EVALUATION OF THE COST EFFECTIVENESS OF THE 1983 STREAM-GAGING PROGRAM IN KANSAS

By K. D. Medina and C. O. Geiger

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CONVERSION TABLE

Factors for converting the inch-pound units given in this report to the International System (SI) of Units are given below:

Multiply inch-pound unit	By	To obtain SI units
	Length	
mile	1.609	kilometer
	Area	
square mile	2.590	square kilometer
	Volume	
cubic foot	0.02832	cubic meter
	Flow	
cubic foot per second	0.02832	cubic meter per second

EVALUATION OF THE COST EFFECTIVENESS OF THE 1983

STREAM-GAGING PROGRAM IN KANSAS

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ABSTRACT

This report documents the results of an evaluation of the cost effectiveness of the 1983 stream-gaging program in Kansas. Data uses and funding sources were identified for the 140 complete-record, streamflow-gaging stations operated in Kansas during 1983 with a budget of $793,780. As a result of the evaluation of the needs and uses of data from the stream-gaging program, it was found that the 140 gaging stations were needed to meet these data requirements.

The average standard error of estimate for records of instantaneous discharge was 21 percent, assuming the 1983 budget and operating schedule of 6-week interval visitations and based on 85 of the 140 stations. It was shown that this overall degree of accuracy could be improved to 19 percent by altering the 1983 schedule of station visitations. A minimum budget of $760,000, with a corresponding average standard error of estimate of 25 percent, is required to operate the 1983 program; a budget of less than this would not permit proper service and maintenance of the stations or adequate definition of stage-discharge relations. The maximum budget analyzed was $1,191,000, which resulted in an average standard error of estimate of 9 percent.

None of the stations investigated were suitable for the application of alternative methods for simulating discharge records. Improved instrumentation can have a very positive impact on streamflow uncertainties by decreasing lost record.

INTRODUCTION

The U.S. Geological Survey is the principal Federal agency collecting surface-water data in the Nation. The data are collected in cooperation with State and local governments and with other Federal agencies. The Survey is presently (1983) operating approximately 8,000 complete-record, streamflow-gaging stations throughout the Nation. Some of these records extend back to the turn of the 20th century. Any activity of long standing, such as the collection of surface-water data, needs to be re-examined at intervals, if not continuously, because of changes in objectives, technology, or external constraints. The last systematic, nationwide evaluation of the streamflow-information program was completed in 1970 and is documented by Benson and Carter (1973). The Survey is presently (1983) undertaking another nationwide evaluation of the stream-gaging program that will be completed during 5 years with 20 percent of the program being analyzed each year on a State-by-State basis. The objective of this evalution is to define and document the most cost-effective means of providing streamflow information.

For Kansas, a major part of the evaluation was done in cooperation with the Kansas Water Office (formerly the Kansas Water Resources Board), which is the principal State agency supporting the Kansas stream-gaging program.

For every complete-record gaging station, the evaluation identified the principal uses of the data and related these uses to funding sources. In addition, gaging stations were categorized as to whether the data were available to users by telemetry for immediate use, by release on a provisional basis, or at the end of the water year.

The second part of this evaluation was to identify less costly alternative methods of providing the needed information. Among these methods are streamflow-routing models and statistical analysis. The Kansas stream-gaging program no longer is considered as a network of observation points, but rather as an integrated information system in which data are provided both by observation and synthesis.

The final part of the evaluation involved the use of Kalman-filtering and mathematical-programing techniques to define strategies for operation of the necessary stations that minimized the uncertainty in the streamflow records for given operating budgets. Kalman-filtering techniques (Moss and Gilroy, 1980) were used to compute uncertainty functions by relating the standard errors of computation or estimation of streamflow records to the frequencies of visits to the stream gages for all stations in the analysis. A steepest-descent optimization program used these uncertainty functions, information on practical stream-gaging routes, the various costs associated with stream gaging, and the total operating budget to identify the visit frequency for each station that minimized the overall uncertainty in the streamflow record. A stream-gaging program that resulted from this evaluation should meet the expressed water-data needs in the most cost-effective manner.

This report is organized into five sections, the first being an introduction to the stream-gaging activities in Kansas and to the study itself. The middle three sections each contain discussions of individual parts of the evaluation. The study is summarized in the final section.

History of Stream-Gaging Program in Kansas

A graphic history of the number of complete-record, streamflow-gaging stations in operation in Kansas since water year 1895 is shown in figure 1. The records from these stations consist of daily streamflows obtained from operation at selected sites. Only a few records were collected until about 1920 (fig. 1), when several new stations began operation, and an effort was made to establish a more permanent and continuous data-collection program. There was a further expansion beginning in about 1940, when additional stream-gaging stations were started in an attempt to define areal variations in streamflow, to collect data specifically required by Federal agencies, to manage water supplies, and to define the magnitude and frequency of floods in critical areas.

The need for a more specific plan for collecting streamflow data was recognized about 1954, when it was shown that little useful hydrologic information was added after sufficient records had been collected to establish the relation of runoff at the station to runoff at a key streamflow station. The U.S. Geological Survey and the Kansas Water Office joined in a cooperative program to investigate the degree of accuracy with which streamflow characteristics can be defined, how much data are needed, and the most economical method of obtaining the data. From the resulting report (Furness, 1957), an improved program of stream gaging was formulated during 1957 and began operation in fiscal year 1960.

The Kansas Water Office again entered into a cooperative program with the U.S. Geological Survey during 1970 to re-evaluate the 1957 plan for Kansas. As a result of this study (Jordan and Hedman, 1970), several complete-record stations were discontinued in the next few years. Some of these stations subsequently were replaced by partial-record stations.

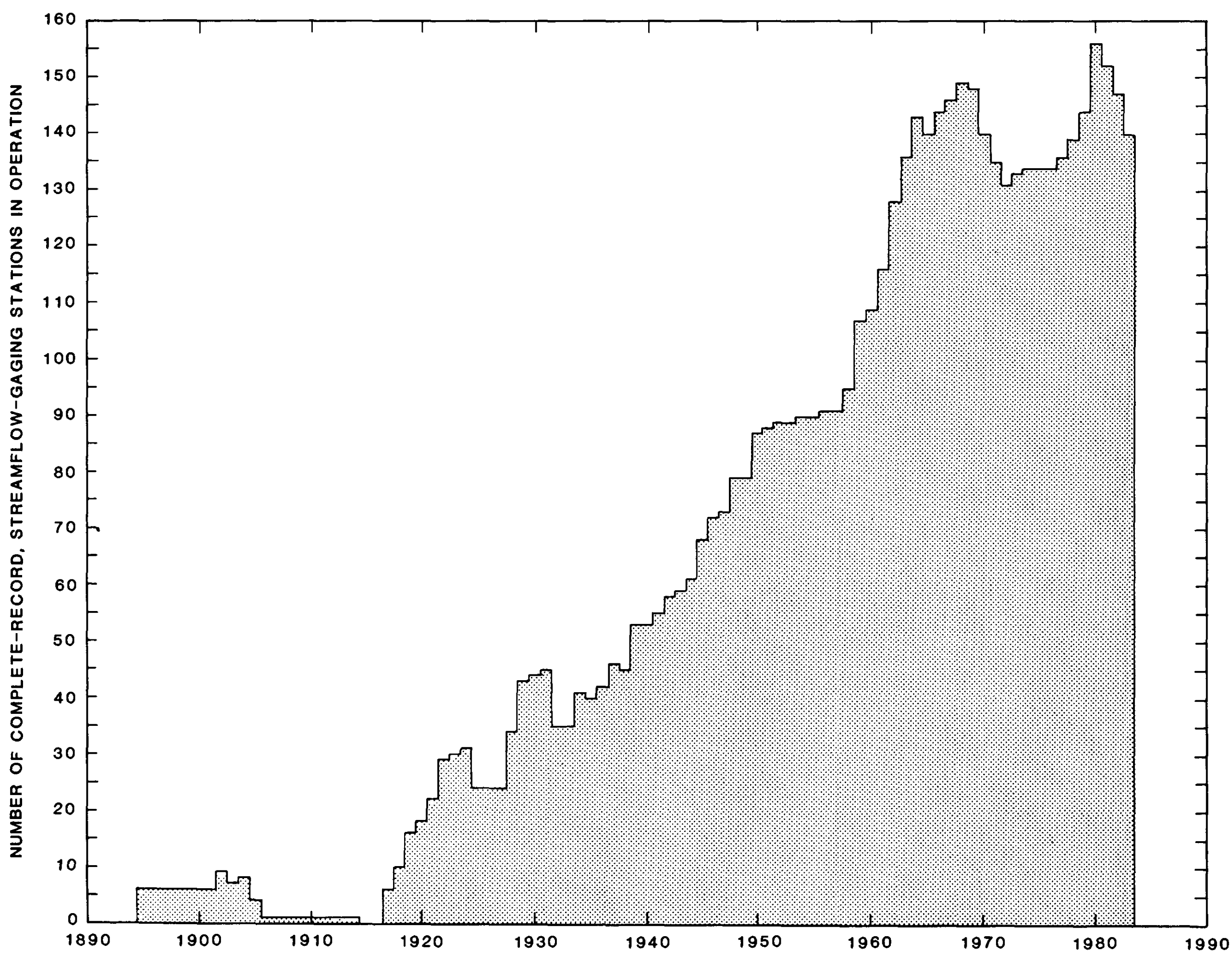


Figure 1.--Number of complete-record, streamflow-gaging stations in operation in Kansas, water years 1895-1983.

As shown in figure 1, an increase in the number of complete-record stations occurred during 1980. This was the result of a substantial increase in the number of stations operated for specific project information. These stations subsequently have been discontinued, and the level of operation now has returned to a network similar to that of the mid-1970's.

Stream-Gaging Program in Kansas, 1983

The stream-gaging program in Kansas is operated and maintained from two offices of the Geological Survey, a Subdistrict office in Garden City and a Field Headquarters office in Lawrence, which also is the location of the District office. The general area of responsibility for 1983 program operation, as well as the location and distribution of the 140 complete-record stations, is shown in figure 2. The 1983 program also included systematic collection of information on annual peak discharge, seasonal precipitation, river stage, and reservoir contents at 137 additional sites in the State. The U.S. Geological Survey number and name for each complete-record gaging station in the 1983 stream-gaging program, as well as selected hydrologic data that include drainage area, period of record, and mean annual flow, are given in table 1. Station-identification numbers used throughout this report are based on a downstream-order numbering system used by the Survey.

DATA USES, FUNDING, AND AVAILABILITY FROM STREAM-GAGING PROGRAM

Data-Use Categories

The relevance of a gaging station is defined by the uses that are made of the data collected at the station. The data uses from each complete-record station in the 1983 Kansas program were identified by a survey of known data users. The survey documented the importance of each station and provided for the identification of those gaging stations that could be considered for discontinuation. Data-use and ancillary information are presented for each complete-record station in table 2, which contains an explanation on each page to expand the information conveyed. The entry of an asterisk in the table indicates that no additional explanation is required. Data uses identified by the survey were placed in the nine categories defined below.

Regional Hydrology

For streamflow data to be useful in defining regional hydrology, a stream must be largely unaffected by manmade storage or diversion. In this category of use, the effects of man on streamflow are not necessarily insignificant, but the effects are limited to those caused primarily by land use and climatic changes. Large quantities of manmade storage can occur in the basin, providing the outflow from storage is uncontrolled.

Stations in this category are useful in developing regionally transferable information about the relationship between basin characteristics and streamflow.

Seventy-three stations in the 1983 Kansas program were listed in the regional-hydrology data-use category. One of these stations was a hydrologic bench-mark station, which served as an indicator of hydrologic conditions in watersheds relatively free of manmade alteration. Forty-two of the stations, located in different areas of the State, were long-term-trend index stations and also were used to indicate current streamflow conditions.

Hydrologic Systems

Hydrologic-systems stations were those that accounted for or helped to define current streamflow conditions and to identify the sources and flows of water in various hydrologic systems, including those under regulation. The bench-mark and trend index stations were included in the hydrologic-systems category because they also accounted for current and long-term conditions of the hydrologic systems that they gaged. Stations that measured reservoir inflow and outflow, provided information for the adjudication of water rights, and quantified streamflow diversions also were included in this category.

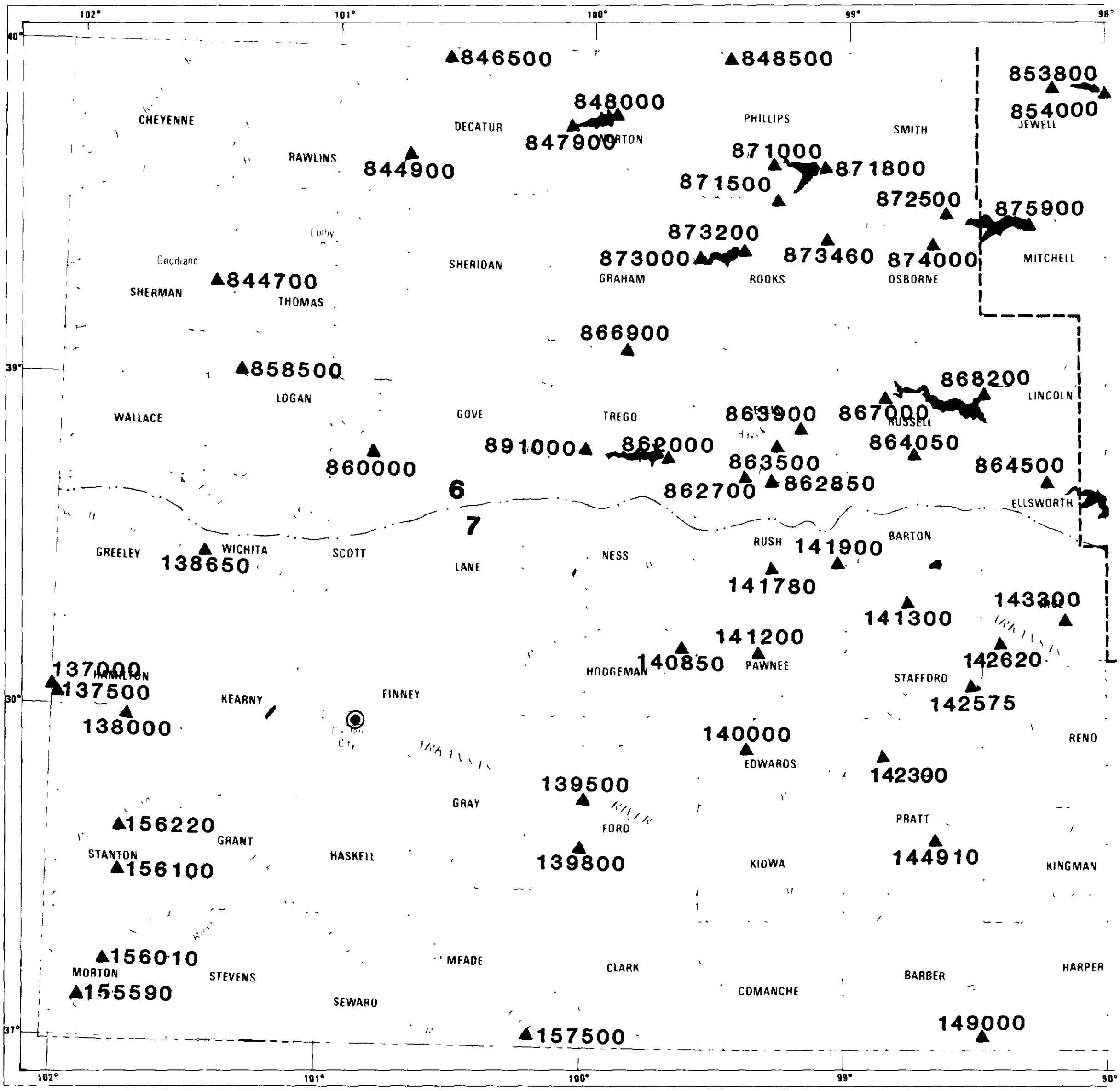
Twenty-two complete-record stations in the 1983 Kansas stream-gaging program were used to determine reservoir inflow, whereas 23 stations were used for reservoir-outflow determinations. Fifteen stations were used for adjudication of water rights, 7 for diversion quantification, and 1 for canal-diversion measurements.

Legal Obligations

Some stations in the 1983 stream-gaging program provided records of flows for the verification or enforcement of existing treaties, compacts, and decrees. The legal-obligation category contained only those stations that the Survey was required to operate to fulfill a legal responsibility. Five stations in the program were operated because of legal obligations. Three stations were operated to fulfill obligations of the Republican River Compact Administration, and two stations were operated to fulfill obligations of the Arkansas River Compact Administration.

Planning and Design

Gaging stations in this category of data use were used for the planning and design of a specific structure or group of structures (for example, a dam, levee, floodwall, navigation system, water-supply diversion, hydropower plant, or waste-treatment facility). The planning-and-design category was limited to those stations that were instituted for such purposes and where this purpose was still valid. The U.S. Bureau of Reclamation used the data from two stations in the 1983 program as a basis for planning and design.



EXPLANATION

------- BOUNDARY OF PROGRAM RESPONSIBILITY

▲ 887500 COMPLETE-RECORD STATION AND NUMBER

··——·· BASIN BOUNDARY

7 ARKANSAS RIVER BASIN

6 MISSOURI RIVER BASIN

◉ DISTRICT OFFICE AND LAWRENCE FIELD HEADQUARTERS

◉ GARDEN CITY SUBDISTRICT OFFICE

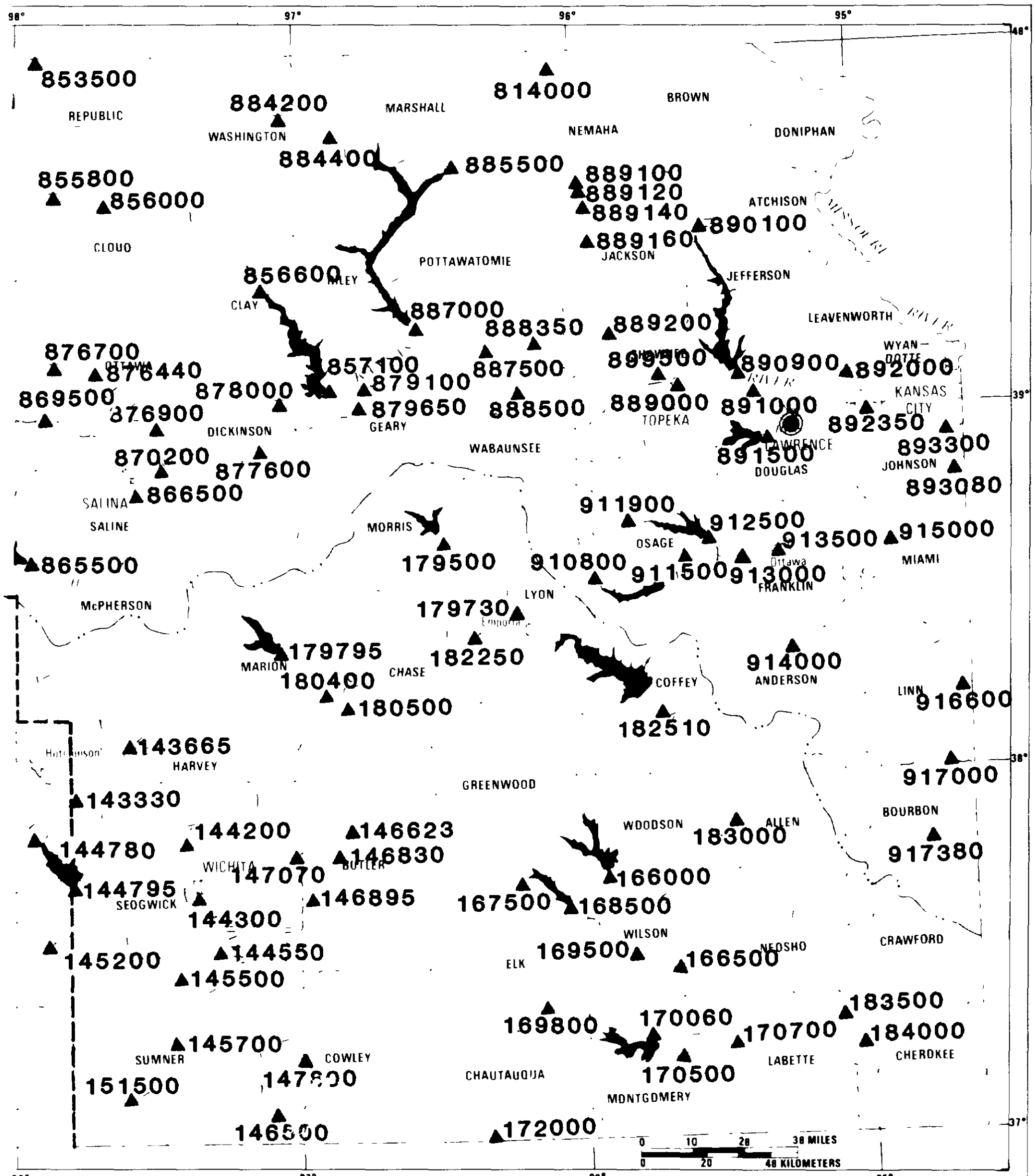


Figure 2.--Area of program responsibility and location of complete-record, streamflow-gaging stations, water year 1983.

Table 1.--Selected hydrologic data from complete-record stations in the 1983 Kansas stream-gaging program
[Data from Geiger and others, 1983]

Station number	Station name	Drainage area (square miles)	Period of record	Mean annual flow (cubic feet per second)
06814000	Turkey Creek near Seneca	276	October 1948 to...	124
06844700	South Fork Sappa Creek near Brewster	74	October 1967 to...	0.25
06844900	South Fork Sappa Creek near Achilles	446	July 1959 to...	4.54
06846500	Beaver Creek at Cedar Bluffs	1,618	October 1945 to...	18.1
06847900	Prairie Dog Creek above Keith Sebelius Lake	590	June 1962 to...	9.66
06848000	Prairie Dog Creek at Norton	684	October 1943 to...	24.5
06848500	Prairie Dog Creek near Woodruff	1,007	October 1928 to September 1932, October 1944 to...	35.4
06853500	Republican River near Hardy, Nebr.	22,401	June 1904 to 1/ September 1915, April 1931 to...	571
06853800	White Rock Creek near Burr Oak	227	October 1957 to...	24.4
06854000	White Rock Creek at Lovewell	345	October 1945 to...	(2)
06855800	Buffalo Creek near Jamestown	330	July 1959 to...	67.5
06856000	Republican River at Concordia	23,560	October 1945 to...	708
06856600	Republican River at Clay Center	24,542	June 1917 to...	991
06857100	Republican River below Milford Dam	24,890	October 1963 to...	837
06858500	North Fork Smoky Hill River near McAllaster	670	October 1946 to September 1953, July 1959 to...	3.76
06860000	Smoky Hill River at Elkader	3,555	October 1939 to...	30.8
06861000	Smoky Hill River near Arnold	5,220	February 1950 to...	58.0
06862000	Smoky Hill River at Cedar Bluff Dam	5,530	February 1952 to...	(2)
06862700	Smoky Hill River near Schoenchen	5,750	July 1964 to...	29.4
06862850	Smoky Hill River below Schoenchen	5,810	October 1981 to...	(3)

Table 1.--Selected hydrologic data from complete-record stations in the 1983 Kansas stream-gaging program--Continued

Station number	Station name	Drainage area (square miles)	Period of record	Mean annual flow (cubic feet per second)
06863500	Big Creek near Hays	594	April 1946 to...	36.3
06863900	North Fork Big Creek near Victoria	54	April 1962 to...	3.57
06864050	Smoky Hill River near Bunker Hill	7,075	October 1939 to...	183
06864500	Smoky Hill River at Ellsworth	7,580	April 1895 to October 1905, July 1918 to July 1925, August 1928 to...	248
06865500	Smoky Hill River near Langley	7,857	October 1940 to...	318
06866500	Smoky Hill River near Mentor	8,358	December 1923 to October 1930, May 1931 to June 1932, October 1947 to...	404
06866900	Saline River near WaKeeney	696	October 1955 to September 1966, October 1981 to...	4/37.7
06867000	Saline River near Russell	1,502	October 1945 to September 1953, June 1959 to...	98.8
06868200	Saline River at Wilson Dam	1,917	March 1963 to...	44.1
06869500	Saline River at Tescott	2,820	September 1919 to...	212
06870200	Smoky Hill River at New Cambria	11,730	October 1962 to ...	599
06871000	North Fork Solomon River at Glade	849	October 1952 to...	28.3
06871500	Bow Creek near Stockton	341	November 1950 to...	13.6
06871800	North Fork Solomon River at Kirwin	1,367	August 1919 to June 1925, August 1928 to June 1932, December 1941 to...	(2)
06872500	North Fork Solomon River at Portis	2,315	September 1945 to...	127

Table 1.--Selected hydrologic data from complete-record stations in the 1983 Kansas stream-gaging program--Continued

Station number	Station name	Drainage area (square miles)	Period of record	Mean annual flow (cubic feet per second)
06873000	South Fork Solomon River above Webster Reservoir	1,040	January 1945 to...	61.8
06873200	South Fork Solomon River below Webster Reservoir	1,150	October 1956 to...	40.5
06873460	South Fork Solomon River at Woodston	1,502	October 1978 to...	(3)
06874000	South Fork Solomon River at Osborne	2,012	March 1946 to...	114
06875900	Solomon River near Glen Elder	5,340	October 1964 to...	145
06876440	Solomon River near Minneapolis	6,060	October 1978 to...	(3)
06876700	Salt Creek near Ada	384	June 1959 to...	60.2
06876900	Solomon River at Niles	6,770	May 1897 to November 1903, October 1917 to...	555
06877600	Smoky Hill River at Enterprise	19,260	October 1934 to...	1,571
06878000	Chapman Creek near Chapman	300	December 1953 to...	86.1
06879100	Kansas River at Fort Riley	44,870	December 1963 to...	2,618
06879650	Kings Creek near Manhattan	4.09	April 1979 to...	(3)
06884200	Mill Creek at Washington	344	October 1959 to...	97.8
06884400	Little Blue River near Barnes	3,324	April 1958 to...	644
06885500	Black Vermillion River near Frankfort	410	October 1953 to...	144
06887000	Big Blue River near Manhattan	9,640	May to July 1951, October 1954 to...	2,007
06887500	Kansas River at Wamego	55,280	January 1919 to...	4,874
06888350	Kansas River near Belvue	55,870	September 1982 to...	(3)
06888500	Mill Creek near Paxico	316	December 1953 to...	170
06889000	Kansas River at Topeka	56,720	April to August 1904, June 1917 to...	5,438

Table 1.--Selected hydrologic data from complete-record stations the 1983 Kansas stream-gaging program--Continued

Station number	Station name	Drainage area (square miles)	Period of record	Mean annual flow (cubic feet per second)
06889100	Soldier Creek near Goff	2.06	March 1964 to...	1.26
06889120	Soldier Creek near Bancroft	10.5	March 1964 to...	6.06
06889140	Soldier Creek near Soldier	16.9	March 1964 to...	9.45
06889160	Soldier Creek near Circleville	49.3	March 1964 to...	31.5
06889200	Soldier Creek near Delia	157	October 1958 to...	93.9
06889500	Soldier Creek near Topeka	290	May 1929 to September 1932, August 1935 to...	143
06890100	Delaware River near Muscotah	431	July 1969 to...	271
06890900	Delaware River below Perry Dam	1,117	March 1969 to...	681
06891000	Kansas River at Lecompton	58,460	January to November 1896, April to July 1906, March 1936 to...	6,940
06891500	Wakarusa River near Lawrence	425	April 1929 to...	196
06892000	Stranger Creek near Tonganoxie	406	April 1929 to...	225
06892350	Kansas River at DeSoto	59,756	July 1917 to...	6,956
06893080	Blue River near Stanley	46	October 1974 to...	22.1
06893300	Indian Creek at Overland Park	26.6	March 1963 to...	24.6
06910800	Marais des Cygnes River near Reading	177	May 1969 to...	113
06911500	Salt Creek near Lyndon	111	September 1939 to...	60.8
06911900	Dragoon Creek near Burlingame	114	March 1960 to...	66.1
06912500	Hundred and Ten Mile Creek near Quenemo	322	September 1939 to...	174
06913000	Marais des Cygnes River near Pomona	1,040	July 1922 to February 1938, October 1968 to...	499
06913500	Marais des Cygnes River near Ottawa	1,250	August 1902 to October 1905, October 1918 to...	645

Table 1.--Selected hydrologic data from complete-record stations in the 1983 Kansas stream-gaging program--Continued

Station number	Station name	Drainage area (square miles)	Period of record	Mean annual flow (cubic feet per second)
06914000	Pottawatomie Creek near Garnett	334	October 1939 to...	220
06915000	Big Bull Creek near Hillsdale	147	July 1958 to...	94.3
06916600	Marais des Cygnes River near Kansas-Missouri State line	3,230	October 1958 to...	1,963
06917000	Little Osage River at Fulton	295	November 1948 to...	200
06917380	Marmaton River near Marmaton	292	May 1971 to...	262
07137000	Frontier Ditch near Coolidge	(5)	October 1950 to...	(5)
07137500	Arkansas River near Coolidge	25,410	May to October 1903, March to May 1921, October 1950 to...	176
07138000	Arkansas River at Syracuse	25,763	August 1902 to September 1906, October 1920 to...	311
07138650	White Woman Creek near Leoti	750	October 1966 to...	1.18
07139500	Arkansas River at Dodge City	30,600	October 1902 to September 1906, September 1944 to...	172
07139800	Mulberry Creek near Dodge City	73.8	March 1968 to...	0.98
07140000	Arkansas River near Kinsley	31,066	September 1944 to...	161
07140850	Pawnee River near Burdett	1,091	October 1981 to...	(3)
07141200	Pawnee River near Larned	2,148	April to September 1924, October 1924 to...	71.6
07141300	Arkansas River at Great Bend	34,356	September 1940 to...	323
07141780	Walnut Creek near Rush Center	1,256	October 1969 to...	21.1
07141900	Walnut Creek at Albert	1,410	May 1958 to...	52.8
07142300	Rattlesnake Creek near Macksville	784	October 1959 to...	33.2
07142575	Rattlesnake Creek near Zenith	1,052	May 1973 to...	66.9
07142620	Rattlesnake Creek near Raymond	1,167	April 1960 to...	56.1

Table 1.--Selected hydrologic data from complete-record stations in the 1983 Kansas stream-gaging program--Continued

Station number	Station name	Drainage area (square miles)	Period of record	Mean annual flow (cubic feet per second)
07143300	Cow Creek near Lyons	728	October 1937 to September 1951, October 1961 to...	81.0
07143330	Arkansas River near Hutchinson	38,910	October 1959 to...	594
07143665	Little Arkansas River at Alta Mills	736	June 1973 to...	229
07144200	Little Arkansas River at Valley Center	1,327	June 1922 to...	283
07144300	Arkansas River at Wichita	40,490	July 1934 to...	1,066
07144550	Arkansas River at Derby	40,830	October 1968 to...	1,208
07144780	North Fork Ninnescah River above Cheney Reservoir	787	July 1965 to...	140
07144795	North Fork Ninnescah River at Cheney Dam	901	October 1964 to...	109
07144910	South Fork Ninnescah River near Pratt	117	October 1980 to...	(3)
07145200	South Fork Ninnescah River near Murdock	650	August 1950 to September 1959, June 1964 to...	204
07145500	Ninnescah River near Peck	2,129	October 1937 to...	505
07145700	Slate Creek at Wellington	154	April 1969 to...	57.7
07146500	Arkansas River at Arkansas City	43,713	September 1902 to September 1906, September 1921 to...	1,809
07146623	Walnut River below El Dorado Lake	247	October 1980 to...	(3)
07146830	Walnut River at Highway 54, East of El Dorado	350	October 1981 to...	(3)

Table 1.--Selected hydrologic data from complete-record stations in the 1983 Kansas stream-gaging program--Continued

Station number	Station name	Drainage area (square miles)	Period of record	Mean annual flow (cubic feet per second)
07146895	Walnut River at Augusta	452	October 1981 to...	(3)
07147070	Whitewater River at Towanda	426	October 1961 to...	182
07147800	Walnut River at Winfield	1,880	October 1921 to...	784
07149000	Medicine Lodge River near Kiowa	903	May 1895 to October 1896, October 1937 to September 1950, October 1954 to September 1955, June 1959 to...	136
07151500	Chikaskia River near Corbin	794	August 1950 to September 1965, October 1975 to...	205
07155590	Cimarron River near Elkhart	2,899	April 1971 to...	20.5
07156010	North Fork Cimarron River at Richfield	463	April 1971 to...	6.59
07156100	Sand Arroyo Creek near Johnson	619	April 1971 to...	0.31
07156220	Bear Creek near Johnson	835	October 1966 to...	4.78
07157500	Crooked Creek near Nye	1,157	August 1942 to...	39.0
07166000	Verdigris River near Coyville	747	August 1939 to...	492
07166500	Verdigris River near Altoona	1,138	October 1938 to...	703
07167500	Otter Creek at Climax	129	August 1946 to...	75.2
07168500	Fall River near Fall River	585	April 1904 to [6] September 1905, May 1939 to...	331
07169500	Fall River at Fredonia	827	October 1938 to...	462
07169800	Elk River at Elk Falls	220	January 1967 to...	152
07170060	Elk River below Elk City Lake	634	October 1965 to...	381
07170500	Verdigris River at Independence	2,892	August 1895 to September 1904, October 1921 to...	1,657
07170700	Big Hill Creek near Cherryvale	37	October 1957 to...	24.3
07172000	Caney River near Elgin	445	October 1938 to...	233

Table 1.--Selected hydrologic data from complete-record stations in the 1983 Kansas stream-gaging program--Continued

Station number	Station name	Drainage area (square miles)	Period of record	Mean annual flow (cubic feet per second)
07179500	Neosho River at Council Grove	250	October 1938 to...	121
07179730	Neosho River near Americus	622	June 1963 to...	293
07179795	Cottonwood River below Marion Lake	200	July 1968 to...	76.2
07180400	Cottonwood River near Florence	754	June 1961 to...	310
07180500	Cedar Creek near Cedar Point	110	October 1938 to...	53.7
07182250	Cottonwood River near Plymouth	1,740	March 1963 to...	854
07182510	Neosho River at Burlington	3,042	June 1961 to...	1,513
07183000	Neosho River near Iola	3,818	August 1895 to [7] December 1903, October 1917 to...	1,739
07183500	Neosho River near Parsons	4,905	October 1921 to...	2,533
07184000	Lightning Creek near McCune	197	October 1938 to September 1946, October 1959 to...	136

[1] No winter records June 1904 to September 1915.
[2] No mean annual flow published, part of the flow diverted upstream from gage for irrigation.
[3] No mean annual flow published, less than 5 years of streamflow record.
[4] Based on record for October 1955 to September 1966.
[5] No drainage area or mean annual flow published, irrigation canal.
[6] Gage height only, April 1904 to September 1905.
[7] Figures of daily discharge for August 1895 to January 1896 have been determined to be unreliable.

Table 2.--Data use, funding, and frequency of data availability for complete-record stations in the 1983 Kansas stream-gaging program

[A, data provided in annual report; T, data provided by telemetry; P, provisional data provided subject to revision; # and *, no footnote required]

Station number	Data use: Regional hydrology	Data use: Hydrologic systems	Data use: Legal obligations	Data use: Planning and design	Data use: Project operation	Data use: Hydrologic forecasts	Data use: Water-quality monitoring	Data use: Research	Data use: Other	Funding: Federal program	Funding: Other Federal agency program	Funding: Federal-non-Federal program	Funding: Other non-Federal agency	Frequency of data availability
06814000	# 1	1					2					3		A
06844700	# 1	1					4					3		A
06844900	# 1	1										3		A
06846500	# 1	1	5			6,7	4			*				A
06847900	# 1	1,8,9			10	7	2,4				11			A
06848000		9,12			10		2					3		A
06848500		9	5		10	6,7	2			*				A
06853500		9	5		10	7	2			*				A, T
06853800	# 1	1,8,9			10		2				11			A
06854000		9,12			10	7	2					3		A
06855800						6						3		A
06856000					10	6,7	2				11			A, T
06856600		8			10	6,7	2,4,13			*				A, T
06857100		9,12			10	7	2				11			A, T
06858500	# 1	1				6	4					3		A
06860000	# 1	1				6	2				11			A
06861000	# 1	1,8			10	6					11			A
06862000		12			10	6,7	2					3		A, T
06862700		9,14			10,14	6,7	2					3		A
06862850		9,14			14							15		A

EXPLANATION

1. Long-term-trend index station.
2. Water-quality-monitoring station, other.
3. Kansas Water Office.
4. Sediment-transport-monitoring station.
5. Republican River Compact Administration station, as provided by Article IX, Republican River Compact, 1942.
6. Flood-forecasting station, National Weather Service.
7. Streamflow-forecasting station, Kansas Fish and Game Commission.
8. Reservoir-inflow station.
9. Adjudication-of-water-rights station.
10. Reservoir-management station.
11. U.S. Army Corps of Engineers, Kansas City District.
12. Reservoir-outflow station.
13. Water-quality-monitoring station, NASQAN program.
14. Diversion-quantification station.
15. City of Hays.

Table 2.--Data use, funding, and frequency of data availability for complete-record stations in the 1983 Kansas stream-gaging program--Continued

Station number	Data use									Funding				Frequency of data availability
	Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Federal program	Other Federal agency program	Federal-non-Federal program	Other non-Federal agency	
06863500	# 1	1			10	6,7	4					3		A
06863900	#						4					3		A
06864050					10	6,7	2				11			A
06864500		8			10	6,7	2				11			A
06865500		12			10	7	2				11			A,T
06866500					10	6,7	2				11			A,T
06866900	#					6						3		A
06867000	# 1	1,8			10	6,7	2,4					3		A,P
06868200		12			10	7	2				11			A,T
06869500					10	6,7	4					3		A,T
06870200					10	6,7	2			*				A
06871000	# 1	1,8			10	6,7	2,4				11			A
06871500	# 1	1,8			10	6,7	2					3		A
06871800		12			10		2					3		A
06872500		8			10	6,7	2,16				11			A
06873000	# 1	1,8			10	7	2,4				11			A
06873200		12,14			10,14	7	2					3		A
06873460		14		17	14		18				19			A
06874000		8			10	6,7	2,16					3		A
06875900		12			10	7	2,16					3		A

EXPLANATION

Long-term-index station.
Water-quality-monitoring station, other.
3. Kansas Water Office.
4. Sediment-transport-monitoring station.
6. Flood-forecasting station, National Weather Service.
7. Streamflow-forecasting station, Kansas Fish and Game Commission.
8. Reservoir-inflow station.
10. Reservoir-management station.
11. U.S. Army Corps of Engineers, Kansas city District.
12. Reservoir-outflow station.
14. Diversion-quantification station.
16. Water-quality-monitoring station, Missouri River Basin program.
17. Used for planning and design, U.S. Bureau of Reclamation.
18. Water-quality-monitoring station, U.S. Bureau of Reclamation program.
19. U.S. Bureau of Reclamation.

Table 2.--Data use, funding, and frequency of data availability for complete-record stations in the 1983 Kansas stream-gaging program--Continued

Station number	Data use: Regional hydrology	Data use: Hydrologic systems	Data use: Legal obligations	Data use: Planning and design	Data use: Project operation	Data use: Hydrologic forecasts	Data use: Water-quality monitoring	Data use: Research	Data use: Other	Funding: Federal program	Funding: Other Federal agency program	Funding: Federal-non-Federal program	Funding: Other non-Federal agency	Frequency of data availability
06876440				17	10	6,7	18				19			A
06876700	#					6						3		A
06876900					10	6,7	2				11			A,T
06877600					10	6,7	2,4,13				11			A,T
06878000	# 1	1			10	6,7						3		A
06879100					10	6	2				11			A,T
06879650	# 20	20					4,20			*				A,P
06884200	#				10	6						3		A
06884400	# 1	1,8			10	7	4				11			A,P
06885500	# 1	1,8			10	6	2				11			A
06887000		12			10	7	2,4,13				11			A,T
06887500		14			10,14	6,7	2,4				11			A,T
06888350		14			14	7							21	A,T,P
06888500	# 1	1			10	6,7						3		A,T
06889000					10	6,7	2				11			A,T
06889100	#						2					3		A
06889120	#						2					3		A
06889140	#						2					3		A

EXPLANATION

1. Long-term-trend index station.
2. Water-quality-monitoring station, other.
3. Kansas Water Office.
4. Sediment-transport-monitoring station.
6. Flood-forecasting station, National Weather Service.
7. Streamflow-forecasting station, Kansas Fish and Game Commission.
8. Reservoir-inflow station.
10. Reservoir-management station.
11. U.S. Army Corps of Engineers, Kansas City District.
12. Reservoir-outflow station.
13. Water-quality-monitoring station, NASQAN program.
14. Diversion-quantification station.
17. Used for planning and design, U.S. Bureau of Reclamation.
18. Water-quality-monitoring station, U.S. Bureau of Reclamation program.
19. U.S. Bureau of Reclamation.
20. Hydrologic bench-mark station.
21. Kansas State Board ofAgriculture, Division of Water Resources.

Table 2.--Data use, funding, and frequency of data availability for complete-record stations in the 1983 Kansas stream-gaging program--Continued

Station number	Data use: Regional hydrology	Data use: Hydrologic systems	Data use: Legal obligations	Data use: Planning and design	Data use: Project operation	Data use: Hydrologic forecasts	Data use: Water-quality monitoring	Data use: Research	Data use: Other	Funding: Federal program	Funding: Other Federal agency program	Funding: Federal-non-Federal program	Funding: Other non-Federal agency	Frequency of data availability
06889160	#						2					3		A
06889200	#					6	2					3		A
06889500	# 1	1			10	6,7	2				11			A
06890100	# 1	1,8			10	6,7	2				11			A,T
06890900		12			10	7	2				11			A
06891000	1	1			10	6,7	2				11			A,T
06891500		12			10	6,7					11			A,T
06892000	# 1	1			10	6,7	4				11			A,T
06892350					10	6,7	2,4,13				11	3		A,T
06893080	#					7	2					3		A
06893300	#						2					3		A
06910800	#	8			10	6,7					11			A
06911500	# 1	1,8			10	6,7						3		A
06911900	#	8			10	7	4				11			A
06912500		12			10	7	2				11			A,T
06913000					10	6,7	2				11			A,T
06913500					10	6,7	2				11			A,T
06914000	# 1	1			10	6,7	4					3		A,T
06915000		12			10	7					11			A
06916600					10	6,7	2,4					3		A,T
06917000	# 1	1			10	6,7	2,4					3		A
06917380	# 1	1			10	7	2				11			A

EXPLANATION

1. Long-term-trend index station.
2. Water-quality-monitoring station, other.
3. Kansas Water Office.
4. Sediment-transport-monitoring station.
6. Flood-forecasting station, National Weather Service.
7. Streamflow-forecasting station, Kansas Fish and Game Commission.
8. Reservoir-inflow station.
10. Reservoir-management station.
11. U.S. Army Corps of Engineers, Kansas City District.
12. Reservoir-outflow station.
13. Water-quality-monitoring station, NASQAN program.

Table 2.--Data use, funding, and frequency of data availability for complete-record stations in the 1983 Kansas stream-gaging program--Continued

Station number	Data use									Funding				Frequency of data availability
	Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Federal program	Other Federal agency program	Federal-non-Federal program	Other non-Federal agency	
07137000		9,22	23		22		2			*		24		A,T,P
07137500		9,14	23		14	7	2,4,13			*		24		A,T,P
07138000		9				6,7	4					3		A,T,P
07138650	#						4					3		A
07139500						6,7	2			*	25			A,T
07139800	# 1	1										3		A
07140000						6,7	4				25			A,T
07140850	#					7						3		A
07141200	# 1	1				6,7	2,4					3		A
07141300						6,7	2				25			A,T
07141780	#											3		A
07141900	# 1	1				6,7	2,4					3		A
07142300	#					7	4					3		A
07142575	#					7	2					3		A
07142620	#					6,7	2					3		A
07143300	# 1	1				6,7	4					3		A,T
07143330						6,7	2,4					3		A
07143665	#						2,4					3		A
07144200	# 1	1				7	2,4					3,26		A

EXPLANATION

1. Long-term-trend index station.
2. Water-quality-monitoring station, other.
3. Kansas Water Office.
4. Sediment-transport-monitoring station.
6. Flood-forecasting station, National Weather Service.
7. Streamflow-forecasting station, Kansas Fish and Game Commission.
9. Adjudication-of-water-rights station.
13. Water-quality-monitoring station, NASQAN program.
14. Diversion-quantification station.
22. Diversion-canal station.
23. Arkansas River Compact Administration station, as provided by Article VIII, G2, Arkansas River Compact, 1948.
24. Arkansas River Compact Administration.
25. U.S. Army Corps of Engineers, Tulsa District.
26. City of Wichita.

Table 2.--Data use, funding, and frequency of data availability for complete-record stations in the 1983 Kansas stream-gaging program--Continued

Station number	Data use: Regional hydrology	Data use: Hydrologic systems	Data use: Legal obligations	Data use: Planning and design	Data use: Project operation	Data use: Hydrologic forecasts	Data use: Water-quality monitoring	Data use: Research	Data use: Other	Funding: Federal program	Funding: Other Federal agency program	Funding: Federal-non-Federal program	Funding: Other non-Federal agency	Frequency of data availability
07144300						7	2					3,26		A,T
07144550					10	6,7	2				25			A,T
07144780	#	8			10		4					26		A
07144795		12			10		2					26		A
07144910	#					7	4					3		A
07145200	# 1	1			10	6,7	2,4					3		A
07145500					10	6,7	2,4				25			A,T
07145700	#					7	4					3		A
07146500	1	1,9			10	6,7	2,4,13			*	25			A,T,P
07146623		12			10	7					25			A,T
07146830					10	6					25			A,T
07146895					10	6,7					25			A,T
07147070	#				10	6,7	2,4					3		A,T
07147800	1	1			10	6,7	2,4				25			A,T
07149000	# 1	1				7	2					3		A
07151500	#	9				7	2					3		A
07155590	#					7						3		A
07156010	#						4					3		A
07156100	#											3		A
07156220	#						4					3		A

EXPLANATION

1. Long-term-trend index station.
2. Water-quality-monitoring station, other.
3. Kansas Water Office.
4. Sediment-transport-monitoring station.
6. Flood-forecasting station, National Weather Service.
7. Streamflow-forecasting station, Kansas Fish and Game Commission.
8. Reservoir-inflow station.
9. Adjudication-of-water-rights station.
10. Reservoir-management station.
12. Reservoir-outflow station.
13. Water-quality-monitoring station, NASQAN program.
25. U.S. Army Corps of Engineers, Tulsa, District.
26. City of Wichita.

Table 2.--Data use, funding, and frequency of data availability for complete-record stations in the 1983 Kansas stream-gaging program--Continued

Station number	Data use: Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Funding: Federal program	Other Federal agency program	Federal-non-Federal program	Other non-Federal agency	Frequency of data availability
07157500	# 1	1				6,7	4					3		A
07166000		12			10	7	2				25			A
07166500					10	6,7					25			A,T
07167500	# 1	1,8			10	7	4					3		A
07168500		12			10	7	2				25			A,T
07169500					10	6,7	2				25			A,T
07169800	#	8			10	7	4					3		A
07170060		12			10	7	2				25			A
07170500		9			10	6,7					25			A,T
07170700		12			10	7	4				25			A,T
07172000	# 1	1				7	2					3		A
07179500		12			10	6,7	2,4				25			A
07179730		8			10	6,7	4				25			A,T
07179795		12			10	6,7	2,4				25			A
07180400					10	6,7	2				25			A,T
07180500	# 1	1				7						3		A
07182250		8			10	6,7	2,4				25			A,T
07182510		12			10	6,7	2				25			A,T
07183000	1	1			10	6,7	2				25			A,T
07183500	1	1			10	6,7	4,13					3		A,T
07184000	# 1	1					4					3		A

EXPLANATION

1. Long-term-trend index station.
2. Water-quality-monitoring station, other.
3. Kansas Water Office.
4. Sediment-transport-monitoring station.
6. Flood-forecasting station, National Weather Service.
7. Streamflow-forecasting station, Kansas Fish and Game Commission.
8. Reservoir-inflow station.
9. Adjudication-of-water-rights station.
10. Reservoir-management station.
12. Reservoir-outflow station.
13. Water-quality-monitoring station, NASQAN program.
25. U.S. Army Corps of Engineers, Tulsa District.

Project Operation

Gaging stations in this category were used to assist water managers in making operational decisions, such as reservoir releases, hydropower operations, or diversions. The project-operation use generally indicates that the data were routinely available to the operators on a rapid-reporting basis. For projects on large streams, data may have been needed only every few days.

Ninety-two stations in the 1983 Kansas stream-gaging program were used for this purpose. Eighty-seven of these stations were used by the U.S. Army Corps of Engineers in the management of Federal reservoirs. Seven stations, three of which also were used in reservoir management, were used to determine the volume of water diverted from the stream, and one station was located on a diversion canal that was used for irrigation.

Hydrologic Forecasts

Gaging stations in this category were used regularly to provide information to other Federal and State agencies for hydrologic forecasting, including flood forecasts for a specific river reach or periodic (daily, weekly, monthly, or seasonal) streamflow forecasts for a specific site or region. The hydrologic-forecast category generally indicates that the data were routinely available to the forecasters on a rapid-reporting basis. Some of these data were made available from observer readings as needed. On large streams, data may have been needed only every few days.

One hundred fourteen stations in the 1983 Kansas program were included in the hydrologic-forecast category and were used for forecasting reservoirs inflows, flood forecasting, and low-flow forecasting. The data obtained from these stations were used by the U.S. Army Corps of Engineers, the National Weather Service, the Kansas Water Office, the Kansas Fish and Game Commission, and the Division of Water Resources of the Kansas State Board of Agriculture. Additionally, during winters of significant snow accumulation, the National Weather Service uses the data at hydrologic-forecast stations, along with other pertinent data, in seasonal forecasting models to predict probable flooding.

Water-Quality Monitoring

One hundred fifteen complete-record stations in 1983, where either regular water-quality or sediment-transport monitoring was being conducted and where the availability of streamflow data contributed to the utility or was essential to the interpretation of the water-quality or sediment data, were designated as water-quality-monitoring stations. One such station in the 1983 program was designated as a hydrologic bench-mark station, and seven were National Stream-Quality Accounting Network (NASQAN) stations.

Water-quality samples from the bench-mark station were used to indicate water-quality characteristics of the stream that has been and probably will continue to be relatively free of man's activities. NASQAN stations are part of a nationwide network designed to assess water-quality trends in significant streams. At some selected stations, water-quality data were collected by various cooperating agencies for studies undertaken solely by these agencies.

Research

Gaging stations that would be in this category are operated for a particular research or water-investigations study. Typically, these stations are operated only for a few years. No stations in the 1983 Kansas program were placed in the research category.

Other

No stations in the 1983 Kansas program were operated for purposes other than those described above.

Funding

Four sources of funding for the 1983 Kansas stream-gaging program were:

1. Federal program.--Funds that were allocated directly to the Survey.

2. Other Federal agency (OFA) program.--Funds that were transferred to the Survey by other Federal agencies.

3. Federal- non-Federal cooperative program.--Funds that came jointly from Survey cooperative-designated funding and from a non-Federal cooperating agency. Cooperating agency funds may be in the form of direct services or cash.

4. Other non-Federal agency.--Funds that were provided entirely by a non-Federal agency or a private concern under the auspices of a Federal agency. In this study, funding from private concerns was limited to licensing and permitting requirements for hydropower development by the Federal Energy Regulatory Commission. Funds in this category are not matched by Survey cooperative funds.

In all four categories, the identified sources of funding pertained only to the collection of streamflow data; sources of funding for other activities, particularly collection of water-quality samples, that might be done at the site may not necessarily be the same as those identified herein. Nine entities contributed funds to the 1983 Kansas stream-gaging program.

Frequency of Data Availability

Frequency of data availability refers to the times at which the streamflow data may be provided to the users. In this category, three possibilities occur. Data can be provided by direct-access telemetry equipment for immediate use, by periodic release of provisional data, or in publication format through the annual data report published by the Survey for Kansas (Geiger and others, 1983). These three categories are designated T, P, and A, respectively, in table 2. Some agencies employ their own observers for stations without telemetry equipment; this is not indicated in table 2. In the 1983 Kansas program, data for all 140 complete-record stations were made available through the annual report, data from 54 stations were available by telemetry equipment for immediate use, and data from 8 stations were released on a provisional basis.

Plans for Future Program Evaluation

As a result of data-use evaluation of the 1983 stream-gaging program in Kansas, table 2 shows at least one use (need) for data at every current station. Therefore, no gaging stations in the 1983 program were selected for discontinuance. However, in the event of changes in data needs, reevaluation may be necessary.

As an adjunct to this study, a study using the procedure, known as Network Analysis for Regional Information (NARI), is planned (Benson and Matalas, 1967). NARI is a procedure for identifying the contributions to error reduction in a regional regression analysis of statistical characteristics of streamflow that can be expected from future stream-gaging activities. These activities include continuing data collection at existing gaging stations, establishing new gaging stations, or various combinations of each of these activities (Moss and others, 1982).

ALTERNATIVE METHODS OF DEVELOPING STREAMFLOW INFORMATION

The second step of the evaluation of the 1983 Kansas stream-gaging program was to investigate alternative methods of providing daily streamflow information in lieu of operating complete-record gaging stations. The objective of this second step was to identify gaging stations where an alternative technology, such as streamflow routing or regression analysis, may efficiently provide accurate estimates of mean daily streamflow. No guidelines have been established concerning suitable accuracies for particular uses of data; therefore, judgment was required in deciding whether the accuracy of the estimated daily flows was adequate for the intended purpose.

The data uses at a station affect whether information can potentially be provided by alternative methods. For example, those stations for which flood hydrographs are required for immediate use, such as hydrologic forecasts and project operation, are not candidates for alternative methods.

The primary candidates for alternative methods are stations that are operated upstream or downstream from other stations on the same stream. The accuracy of the estimated streamflow at these sites may be adequate if flows are significantly correlated between sites. Similar watersheds, located in the same physiographic and climatic area, also may have potential for alternative methods.

Discussion of Methods

Desirable attributes of a proposed alternative method are that: (1) The proposed method needs to be computer-oriented and easy to apply, (2) the proposed method needs to have an available interface with the Survey's WATSTORE Daily Values File (Hutchison, 1975), (3) the proposed method needs to be technically sound and generally acceptable to the hydrologic community, and (4) the proposed method needs to provide a measure of the accuracy of the simulated streamflow records. Because of the short time allowed for evaluation of alternative methods, only regression analysis was considered.

Regression Analysis

Simple- and multiple-regression methods can be used to estimate daily streamflow records. Unlike streamflow routing, this method is not limited to locations where an upstream station is present on the same stream. Regression equations can be computed that relate daily flows (or their logarithms) at a station (dependent variable) to daily flows at another station or at a combination of upstream, downstream, and tributary stations. The independent variables in the regression analysis can include streamflow at stations from different watersheds.

The regression method is easy to apply, provides indices of accuracy, and is widely used and accepted in hydrology. The theory and assumptions of regression analysis are described in numerous textbooks, such as Draper and Smith (1966) and Kleinbaum and Kupper (1978). The application of regression analysis to hydrologic problems is described and illustrated by Riggs (1973) and Thomas and Benson (1970). Only a brief description of regression analysis is provided in this report.

A linear-regression model of the following form commonly is used for estimating daily mean discharges:

$$Q_i = B_0 + \sum_{j=1}^{n} B_j Q_j + e_i, \tag{1}$$

where

Q_i = daily mean discharge at station i (dependent variable);
B_0 and B_j = regression constant and coefficients;
Q_j = daily mean discharges at station(s) j (independent variables); these values may be time lagged to approximate traveltime between stations i and j; and
e_i = the random error term.

Equation 1 is calibrated (B_0 and B_j are estimated) using measured values of Q_i and Q_j. These daily mean discharges can be retrieved from the Survey's WATSTORE Daily Values File (Hutchison, 1975). The values of discharge for the independent variables may be for the same day as discharges at the dependent station or may be determined for previous or future days, depending on whether station j is upstream or downstream of station i. During calibration, the regression constant and coefficients (B_0 and B_j) are tested to determine if they are significantly different from zero. A given independent variable only is retained in the regression equation if its regression coefficient is significantly different from zero.

The regression equation needs to be calibrated using data for one period and verified or tested using data for a different period to obtain a measure of the true predictive accuracy. Both the calibration and verification periods need to be representative of the expected range of flows. The equation needs to be verified by: (1) Plotting the residuals (difference between simulated and measured discharges) against both the dependent and the independent variables in the equation, and (2) plotting the simulated and measured discharges versus time. These tests are needed to confirm that the linear model is appropriate and there is no bias in the equation. The presence of either nonlinearity or bias requires that the data be transformed (for example, by converting to logarithms) or that a different form of model be used.

The use of a regression relation to produce a simulated record at a discontinued gaging station causes the variance of the simulated record to be less than the variance of an actual record of streamflow at the site. The decrease of variance is not a problem if the only concern is with deriving the best estimate of a given mean daily discharge record. If, however, the simulated discharges are to be used in additional analyses where the variance of the data is important, least-squares regression models are not appropriate. Hirsch (1982) discusses this problem and describes several models that preserve the variance of the original data.

Categorization of Stream Gages by Their Potential for Alternative Methods

A two-level screening process was applied to the gaging stations in the 1983 program to evaluate the potential for use of alternative methods. The first level was based only on hydrologic considerations; the only concern at this level was whether it was hydrologically reasonable to simulate flows at a given station from information at other stations. The first-level screening was subjective; there was no attempt at that level to apply any mathematical procedures. Those stations that passed the first level of screening then were screened again to determine if simulated data would be acceptable with respect to the data uses shown in table 2. Even if simulated data were not acceptable for the given data uses, the screening process continued. Mathematical procedures were applied to determine if it were technically possible to simulate data. Statistical tests, including correlation and regression, were used on these combinations to eliminate from consideration those that showed little correlation with corresponding stations.

An evaluation of the data uses presented in table 2 identified eight stations at which alternative methods for providing the needed streamflow information could be applied. These eight stations were Buffalo Creek near Jamestown (06855800), Republican River at Concordia (06856000), Smoky Hill River near Bunker Hill (06864050), Saline River at Tescott (06869500), Kansas River at Fort Riley (06879100), Marais des Cygnes River near Pomona (06913000), Arkansas River at Hutchinson (07143330), and Arkansas River at Wichita (07144300).

Results of Regression Analysis

Linear-regression techniques were applied to all eight of the selected sites in the combinations shown in table 3. The daily streamflow values for each station considered for simulation (the dependent variable) were related to concurrent daily streamflow values at other stations (explanatory variables) during a given period of record (the calibration period).

The results of regression for station 06879100 (Kansas River at Fort Riley) are used as an example to illustrate what can be expected (results from the other stations were less satisfactory), and the possible direction for further refinement. The regression equation for daily mean discharge, Q, in cubic feet per second, was defined as:

$$Q_{06879100} = 111 + 1.15(Q_{06877600}) + 1.13(Q_{06857100}), \qquad (2)$$

and the standard error was 23 percent. It is possible that a time-lagging procedure of the technique needs to be considered before the results can be satisfactory for alternative methods.

Table 3.--Combinations of stations used in regression analysis

[See table 1 for station names]

Primary station	Combinations investigated		
06879100	06878000	06877600	06857100
06856000	06856600		
06864050	06864500		
06869500	06868200		
06855800	06853800		
06913000	06913500		
07143330	07144300	07144200	
07144300	07144550		

As a result of this preliminary evaluation by regression analysis, it may be beneficial to pursue the application of streamflow-routing, regression methods, and possibly other alternative methods at a later date to determine if the simulated data are sufficiently accurate for the intended data use in lieu of operating a complete-record gaging station. However, none of the stations investigated can presently be simulated with sufficient accuracy from data at other sites.

COST-EFFECTIVE RESOURCE ALLOCATION

Kalman Filtering for Cost-Effective Resource Allocation (K-CERA)

In a study of the cost effectiveness of a network of gaging stations operated to determine water consumption in the Lower Colorado River Basin, a set of techniques called Kalman filtering for cost-effective resource allocation (K-CERA) was developed (Moss and Gilroy, 1980). Because of the water-balance nature of that study, the measure of effectiveness of the stream-gaging network was chosen to be the minimization of the sum of variances of errors of estimate of annual mean discharges at each site in the network. This measure of effectiveness tends to concentrate stream-gaging resources on the larger, less stable streams where potential errors are greatest. While such a tendency is appropriate for a water-balance network, in the broader context of the multitude of uses of the streamflow data collected in the Survey's streamflow-information program, this tendency causes undue concentration on larger streams. Therefore, the original version of K-CERA was extended to include as optional measures of effectiveness the sums of the variances of errors of estimate of the following streamflow variables: annual mean discharge, in cubic feet per second, or average instantaneous discharge, as a percentage. The use of percentage errors does not unduly weight activities at large streams to the detriment of records on small streams. In addition, the instantaneous discharge is the basic variable from which all other streamflow data are derived. For these reasons, this study used the K-CERA techniques with the sums of the variances of the percentage errors of the instantaneous discharges at all complete-record gaging stations as the measure of the effectiveness of the data-collection activity.

The original version of K-CERA also did not account for error contributed by missing stage or other correlative data that are used to compute streamflow data. The probabilities of missing correlative data increase as the period between service visits to a gaging station increases. A procedure for dealing with the missing record was developed and incorporated into this study.

Brief descriptions of the mathematical program used to optimize cost effectiveness of the data-collection activity and of the application of Kalman filtering (Gelb, 1974) to the determination of the accuracy of a stream-gaging record are presented below. For more detail on either the theory or the applications of K-CERA, see Moss and Gilroy (1980), Gilroy and Moss (1981), and Fontaine and others (1984).

Description of Mathematical Program

The mathematical program used in K-CERA, called "The Traveling Hydrographer," attempts to allocate among gaging stations a predefined budget for the collection of streamflow data in such a manner that operation is the most cost effective possible. The measure of effectiveness was discussed in the preceding section. The set of decisions available to the manager is the frequency of use (number of times per year) of each of a number of routes that may be used to service the gaging stations and to make discharge measurements. The range of options within the program is from zero usage to daily usage for each route. A route is defined as a set of one or more gaging stations and the least-cost travel that takes the hydrographer from his base of operations to each of the stations and back to base. A route will have associated with it an average cost of travel and an average cost of servicing each gaging station visited along the way. The first step in this part of the program is to define the set of practical routes. This set of routes frequently will contain the path to an individual gaging station with that station as the lone stop and return to base so that the individual needs of a gaging station can be considered in isolation from the other stations.

Another step in this part of the program is the determination of any special requirements for visits to each of the stations for such things as necessary periodic maintenance, rejuvenation of recording equipment, or required periodic sampling of water-quality data. Such special requirements are considered to be inviolable constraints in terms of the minimum number of visits to each station.

The final step is to use all of the above to determine the number of times, N_i, that the ith route for i = 1, 2, ..., NR, where NR is the number of practical routes, is used during a year such that (1) the budget for the network is not exceeded, (2) the minimum number of visits to each station is made, and (3) the total uncertainty in the network is minimized. Figure 3 represents this step in the form of a mathematical program. Figure 4 presents a tabular layout of the problem. Each of the NR routes is represented by a row of the table, and each of the stations is represented by a column. The zero-one matrix (ω_{ij}) defines the routes in terms of the stations that comprise it. A value of 1 in row i and column j indicates that gaging station j will be visited on route i; a value of 0 indicates that it will not. The unit travel costs (β_i) are the per-trip costs of the hydrographer's travel time and any related per diem and operation, maintenance, and rental costs of vehicles. The sum of the products of β_i and N_i for i = 1, 2, ..., NR is the total travel cost associated with the set of decisions $N = (N_1, N_2, \ldots, N_{NR})$.

The unit-visit cost (α_j) is comprised of the average service and maintenance costs incurred on a visit to the station plus the average cost of making a discharge measurement. The set of minimum visit constraints is denoted by the row λ_j, j = 1, 2,..., MG, where MG is the number of stations. The row of integers M_j, j = 1, 2, ..., MG, specifies the number of visits to each station. M_j is the sum of the products of ω_{ij} and N_i for all i and must equal or exceed λ_j for all j if N is to be a feasible solution to the decision problem.

$$\underset{\underline{N}}{\text{Minimize}}\; V = \sum_{j=1}^{MG} \phi_j\,(M_j),$$

where

$V \equiv$ total uncertainty in the network;

$\underline{N} \equiv$ vector of annual number times each route was used;

$MG \equiv$ number of gages in the network;

$M_j \equiv$ annual number of visits to station j; and

$\phi_j \equiv$ function relating number of visits to uncertainty at station j.

Such that

Budget $\geq T_c \equiv$ total cost of operating the network

$$T_c = F_c + \sum_{j=1}^{MG} \alpha_j M_j + \sum_{i=1}^{NR} \beta_i N_i \quad ,$$

where

$F_c \equiv$ fixed cost;

$\alpha_j \equiv$ unit cost of visit to station j ;

$NR \equiv$ number of practical routes chosen;

$\beta_i \equiv$ travel cost for route i; and

$N_i \equiv$ annual number times route i is used (an element of $\underline{N}$);

and such that

$$M_j \geq \lambda_j \quad ,$$

where $\lambda_j \equiv$ minimum number of annual visits to station j .

Figure 3.--Mathematical-programing form for optimization of hydrographer routing.

The total cost expended at the stations is equal to the sum of the products of α_j and M_j for all j. The costs of record computation, documentation, and publication are assumed to be influenced negligibly by the number of visits to the station and are included along with overhead in the fixed cost of operating the network. The total cost of operating the network equals the sum of the travel costs, the onsite costs, and the fixed cost, and must be less than or equal to the available budget.

The total uncertainty in the estimates of discharges at the MG stations is determined by summing the uncertainty functions (ϕ_j) evaluated at the value of M_j from the row above it, for j = 1, 2, ..., MG.

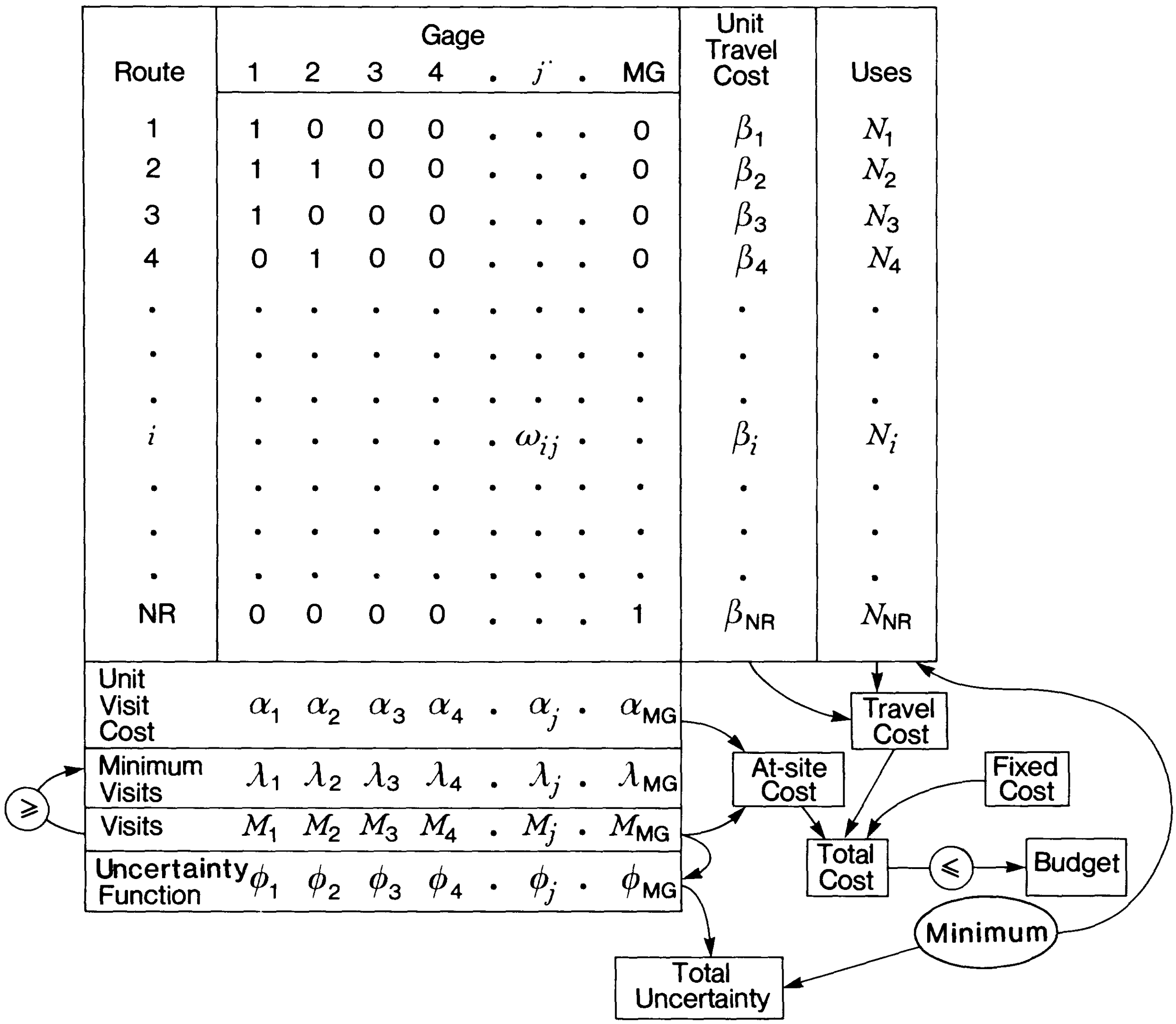


Figure 4.--Tabular form for optimization of hydrographer routing.

As pointed out in Moss and Gilroy (1980), the steepest-descent search used to solve this mathematical program does not guarantee a true optimum solution. However, the locally optimum set of values for $\underline{N}$ obtained with this technique specify an efficient strategy for operating the network, which may be the true optimum strategy. The true optimum cannot be guaranteed without testing all undominated, feasible strategies.

Description of Uncertainty Functions

As noted earlier, uncertainty in streamflow records is measured in this study as the average relative variance of estimation of instantaneous discharges. The accuracy of a streamflow estimate depends on how that estimate was obtained. Three situations were considered in this study: (1)

streamflow was estimated from measured discharge and correlative data using a stage-discharge relation (rating curve); (2) the streamflow record was reconstructed using secondary data at nearby stations because primary correlative data were missing; and (3) primary and secondary data were unavailable for estimating streamflow. The variances of the errors of the estimates of flow that would be employed in each situation were weighted by the fraction of time each situation was expected to occur. Thus, the average relative variance would be

$$\overline{V} = \varepsilon_f V_f + \varepsilon_r V_r + \varepsilon_e V_e, \tag{3}$$

with

$$1 = \varepsilon_f + \varepsilon_r + \varepsilon_e,$$

where $\overline{V}$ is the average relative variance of the errors of streamflow estimates;

ε_f is the fraction of time that the primary recorders are functioning;

V_f is the relative variance of the errors of flow estimates from primary recorders;

ε_r is the fraction of time that secondary data are available to reconstruct streamflow records given that the primary data are missing;

V_r is the relative variance of the errors of estimate of flows reconstructed from secondary data;

ε_e is the fraction of time that primary and secondary data are not available to compute streamflow records; and

V_e is the relative error variance of the third station.

The fractions of time that each source of error is relevant are functions of the frequencies at which the recording equipment is serviced.

The time (τ) since the last service visit until failure of the recorder or recorders at the primary site was assumed to have a negative-exponential probability distribution truncated at the next service time; the distribution's probability density function is

$$f(\tau) = kd^{-k\tau}/(1-e^{-ks}), \tag{4}$$

where k is the failure rate in units of $(\text{day})^{-1}$;
e is the base of natural logarithms; and
s is the interval between visits to the site, in days.

It was assumed that, if a recorder failed it continued to malfunction until the next service visit. As a result,

$$\varepsilon_f = (1-e^{-ks})/(ks) \tag{5}$$

(Fontaine and others, 1984, equation 21).

The fraction of time (ε_e) that no records existed at either the primary or secondary sites also could be derived assuming that the time between failures at both sites was independent and had negative-exponential distributions with the same rate constant. It then follows that

$$\varepsilon_e = 1 - [2(1-e^{-ks}) + 0.5(1-e^{-2ks})]/(ks)$$

(Fontaine and others, 1984, equations 23 and 25).

Finally, the fraction of time (ε_r) that records were reconstructed based on data from a secondary site was determined by the equation

$$\begin{aligned} \varepsilon_r &= 1 - \varepsilon_f - \varepsilon_e \\ &= [(1-e^{-ks}) + 0.5(1-e^{-2ks})]/(ks). \end{aligned} \tag{6}$$

The relative variance (V_f) of the error derived from primary-record computation was determined by analyzing a time series of residuals that were the differences between the logarithms of measured discharge and the rating-curve discharge. The rating-curve discharge was determined from a relationship between discharge and some correlative data, such as water-surface elevation at the gaging station. The measured discharge was the discharge determined by onsite observations of depths, widths, and velocities. Let $q_T(t)$ be the true instantaneous discharge at time t, and let $q_R(t)$ be the value that would be estimated using the rating curve. Then, the equation

$$x(t) = \ln q_T(t) - \ln q_R(t) = \ln [q_R(t)] \tag{7}$$

is the instantaneous difference between the logarithms of the true discharge and the rating-curve discharge.

In computing estimates of streamflow, the rating curve may be continually adjusted on the basis of periodic measurements of discharge. This adjustment process resulted in an estimate, $q_c(t)$, that was a better estimate of the stream's discharge at time t. The difference between the variable $\hat{x}(t)$, which is defined as

$$\hat{x}(t) = \ln q_c(t) - \ln q_R(t), \tag{8}$$

and $x(t)$ was the error in the streamflow record at time t. The variance of this difference over time was the desired estimate of V_f.

Unfortunately, the true instantaneous discharge, $q_T(t)$, could not be determined, and thus $x(t)$ and the difference, $x(t) - \hat{x}(t)$, could not be determined as well. However, the statistical properties of $x(t) - \hat{x}(t)$, particularly its variance, could be inferred from the available discharge measurements. Let the observed residuals of measured discharge from the rating curve be $z(t)$ so that

$$z(t) = x(t) + v(t) = \ln q_m(t) - \ln q_R(t), \tag{9}$$

where $v(t)$ is the measurement of error; and

$\ln q_m(t)$ is the logarithm of the measured discharge equal to $\ln q_T(t)$ plus $v(t)$.

In the Kalman-filtering analysis, the $z(t)$ times series was analyzed to determine three site-specific parameters. The Kalman-filter technique used in this study assumes that the time residuals $x(t)$ arise from a continuous first-order Markovian process that has a Gaussian (normal) probability distribution with zero mean and variance (subsequently referred to as process variance) equal to p. Another important parameter is β, the reciprocal of the correlation time of the Markovian process giving rise to $x(t)$; the correlation between $x(t_1)$ and $x(t_2)$ is $\exp[-\beta\ |t_1-t_2|]$. Fontaine and others (1984) also define q, the constant value of the spectral density function of the white noise, which drives the Gauss-Markov x-process. The parameters p, β, and q, are related by

$$\mathrm{Var}[x(t)] = p = q/(2\beta). \tag{10}$$

The variance of the observed residuals $z(t)$ is

$$\mathrm{Var}[z(t)] = p + r, \tag{11}$$

where r is the variance of the measurement error $v(t)$. The three parameters p, β, and r are computed by analyzing the statistical properties of the $z(t)$ time series. These three site-specific parameters are needed to define this component of the uncertainty relationship. The Kalman-filter technique utilizes these three parameters to determine the average relative variance of the errors of estimate of discharges as a function of the number of discharge measurements per year (Moss and Gilroy, 1980).

If the recorder at the primary site failed and there were no concurrent data at other sites that could be used to reconstruct the missing record at the primary site, there were at least two ways of estimating discharges at the primary site. A recession curve could be applied from the time of recorder stoppage until the gage was once again functioning, or the expected value of discharge for the period of missing data could be used as an estimate. The expected-value approach was used in this study to estimate V_e, the relative error variance during periods of no concurrent data at nearby stations. If the expected value was used to estimate discharge, the value that was used should have been the expected value of discharge at the time of year of the missing record because of the seasonality of the streamflow processes. The variance of streamflow, which also is a seasonally varying parameter, is an estimate of the error variance that results from using the expected value as an estimate. Thus, the coefficient of variation squared $[(C_v)^2]$ is an estimate of the required relative error variance V_e. Because C_v varies seasonally and the times of failures cannot be anticipated, a seasonally averaged value of C_v was used:

$$\overline{C}_v = \left[\frac{1}{365}\sum_{i=1}^{365}\left(\frac{\sigma i}{\mu i}\right)^2\right]^{1/2}, \tag{12}$$

where σ_i is the standard deviation of daily discharges for the i^{th} day of the year;

μ_i is the expected value of discharge on the i^{th} day of the year;

and $(\overline{C}_v)^2$ is used as an estimate of V_e.

The variance (V_r) of the relative error during periods of reconstructed streamflow records was estimated on the basis of correlation between records at the primary site and records from other nearby gaged sites. The correlation coefficient (ρ_c) between the streamflows with seasonal trends removed at the site of interest and detrended streamflows at the other sites is a measure of the "goodness" of their linear relationship. The fraction of the variance of streamflow at the primary site that is explained by data from other sites is equal to ρ_c^2. Thus, the relative error variance of flow estimates at the primary site obtained from secondary information will be

$$V_r = (1 - \rho_c^2)\ \overline{C}_v^2 \ . \qquad (13)$$

Because errors in streamflow estimates arise from three different sources with widely varying precisions, the resultant distribution of those errors may differ significantly from a normal or log-normal distribution. This lack of normality causes difficulty in interpretation of the resulting average estimation variance. When primary and secondary data are unavailable, the relative error variance V_e may be very large. This could yield correspondingly large values of $\overline{V}$ in equation (3) even if the probability that primary and secondary information are not available, ε_e, is quite small.

A new parameter, the equivalent Gaussian spread (EGS), is introduced here to assist in interpreting the results of the analyses. If it is assumed that the various errors arising from the three situations represented in equation (3) are log-normally distributed, the value of EGS was determined by the probability statement that

$$\text{Probability}\ [e^{-EGS} \leq (q_c(t)\ /q_T(t)) \leq e^{+EGS}] = 0.683 \ . \qquad (14)$$

Thus, if the residuals $\ln q_c(t) - q_T(t)$ were normally distributed, $(EGS)^2$ would be their variance. Here EGS is reported in units of percent because EGS is defined so that nearly two-thirds of the errors in instantaneous streamflow data will be within plus or minus EGS percent of the reported values.

Application of K-CERA in Kansas

In the 1983 operation of routine visits to data-collection sites in Kansas, there were 140 complete-record stations and 137 other stations (reservoir stage, crest-stage, precipitation, and flood rating) that were considered or accounted for in this evaluation. As a result of the first two parts of this evaluation, it has been found that the 140 complete-record stations operated during 1983 in Kansas were needed to meet the data-use requirements. The station records were examined and screened for those stations that were acceptable for further analysis. However, uncertainty functions could not be defined for those stations that were typically ephemeral and had a large number of zero-flow days, or those that did not have sufficient number of discharge measurements for rating definition (period of record at present site was short, or rating not adequately defined due to backwater conditions); these stations were considered in a different category for the application of the "Traveling Hydrographer Program" that will follow. Ninety-one stations were selected for the K-CERA analysis with results that are described below.

Definition of Missing-Record Probabilities

As was described earlier, the statistical characteristics of missing stage or other correlative data for computation of streamflow records can be defined by a single parameter, the value of k in the truncated negative-exponential probability distribution of times to failure of the equipment. In the representation of $f(\tau)$ as given in equation 4, the average time to failure is 1/k. The value of 1/k will vary from station to station depending on the type of equipment at the station and on its exposure to natural elements and vandalism. The value of 1/k can be changed by advances in the technology of data collection and recording. For the value of 1/k in Kansas, it was estimated that a gage could be expected to malfunction 5.5 percent of the time (D. L. Lacock, U.S. Geological Survery, oral commun., 1983). There was no reason to distinguish between gages on the basis of their exposure or equipment, so a 5.5-percent lost record and a 6-week visit frequency were used to determine a value of 1/k for 305 days, which was used to determine ε_f, ε_e, and ε_r for each of the 91 gaging stations as a function of the individual frequencies of visit.

Definition of Cross-Correlation Coefficient and Coefficient of Variation

To compute the values of V_e and V_r of the needed uncertainty functions, daily streamflow records for each of the 91 stations for the last 30 years or the part of the last 30 years for which daily streamflow values are stored in WATSTORE (Hutchison, 1975) were retrieved. For each of the stations that had 3 or more complete water years of data, the value of $\overline{C}_v$ was computed.

Many different sources of information are normally used to reconstruct periods of missing record. These sources include, but are not limited to, recorded ranges in stage (for graphic recorders with clock stoppage), known discharges on adjacent days, recession analysis, observers' staff-gage readings, weather records, high-water-mark elevations, and comparisons with nearby stations. However, most of these techniques are unique to a given station or to a specific period of lost record. Using all the tools available, short periods (several days) of lost record usually can be reconstructed quite accurately. Even longer periods (more than a month) of missing record can be reconstructed with reasonable accuracy if observers' readings are available. If, however, none of these tools are available, long reconstructions can be subject to large errors.

The study could not reasonably quantify the uncertainty that is associated with all the possible methods of reconstructing missing record at the individual stations. Therefore, this evaluation assumed that missing record would be reconstructed based on historical discharges for that season or from correlation with data from another gaging station. The fraction of time each approach was used was dependent on the frequency at which the gage was serviced. Both of the approaches used in this evaluation undoubtedly overstated the uncertainty of reconstructing a short period of missing record; the stated uncertainty may be reasonable for long periods of missing record.

Historically, operating procedures have caused most periods of missing record to be measured in days rather than months. Given the small cross-correlations and the relatively large variability of flow usually occurring in Kansas, this evaluation seemed to significantly overstate the uncertainty associated with missing record. Therefore, in Kansas, a value of 0.95 was used for the cross-correlation coefficient. In reconstructing records, the cross-correlation coefficient, therefore, was used as a surrogate for the knowledge of basin response that remains unquantified in the present study. This assumption is believed to be reasonable for short periods of missing record; it probably caused the uncertainty to be understated for long periods of lost record.

The value of $\overline{C}_v$ for each station is summarized in table 4. In the table, there are six stations that are flagged for a computed coefficient for the process variance that is larger than acceptable. The probable reason could be that the rating from which the residuals were determined may not be described properly with a single continuous function. This meant that the error was overestimated. The stations were kept in the analysis, but the uncertainty functions were given zero weight. The consequences of this decision are discussed later with the K-CERA results.

Kalman-Filtering Definition of Variance

The determination of the variance V_f for each of the 91 gaging stations required three distinct steps: (1) Long-term rating analysis and computation of residuals of measured discharges from the long-term rating, (2) time-series analysis of the residuals to determine the input parameters for the Kalman-filtering process, and (3) computation of the error variance (V_f) as a function of the time-series parameters, the discharge-measurement-error variance, and the frequency of discharge measurement.

In the evaluation of the 1983 Kansas program, definition of long-term rating functions was complicated by the fact that most gaging stations in Kansas have the dual seasonal characteristic of a summer or open-water period and a winter or backwater period. As a result of this characteristic, a single-rating function to define the entire year was not feasible. The winter discharge at a given station is typically determined from possible combinations of: (1) Data from the station, measured stage, and the discharge corresponding to the measured stage determined from the open-water

Table 4.--Summary of autocovariance analysis and coefficient of variation

Station number	RHO[1]	Process variance (log base e)[2]	Coefficient of variation $\bar{C}_v$	Number of observations
06814000	0.988	[2]0.244	2.583	95
06853500	.9916	.0613	1.381	92
06856000	.988	.0484	1.347	87
06856600	.9742	.0174	1.444	78
06857100	.985	.133	1.360	90
06860000	.981	.132	2.546	102
06861000	.926	[2].224	2.419	119
06862700	.975	.0392	1.292	93
06863500	.992	.0987	2.064	96
06864050	.974	.0639	1.982	70
06864500	.987	.109	1.941	99
06865500	.992	.106	1.785	76
06866500	.985	.0593	1.583	85
06867000	.997	.074	1.676	110
06868200	.996	.0997	2.465	106
06869500	.999	.0428	2.087	104
06870200	.999	.0079	1.748	34
06872500	.996	.0763	1.929	94
06874000	.995	.0942	1.989	96
06875900	.990	.00124	2.169	40
06876440	.985	.0734	1.089	34
06876700	.991	.087	2.486	96
06876900	.993	.0524	1.902	106
06877600	.987	.0226	1.588	112
06878000	.997	.0445	2.328	94
06879100	.989	.0268	1.426	87
06884200	.994	.1225	2.313	93
06884400	.419	.0293	1.562	108
06885500	.978	.0883	2.597	96
06887000	.983	.113	1.595	98
06887500	.972	.011	1.305	90
06888500	.984	.0620	2.006	117
06889000	.989	.0395	1.280	189
06889140	.951	[2].219	2.474	112
06889160	.989	.142	2.337	116
06889200	.992	.158	2.230	125
06889500	.993	.0902	2.423	118
06890100	.991	.1035	2.068	116
06891000	.992	.0125	1.299	104
06892000	.999	[2].221	2.459	108

Table 4.--Summary of autocovariance analysis and coefficient of variation--Continued

Station number	RHO[1]	Process variance (log base e)[2]	Coefficient of variation $\overline{C}_v$	Number of observations
06892350	0.986	0.0142	1.306	165
06910800	.996	.0836	1.979	108
06911500	.978	.0700	2.920	121
06911900	.406	.0801	2.410	103
06912500	.994	.0726	2.444	120
06813000	.969	.0291	1.672	122
06913500	.938	.0091	2.191	122
06914000	.923	.1007	2.934	129
06916600	.953	.0304	1.923	100
06917000	.982	.0646	2.674	115
06917380	.936	.0906	1.971	129
07137500	.992	.121	1.324	288
07138000	.985	.165	1.315	217
07140000	.996	.0839	1.569	122
07141300	.992	.165	1.835	92
07142300	.998	.157	1.378	108
07142575	.991	.111	1.137	80
07142620	.991	.186	1.489	98
07143300	.973	.083	2.208	103
07143330	.993	.0926	1.363	107
07143665	.994	.0709	1.897	96
07144200	.995	.0832	2.392	71
07144300	.987	.0468	1.611	103
07144550	.995	.0837	1.297	96
07144780	.991	.1437	1.472	193
07144795	.990	.0947	2.386	112
07145200	.982	.074	1.330	98
07145500	.989	.058	1.583	94
07145700	.994	[2].297	2.152	108
07146500	.993	.0795	1.407	108
07147070	.989	.0588	2.215	109
07147800	.987	.0938	2.285	107
07149000	.988	.081	1.504	101
07151500	.994	.0945	1.635	54
07157500	.961	.1004	2.042	99

Table 4.--Summary of autocovariance analysis and coefficient of variation--Continued

Station number	RHO[1]	Process variance (log base e)	Coefficient of variation $\bar{C}_v$	Number of observations
07166000	0.999	0.0961	2.225	223
07166500	.941	.0818	2.122	173
07168500	.975	.0651	2.211	204
07169500	.916	.0256	2.137	188
07170060	.987	[2] .317	2.212	222
07170500	.959	.0427	2.049	196
07172000	.982	.106	2.544	186
07179500	.986	.0814	2.55	100
07179730	.987	.0877	1.914	100
07179795	.984	.0924	2.204	54
07180400	.982	.048	1.861	102
07180500	.989	.102	2.218	94
07182250	.991	.0284	1.682	97
07182510	.982	.0717	1.665	113
07183000	.983	.0155	1.789	110
07183500	.991	.0443	1.792	114

[1] One-day autocorrelation coefficient.
[2] The value of the process variance indicates that the rating is not adequately defined.

rating; (2) climatological data obtained from the National Weather Service sites closest to the gaging station, including the maximum and minimum temperature for the given day and the total precipitation that occurred as rain for the day and the previous day; and (3) the daily mean discharge, based on the open-water rating curve, for stations that are proximate or physiographically similar or both to the stations being considered. The winter period is not long enough and the effects of ice are too variable to define a winter rating, and there can be alternate freezing and thawing during the winter period. Therefore, only the open-water period was considered for this evaluation. The stations in the northern part of the State have a longer winter period than those in the southern part, so an average open-water period of 305 days was used for the entire State (D. L. Lacock, U.S. Geological Survey, oral commun., 1983).

The time series of residuals for open-water measurements is used to compute sample estimates of q and β, two of the three parameters required to compute V_f, by determining a best-fit autocovariance function to the time series of residuals. Measurement variance, the third parameter, is determined from an assumed constant percentage standard error. For the Kansas program, all open-water measurements were assumed to have a measurement error of 3.5 percent.

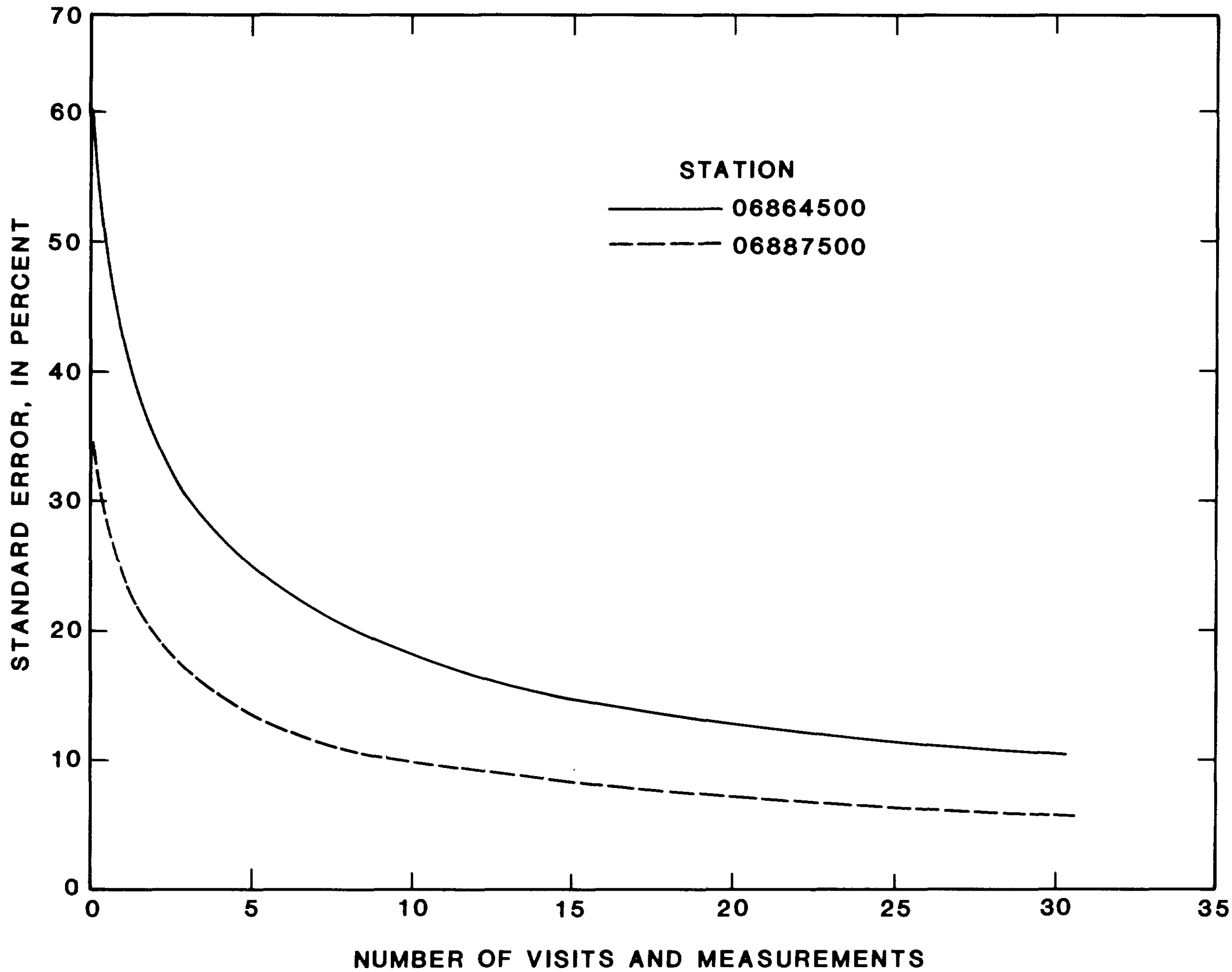


Figure 5.--Typical uncertainty functions for instantaneous discharge.

The autocovariance parameters and data from the definition of missing-record probabilities, summarized in table 4, are used jointly to define uncertainty functions for each gaging station. The uncertainty functions give the relationship of total error variance to the number of visits and discharge measurements. Typical examples of the uncertainty functions are given in figure 5. These functions are based on the assumption that a measurement was made during each visit to the station. Some stations are not measured every visit due to conditions such as zero flow. Therefore, the probability of making a discharge measurement during any visit (less than 1.0 and varies according to each station) is part of the analysis.

In Kansas, feasible routes to service the data-collection sites were determined after consultation with personnel responsible for the data collection and after review of the uncertainty functions. The 277 sites considered included 91 complete-record stations with the determined uncertainty functions, 49 complete-record stations without uncertainty functions that were also part of the 1983 program, and the other 137 partial-record stations that were visited on a routine schedule. In summary, 65 routes were selected to service all the stations in Kansas. These routes included possible combinations that described the 1983 operating practice, alternatives that were under consideration as future possibilities, routes that visited certain key individual stations, and combinations that included proximate stations where the levels of uncertainty indicated more frequent visits might be useful. In addition, minimum visits were considered, as well as special scheduled requirements, such as water-quality sampling, monthly requirements for the National Water Conditions Report, and crest-stage gage inspections.

The costs associated with the practical routes were determined. Fixed costs to operate a station typically included equipment rental, batteries, electricity, data processing and storage, computer charges, maintenance and miscellaneous supplies, and analysis and supervisory charges. For Kansas, average values were applied to each station in the 1983 program for all the above categories, and additional costs for telemetry maintenance and special-measurement requirements were added, where applicable. Costs of the travel for the winter-period visits were added to the fixed costs of each station.

Visit costs were those associated with paying the hydrographer for the time actually spent at a station servicing the equipment and making a discharge measurement. These costs varied from station to station and were a function of the difficulty and time required to make the discharge measurement. Average visit times were calculated for each station based on an analysis of discharge-measurement data available. This time then was multiplied by the average hourly salary of hydrographers in the Kansas office of the Survey to determine total visit costs.

Route costs included the vehicle cost associated with driving the number of miles it takes to cover the route, the cost of the hydrographer's time while in transit, and any per diem associated with the time it takes to complete the trip.

K-CERA Results

The "Traveling Hydrographer Program" utilizes the uncertainty functions along with the appropriate cost data and route definitions to compute the most cost-effective way of operating the stream-gaging program. In this application, the first step was to simulate the 1983 practice and determine the total uncertainty associated with it. To accomplish this, the number of visits being made to each station and the specific routes that were being used to make these visits were fixed. In Kansas, 1983 practice indicated that station visits were being made on a 6-week basis, which is nine visits a year. One visit a year was allowed for the winter season; therefore, the 1983 practice for the open-water analysis was eight visits per year. The resulting average error of estimate for the 1983 practice in Kansas was plotted as 20.8 percent in figure 6. The solid line in figure 6 represents the minimum level of average uncertainty that can be obtained for a given budget with the existing instrumentation and technology. The line was defined by several runs of the "Traveling Hydrographer Program"

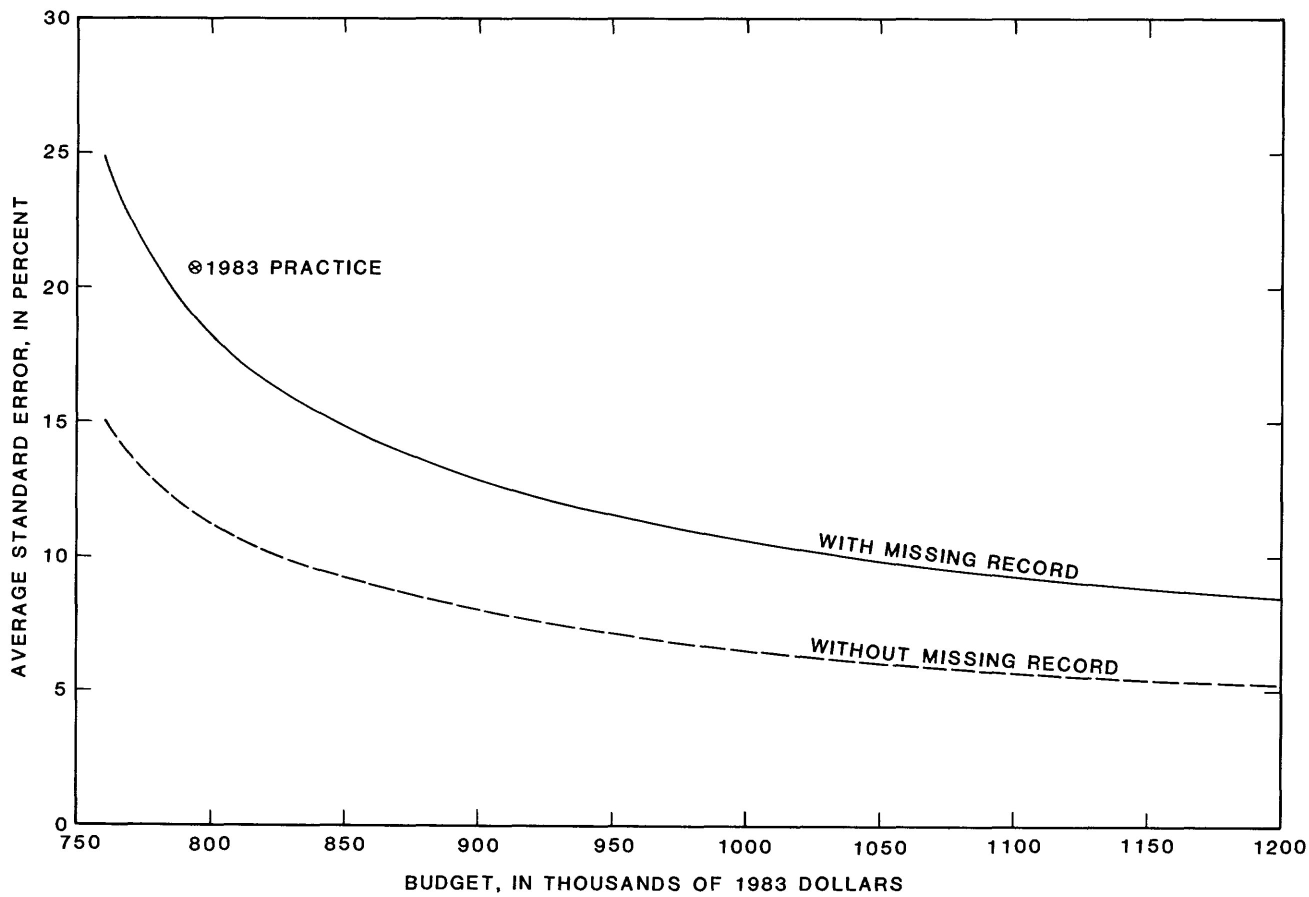


Figure 6.--Temporal, average standard error per stream gage.

with different budgets. Constraints on the operations other than budget were defined as described below.

To determine the minimum number of times each station needs to be visited, consideration was given only to the physical limitations of the method used to record data. The effect of visitation frequency on the accuracy of the data and on the length of lost record was taken into account in the uncertainty analysis. In Kansas, a minimum requirement of five visits per year was calculated and applied to all stations. This value was based on limitations of the batteries used to drive recording equipment, capacities of the uptake spools on the digital recorders, and the duration of the negator-spring tension for graphical recorders.

Minimum visit requirements also may reflect the need to visit stations for special reasons, such as water-quality sampling. In Kansas, the water-quality work is integrated with surface-water operations, and the scheduled work could be met within the minimum visit requirements. For those stations without uncertainty functions, the 1983 practice was used as the minimum requirement, as well as for reservoirs.

The results in figure 6 and table 5 summarize the K-CERA analysis and are predicated on the basis that a discharge measurement was made at the estimated probability of making the measurement of each respective station, each time that a station was visited.

The six stations that were footnoted in table 4 were given a weight of zero for the "Traveling Hydrographer Program." Although an estimate of error was computed, based on the 1983 visitation schedule, this did not contribute to the total variance of error. Because of this special treatment of the six stations, the total variance of error was based on 85 of 140 stations.

It should be emphasized that figure 6 and table 5 are based on various assumptions (stated previously) concerning both the time series of shifts to the stage-discharge relationship and the methods of record construction. Where a choice of assumptions was available, the assumption that would not underestimate the magnitude of the error variances was chosen.

It can be seem that the 1983 schedule results in an average standard error of estimate of instantaneous discharge of 20.8 percent. This schedule required a budget of $793,780 to operate the 140 continuous-record stations and the 137 other sites in the stream-gaging program. It should be noted that the error of estimate is based on only 85 of the 140 complete-record stations. The range in standard errors was from a minimum of 9.6 percent for station 06892350 to a maximum of 36.5 percent for station 06914000.

It would be possible to decrease the average standard error by altering the travel routes and the measurement frequency while maintaining the same budget of $793,780. In this case, the average standard error would decrease from 20.8 to 18.9 percent. Extremes of standard errors for individual sites would be 9.4 and 31.0 percent for stations 06892350 and 06914000, respectively.

A minimum budget of $760,000 is required to operate the 1983 stream-gaging program; a budget of less than this would not permit proper service and maintenance of the gages and recorders. Stations would have to be eliminated from the program if the budget were less than this minimum. At the minimum budget, the average standard error would be 24.9 percent. The minimum standard error of 9.4 percent would occur at station 06892350, whereas the maximum standard error of 39.8 percent would occur at station 06914000.

The maximum budget analyzed was $1,191,000, which resulted in an average standard error of estimate of 8.6 percent. Thus, a budget almost one-half again as large, in conjunction with schedule change would almost halve the average standard error that would result fom the 1983 schedule and budget. For the $1,191,000 budget, the extremes of standard error were 4.6 percent for station 06891000 and 14.5 percent for station 06914000. Thus, it is apparent that significant improvements in accuracy of streamflow records can be obtained if larger budgets become available.

Table 5.--Selected results of K-CERA analysis

Station number	Standard error in instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1982 dollars 760	779	793.8	834	1191
Average per station 1/	20.8	24.9	20.8	18.9	15.6	8.6
06853500	10.2 [3.1] (8)	12.8 [4.0] (5)	12.8 [4.0] (5)	11.7 [3.6] (6)	9.2 [2.8] (10)	5.2 [1.9] (33)
06856000	13.0 [9.6] (8)	16.2 [12.3] (5)	16.2 [12.3] (5)	14.9 [11.2] (6)	11.7 [8.6] (10)	6.6 [4.6] (33)
06856600	12.8 [8.3] (8)	15.6 [10.2] (5)	15.6 [10.2] (5)	14.5 [9.4] (6)	11.5 [7.4] (10)	6.5 [4.1] (33)
06857100	17.1 [15.2] (8)	21.1 [19.2] (5)	21.1 [19.2] (5)	19.5 [17.6] (6)	15.4 [13.5] (10)	8.6 [7.3] (33)
06860000	25.3 [18.2] (8)	25.3 [18.2] (8)	20.9 [14.8] (12)	19.4 [13.6] (14)	18.8 [13.2] (15)	8.9 [6.0] (68)
06862700	14.5 [12.1] (8)	16.3 [13.8] (6)	13.1 [10.9] (10)	13.1 [10.9] (10)	11.2 [9.2] (14)	5.9 [4.7] (53)
06863500	18.5 [11.3] (8)	21.2 [13.3] (6)	16.7 [10.0] (10)	16.7 [10.0] (10)	14.1 [8.3] (14)	7.4 [4.3] (53)
06864050	20.2 [15.8] (8)	22.9 [17.9] (6)	18.3 [14.2] (10)	18.3 [14.2] (10)	15.7 [12.0] (14)	8.2 [6.1] (53)
06864500	20.0 [15.1] (8)	24.8 [19.3] (5)	20.0 [15.0] (8)	20.0 [15.0] (8)	18.0 [13.3] (10)	8.9 [6.3] (42)
06865500	16.1 [11.5] (8)	20.1 [14.9] (5)	20.1 [14.9] (5)	17.1 [12.4] (7)	13.8 [9.7] (11)	8.1 [5.5] (34)

1 Square root of seasonally averaged station variance.

Table 5.--Selected results of K-CERA analysis--Continued

Station number	Standard error in instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1982 dollars				
		760	779	793.8	834	1191
06866500	15.3 [11.8] (8)	18.9 [14.9] (5)	18.9 [14.9] (5)	16.2 [12.6] (7)	13.1 [10.0] (11)	7.6 [5.6] (34)
06867000	12.8 [5.5] (10)	12.8 [5.5] (10)	12.2 [5.2] (11)	12.2 [5.2] (11)	10.9 [4.6] (14)	5.4 [2.4] (61)
06868200	20.6 [8.1] (8)	25.7 [10.8] (5)	19.5 [7.7] (9)	19.5 [7.7] (9)	18.5 [7.2] (10)	8.5 [3.3] (50)
06869500	15.8 [3.0] (8)	19.7 [3.8] (5)	18.1 [3.4] (6)	15.0 [2.8] (9)	12.1 [2.2] (14)	6.8 [1.4] (45)
06870200	11.1 [1.3] (8)	13.9 [1.7] (5)	13.9 [1.7] (5)	11.8 [1.4] (7)	9.5 [1.2] (11)	5.4 [0.75] (34)
06872500	15.1 [7.0] (8)	18.9 [9.3] (5)	15.1 [7.0] (8)	15.1 [7.0] (8)	13.6 [6.2] (10)	6.8 [3.2] (42)
06874000	16.9 [8.8] (8)	21.0 [11.5] (5)	16.8 [8.8] (8)	16.9 [8.8] (8)	15.2 [7.8] (10)	7.6 [3.8] (42)
06875900	10.6 [2.4] (8)	13.3 [2.9] (5)	12.2 [2.7] (6)	10.0 [2.3] (9)	8.1 [1.9] (14)	4.6 [1.2] (45)
06876440	14.0 [12.9] (8)	17.2 [16.2] (5)	17.2 [16.2] (5)	14.9 [13.8] (7)	12.0 [11.0] (11)	6.9 [6.1] (34)
06876700	21.5 [11.9] (8)	26.8 [15.6] (5)	24.6 [14.0] (6)	20.0 [11.2] (9)	16.4 [8.7] (14)	9.3 [4.8] (45)

Table 5.--Selected results of K-CERA analysis--Continued

Station number	Standard error in instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1982 dollars 760	779	793.8	834	1191
06876900	16.5 [7.8] (8)	20.5 [10.3] (5)	18.8 [9.3] (6)	15.6 [7.4] (9)	12.6 [5.8] (14)	7.1 [3.2] (45)
06877600	13.9 [7.1] (8)	17.3 [9.1] (5)	17.3 [9.1] (5)	15.9 [8.3] (6)	12.5 [6.3] (10)	7.0 [3.4] (33)
06878000	17.1 [4.8] (8)	21.4 [6.3] (5)	19.6 [5.6] (6)	17.1 [4.8] (8)	13.5 [3.8] (13)	7.5 [2.1] (44)
06879100	12.0 [7.0] (8)	14.9 [9.0] (5)	12.8 [7.5] (7)	12.0 [7.0] (8)	9.5 [5.4] (13)	5.2 [3.0] (45)
06884200	18.7 [9.8] (8)	23.4 [12.9] (5)	18.7 [9.8] (8)	16.8 [8.7] (10)	13.4 [6.8] (16)	7.3 [3.7] (56)
06884400	11.0 [1.2] (10)	11.0 [1.2] (10)	11.0 [1.2] (10)	11.0 [1.2] (10)	9.7 [0.87] (13)	5.3 [0.80] (45)
06885500	25.1 [17.4] (8)	30.8 [21.8] (5)	25.1 [17.4] (8)	22.6 [15.7] (10)	18.1 [12.2] (16)	9.8 [6.4] (56)
06887000	19.9 [17.3] (8)	24.4 [21.7] (5)	21.1 [18.5] (7)	19.9 [17.3] (8)	15.9 [13.5] (13)	8.6 [7.0] (45)
06887500	11.2 [6.8] (8)	13.7 [8.3] (5)	13.7 [8.3] (5)	13.7 [8.3] (5)	13.7 [8.3] (5)	7.5 [4.6] (19)
06888500	19.9 [12.8] (8)	24.6 [16.4] (5)	21.2 [13.7] (7)	18.9 [12.0] (9)	17.2 [10.7] (11)	8.7 [5.2] (44)

Table 5.--Selected results of K-CERA analysis--Continued

Station number	Standard error in instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1982 dollars				
		760	779	793.8	834	1191
06889000	9.7 [5.3] (20)	9.7 [5.3] (20)	9.7 [5.3] (20)	9.7 [5.3] (20)	9.7 [5.3] (20)	5.8 [3.1] (58)
06889160	22.6 [13.5] (8)	28.0 [17.7] (5)	20.3 [12.0] (10)	17.9 [10.3] (13)	15.2 [8.6] (18)	8.6 [4.8] (58)
06889200	20.9 [11.6] (8)	26.0 [15.7] (5)	18.8 [10.2] (10)	16.6 [8.8] (13)	14.2 [7.4] (18)	8.0 [4.1] (58)
06889500	21.8 [10.3] (8)	27.1 [13.6] (5)	19.6 [9.1] (10)	17.3 [7.9] (13)	14.8 [6.6] (18)	8.3 [3.7] (58)
06890100	20.2 [12.5] (8)	25.1 [16.3] (5)	18.1 [10.9] (10)	16.0 [9.5] (13)	13.7 [8.0] (18)	7.7 [4.4] (58)
06891000	10.4 [4.2] (8)	13.0 [5.5] (5)	11.1 [4.5] (7)	10.4 [4.2] (8)	8.0 [3.1] (14)	4.6 [1.8] (44)
06892350	9.6 [3.8] (20)	9.4 [3.6] (21)	9.4 [3.6] (21)	9.4 [3.6] (21)	9.4 [3.6] (21)	6.5 [2.5] (45)
06910800	16.9 [7.4] (8)	21.0 [9.9] (5)	16.0 [7.0] (9)	14.5 [6.3] (11)	11.8 [5.0] (17)	6.5 [2.9] (58)
06911500	27.7 [15.8] (8)	34.1 [20.0] (5)	26.2 [14.8] (9)	23.8 [13.4] (11)	19.3 [10.6] (17)	10.6 [5.6] (58)
06911900	18.1 [1.9] (8)	22.6 [2.0] (5)	17.1 [1.8] (9)	15.5 [1.7] (11)	12.6 [1.4] (17)	6.9 [1.1] (58)

Table 5.--Selected results of K-CERA analysis--Continued

Station number	Standard error in instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1982 dollars				
		760	779	793.8	834	1191
06912500	21.3 [8.6] (8)	26.6 [11.4] (5)	20.2 [8.0] (9)	18.3 [7.2] (11)	14.9 [5.7] (17)	8.2 [3.2] (58)
06913000	17.2 [11.7] (8)	20.8 [14.3] (5)	18.2 [12.4] (7)	17.2 [11.7] (8)	13.4 [9.0] (14)	7.7 [5.1] (44)
06913500	19.3 [8.3] (8)	23.6 [9.6] (5)	18.3 [8.0] (9)	16.8 [7.4] (11)	13.7 [6.2] (17)	7.6 [3.6] (58)
06914000	36.5 [29.7] (8)	39.8 [32.0] (6)	33.9 [27.9] (10)	31.0 [25.6] (13)	25.1 [20.9] (22)	14.5 [11.9] (70)
06916600	19.0 [13.7] (8)	22.6 [15.9] (5)	18.2 [13.1] (9)	16.1 [11.6] (12)	13.1 [9.5] (19)	7.6 [5.4] (60)
06917000	25.0 [13.8] (8)	28.6 [16.1] (6)	22.6 [12.3] (10)	19.9 [10.7] (13)	15.4 [8.1] (22)	8.7 [4.5] (70)
06917380	28.7 [25.7] (8)	32.6 [29.0] (5)	27.7 [24.8] (9)	25.2 [22.6] (12)	21.0 [18.8] (19)	12.2 [10.7] (60)
07137500	13.1 [7.8] (18)	13.1 [7.8] (18)	13.1 [7.8] (18)	13.1 [7.8] (18)	13.1 [7.8] (18)	7.9 [4.4] (52)
07138000	19.7 [16.2] (8)	22.3 [18.9] (6)	18.7 [15.2] (9)	18.7 [15.2] (9)	16.4 [12.9] (12)	8.2 [5.9] (51)
07140000	14.4 [7.5] (8)	18.0 [9.9] (5)	14.4 [7.5] (8)	13.0 [6.6] (10)	11.9 [6.0] (12)	6.1 [3.1] (49)

Table 5.--Selected results of K-CERA analysis--Continued

Station number	Standard error in instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site) Current operation	Budget, in thousands of 1982 dollars 760	779	793.8	834	1191
07141300	18.6 [11.6] (8)	21.3 [13.7] (6)	16.8 [10.2] (10)	16.8 [10.2] (10)	14.2 [8.5] (14)	7.5 [4.3] (53)
07142300	12.0 [5.9] (8)	14.9 [7.6] (5)	12.0 [5.9] (8)	10.8 [5.2] (10)	9.9 [4.7] (12)	5.0 [2.5] (49)
07142575	13.9 [11.9] (8)	17.2 [15.3] (5)	13.9 [11.9] (8)	12.4 [10.5] (10)	11.4 [9.6] (12)	5.8 [4.7] (49)
07142620	15.6 [12.0] (8)	19.4 [15.5] (5)	15.6 [12.0] (8)	14.0 [10.6] (10)	12.8 [9.6] (12)	6.5 [4.7] (49)
07143300	23.6 [18.4] (8)	28.5 [22.5] (5)	22.4 [17.4] (9)	20.4 [15.8] (11)	19.6 [15.1] (12)	9.2 [6.8] (57)
07143330	14.1 [10.2] (8)	17.6 [13.4] (5)	16.2 [12.0] (6)	14.1 [10.2] (8)	11.2 [7.9] (13)	6.5 [4.4] (41)
07143665	17.2 [8.5] (8)	21.4 [11.2] (5)	19.7 [10.0] (6)	17.2 [8.5] (8)	13.6 [6.4] (13)	7.8 [3.7] (41)
07144200	19.4 [8.3] (8)	24.2 [10.9] (5)	20.6 [8.9] (7)	18.3 [7.7] (9)	14.8 [6.1] (14)	8.4 [3.5] (45)
07144300	15.1 [9.9] (8)	18.7 [12.8] (5)	17.2 [11.6] (6)	16.0 [10.7] (7)	12.9 [8.4] (11)	7.1 [4.4] (38)
07144550	12.3 [8.2] (8)	15.3 [10.7] (5)	14.0 [9.7] (6)	13.0 [8.8] (7)	10.5 [6.9] (11)	5.8 [3.8] (38)

Table 5.--Selected results of K-CERA analysis--Continued

Station number	Standard error in instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1982 dollars 760	779	793.8	834	1191
07144780	18.4 [12.7] (8)	22.6 [16.7] (5)	18.4 [12.7] (8)	16.5 [11.1] (10)	15.2 [10.0] (12)	7.8 [4.8] (49)
07144795	21.8 [12.5] (8)	27.1 [16.3] (5)	23.2 [13.5] (7)	20.6 [11.7] (9)	16.7 [9.2] (14)	9.4 [5.0] (45)
07145200	16.5 [14.3] (8)	20.3 [18.0] (5)	16.5 [14.3] (8)	15.0 [12.9] (10)	13.7 [11.7] (12)	6.9 [5.7] (49)
07145500	14.6 [10.1] (8)	18.2 [13.0] (5)	16.7 [11.8] (6)	15.5 [10.9] (7)	12.5 [8.5] (11)	6.9 [4.5] (38)
07146500	12.6 [8.5] (10)	12.6 [8.4] (10)	12.6 [8.4] (10)	12.6 [8.4] (10)	12.0 [8.0] (11)	6.6 [4.3] (38)
07147070	19.7 [10.4] (8)	24.5 [13.6] (5)	21.0 [11.2] (7)	19.7 [10.4] (8)	16.2 [8.3] (12)	8.8 [4.4] (42)
07147800	21.9 [14.1] (8)	27.2 [18.3] (5)	23.4 [15.2] (7)	21.9 [14.1] (8)	18.1 [11.3] (12)	9.8 [5.9] (42)
07149000	16.5 [13.1] (8)	20.4 [16.8] (5)	16.4 [13.1] (8)	14.8 [11.6] (10)	13.6 [10.6] (12)	6.8 [5.1] (49)
07151500	14.5 [9.5] (8)	18.2 [12.4] (5)	16.7 [11.2] (6)	15.5 [10.2] (7)	12.5 [8.0] (11)	6.8 [4.3] (38)
07157500	26.3 [23.1] (8)	27.6 [24.3] (7)	24.0 [21.1] (10)	23.1 [20.3] (11)	21.6 [18.8] (13)	10.4 [8.8] (59)

Table 5.--Selected results of K-CERA analysis--Continued

Station number	Standard error in instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1982 dollars				
		760	779	793.8	834	1191
07166000	24.2 [2.2] (8)	29.8 [2.7] (5)	21.8 [2.0] (10)	19.3 [1.6] (13)	15.0 [1.5] (22)	8.4 [1.1] (73)
07166500	30.3 [24.8] (8)	35.1 [28.6] (5)	28.0 [22.9] (10)	25.4 [20.7] (13)	20.3 [16.3] (22)	11.4 [8.9] (73)
07168500	26.9 [16.8] (8)	32.7 [21.4] (5)	24.3 [14.9] (10)	21.6 [12.9] (13)	16.8 [9.7] (22)	9.4 [5.2] (73)
07169500	25.2 [15.3] (8)	29.9 [17.6] (5)	23.1 [14.3] (10)	20.8 [13.1] (13)	16.7 [10.7] (22)	9.5 [6.1] (73)
07170500	25.3 [16.4] (8)	30.3 [20.0] (5)	23.0 [14.9] (10)	20.6 [13.1] (13)	16.1 [10.1] (22)	9.0 [5.4] (73)
07172000	32.2 [22.9] (8)	38.8 [28.4] (5)	29.2 [20.4] (10)	26.0 [17.8] (13)	20.3 [13.5] (22)	11.3 [7.2] (73)
07179500	22.7 [13.6] (8)	28.2 [17.5] (5)	21.5 [12.7] (9)	20.4 [12.0] (10)	16.2 [9.3] (16)	8.9 [5.0] (55)
07179730	18.9 [13.5] (8)	23.4 [17.4] (5)	17.9 [12.7] (9)	17.0 [12.0] (10)	13.5 [9.3] (16)	7.4 [5.0] (55)
07179795	20.4 [15.2] (8)	25.3 [19.2] (5)	20.4 [15.2] (8)	18.4 [13.5] (10)	14.6 [10.5] (16)	8.3 [5.8] (51)
07180400	17.5 [11.7] (8)	21.6 [14.9] (5)	20.0 [13.6] (6)	17.5 [11.7] (8)	14.0 [9.1] (13)	8.0 [5.0] (41)

Table 5.--Selected results of K-CERA analysis--Continued

Station number	Standard error in instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1982 dollars				
		760	779	793.8	834	1191
07180500	20.9 [14.9] (8)	25.9 [19.1] (5)	20.9 [14.9] (8)	18.8 [13.2] (10)	14.9 [10.3] (16)	8.5 [5.7] (51)
07182250	13.9 [6.6] (8)	17.3 [8.5] (5)	15.9 [7.7] (6)	13.9 [6.6] (8)	11.0 [5.0] (13)	6.3 [2.9] (41)
07182510	18.4 [14.3] (8)	22.6 [18.1] (5)	16.6 [12.8] (10)	14.7 [11.1] (13)	11.4 [8.4] (22)	6.4 [4.7] (73)
07183000	15.2 [6.7] (8)	18.9 [8.5] (5)	14.4 [6.3] (9)	12.6 [5.4] (12)	10.0 [4.3] (19)	5.7 [2.5] (60)
07183500	15.8 [8.2] (8)	19.7 [10.7] (5)	15.0 [7.7] (9)	13.0 [6.5] (12)	10.4 [5.1] (19)	6.0 [3.0] (60)

The K-CERA analysis also was performed under the assumption that no correlative data at a stream gage were lost in order to estimate the uncertainty that was added to the stream-gaging records because of less than perfect instrumentation. The curve, labeled "Without missing record" in figure 6, shows the average standard errors of estimate of streamflow that could be obtained if perfectly reliable systems were available to measure and record the correlative data. For the minimal operational budget of $760,000, the impacts of less than perfect equipment were greatest; average standard errors would increase from 15.0 to 24.9 percent.

At the other budgetary extreme of $1,191,000, under which stations are visited more frequently and the reliability of equipment should be less sensitive, average standard errors would increase from 5.3 percent for ideal equipment to 8.6 percent for the 1983 systems of sensing and recording of hydrologic data. Thus, improved equipment can have a very positive impact on streamflow uncertainties throughout the range of operational budgets that possibly could be anticipated for the stream-gaging program in Kansas.

As a result of the K-CERA analysis, the following observations were made:

1. The schedule of visitations in the stream-gaging program could be altered to decrease the 1983 average standard error of estimate of streamflow records from 20.8 percent to 18.9 percent at a budget of approximately $793,780, by changes in frequency of visitation. This shift could result in some increases in accuracy of records at individual sites.

2. Stations with accuracies that are not acceptable for the data uses could benefit from renegotiation of funding levels with the data users.

3. An exploration of methods or means of including all of the stations in the K-CERA analysis could provide sufficient information about the characteristics of each station so that it can be weighted as to its possible decrease of the total standard error of estimate of streamflow records.

4. Methods for decreasing the probabilities of missing record, such as, increased use of local gage observers, satellite relay of data, and improved instrumentation, need to be explored and evaluated as to their cost effectiveness in providing streamflow information.

SUMMARY

The 1983 stream-gaging program was operated in Kansas at a cost of $793,780. Nine separate sources of funding contributed to this program, and as many as nine separate uses were identified for data from a single station. In spite of the number of stations in the program, only 85 of the 140 complete-record stations could be evaluated as to their contribution to decreasing the errors and increasing the cost effectiveness of the program. This is one area that may deserve consideration for further study, as funds become available.

It was shown that the overall level of accuracy of the records at 85 of the 140 stations could be improved at the 1983 budget of $793,780, if the frequency of visitations was altered in a cost-effective manner. A major component of the error in streamflow records is caused by loss of primary record (stage or other correlative data) at the stream gages because of malfunctions of sensing and recording equipment. Upgrading of equipment and development of strategies to minimize lost record appear to be key actions required to improve the reliability and accuracy of the streamflow data generated in the State.

Future studies of the cost effectiveness of the stream-gaging program could include an investigation to determine how to incorporate the effect of a zero-discharge measurement with an uncertainty function, so that all stations can be included in the analysis, and an investigation of cost-effective ways to decrease the probabilities of lost correlative data.

Further studies of this type may be necessary because of changes in demands for streamflow information with subsequent addition and deletion of stream gages. Such changes will impact the operation of other stations in the program both because of the dependence between stations of the information that is generated (data redundancy) and because of the dependence on the costs of collecting the data from which the information is derived.

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