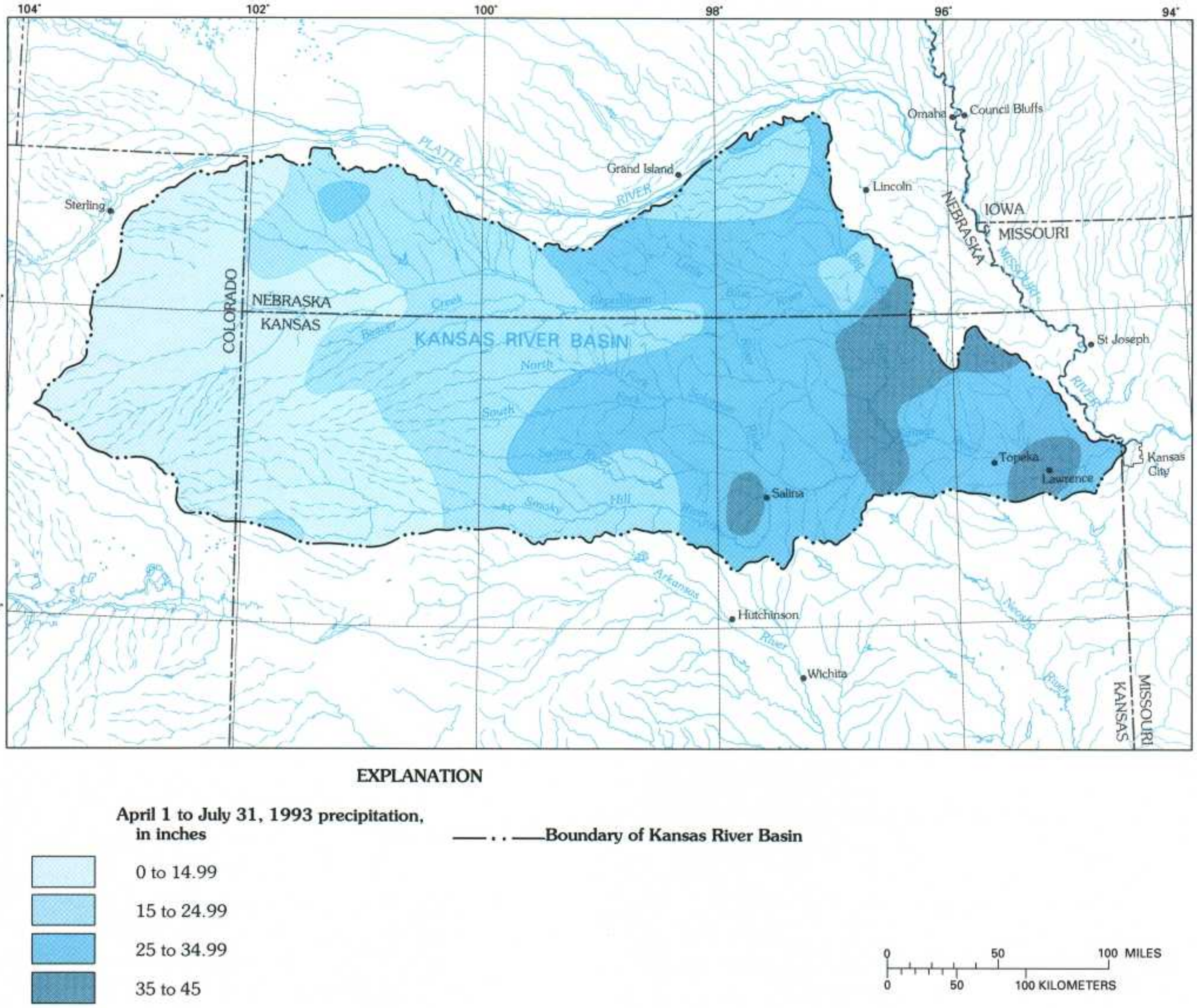

Figure 18. Total precipitation in the Kansas River Basin, April 1 to July 31, 1993.

Daily streamflow records for the Kansas River at DeSoto extend back to 1917. When the entire water year (October 1–September 30) is considered, the Kansas River flood volume for 1993 exceeded the previous maximum of 21,300,000 acre-ft recorded during the 1951 water year by slightly more than 1,000,000 acre-ft.

SUMMARY

The floods of 1993 were of historic magnitude as water in the Missouri and the Mississippi Rivers reached levels that exceeded many of the previous observed maximums. The floods were generated by large-scale climatic patterns that resulted in greater-than-normal rainfall from the Rocky Mountains to the Great Lakes. Runoff from the intense spring and summer rainfall converged on the Mississippi River at St. Louis to produce a historic peak discharge of 1,080,000 ft^3/s on August 1, 1993. During spring and summer, record or near-record discharges in many other streams resulted in substantial flood damage throughout the Midwest.

As severe as the flooding was in 1993, stream and river levels could have been even higher had a system of flood-control reservoirs not been in place throughout the Missouri River Basin. More than 10,000,000 acre-ft of additional water was stored in the upper Missouri River main-stem reservoirs in Montana, North Dakota, and South Dakota from April 1 to August 1, 1993. In the lower sections of the Missouri River Basin, the 4-month storage held in reservoirs on the Kansas River was 4,500,000 acre-ft,

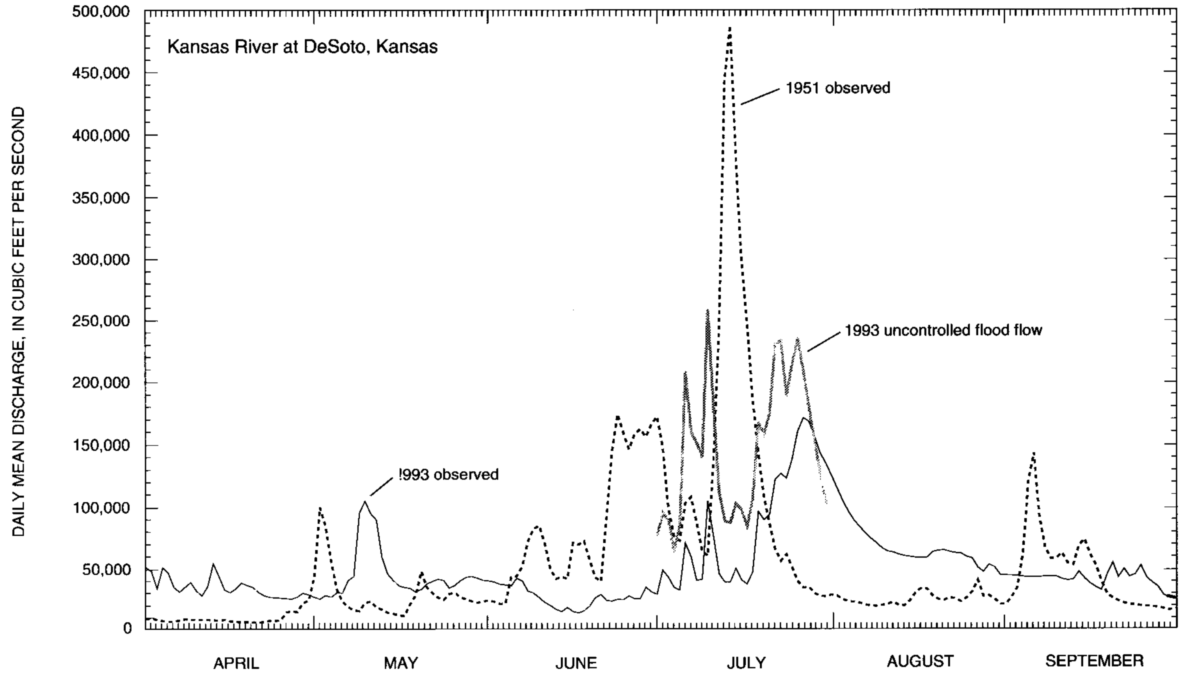

Figure 19. Floods in the Kansas River at DeSoto, Kansas, 1951 and 1993.

while the other Missouri River tributaries held back 3,900,000 acre-ft. If the total 18,700,000 acre-ft stored in the system had been allowed to flow to St. Louis, then the average discharge of the Missouri River would have been 77,300 ft^3/s greater for this 4-month period. During July alone, flood storage of 13,000,000 acre-ft in flood-control reservoirs in the Missouri River Basin reduced the average discharge for the month at its confluence with the Mississippi River by 211,000 ft^3/s.

An analysis of flood discharges in the Kansas River Basin demonstrated the storage capacity of its reservoirs and how peak discharges were reduced substantially. The greatest effect was observed on the Big Blue River near Manhattan where Tuttle Creek Lake withheld a daily mean flow of 107,000 ft^3/s on July 5. The instantaneous peak for this day would have been higher, which would have caused much greater damage than the 60,000-ft^3/s release later in the month. Many other cities and hundreds of thousands of acres of farmland along the tributaries and main stem of the Kansas River benefited from the flood-control reservoirs as flood discharges were reduced by 30 to 70 percent.

The flood-control reservoirs and the Federal levee system working in concert protected Junction City, Manhattan, Topeka, Lawrence, and Kansas City. Without the levees, these cities would have been flooded. Without the reservoirs, Manhattan and Kansas City would have had their levees overtopped.

Flooding in the Kansas River Basin is always compared with the great flood of 1951 when 510,000 ft^3/s flowed past DeSoto on July 13, 1951. Precipitation totals and patterns were similar for 1951 and 1993. The total volume of floodwater in the Kansas River from April 1 to September 30 was 19,500,000 acre-ft in 1951 and 18,500,000 acre-ft in 1993. The total flood volumes were similar, but the timing of the flood discharges from the tributaries was different, thus producing an estimated uncontrolled flood discharge in 1993 that was about 50 percent of that of 1951. The total flow volume for the Kansas River at DeSoto for the entire 1993 water year was the greatest of any water year since daily records began in 1917.

Reservoirs throughout the Missouri River Basin and also those in the rest of the upper Mississippi River Basin reduced peak discharges downstream during 1993. As many levee systems reached capacity conveyance, the reduction of the flood discharges by those reservoirs prevented additional destruction of agricultural lands, urban environment, and, most importantly, human lives.

REFERENCES

Flood Insurance Administration, 1981, Flood insurance study, City of Kansas City, Kansas: U.S. Department of Housing and Urban Development, February 1981, 31 p.

Matthai, H.F., 1968, Missouri River Basin below Sioux City, Iowa, pt. 6–B *of* Magnitude and frequency of floods in the United States: U.S. Geological Survey Water-Supply Paper 1680, 491 p.

National Weather Service, 1993, Update on Midwestern floods—Heat and drought in the East, special climate summary: Ashville, N.C., v. 93, no. 2, 8 p.

Parrett, Charles, Melcher, N.B., and James, R.W., Jr., 1993, Flood discharges in the upper Mississippi River Basin, 1993, *in* Floods in the upper Mississippi River Basin, 1993: U.S. Geological Survey Circular 1120–A, 14 p.

U.S. Army Corps of Engineers, 1965, Flood plain information—Kansas River, Kansas, Junction City to the mouth: U.S. Army Corps of Engineers, Kansas City District, April 1965, 13 p.

U.S. Geological Survey, 1992, Water resources data for Kansas, Missouri, Nebraska, Iowa, Nebraska, South Dakota, North Dakota, Montana and Colorado, Water Year 1992: U.S. Geological Survey Water-Data Reports KS–92–1, MO–92–1, NE–92–1, IA–92–1, SD–92–1, ND–92–1, MT–92–1, and CO–92–1.

Viessman, Warren, Jr., Harbaugh, T.E., and Knapp, J.W., 1972, Introduction to hydrology: New York, Intext Educational Publications, p. 173–221.

Wahl, K.L., Vining, K.C., and Wiche, G.J., 1993, Precipitation in the upper Mississippi River Basin, January 1 through July 31, 1993, in Floods in the upper Mississippi River Basin, 1993: U.S. Geological Survey Circular 1120–B, 13 p.