COST-EFFECTIVENESS OF THE U.S. GEOLOGICAL SURVEY STREAM-GAGING PROGRAM IN ARKANSAS

By M. E. Darling and T. E. Lamb

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CONVERSION FACTORS

For use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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ABSTRACT

This report documents the results of the cost-effectiveness of the stream-gaging program in Arkansas. The total surface-water program operation of 49 daily-discharge stations, 30 partial-record stations, 54 crest gages, and 13 pollution-control stations are currently operated in Arkansas (October 1, 1982) with a budget of $450,000. The first step of this report is a survey of all daily-discharge stations in the Arkansas District. One or more data-use categories, funding sources and availability of data designations were assigned to each station. Any station which did not have a funding source or data use was suggested for discontinuation and dropped from further analysis. Results of this study show that all daily-discharge stations in Arkansas were found to have one or more data uses and all were funded operations.

The second step of this report is the selection of several daily-discharge stations for possible synthesis of data from index stations using regression and streamflow routing models. Any candidates which could be synthesized within an acceptable limit of error would be suggested for discontinuation or conversion to partial-record stations and dropped from the Kalman-Filtering Cost Effective Resource Allocation analysis. Results indicate that data from all candidate stations for these alternative methods could not be synthesized within acceptable limits of error; and no stations were offered for discontinuation or conversion.

The total cost for operation of daily-discharge stations and the route costs associated with partial-record stations, crest gages, pollution-control stations, and seven recording ground-water stations was evaluated in the Kalman-Filtering Cost-Effective Resource Allocation analysis (the third step of the report). This operation under current practices requires a budget of $292,150. The average standard error of estimate of streamflow record for the Arkansas District, using the method of analysis explained in this report, is 33 percent. The standard errors of estimate presented in this report are used to evaluate the relative accuracies at various stations and may not be a true measure of streamflow error. By altering the routing and frequency of visits for each gaging station to a more cost-effective manner, less than 1 percent of the existing budget could be saved (about $2,000). However, increases in budget yield significant increases in accuracy from current operations. Using the cost-effective approach outlined in this report, an increase in budget of $50,000 could reduce the average standard error for the District to 23 percent.

Different budgets were analyzed to estimate changes in average standard error for streamflow record. The budget range studied is $272,000 to $600,000 with standard errors of 41 to 14 percent, respectively.

In terms of regional hydrology, there are significant parts of Arkansas which have insufficient streamflow information. This report outlines these areas.

INTRODUCTION

The U.S. Geological Survey is the principal Federal agency collecting surface-water data in the Nation. The collection of these data is a major activity of the Water Resources Division of the Geological Survey. These data are collected in cooperation with State and local governments and other Federal agencies. In 1983 the Survey is operating approximately 8,000 daily-discharge stations throughout the Nation with some records extending back to the turn of the century. Any activity of long standing, such as the collection of surface-water data, should be reexamined periodically, because of changes of objectives, technology, and external constraints. The last systematic nationwide evaluation of the streamflow information program was completed in 1970 and is documented by Carter and Benson (1973). The Survey is presently (1983) undertaking another nationwide analysis of the stream-gaging program that will be completed over a 5-year period with 20 percent of the program being analyzed each year. The objective of this analysis is to define and document the most cost-effective means of furnishing streamflow information.

For every continuous-record daily-discharge gaging station, the analysis identifies the principal use of the data and relates these uses to funding sources. Gaged sites for which data are no longer needed are identified, as are deficient or unmet data demands. In addition, gaging stations are categorized as to whether the data are available to users in a real-time sense, on a monthly basis, or at the end of the water year.

The second aspect of the analysis is to identify gaging stations whose information can be obtained from less costly alternate methods. Among these are flow-routing models and statistical methods. The stream-gaging activity no longer is considered a program of observation points, but rather an information system in which data are provided both by observation and synthesis.

The final part of the analysis involves the use of Kalman-filtering and mathematical-programing techniques to define strategies for operation of the necessary stations that minimize the uncertainty in the streamflow records for given operating budgets. Kalman-filtering techniques are used to compute uncertainty functions (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 utilizes 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 minimizes the overall uncertainty in the streamflow. The stream-gaging program that results from this analysis will meet the expressed water-data needs in the most cost-effective manner.

This report is organized into five sections; the first section is an introduction to the stream-gaging activities in Arkansas and to the study itself. The middle three sections each contain discussions of an individual step of the analysis. These sections are data-use, alternate methods, and cost-effective resource allocation sections. Because of the sequential nature of the steps and the dependence of subsequent steps on the previous results, recommendations are made at the end of each section. The study, including all recommendations, is summarized in the final section.

History of Stream-Gaging Program in Arkansas

The program of surface-water investigations by the Survey in Arkansas has grown through the years as Federal and State interest in water resources has increased. The Arkansas office of the Survey began collecting surface-water data, as part of a statewide water resources program, with the establishment of eight gaging stations in 1927. Prior to this time discharge records were collected for short periods at several sites in the State during 1903-26, primarily to evaluate the hydroelectric power potential of the streams. The program expanded to 16 gaging stations by 1930 and then declined during the early years of the depression as State cooperation was reduced. Disastrous floods in the mid-1930's and the resulting emphasis on flood control brought out the great need for basic streamflow data in the State. During the last half of the decade, much of the Survey's present program of streamflow stations was established in cooperation with State agencies and the U.S. Army Corps of Engineers. The war effort during the 1940's curtailed expansion of the program, but during the period 1950-1970, there was a gradual increase in the program. By 1970 the Survey was operating 76 daily-discharge surface-water stations in Arkansas.

Patterson (1969) previously evaluated the Arkansas District surface-water program. Based on this study and consultation with cooperating agencies, 20 daily-discharge stations were discontinued at the end of the 1970 water year. Nine of these stations were converted to partial-record stations at the request of cooperators. The partial-record station operation consists of a stage record and occasional discharge measurements in order to maintain the high end of the rating curve or in some cases a complete rating curve. Annual peaks only are published for the partial record stations.

During the period 1971 through 1978 a few daily-discharge stations were either dropped or converted to partial-record stations. Beginning in the 1979 water year, the Survey took over operations of eight additional daily-discharge stations at the request of the Little Rock District, Corps of Engineers. By the 1982 water year, most of these additional stations had been converted to partial-record stations due to reevaluation of data needs both by the Corps and the Survey. These reductions leave the Arkansas District, at the beginning of the 1983 water year with 49 daily-discharge stations, 16 partial-record stations that have been converted from daily-discharge stations, and 14 partial-record stations that have been established to fill specific project operation needs.

The number of continuous record-gaging stations, both daily-discharge and converted partial-record, operated by the Survey in the State of Arkansas since 1927 is shown in figure 1.

A study of characteristics of peak flows on streams with small drainage areas was started in 1961. At its maximum, there were 105 crest-stage gages in this program, 25 of which were equipped with continuous stage and rainfall recorders. There are now 54 crest-stage gages being operated in the Arkansas District.

A program of pollution-control discharge stations was established in 1971 to provide discharge data for water-quality sampling done by the Arkansas Department of Pollution Control and Ecology. These stations, equipped with a nonrecording gage, are measured several times a year to maintain a rating curve. There are now 13 pollution-control sites being operated in the Arkansas District.

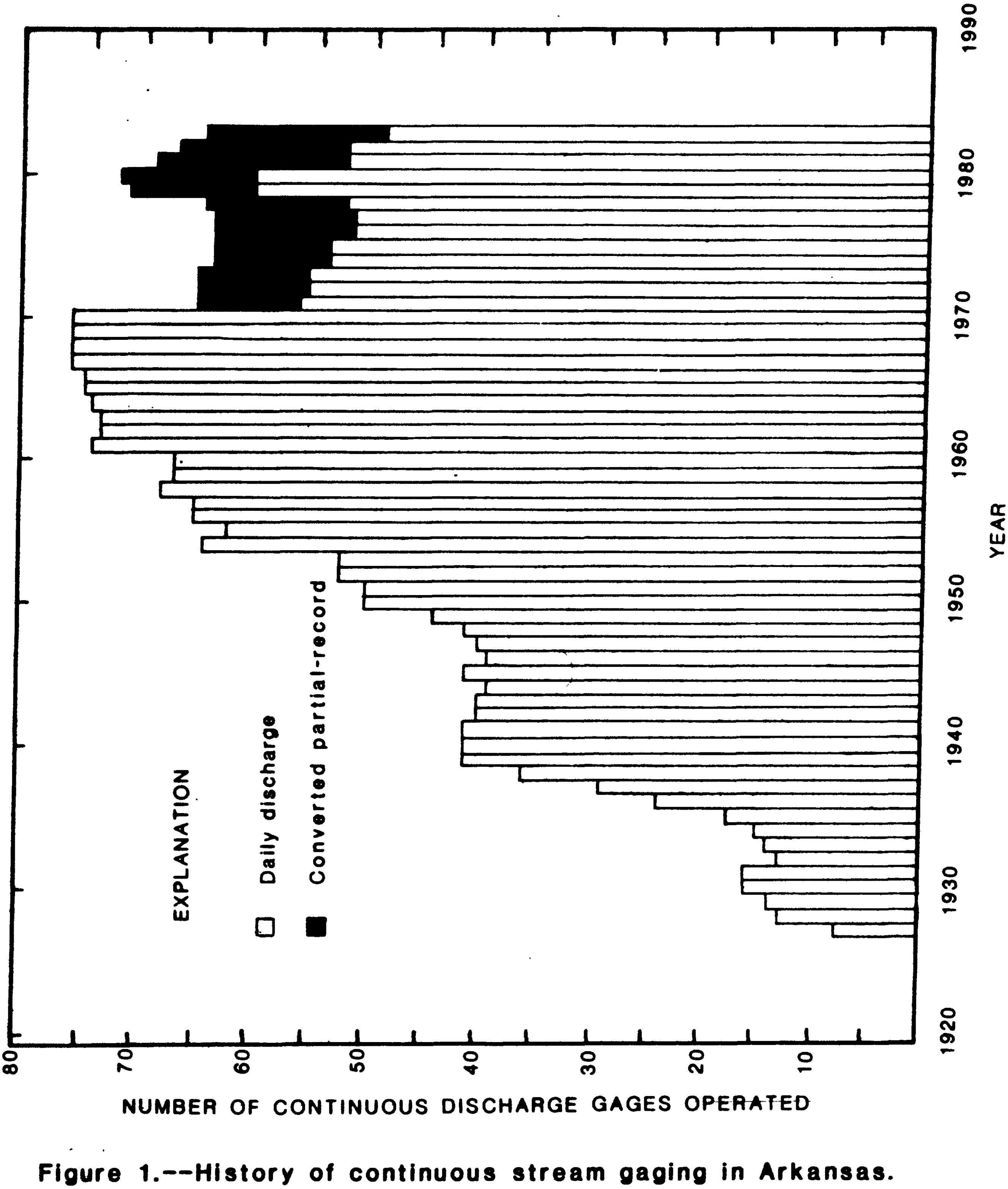


Figure 1.--History of continuous stream gaging in Arkansas.

Current Arkansas Stream-Gaging Program

Arkansas can be divided into four major physiographic areas: the Coastal Plain, the Ozark Plateaus, the Arkansas Valley, and the Ouachita Mountains. The location of these areas and the distribution of the 49 daily-discharge stations currently operated by the Arkansas District of the U.S. Geological Survey can be found in figure 2. Twenty gages are located in the Coastal Plain, 17 are located in the Ozark Plateaus, six are located in the Arkansas Valley, and six are located in the Ouachita Mountains. Figure 2 illustrates that although the majority of the gages are located in the Coastal Plain and the Ozark Plateaus, there are large areas sparsely gaged in the eastern part of the Coastal Plain and the central part of the Ozark Plateaus.

Drainage area, period of record, and mean annual flow, for the 49 daily-discharge stations are given in table 1. Station identification numbers used throughout this report are the last six digits of the Survey's eight-digit downstream-order station number; the first two digits of the standard Survey station number for all stations used in this report are "07". Table 1 also provides the official name of each stream gage, as well as an abbreviated version of each name; abbreviated names will be used in the remainder of this report.

In addition to those stations listed in table 1, the Arkansas District operates a number of other surface-water stations where less than daily-discharge data is collected. These include 14 other partial-record stations, 54 crest-stage nonrecording stations, and 13 pollution-control stations. These stations are visited by the hydrographers on routine stream gaging trips. Also visited on stream gaging trips are seven recording ground-water wells. These stations are shown in figure 3.

The total cost of operating these 49 daily-discharge stations, 30 partial-record stations, 54 crest-stage stations, and 13 pollution-control stations was $450,000 (October 1, 1982).

USES OF CONTINUOUS STREAMFLOW DATA

A survey of known data uses for each continuous-record gaging station in Arkansas was undertaken to document the importance of each gage and identify particular gaging stations that may be considered for discontinuation.

Data uses identified by this survey were categorized into the nine classes defined below. The sources of funding for each gage and the frequency at which data are provided to the users were compiled in table 2.

Data-Use Classes

The following definitions were used to categorize each known use of streamflow data for each daily-discharge station.

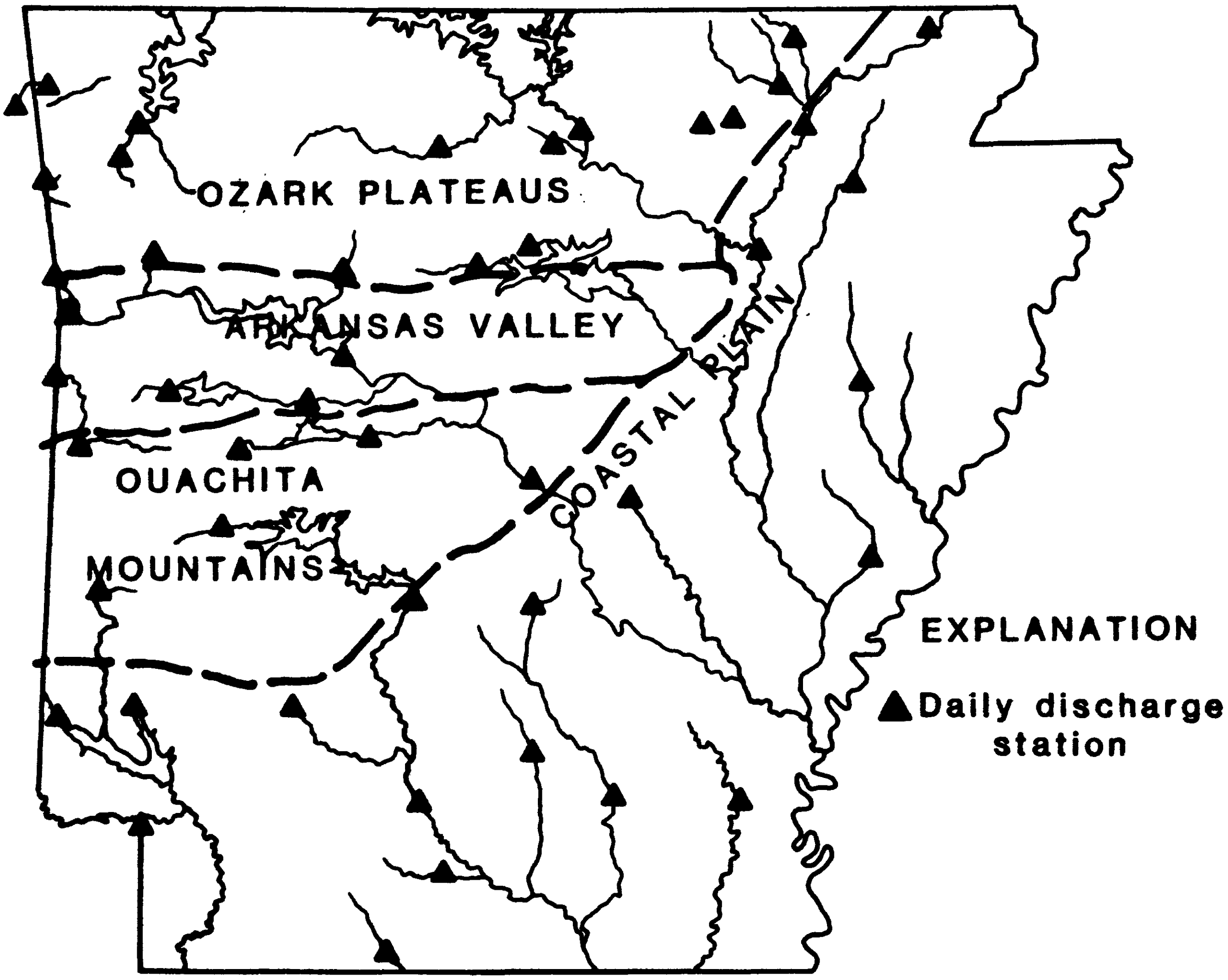


Figure 2.--Location of daily-discharge stations operated by Arkansas District.

Table 1.--Selected hydrologic data for stations in the Arkansas surface-water program

Abbreviated Station number	Station name (abbreviated name)	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
047942	L'Anguille River near Colt (Colt)	535	October 1970-	751
048000	West Fork White River at Greenland (Greenland)	83.1	October 1945-	107
048600	White River near Fayetteville (Fayetteville)	400	October 1963-	508
056000	Buffalo River near St. Joe (St. Joe)	829	October 1939-	1,018
060500	White River at Calico Rock (Calico Rock)	9,978	October 1939-	9,810
060710	North Sylamore Creek near Fifty Six (North Sylamore)	58.1	December 1965-	47.1
064000	Black River near Corning (Corning)	1,749	October 1938-	1,778
069200	Mammoth Spring at Mammoth Spring (Mammoth Spring)	-----	February 1981-	1,349 1/

See footnote at end of table.

Table 1.--Selected hydrologic data for stations in the Arkansas surface-water program--Continued

Abbreviated Station number	Station name (abbreviated name)	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
069500	Spring River at Imboden (Imboden)	1,183	February 1936-	1,349
072000	Eleven Point River near Ravenden Springs (Eleven Point)	1,134	October 1929-September 1983 and October 1935	1,113
072500	Black River at Black Rock (Black Rock)	7,369	June 1929-September 1931 and October 1939-	8,336
073500	Piney Fork at Evening Shade (Piney Fork)	99.2	February 1939-	89.9
074000	Strawberry River near Poughkeepsie Poughkeepsie)	473	February 1936-	504
074500	White River at Newport (Newport)	19,860	September 1927-1931 and October 1937	22,380
075000	Middle Fork Little Red River at Shirley (Shirley)	302	February 1939	463
075300	South Fork Little Red River at Clinton (Clinton)	148	October 1961-	232

Table 1.--Selected hydrologic data for stations in the Arkansas surface-water program--Continued

Abbreviated Station number	Station name (abbreviated name)	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
077380	Cache River at Egypt (Cache)	701	October 1964-	813
077950	Big Creek at Poplar Grove (Big Creek)	448	October 1970-	606
195800	Flint Creek at Springtown (Springtown)	14.2	June 1961-	13.5
195855	Flint Creek near West Siloam Springs (West Siloam)	59.8	June 1979-	------1/
196900	Baron Fork at Dutch Mills (Baron Fork)	46.0	April 1958-	37.6
247000	Poteau River at Cauthron (Poteau)	203	February 1939-	214
249400	James Fork near Hackett (James Fork)	147	April 1958-	128

See footnote at end of table.

Table 1.--Selected hydrologic data for stations in the Arkansas surface-water program--Continued

Abbreviated Station number	Station name (abbreviated name)	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
250000	Lee Creek near Van Buren (Lee Creek)	426	September 1930-June 1937 and October 1950-	486
250550	Arkansas River at Dam No. 13 near Van Buren (Dam 13)	150,547	October 1927-	30,610
252000	Mulberry River near Mulberry (Mulberry)	373	May 1938-	532
257000	Big Piney Creek near Dover (Big Piney)	274	October 1950-	392
258000	Arkansas River at Dardanelle (Dardanelle)	153,670	July 1937	34,700
258500	Petit Jean River near Booneville (Booneville)	241	November 1938-	247
260500	Petit Jean River at Danville (Danville)	764	June 1916-	806

Table 1.--Selected hydrologic data for stations in the Arkansas surface-water program--Continued

Abbreviated Station number	Station name (abbreviated name)	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
261000	Cadron Creek near Guy (Guy)	169	October 1954-	288
261500	Fourche LaFave River near Gravelly (Gravelly)	410	February 1939-	523
263000	South Fourche LaFave River near Hollis (Hollis)	210	May 1941-	290
263450	Arkansas River at Murray Dam at Little Rock (Murray Dam)	158,030	September 1927-	40,080
264000	Bayou Meto near Lonoke (Lonoke)	207	October 1954-	290
337000	Red River at Index (Index)	48,030	July 1936-	11,490

Table 1.--Selected hydrologic data for stations in the Arkansas surface-water program--Continued

Abbreviated Station number	Station name (abbreviated name)	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
340000	Little River near Horatio (Horatio)	2,662	October 1930-	3,739
340300	Cossatot River near Vandervoort (Vandervoort)	89.6	June 1967-	194
341200	Saline River near Lockesburg (Lockesburg)	256	June 1963-	387
356000	Ouachita River near Mount Ida (Mount Ida)	414	October 1941-	708
359500	Ouachita River near Malvern (Malvern)	1,585	March 1903-April 1905 and June 1922-	2,361
361500	Antoine River at Antoine (Antoine)	178	October 1954-	267
362000	Ouachita River at Camden (Camden)	5,357	September 1928-September 1960 and October 1965-	7,463
362100	Smackover Creek near Smackover (Smackover)	358	October 1961-	379

Table 1.--Selected hydrologic data for stations in the Arkansas surface-water program--Continued

Abbreviated Station number	Station name (abbreviated name)	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
362500	Moro Creek near Fordyce (Fordyce)	240	August 1951-	237
363300	Hurricane Creek near Sheridan (Hurricane)	204	October 1961-	227
363500	Saline River near Rye (Rye)	2,102	August 1937-	2,586
364150	Bayou Bartholomew near McGehee (McGehee)	576	October 1938-September 1942 and October 1945-	677
365800	Cornie Bayou near Three Creeks (Cornie Bayou)	180	February 1956-	178

1/ No mean annual flow published, less than 5 years of streamflow record.

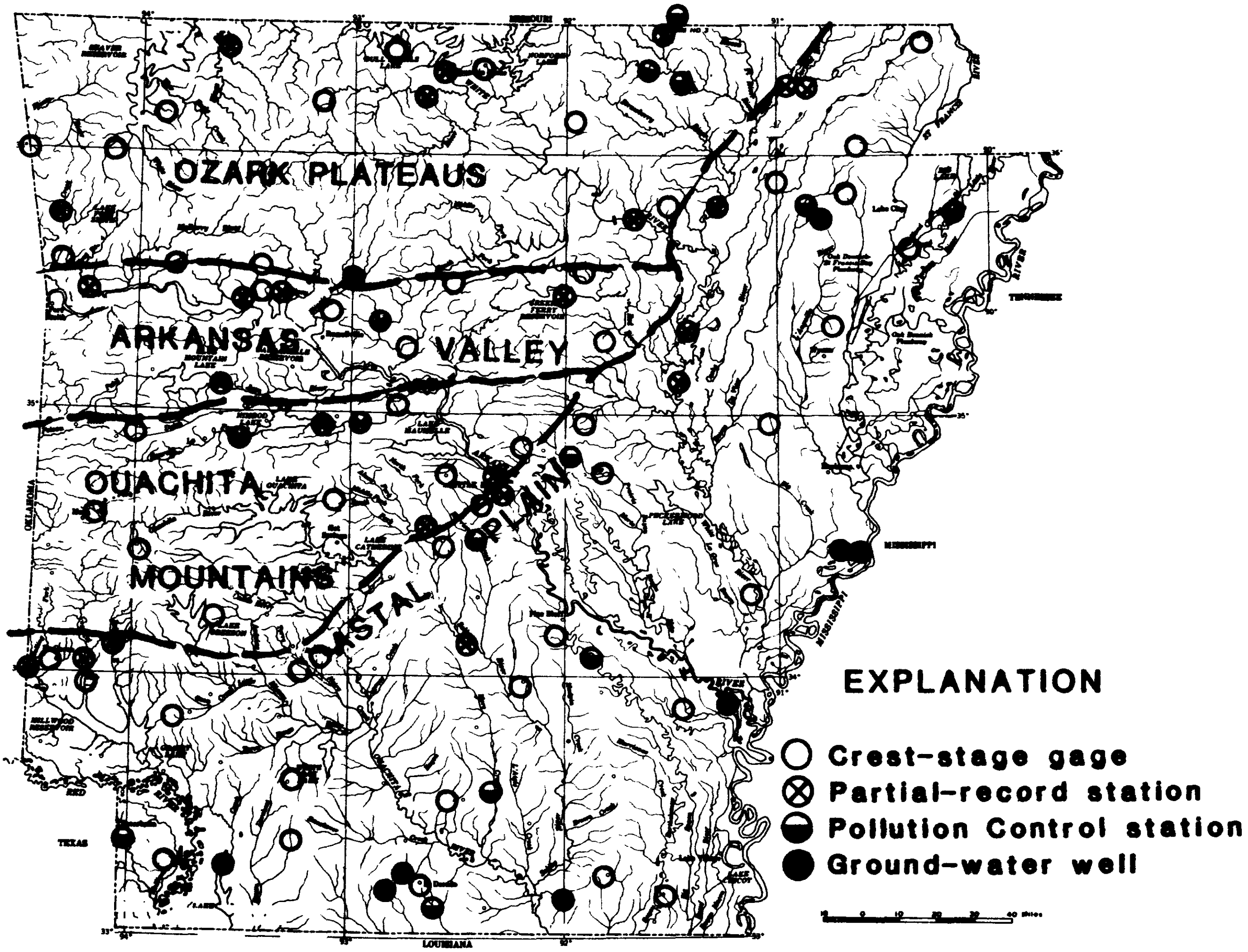


Figure 3.--Location of other stations operated in the Arkansas District stream-gaging program.

Table 2.--Data-use table

STATION NUMBER	DATA USE: REGIONAL HYDROLOGY	HYDROLOGIC SYSTEMS	LEGAL OBLIGATIONS	PLANNING & DESIGN	PROJECT OPERATION	HYDROLOGIC FORECASTS	WATER-QUALITY MONITORING	RESEARCH	OTHER	FUNDING: FEDERAL PROGRAM	OFA PROGRAM	CO-OP PROGRAM	OTHER NON-FEDERAL	FREQUENCY OF DATA AVAILABILITY
047942	*						1					1		A
048000		2			2						2			AP
048600		2			2		1				2	1		AP
056000	3 4	3				5 6	7		6		2			APT
060500		2			2	5	8				2			APT
060710	9	9					9			*				A
064000		2			2	5	7				2			APT
069200		10			10							10		A
069500	3	3				5						1		AT
072000	*				2						2			AP
072500	*				2	5	1				2			AP
073500	*	2		11							2			A
074000	*	2		11							2			A
074500		2			2	5	12				2			APT

1 Arkansas Geological Commission.
2 Little Rock District, Corps of Engineers, Reservoir Operation-White River system.
3 Long term index gaging station.
4 National Water Conditions station.
5 National Weather Service-flood forecasting.
6 Daily recreational planning-Buffalo National River.
7 Arkansas Department of Pollution Control and Ecology.
8 Arkansas Game and Fish Commission-temperature monitoring.
9 USGS Benchmark station.
10 Arkansas Parks and Tourism Department, spring flow used for power production.
11 Planning for proposed reservoir projects, Little Rock District, Corps of Engineers.
12 NASQAN station.
* No additional information.
A Data published in Geological Survey Annual Data Report for Arkansas.
P Periodic release of provisional data.
T Data furnished by direct-access telemetry equipment.

Table 2.--Data-use table--Continued

STATION NUMBER	DATA USE									FUNDING				FREQUENCY OF DATA AVAILABILITY
	REGIONAL HYDROLOGY	HYDROLOGIC SYSTEMS	LEGAL OBLIGATIONS	PLANNING & DESIGN	PROJECT OPERATION	HYDROLOGIC FORECASTS	WATER-QUALITY MONITORING	RESEARCH	OTHER	FEDERAL PROGRAM	OFA PROGRAM	CO-OP PROGRAM	OTHER NON-FEDERAL	
075000	3	2 3			2						2			AP
075300	*	2			2						2			AP
077380	3	3		13		5						1		A
077950	3	3								*				A
195800	*	14										14		A
195855	*						7					7		AP
196900	*	14					7					14		AP
247000		14										1 14		A
249400	*	14										14		A
250000	*	14		15	16							14		AT
250550		14			16		12 17					16		APT
252000	3	3			16						16	1		AT
257000	*				16						16	1		AT
258000					16	5	1 7				16			AP
258500	*				16		7				16	1		AP
260500	3	3			16						16			APT
261000	*											1		A
261500	*				16		7				16	1		AP
263000	*				16						16			AT

1 Arkansas Geological Commission.
2 Little Rock District Corps of Engineers, Reservoir Operation--White River System.
3 Long term index gaging station.
5 National Weather Service-flood forecasting.
7 Arkansas Department of Pollution Control and Ecology.
12 NASQAN station.
13 Memphis District, Corps of Engineers-Cache River Project.
14 Arkansas Soil and Water Conservation Commission-Arkansas River Compact station.
15 City of Fort Smith-future water supply.
16 Little Rock District, Corps of Engineers, Reservoir Operation-Arkansas River system.
17 National Tritium and Pesticide station.
* No additional information.
A Data published in Geological Survey Annual Data Report for Arkansas.
P Periodic release of provisional data.
T Data furnished by direct-access telemitry equipment.

Table 2.--Data-use table--Continued

STATION NUMBER	DATA USE									FUNDING				FREQUENCY OF DATA AVAILABILITY
	REGIONAL HYDROLOGY	HYDROLOGIC SYSTEMS	LEGAL OBLIGATIONS	PLANNING & DESIGN	PROJECT OPERATION	HYDROLOGIC FORECASTS	WATER-QUALITY MONITORING	RESEARCH	OTHER	FEDERAL PROGRAM	OFA PROGRAM	CO-OP PROGRAM	OTHER NON-FEDERAL	
263450					16	5	7 12			*	16			APT
264000	*				18		7				18	1		AP
337000		19			20	5	12				20			APT
340000		19			20		7			*				APT
340300	9	9								*				A
341200					20		7				20			APT
356000	*				18		7				18	1		AP
359500			21		18 22						18		21	APT
361500	3	3			18						18	1		AP
362000					18	5	12 17				18			APT
362100	*				18						18	1		AP
362500	*				18		7				18	1		AP
363300	*				18						18	1		AP
363500	3 4	3			18					*	18			AP
364150	*				18						18	1		AP
365800	3	3			18		7				18	1		AP

1	Arkansas Geological Commission.
3	Long term index gaging station.
4	National Weather Conditions station.
5	National Weather Service-flood forecasting.
7	Arkansas Department of Pollution Control and Ecology.
9	USGS Benchmark station.
12	NASQAN station.
16	Little Rock District Corps of Engineers, Reservoir Operation--Arkansas River system.
17	National Tritium and Pesticide station.
18	Vicksburg District, Corps of Engineers, Reservoir Operation--Ouachita River system.
19	Red River Compact station.
20	Little Rock District, Corps of Engineers, Reservoir Operation-Red River system.
21	Arkansas Power and Light Company-hydropower system operation.
*	No additional information.
A	Data published in Geological Survey Annual Data Report for Arkansas.
P	Periodic release of provisional data.
T	Data furnished by direct-access telemitry equipment.

Regional Hydrology

Stations useful in developing regionally transferable information about the relationship between basin characteristics and streamflow must be largely unaffected by manmade storage or diversion. Large amounts of manmade storage may exist in the basin provided that the outflow is uncontrolled. For streams under this classification, effects are limited to those caused primarily by land-use and climate changes.

In the Arkansas program 34 stations are classified in this data use category. Some of these stations are special cases in that they are designated benchmark and index stations. Hydrologic benchmark stations, of which there are two in Arkansas, were established nationwide to serve as indicators of hydrologic conditions of watersheds that have been and probably will continue to be relatively free of manmade alteration. Two regionally located index stations are used to indicate current hydrologic conditions in the State.

Hydrologic Systems

Stations that can be used for accounting are designated as hydrologic system stations. These hydrologic system stations are used to define current hydrologic conditions, sources, sinks, and fluxes of water through regulated or unregulated hydrologic systems. They include diversions and return flows and stations that are useful for defining the interaction of water systems. Benchmark and Federal Energy Regulatory Commission (FERC) stations are included in this category. Arkansas has two benchmark stations and one FERC station.

Legal Obligations

Some stations provide records of flows for the verification or enforcement of existing treaties, compacts, and decrees. This category contains only one station (a FERC station) which the Survey is required to operate to satisfy a legal responsibility.

Planning and Design

This category includes gaging stations which provide information for the planning and design of specific projects such as a dam, levee, floodwall, navigation system, water-supply diversion, hydropower plant, or waste-treatment facility. The planning and design category is limited to those stations that were instituted for such purposes and where this purpose is still valid.

Currently, four stations in the Arkansas program are being operated for planning or design purposes.

Project Operation

Gaging stations in this category assist water managers in making operation decisions such as reservoir releases, hydropower operations, or diversions. Data from these gaging stations are quickly and routinely available to the operators.

All 34 stations in the Arkansas program that are used in this manner are used to control reservoir releases and hydropower operations.

Hydrologic Forecasts

Gaging stations in this category regularly provide information for hydrologic forecasting, such as flood forecasts for a specific river reach, or periodic flow-volume forecasts for a specific site or region. Data from these gaging stations are routinely available daily, weekly, monthly, or seasonally.

All 11 stations in the Arkansas program that are included in this category are those used for flood forecasting. One station is also used to forecast floating and camping conditions on the Buffalo National River.

Water-Quality Monitoring

Gaging stations which include regular water-quality or sediment-transport monitoring are grouped in this category. Often the interpretation of the water-quality or sediment data require information obtained from streamflow data. These stations are collectively known as water-quality monitoring sites.

Two stations in the Arkansas District program are designated as benchmark stations and five are National Accounting Stream Quality Network (NASQAN) stations. Water-quality samples from benchmark stations are used to indicate water-quality characteristics of streams and probably will continue to be relatively free of manmade influence. NASOAN stations are part of a nationwide network designed to assess water-quality trends of significant streams. Two stations are a part of the National Tritium and Pesticide Network.

Research

Gaging stations in this category are operated for a particular research or water-investigations study. Typically, these are only operated for a limited duration.

No stations in the Arkansas program are used solely in the support of research activities. Various government agencies and academic institutions use the data from a number of sites for various research activities.

Other

This category is a collection of other uses not described in the previous eight data-use classes. They include recreational needs, such as multiple-use planning, boating, swimming and fishing.

Funding

The four types of sources for funding the streamflow-data program are:

1. Federal program--Funds directly allocated to the Survey.
2. OFA program--Funds transferred to the Survey by other Federal agencies.
3. Federal-State cooperative program--Funds allocated jointly from Survey joint-funding agreements and from a non-Federal cooperating agency. Cooperating agency funds may be in the form of direct services or cash.
4. Other non-Federal--Funds provided entirely by a non-Federal agency and are not matched by Survey cooperative funds.

In all four categories, the identified sources of funding pertain only to the collection of streamflow data; sources of funding for other activities, particularly collection of water-quality samples, that might be carried out at the site may not necessarily be the same as those identified herein.

Nine entities currently are contributing funds to the Arkansas stream-gaging program.

Frequency of Data Availability

Frequency of data availability refers to the frequency at which the streamflow data may be furnished to the users. Data can be furnished in three ways: (1) by direct-access telemetry equipment for immediate use, (2) by periodic release of provisional data, or (3) in publication format through the annual data report published by the Geological Survey for Arkansas. These three categories are designated T, P, and A, respectively, and are tabulated in table 2. In the current Arkansas program, data for all stations are made available through the annual report, data from 17 stations are available on a real-time basis, and data are released on a provisional basis at 32 stations. In addition, for some of the stations used for project operation and hydrologic forecasts, the users have observers that read the gages and call the reading directly to them.

Data-Use Presentation

Data-use funding and frequency information is presented for each continuous gaging station in table 2. Footnote numbers are provided in each category column in table 2. The entry of an asterisk in these columns indicates that no additional information is necessary.

Data-Use Conclusions

As indicated in the previous section, "History of Stream-Gaging Program in Arkansas," a major reduction in the Arkansas District surface-water network was made in 1970 as a result of a study by Patterson (1969). Table 2 shows that most stations have multiple data uses and all are being funded at this time. We suggest that operation of all 49 of the stations in the current program be continued.

There is a deficiency of information in the central Ozark Plateaus and the northwestern part of the Coastal Plain as indicated in figure 2. We suggest that one or two gages be established in each of these areas if funding can be found.

The record at Mammoth Spring was too short to develop an uncertainty function; therefore, the station was grouped with the partial-record stations in this study. The Dardanelle station consists of Survey operated force-balance type flow meters. Because this station record is computed so differently from the other stations in the program, and because there is minimal error involved in computing discharge, Dardanelle was not included in this study.

Based on the above conclusions, Dardanelle will not be considered in this study; and Mammoth Spring will be included as a partial-record station, leaving 47 daily-discharge stations to be included in the next step of this analysis.

ALTERNATIVE METHODS FOR DEVELOPMENT OF STREAMFLOW INFORMATION

A second step of the surface-water program analysis is an investigation of alternative methods for daily streamflow information. The objective of the analysis is to identify gaging stations where alternative cost-effective technology, such as flow-routing or statistical methods, will provide daily mean streamflow information in lieu of operating continuous-flow gaging stations. Judgment is required in deciding whether the accuracy of the estimated daily flows is suitable for the intended purpose because there are no established guidelines. The data uses at a station will influence whether a site has potential for alternative methods. For example, those stations for which flood hydrographs are required in a real-time sense, such as hydrologic forecasts and project operation, are not candidates for the alternative methods. Likewise, there may be a legal obligation to operate an actual gaging station that would preclude using alternative methods. The primary candidates for alternative methods are stations that are operated near other stations on the same stream. The accuracy of the estimated streamflow at these sites may be suitable because of the high redundancy of flow information. Similar watersheds, located in the same physiographic and climatic area, also may have potential for alternative methods.

All stations in the Arkansas stream-gaging program were categorized into three groups. The first are stations which cannot be considered for alternative methods because of their data-use category or geographic location. The second are stations which could be modeled by more elaborate techniques but are outside the guidelines of this program. The third are candidates for test of regression and digital routing models. Three stations were selected as candidates for alternative methods. The application of the specific alternative methods are described in subsequent sections of this report. This section briefly describes the two alternative methods that were used in the Arkansas analysis.

Because of the short time frame of this analysis, only certain alternative methods were considered. Desirable attributes of a proposed method are (1) easy computer application, (2) available interface with the Geological Survey WATSTORE Daily Values File (Hutchinson, 1975), and (3) technically sound methods generally acceptable to the hydrologic community. The above selection criteria were used to select two methods--a flow-routing model and multiple-regression analysis.

Description of Flow-Routing Model

Hydrologic flow-routing methods use the law of conservation of mass and the relationship between the storage in the reach and outflow from the reach. The hydraulics of the system are not considered. Usually the method requires only a few parameters; such as wave celerity, dispersion coefficients, and reach length. From the WATSTORE Daily Values File a discharge hydrograph is input into the model for the upstream end of the reach. The discharge is routed mathematically to a downstream point. Several different types of hydrologic routing methods are available such as Muskingum, Modified Pulse, and Kinematic Wave. The unit-response flow-routing method was selected for this analysis.

A computer model (Doyle and others, 1983) for the unit-response method can allow routing from one or more upstream locations to a downstream site. One advantage of this model is its application to regulated stream systems. Techniques for routing through reservoirs can also be used in the model providing the operating rules are known. The model is a linear one-dimensional system in which the system output (downstream hydrograph) is computed by multiplying (convolution) the ordinates of the upstream hydrograph by a unit-response function. Lags can also be imposed on this function. The model has the capability of combining hydrographs, multiplying a hydrograph by a ratio, and changing the timing of a hydrograph. In this analysis, the model is only used to route an upstream hydrograph to a downstream point. Input discharge hydrographs were developed from daily 24-hour data for both calibration and verification sets; however, hourly data could be used.

The routing convolution process makes no accounting of flow from the intervening area between the upstream and downstream locations. However, estimating technique that should prove satisfactory in many instances is the multiplication of known flows at an index gaging station by a factor (a drainage-area ratio).

The program offers two different methods for computation of a single unit-response function. These methods are: (1) a storage-continuity method developed by Sauer (1973), and (2) a diffusion-analogy method developed by Keefer (1974). The objective in either the storage-continuity or diffusion analogy flow-routing is to calibrate two parameters that describe the storage-discharge relationship in a given reach and the traveltime of flow passing through the reach. In the storage-continuity method, a response function is derived by modifying a translation hydrograph technique developed by Mitchell (1962) to apply to open channels. A triangular pulse (Sauer, 1973) is routed through reservoir-type storage and then transformed by a summation curve technique to a unit response of desired duration. The two parameters that describe the routing reach are K_s, a storage coefficient which is the slope of the storage-discharge relation, and W_s, the translation hydrograph time base. These two paremeters determine the shape of the resulting unit-response function. In the diffusion analogy theory, the two parameters requiring calibration are K_o, a wave dispersion or damping coefficient, and C_o, the floodwave celerity. K_o controls the spreading of the wave (analogous to K_s in the storage-continuity method) and C_o controls the traveltime (analogous to W_s in the storage-continuity method). The coefficients C_o and K_o are functions of channel width (W_o) in feet, channel slope (S_o) dimensionless, the slope of the stage discharge relation ($\Delta Q_o/\Delta Y_o$) in ft^2/s, and the discharge (Q_0) in ft^3/s representative of the reach in question and are determined as follows:

$$C_o = \frac{1}{W_o} \frac{dQ_o}{dY_o} \tag{1}$$

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

Several options are available for determining the unit (system) response function for the diffusion-analogy method. The options involve either a single unit response function or a multiple unit response function. Adequate routing of daily flows can usually be accomplished using a single unit-response function (linearization about a single dicharge) to represent the system response. However, if constant routing coefficients used in the unit-response function cannot accurately estimate downstream hydrographs over the range of discharge, a single unit-response function may not provide acceptable results. Therefore, the option of multiple linearization (Keefer and McQuivey, 1974), which uses a family of unit-response functions to represent the system response, is available. In the single linearization method, only one K_o and C_o value are used. In the multiple linearization method, C_o and K_o are varied with discharge so a table of wave celerity (C_o) versus discharge (O) and a table of dispersion coefficient (K_o) versus discharge (Q) are used. In both the storage-continuity and diffusion-analogy methods, the two parameters are calibrated by trial and error. The analyst must decide if suitable parameters have been derived by comparing the simulated discharge to the observed discharge.

The basic theory of flow-routing techniques, the computation details, the data-handling requirements, and file structures are described by Doyle and others (1983).

Description of Regression Model

Simple- and multiple-regression techniques can also be utilized to estimate daily flow records. Regression equations can be computed from a combination of upstream, downstream and tributary stations. Unlike the flow-routing method, this statistical method is not limited to downstream stations. The independent variables in the regression analysis can also be stations from different watersheds. The regression method has many of the same attributes as the flow-routing method in that it is easy to apply, provides indices of accuracy, and is generally accepted as a good tool for estimation. The theory and assumptions of regression analysis are described in 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 was developed for estimating daily mean discharges in Arkansas:

$$y_i = B_o + \sum_{j=1}^{P} B_j \, x_j + e_i \qquad (3)$$

where

y_i = daily mean discharge at station i (dependent variable),
x_j = daily mean discharges at nearby stations (independent variables),
B_o and B_j = regression constant and coefficients.
e_i = the random error term, and
P = the number of discharge relations.

Equation 3 is calibrated (B_o and B_j are estimated) using observed values of y_i and x_j. These observed daily mean discharges can be retrieved from the WATSTORE Daily Values File. The values of x_j may be discharges observed on the same day as discharges at station i or different days if lag periods are to be considered. The regression constant and coefficients (B_o and B_j) are tested to determine if they are significantly different from zero. The regression equation should be calibrated using one period of record and then verified on a different period to obtain a measure of the true predictive accuracy. Both the calibration and verification period should be representative of the range of flows that could occur at station i. The equation should be verified by (1) comparing the variability (variance) of the simulated daily mean discharges to the observed values of variance (2) plotting the residuals e_i (difference between simulated and observed discharges) against the dependent and all independent variables in the equation, and (3) plotting the simulated and observed discharges versus time. These tests are intended to identify if (1) the simulated discharges have the same range of variability as the observed values (2) the linear model is appropriate or whether some transformation of the variables is needed, and (3) there is any bias in the equation such as overestimating low flows. These tests might indicate, for example, that a logarithmic transformation is desirable, that a nonlinear regression equation is appropriate, or that the regression equation is biased in some way. The application of linear-regression techniques to three watersheds in Arkansas is described in a subsequent section of this report.

It should be noted that the use of a regression relation to synthesize data at a discontinued gaging station entails a reduction in the variance of the streamflow record relative to that which would be computed from an actual record of streamflow at the site. The reduction in variance expressed as a fraction is approximately equal to one minus the square of the correlation coefficient that results from the regression analysis.

Categorization of Stream Gages by Their Potential for Alternative Methods

From an analysis of funding and data uses presented in table 2, three stations were selected as candidates using simple linear regression and the digital routing model available. Judgements were made concerning suitable accuracy of synthesized daily-flow data. These stations are listed in table 3.

Table 3.—Gaging stations as candidates for alternative methods of modeling

Abbreviated station no.	Station name
048600	White River near Fayetteville, Ark. (Fayetteville)
074500	White River at Newport, Ark. (Newport)
340000	Little River near Horatio, Ark. (Horatio)

A summary of error statistics for these stations is listed in table 4 for digital modeling and table 5 for regression analysis. Results from both table 4 and table 5 indicate that daily discharges can best be estimated for the station at Newport (074500). The alternative methods analysis will only be discussed for Newport.

Table 4.—A statistical summary of the digital routing model for Fayetteville, Newport, and Horatio

Station	Percent error						Mean absolute error	Number of observations	Percent volume error	Years
	≤5	≤10	≤15	≤20	≤25	>25				
048600 Fayetteville	10	20	28	35	42	58	52.6	3195	-0.15	1974-1982
074500 Newport (single-linearization)	30	58	76	88	94	6	10.20	2830	-3.00	1974-1981
074500 Newport (multiple-linearization	34	64	82	92	96	4	9.05	1628	-3.66	1974-1981
340000 Horatio	16	31	45	55	64	36	25.72	2192	2.47	1976-1981

Table 5.--Summary of calibration for regression modeling of mean daily streamflow at selected gaging stations in Arkansas

Station	Model Equation	Percent of simulated flow within 5 percent error	Percent of simulated flow within 10 percent error	Calibration period
048600 Fayetteville	$\ln(Q_{048600})=1.01+0.83\ln(Q_{048000})$	3.8	8.1	1974-1981
7074500 Newport	$\ln(Q_{074500})=-41.5+0.16\ln(Q_{060500})+ 0.31\ln(\mathrm{LAG1}\ Q_{060500})+0.46\ln(\mathrm{LAG2}\ Q_{060500})+ 0.65\ln(Q_{072500})+0.08\ln(\mathrm{LAG1}\ Q_{072500})+ 0.74\ln(\mathrm{LAG2}\ Q_{072500})$	38.9	67.1	1974-1981
340000 Horatio	$\ln(Q_{34000})=220.4+1.01\ln(Q_{338500})+ 0.63\ln(\mathrm{LAG1}\ Q_{338500})-0.09\ln(\mathrm{LAG2}\ Q_{338500})+ 0.21\ln(Q_{339000})+0.66\ln(\mathrm{LAG1}\ Q_{339000})- 0.14\ln(\mathrm{LAG2}\ Q_{339000})$	15.7	31.2	1974-1981

Alternative methods for White River at Newport, Arkansas

Newport (074500) is a daily-discharge gage located on the White River just below the tributary inflow of the Black River which accounts for a significant percentage of the total flow. Stations used in the digital routing model are listed in table 6.

Table 6.- Stations selected as indexes for the Newport flow-routing study

Abbreviated station no.	Station name
060500	White River at Calico Rock, Ark. (Calico Rock)
060710	North Sylamore Creek near Fifty Six, Ark. (North Sylamore)
072500	Black River at Black Rock, Ark. (Black Rock)
074000	Strawberry River near Poughkeepsie, Ark. (Poughkeepsie)

Calico Rock (060500) and Black Rock (072500) were selected as the principal gaged sites on the primary inflows above Newport. Two additional gaging sites were selected, North Sylamore (060710) and Poughkeepsie (074000), to represent smaller tributaries flowing into the White River and Black River, respectively. A schematic diagram of the Newport study area is shown in Figure 4. Six separate hydrograph routings were chosen which would simulate daily discharge at Newport. Separate routing coefficients (Q, S_o, W_o, C_o, etc.) were calculated for each of the six reaches modeled. Routing reaches are listed in table 7.

Table 7.—Routing sections in the Newport flow-routing study

Sub-route	Beginning of route	End of route
1	Calico Rock (060500)	White R. at mouth of Sylamore Creek
2	North Sylamore (060710)	White R. at mouth of Sylamore Creek
3	White R. at mouth of Sylamore	Newport (074500)
4	Black Rock (072500)	Black R. at mouth of Strawberry R.
5	Poughkeepsie (074000)	Black R. at mouth of Strawberry R.
6	Black R. at mouth of Strawberry R.	Newport (074500)

Simulated hydrographs on subroutes three and six (as defined in table 7) are added together and represent the observed daily discharge at Newport. Both single linearization and multiple linearization methods were applied in simulating Newport data.

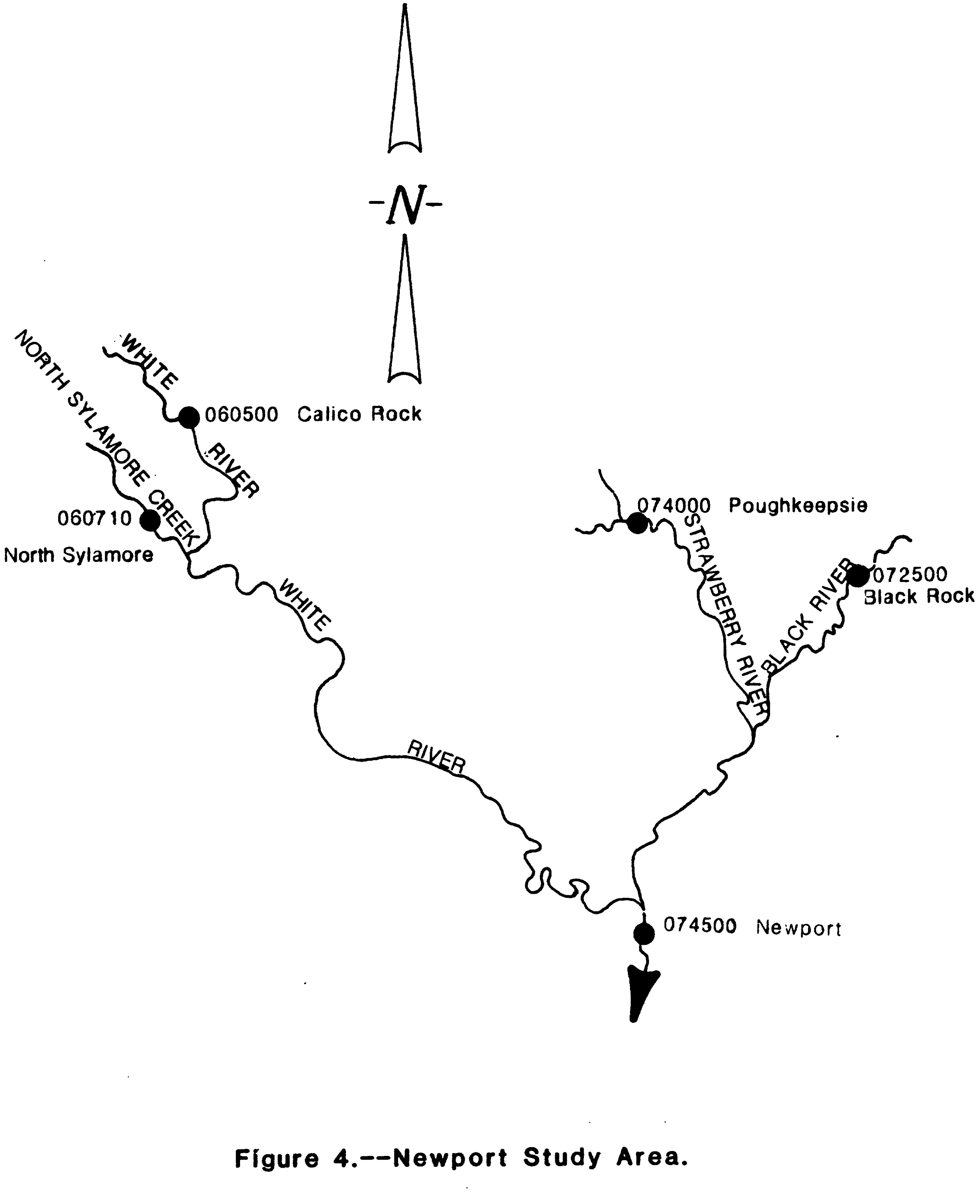


Figure 4.--Newport Study Area.

Table 8.--Routing coefficients for Newport flow-routing study (Multiple linearization method)

Sub-route	Q	C_o	K_o	Ratio	Geographic Location
1	1,400	2.96	777	.04	Calico Rock to Rivermile 341
1	4,000	3.75	19,739	do	do
1	9,840	4.95	46,857	do	do
1	15,000	5.29	69,444	do	do
1	50,000	5.72	223,214	do	do
2	47.1	2.66	207	2.77	N. Sylamore to Rivermile 341
3	1,400	2.96	777	.08	Rivermile 341 to Newport
3	4,000	3.75	19,739	do	do
3	9,840	4.95	46,857	do	do
3	15,000	5.29	69,444	do	do
3	50,000	5.72	223,214	do	do
4	3,000	3.00	11,628	.67	Black Rock to Rivermile 32.7
4	5,000	3.76	18,939	do	do
4	8,336	4.26	29,560	do	do
4	10,000	4.63	34,722	do	do
5	504	3.17	5,479	.02	Poughkeepsie Rivermile 32.7
6	3,000	3.00	11,628	.03	Rivermile 32.7 to Newport
6	5,000	3.76	18,939	do	do
6	8,336	4.26	29,560	do	do
6	10,000	4.63	34,722	do	do

The best flow-routing for the Newport model was the multiple linearization method. Intervening flow (used to calculate ratio coefficients) was estimated from drainage area information obtained in Sullavan (1974). Based on four or five selected discharges, a set of dispersion and celerity coefficients (table 8) were estimated from several calibration trials. The period of record for the multiple linearization method includes water year 1974 through 1981 and a statistical summary is listed in Table 9.

Table 9.--Results of routing model for White River at Newport (Multiple linearization method)

Mean absolute error (2,799 days) = 9.05 percent
Mean negative error (1,628 days) = -9.76 percent
Mean positive error (1,171 days) = 8.08 percent
Total volume error = -3.66 percent

34 percent of the total observations had errors $\leq$ 5 percent
64 percent of the total observations had errors $\leq$ 10 percent
82 percent of the total observations had errors $\leq$ 15 percent
92 percent of the total observations had errors $\leq$ 20 percent
96 percent of the total observations had errors $\leq$ 25 percent
4 percent of the total observations had errors $>$ 25 percent

The best agreement between observed and synthesized daily discharge occurred in water year 1975 in which 73 percent of all observations had errors of less than 10 percent. A typical hydrograph comparison using the multiple linearization method is given in figure 5 for the winter of 1980.

A second alternative method (linear regression) was also used to predict daily mean discharge values for Newport. Only the two upstream index gaging stations were included in the model, Black Rock and Calico Rock, because they represent the majority of drainage to Newport. Lagged comparisons of one and two days were included in the regression model. The discharge at Newport was regressed against these six independent variables including a combination of lag and index station daily discharge values. The model equation and the percent of observations within 5 and 10 percent error are displayed in table 5. The statistics of the digital routing model and the regression model are in close agreement. For example, the percent of simulation flow with 10 percent error for period of record 1974 to 1981 using linear regression is 67 percent and 64 percent using the multiple linearization method of the digital routing model. However, both methods did not achieve a significant acceptable limit of error for reason mentioned in the Recommendation section for Alternative Methods.

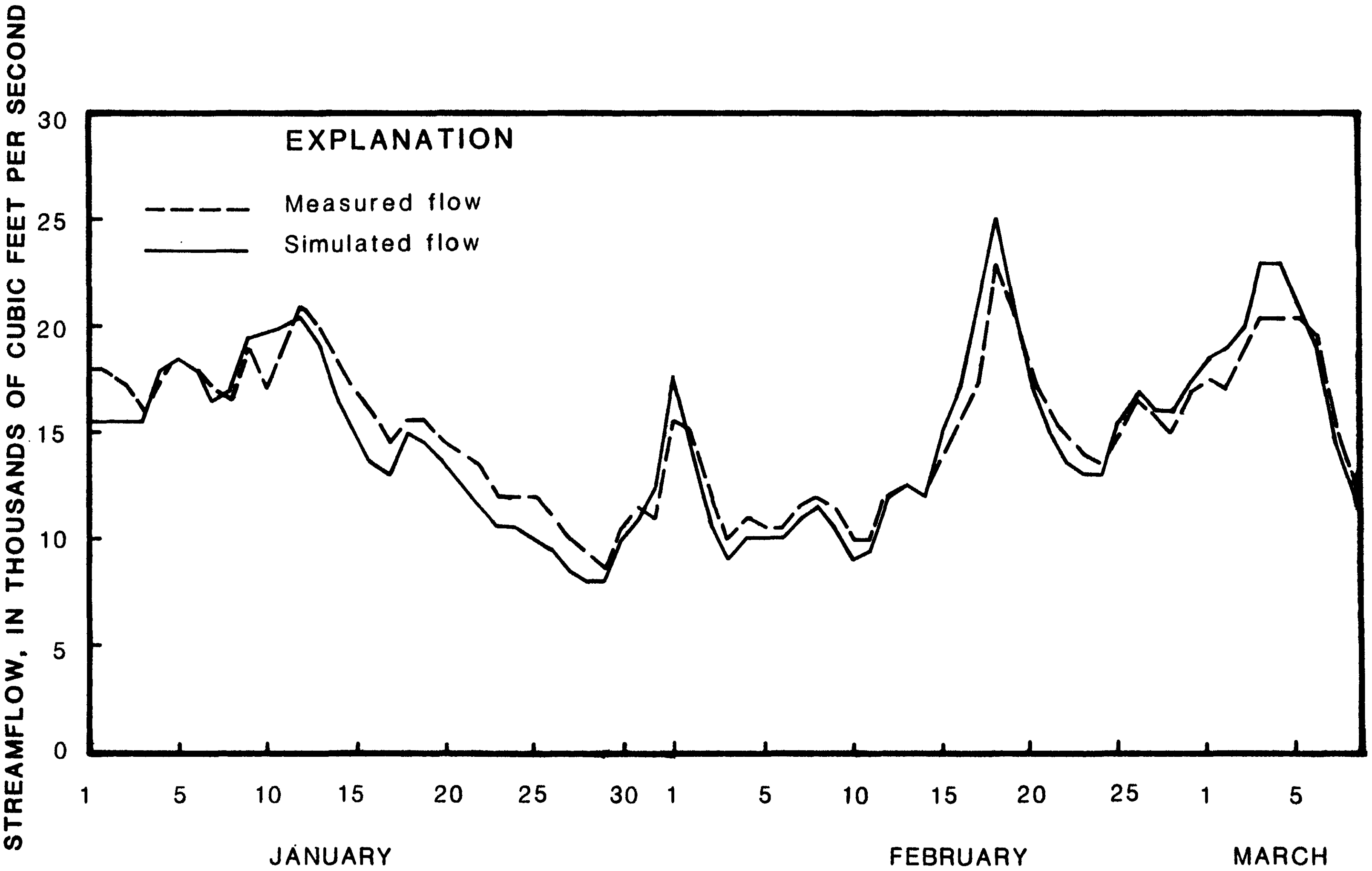


Figure 5.--Daily hydrograph using digital routing model for Newport, Arkansas. (multiple linearization method) winter 1980.

Conclusions on Alternative Methods for Development of Streamflow Infomation

Three stations tested for the possibility of discontinuation or conversion to partial-record stations were White River near Fayetteville, White River at Newport, and Little River at Horatio. Statistical summaries are listed in table 4 for the streamflow routing model and table 5 for the linear regression model. None of these stations were found to be suitable candidates. Using both the linear regression and the digital routing model, the best results were obtained at Newport using the multiple linearization of the digital routing model. As shown in table 13 for Calico Rock 060500 and for Black Rock 072500 (the two primary index stations used to estimate daily flows for Newport), the estimates of standard errors are about 10 percent (K-CERA analysis at current operation levels). Using alternative methods for Newport only 64 percent of the total daily flows have errors within 10 percent of measured results.

Based on the results the operation of all stream gages under current investigation will continue until a higher accuracy can be obtained using other hydraulic or hydrologic models. Both manpower and funding, however, would have to become available in the future for such time and labor intensive projects.

COST-EFFECTIVE RESOURCE ALLOCATION

Introduction to Kalman-filtering for Cost-Effective Resource Allocation (K-CERA)

Moss and Gilroy (1980), developed a set of techniques known as the Kalman-Filtering for Cost-Effective Resource Allocation (K-CERA) which was applied to a program of stream gages in the Lower Colorado Basin. Our study will use this same set of techniques (K-CERA) in order to measure the cost effectiveness of the Arkansas stream gaging program. Because of a water balance emphasis of the Lower Colorado River study, the effectiveness of the program was measured by the minimization of the sum of variances of errors of estimation; and the streamflow variable was annual mean discharges in cubic feet per second at each site in the program. 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 program, in the broader context of the multitude of uses of the streamflow data collected in the Geological Survey's Streamflow Information Program, this tendency causes undue concentration on larger streams. Therefore, the original version of K-CERA was extended to include alternate measures of effectiveness in terms of annual mean and instantaneous discharge percentage. The reason for the use of these streamflow-variable units is twofold. First, percentage errors do not unduly weight activities at large streams to the detriment of records on small streams. Second, instantaneous discharge is the basic variable from which all other streamflow data are derived. This study used the average instantaneous discharge percent at all continuously gaged sites 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. A procedure for handling missing records has been developed and is incorporated in this study. Theory and applications of K-CERA are in Moss and Gilroy (1980) and Gilroy and Moss (1981).

Cost Routing and Budgetary Considerations for Stream Gaging Record

There are many possible sets of routes and frequencies that can be used to service and monitor all surface-water gaging stations for a district over the period of a year. The program, called "The Traveling Hydrographer," attempts to allocate among stream gages a predefined budget for the collection of streamflow data in such a manner that the field operation is the most cost effective possible. The measure of effectiveness was discussed previously (Kalman filtering) by Gelb (1974). The frequency option within the program is zero to 365 measurements per year per route. A route is defined as the travel costs attributed to a set of one or more stream gages, and related partial record, crest-stage, and ground-water stations, that takes the hydrographer from his base of operations to each of the gages and back. A route will have associated with it an average cost of travel and average cost of servicing at each daily discharge station visited. Only average cost of travel is applied to partial-record, crest, and ground-water stations. The first step in this part of the analysis is to define the set of practical routes. All surface-water stations and associated ground-water wells should be included in the total set of routes for the program. In addition many stations should be included in several alternative routes. For those stations of highest variance of errors, (determined from K-CERA analysis) routes should be devised which include only that station.

Special requirements for visits to each of the gages for necessary periodic maintenance, rejuvenation of recording equipment, or required periodic sampling of water quality are considered constraints. These constraints impose a minimum number of visits to each gage. This number can be input into the program.

Using the traveling hydrographer program with associated route costs, K-CERA estimates of variance for each station, and constraints which impose a minimum number of visits per gage, a selection of the best routes and their frequencies can be obtained. The selection is based on the minimization of the total uncertainty in the program. Figure 6 represents equations and definitions relating to the traveling hydrographer program. Figure 7 presents a tabular layout of the routing problem. Each of the practical routes chosen is represented by a row of the table and each of the stations is represented by a column. The zero-one matrix, (w_{ij}), defines the terms of the stations it comprises. 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 traveltime 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 $i = 1, 2 \ldots,$ NR is the total travel cost associated with the set of decisions $\underline{N} = (N_1, N_2, \ldots, N_{NR})$.

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

$V \equiv$ 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

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

Such that

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

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

$F_c \equiv$ 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

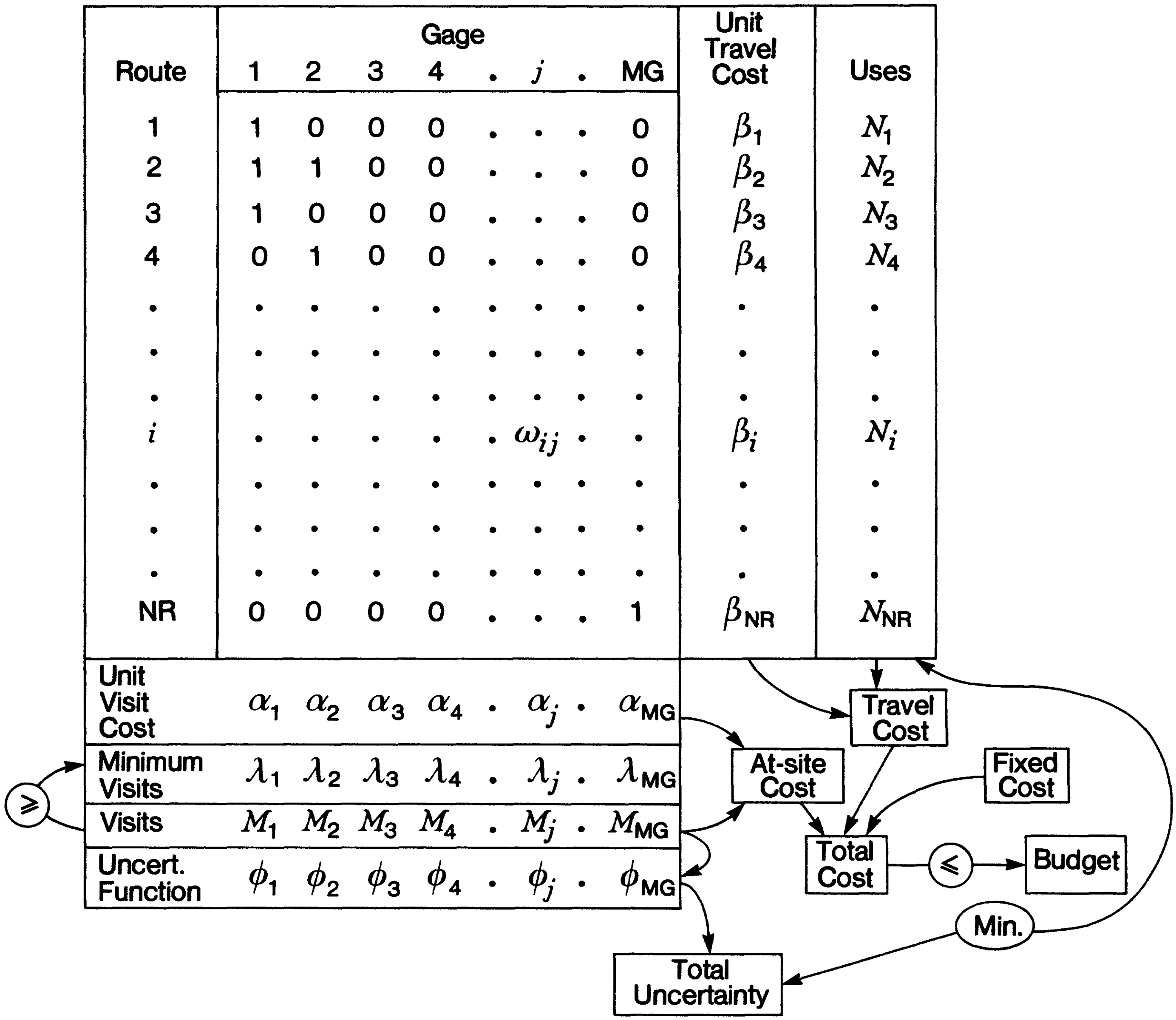
$N_i \equiv$ annual number times route i is used (an element of $\underline{N}$)

and such that

$$M_j \geq \lambda_j$$

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

Figure 6.--Mathematical programing form of the optimization of the routing of hydrographers.



Route	Gage 1	2	3	4	.	j	.	MG	Unit Travel Cost	Uses
1	1	0	0	0	.	.	.	0	β_1	N_1
2	1	1	0	0	.	.	.	0	β_2	N_2
3	1	0	0	0	.	.	.	0	β_3	N_3
4	0	1	0	0	.	.	.	0	β_4	N_4
•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•
i	•	•	•	•	•	ω_{ij}	•	•	β_i	N_i
•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•
NR	0	0	0	0	.	.	.	1	β_{NR}	N_{NR}
Unit Visit Cost	α_1	α_2	α_3	α_4	.	α_j	.	α_{MG}		
Minimum Visits	λ_1	λ_2	λ_3	λ_4	.	λ_j	.	λ_{MG}		
Visits	M_1	M_2	M_3	M_4	.	M_j	.	M_{MG}		
Uncert. Function	ϕ_1	ϕ_2	ϕ_3	ϕ_4	.	ϕ_j	.	ϕ_{MG}		

Figure 7.--Tabular form of the optimization of the routing of hydrographers.

The unit-visit cost, α_j, is the average service and maintenance costs incurred on a visit to the station plus the average cost of making a discharge measurement. The minimum number of visits is imposed by a number of constraints denoted by the row g_j, $j = 1, 2, \ldots, MG$. The row of integers Mj, $j = 1, 2, \ldots, MG$ specifies the number of visits to each station. M_j is the sum of the products of w_{ij}, and N_i for all i and must equal or exceed g for all j if $\underline{N}$ is to be a feasible solution to the decision problem.

The total cost expended at the stations is equal to the sum of the products of λ_j and M_j for all j. The cost of record computation, documentation, and publication is assumed to be influenced negligibly by the number of visits to the station and is included along with overhead in the fixed cost of operating the program. The total cost of operating the program equals the sum of the travel costs, the at-site 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 $j = 1, 2, \ldots, MG$.

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 program and may be the true optimum strategy. A guarantee of the true optimum cannot be obtained 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 are considered in this study: (1) streamflow is estimated from measured discharge and correlative data using a stage-discharge relation (rating curve), (2) the streamflow record is reconstructed using secondary data at nearby stations because primary correlative data are missing, and (3) primary and secondary data are 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 is expected to occur. Thus the average relative variance would be

$$\bar{V} = \varepsilon_f V_f + \varepsilon_r V_r + \varepsilon_e V_e$$

with (4)

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

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 estimation 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 situation.

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 is assumed to have a negative-exponential probability distribution truncated at the next service time; the distribution's probability density function is

$$f(\tau) = ke^{-k\tau}/(1-e^{-ks}) \tag{5}$$

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 is assumed that, if a recorder fails, it continues to malfunction until the next service visit. As a result,

$$\varepsilon_f = (1-e^{-ks})/(ks) \tag{6}$$

(Fontaine and others, 1983, eq. 21).

The fraction of time ε_e that no records exist at either the primary or secondary sites can also be derived assuming that the time between failures at both sites are independent and have negative exponential distributions with the same rate constant. It then follows that

$$\varepsilon_e = 1 - [2(1-e^{-ks}) + 0.5(1-e^{-2ks})]/(ks) \tag{7}$$

(Fontaine and others, 1983, eqs. 23 and 25).

Finally, the fraction of time ε_r that records are reconstructed based on data from a secondary site is determined by the equation

$$\begin{aligned} \varepsilon_r &= 1 - \varepsilon_f - \varepsilon_e. \\ &= [(1-e^{-ks}) + 0.5(1-e^{-2ks})]/(ks) \end{aligned} \tag{8}$$

The relative variance, V_f, of the error derived from primary record computation is determined by analyzing a time series of residuals that are the differences between the logarithms of measured discharge and the rating curve discharge. The rating curve discharge is determined from a relationship between discharge and some correlative data, such as water-surface elevation at the gaging station. The measured discharge is the discharge determined by field 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

$$x(t) = \ln q_T(t) - \ln q_R(t) = \ln [q_T(t)/q_R(t)] \qquad (9)$$

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 measurments of discharge. This adjustment process results in an estimate, $q_c(t)$, that is a better estimate of the stream's discharge at time t. The difference between the variable $x(t)$, which is defined

$$x(t) = \ln q_c(t) - \ln q_R(t) \qquad (10)$$

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

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

$$z(t) = x(t)+v(t) = \ln q_m(t) - \ln q_R(t) \qquad (11)$$

where

$v(t)$ is the measurement 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-filter analysis, the z(t) time series was analyzed to determine three site-specific parameters. The Kalman filter 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. A second 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 (1983) also define q, the constant value of the spectral density function of the white noise which drive the Gauss-Markov x-process. The parameters, p, q, and β are related by

$$\mathrm{Var}[x(t)] = p = q/(2\beta) \tag{12}$$

The variance of the observed residuals z(t) is

$$\mathrm{Var}[z(t)] = p + r \tag{13}$$

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 utilizes these three parameters to determine the average relative variance of the errors of estimation of discharges as a function of the number of discharge measurements per year (Moss and Gilroy, 1980).

If the recorder at the primary site fails and there are no concurrent data at other sites that can be used to reconstruct the missing record at the primary site, there are 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 fucntioning or the expected value of discharge for the period of missing data could be used as an estimate. The expected-value approach is 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 is used to estimate discharge, the value that is used should be 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 square $(C_v)^2$ 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 is used:

$$\overline{C}_v = \left[\frac{1}{365} \sum_{i=1}^{365} \left(\frac{\sigma i}{\mu i} \right)^2 \right]^{1/2} \tag{14}$$

where

σi is the standard deviation of daily discharges for the i_{th} day of the year,

μi is the expected value of discharge on the i^{th} day of the year, and

$(C_v)^2$ is used as an estimate of V_e.

The variance V_r of the relative error during periods of reconstructed streamflow records is estimated on the basis of correlation between records at the primary site and records from other gaged nearby 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 the 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

$$V_r = (1- \rho_c^2)\ \overline{C}_v^2 \qquad (15)$$

Because errors in streamflow estimates arise from three difference sources with widely varying precisions, the resultant distribution of those errors may differ significantly form 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 (4) even if the probability that primary and secondary information are not available, ε_r, is quite small.

A new paramter, 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 (4) are log-normally distributed, the value of EGS was determined by the probability statement that

$$\text{Probability } [e^{-EGS} \leq (q_c(t) / q_T(t) \leq e^{+EGS}] = 0.683 \qquad (16)$$

Thus, if the residuals $\ln q_c(t) - \ln q_T(t)$ were normally distributed, $(EGS)^2$ would be their variance. Here EGS is reported inunits 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.

The Application of K-CERA in Arkansas

As a result of the first two parts of this analysis, it has been recommended that all of the currently existing daily-discharge stations operated by the Arkansas District be continued. However, two of the existing 49 daily-discharge stations will not be analyzed in the final step of the study (K-CERA) for reasons previously mentioned. The remaining 47 discharge stations were subjected to the K-CERA analysis with results that are described below.

Definition of Missing Record Probabilities

As described earlier, the statistical characteristics of missing stage or other correlative data for computation of streamflow records can be defined by a single parameter. This parameter (1/k) in the negative exponential probability distribution is the average time to failure of the equipment. The value of 1/k will vary from site to site depending on the type of equipment at the site and upon 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.

Missing record was estimated for all gaging stations in the Arkansas program in which K-CERA analyses were performed during the period 1969-1983. The estimate was made by a total count of all days when there was no gage-height record or when the record was faulty. This beginning date was selected because of conversion of all gaging recorders to a digital type. Both the frequency of visits per year and the percent of lost record were grouped together in terms of the District as a whole instead of individual station estimates because of the limited number of years and the number of K-CERA stations available in the Arkansas program. The estimate of lost record was five percent of the total record with a frequency of nine visits per year. A value of 1/k of 392 days was obtained which was used to determine ε_f, ε_e, and ε_f for each of the 47 daily-discharge stations as a function of the individual frequencies of visit. Lost record analysis for locks and dams (gate rating) in the computation of uncertainty functions was not handled in the same manner as other daily-discharge stations. The equipment used at the turbines for the calculation of discharge requires a minimum of weekly maintenance; however, only a few measurements were made each year because the gate ratings are very accurate and stable with standard errors of less than 5 percent based on only one measurement per year (table 13). For the computation of the percent of lost record with lock and dams both "measurement" and "maintenance" visits were included. The total number of visits is large (50 per year or greater) and thus the percent of lost record is quite small because detection and correction of faulty equipment can be made each week. Thus for Lock and Dam #7 (gate rating) the uncertainty function was computed without lost record computation. Because of large uncertainty with lock and dam records at Lock and Dam #13, a constant standard error of 5.6 percent was used. This computation (5.6 percent) assumed that the recorder is functioning at 4 percent error, 80 percent of the time; secondary stations used to synthesize lost record is functioning at 4 percent error, 16 percent of the time; and lock and dam records (used in error computation when both primary and secondary stations are down) are functioning at 20 percent error, 4 percent of the time. Individual errors and percent operation time were estimated from district evaluation of Lock and Dam 13.

Definition of Cross-Correlation Coefficient and Coefficient of Variation

To compute the values of V_e and V_r of the needed uncertainty functions, a computer program is used in conjuction with a WATSTORE retreival for daily streamflow records. For most stations thirty years of record were retrieved. This period of record was determined as a large enough statistical sampling set for the analysis. For each of the 47 daily-discharge stations (except Siloam Spring 195855 having less than three years of record), values of C_v and ρ_c were computed and various options based on combinations of other index stream gages.

Due to poor interstation correlation at Springtown (195800) and the short record for Siloam Spring (195855), the cross correlation coefficient (C_v) and the interstation correlation (ρ_c) were estimated. The value of C_v and ρ_c at Dutch Mills, were selected as estimates for these two stations because of the geographic location and similar basin characteristics.

Several alternative sets of index stations or groups of index stations were used in order to determine the best ρ_c values. Lag periods were also adjusted to optimize values. For 37 percent of K-CERA stations, two index stations are used in the final calculation of ρ_c and C_v. Sixty-four percent of the K-CERA stations input into the program have only one index station for reconstruction of the record. Some of the largest ρ_c coefficients are obtained for Arkansas River lock and dams. These values were greater than 0.96. This result is quite understandable due to the regulated nature of the control pattern in the Arkansas River. The lowest correlation of ρ_c was at Lonoke (264000). There are backwater conditions and no stations in close proximity to this site. This may account for the low correlation. Missing record parameters for each station and associated index stations used in the analysis that gave the highest cross correlation coefficient along with associated lag periods are listed in table 10.

Kalman-Filtering Definition of Variance

The variance of streamflow error when stage record is available (V_f) was determined by utilizing discharge measurements. V_f for each of the 47 daily-discharge stations requires a long-term rating analysis and computation of residuals of measured discharges from the long-term rating, and a time-series analysis of the residuals to determine the input parameters of the Kalman-filter streamflow records.

A calculation of the variance, V_f, for each of the 47 daily-discharge stations required the execution of three 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 three input parameters for the Kalman-Filter, 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.

Table 10.—Statistics of record reconstruction

[* Estimated value]

Station number	C_v	P_c	Stations used to reconstruct records (lag days)	
047942	116	0.769	077380 (-2)	077950 (-1)
048000	232	.852	048600 (0)	
048600	189	.852	048000 (0)	
056000	180	.859	257000 (0)	
060500	80	.834	074500 (1)	
060710	158	.682	257000 (0)	
064000	95	.833	072500 (0)	
069500	111	.846	072000 (0)	
072000	84	.846	069500 (0)	
072500	74	.888	064000 (-1)	074500 (1)
073500	188	.903	074000 (0)	
074000	157	.903	073500 (0)	
074500	68	.956	060500 (-1)	072500 (-1)
075000	207	.836	075300 (0)	
075300	177	.836	075000 (0)	
077380	132	.647	077950 (1)	047942 (1)
077950	111	.710	047942 (0)	077380 (-1)
195800	217*	.813*		
195855	217*	.813*		
196900	217	.813	250000 (0)	
247000	246	.855	258500 (0)	249400 (0)
249400	212	.779	247000 (0)	
250000	234	.813	196900 (0)	
250550	121	.967	258000 (1)	263450 (2)
252000	199	.864	257000 (0)	
257000	198	.888	261000 (0)	252000 (0)
258500	264	.856	261500 (0)	247000 (0)
260500	168	.586	258000 (-1)	263000 (0)
261000	192	.631	257000 (0)	
261500	220	.786	258500 (0)	263000 (0)
263000	236	.684	260500 (0)	261500 (0)
263450	111	.978	250550 (-2)	258000 (-1)
264000	165	.620	363300 (0)	
337000	113	.895	336820 (-1)	
340000	151	.940	339000 (0)	338500 (0)
340300	150	.764	356000 (0)	
341200	201	.652	340000 (1)	
356000	189	.791	359500 (0)	340300 (0)
359500	102	.735	362000 (2)	
361500	223	.610	363300 (0)	
362000	116	.583	359500 (0)	
362100	193	.876	362500 (0)	365800 (0)
362500	275	.721	362100 (0)	
363300	191	.690	264000 (0)	362500 (0)
363500	162	.663	363300 (-3)	
364150	143	.841	364200 (2)	
365800	220	.848	362100 (0)	

Several types of long-term ratings were used to compute the time-series residuals for continuous recording gaging stations in the Arkansas program in accordance with procedures outlined in Fontaine and others, 1983. For most stations, the analysis included at least eight years of record from January 1974 to February 1983. Only at Siloam Springs (195855) was present operation less than three years. The period of record for each station in the Arkansas program is listed in table 1.

The time series of residuals was 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 time series of residuals. Table 11 presents a summary of the autocovariance analysis (expressed in terms of process variance and 1-day autocorrelation). Measurement variance, the third parameter, was determined from an assumed constant percentage standard error. For the Arkansas program, all open-water measurements are estimated to have a measurement error of 2.5 percent. This estimate was based on the variance of partial errors (current meter, velocity fluctuations, shape of vertical velocity curve, number of observations on vertical cross-sections, time per measurement) as outlined in Carter and Anderson, 1963.

Finally, uncertainty functions were computed for each daily-discharge station using values in table 11 (autocovariance analysis) and table 10 (missing record statistics). Figure 8 shows a relationship of uncertainty (standard error) versus the number of measurements per year for three typical stations which have reasonably good graphical fits of the autocovariance function. The relationships shown in each of the previous figures assumes that the probability of a measurement being obtained during the visit is 100 percent. For lock and dams (gate ratings) only "measurement" visits were included and not "maintenance" visits in the computation of the uncertainty functions. The probability of measurement was also assumed to be 100 percent.

In Arkansas, feasible routes to service the 47 daily-discharge stations were determined after consultation with personnel in the District Hydrologic Data Section and after review of the computed uncertainty functions. In summary, 151 routes were selected to service all the daily-discharge stations in Arkansas. These routes included all possible combinations that describe the current operating practice. The selection of routes also involves alternative practical routes; routes that visited certain key individual stations, and combinations that grouped proximate gages where the levels of uncertainty indicated more frequent visits might be useful. A summary of selected routes is given in table 12.

The costs associated with the practical routes were determined. Fixed costs to operate a gage typically include equipment rental, batteries, electricity, data processing and storage, computer charges, maintenance and miscellaneous supplies, and analysis and supervisory charges. For Arkansas, average values were applied to each station in the program for all the above categories.

Table 11.--Summary of the autocovariance analysis

Station number	Abbreviated station name	RHO*	Measurement variance (log base$_e$)	Process variance (log base$_e$)	Length of period (days)
047942	Colt	0.967	0.00062	0.06362	365
048000	Greenland	.954	.00062	.01136	365
048600	Fayetteville	.967	.00062	.01585	365
056000	St. Joe	.996	.00062	.19116	365
060500	Calico Rock	.948	.00062	.00115	365
060710	North Sylamore	.992	.00062	.19340	365
064000	Corning	.976	.00062	.00204	365
069500	Imboden	.729	.00062	.00145	365
072000	Eleven Point	.966	.00062	.00059	365
072500	Black Rock	.973	.00062	.00165	365
073500	Piney Fork	.993	.00062	.09495	365
074000	Poughkeepsie	.991	.00062	.15080	365
074500	Newport	.947	.00062	.00290	365
075000	Shirley	.942	.00062	.10899	365
075300	Clinton	.663	.00062	.02913	365
077380	Cache	.718	.00062	.02177	365
077950	Big Creek	.975	.00062	.04547	365
195800	Springtown	.616	.00062	.15341	365
195855	Siloam	.990	.00062	.10998	365
196900	Baron Fork	.584	.00062	.14727	365
247000	Poteau	.972	.00062	.10324	365
249400	James Fork	.978	.00062	.75084	365
250000	Lee Creek	.942	.00062	.15940	365
250550	Dam #13 (gate rating)	0	.00062	.00161	365
250550	Dam #13 (tailwater rating)	.897	.00062	.00422	365
252000	Mulberry	.902	.00062	.07784	365
257000	Big Pine	.952	.00062	.12650	365
258500	Booneville	.969	.00062	.24292	365
260500	Danville (rating with fall)	.975	.00062	.04500	365
260500	Danville (rating without fall)	.875	.00062	.01190	365
261000	Guy	.978	.00062	.04633	365
261500	Gravelly	.964	.00062	.49209	365
263000	Hollis	.969	.00062	.27149	365
263450	Murray Dam (gate rating)	.963	.00062	.00103	365
263450	Murray Dam (tailwater rating)	.875	.00062	.01190	365
264000	Lonoke	.996	.00062	.15321	365
337000	Index	.980	.00062	.01408	365

Table 11.--Summary of the autocovariance analysis--Continued

Station number	Abbreviated station name	RHO*	Measurement variance (log basee)	Process variance (log basee)	Length of period (days)
340000	Horatio	0.885	0.00062	0.00156	365
340300	Vandervoort	.960	.00062	.00342	365
341200	Lockesburg	.650	.00062	.00287	365
356000	Mount Ida	.972	.00062	.00485	365
359500	Malvern	.973	.00062	.01030	365
361500	Antoine	.874	.00062	.03857	365
362000	Camden	.959	.00062	.01056	365
362100	Smackover	.963	.00062	.15050	365
362500	Fordyce	.954	.00062	.29826	365
363300	Hurricane	.978	.00062	.09787	365
363500	Rye	.700	.00062	.01031	365
364150	McGehee (rating with fall)	.991	.00062	.01839	365
364150	McGehee (rating without fall)	.971	.00062	.01004	365
365800	Cornie Bayou	.982	.00062	.26060	365

* One-day autocorrelation coefficient.

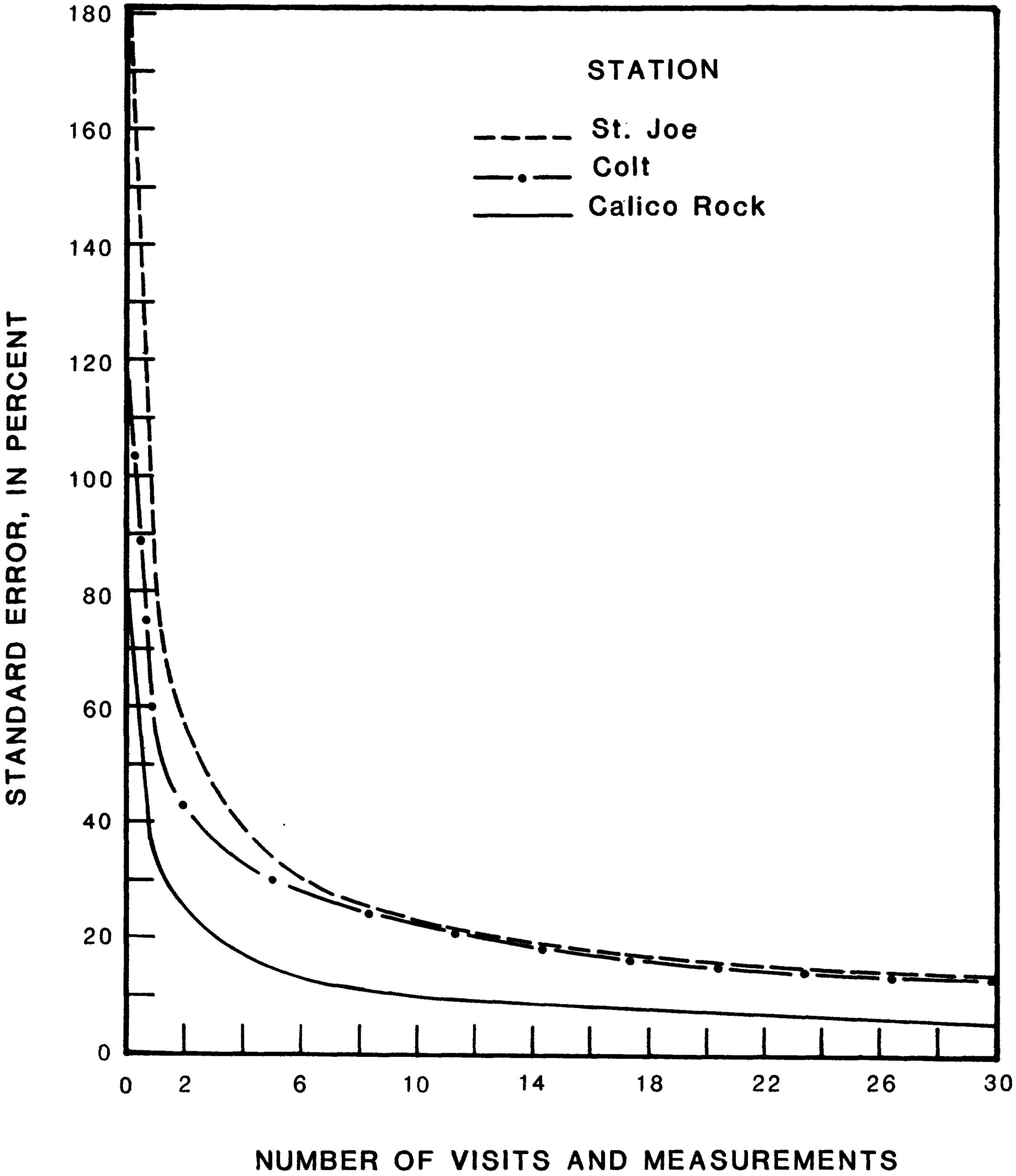


Figure 8.--Typical uncertainty function for instantaneous discharge.

Table 12.--Summary of the routes that may be used to visit stations in Arkansas

Route number	Stations serviced on the route						
1	250550						
2	263450						
3	258500	260500	261500				
4	258500	260500	261500	260000	259500		
5	048000	048600	195800	195855	196900	050500	249950
	195450						
6	048000	048600	195800	195855	196900	050500	047990
	048900						
7	056000	060500	060710	075000	075300	055000	055608
	075600	074900	055550				
8	056000	060500	060710	075000	075300	055000	055608
	054450	057300	060600				
9	263000	264000	359500	262500	263012	263530	363000
	263580	263570	264050	076870	264100	263100	357700
10	263000	264000	359500	262500	263012	263530	363000
	263580	263570	364115	363270	263910	364110	263400
	363050						
11	073500	074000	261000	261250	076000	075800	
12	073500	074000	261000	261250	076000	076630	061100
13	361500	362000	362100	365800	344300	349440	344320
	348630	361680	18S08W28DDD2	17S15W18DBB1	18S17W22BDD1		
14	361500	362000	362100	365800	364600	362330	364260
	364550	18S08W28DDD2	17S15W18DBB1	18S17W22BDD1			
15	047942	064000	069500	072000	077380	069200	069000
	064080	070660	069170	13N02E35DAA1		047880	069250
	072200	077430					
16	047942	064000	069500	072000	077380	069200	069000
	064080	047400	069266	069295	047200	047820	077200
	077340	077920					
17	337000	340000	341200	341000	339500	340500	339800
	340530						
18	337000	340000	341200	341000	339500	340500	361020
	361180						
19	247000	249400	340300	356000	360200	359900	
20	247000	249400	340300	356000	355800	258200	
21	252000	257000	257500	257200	256500	260673	252200
	257060	257100					
22	252000	257000	257500	257200	256500	260673	257700
	260679						
23	072500	074500	076634	061000	074420		
24	072500	074500	076634	076750	074853		
25	077950	362500	363300	363500	364150	363200	362550
	367658	364030	078210				
26	077950	362500	363300	363500	364150	363200	363450
	367740	02S05E29CCC1	02S03E15ACD1	09S02W26DDC1			
27	250000	249500	251500				

Table 12.--Summary of the routes that may be used to visit stations in Arkansas--Continued

Route number	Stations serviced on the route
28	048000
29	075000
30	195800
31	196900
32	247000
33	249400
34	250000
35	252000
36	258500
37	261500
38	263000
39	361500
40	362100
41	362500
42	260500
43	195855
44	048600
45	075300
46	056000
47	060500
48	060710
49	264000
50	359500
51	074000
52	073500
53	261000
54	362000
55	365800
56	047942
57	064000
58	069500
59	072000
60	077380
61	337000
62	341200
63	340000
64	340300
65	356000
66	257000
67	074500
68	072500
69	077950
70	363300
71	363500
72	364150
73	250551

Table 12.--Summary of the routes that may be used to visit stations in Arkansas--Continued

Route number	Stations serviced on the route						
74	263451						
75	263530	263580	263570				
76	258500	260500	261500				
77	260000	259500					
78	260000	259500	261800				
79	247000	249400	340300	356000			
80	360200	359900	355800	258200			
81	247000	249400	258500	260500	261500	340300	356000
82	359900	360200					
83	260000	259500	360200	261800	359900	355800	258200
84	048000	048600	195800	195855	196900		
85	258500	261500					
86	247000	249400					
87	340300	356000					
88	048000	196900					
89	048600	195800	195855	050500	249950	195450	047990
	048900						
90	249500	251500					
91	257000	257500	257200	256500	260673	252200	257060
	257100						
92	257000	257500	257200	256500	260673	257700	260679
93	048600	195855	257000	050500	2$9500	251500	257500
	257200	256500	260673	249950	195450	252200	257060
	257100						
94	048600	195855	257000	050500	249500	251500	257500
	257200	256500	260673	047990	048900	257700	260679
95	362000	365800					
96	361500	362100					
97	362000	365800	18S08W28DDD2	17S15W18DBB1	18S17W22BDD1		
98	362000	365800	18S08W28DDD2	17S15W18DBB1	18S17W22BDD1	364600	
	362330	364260	364550				
99	362000	365800	18S08W28DDD2	17S15W18DBB1	18S17W22BDD1	344300	
	349440	344320	348630	361608			
100	359500	362000	365800	18S08W28DDD2	17S15W18DBB1	18S17W22BDD1	
	364600	362330	364260	364550	357700	363000	
101	359500	362000	365800	18S08W28DDD2	17S15W18DBB1	18S17W22BDD1	
	363000	344300	349440	363050	344320	348630	361680
102	077950	363300	363500	364150	363200	363450	367740
	364115	363270	364110	02S05E29CCC1	02S03E15ACD1	09S02W26DDC1	
103	077950	363300	363500	364150	363200	362550	367658
	364030	078210					
104	364115	363270	362550	364110	363450	367658	367740
	364030	078210	02S05E29CCC1	02S03E15ACD1	09S02W26DDC1		
105	364115	363270	364110	363450	367740	02S05E29CCC1	
	02S03E15ACD1	09S02W26DDC1					

Table 12.—Summary of the routes that may be used to visit stations in Arkansas—Continued

Route number	Stations serviced on the route						
106	344300	349440	364600	357700	363050	344320	348630
	361680	362330	364260	364550			
107	344300	349440	363050	344320	348630	361680	
108	337000	340000	341200	361500	362000	362100	365800
109	337000	340000	341200	362000	365800	341000	339500
	340500	18S08W28DDD2	17S15W18DBB1	18S17W22BDD1			
110	344300	349440	364600	339800	340530	361020	361180
	344320	348630	361680	362330	364260	364550	
111	344300	349440	339800	340530	344320	348630	361680
112	047942	064000	069500	072000	077380	264000	069200
	069000	064080					
113	264050	077660	047400	069266	069295	069170	076870
	263910	264100	047200	047820	047880	069250	072200
	077200	077340	077430	077920			
114	047400	069266	069295	263910	047200	047820	077200
	077340	077920					
115	056000	060500	060710	073500	077400	077500	075300
	261000	055000	055608	261250	076000		
116	075800	076630	061100	075600	074900	055550	054450
	057300	060600					
117	077663	061100	054450	057300	060600		
118	262500	263012	263100	263400			
119	262500	263012	263400				
120	056000	060500	060710	073500	074000	075300	261000
	055608	055000	261250	076000			
121	260501						
122	258500	260501	261500	260000	259500	261800	
123	258500	260501	261500	260000	259500		
124	258500	260501	261500				
125	247000	249400	258500	260501	261500	340300	356000
126	364151						
127	077950	362500	363300	363500	364151	363200	362550
	367658	364030	078210				
128	077950	362500	363300	363500	364151	363200	363450
	367740	02S05E29CCC1	02S03E15ACD1				
129	077950	362500	363300	364151	363200	363450	367740
	364115	363270	364110	02S05E29CCC1	02S03E15ACD1	09S02W26DDC1	
130	077950	363300	363500	364151	363200	362550	367658
	364030	078210					
131	364115	363270					
132	18S08W28DDD2	17S15W18DBB1	18S17W22BDD1				
133	341000	339500	340500				
134	363200						
135	050500	249950	195450				
136	050500	047990	048900				
137	257500	257200	256500	260673	252200	257060	257100

Table 12.--Summary of the routes that may be used to visit stations in Arkansas--Continued

Route number	Stations serviced on the route					
138	257500	257200	256500	260673	257700	260679
139	076634	061000	074420			
140	076634	076750	074853			
141	069200	069000	064080	13N02E35DAA1		
142	261250	076000				
143	055000	055608				
144	362550					
145	075800					
146	13N02E35DAA1					
147	047990					
148	075600	074900	055550			
149	263910					
150	364110					
151	367658	364030	078210			

Visit costs are costs of the hydrographer's time servicing the station equipment and making a discharge measurement. These costs vary from station to station and are 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 was then multiplied by the average hourly salary of hydrographers in the Arkansas office to determine total visit costs.

Route costs include the vehicle cost associated with driving 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. The first step in this analysis is to determine a total uncertainty for the current operations and budget. It should be noted that standard error of estimate of streamflow as computed in this report may not be a true estimate of error of the daily-discharge record published by the U.S. Geological Survey. However, this estimate of standard error of streamflow can be used for comparative purposes within the District to determine a more cost-effective operation of the stream-gaging program. Based on the specified routes and number of visits to each station an average standard error of 33.3 percent was determined for current district operations. The value is plotted as a labelled "current practice" in figure 9. This percentage is based on the assumption that every time the stream gager goes out to gage, a measurement will be made. This is a fair assumption. If a stream gager cannot make the measurement due to equipment breakdown or bad weather prevents access to the site, a second visit within a day is always made. For both dam and slope stations, two uncertainty functions were reserved for each. Applied to the travel program, uncertainty for these stations is a weighted average based on the percent of the time a particular regime is in place.

The solid line on figure 9 presents the minimum level of average uncertainty that can be obtained for a given budget with existing instrumentation and technology. The line was defined by several runs of the "Traveling Hydrographer Program" at different gross budgets. Constraints on the operations other than budget were defined as described below.

The primary constraint on the program is the minimum number of visits to maintain the equipment in working order. This number of visits was set at four visits per year for daily discharge stations. Dam stations were estimated to have a constraint of one visit for gate measurements and one visit for tailwater measurement. Maintenance for these dam sites were put into fixed costs in the travel program. Slope stations were divided in the travel program into stations which include measurements with fall and those without. The slope stations, which include fall measurements, were set at four visits per year and those without fall at two visits per year. All of these estimates were based on the limitations of the batteries used to drive recording equipment and the capacities of the uptake spools on the digital recorders.

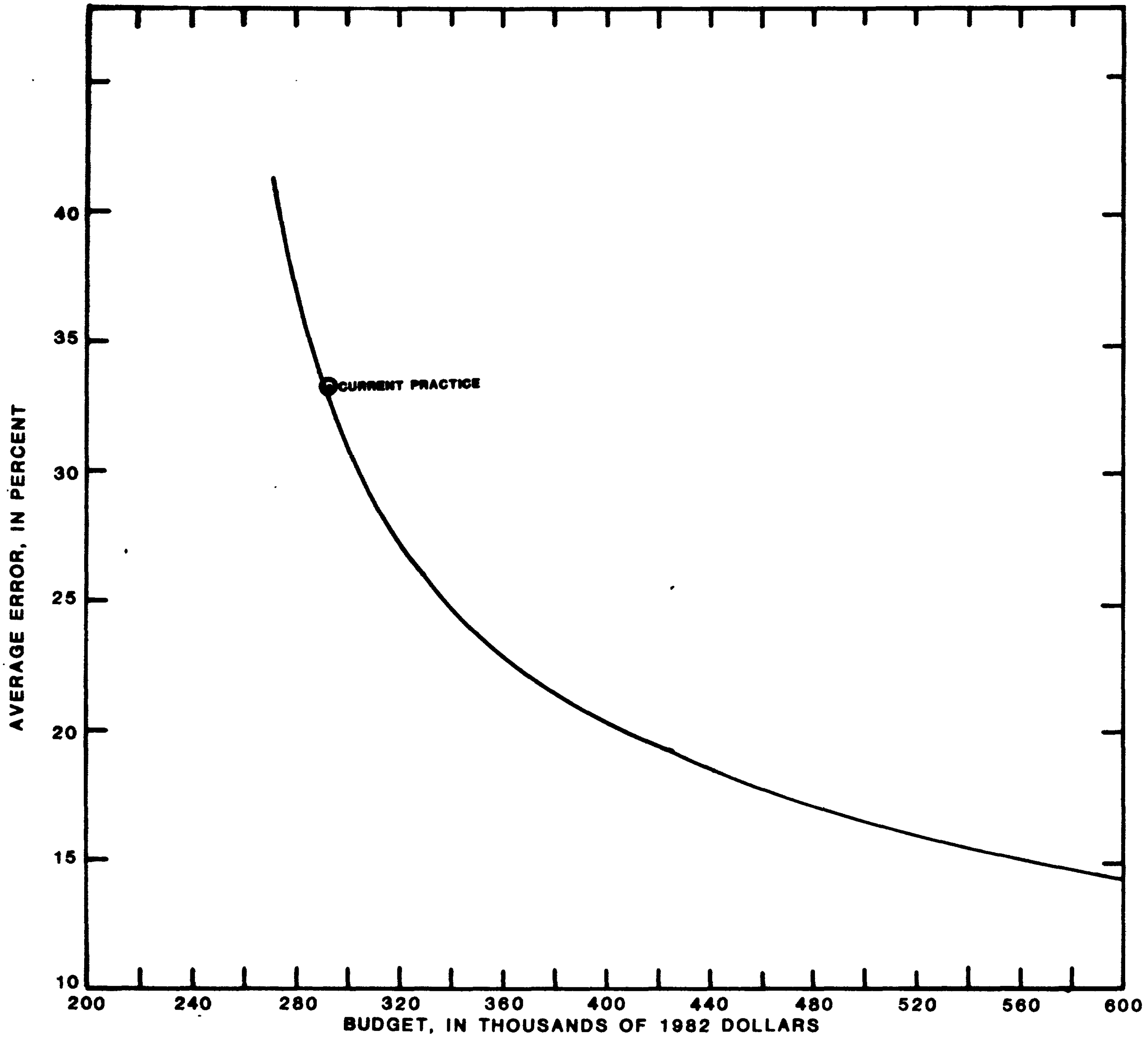


Figure 9.--Temporal average standard error per stream gage.

Minimum visit requirements should also reflect the need to visit stations for special reasons such as water-quality sampling. In Arkansas, water-quality field work is not usually integrated with surface-water fieldwork, and, therefore, did not influence minimum visit requirements.

Table 13 and figure 9 summarize the K-CERA analysis. These statistical errors reflect a time-series of shifts to stage-discharge relationship and include methods of record reconstruction. The results are in no case an underestimate of error variances.

Current policy results in an average standard error of estimate of streamflow of 33.3 percent. This policy requires a budget of $292,150 to operate the 47-station stream-gaging program plus transportation to other stations (present in the Arkansas program plus six ground-water stations) for which uncertainty estimates are not available. Standard errors range from 2.9 percent for Murray Dam (263450) (gate rating) to a high of 67.1 percent for Danville (260500) (slope rating). It is possible to obtain the same average budget standard error with a reduced budget of about $290,000 with a change of policy in the field activities of the stream-gaging program. This policy and budget change would result in a decrease in standard error at Danville (7260500) (slope rating) from 67.1 to 55.9 percent. The lowest uncertainty values for this new regime is Murray Dam (263450) (gate rating), with a value of 3.1 percent and the highest is at Danville (260500) (slope rating) with an uncertainty of 55.9 percent. This savings however is less than one percent of the existing budget and may not be worth the time and effort to reroute the program from current practice.

It also would be possible to reduce the average standard error by a policy change while maintaining the same budget of $292,150. In this case, the average would decrease from 33.3 percent to 32.6 percent. Extremes of standard error for invividual sites would be 3.1 and 51.3 percent for Murray Dam (263450) (gate rating) and Fordyce (362500), respectively.

The minimum budget run was $272,000 which approaches the lowest budget that can permit proper service and maintenance of the gages and recorders for the 47-station program plus routing of partial record, pollution control crest-stage and well stations. At this budget of $272,000, the average standard error is 41.3 percent. The minimum standard error of 3.1 percent is at Murray Dam (263450) (gate rating), and the maximum is 75.8 percent at Fordyce (362500).

The maximum budget analyzed is $600,000, which resulted in an average standard error of estimate of 14.2 percent. Results show a significant reduction in average standard error of 19.1 percent when the budget is doubled from current operations. The range in standard error for a budget of $600,000 is 5.2 percent to 26.6 percent for Calico Rock (060500) and Springtown (195800), respectively. As shown from these results, significant improvements in accuracy of streamflow records can be obtained if larger budgets become available.

As shown in Figure 9, the current practice point ($292,150) is located on a steep section of the budget versus uncertainty curve. As an example, for about $50,000 the average standard error for the Arkansas District could be reduced as much as 10.0 percent using cost effective methods.

Table 13.--Selected results of K-CERA analysis

	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1982 dollars				
Identification		272	292	350	450	600
Average per station	33.3	41.3	32.6	23.7	18.11	14.2
047942	23.8	33.4	30.5	22.8	16.4	12.8
Colt	[17.7]	[23.6]	[22.0]	[16.9]	[12.2]	[9.5]
	(9)	(4)	(5)	(10)	(20)	(33)
048000	30.4	37.9	27.4	19.0	13.8	11.0
Greenland	[8.5]	[9.7]	[7.9]	[5.8]	[4.3]	[3.5]
	(9)	(6)	(11)	(22)	(41)	(64)
048600	25.3	34.8	25.3	16.7	12.9	10.3
Fayetteville	[8.9]	[11.3]	[8.9]	[6.2]	[4.8]	[3.9]
	(9)	(5)	(9)	(20)	(33)	(51)
056000	24.7	38.8	30.9	19.5	14.7	11.8
St. Joe	[11.3]	[18.3]	[14.3]	[8.8]	[6.6]	[5.4]
	(9)	(4)	(6)	(14)	(24)	(37)
060500	10.9	16.9	13.5	8.6	6.5	5.2
Calico Rock	[2.8]	[3.6]	[3.2]	[2.4]	[1.9]	[1.6]
	(9)	(4)	(6)	(14)	(24)	(37)
060710	30.4	45.6	37.3	24.3	18.6	14.9
N. Sylamore	[16.1]	[25.8]	[20.4]	[12.6]	[9.4]	[7.5]
	(9)	(4)	(6)	(14)	(24)	(37)
064000	12.8	20.1	20.1	14.7	11.0	8.4
Corning	[2.9]	[4.1]	[4.1]	[3.2]	[2.5]	[2.0]
	(9)	(4)	(4)	(7)	(12)	(20)
069500	14.7	22.9	22.9	16.8	12.7	9.9
Imboden	[3.9]	[4.4]	[4.4]	[4.1]	[3.8]	[3.6]
	(9)	(4)	(4)	(7)	(12)	(20)
072000	11.0	17.3	17.3	12.6	9.4	7.2
Eleven Point	[1.8]	[2.4]	[2.4]	[1.9]	[1.6]	[1.3]
	(9)	(4)	(4)	(7)	(12)	(20)
072500	8.9	14.1	14.1	14.1	11.1	8.9
Black Rock	[2.7]	[3.8]	[3.8]	[3.8]	[3.2]	[2.7]
	(9)	(4)	(4)	(4)	(6)	(9)
073500	22.7	36.6	32.0	21.4	15.9	12.4
Piney Fork	[10.6]	[17.0]	[14.9]	[10.0]	[7.5]	[5.9]
	(9)	(4)	(5)	(10)	(17)	(27)
074000	17.7	28.9	25.2	16.7	12.4	9.6
Poughkeepsie	[4.9]	[7.8]	[6.8]	[4.6]	[3.5]	[2.8]
	(9)	(4)	(5)	(10)	(17)	(27)
074500	7.1	11.3	11.3	11.3	8.9	7.1
Newport	[4.4]	[5.5]	[5.5]	[5.5]	[5.0]	[4.4]
	(9)	(4)	(4)	(4)	(6)	(9)

Table 13.—Selected results of K-CERA analysis—Continued

	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1982 dollars				
Identification		272	292	350	450	600
075000 Shirley	49.3 [43.9] (9)	52.9 [47.3] (4)	50.3 [44.3] (8)	44.1 [41.3] (18)	34.4 [33.2] (59)	26.0 [25.2] (126)
075300 Clinton	28.4 [17.7] (9)	40.1 [19.4] (4)	31.3 [18.1] (7)	24.4 [17.0] (14)	20.9 [16.1] (24)	17.6 [14.7] (44)
077380 Cache	26.9 [15.2] (9)	37.3 [16.8] (4)	37.3 [16.8] (4)	26.9 [15.2] (9)	22.0 [14.3] (16)	18.5 [13.4] (27)
077950 Big Creek	21.9 [13.5] (9)	31.7 [18.9] (4)	28.7 [17.4] (5)	17.7 [10.9] (14)	13.5 [8.2] (24)	10.6 [6.4] (39)
195800 Springtown	48.9 [41.5] (9)	56.4 [43.6] (5)	48.9 [41.5] (9)	42.6 [39.0] (20)	35.1 [33.6] (58)	26.6 [25.7] (138)
195855 West Siloam	30.3 [4.4] (9)	41.7 [6.2] (5)	30.3 [4.4] (9)	19.9 [3.0] (20)	15.4 [2.4] (33)	12.3 [2.0] (51)
196900 Baron Fork	48.3 [40.7] (9)	53.1 [42.1] (6)	46.5 [40.2] (11)	41.2 [38.0] (23)	32.3 [31.1] (81)	24.4 [23.7] (179)
247000 Poteau	36.7 [21.3] (9)	38.9 [22.5] (8)	31.7 [18.6] (12)	21.3 [12.6] (26)	16.9 [9.9] (41)	13.0 [7.6] (68)
249400 James Fork	58.9 [53.5] (9)	51.2 [46.0] (12)	37.5 [33.0] (22)	25.6 [22.1] (46)	19.6 [16.8] (77)	15.5 [13.2] (123)
250000 Cove Creek	45.1 [34.0] (9)	47.2 [35.2] (8)	35.6 [27.6] (16)	24.7 [19.3] (35)	18.1 [14.1] (65)	14.3 [11.1] (104)
250550 Dam 13 (gate)	5.6 [5.6] (3)	5.6 [5.6] (1)	5.6 [5.6] (1)	5.6 [5.6] (1)	5.6 [5.6] (1)	5.6 [5.6] (1)
250551 Dam 13 (tailwater)	6.4 [6.4] (1)	6.4 [6.4] (1)	6.4 [6.4] (1)	6.4 [6.4] (1)	6.4 [6.4] (1)	6.4 [6.4] (1)
025200 Mulberry	34.4 [26.1] (9)	42.6 [29.0] (5)	33.2 [25.5] (10)	23.7 [19.6] (25)	17.4 [14.7] (50)	14.2 [11.9] (77)

Table 13.—Selected results of K-CERA analysis—Continued

	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1982 dollars				
Identification		272	292	350	450	600
257000	34.8	47.9	38.4	26.5	19.6	15.5
Big Piney	[28.4]	[35.6]	[30.7]	[22.1]	[16.4]	[12.9]
	(9)	(4)	(7)	(17)	(32)	(51)
258500	45.9	51.5	35.9	25.7	19.1	15.0
Booneville	[34.3]	[38.1]	[26.9]	[19.2]	[14.1]	[11.0]
	(9)	(7)	(15)	(29)	(52)	(83)
260500	67.1	67.1	48.9	33.3	24.4	19.4
Danville	[25.5]	[25.5]	[19.3]	[13.5]	[9.8]	[7.7]
(slope)	(2)	(2)	(4)	(9)	(17)	(27)
260501	36.4	47.4	36.4	23.6	17.8	14.1
Danville	[11.1]	[12.2]	[11.1]	[9.2]	[7.8]	[6.2]
	(7)	(4)	(7)	(18)	(33)	(54)
261000	36.0	48.0	34.2	24.9	18.6	14.5
Guy	[12.9]	[17.1]	[12.3]	[8.8]	[6.5]	[5.0]
	(9)	(5)	(10)	(19)	(34)	(56)
261500	58.7	61.1	45.4	32.1	24.5	19.1
Gravelly	[52.7]	[55.3]	[40.4]	[28.1]	[21.3]	[16.4]
	(9)	(8)	(16)	(32)	(54)	(88)
263000	51.9	54.7	42.2	30.0	22.4	17.9
Hollis	[36.5]	[38.4]	[29.6]	[20.7]	[15.2]	[12.0]
	(9)	(8)	(14)	(28)	(50)	(78)
263450	2.9	3.1	3.1	3.1	3.1	3.1
Murray Dam	[2.9]	[3.1]	[3.1]	[3.1]	[3.1]	[3.1]
(gate)	(3)	(1)	(1)	(1)	(1)	(1)
263451	10.8	10.8	10.8	10.8	10.8	10.8
Murray Dam	[10.8]	[10.8]	[10.8]	[10.8]	[10.8]	[10.8]
(tailwater)	(1)	(1)	(1)	(1)	(1)	(1)
264000	31.0	32.8	29.4	19.4	14.9	11.6
Lonoke	[10.1]	[10.8]	[9.5]	[6.1]	[4.7]	[3.7]
	(9)	(8)	(10)	(23)	(39)	(65)
337000	14.1	22.3	16.3	10.7	7.9	6.0
Index	[6.8]	[10.0]	[7.7]	[5.3]	[3.9]	[3.0]
	(9)	(4)	(7)	(15)	(27)	(45)
340000	14.5	24.6	17.0	10.8	7.8	6.0
Horatio	[3.8]	[4.4]	[4.0]	[3.4]	[2.9]	[2.4]
	(9)	(4)	(7)	(15)	(27)	(45)
340300	23.0	35.1	28.4	17.7	13.4	10.5
Vandervoort	[4.5]	[5.9]	[5.2]	[3.6]	[2.8]	[2.3]
	(9)	(4)	(6)	(15)	(26)	(42)

Table 13.—Selected results of K-CERA analysis—Continued

Identification	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1982 dollars				
		272	292	350	450	600
341200 Lockesburg	35.3 [5.6] (9)	52.8 [6.2] (4)	40.0 [5.7] (7)	27.4 [5.3] (15)	20.6 [5.0] (27)	16.2 [4.7] (45)
356000 Mount Ida	27.6 [4.7] (9)	42.6 [6.6] (4)	31.5 [5.2] (7)	21.1 [3.7] (15)	15.9 [2.8] (26)	12.5 [2.3] (42)
359500 Malvern	17.2 [6.7] (9)	18.2 [7.0] (8)	18.2 [7.0] (8)	16.3 [6.4] (10)	11.8 [4.7] (19)	9.4 [3.7] (30)
361500 Antoine	43.9 [19.1] (9)	52.5 [20.5] (6)	41.9 [18.8] (10)	30.4 [15.9] (21)	22.8 [12.7] (40)	17.8 [10.2] (67)
362000 Camden	22.6 [7.9] (9)	33.1 [10.3] (4)	25.5 [8.6] (7)	17.7 [6.4] (15)	13.2 [4.8] (27)	10.3 [3.8] (45)
362100 Smackover	35.0 [28.5] (9)	48.9 [37.3] (4)	35.0 [28.5] (9)	24.8 [20.4] (19)	18.6 [15.2] (34)	14.7 [11.9] (54)
362500 Fordyce	60.1 [44.3] (9)	75.8 [53.6] (5)	51.3 [38.2] (13)	36.4 [27.0] (27)	26.4 [19.4] (51)	20.5 [14.9] (84)
363300 Hurricane	36.2 [18.8] (9)	44.0 [22.8] (6)	32.8 [17.0] (11)	22.7 [11.6] (23)	17.0 [8.5] (41)	13.4 [6.7] (66)
363500 Rye	29.4 [10.5] (9)	43.0 [11.7] (4)	35.5 [11.0] (6)	24.2 [10.0] (14)	19.2 [9.4] (24)	15.8 [8.7] (39)
364150 McGehee (slope)	24.1 [6.8] (6)	30.2 [8.6] (4)	30.2 [8.6] (4)	20.5 [5.8] (8)	15.2 [4.2] (14)	12.0 [3.4] (22)
364151 McGehee	35.7 [10.5] (3)	44.9 [12.3] (2)	35.7 [10.5] (3)	24.4 [8.0] (6)	18.6 [6.5] (10)	14.1 [5.0] (17)
365800 Cornie Bayou	38.2 [28.0] (9)	56.8 [41.4] (4)	43.4 31.8] (7)	29.4 [21.3] (15)	21.8 [15.5] (27)	16.7 [11.9] (45)

Conclusion from the K-CERA Analysis

As a result of the K-CERA analysis, the following conclusions are offered:

1. The frequency of visits for daily-discharge stations with relatively large uncertainty should be increased from current operations in order to reduce the total uncertainty for the program.
2. The amount of funding for stations with accuracies that are not acceptable for the data uses should be renegotiated with data users.
3. Two or more gaging stations should be established in northwest and southeast Arkansas where data is particularly sparse.
4. The K-CERA analysis should be rerun with the new stations included whenever sufficient information about the characteristics of new stations has been obtained.
5. Schemes for reducing the probabilities of missing record (for example, more reliable instrumentation and satellite relay of data) should be explored and evaluated as to their cost-effectiveness in providing streamflow information.

SUMMARY

Currently, the Arkansas District has a surface-water program which includes 49 continuous-stream gages, partial-record gages, crest-stage program and pollution control stations. The total cost to operate this program in Arkansas is $450,000.

In analyzing the results of the reconstruction of record statistics (K-CERA analysis) and information accumulated over the years in operation of the program, it can be concluded there are many sparse areas of the State which are in need of gaging. Gages in these areas would provide a more valid estimate of streamflow characteristics throughout the State.

Based on the K-CERA analysis of total uncertainty for 47 daily discharge stations with routing costs to 105 other stations in the surface-water program and six ground-water stations, current budget for district operations was established at a cost of $292,150. The resulting uncertainty was 33 percent for the period analyzed in this report. Less than one percent reduction could be obtained by rerouting the current operation.

As a result of this study, it is concluded that all continuous stream gages in the Arkansas district should be maintained in operation through the next few years. Studies of the cost-effectiveness of the stream-gaging program should be continued and should include investigation of the optimum ratio of discharge measurements to total site visits for each station, as well as investigation of cost-effective ways of reducing the probabilities of lost correlative data. Future studies will also be required 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; because of the dependence between stations for information that is generated (data redundancy) and the dependence of the costs of collecting the data from which the information is derived.

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