SEDIMENT AND CHANNEL-GEOMETRY INVESTIGATIONS FOR THE KANSAS RIVER BANK-STABILIZATION STUDY, KANSAS, NEBRASKA, AND COLORADO

By W. R. Osterkamp, R. E. Curtis, Jr., and H. G. Crowther

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ILLUSTRATIONS

TABLES

CONVERSION FACTORS

Inch-pound units of measurement used in this report may be converted to International System (SI) of Metric Units using the following factors:

Multiply inch-pound units	By	To obtain SI units
inch	[1]25.4	millimeter (mm)
foot	0.3048	meter
mile	1.609	kilometer
foot per mile (ft/mi)	0.1894	meter per kilometer
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.0283	cubic meter per second
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.0109	cubic meter per second per square kilometer
ton, short (2,000 lb)	0.9072	megagram
ton per square mile per year [$(ton/mi^2)/yr$]	0.3503	megagram per square kilometer per year

[1] Exact conversion factor.

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ABSTRACT

Sediment yields under unregulated conditions in the Kansas River basin range from less than 50 tons per square mile per year in areas of little topographic slope (western part) to nearly 2,000 tons per square mile per year in areas of dissected till (eastern part). Sediment storage in reservoirs has resulted in reduced sediment discharge at downstream sites. The effects of reservoir construction and streamflow regulation on sediment yields per unit area and time, however, have been difficult to evaluate owing to variable discharge rates and changes in land-use practices.

Analyses of discharge, channel-geometry, stage-time, and channel-sediment data indicate that the channels of the lower Solomon, Saline, and Smoky Hill Rivers are relatively narrow and resistant to changes resulting from trapping of sediment and regulation of streamflow by upstream reservoirs. However, the Kansas River channel, which probably was vulnerable to modification by alteration of the water- or sediment-discharge rates prior to regulation, remains locally active. The present areas of channel activity and large width are mainly in reaches that have been active historically.

A deficiency of sediment inflow to the Kansas River is likely to cause continuing change in the channel. Reduced inflow of coarse sediment probably results in a decrease of channel gradient by bed degradation or increased meandering, and the supply of fine-grained sediment apparently is insufficient to maintain alluvial banks that are resistant to erosion.

Significant rates of channel degradation of the Kansas River presently are not occurring at most sites, but may occur in response to long-term (decades to centuries) regulation. Recent channel degradation near Bonner Springs, Kansas, is largely the result of extraction of sand and gravel. Any natural or imposed changes that shorten the channel or further reduce the sediment inflow to the Kansas River are expected to result in additional channel changes.

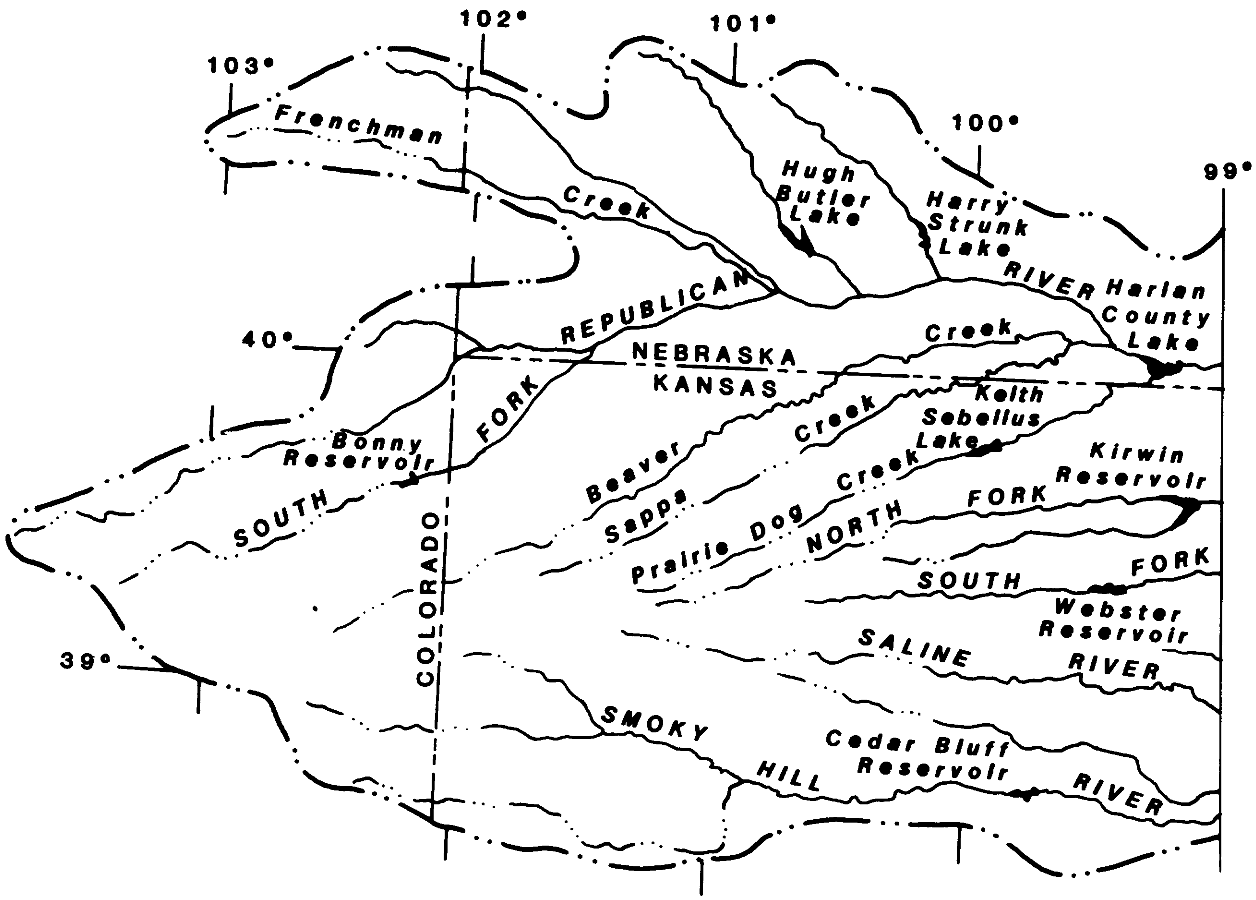
INTRODUCTION

Various forms of channel activity, including widening, bank erosion, meander movement, and degradation, have been identified in the downstream part of the Kansas River basin during recent years. Because the channel activity seemingly has intensified during the period following impoundment of streamflow and sediment by several major reservoirs, it is possible that part of the channel changes are the result of changes in hydrologic regimen by the reservoirs. To investigate this possibility, as well as to explore feasible methods of reducing the economic losses and enhancing the environmental character resulting from the channel changes, the U.S. Army Corps of Engineers began the Kansas River Bank-Stabilization Study during 1976.

The investigation described in this report was conducted by the U.S. Geological Survey, in cooperation with the U.S. Army Corps of Engineers, as part of the Kansas River Bank-Stabilization Study. The general purpose of the investigation was to provide sediment and channel-geometry data and interpretations of those data pertinent to the bank-stabilization project. This report, therefore, describes the analyses of sediment data and provides data and interpretations of the channel geometry of the Kansas River and several major tributaries. The content and conclusions of this report do not necessarily represent the views of the Corps of Engineers.

An objective of the investigation was to determine whether significant alterations in sediment size and supplies to the downstream part of the Kansas River basin have occurred during the last few decades. If changes have occurred, an additional objective was to describe those changes quantitatively. The information may be related to man's effects on land use and construction of major reservoirs in the basin and to natural effects of topography, geology, climate, and physiography.

The area of interest in the Kansas River Bank-Stabilization Study is the Kansas River basin downstream from major reservoirs. To permit reasonable evaluations of areal and temporal variations in sediment yield, sediment size, and channel characteristics for this report, data were considered from the entire Kansas River basin in parts of Kansas, Nebraska, and Colorado (fig. 1), as well as from adjacent parts of other drainage basins. The report presents fluvial-sediment transport and channel-morphology data for the period of extensive streamflow regulation in the basin (approximately the last two to three decades) and for the period immediately preceding regulation. All of the data and generalizations presented are intended to represent controlled hydrologic conditions or uncontrolled conditions of a generally agricultural, rather than a pristine, watershed.


103°
102°
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Frenchman
Creek
Hugh Butler Lake
Harry Strunk Lake
RIVER
Harlan County Lake
REPUBLICAN
Creek
NEBRASKA
KANSAS
Keith Sebelius Lake
Bonny Reservoir
FORK
Creek
Beaver
Creek
Kirwin Reservoir
SOUTH
Sappa
Prairie Dog
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Webster Reservoir
SALINE
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SMOKY
Cedar Bluff Reservoir
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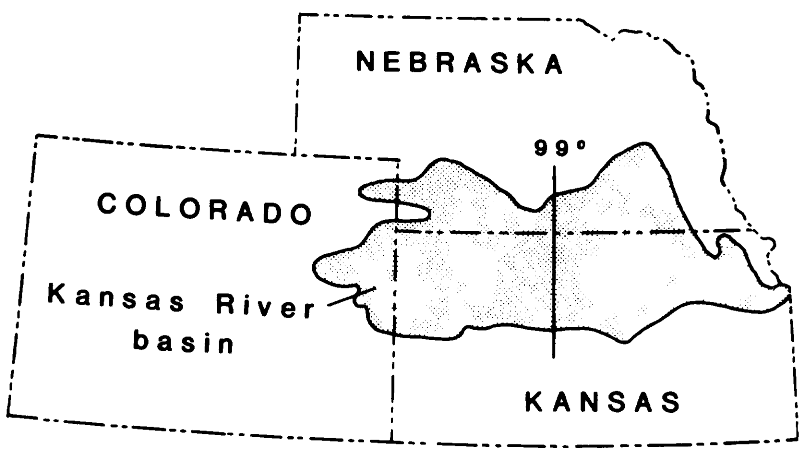

NEBRASKA
99°
COLORADO
Kansas River basin
KANSAS

Index map

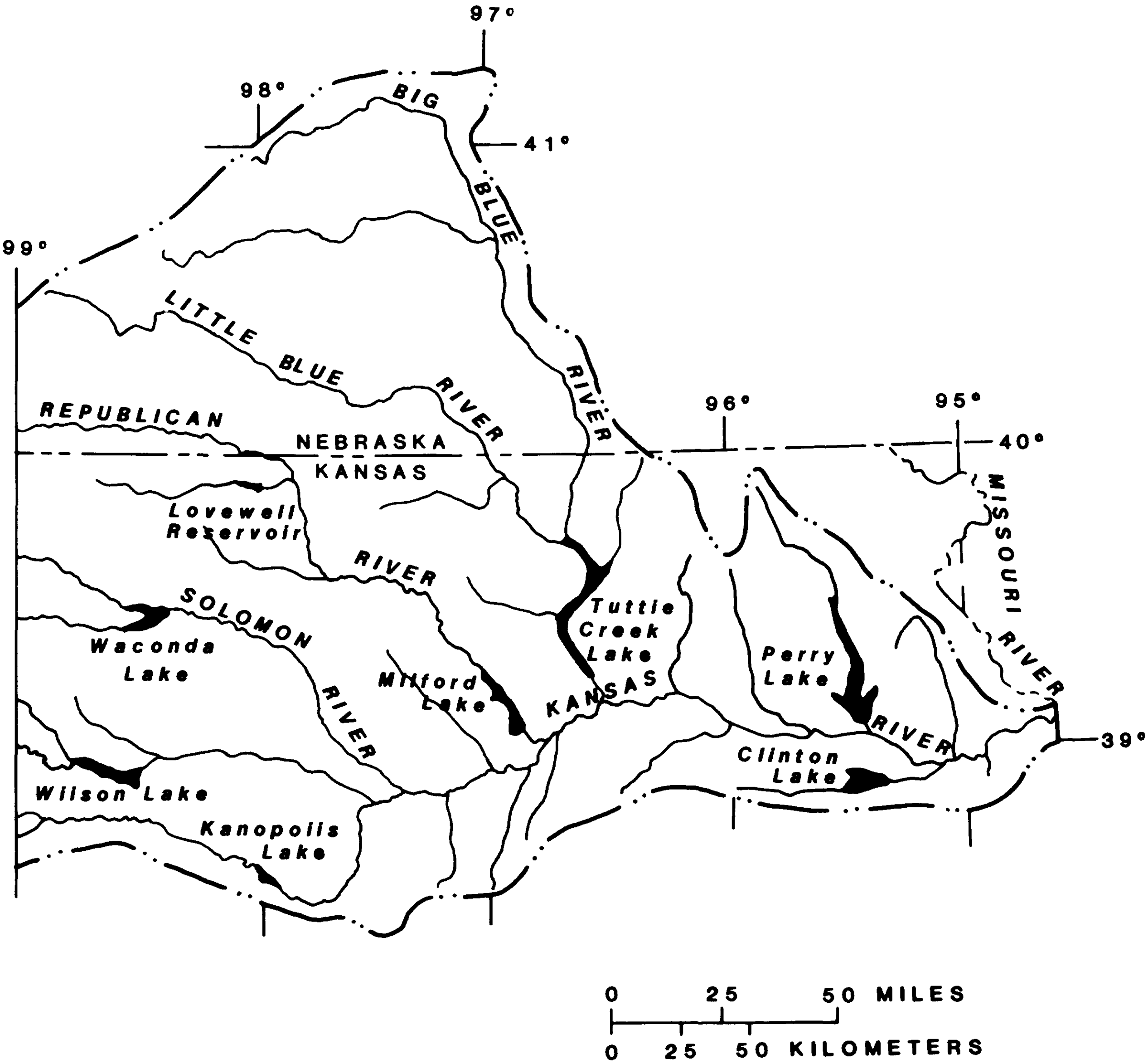


Figure 1.--Locations of streams and reservoirs in Kansas River basin, Kansas, Nebraska, and Colorado.

FLUVIAL SEDIMENT

Available Data

The sediment-concentration data used for this report were collected by personnel of the U.S. Geological Survey and the U.S. Army Corps of Engineers. Most of the Corps of Engineers' data are from drainages with sites suitable for reservoir construction in the downstream part of the basin. Generally, these data were collected at intervals of 1 to several weeks at streamflow-gaging stations both upstream and downstream from proposed or constructed reservoirs. Many of the data collected by the Geological Survey are from streamflow-gaging stations on unregulated or relatively small streams.

Particle-size analyses of suspended sediment and bed material were made on samples collected infrequently at sediment-sampling sites. Sampling sites generally are at streamflow-gaging stations in order that sediment concentrations may be related to water discharge (fig. 2). All streamflow data used to calculate sediment discharges were collected at gaging stations operated by the U.S. Geological Survey. Other data considered in making the interpretations of fluvial-sediment discharge included reservoir surveys by the U.S. Soil Conservation Service (Holland, 1971) and various maps and reports describing the topography, geology, and climate of the Kansas River basin.

Methods of Analysis

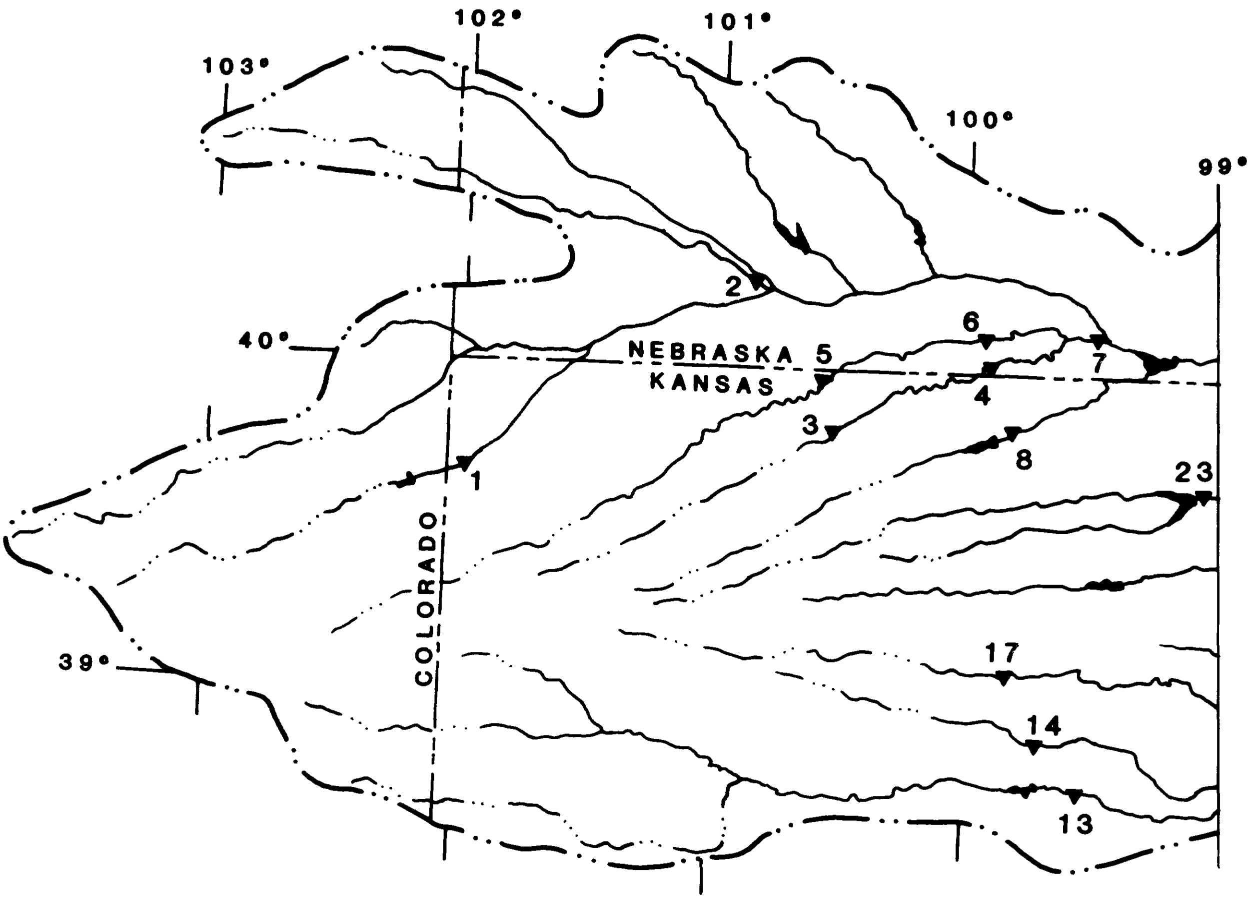
Suspended-sediment data are available for 25 sites at which samples were collected daily or more frequently and for 39 sites at which samples were collected periodically (less frequently than daily). Because both types of data were collected from 18 sites, 46 locations (shown in figure 2) are represented by 64 data sets. Both types of data, when related to water discharge, permit calculations of sediment yield per unit area and time (tables 1 and 2).

Daily sediment records were used to construct concentration curves based on the fluctuations of the water-discharge hydrographs. Average sediment concentrations and water-discharge values, rather than instantaneous values, for periods of a day or less were used to calculate the daily sediment loads and the monthly and annual totals. For those stations having a sufficient length of record, generally 8 years or more, average annual sediment loads were considered to be most accurate when calculated from daily sediment data. Records from daily stations commonly are used as the basis for comparison when evaluating the accuracy of sediment loads calculated from less frequently collected samples.

Most sediment yields given in this report (table 2) were calculated from data collected less frequently than daily. Instantaneous values of sediment concentration and water discharge were plotted to develop a sediment-rating curve for a sampling site at or near an applicable streamflow-gaging station. The available streamflow data were used to construct a flow-duration curve. By combining the information from a sediment-rating curve and a flow-duration curve, a sediment-duration curve was drawn. This curve indicates the percentage of time that a specified sediment concentration was equaled or exceeded during the period of streamflow record, assuming that the relation of sediment concentration to water discharge was unchanged. By multiplying a mean sediment-concentration value and the corresponding water discharge for a specified duration interval (expressed as a percentage range of time) by a coefficient, the amount of suspended sediment transported in that time range was calculated. When similar calculations are made for time ranges accounting for all periods of discharge and the results are summed, the average annual suspended-sediment discharge is computed (Colby, 1956). By considering contributing drainage area (for sediment), the computations give the yield of fluvial sediment as weight per unit area and time. The coefficient used in this report results in yields expressed in tons per square mile per year. A sediment-rating curve, a flow-duration curve, and a sediment concentration-duration curve are given as examples (fig. 3) for data collected from Clark Creek near Junction City, Kans.

A short period of sediment record commonly is a period when the sediment yield is higher or lower than typical because of higher or lower precipitation and runoff. The use of a period of streamflow record longer than the period of sediment record, as described above, often compensates for the atypical period of sediment record. Because the relation of sediment concentration to water discharge varies seasonally and with rising and falling stream stages, the conditions needed for this compensation to occur are: (1) The sediment sampling was well balanced seasonally; (2) the sampling was well balanced between rising and falling stream stages; and (3) the sampling covered a wide range of discharges so large extrapolation of the sediment-rating curve was not necessary. The shorter the period of sediment record, the less chance that these conditions are met; therefore, in table 2 the sediment yields based on less than 3 years of sediment record are regarded as less reliable than the others.

Other major factors affecting the relation of sediment concentration to water discharge are farming practices, land use, and reservoirs. In table 2 the sediment yields are shown separately for periods of different effects of major reservoirs; minor reservoirs and farm ponds were not considered. Because of changes in farming practices and land use, where the period of streamflow record is much longer than the period of sediment record, the calculated sediment yield is not an estimate of the actual yield for the period of streamflow record. Instead, it is an estimate of the average sediment yield that would have occurred for that period of sediment record if the precipitation and runoff had been as they were during the period of streamflow record.



EXPLANATION

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Suspended-sediment sampling site

Index number gives location of station listed in tables 1 and 2

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Basin boundary

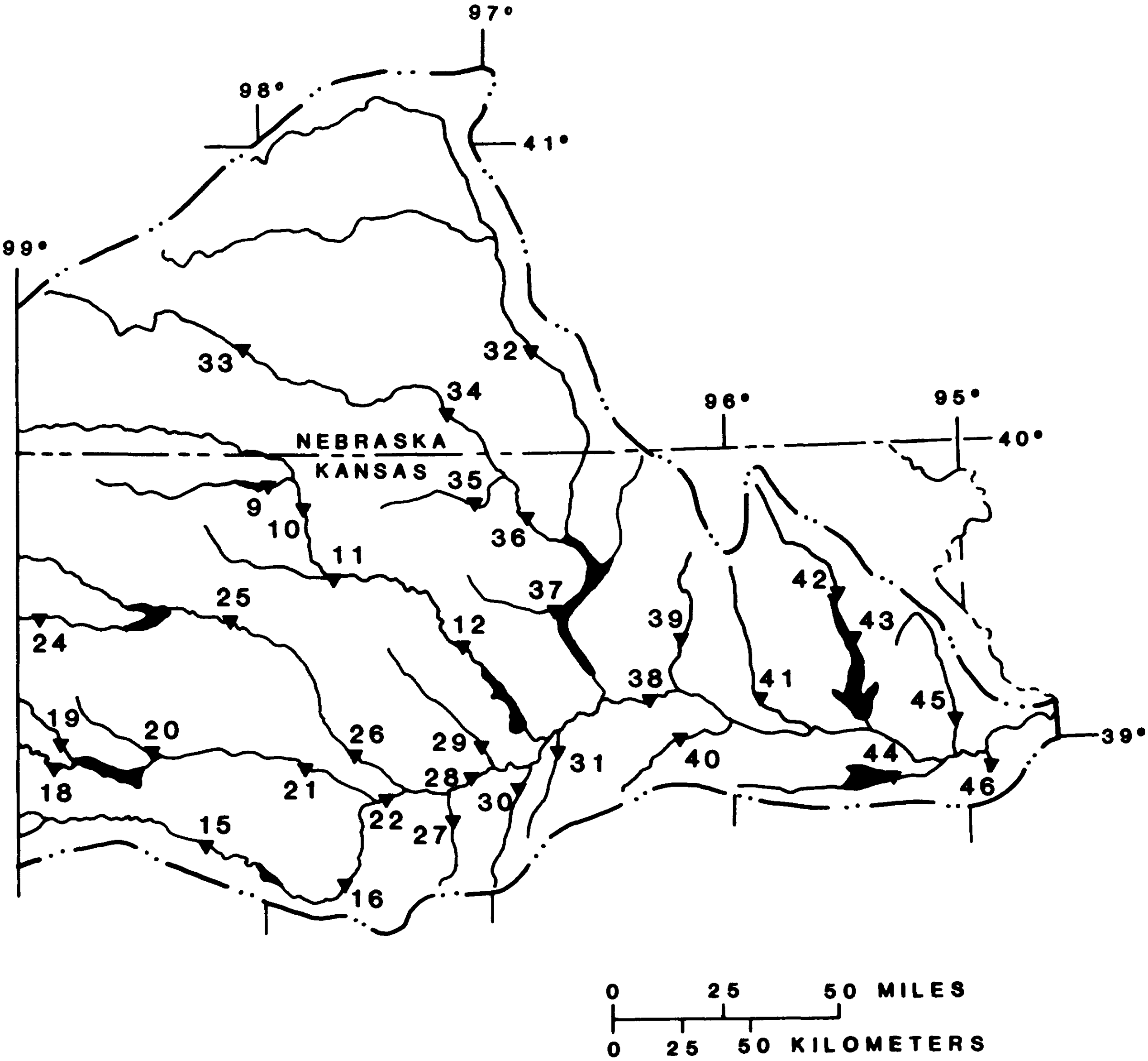


Figure 2.--Locations of suspended-sediment sampling sites.

Table 1.--Suspended-sediment data, by water year, for daily sampling sites

Station number	Index number (figure 2)	Station name	Water year	Contributing drainage area, in square miles (for sediment)	Suspended-sediment load (tons)	Suspended-sediment yield (tons per square mile)	Remarks
06845000	3	Sappa Creek near Oberlin, Kans.	1963	900	11,674	13	------------------------
			1964	900	8,794	9.8	
			1968	900	9,271	10	
			1969	900	6,882	7.6	
06845200	4	Sappa Creek near Beaver City, Nebr.	1948	1,500	182,200	120	------------------------
			1949	1,500	466,900	310	
			1950	1,500	376,100	250	
			1951	1,500	488,616	330	
			1952	1,500	103,192	69	
06846500	5	Beaver Creek at Cedar Bluffs, Kans.	1962	1,324	100,679	76	------------------------
			1963	1,324	14,734	11	
			1964	1,324	24,377	18	
			1965	1,324	123,542	93	
			1966	1,324	27,084	20	
			1968	1,324	7,409	5.6	
			1969	1,324	7,552	5.7	
06847000	6	Beaver Creek near Beaver City, Nebr.	1951	2,060	304,787	150	------------------------
			1952	2,060	51,386	25	
			1953	2,060	9,865	4.8	
06847500	7	Sappa Creek near Stamford, Nebr.	1948	3,840	264,000	69	------------------------
			1949	3,840	794,100	210	
			1950	3,840	498,600	130	
			1951	3,840	772,195	200	
			1953	3,840	161,020	42	
06848000	8	Prairie Dog Creek at Norton, Kans.	1948	721	113,700	160	Before construction of Norton Reservoir
			1949	721	321,000	450	
			1950	721	410,300	570	
			1951	721	671,472	930	
			1952	721	38,192	50	
06854000	9	White Rock Creek at Lovewell, Kans.	1951	345	1,274,120	3,690	Before construction of Lovewell Reservoir
			1952	345	193,778	560	
			1953	345	138,870	400	
06854500	10	Republican River at Scandia, Kans.	1968	1,555	353,287	230	After construction of Harlan County Lake and Lovewell Reservoir
			1969	1,555	630,638	410	

Table 1.--Suspended-sediment data, by water year, for daily sampling sites--Continued

Station number	Index number (figure 2)	Station name	Water year	Contributing drainage area, in square miles (for sediment)	Suspended-sediment load (tons)	Suspended-sediment yield (tons per square mile)	Remarks
06856600	12	Republican River at Clay Center, Kans.	1958	3,167	2,105,048	660	After completion of Harlan County Lake and Lovewell Reservoir.
			1959	3,167	941,835	300	Do.
			1960	3,167	2,576,636	810	Do.
			1961	3,167	1,715,375	540	Do.
			1962	3,167	1,871,846	590	Do.
			1963	3,167	493,264	160	Do.
			1969	3,167	1,347,227	425	Do.
			1970	3,167	791,448	250	Do.
			1971	3,167	1,038,051	328	Do.
			1973	3,167	2,107,526	665	Do.
			1974	3,167	1,207,497	381	Do.
			1975	3,167	660,671	209	Do.
			1976	3,167	273,170	86	Do.
			1977	3,167	889,054	281	Do.
			1978	3,167	662,080	209	Do.
			1979	3,167	1,382,923	437	Do.
			1980	3,167	722,017	328	Do.
06862500	13	Smoky Hill River near Ellis, Kans.	1948	5,630	128,300	23	-----------------------
			1949	5,630	523,800	93	
			1950	5,630	1,180,000	210	
06863300	14	Big Creek near Ogallah, Kans.	1956	297	5,477	18	-----------------------
			1957	297	619,010	2,100	
			1958	297	41,154	140	
			1959	297	2,553	9	
			1962	297	8,121	27	
06866900	17	Saline River near Wakeeney, Kans.	1956	696	85,584	120	-----------------------
			1957	696	446,263	640	
			1958	696	70,315	100	
			1959	696	15,260	20	
06867000	18	Saline River near Russell, Kans.	1947	1,502	738,700	490	-----------------------
			1948	1,502	276,000	180	
			1949	1,502	226,900	150	
			1950	1,502	971,100	650	
			1951	1,502	2,306,254	1,500	
06867500	19	Paradise Creek near Paradise, Kans.	1948	212	95,200	450	-----------------------
			1949	212	29,080	140	
			1950	212	285,600	1,400	
			1951	212	570,974	2,700	

Table 1.--Suspended-sediment data, by water year, for daily sampling sites--Continued

Station number	Index number (figure 2)	Station name	Water year	Contributing drainage area, in square miles (for sediment)	Suspended-sediment load (tons)	Suspended-sediment yield (tons per square mile)	Remarks
06868500	20	Wolf Creek near Sylvan Grove, Kans.	1948	261	66,300	250	- - - - - - - - - - - - - - - - - - - -
			1949	261	57,250	220	
			1950	261	220,200	840	
06869500	21	Saline River at Tescott, Kans.	1960	2,820	1,196,063	420	Before construction of Wilson Lake.
			1961	2,820	1,377,004	490	During construction of Wilson Lake.
			1962	2,820	1,044,650	370	Do.
			1963	2,820	61,161	20	Do.
			1964	2,820	80,212	30	Do.
			1965	903	133,753	150	After construction of Wilson Lake.
			1966	903	17,215	20	Do.
			1967	903	246,357	270	Do.
			1968	903	29,144	30	Do.
			1969	903	113,367	120	Do.
06870200	22	Smoky Hill River at New Cambria, Kans.	1963	3,873	140,544	36	Kanopolis Lake complete; Wilson Lake under construction.
			1964	3,873	153,255	40	Do.
			1965	1,956	794,392	410	Wilson and Kanopolis Lakes complete.
			1966	1,956	146,643	70	Do.
			1967	1,956	1,030,535	530	Do.
			1968	1,956	97,848	50	Do.
06871800	23	North Fk. Solomon River at Kirwin, Kans.	1951	1,360	2,042,232	1,500	Before construction of Kirwin Reservoir.
06873500	24	South Fk. Solomon River at Alton, Kans.	1947	1,720	713,100	410	Before construction of Webster Reservoir.
			1948	1,720	395,300	230	Do.
			1949	1,720	322,600	190	Do.
			1950	1,720	992,300	580	Do.
06876000	25	Solomon River at Beloit, Kans.	1949	5,530	2,307,000	420	Before construction of Kirwin, Webster, and Waconda Lakes.
			1950	5,530	4,160,000	750	Do.
			1951	5,530	7,723,241	1,400	Do.
			1952	5,530	449,665	80	Do.

Table 1.--Suspended-sediment data, by water year, for daily sampling sites--Continued

Station number	Index number (figure 2)	Station name	Water year	Contributing drainage area, in square miles (for sediment)	Suspended-sediment load (tons)	Suspended-sediment yield (tons per square mile)	Remarks
06877600	28	Smoky Hill River at Enterprise, Kans.	1958	8,886	4,454,215	500	After completion of Kanopolis, Cedar Bluff, Webster, and Kirwin Reservoirs.
			1959	8,886	2,514,001	280	Do.
			1960	8,886	6,256,714	700	Do.
			1961	8,886	5,963,405	670	During construction of Wilson and Waconda Lakes.
			1962	8,886	6,116,606	690	Do.
			1963	8,886	884,040	99	Do.
			1964	8,886	400,393	45	Do.
			1965	8,886	2,705,261	300	Do.
			1966	8,886	499,279	56	Do.
			1967	8,886	3,997,638	450	Do.
			1968	8,886	400,556	45	Do.
			1969	8,886	2,234,247	250	Do.
			1970	4,410	474,878	110	After completion of all reservoirs.
			1971	4,410	2,204,209	500	Do.
			1972	4,410	740,437	170	Do.
			1973	4,410	4,382,806	990	Do.
			1974	4,410	3,378,586	770	Do.
			1975	4,410	953,618	220	Do.
06881000	32	Big Blue River near Crete, Nebr.	1962	2,716	535,938	200	----------------------
06883000	33	Little Blue River near DeWeese, Nebr.	1957	979	496,041	510	----------------------
			1958	979	269,163	270	
			1959	979	602,488	620	
			1960	979	908,077	930	
			1961	979	288,699	290	

Table 1.--Suspended-sediment data, by water year, for daily sampling sites--Continued

Station number	Index number (figure 2)	Station name	Water year	Contributing drainage area, in square miles (for sediment)	Suspended-sediment load (tons)	Suspended-sediment yield (tons per square mile)	Remarks
06887500	38	Kansas River at Wamego, Kans.	1958	23,531	17,364,456	740	During construction of Milford and Tuttle Creek Lakes.
			1959	23,531	12,761,489	540	Do.
			1960	23,531	19,778,532	840	Do.
			1961	23,531	13,261,536	560	Do.
			1962	23,531	14,579,723	620	Do.
			1963	13,903	1,910,290	140	After construction of Tuttle Creek Lake.
			1964	13,903	1,726,040	120	Do.
			1965	11,986	6,070,546	510	After construction of Wilson Lake.
			1966	11,986	1,062,810	89	Do.
			1967	8,539	5,876,412	690	After construction of Milford Lake.
			1968	8,539	1,727,726	200	Do.
			1969	8,539	5,759,848	680	Do.
			1970	8,539	1,104,402	130	Do.
			1971	8,539	4,188,934	490	Do.
			1972	8,539	1,222,227	140	Do.
			1973	8,539	10,339,137	1,210	Do.
			1974	8,539	14,594,442	1,710	Do.
			1975	8,539	1,984,204	230	Do.
06888000	39	Vermillion Creek near Wamego, Kans.	1959	243	446,324	1,800	-----------------------
			1960	243	360,152	1,500	
			1961	243	313,901	1,300	
			1962	243	483,418	2,000	
			1963	243	77,784	320	

Table 2.--Suspended-sediment yields for periodic sampling sites

Station number	Index number (figure 2)	Station name	Period of sediment record (water years)	Period of streamflow record (water years)	Suspended-sediment yield (tons per square mile)	Contributing drainage area, in square miles (for sediment)	Remarks
06827000	1	South Fork Republican River near Colo.-Kans. State line	1946-50	1946-50	25	1,860	Before construction of Bonny Reservoir.
06834000	2	Frenchman Creek at Palisade, Nebr.	1963-66,68 1971-74	1952-79	78	950	- -
06845000	3	Sappa Creek near Oberlin, Kans.	1962-71	1930-72	28	900	- -
06847500	7	Sappa Creek near Stamford, Nebr.	1948-53	1947-78	50	3,280	- -
06848000	8	Prairie Dog Creek at Norton, Kans.	1948-52, 1958	1945-60	350	721	Before construction of Norton Reservoir.
06854000	9	White Rock Creek at Lovewell, Kans.	1949-53	1947-54	1,800	345	Before construction of Lovewell Reservoir.
06856000	11	Republican River at Concordia, Kans.	1966-68	1953-77	320	2,185	After completion of Harlan County Lake; sediment record after completion of Lovewell Reservoir.
06856600	12	Republican River at Clay Center, Kans.	1949-51 1957-61,63	1949-52 1957-63	910 510	17,042 3,167	During construction of Harlan County Lake. After construction of Harlan County Lake and Lovewell Reservoir.
06862500	13	Smoky Hill River near Ellis, Kans.	1946-50	1943-50	67	5,630	Before construction of Cedar Bluff Reservoir.
06863300	14	Big Creek near Ogallah, Kans.	1956-58	1956-58	240	297	- -
06864500	15	Smoky Hill River at Ellsworth, Kans.	1951-67	1951-77	420	2,050	After construction of Cedar Bluff Reservoir.
06866000	16	Smoky Hill River at Lindsborg, Kans.	1952-63	1952-63	670	253	After construction of Kanopolis Lake
06866900	17	Saline River near Wakeeney, Kans.	1956-58	1956-66	170	696	- -
06867000	18	Saline River near Russell, Kans.	1948-75	1946-77	200	1,502	- -
06867500	19	Paradise Creek near Paradise, Kans.	1948-51	1947-53, 1964-74	470	212	- -
06868500	20	Wolf Creek near Sylvan Grove, Kans.	1948-51	1946-53	990	261	- -

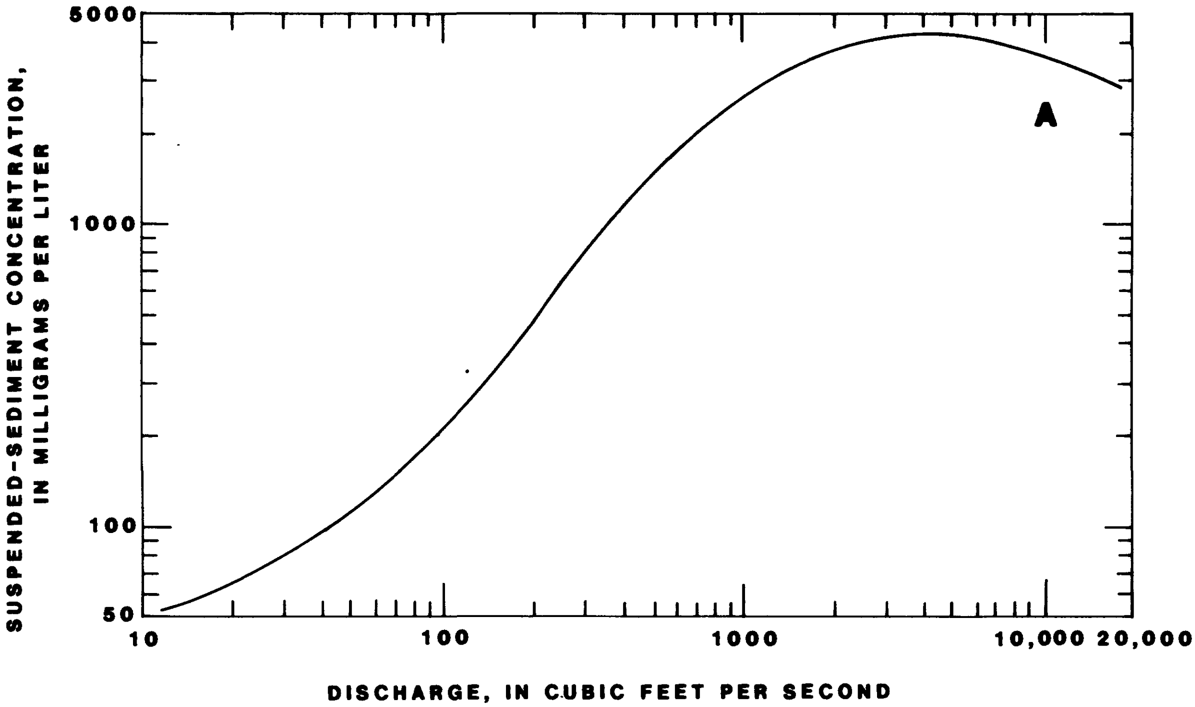
Table 2.--Suspended-sediment yields for periodic sampling sites--Continued

Station number	Index number (figure 2)	Station name	Period of sediment record (water years)	Period of streamflow record (water years)	Suspended-sediment yield (tons per square mile)	Contributing drainage area, in square miles (for sediment)	Remarks
06869500	21	Saline River at Tescott, Kans.	1957-60	1920-60	230	2,820	Before construction of Wilson Lake.
			1961,63,64	1961-64	280	2,820	During construction of Wilson Lake.
			1965,68, 1971-77	1965-77	150	903	After construction of Wilson Lake.
06871800	23	North Fork Solomon River at Kirwin, Kans.	1947-52	1920-52	410	1,367	Before construction of Kirwin Reservoir.
06873500	24	South Fork Solomon River at Alton, Kans.	1948-52	1920-52	300	1,720	Before construction of Webster Reservoir.
06876000	25	Solomon River at Beloit, Kans.	1948-51	1930-51	400	5,530	Before construction of Kirwin and Webster Reservoirs.
			1960,61	1960-65	230[1/]	3,013	After construction of Kirwin and Webster Reservoirs.
06876900	26	Solomon River at Niles, Kans.	1957-63	1957-63	340	4,253	Kirwin and Webster Reservoirs complete; Waconda Lake not started.
			1964,65	1964-67	230[1/]	4,253	During construction of Waconda Lake.
			1968,71-77	1968-77	360	1,694	After Waconda Lake completed.
06877500	27	Turkey Creek near Abilene, Kans.	1958-65,77	1959-65	910	143	- -
06877600	28	Smoky Hill River at Enterprise, Kans.	1957-60	1957-60	460	8,886	Kanopolis, Kirwin, and Webster Reservoirs completed.
			1961,63-65, 1968	1961-68	300	8,886	During construction of Wilson and Waconda Lakes.
			1971-77	1971-77	360	4,410	After construction of all major reservoirs.
06878000	29	Chapman Creek near Chapman, Kans.	1970-76	1955-77	250	300	- -
06878500	30	Lyon Creek near Woodbine, Kans.	1964-70	1956-74	760	230	- -
06879200	31	Clark Creek near Junction City, Kans.	1958-62	1958-65	730	200	- -
06884000	34	Little Blue River near Fairbury, Nebr.	1951-57, 1961	1911-15, 1930-79	560	2,350	- -
06884200	35	Mill Creek at Washington, Kans.	1970-76	1960-77	320	344	- -
06884400	36	Little Blue River near Barnes, Kans.	1960-71	1959-77	380	3,324	- -

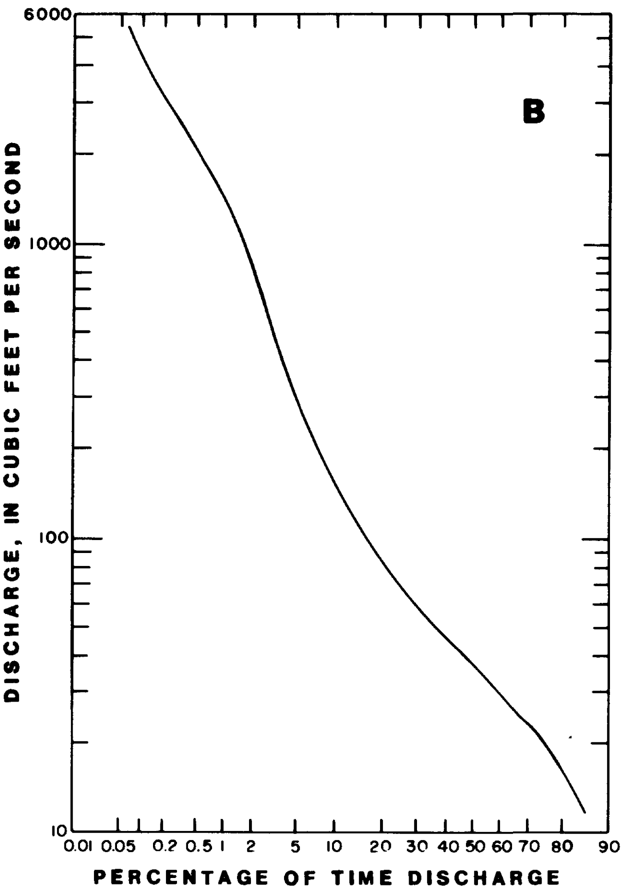
Table 2.--Suspended-sediment yields for periodic sampling sites--Continued

Station number	Index number (figure 2)	Station name	Period of sediment record (water years)	Period of streamflow record (water years)	Suspended-sediment yield (tons per square mile per year)	Contributing drainage area, in square miles (for sediment)	Remarks
06886000	37	Big Blue River at Randolph, Kans.	1943-59	1919-60	610	9,100	Before construction of Tuttle Creek Lake
06887500	38	Kansas River at Wamego, Kans.	1957-65	1957-67	470	23,531	Kanopolis, Webster, Kirwin, Lovewell, and Harlan County Reservoirs complete; Milford, Tuttle Creek, Waconda, and Wilson Lakes under construction.
			1968-77	1968-77	790	8,539	All major reservoirs completed.
06888000	39	Vermillion Creek near Wamego, Kans.	1958-61,63, 1971	1937-71	1,500	243	------------------------
06888500	40	Mill Creek near Paxico, Kans.	1970-76	1955-77	410	316	------------------------
06889200	41	Soldier Creek near Delia, Kans.	1963-70	1959-77	1,400	157	------------------------
06890100	42	Delaware River near Muscotah, Kans.	1969-77	1970-77	1,400	431	------------------------
06890500	43	Delaware River at Valley Falls, Kans.	1949-54	1923-62	1,600	922	------------------------
06891500	44	Wakarusa River near Lawrence, Kans.	1963-70	1930-72	470	425	------------------------
06892000	45	Stranger Creek near Tonganoxie, Kans.	1965-71	1930-77	1,700	406	------------------------
06892490	46	Cedar Creek near Cedar Junction, Kans.	1968	1966-68	290 1/	38.9	------------------------

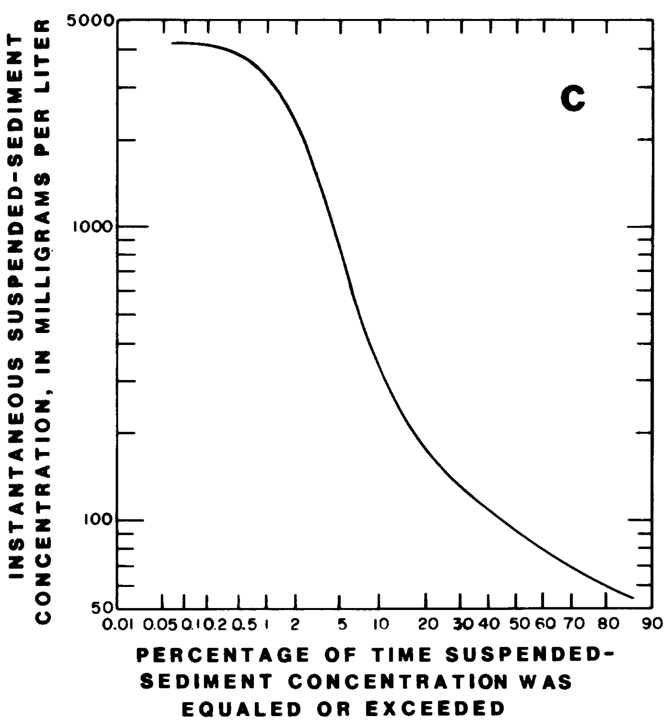
1/ Based on less than 3 years of sediment sampling; possibly less reliable than other sediment yield data.



A. Sediment-rating curve from periodic sampling during 1958-62.



B. Flow-duration curve for 1958-65.



C. Sediment concentration-duration curve for 1958-65, derived from parts A and B.

Figure 3.--Discharge and sediment-concentration relations, Clark Creek near Junction City, Kans. (06879200).

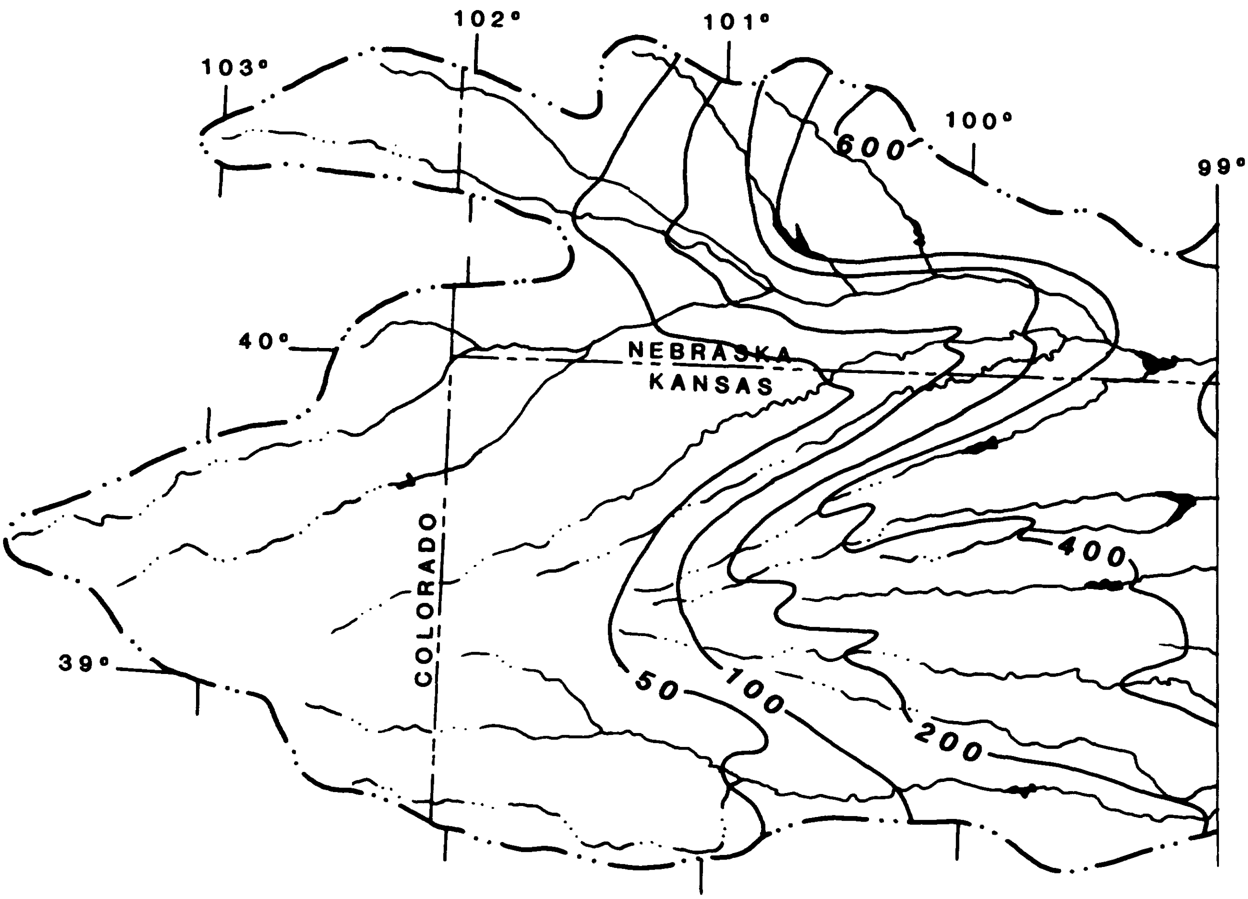
No attempt has been made to include bedload in the sediment load computations. Based on other studies in Kansas (Mundorff and Scott, 1964; Albert, 1969; Osterkamp, 1977) and adjacent States, however, it is inferred that sustained total sediment loads in the regulated streams of the Kansas River basin are rarely more than 10 percent greater than the suspended load. An exception is the main-stem Kansas River at Wamego, Kans.(06887500), which had a bedload that was about 11 percent of the total sediment load during 1957-65 (Albert, 1969, p. 3-4). Unless otherwise specified, all values and discussion of sediment discharge given in this report refer to the suspended load. The bedloads of regulated reaches of the Solomon, Saline, and Smoky Hill Rivers normally account for less than 3 percent of the total sediment load.

Sediment Yields

Results of the sediment-yield computations are summarized in table 2. Annual sediment loads and yields, by water year, are given in table 1 for sites where daily sediment records are available. Data at some periodic sampling sites were collected before, during, and after construction of upstream reservoirs and, to the extent practical, have been separated into two or more time periods to represent the differing conditions (table 2). For some sampling sites, particularly on the Kansas and Solomon Rivers, sediment discharges have been affected by a complex series of changes resulting from varying stages of reservoir construction. In these instances, the possible effects of one reservoir as opposed to another may be impossible to distinguish, and the data have been divided only into general, well-defined time periods.

Using the computed values of sediment discharge for sampling sites unaffected by construction activities (tables 1 and 2), an interpretation of areal variations in sediment yield for the Kansas River basin, under typical agrarian conditions of recent decades, is presented in figure 4. Although the zones of this map are based on sediment data, the positions of the lines separating the zones are defined largely by areal variations in topography, geology, and climate. A similar map for the Arkansas River basin of Kansas and an explanation of the manner by which these other variables are used to augment the sediment-yield values are presented by Osterkamp (1977).

Several general features or trends can be identified on the sediment-yield map that are related to conditions in the physiographic areas shown in figure 5. These general features include: (1) Relatively small sediment yields [less than 200 (tons/mi^2)/yr] in areas of little land-surface slope, mainly flood plains and the High Plains of eastern Colorado, southwestern Nebraska, and northwestern Kansas; (2) moderate sediment yields [200 to 600 (tons/mi^2)/yr] in areas where local conditions of land slope and runoff largely determine rates of erosion, such as the Dissected High Plains and parts of the Flint Hills Upland; and (3) relatively large sediment yields [600 to 2,000 (tons/mi^2)/yr] in areas where geologic conditions induce large rates of erosion, such as the Dissected Till Plains and parts of the Flint Hills Upland. The largest sediment yields in the basin occur in the Dissected Till Plains of northeastern Kansas and southeastern Nebraska where streams easily incise the poorly consolidated glacial deposits, thus producing relatively large values of average basin slope.



EXPLANATION

—— 400 ——
Line of inferred sediment yield
Intervals are 50, 100, 200, and 400 tons per square mile per year

—— · · ——
Basin boundary

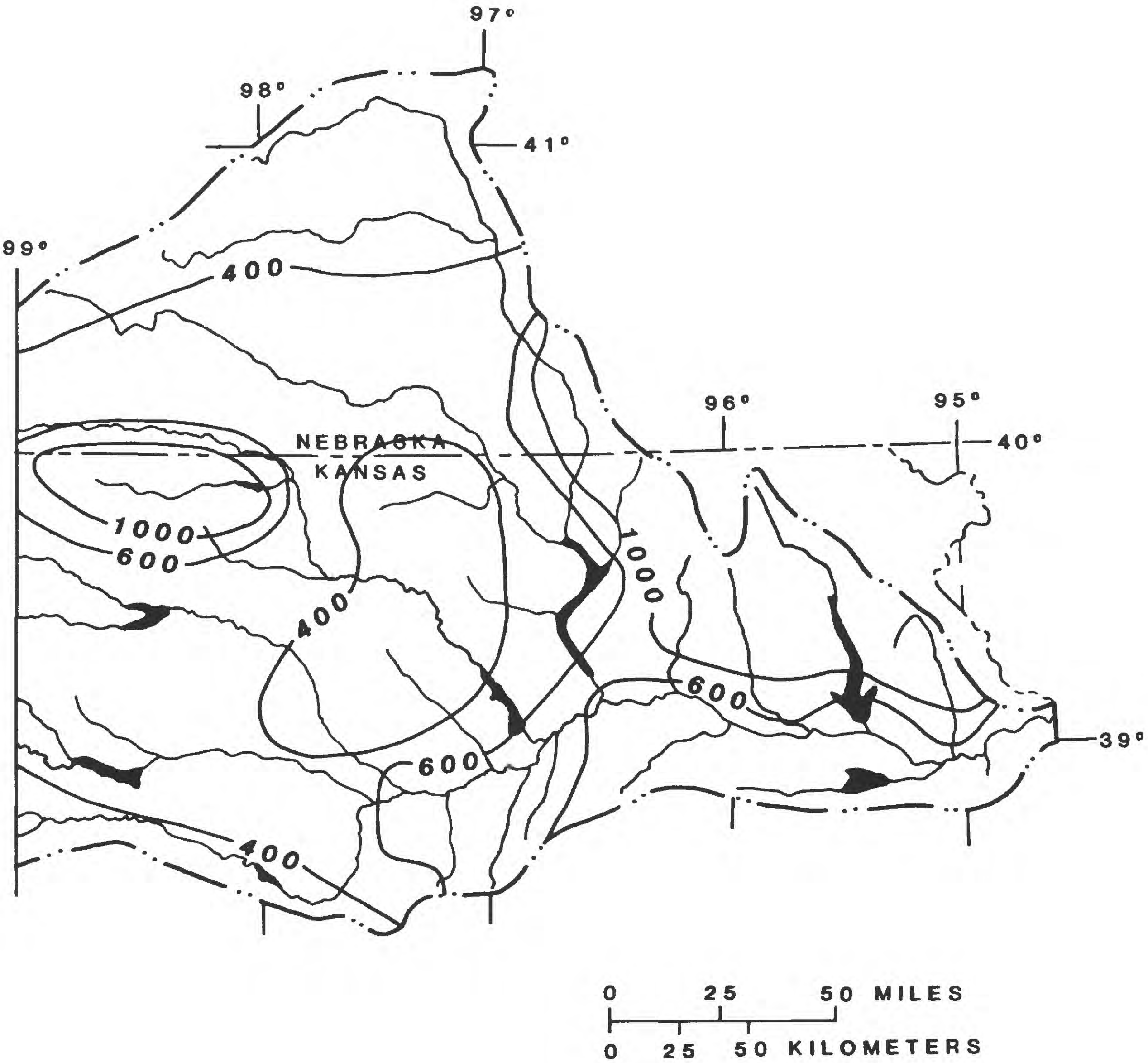


Figure 4.--Sediment yields under unregulated agrarian conditions in Kansas River basin.

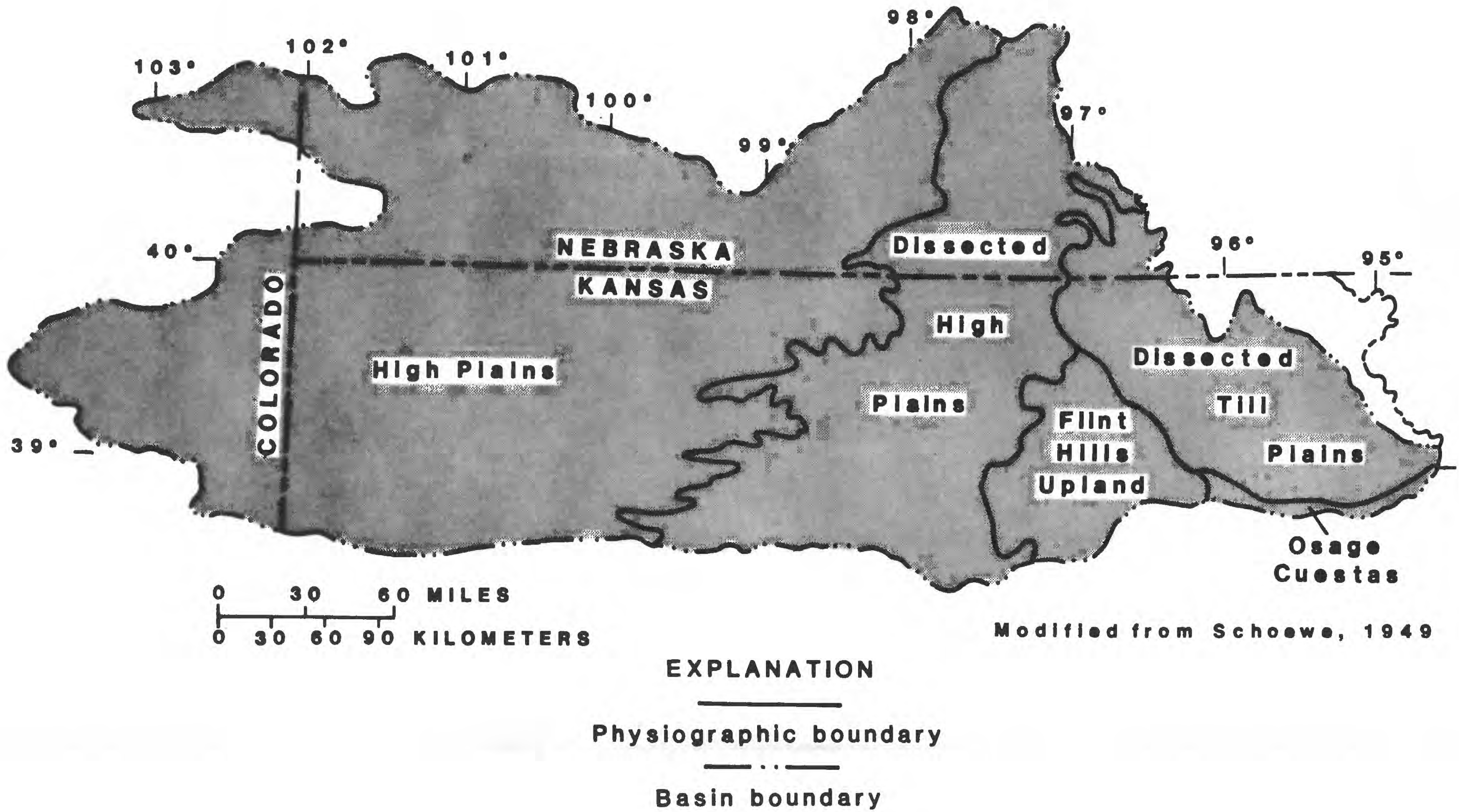


Figure 5.--Physiographic map of Kansas River basin.

Other areas where sediment yields exceed 600 (tons/mi^2)/yr (fig. 4) include parts of north-central Kansas and south-central Nebraska, where soft limestone, shale, and loess deposits are susceptible to erosion, and parts of the Flint Hills Upland, where outcroppings of evaporite deposits yield large amounts of fine-grained sediment. An area north of Salina, Kans., which has smaller sediment yields than the surrounding areas, is dominated by sandstone outcrops of the Cretaceous Dakota Formation. The sandy soils of this area apparently are more resistant to erosion than the finer grained soils that are typical in much of the eastern one-half of the basin.

Computed average sediment yields for various subbasins for time intervals during which upstream reservoirs were either closed or under construction (table 2) are shown in figures 6 and 7 for comparison with the inferred sediment yields from figure 4. All computations for regulated streams were made assuming a 100-percent trap efficiency for sediment in the upstream reservoirs (table 2). After the reservoirs were closed, only the downstream contributing areas were used to compute yields. The computed average sediment yields shown in figures 6 and 7 provide a comparison of sediment-yield conditions for periods of dam construction or streamflow regulation with unregulated conditions for various subbasins.

Because the calculated yields of figures 6 and 7 account for variables other than regulation of streamflow, such as land-use and hydrologic conditions for the period of consideration, the significance of these data comparisons is uncertain. Several inferences and observations do seem warranted, however, for some of the results illustrated in figures 6 and 7 and are summarized as follows:

Figure 6.--1. Since 1965, calculated sediment yields in the Saline River basin downstream from Wilson Lake have been anomalously small. Possible causes are small runoff rates and terracing of farmlands.

2. Sediment yields since 1971 in the Smoky Hill River basin downstream from all major reservoirs have been consistent with yields described in figure 4.

3. Smaller calculated sediment yields during 1961-68 than during 1957-60 for the Smoky Hill River basin are possibly the result of large runoff rates during the earlier period.

Figure 7.--1. The computed sediment yield for Republican River at Clay Center, 1949-52, probably is much larger than the long-term average owing to historic flooding and sediment transport during 1951.

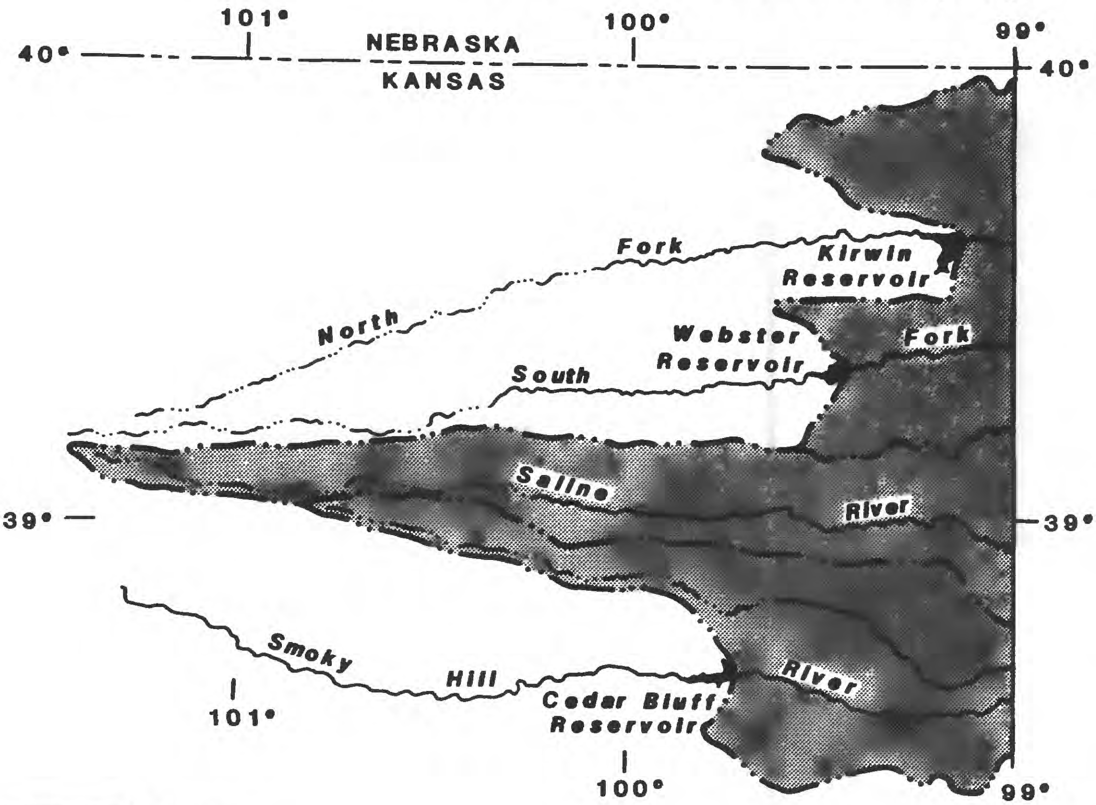
2. Since 1968, sediment yield for the Kansas River basin at Wamego, after closing of all major reservoirs, has been larger than would be inferred from figure 4.

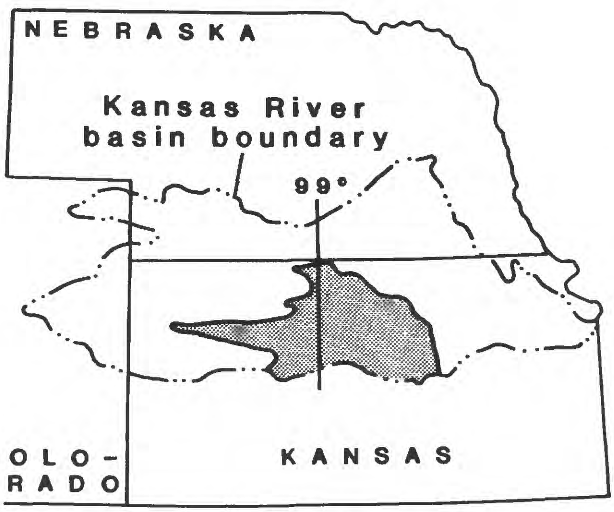
Smoky Hill River at Ellsworth
(06864500)

1951-77 (420 tons per square mile per year) after closing of Cedar Bluff Reservoir

Solomon River at Beloit
(06876000)

1960-65 (230 tons per square mile per year) after closing of Kirwin and Webster Reservoirs, and during construction of Waconda Lake (data based on short period of sampling)





INDEX MAP

Saline River at Tescott
(06869500)

1920-60 (230 tons per square mile per year) before construction of Wilson Lake

1961-64 (280 tons per square mile per year) during construction of Wilson Lake

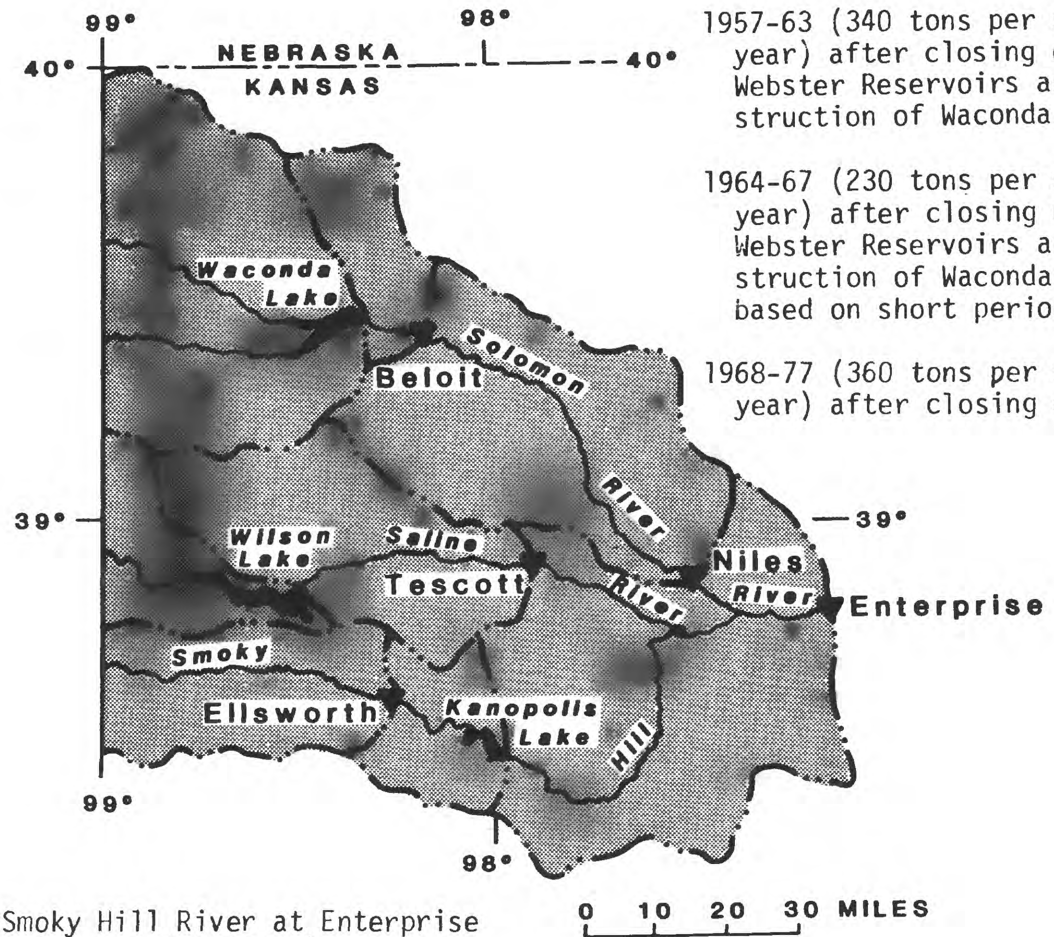
1966-77 (150 tons per square mile per year) after closing of Wilson Lake

Solomon River at Niles
(06876900)

1957-63 (340 tons per square mile per year) after closing of Kirwin and Webster Reservoirs and before construction of Waconda Lake

1964-67 (230 tons per square mile per year) after closing of Kirwin and Webster Reservoirs and during construction of Waconda Lake (data based on short period of sampling)

1968-77 (360 tons per square mile per year) after closing of Waconda Lake



Smoky Hill River at Enterprise
(06877600)

1957-60 (460 tons per square mile per year) after closing of Kanopolis, Webster, and Kirwin Reservoirs, and before construction of Wilson Lake

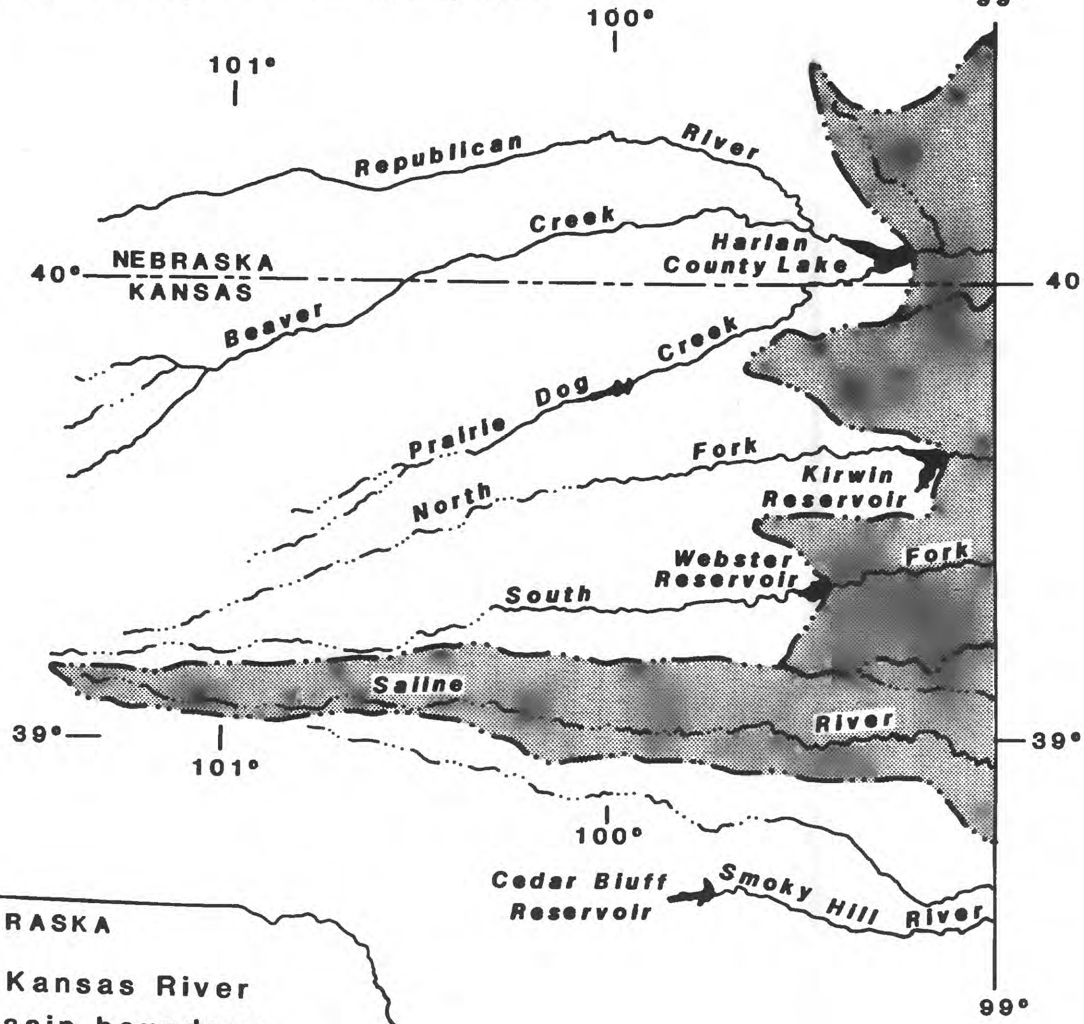
1961-68 (300 tons per square mile per year) after closing of Kanopolis, Webster, and Kirwin Reservoirs, and during construction of Waconda and Wilson Lakes

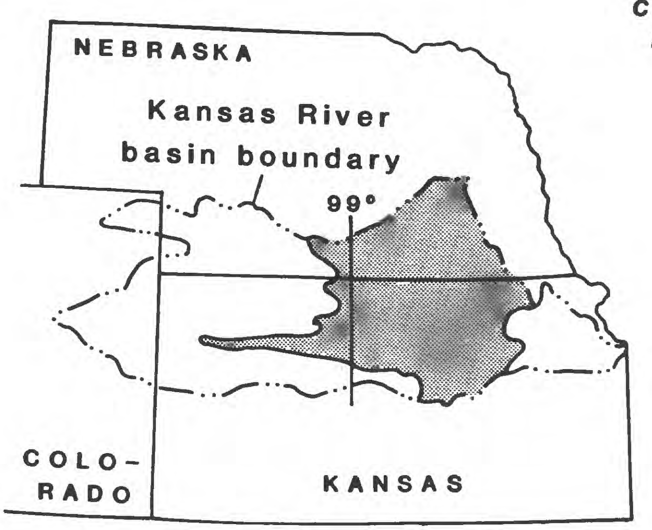
1971-77 (360 tons per square mile per year) after closing of all major reservoirs

Figure 6.--Sediment yields from parts of Smoky Hill River basin upstream from Enterprise, Kans.

Republican River at Concordia
(06856000)

1953-77 (320 tons per square mile per year)
after closing of Harlan County Lake





INDEX MAP

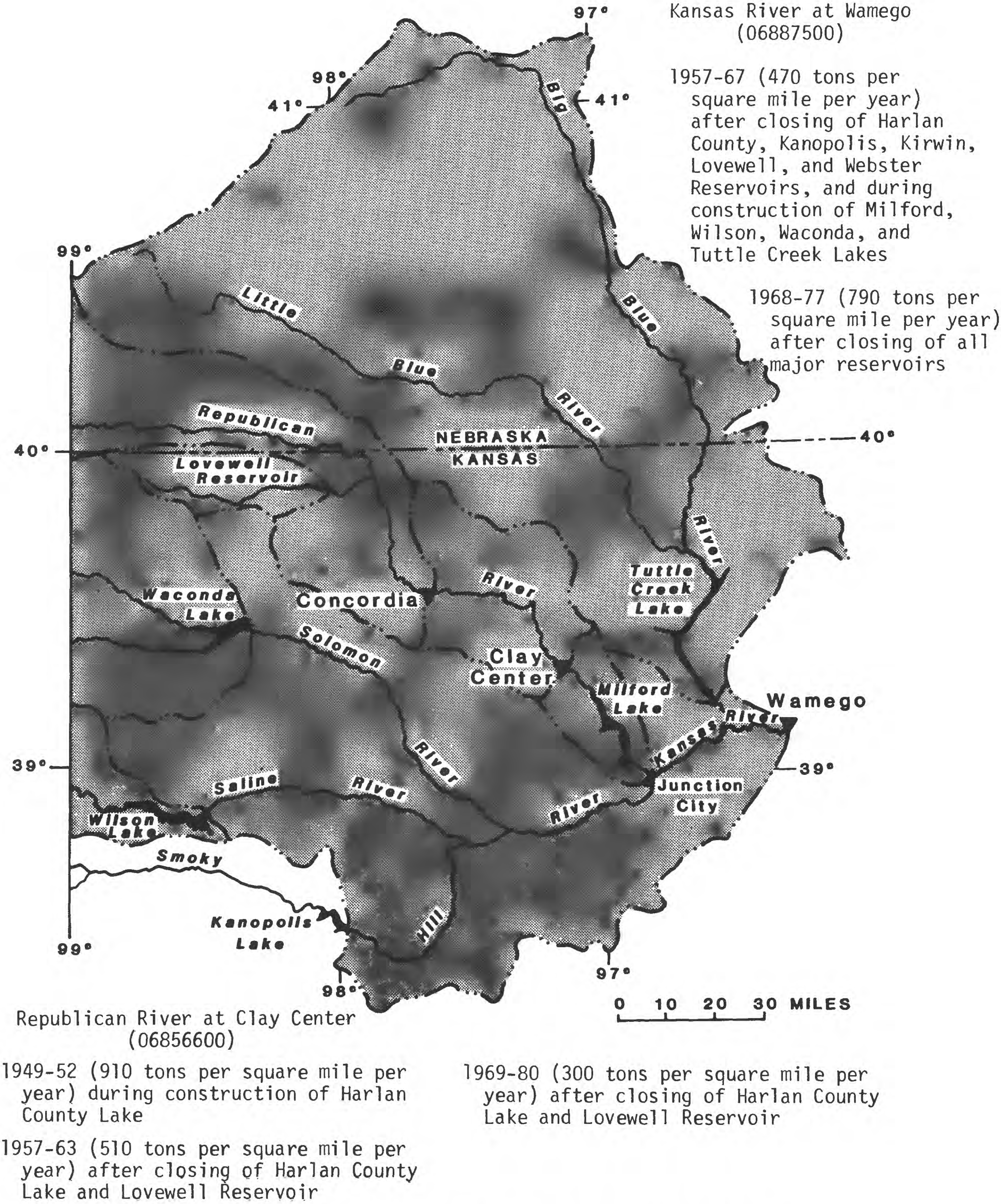


Figure 7.--Sediment yields from parts of Kansas River basin upstream from Wamego, Kans.

General observations from tables 1 and 2 and figures 4, 6, and 7 are the following:

1. Sediment yields are dependent on runoff rates for the period of record, and therefore meaningful comparisons between different periods for the same drainage area are difficult to make.

2. The effects of streamflow regulation by major reservoirs of the Kansas River basin on sediment yields either have been of minor consequence or have been difficult to recognize owing to other variables that affect fluvial-sediment discharge.

Temporal Changes in Sediment Yields

The preceding observations and inferences can be augmented by considering changes of the characteristics of water and sediment discharge with time. Data (table 1) are adequate to permit relatively detailed analyses of three representative sites for which daily sediment records are available. The sites and periods of sediment record (as water years, October 1 to September 30) are: Saline River at Tescott, Kans. (06869500), 1960-69; Smoky Hill River at Enterprise, Kans. (06877600), 1958-75; and Kansas River at Wamego, Kans. (06887500), 1958-75. For each of the three sites, a three-part figure provides (A) a graph comparing mean annual water discharge ($\bar{Q}_A$), mean annual suspended-sediment concentration (S_{CM}), and annual suspended-sediment discharge ($\bar{Q}_{SA}$), (B) a power-function relation between annual sediment yield per unit area and mean annual discharge, and (C) a plot of the deviation, by water year, of annual sediment yields from the power-function relation of part B.

The effect of impoundment and streamflow regulation can be studied by comparing changes relative to water discharge, to suspended-sediment concentrations, and to annual discharges of suspended sediment (part A). A power function (part B) relating water and sediment yield is provided to minimize the effect that changes in water discharge have on the study of changes in sediment yield and to indicate possible effects of imposed basin or channel changes. Deviations from the power-function relation, by year (part C), indicate the effect of imposed changes, such as reservoir construction.

Relations of water and sediment for the Saline River at Tescott, Kans., are shown in figure 8. Part A shows that during the period of record (1960-69), discharges of water ($\bar{Q}_A$) and sediment ($\bar{Q}_{SA}$) suffered substantial reduction but that suspended-sediment concentrations (S_{CM}) were approximately stable. The unusually long period of filling Wilson Lake's conservation pool, when only a low flow was released from the impoundment, resulted in lower than normal discharge at the Tescott station during 1965-69.

Substantial variation in the relation between annual sediment yield (per unit of contributing area) and mean annual discharge is shown in figure 8B. A representation of that variation with time (fig. 8C) shows a more consistent relation for 1960-64 followed by a large change during 1965 when Wilson Lake began storage. The increased sediment yield relative to water discharge from 1965 to 1969 is directly related to the reduction in contributing drainage area for sediment that no longer included the small-yield part upstream from Wilson Lake (fig. 4), as well as to the below-normal water discharge.

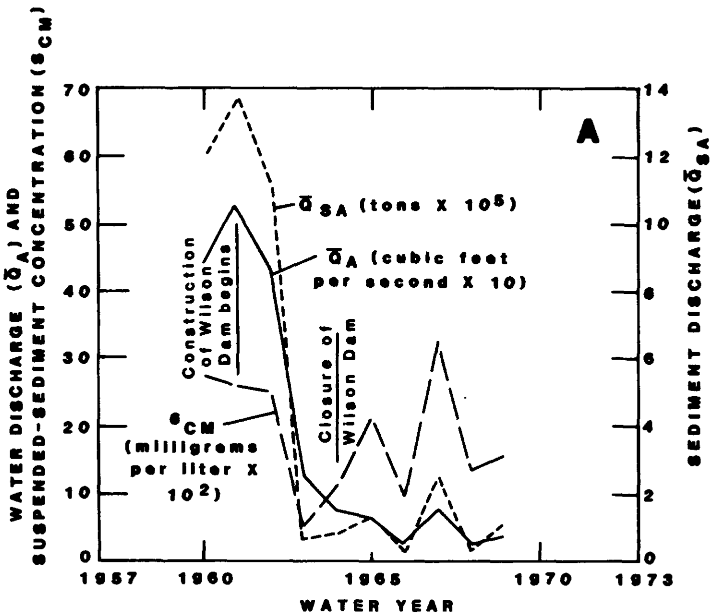
Comparisons of mean water discharge, suspended-sediment concentrations, and suspended-sediment discharges (unadjusted for contributing drainage area), for Smoky Hill River at Enterprise, Kans., are shown in figure 9A. Sediment discharges after 1968, when sediment was being trapped in both Wilson and Waconda Lakes, were substantially smaller than those before 1965. Sediment concentrations through the period of record seem to reflect closely the changes in runoff rates until the 1973 and 1974 water years, when concentrations remained small despite large discharges.

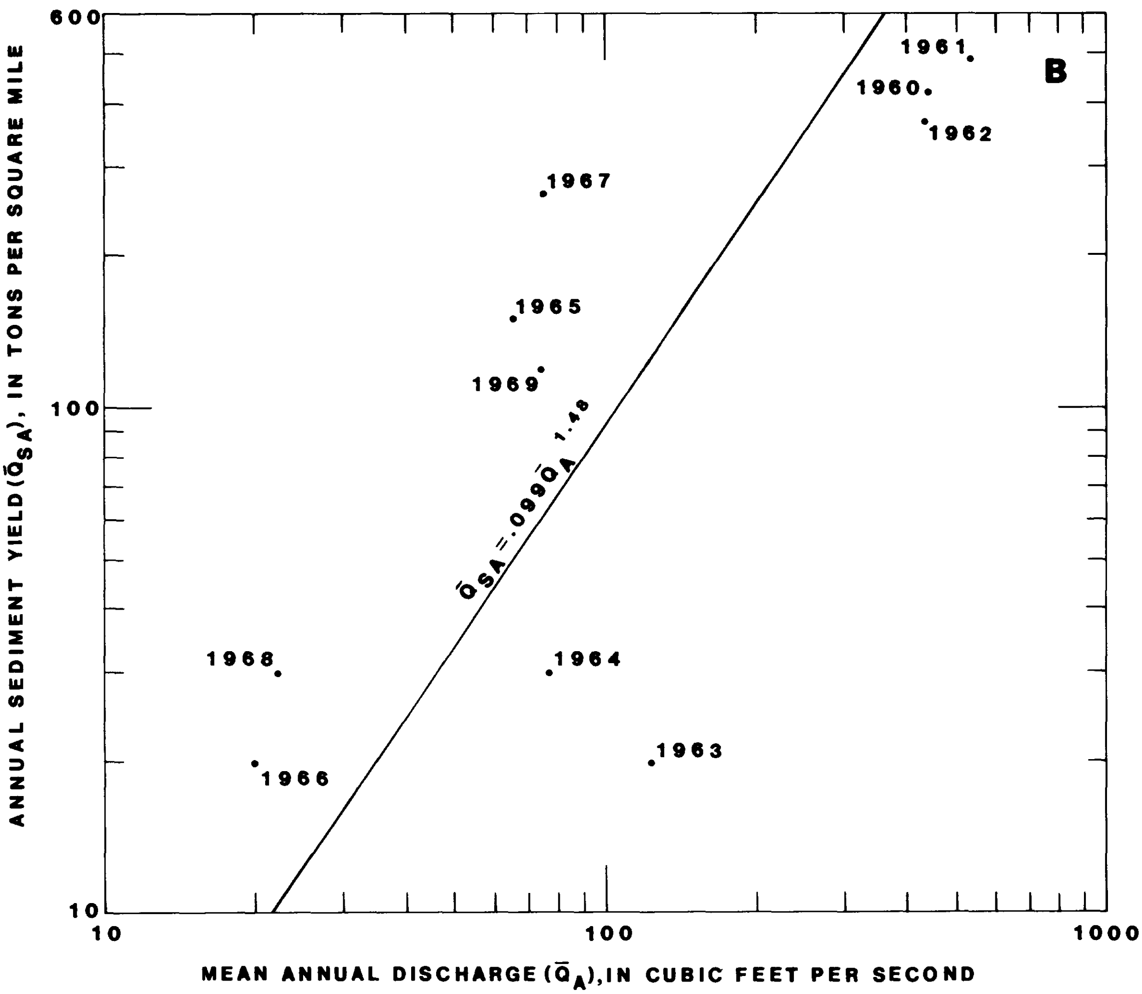
The trends for sediment yields in the Smoky Hill River (figs. 9B and 9C) are less pronounced than those indicated for the Saline River (fig. 8C). Following the initial construction activities for upstream reservoirs in the basin, sediment yields decreased for the Smoky Hill River basin. Two years after the closure of the dam at Waconda Lake, sediment yields (per unit area) increased relative to mean discharge.

The close relations among temporal changes of water and suspended-sediment discharges and suspended-sediment concentrations of the Kansas River at Wamego, Kans., are shown in figure 10A. The increasing storage of sediment in reservoirs is indicated by decreasing sediment concentrations relative to discharge, except during 1967 when most of the discharge originated in the areas of higher sediment yield downstream from the reservoirs.

The power-function relation of figure 10B shows a larger rate (larger exponent) of increasing sediment yield with increase of mean discharge for the Wamego site than for the gages at Tescott (fig. 8B) and Enterprise, Kans. (fig. 9B). The probable causes are general increases in mean land-surface slope and in silt-clay content of the soils from west to east across northern Kansas. These west-to-east changes presumably increase the soil susceptibility to erosion during wet periods and result in larger erosion rates downstream from Tescott and Enterprise. The same general west-east trend is illustrated in figure 4.

Time-ordered deviations, shown in figure 10C, of annual sediment yields from the power-function relation of figure 10B indicate similar, though less pronounced, trends to those indicated for the Tescott and Enterprise gage sites. The trend changes shown in figure 10C probably are poorly defined because streamflow at Wamego is regulated more complexly by several reservoirs than is the case at the Tescott or Enterprise sites.


A
WATER DISCHARGE ($\bar{Q}_A$) AND SUSPENDED-SEDIMENT CONCENTRATION (S_{CM})
SEDIMENT DISCHARGE ($\bar{Q}_{SA}$)
WATER YEAR
$\bar{Q}_{SA}$ (tons X 10^5)
$\bar{Q}_A$ (cubic feet per second X 10)
S_{CM} (milligrams per liter X 10^2)
Construction of Wilson Dam begins
Closure of Wilson Dam
0
10
20
30
40
50
60
70
2
4
6
8
10
12
14
1957
1960
1965
1970
1973


B
ANNUAL SEDIMENT YIELD ($\bar{Q}_{SA}$), IN TONS PER SQUARE MILE
MEAN ANNUAL DISCHARGE ($\bar{Q}_A$), IN CUBIC FEET PER SECOND
$\bar{Q}_{SA} = .099\bar{Q}_A^{1.48}$
1961
1960
1962
1967
1965
1969
1968
1964
1963
1966
10
100
600
10
100
1000

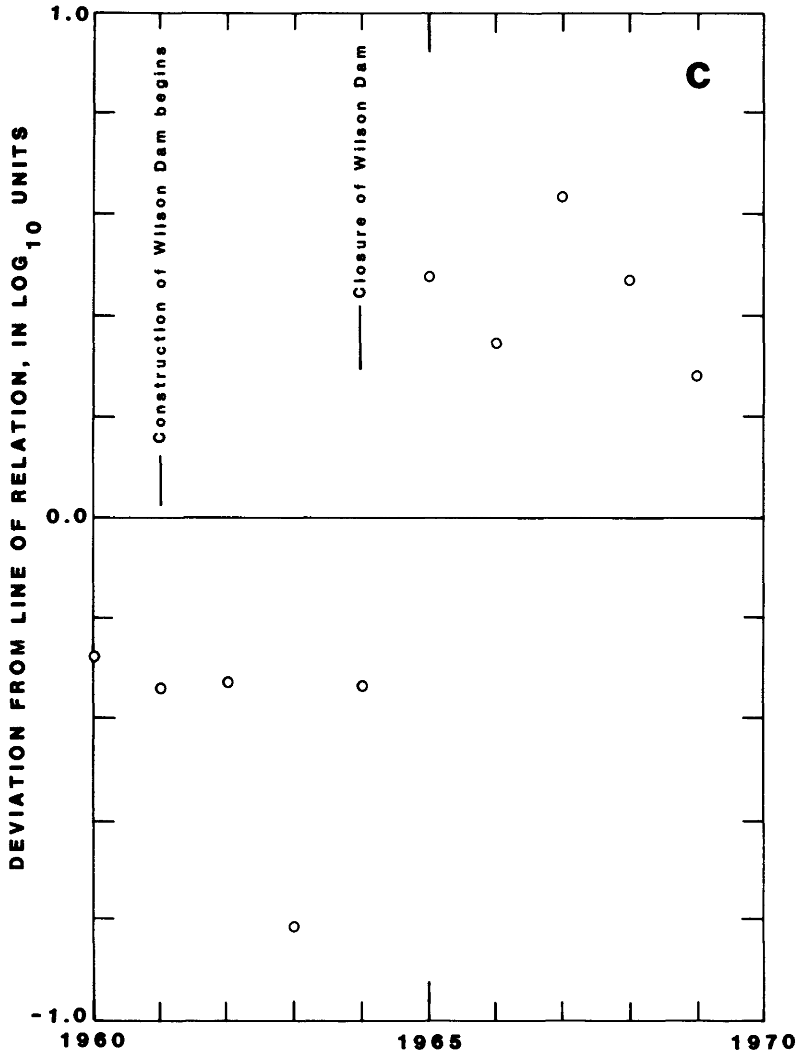
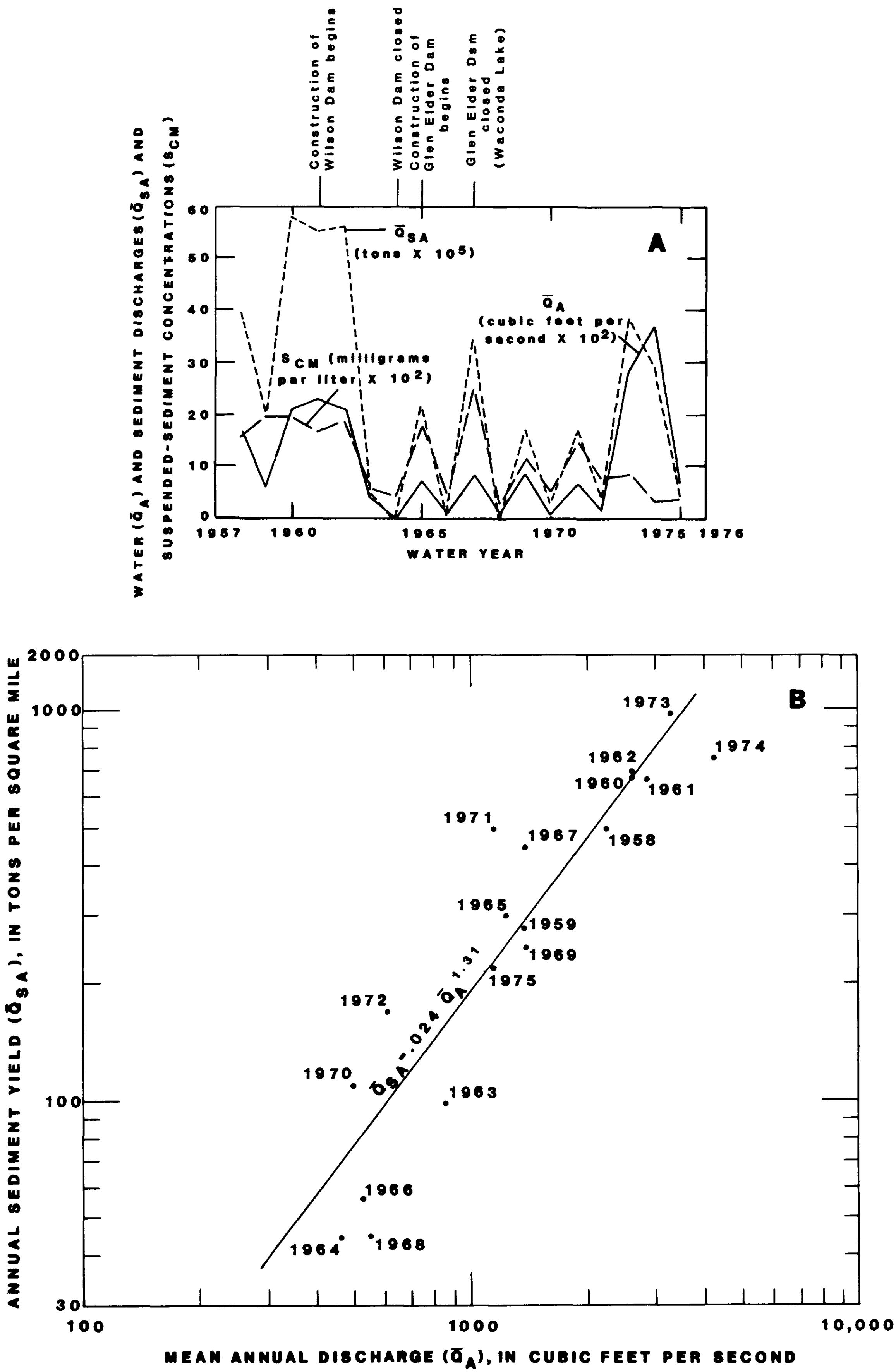


Figure 8.--Water and sediment relations, Saline River at Tescott, Kans. (06869500).

A. Annual values of mean water discharge, mean suspended-sediment concentration, and suspended-sediment discharge.
B. Power-function relation between annual sediment yields and mean annual discharges.
C. Deviation of annual sediment yields from power-function relation of part B.


Construction of Wilson Dam begins
Wilson Dam closed
Construction of Glen Elder Dam begins
Glen Elder Dam closed (Waconda Lake)
A
$\bar{Q}_{SA}$ (tons X 10^5)
$\bar{Q}_A$ (cubic feet per second X 10^2)
S_{CM} (milligrams per liter X 10^2)
WATER ($\bar{Q}_A$) AND SEDIMENT DISCHARGES ($\bar{Q}_{SA}$) AND SUSPENDED-SEDIMENT CONCENTRATIONS (S_{CM})
WATER YEAR
B
$\bar{Q}_{SA}$ = .024 $\bar{Q}_A^{1.31}$
ANNUAL SEDIMENT YIELD ($\bar{Q}_{SA}$), IN TONS PER SQUARE MILE
MEAN ANNUAL DISCHARGE ($\bar{Q}_A$), IN CUBIC FEET PER SECOND

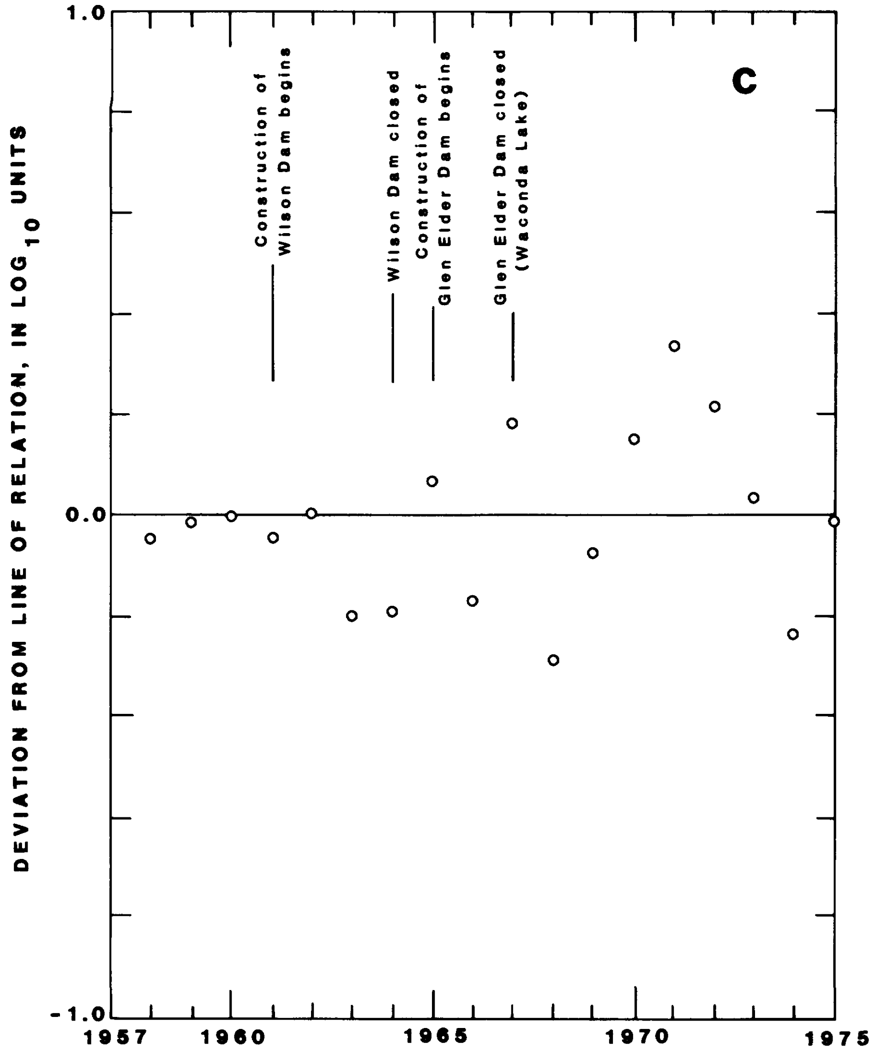
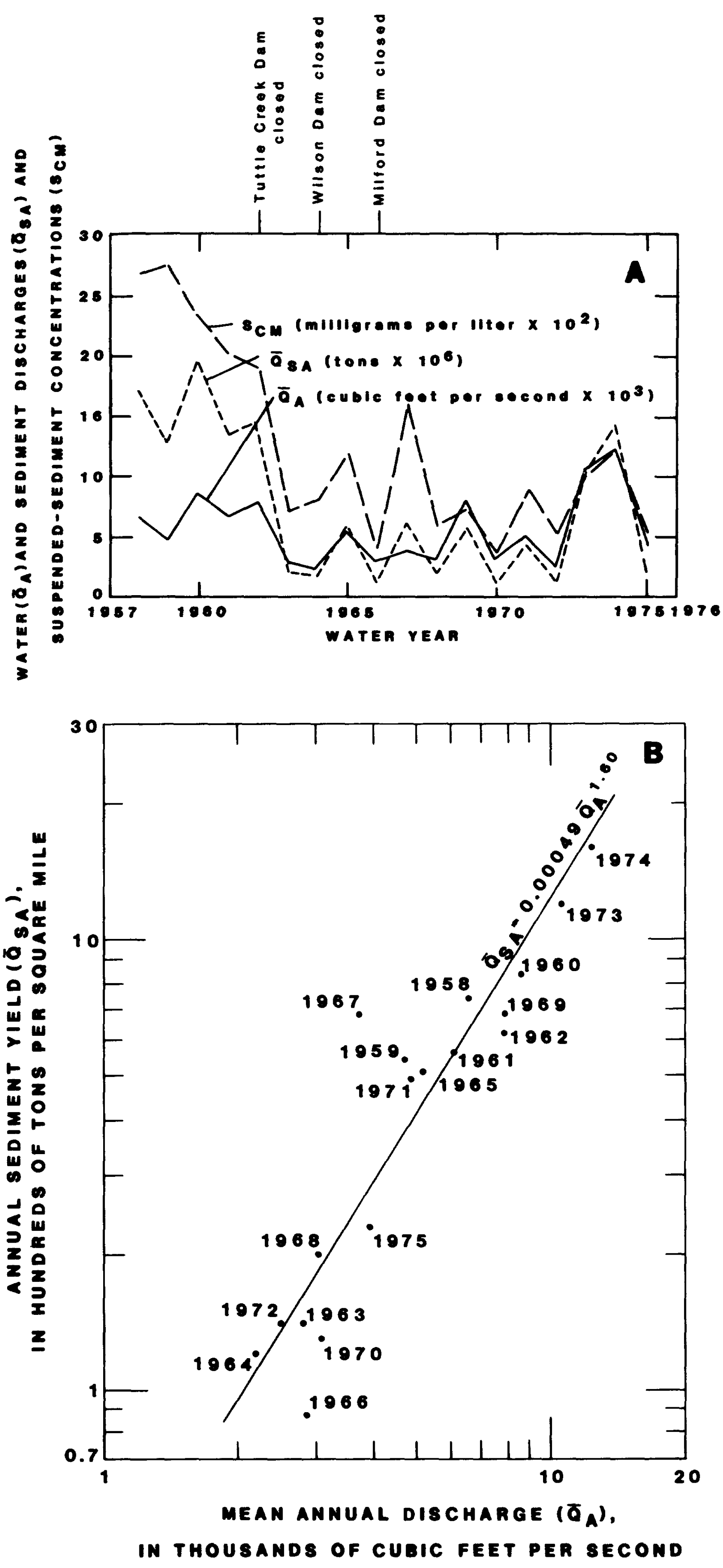


Figure 9.--Water and sediment relations, Smoky Hill River at Enterprise, Kans. (06877600).

A. Annual values of mean water discharge, mean suspended-sediment concentration, and suspended-sediment discharge.
B. Power-function relation between annual sediment yields and mean annual discharges.
C. Deviation of annual sediment yields from power-function relation of part B.


Tuttle Creek Dam closed
Wilson Dam closed
Milford Dam closed
A
S_{CM} (milligrams per liter X 10^2)
$\bar{Q}_{SA}$ (tons X 10^6)
$\bar{Q}_A$ (cubic feet per second X 10^3)
WATER ($\bar{Q}_A$) AND SEDIMENT DISCHARGES ($\bar{Q}_{SA}$) AND SUSPENDED-SEDIMENT CONCENTRATIONS (S_{CM})
WATER YEAR
B
$\bar{Q}_{SA} = 0.00049\,\bar{Q}_A^{1.60}$
ANNUAL SEDIMENT YIELD ($\bar{Q}_{SA}$), IN HUNDREDS OF TONS PER SQUARE MILE
MEAN ANNUAL DISCHARGE ($\bar{Q}_A$), IN THOUSANDS OF CUBIC FEET PER SECOND

Temporal Changes in Particle-Size Distributions

For those sampling sites where data are sufficient, particle-size analyses of suspended sediment and bed material were compiled to recognize possible changes with time (figs. 11 and 12). Generalizations regarding changes in particle sizes of suspended sediment are based largely on comparisons of median-particle size (d_{50}); generalizations for bed material are based on the sorting index (S). The sorting index is defined as

$$S = \frac{1}{2} \left(\frac{d_{84}}{d_{50}} + \frac{d_{50}}{d_{16}}\right) ,$$

where d_{16}, d_{50}, and d_{84} are the particle sizes for which 16, 50, and 84 percent by weight of the sample material is of finer diameter. A value of S less than 3.0 for a bed-material sample indicates well-sorted, channel alluvium; values of S increasing from 3.0 signify increasingly poorer sorting.

Average results of particle-size analyses for samples collected at Solomon River at Niles, Kans., and Saline River at Tescott, Kans., are shown in figure 11, and results of particle-size analyses for samples collected at Smoky Hill River at Enterprise, Kans., and Kansas River at Wamego, Kans., are shown in figure 12. The data are grouped generally to define periods preceding, during, and following construction activities of major upstream reservoirs. Each curve represents the composite of all particle-size analyses obtained during the indicated time interval, thereby tending to average differences due to seasonal effects, sampling and analytical error, variable discharge rates, and other causes of variation among samples. The numbers of analyses used to define the various curves (figs. 11 and 12) ranged from 14 to 76.

Changes in suspended-sediment sizes do not appear to be significant through time for the Solomon, Saline, and Smoky Hill Rivers. Changes for the Kansas River at the Wamego gage site indicate that the suspended load contained a substantially greater portion of coarse silt and very fine sand during 1970-77 than during 1957-60 and 1961-67. A general coarsening and decrease of the sorting index of the bed material through time is consistent with this trend, but the changes are not large enough to be considered significant. Particle-size data for bed material from the Saline River are insufficient to define curves in figure 11. Data are available for the Solomon and Smoky Hill Rivers, but changes in median particle size do not appear to be sufficiently large to indicate trends. The large changes in sorting index for the Solomon River bed material are largely a function of small changes in silt content associated with the low streamflows of 1964-67 and probably are not meaningful.

Particle-size distributions of bed material from the Smoky Hill River at Enterprise (fig. 12) indicate small sizes and better sorting during the 1971 to 1977 water years than during 1964 to 1968. The changes may have statistical significance, but the meaning of the changes is unclear. From 1964-77, the content of fine sizes in bed material remained constant, but there has been a reduction of the amount of coarser sizes in recent years. The change in bed-material sizes possibly is the result of a section of a low dam, a short distance downstream from the gage site, being washed out in June 1971. Complicating effects, such as river channelization in the Salina area about 1960 and the construction of Wilson and Waconda Lakes, however, make interpretation of the data difficult.

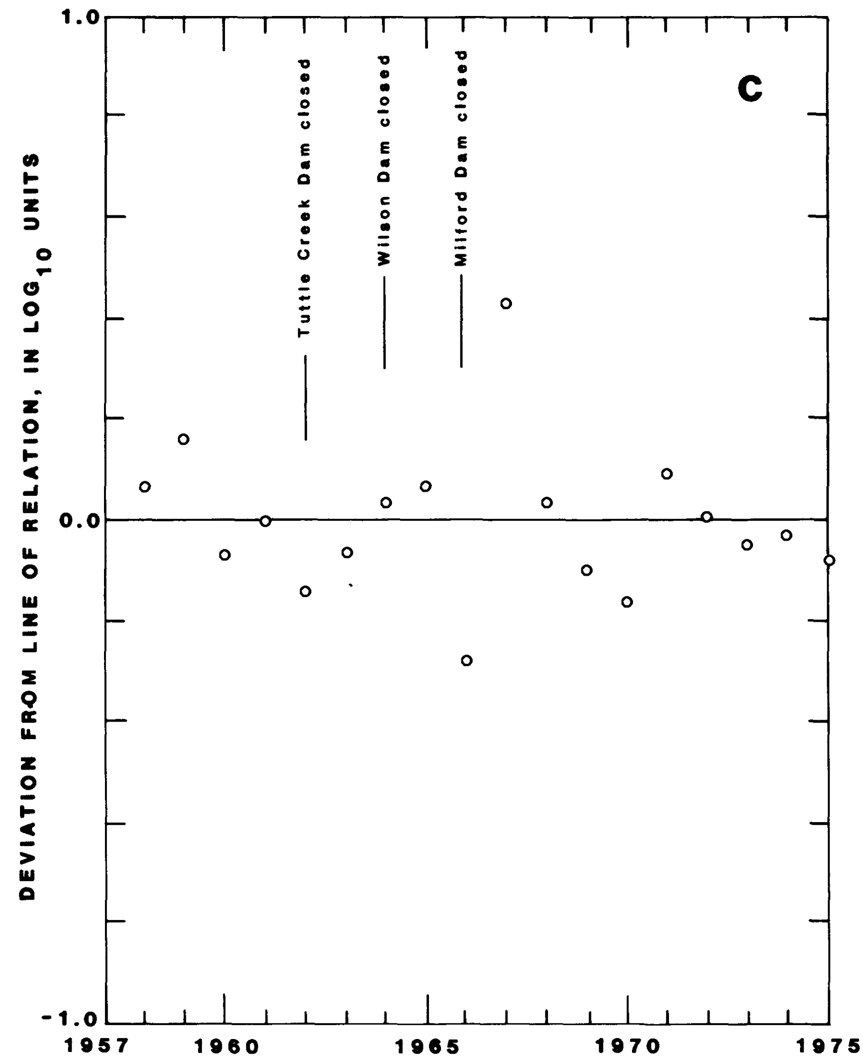


Figure 10.--Water and sediment relations, Kansas River at Wamego, Kans. (06887500).

A. Annual values of mean water discharge, mean suspended-sediment concentration, and suspended-sediment discharge.
B. Power-function relation between annual sediment yields and mean annual discharges.
C. Deviation of annual sediment yields from power-function relation of part B.

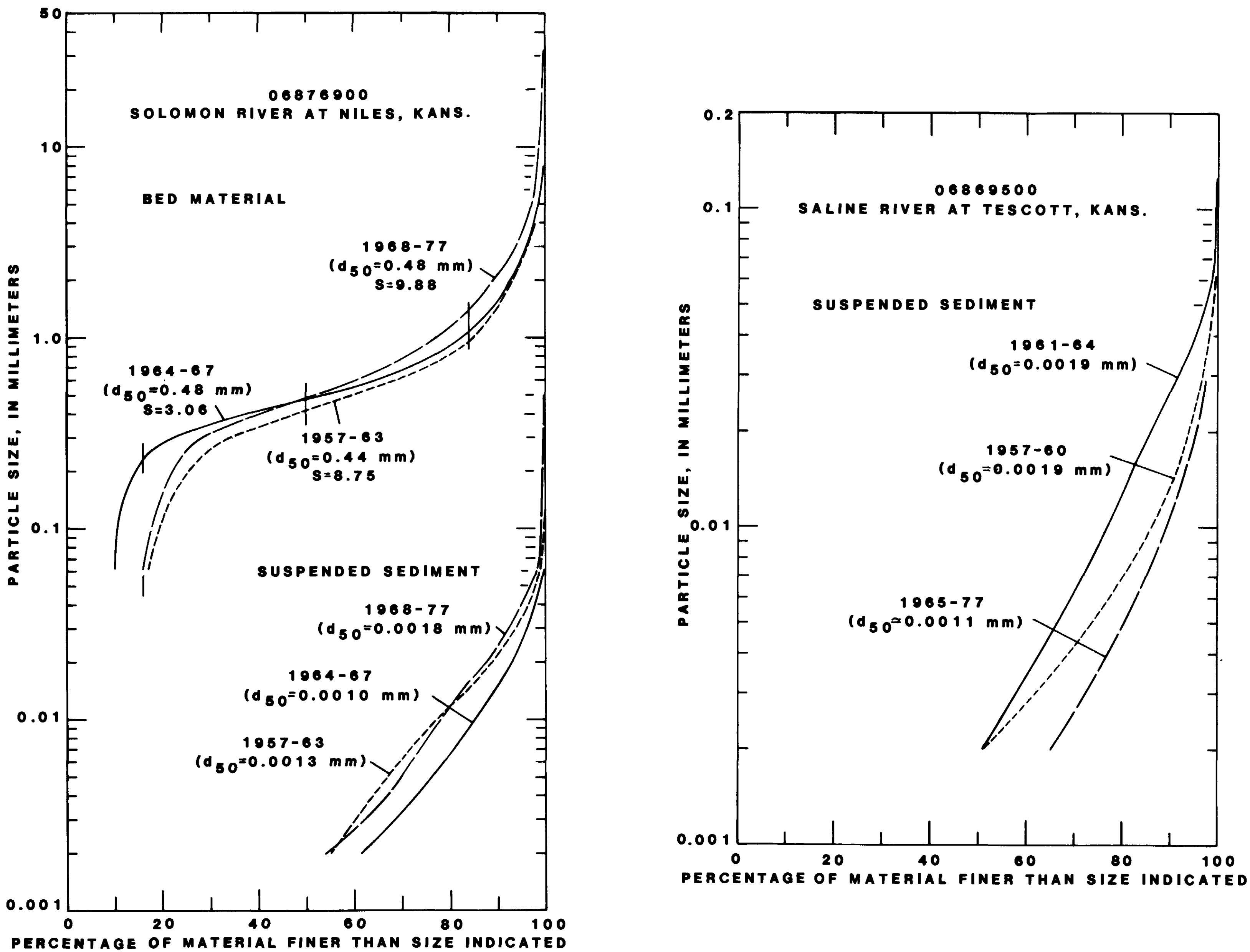


Figure 11.--Particle-size curves for averages of suspended-sediment and bed-material analyses, Solomon and Saline Rivers.

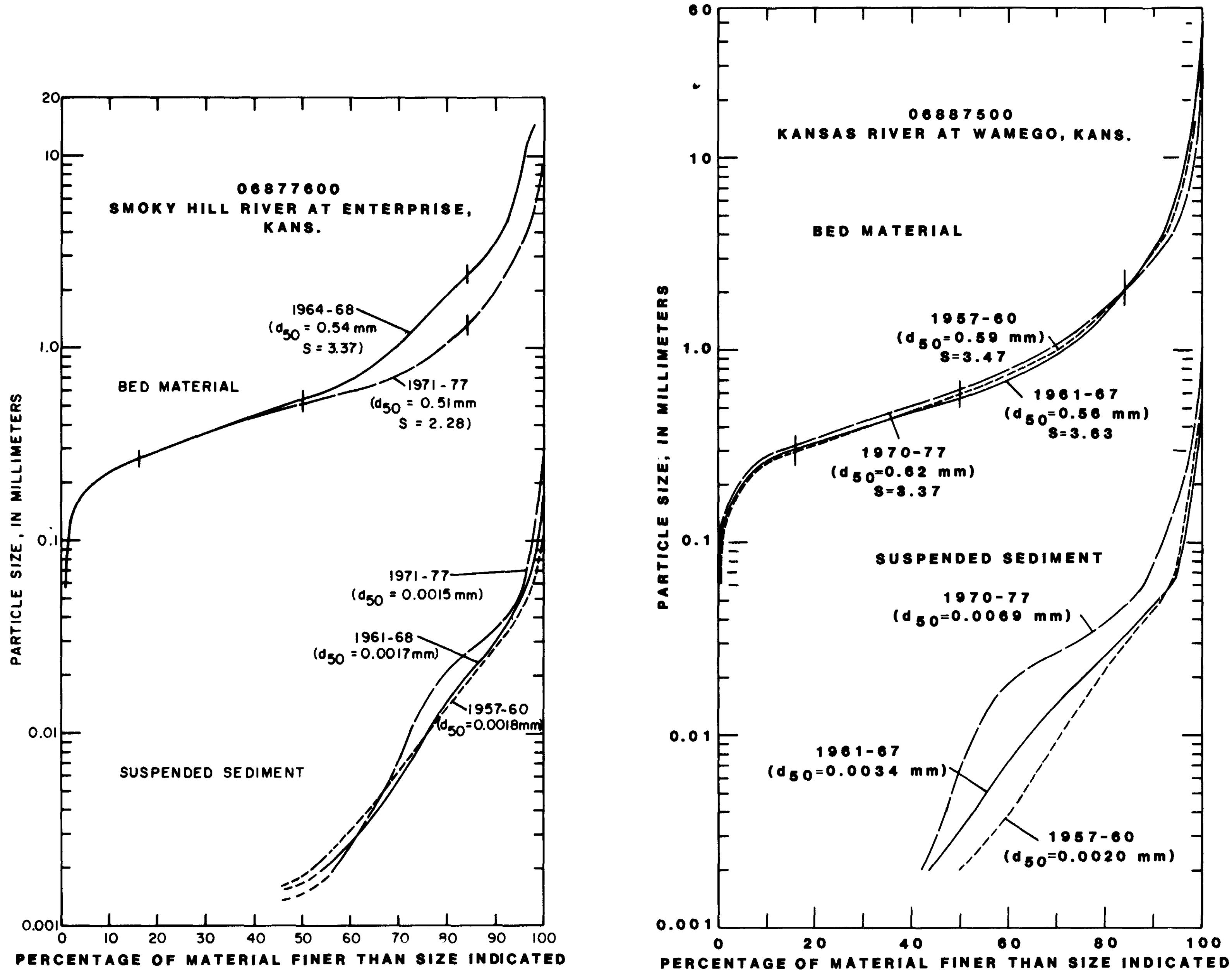


Figure 12.--Particle-size curves for averages of suspended-sediment and bed-material analyses, Smoky Hill and Kansas Rivers.

CHANNEL-GEOMETRY RELATIONS

Fluvial systems always tend towards a balance among characteristics of water and sediment discharge and channel properties (size, shape, gradient, and bed and bank material). A change in one or more of these variables, such as those caused by upstream impoundments, ultimately must result in adjustments by other variables to compensate for the imposed stress. Channel-geometry investigations provide one means of evaluating the relative instability of a stream channel and of inferring possible causes for the instability. As used here, instability refers to the deviation from an adjusted or balanced condition that may be indicated in the cross-sectional geometry of a stream channel. Instability is distinguished from channel activity, which refers to lateral channel movement (changes in meander pattern). Hence, a channel reach can be active yet relatively stable, or conversely, inactive yet unstable. For a well-developed and regulated system, such as that of the Kansas River, instability or activity may result from either imposed or naturally occurring causes.

Available Data

Channel-geometry measurements and bed- and bank-material samples have been collected by personnel of the U.S. Geological Survey and the U.S. Army Corps of Engineers from various gaged and ungaged sites on the Smoky Hill and Kansas Rivers. Limited data also were collected from the Solomon and Saline Rivers. Data were not obtained from the Republican River owing to the short channel length between Milford Dam and the confluence with the Kansas River. The onsite data for the Smoky Hill and Kansas Rivers have been supplemented by a large number of channel-width and gradient measurements determined from low-altitude aerial photographs and topographic maps. The onsite data and representative supplementary data are listed in table 3.

Geometry data for most sites listed in table 3 include active-channel width (Osterkamp and Hedman, 1977) and gradient. For selected sites, other geometry data include active-channel depth and bankfull width. The active channel is inferred to be indicative of recent conditions of water and sediment discharge, whereas the bankfull section indicates previous, probably preregulated, conditions. For this reason and because bankfull measurements were not feasible at many sites, the channel-geometry relations given in this report are based on the active-channel section.

Channel-material data listed in table 3 are summaries (arithmetic averages) of particle-size analyses for all samples collected for this investigation. The samples were collected from the bed and banks of active-channel sections in accordance with established sampling and measurement procedures (Osterkamp, 1979). The particle-size data were not included in computer analyses but were used to permit comparisons of width-discharge relations of Kansas River basin channels with previously established relations for channels of similar sediment characteristics. Other information considered (but not provided in table 3) is that of stage-time relations at gaged sites. Changes through time of the water-surface elevation for specified discharge rates define various trends of channel aggradation or degradation and thereby indicate possible instability of the channel.

Table 3.--Discharge, geometry, and channel-sediment data of selected channel sites of the Kansas River basin

[Station numbers and names are those assigned by the U.S. Geological Survey. Discharges at ungaged sites have been computed by interpolation. Average discharges are given in cubic feet per second (ft^3/s); channel width and depth in feet (ft); silt and clay (sizes finer than 0.062 mm) content of bed sample, of bank sample with the higher and lower silt-clay content, in percent; median particle size of bed sample, in millimeters (d_{50} mm). Channel gradient (dimensionless) is the change in base-flow elevation divided by channel length]

Station number	Location	Average discharge (ft^3/s)	Active-channel width (ft)	Active-channel depth (ft)	Bankfull width (ft)	Silt-clay content: Bed (percent)	Silt-clay content: Bank high (percent)	Silt-clay content: Bank low (percent)	Bed d_{50} (mm)	Channel gradient
06875900	Solomon River near Glen Elder, Kans.	127	56	3.01	---	4	48	38	0.92	0.00033
--------	Solomon River 2 miles east of Solomon Rapids, Kans.	150	55	4.06	81	26	49	49	.50	.00022
06876000	Solomon River at Beloit, Kans.	170	56	4.53	---	18	49	49	1.00	.00031
--------	Solomon River 1.5 miles south of Simpson, Kans.	220	62	5.60	94	10	49	49	1.00	.00029
--------	Solomon River 2 miles west of Delphos, Kans.	270	55	5.42	---	2	50	43	.78	.00026
06876900	Solomon River at Niles, Kans.	418	77	5.70	---	13	57	36	.58	.00017
--------	Solomon River southwest of Niles, Kans.	419	67	----	---	1	--	--	2.16	.00017
--------	Solomon River 1 mile south of Niles, Kans.	419	65	----	---	1	--	--	1.86	.00017
--------	Solomon River 2 miles southeast of Niles, Kans.	420	65	----	---	1	--	--	.84	.00022
--------	Solomon River 3 miles southeast of Niles, Kans.	420	78	----	---	2	--	--	1.05	.00031
--------	Solomon River 3 miles west-northwest of Solomon, Kans.	421	78	----	---	5	--	--	.62	.00031
--------	Solomon River 1.5 miles west-southwest of Solomon, Kans.	421	62	----	---	1	--	--	.71	.00023
--------	Solomon River at Hwy 40 bridge west of Solomon, Kans.	422	85	----	---	2	--	--	1.07	.00023
--------	Solomon River south of Solomon, Kans.	423	75	----	---	2	--	--	.69	.00023
06868200	Saline River at Wilson Dam, Kans.	64	30	3.17	110	36	30	27	.13	.00038
--------	Saline River south of Sylvan Grove, Kans.	115	36	3.28	86	--	--	--	----	.00028
--------	Saline River south of Vesper, Kans.	130	34	2.30	112	--	--	--	----	.00043
--------	Saline River 3 miles east of Lincoln, Kans.	140	34	4.73	160	25	90	90	.26	.00029
06869500	Saline River at Tescott, Kans.	176	42	4.20	---	37	52	52	1.80	.00058
--------	Saline River 4 miles southeast of Culver, Kans.	193	40	----	---	2	--	--	.64	.00032
--------	Saline River at county road bridge 6 miles northwest of Salina, Kans.	194	44	----	---	3	--	--	.30	.00032
--------	Saline River 5.5 miles north-northwest of Salina, Kans.	195	45	----	---	1	--	--	.61	.00039
--------	Saline River at county road bridge west of U.S. Hwy 81, Kans.	196	48	----	---	20	--	--	2.00	.00039
--------	Saline River 4 miles northwest of Salina, Kans.	197	44	----	---	6	--	--	.76	.00029
--------	Saline River 3 miles north-northwest of Salina, Kans.	198	45	----	---	15	--	--	1.81	.00029
--------	Saline River near Mulberry Creek, Kans.	199	52	----	---	19	--	--	.72	.00029
--------	Saline River 1.5 miles northwest of Salina, Kans.	200	50	----	---	15	--	--	.36	.00027
--------	Saline River 3 miles west of New Cambria, Kans.	200	56	----	---	7	--	--	.62	.00027
--------	Saline River 2.5 miles west-northwest of New Cambria, Kans.	202	55	----	---	2	--	--	.38	.00027
--------	Saline River 2 miles west of New Cambria, Kans.	203	52	----	---	1	--	--	.82	.00027

Table 3.--Discharge, geometry, and channel-sediment data of selected channel sizes of the Kansas River basin--Continued

Station number	Location	Average discharge (ft^3/s)	Active channel width (ft)	Active channel depth (ft)	Bankfull width (ft)	Silt-clay content: Bed (percent)	Silt-clay content: Bank high (percent)	Silt-clay content: Bank low (percent)	Bed d_{50} (mm)	Channel gradient
--------	Saline River 1 mile northwest of New Cambria, Kans.	203	50	----	---	0	--	--	0.77	0.00027
--------	Saline River at county road bridge southwest of New Cambria, Kans.	204	52	----	---	4	--	--	1.18	.00027
06865500	Smoky Hill River near Langley, Kans.	323	102	2.73	---	1	28	6	1.90	.00063
--------	Smoky Hill River at Langley Creek, Kans.	326	95	----	---	1	--	--	1.36	.00070
--------	Smoky Hill River 3 miles northwest of Marquette, Kans.	333	89	----	---	0	--	--	.81	.00053
--------	Smoky Hill River at county road northwest of Marquette, Kans.	337	89	----	---	0	--	--	.77	.00055
--------	Smoky Hill River at Hwy 4 bridge northwest of Marquette, Kans.	340	89	2.67	---	2	40	39	.65	.00058
--------	Smoky Hill River at Mo. Pac. Railroad bridge west of Marquette, Kans.	343	85	----	---	1	--	--	.89	.00056
---------	Smoky Hill River at Marquette, Kans.	350	69	2.52	100	1	56	33	.50	.00045
--------	Smoky Hill River 1.5 miles west of Freemount, Kans.	356	72	----	---	0	--	--	.86	.00038
--------	Smoky Hill River south of Freemount, Kans.	361	72	----	---	0	--	--	.67	.00045
--------	Smoky Hill River 3.5 miles southwest of Lindsborg, Kans.	367	74	----	---	0	--	--	.28	.00047
--------	Smoky Hill River 2.5 miles southwest of Lindsborg, Kans.	372	75	----	---	0	--	--	.41	.00054
06866000	Smoky Hill River at Lindsborg, Kans.	380	77	3.63	---	2	56	33	1.80	.00032
--------	Smoky Hill River east of Lindsborg, Kans.	388	77	----	---	0	--	--	.69	.00032
--------	Smoky Hill River 2.5 miles southwest of Bridgeport, Kans.	394	73	----	---	1	--	--	.40	.00035
--------	Smoky Hill River at Bridgeport, Kans.	400	70	4.00	---	1	66	64	.70	.00035
--------	Smoky Hill River 2 miles northwest of Bridgeport, Kans.	415	75	----	---	1	--	--	.52	.0004
--------	Smoky Hill River 2 miles southeast of Assaria, Kans.	426	68	----	---	0	--	--	.42	.00055
--------	Smoky Hill River east of Assaria, Kans.	430	65	5.26	---	4	64	58	.44	.00055
--------	Smoky Hill River at State Highway 4 bridge, Kans.	437	72	----	---	2	--	--	.40	.00040
--------	Smoky Hill River 1 mile east of Mentor, Kans.	443	80	----	---	5	--	--	.20	.00030
--------	Smoky Hill River 2 miles northwest of Mentor, Kans.	449	85	----	---	1	--	--	3.20	.00030
06866500	Smoky Hill River 1 mile southeast of Salina, Kans.	454	109	4.18	---	10	90	52	.32	.00037
--------	Smoky Hill River at North Street Bridge at Salina, Kans.	485	90	----	---	9	--	--	.23	.00032
--------	Smoky Hill River 2 miles southwest of New Cambria, Kans.	500	84	----	---	1	--	--	.37	.00033
--------	Smoky Hill River 1.5 miles south-southwest of New Cambria, Kans.	535	80	----	255	1	--	--	.22	.00029
--------	Smoky Hill River 2 miles south of New Cambria, Kans.	758	85	----	---	1	--	--	1.85	.00027
06869500	Smoky Hill River 3 miles southeast of New Cambria, Kans.	786	80	8.0	225	5	77	70	.20	.00027
--------	Smoky Hill River 4 miles southwest of Solomon, Kans.	804	82	----	---	0	--	--	.75	.00028

Table 3.--Discharge, geometry, and channel-sediment data of selected channel sites of the Kansas River basin--Continued

Station number	Location	Average discharge (ft^3/s)	Active channel width (ft)	Active channel depth (ft)	Bankfull width (ft)	Silt-clay content: Bed (percent)	Silt-clay content: Bank high (percent)	Silt-clay content: Bank low (percent)	Bed d_{50} (mm)	Channel gradient
--------	Smoky Hill River 3 miles southwest of Solomon, Kans.	812	85	----	---	0	--	--	0.53	0.00028
--------	Smoky Hill River 3 miles south-southwest of Solomon, Kans.	818	105	----	---	1	--	--	.41	.00023
--------	Smoky Hill River south of Solomon, Kans.	1,260	190	----	---	2	--	--	.54	.00023
--------	Smoky Hill River 2.5 miles southeast of Solomon, Kans.	1,270	180	----	---	0	--	--	.63	.00024
--------	Smoky Hill River 4 miles southwest of Abilene, Kans.	1,300	180	----	---	0	--	--	3.12	.00030
--------	Smoky Hill River 1.5 miles south of Abilene, Kans.	1,400	145	2.29	235	2	95	57	.43	.00030
--------	Smoky Hill River 2 miles southeast of Abilene, Kans.	1,430	190	----	---	0	--	--	3.62	.00026
06877600	Smoky Hill River at Enterprise, Kans.	1,460	195	7.5	---	2	94	57	.43	.00036
--------	Smoky Hill River 1 mile east of Detroit, Kans.	1,460	190	7.5	---	0	--	--	.57	.00036
--------	Smoky Hill River 2.5 miles northeast of Enterprise, Kans.	1,470	185	----	---	0	--	--	.53	.00020
--------	Smoky Hill River 2 miles southwest of Chapman, Kans.	1,470	205	----	---	1	--	--	1.39	.00020
--------	Smoky Hill River at Chapman, Kans.	1,480	200	----	---	1	--	--	.58	.00026
--------	Smoky Hill River 2.5 miles west of U.S. Highway 77, Kans.	1,620	205	----	---	0	--	--	.50	.00030
--------	Smoky Hill River 4 miles southwest of Junction City, Kans.	1,630	195	----	300	0	--	--	1.13	.00030
--------	Smoky Hill River at Lyons, Kans.	1,630	200	----	---	1	--	--	.60	.00034
--------	Smoky Hill River south of Junction City, Kans.	1,630	215	----	---	2	--	--	.78	.00034
--------	Smoky Hill River at U.S. 40 bridge at Junction City, Kans.	1,640	240	----	---	1	--	--	1.09	.00034
--------	Smoky Hill River 1.5 miles northeast of Junction City, Kans.	1,640	330	----	---	3	--	--	.81	.00034
--------	Kansas River at Junction City, Kans.	2,930	510	----	---	0	77	42	.52	.00038
06879100	Kansas River at Fort Riley, Kans.	2,930	470	----	---	4	82	63	.35	.00038
--------	Kansas River at Camp Whiteside, Kans.	2,940	550	----	---	0	--	--	.65	.00038
--------	Kansas River 1 mile southwest of Ogden, Kans.	2,940	520	----	---	0	--	--	.61	.00038
--------	Kansas River northeast of Clark Creek, Kans.	2,960	525	----	---	-	--	--	.39	.00038
--------	Kansas River near Ogden, Kans.	2,970	738	----	---	0	--	--	.64	.00038
--------	Kansas River 1 mile east of Ogden, Kans.	2,980	541	----	---	0	--	--	.84	.00038
--------	Kansas River 1 mile east of Manhattan Airport, Kans.	3,000	787	----	---	0	--	--	.55	.00042
--------	Kansas River 1 mile southeast of Camp Eureka, Kans.	3,050	922	----	---	0	--	--	.68	.00042
--------	Kansas River at McDowell Creek, Kans.	3,090	640	----	---	0	--	--	.79	.00042
--------	Kansas River near Wildcat Creek, Kans.	3,140	558	----	---	0	--	--	.82	.00042
--------	Kansas River at Hunter's Island near Manhattan, Kans.	3,180	617	----	---	0	--	--	.51	.00032
--------	Kansas River at CRI and P.RR. Bridge at Manhattan, Kans.	3,200	430	----	---	4	82	63	.35	.00032
--------	Kansas River west of Big Blue River, Kans.	3,200	430	----	---	1	--	--	.30	.00032
--------	Kansas River 2 miles east of Manhattan, Kans.	5,620	617	----	---	0	--	--	1.52	.00032
--------	Kansas River 3.5 miles east of Manhattan, Kans.	5,610	738	----	---	0	--	--	.98	.00032
--------	Kansas River 4 miles east of Manhattan, Kans.	5,610	558	----	---	0	--	--	2.06	.00032

Table 3.--Discharge, geometry, and channel-sediment data of selected channel sites of the Kansas River basin--Continued

Station number	Location	Average discharge (ft^3/s)	Active channel width (ft)	Active channel depth (ft)	Bankfull width (ft)	Silt-clay content: Bed (percent)	Silt-clay content: Bank high (percent)	Silt-clay content: Bank low (percent)	Bed d_{50} (mm)	Channel gradient
--------	Kansas River 2 miles northwest of Lecompton, Kans.	6,800	869	----	---	5	--	--	0.61	0.00027
06B91000	Kansas River at Lecompton, Kans.	7,520	780	9.0	820	1	78	66	.69	.00027
--------	Kansas River 2 miles southwest of Williamstown, Kans.	7,540	836	----	---	0	--	--	.88	.00027
--------	Kansas River 2 miles south of Wiliamstown, Kans.	7,550	1,100	----	---	2	--	--	.41	.00027
--------	Kansas River 0.5 mile south of Buck Creek, Kans.	7,570	1,050	----	---	2	--	--	.57	.00035
--------	Kansas River at Lawrence Water Plant, Kans.	7,590	530	----	---	0	52	26	.97	.00035
--------	Kansas River at I-70 Bridge at Lawrence, Kans.	7,610	541	----	---	2	--	--	.50	.00035
--------	Kansas River at U.S. 40 Bridge at Lawrence, Kans.	7,620	525	----	---	1	--	--	1.23	.00035
--------	Kansas River 2 miles east of Lawrence, Kans.	7,650	722	----	---	0	--	--	.55	.00034
--------	Kansas River near Mud Creek, Kans.	7,660	804	----	---	0	--	--	.55	.00034
--------	Kansas River 1 mile north of Eudora, Kans.	7,690	886	----	---	20	98	94	.22	.00034
06891100	Kansas River at Eudora, Kans.	7,700	850	----	870	1	56	56	.50	.00034
--------	Kansas River 1.5 miles northeast of Eudora, Kans.	8,040	1,120	----	---	1	--	93	.46	.00034
--------	Kansas River 2.5 miles northeast of Eudora, Kans.	8,050	820	----	---	0	--	--	.74	.00032
--------	Kansas River 1.5 miles southwest of Linwood, Kans.	8,070	1,350	----	---	0	--	--	.44	.00032
--------	Kansas River near mouth of Captain Creek, Kans.	8,070	951	----	---	0	--	--	.71	.00032
--------	Kansas River 1 miles southeast of Linwood, Kans.	8,090	1,180	----	---	7	--	--	.43	.00032
--------	Kansas River east of mouth of Stranger Creek, Kans.	8,510	690	----	---	0	--	--	.57	.00034
--------	Kansas River 1.5 miles east of Linwood, Kans.	8,510	804	----	---	0	--	--	.46	.00034
06892350	Kansas River at Desoto, Kans.	8,530	595	----	---	1	65	51	.55	.00034
--------	Kansas River 1 mile east of Desoto, Kans.	8,530	951	----	---	0	--	--	1.17	.00034
--------	Kansas River 3 miles northeast of Desoto, Kans.	8,530	935	----	---	0	--	--	.67	.00022
--------	Kansas River 2 miles east of Desoto, Kans.	8,540	1,130	----	---	0	--	--	.46	.00022
--------	Kansas River 3 miles south of Bonner Springs, Kans.	8,540	1,850	----	---	0	--	--	1.05	.00022
06892500	Kansas River at Bonner Springs, Kans.	8,550	850	----	900	1	74	69	.50	.00022
-------	Kansas River 1 mile east of Bonner Springs, Kans.	8,550	918	----	---	0	--	--	.62	.00030
--------	Kansas River at Edwardsville, Kans.	8,550	1,120	----	---	12	78	76	.80	.00030
--------	Kansas River 1.5 miles southeast of Edwardsville, Kans.	8,560	1,120	----	---	5	--	--	.33	.00030
--------	Kansas River 1 mile southwest of Muncie, Kans.	8,560	623	----	---	0	--	--	.45	.00030
--------	Kansas River near ATSF RR near Turner, Kans.	8,560	476	----	---	21	--	--	.19	.00049
--------	Kansas River at Turner, Kans.	8,570	570	----	---	2	81	58	.93	.00049

Table 3.--Discharge, geometry, and channel-sediment data of selected channel sites of the Kansas River basin--Continued

Station number	Location	Average discharge (ft^3/s)	Active channel width (ft)	Active channel depth (ft)	Bank full width (ft)	Silt-clay content: Bed (percent)	Silt-clay content: Bank high (percent)	Silt-clay content: Bank low (percent)	Bed d_{50} (mm)	Channel gradient
--------	Kansas River 5 miles east of Manhattan, Kans.	5,620	623	----	---	0	--	--	0.74	0.00032
--------	Kansas River 2 miles northwest of Wabaunsee, Kans.	5,640	984	----	---	0	--	--	.64	.00033
--------	Kansas River 1 mile northwest of Wabaunsee, Kans.	5,650	623	----	---	0	--	--	.46	.00033
--------	Kansas River 2 miles southwest of Wamego, Kans.	5,660	820	----	---	0	--	--	.40	.00033
06887500	Kansas River at Wamego, Kans.	5,660	740	----	750	0	70	12	.58	.00040
--------	Kansas River 2.5 miles southeast of Wamego, Kans.	5,720	715	----	---	0	--	--	.56	.00040
--------	Kansas River near Vermillion Creek, Kans.	5,770	951	----	---	0	--	--	.51	.00046
--------	Kansas River 2.5 miles southwest of Belvue, Kans.	5,800	886	----	---	0	--	--	1.44	.00046
--------	Kansas River 1.5 miles southwest of Belvue, Kans.	5,820	1,660	----	---	1	--	--	.84	.00031
--------	Kansas River near Belvue, Kans.	5,840	2,200	----	---	1	--	--	.71	.00031
--------	Kansas River 1.5 miles south of Belvue, Kans.	5,870	1,150	----	---	0	--	--	1.80	.00031
--------	Kansas River near Paxico, Kans.	5,900	1,040	----	---	0	97	97	.58	.00031
--------	Kansas River 2 miles west-southwest of St. Mary's, Kans.	5,930	1,250	----	---	0	--	--	.59	.00052
--------	Kansas River 2 miles southwest of St. Mary's, Kans.	5,940	918	----	---	1	--	--	.51	.00052
--------	Kansas River 5 miles northwest of Maple Hill, Kans.	5,970	1,260	----	---	0	--	--	.61	.00049
--------	Kansas River 4 miles northwest of Maple Hill, Kans.	5,980	1,610	----	---	0	--	--	.51	.00049
--------	Kansas River 2 miles north of Maple Hill, Kans.	6,000	758	----	---	4	66	46	.42	.00045
--------	Kansas River east of Mill Creek, Kans.	6,310	1,070	----	---	0	--	--	.86	.00042
--------	Kansas River at Willard, Kans.	6,320	1,000	----	1,000	8	58	57	.62	.00042
--------	Kansas River 1 mile northeast of Willard, Kans.	6,330	1,100	----	---	0	--	--	.40	.00042
--------	Kansas River north of Valencia, Kans.	6,350	800	----	---	0	--	--	1.05	.00044
--------	Kansas River 2 miles south of Silver Lake, Kans.	6,360	748	----	---	0	--	--	.80	.00044
--------	Kansas River near Camp Mattingly, Kans.	6,380	722	----	---	0	--	--	1.03	.00051
--------	Kansas River at Westgate Bridge, at Topeka, Kans.	6,410	780	----	---	0	70	41	.72	.00052
--------	Kansas River at Topeka Avenue Bridge, at Topeka, Kans.	6,410	520	----	---	2	90	64	.43	.00027
06889000	Kansas River at Sardou Bridge, at Topeka, Kans.	6,410	560	----	---	1	75	45	.42	.00027
--------	Kansas River north of Topeka sewage disposal, Kans.	6,430	660	----	---	0	--	--	.92	.00027
--------	Kansas River north of Topeka Airport, Kans.	6,440	640	----	---	0	--	--	1.23	.00027
--------	Kansas River 1 mile northeast of Topeka Airport, Kans.	6,650	700	----	---	0	--	--	.41	.00027
--------	Kansas River 2 miles northwest of Tecumseh, Kans.	6,680	620	----	---	0	--	--	.65	.00033
--------	Kansas River at Tecumseh, Kans.	6,700	650	5.5	---	0	53	53	.74	.00033
--------	Kansas River 1 mile below Dupont factory, Kans.	6,710	750	6.5	760	-	71	43	----	.00033
--------	Kansas River 2 miles below Dupont factory, Kans.	6,720	740	5.0	---	1	28	28	2.26	.00033
--------	Kansas River 4 miles east of Tecumseh, Kans.	6,750	1,130	----	---	5	--	--	.52	.00029
--------	Kansas River 4.5 miles west of Lecompton, Kans.	6,770	1,100	----	---	1	--	--	1.28	.00029

Width-Discharge Relations

Active-channel widths, relative to mean discharge, are greatly variable for the Kansas River and, to a lesser extent, for the Smoky Hill River. The variability of width relative to the limited ranges of mean discharge for the two streams precludes the calculation of meaningful equations relating the two variables. Instead, the data (table 3) are compared to well-defined relations developed for mostly unregulated stream channels of similar sediment characteristics in the Missouri River basin (Osterkamp and Hedman, 1982). Most sites sampled along the Smoky Hill and Kansas Rivers have sandy bed material and bank material containing at least 70 percent silt and clay. Thus, the width-discharge data for the Smoky Hill and Kansas Rivers (table 3) are compared to relations developed from data collected throughout the Missouri River basin for channels with sand beds and silt-clay banks (fig. 13, line A) and for channels with sand beds and sand banks (fig. 13, line B).

The data defining lines A and B of figure 13 were collected from relatively stable channel sites and do not include either greatly regulated or braided streams. Because streamflow regulation by reservoirs mostly eliminates erosive channel-widening discharges, regulated-stream channels generally maintain widths smaller than those of unregulated streams having similar sediment characteristics (Osterkamp and Hedman, 1982). Braided streams generally maintain channel widths that are greater than the typical width-discharge relations (fig. 13).

Inspection of figure 13 shows that the entire length of the Smoky Hill River downstream from Kanopolis Lake is narrower than comparable channels, probably indicating cohesiveness of the banks and an absence of extremely high discharges. The Kansas River has a smaller proportion of regulated streamflow than the Smoky Hill River, and the regulation is a complex result of several major reservoirs. Although the Kansas River is well regulated, most measured sites have widths greater than those of unregulated streams of similar mean discharge and channel-sediment characteristics. For those channel reaches that are obviously braided, data indicate significantly wider channels than those of the reference relations (fig. 13).

Data relating active-channel width and mean discharge for regulated parts of the Solomon and Saline Rivers are plotted in figure 14. Also shown is a reference line relating widths and discharges of unregulated streams in the Missouri River basin with generally similar channel-sediment properties (Osterkamp and Hedman, 1982). The power-function relation of figure 14 is defined by data from channels having principally sandy beds (11 to 30 percent silt and clay) and principally silt and clay banks. Most of the data for the Solomon and Saline Rivers plot to the left of the reference line (fig. 14), indicating the narrow channels and probably cohesive banks of these rivers downstream from the reservoirs.

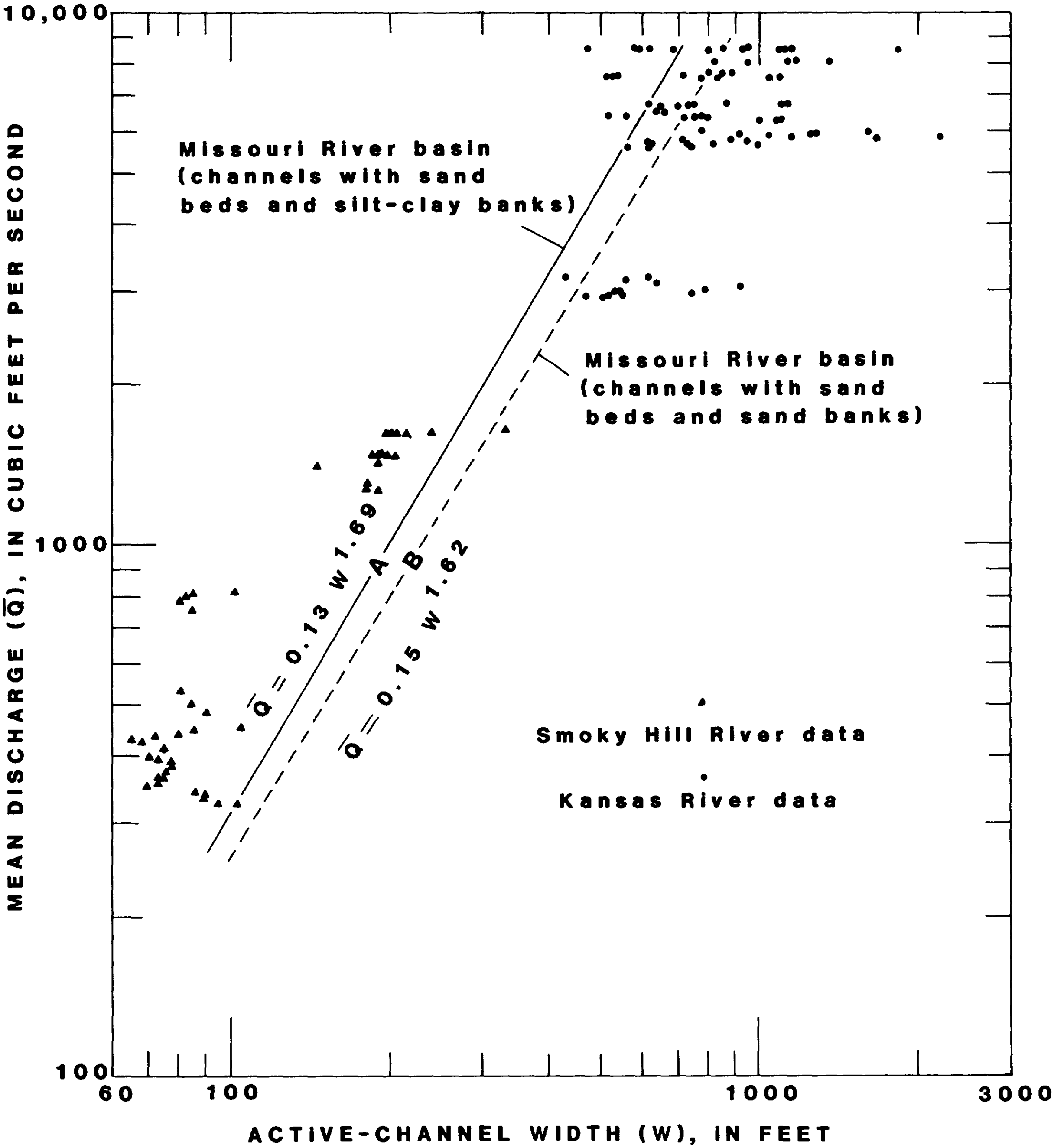


Figure 13.--Width and mean-discharge data for regulated sites of the Smoky Hill and Kansas Rivers.

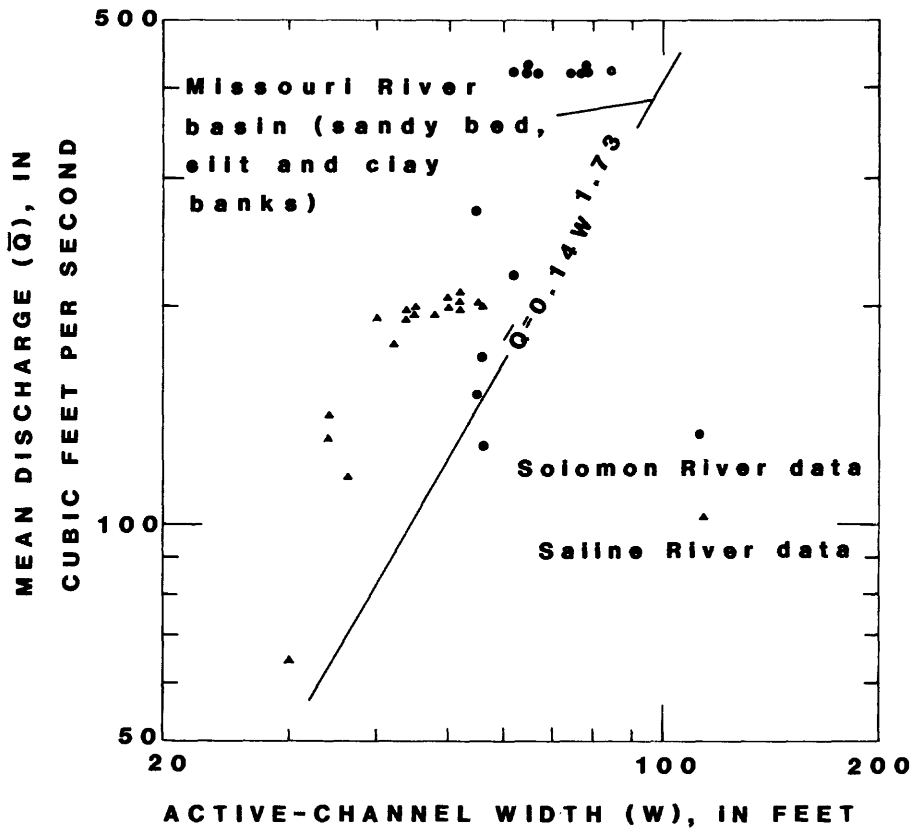


Figure 14.--Width and mean-discharge data for regulated sites of the Solomon and Saline Rivers.

Gradient-Discharge Relations

Relations between gradient and mean discharge have been developed for relatively stable unregulated streams of Kansas (Osterkamp, 1978). As with the width-discharge data, the channels represented by gradient and discharge data were grouped according to channel-sediment characteristics. The relations show that, relative to mean discharge, the channels of gentlest gradient occur when the bed and bank sediment is largely of silt and clay size. For increasingly sandier conditions, the channel gradients of relatively stable Kansas streams increase correspondingly. If a sandy channel has an anomalously large gradient relative to mean discharge, however, the channel is typically wide or braided and subject to frequent changes (Osterkamp, 1978, p. 1261-1262).

When compared to the relations for Kansas streams, the gradient-discharge data (fig. 15) indicate a similar pattern as that indicated by the width-discharge data. Gradients for regulated reaches of the Solomon, Saline, and Smoky Hill Rivers generally are similar to or slightly less than those typical of unregulated Kansas streams (of similar discharge and channel-sediment characteristics). Gradients of the Kansas River are representative of wide, sandy, and commonly braided channel patterns. Channels of this sort are associated with high transport rates of sand and gravel, much of which is transported as bed load (Osterkamp, 1980; L. J. Onesti, University of Indiana,

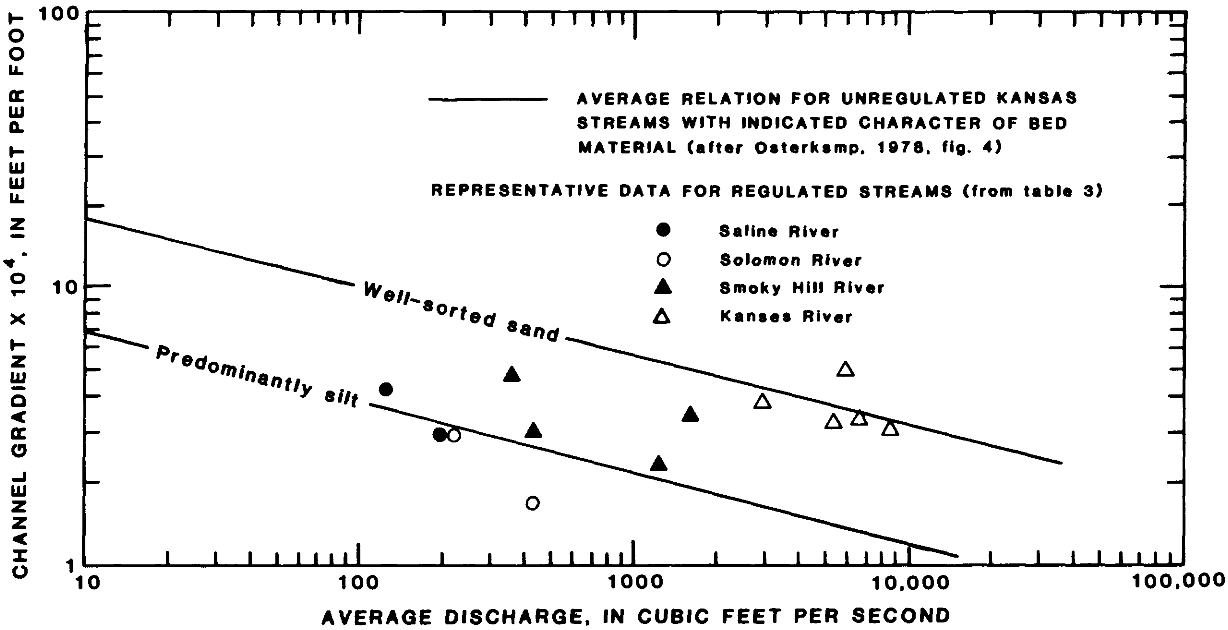


Figure 15.--Gradient-discharge relations for selected Kansas streams.

Bloomington, written commun., 1980). The reduction of sediment supply by storage in reservoirs, therefore, favors a long-term trend of reduction in channel gradient of the Kansas River. Reduction in gradient could occur by degradation of the bed or by increased meandering.

In a related study (Osterkamp and Hedman, 1981), estimates were made of gradient changes through time for various regulated streams in Kansas. The estimated changes in channel sinuosity and gradient are summarized in table 4. The results indicate that very little change, if any, in channel gradient and sinuosity has occurred for the Solomon, Saline, Smoky Hill, and Kansas Rivers during the periods of streamflow regulation. Various studies have demonstrated that measurable channel scour typically occurs downstream from an impoundment within a few years. The results given here, however, indicate that the periods of regulation (several decades or less) for major streams of the Kansas River basin have been too short to reflect measurable changes in channel gradient. When realistic estimates of sediment-transport capacity of the Kansas River are considered, calculations show that the time required to move quantities of sediment necessary to effect a substantial decrease in channel gradient significantly exceeds several decades (Osterkamp and Hedman, 1981).

Stage-Time Relations

Changes in the elevation of a stream channel with time provide an additional means of evaluating channel instability. Degradation commonly occurs in channels downstream from reservoirs. The water released from a dam is largely sediment free and thus has a tendency to restore the sediment load to an amount similar to that of unregulated conditions. The occurrence and extent of channel degradation is a measure of the imbalance that a reservoir has imposed on a stream.

Table 4.--Comparisons of sinuosity and gradient changes for selected reaches of the Kansas River and major tributaries

[Measurements made from aerial photographs, U.S. Geological Survey topographic maps, and interpretive channel-change maps by Dort (1979). Sinuosity (dimensionless) is channel length divided by valley length. Gradient (also dimensionless) is the change in base-flow elevation divided by channel length]

Stream and location of reach	Mean date of maps or photographs	Sinuosity	Gradient	Mean date of maps or photographs	Sinuosity	Gradient
Solomon River below Waconda Lake, T.9 S., R.9 W., sec.2, SE¼NW¼ to T.13 S., R.1 E., sec.14, NW¼SW¼	1955	2.5	0.00027	1976	2.4	0.00027
Saline River below Wilson Lake, T.12 S., R.10 W., sec.30, NW¼SW¼ to T.14 S., R.2 W., sec.2, SE¼SE¼	1961	2.7	.00032	1976	2.6	.00036
Smoky Hill River below Kanopolis Lake, T.16 S., R.6 W., sec. 35, SE¼SW¼ to T.14 S., R.2 W., sec.2, NW¼SE¼	1921	1.9	.00048	1973	1.9	.00049
Kansas River below Junction City, Kans., T.11 S., R.7 E., sec.9, NE¼NW¼ to T.11 S., R.18 E., sec. 35, SE¼SW¼	1937	1.2	.00040	1976	1.2	.00040
Kansas River below Lawrence, Kans., T.12 S., R.20 E., sec.26, NW¼NW¼ to T.11 S., R.24 E., sec.28, NW¼NW¼	1890	1.2	.00044	1976	1.3	.00042

Changes of stage (water-level elevation) with time for gage sites on the Republican, Solomon, Saline, Smoky Hill, and Kansas Rivers (modified from Osterkamp and Hedman, 1981) are shown in figures 16 through 24. The graphs are based on the stages corresponding to the 25- and 10-percent flow-duration rates (those discharges that are equaled or exceeded 25 and 10 percent of the time). The stage changes for the 25-percent rate largely are related to datum changes of the channel bed (aggradation or degradation). Changes of stage elevation for the 10-percent flow-duration rate result both from changes of bed elevation and from changes in channel conveyance at discharge rates exceeding those equivalent to the active-channel stage. For example, records could show that stage changes very little through time at the 25-percent flow-duration rate, but that the stage associated with a discharge of 10-percent flow duration declines through the same time period of regulation. An explanation of these trends would be that aggradation or degradation of the channel bed is not occurring, but that the relatively large release rates from the upstream reservoir are causing erosion of the channel sides below the bankfull stage.

The graphs in figures 16 through 24 are complex because year-to-year variations in stage, mostly associated with scour during wet periods and aggradation during dry periods, partially mask the long-term trends. For periods of regulated streamflow, however, most of the channel reaches downstream from major reservoirs indicate trends of degradation, as shown in figures 16, 18, 19, 23, and 24. Exceptions include gage sites on the Smoky Hill River near Mentor, Kans., and at New Cambria, Kans., where records are too short or too complex to indicate trends (fig. 20). Since the summer of 1951, the channel bed of the Smoky Hill River at Enterprise, Kans., has degraded about 4 feet (fig. 21), but the complex changes cannot be associated with regulation with confidence. The bed elevation at the Enterprise site during 1978 was slightly higher than it was during 1934; the net decrease in stage through time for the 10-percent flow-duration rate indicates that erosion of high banks and an increase of channel conveyance have occurred (fig. 21).

The channel bed of the Kansas River at Wamego, Kans. (fig. 22), aggraded slightly during 1948-50 and later was scoured about 1.5 feet by the flood of 1951. Virtually no net change in channel datum has occurred at the Wamego gage site since 1951. Moderate degradation (about 1.5 feet) has occurred in the channel of the Kansas River at Topeka, Kans., during the last three decades (fig. 23), but the changes may be the result of channel modifications made following the flood of 1951 and dredging of sand and gravel. Almost no net change in recent decades is apparent in stage relations at the gage site for the Kansas River at Lecompton, Kans. (fig. 23). The potential for measurable degradation at the Lecompton site is minimal, however, owing to a stabilizing effect on bed elevation by Bowersock Dam at Lawrence, about 10 miles downstream.

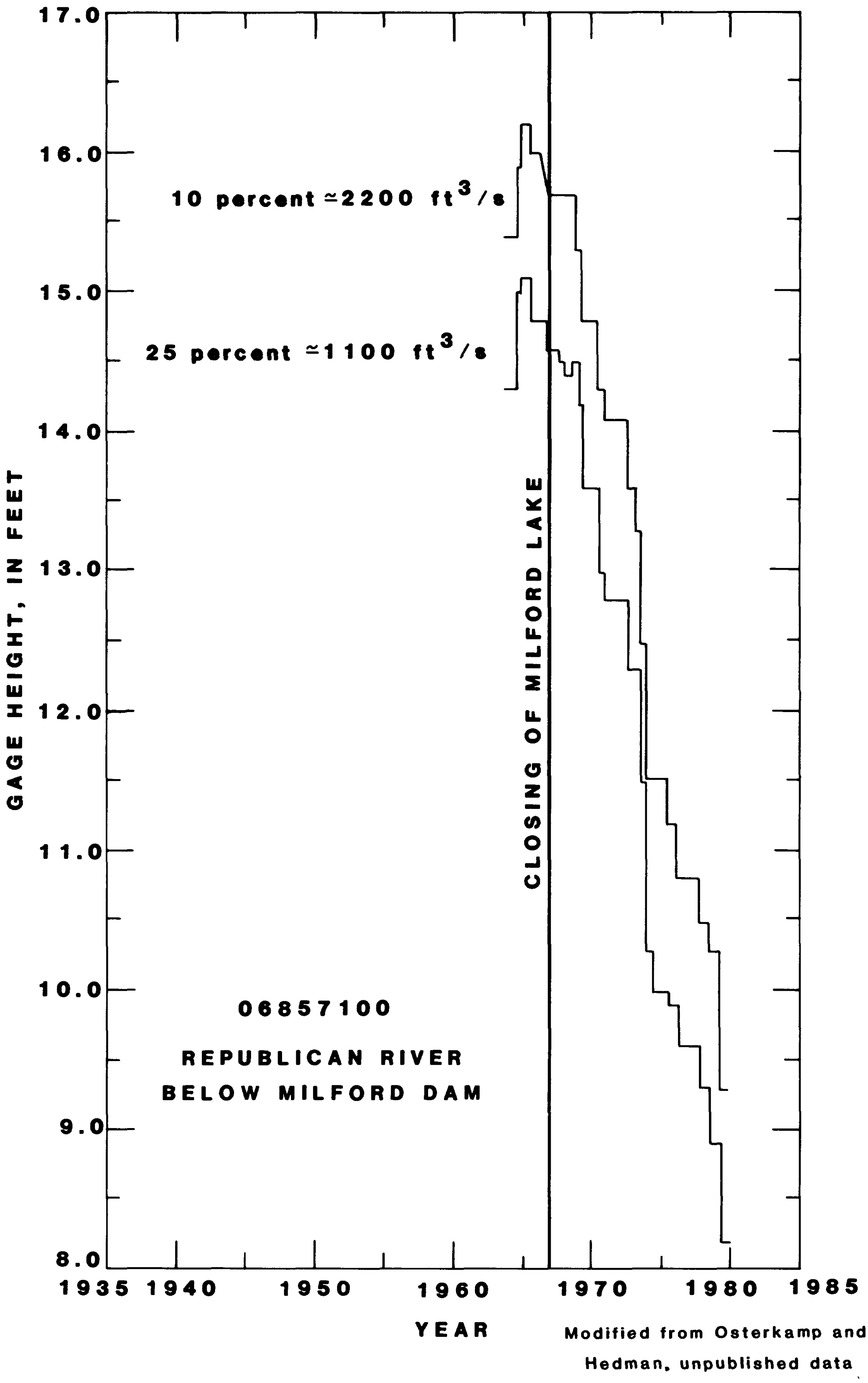


Figure 16.--Stage-time relations corresponding to 25- and 10-percent flow-duration rates for gage site Republican River below Milford Dam, Kans.

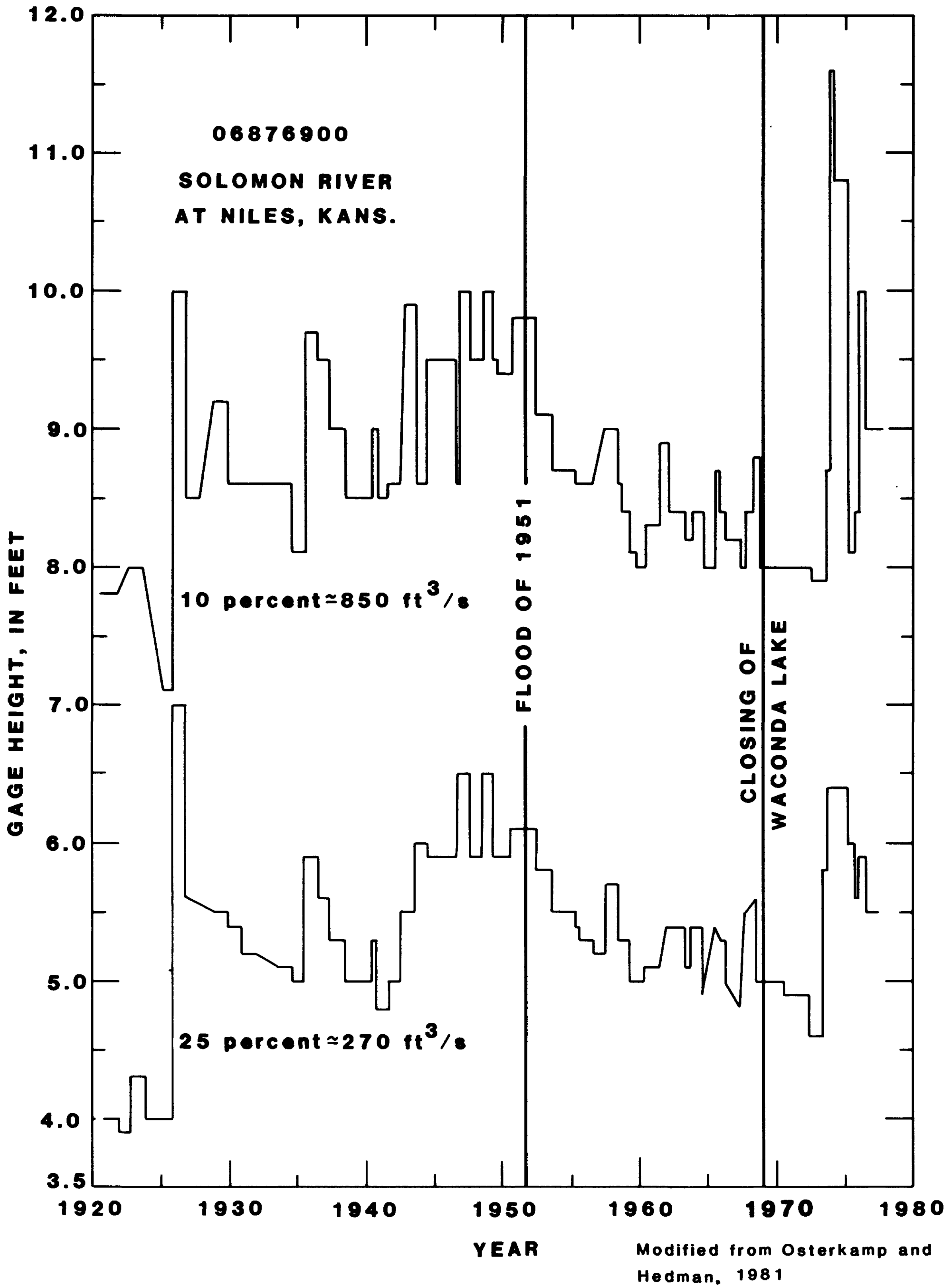


Figure 17.--Stage-time relations corresponding to 25- and 10-percent flow-duration rates for gage site Solomon River at Niles, Kans.

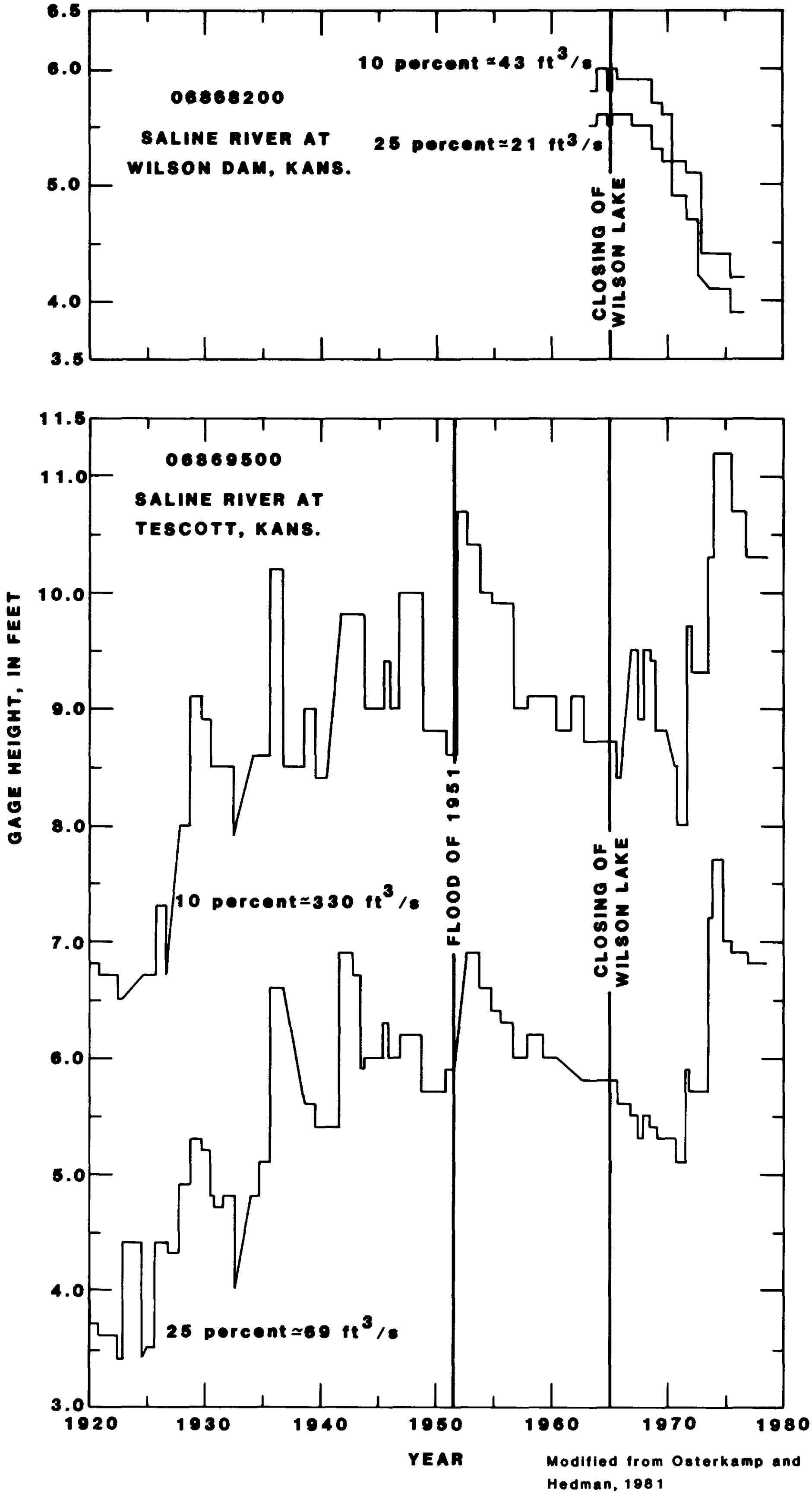


Figure 18.--Stage-time relations corresponding to 25- and 10-percent flow-duration rates for gage sites Saline River at Wilson Dam, Kans., and Saline River at Tescott, Kans.

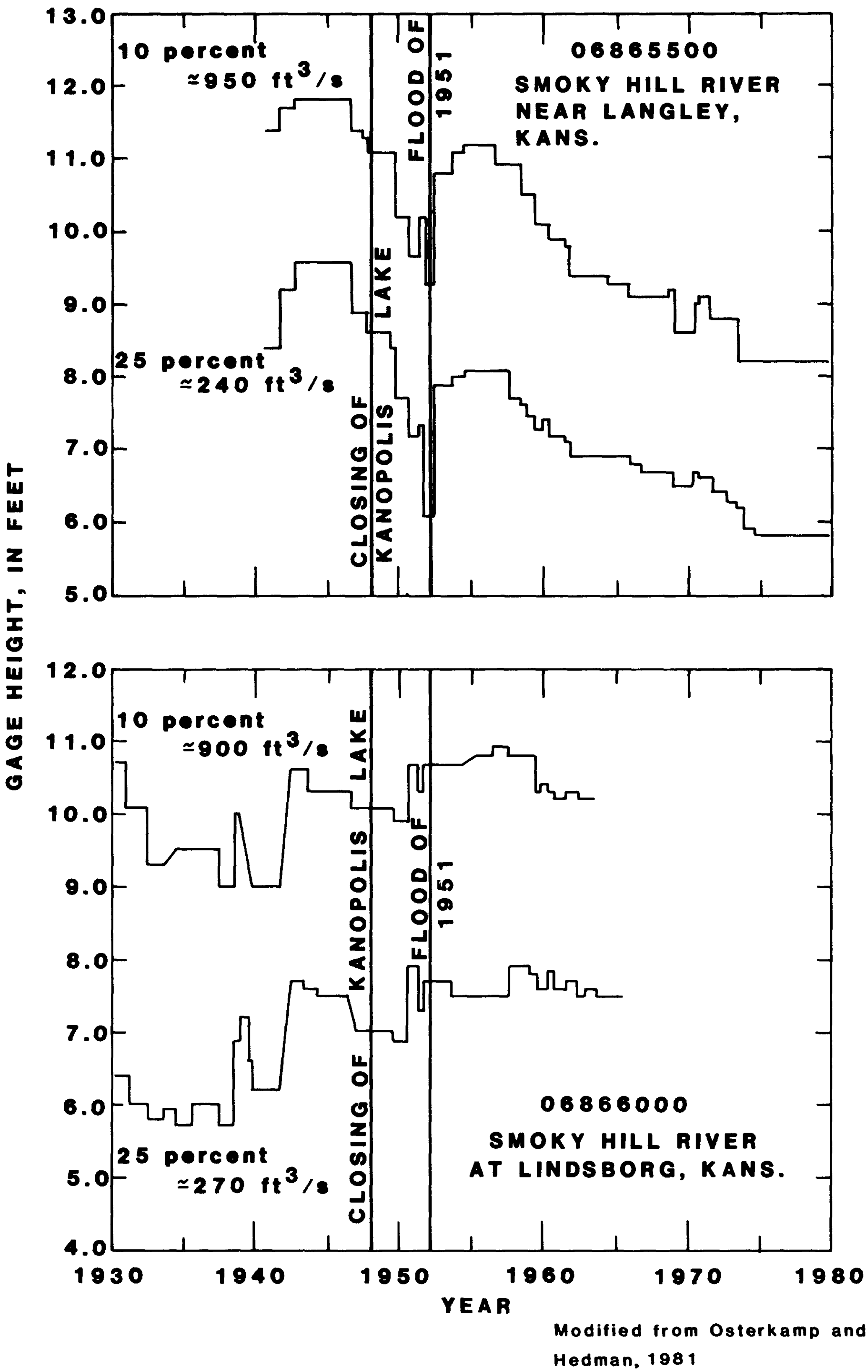


Figure 19.--Stage-time relations corresponding to 25- and 10-percent flow-duration rates for gage sites Smoky Hill River near Langley, Kans., and Smoky Hill River at Lindsborg, Kans.

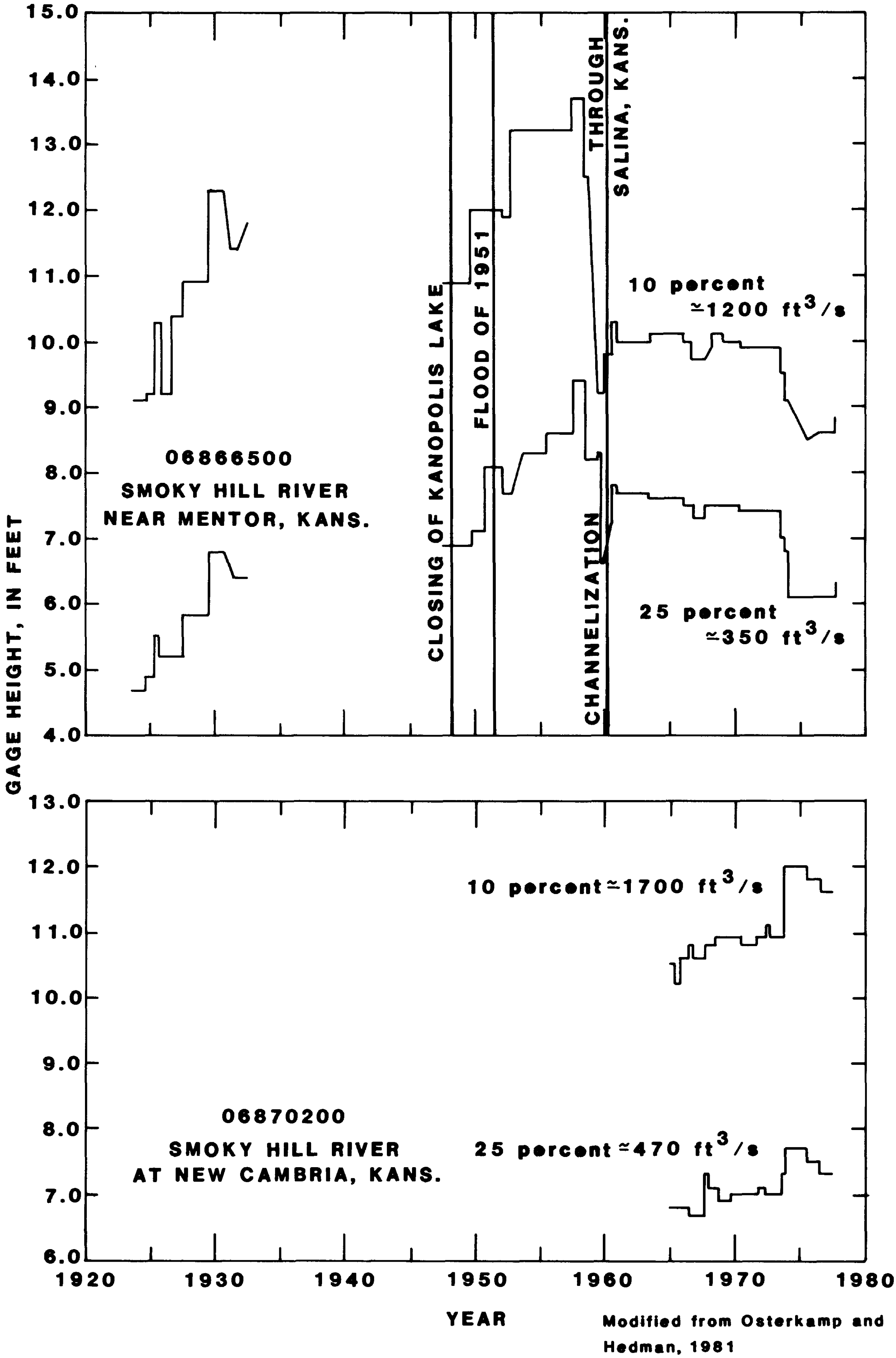


Figure 20.--Stage-time relations corresponding to 25- and 10-percent flow-duration rates for gage sites Smoky Hill River near Mentor, Kans., and Smoky Hill River at New Cambria, Kans.

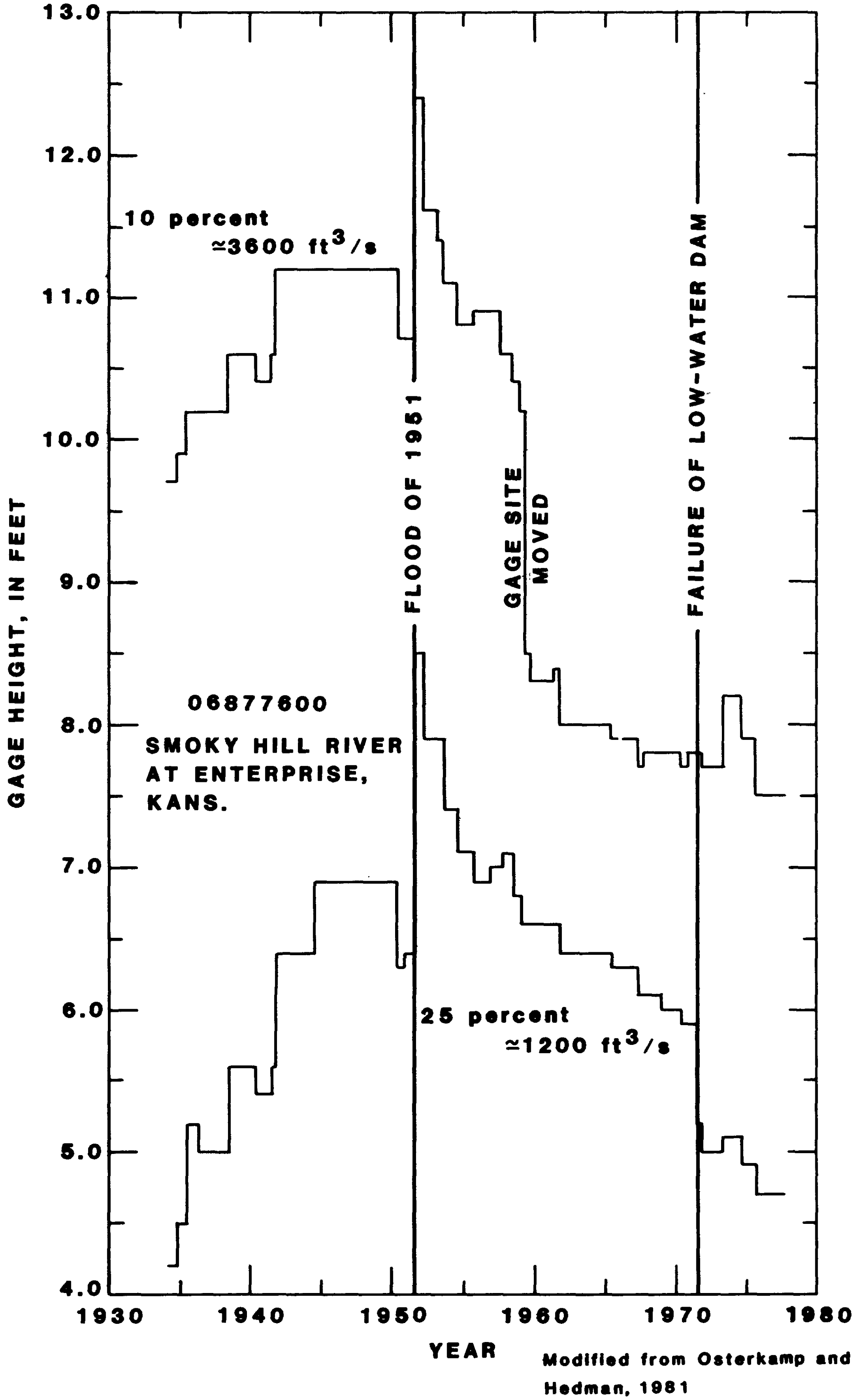


Figure 21.--Stage-time relations corresponding to 25- and 10-percent flow-duration rates for gage site Smoky Hill River at Enterprise, Kans.

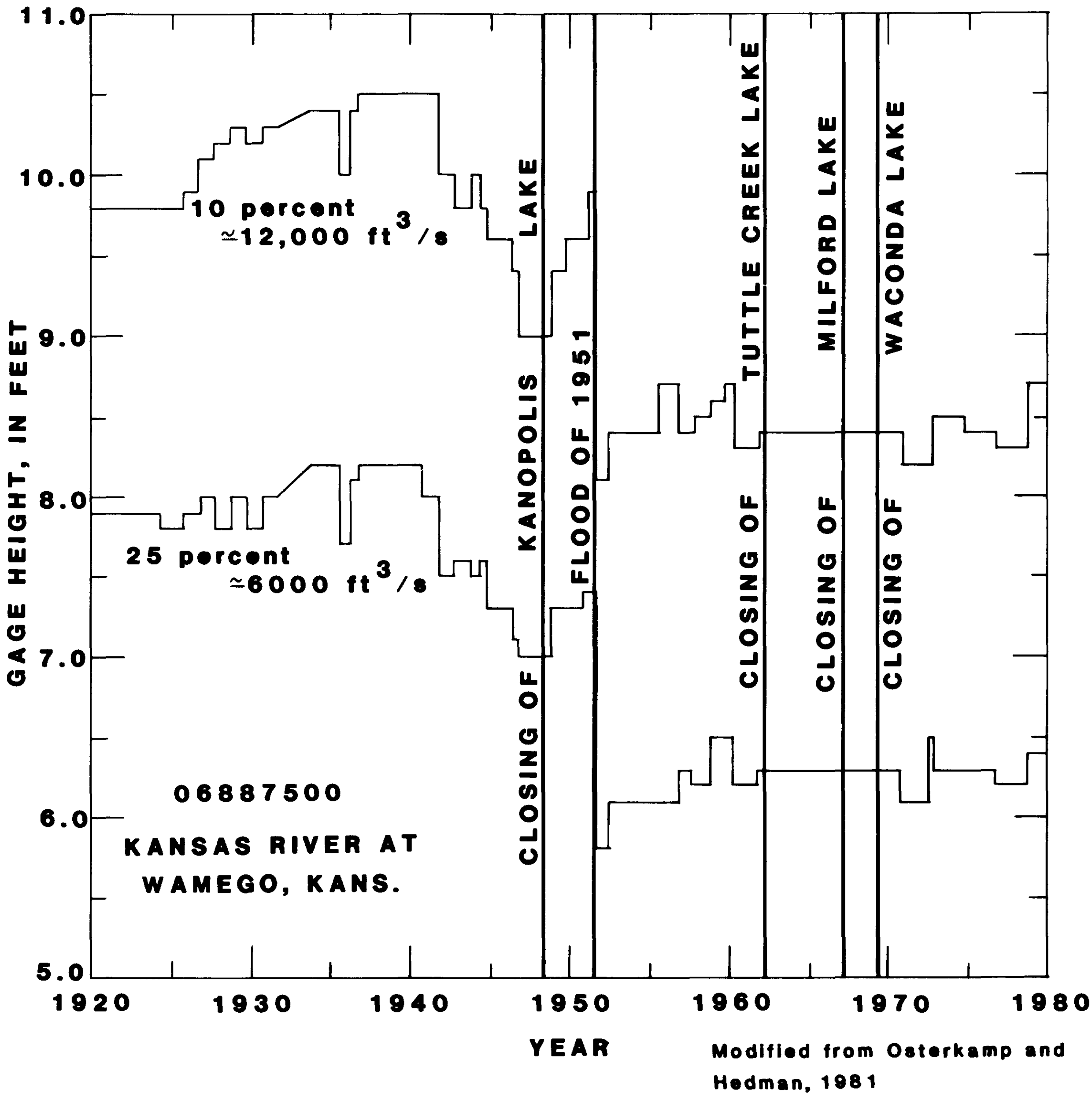


Figure 22.--Stage-time relations corresponding to 25- and 10-percent flow-duration rates for gage site Kansas River at Wamego, Kans.

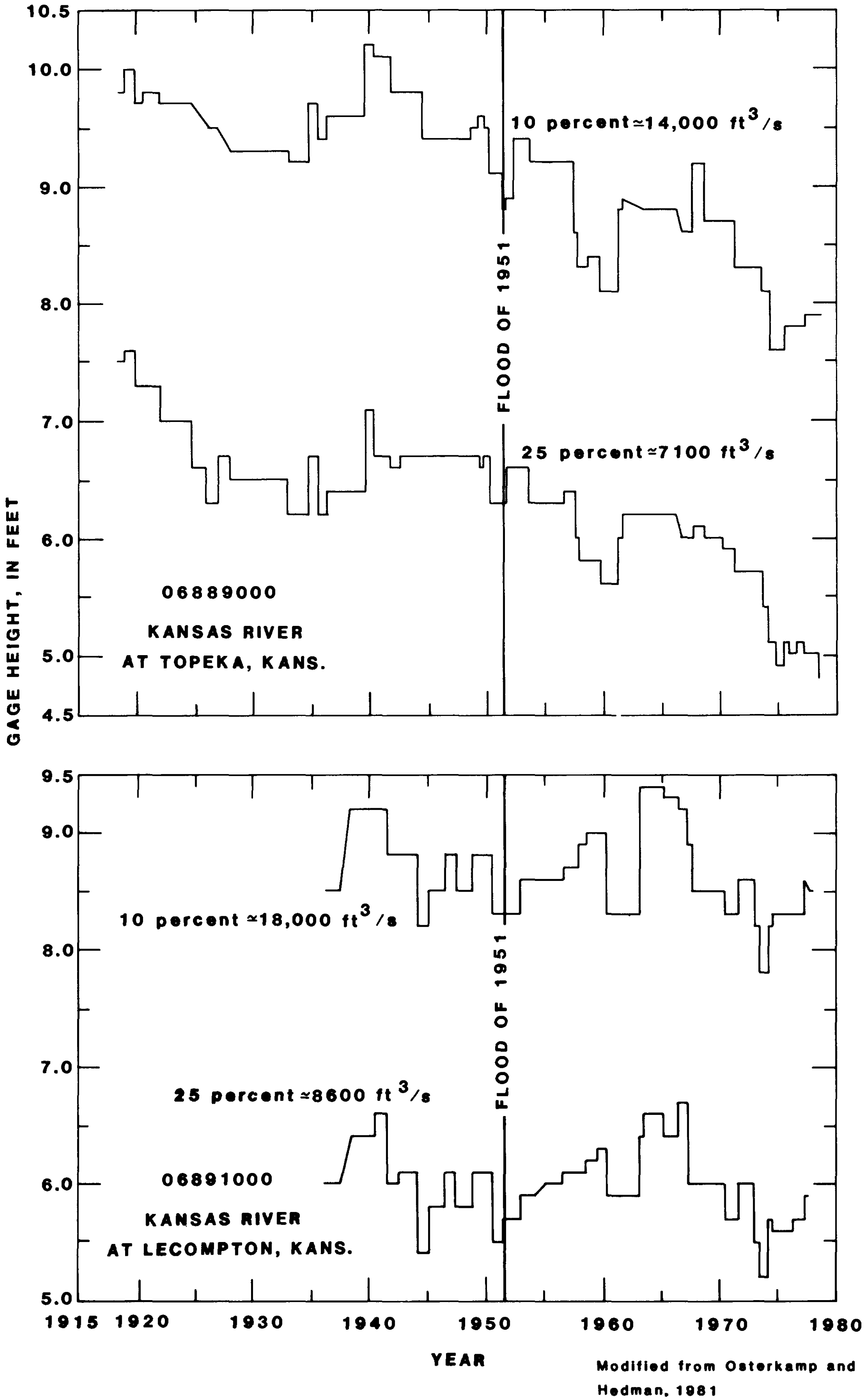


Figure 23.--Stage-time relations corresponding to 25- and 10-percent flow-duration rates for gage sites Kansas River at Topeka, Kans., and Kansas River at Lecompton, Kans.

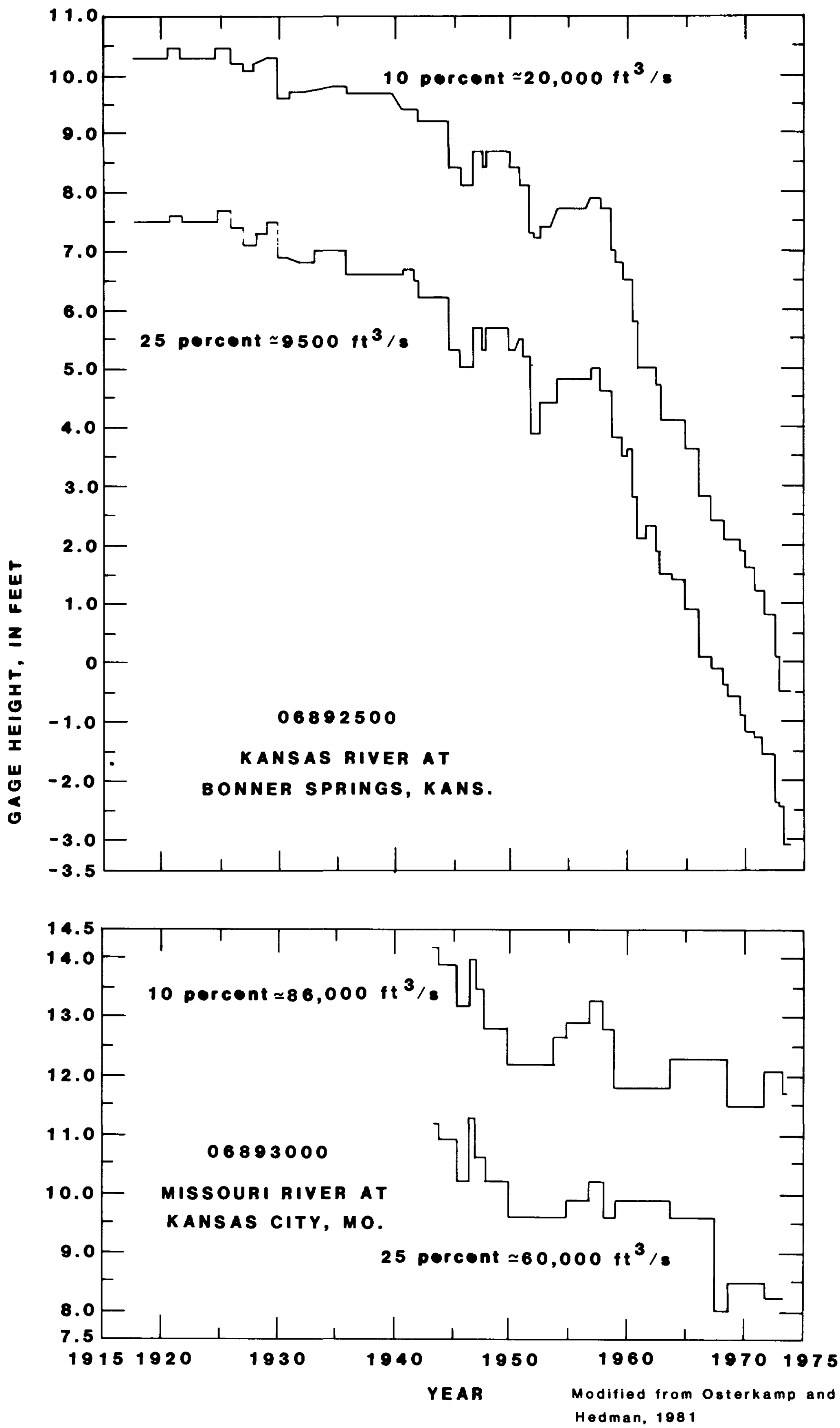


Figure 24.--Stage-time relations corresponding to 25- and 10-percent flow-duration rates for gage sites Kansas River at Bonner Springs, Kans., and Missouri River at Kansas City, Mo.

Records of stage change for flow rates corresponding to 25-percent flow duration show that about 8 feet of channel degradation (as indicated by stage changes) have occurred since 1957 at the Kansas River at Bonner Springs, Kans. A similar reduction of stage has occurred for the 10-percent flow-duration rate (fig. 24). Dredging of sand and gravel has been intensive, but its quantitative effect is not known. To ascertain the part of the degradation that might be attributable to lowering of base level by the Missouri River, stage-time relations also are given for the Missouri River at Kansas City, Mo. In the same period of extensive degradation at Bonner Springs, about 2 feet of scour are indicated for the Missouri River (fig. 24). Only a small part of the lowered bed elevation for the lower Kansas River, therefore, could be the result of base-level changes imposed by the Missouri River. The rate of progression of degradation upstream from Bonner Springs has been slow, owing to armoring of the bed just upstream from Bonner Springs (information provided by U.S. Army Corps of Engineers).

Of the principal tributaries of the Kansas River, only the Republican River shows substantial degradation. Channel scour has been observed by stream-gaging personnel and indicated by changes in the stage-discharge relation at the gaging station 1.7 miles downstream from Milford Dam. Since the closing of Milford Dam during 1967, the river stage has declined by more than 6 feet at the 25-percent flow-duration rate (fig. 16). Similar stage declines at the 10-percent flow-duration rate (fig. 16) indicate that bank erosion has not been significant.

SYNOPSIS OF FLUVIAL PROCESSES

The onsite data and other measurements available for the Kansas River system permit various generalizations regarding the fluvial processes occurring at present (1980). The data also lead to comparisons of current channel dynamics with those of preregulation. The generalizations are divided into observations directly supported or indicated by data and inferences that appear to be reasonable conclusions of the data assembled for this report. The generalizations presented here refer mostly to the entire Kansas River system or to large reaches of the major streams. It is recognized that bank erosion and deposition can occur concurrently at different sites in the same reach. Thus, the generalizations refer to the net changes that occur through substantial stream lengths.

Observations

Sediment Yields

Sediment yields per unit area in the Kansas River basin show a general increase from west to east and reflect changes across the basin in runoff rates, topography, and geology. The major reservoirs of the basin store most fluvial sediment from upstream sources and thereby change the contributing drainage-basin areas for sediment yields. These changes, which have been imposed on the Kansas River system at irregular times through the last three decades, represent complexities that make evaluation of the effects of reservoirs on areal sediment yields very difficult.

The apparent effect of the various impoundments on sediment yields from preregulated conditions has not been consistent. Where sediment yields from contributing basin areas have increased, however, the increases apparently are the result of channel rather than upland erosion. In some instances there is little doubt that construction activities for a reservoir temporarily have increased the sediment supply available for transport. Where sediment yields have been reduced from those of preregulated conditions, several factors probably contribute to the reduction. The factors include the combined effects of reduced sediment by storage in upstream reservoirs and streamflow regulation, which eliminates erosive discharges and possibly permits the storage of part of the available fluvial sediment as channel and flood-plain alluvium downstream from a reservoir. Another possible cause of reduced sediment yields is the increasing use with time of agricultural practices that minimize sediment discharge from croplands.

Owing to differences in runoff rates preceding and following the construction of several reservoirs, the effect of regulation on suspended-sediment concentrations is difficult to assess directly. Data listed in tables 1 and 2, however, indicate that sediment loads (unadjusted for area) after reservoir closures generally have been smaller than those before closures. Using the Kansas River at Wamego, Kans., as an example, suspended-sediment loads since 1967 have been about one-half those of 1957 to 1967. At the Tescott, Enterprise, and Wamego gage sites, therefore, evidence indicates that storage of fluvial sediment in upstream reservoirs is resulting in decreased suspended-sediment concentrations downstream from the reservoirs.

Particle-size analyses of suspended sediment and bed material from the Solomon, Saline, Smoky Hill, and Kansas Rivers (figs. 11 and 12) show that reservoir construction has had little or no effect on size distributions of fluvial sediment in the Kansas River basin. Virtually all suspended sediment (by weight) taken from the rivers, regardless of the time of sampling, has been less than 0.3 mm in diameter and most has been less than 0.01 mm in diameter (fine silt and clay sizes). Median particle sizes of bed material in the Kansas River apparently are slightly greater than those of the major tributaries. Almost all bed material from regulated reaches of the Kansas River system is of sand to fine-gravel size (figs. 11 and 12). Channel scour downstream from reservoirs, which commonly washes the relatively fine bed sizes downstream and thereby coarsens the median particle size of bed material, is not producing measurable size changes in the Kansas River system. Significant scour has occurred in the channel of the Republican River downstream from Milford Dam (fig. 16), but the effect of the scour, if any, on particle sizes of the Kansas River bed is not known.

The channel widths, relative to mean discharge and sediment characteriistics, of downstream reaches of the Solomon, Saline, and Smoky Hill Rivers are more narrow than those of similar unregulated streams. Channels of this type are capable of transporting only small amounts of coarse sediment. Many sites of the Kansas River channel are relatively wide, locally braided (except during high flow), and have greatly variable geometry in the downstream direction, possibly indicating general instability. Some parts of the Kansas River, as indicated by channel islands, have shown a tendency towards wide, braided channels for periods predating flood-plain development. Recent channel widening and braiding may be associated with flood-plain activities and modifications of the water and sediment discharges for the Kansas River. Any activity that disturbs the alluvium and removes vegetation reduces the resistance to erosion and releases both fine and coarse sediment to the river. Gravel bars formed from the coarse fraction under some conditions may promote local widening of the channel.

When compared to a previously determined width-discharge relation for unregulated-stream channels of similar sediment characteristics in the Missouri River basin (Osterkamp and Hedman, 1982), channel sites of the Kansas River are mostly wide relative to mean discharge (fig. 13). At least some of the exceptions occur at sites where a narrow channel is maintained artificially. To provide a general representation of wide reaches of the Kansas River, the data of table 3 were compared with line B of figure 13. Those sites with measured widths at least 25-percent greater than predicted by line B (fig. 13) were plotted in figure 25. The wide reaches indicated in figure 25 have not necessarily had recent bank erosion but are excessively wide compared with unregulated but otherwise similar channels of the Missouri River basin.

Also shown in figure 25 are reaches of the Kansas River designated by Dort (1979) as having been active during the last century. The term active signifies that substantial lateral channel movement, as indicated by previous channel positions, has occurred during the last 100 years. Although the presently wide reaches of the Kansas River do not in all instances coincide with the reaches that have been historically active, there are obvious similarities (fig. 25). Therefore, it is inferred that, for reasons not understood, several specific (active) reaches of the Kansas River are very susceptible to channel change whenever the variables that determine channel geometry are altered. Prior to recent decades, the variations causing channel activity probably were natural occurrences; recent activity could be either of natural or imposed causes.

Temporal Variation of Discharge

Variation through time of the discharge characteristics is, of course, a possible cause for the historical activity and present instability at various sites along the Kansas River. Long-term trends or changes in mean discharge or total runoff for the Kansas River gage sites are not apparent, although mean discharges during 1970-79 have been moderately greater than during 1920-79 (table 5).

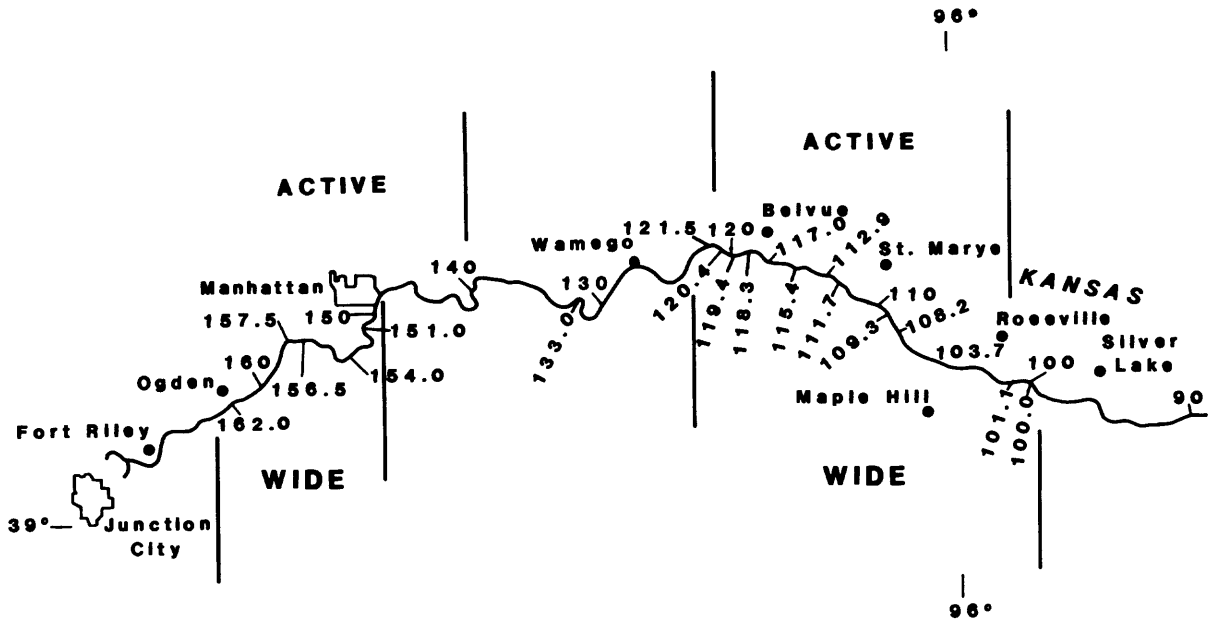
In recent decades, the frequency of large erosive flood discharges has been reduced in the Kansas River. The frequency has been reduced more in the downstream reaches of the Republican, Solomon, Saline, and Smoky Hill Rivers than in the Kansas River because of extensive regulation. The annual occurrences of flows exceeding the long-term discharge rates corresponding to a 2-percent flow duration probably have increased due to sustained release periods from the various reservoirs. For three Kansas River sites, mean daily discharges normally equaled or exceeded the 2-percent flow-duration rate five to six times per year before closure of Kanopolis Dam. Since closure, the 2-percent rate normally has been equaled or exceeded 9 to 10 times per year (table 5). In other words, regulation of the Kansas River has caused a reduction of very large, short-duration discharges by releasing the water over longer periods of time and thereby increasing the frequency of moderately large flows.

Table 5.--Selected discharge characteristics for Kansas River gage sites

[Data from various water-resources data reports of the U.S. Geological Survey]

Water years	Wamego, Kans.	Topeka, Kans.	Bonner Springs/ DeSoto, Kans.
	Mean discharge, in cubic feet per second		
1970-79	5,410	6,230	8,320
1960-79	5,290	5,960	7,900
1950-79	5,470	6,090	7,830
1940-79	5,670	6,350	8,100
1930-79	5,130	5,750	7,300
1920-79	4,890	5,490	7,000
	Days per year $Q_D \geq Q_{2\%}$ [a]		
1920-48	5.2	5.5	5.6
1949-79	9.1	9.0	9.4

[a] Provides frequency, in days per year, that the discharge for a day, Q_D, equaled or exceeded the discharge $Q_{2\%}$, corresponding to a 2-percent flow-duration rate for 1920-79.



EXPLANATION

101.1

Number indicates river miles from mouth of Kansas River

◇

Known sand and gravel operation

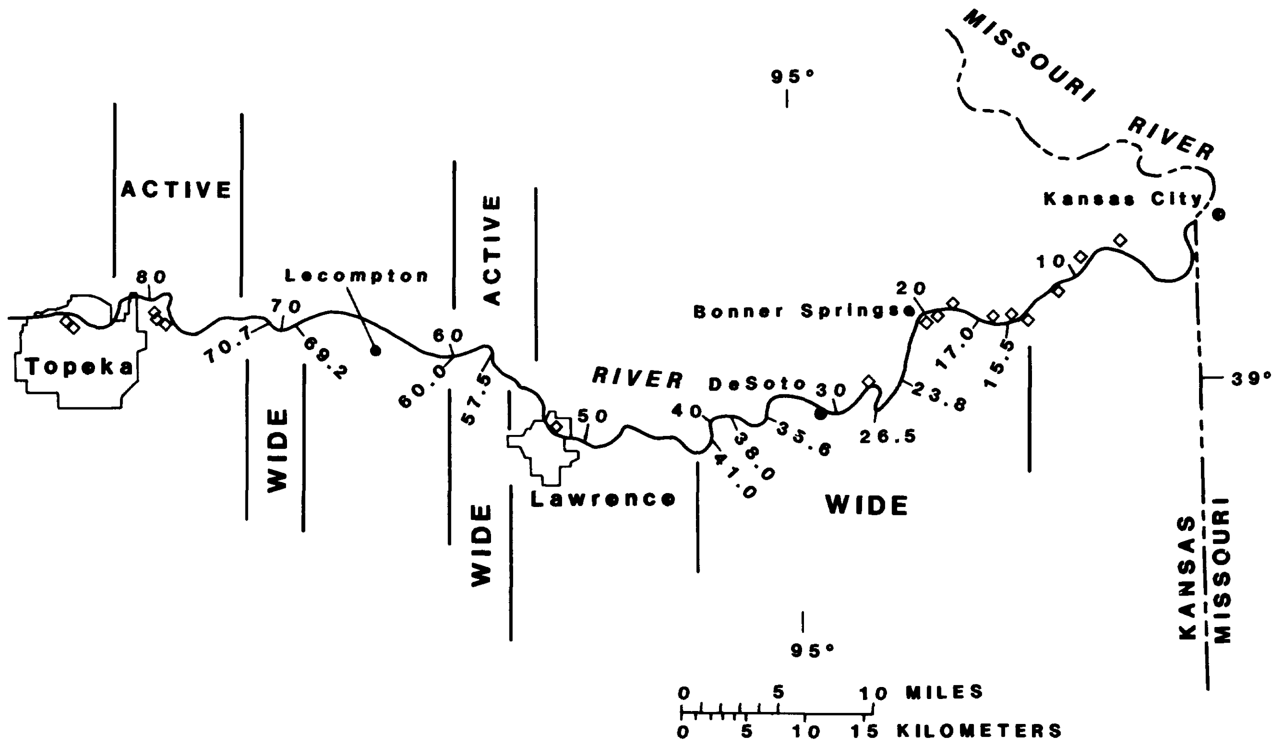


Figure 25.--Kansas River channel reaches identified as being historically active (modified from Dort, 1979) and presently wider than comparable, unregulated channels.

The effect of this change in flow regimen on the channel geometry of the Kansas River is unclear. However, experience with numerous streams of the western United States indicates that discharges representing a 1- to 2-percent flow duration normally cause little channel widening. Most erosion of otherwise stable channels commonly happens during flows that have an average occurrence of less than once per year.

Channel scour at most gage sites downstream from reservoirs in the Kansas River basin has been 3 feet or less. Exceptions are a degradation of 6 feet in the Republican River downstream from Milford Dam and a degradation of 8 feet in the Kansas River at Bonner Springs, Kans. (figs. 16 and 24). Channel degradation has not been sufficient at any site to affect significantly the gradient of the Kansas River or its major tributaries throughout a river length of 20 miles or more. When compared to gradient-discharge relations for Kansas streams in general (fig. 15), channel gradients in the downstream reaches of the Solomon, Saline, and Smoky Hill Rivers are indicative of relatively stable conditions. A similar comparison indicates that gradients of many Kansas River reaches are representative of wide, commonly braided channel conditions.

CONCLUSIONS

Integration of the data and various observations lead to interpretations of the current processes occurring in the Kansas River system, their possible causes, and continuing trends. It is emphasized that several of these conclusions are interpretations of the data and differing interpretations may be justified. They are, however, consistent with specific knowledge of the Kansas River system and with general fluvial processes.

1. Prior to reservoir construction and other intensive flood-plain activity in the Kansas River system, channel conditions of the Kansas River were indicative of frequent changes. Either natural or manmade changes in the characteristics of water or sediment discharge, therefore, were likely to produce additional channel changes. The most probable sites for changes to occur were those where the Kansas River channel has been historically active.

2. Channel-migration studies have demonstrated that the Kansas River channel has been subject to rapid lateral movement in recent centuries. Channel changes presently occurring at historically active sites, therefore, cannot be assumed purely the result of imposed stresses on the Kansas River system.

3. Reservoirs of the Kansas River basin trap and store large amounts of sediment that would otherwise be transported by the Kansas River. Water released from the reservoirs is nearly sediment-free and has a tendency to acquire a sediment load consistent with discharge and channel conditions. The downstream reaches of the Solomon, Saline, and Smoky Hill Rivers have relatively cohesive banks and channel shapes and gradients appropriate for transporting only small amounts of coarse sediment (sand and gravel) and thus have little susceptibility to erosion by the regulated streamflows.

However, the Republican River is wide, relatively steep, and capable of transporting large quantities of coarse sediment, and substantial channel degradation has occurred downstream from Milford Dam. Because the reservoirs are on tributaries rather than on the Kansas River itself, the effects of the reservoirs are less pronounced on the Kansas River than on the Republican. However, the natural response of the Kansas River to the reduction of the inflow of coarse sediment is to reduce its gradient. Reduction of gradient may be accomplished by degrading the bed or by lengthening the channel, which would involve eroding some banks to form larger or more numerous meanders.

4. Regulation of streamflow in the Kansas River system reduces the occurrences of very large flow rates that normally are channel-widening or erosive. The availability and particle sizes of sediment downstream from a reservoir largely determine whether the reduced streamflow has a narrowing or a widening effect on a channel. In the Kansas River, the narrowing effect of stable discharge is counteracted by the suspended-sediment deficiency of the water, and erosion can occur locally at discharge rates that otherwise would be nonerosive.

5. Urbanization, highway construction, sand and gravel operations, and similar human activities on the Kansas River flood plain probably are aggravating the tendency toward local, short-term channel changes. Any flood-plain activity that disturbs the Kansas River alluvium and removes vegetation lessens the resistance to erosion and releases both fine and coarse sediment to the river. The fine fraction is transported through the Kansas River system, whereas the coarse fraction is added to the bed load. Gravel bars formed from the bed load under certain conditions may in turn promote further channel changes, particularly local widening.

6. Channel degradation of the Kansas River at Bonner Springs, Kans., is closely related to the extraction of sand and gravel. No more than a small part of the degradation could be the result of recent degradation in the channel of the Missouri River at Kansas City, Mo. Historically, the Kansas River in the vicinity of Bonner Springs has not been unusually active. The reach, however, is presently wider than normal. Much of the upstream channel adjustment in response to the degradation at Bonner Springs has been widening rather than a progressive extension of the degradation in the upstream direction because of armoring of the bed just upstream.

7. The reduction of sediment supply to the Kansas River favors a long-term trend (decades to centuries) of reduction of channel gradient. If the Kansas River remains sediment deficient in the silt and clay sizes, the gradient reduction is likely to occur principally by channel degradation. If supplies of fine sediment approximating those of preregulated conditions become available to the river, gradient reduction can be expected to occur principally by increased meandering (channel lengthening). Any human activities that further shorten the channel length of the Kansas River, reduce its sediment load, or artificially narrow or degrade the present channel are expected to intensify the tendency for further channel changes. An imposed lengthening of the channel or an increase in the supply of sediment are expected to reduce the tendency for channel changes.

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