COST EFFECTIVENESS OF THE STREAM-GAGING PROGRAM IN WEST VIRGINIA

by G. S. Runner, R. L. Bragg, and J. T. Atkins, Jr.

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MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey, WRD
603 Morris Street
Charleston, West Virginia 25301

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CONTENTS

ILLUSTRATIONS

Page

TABLES

CONVERSION FACTORS

For use of readers who prefer to use metric (International System) units, conversion factors for terms used in this report are listed below.

Multiply inch-pound units	by	To obtain metric units
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
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 a cost-effectiveness study of streamflow-gaging activities in West Virginia. Data uses and sources of funding were identified for 74 streamflow-gaging stations currently operated in West Virginia. One streamflow-gaging station was identified as producing data no longer sufficiently needed to warrant continuing its operation; this station was discontinued. Data collected at three other streamflow-gaging stations were identified as having uses specific only to short-term studies; it is recommended that these stations be discontinued at the end of the data-collection phases of the studies.

The current policy for operation of the 74 streamflow gaging stations requires a budget of $390,000 per year. The average standard error of estimation of streamflow records is 24.6 percent and the range of error at individual stations is from 6.6 to 79.2 percent. It was shown that this overall standard error could be reduced to 22.0 percent if field activities were altered with no change in budget.

A minimum budget of $375,000 is required to operate the 74 stations; a smaller budget would not permit proper service and maintenance of the stations and recorders. At the minimum budget, the average standard error is 22.5 percent. The maximum budget analyzed was $430,000, which resulted in an average standard error of 21.1 percent.

Large areas in West Virginia lack sufficient streamflow data to provide valid estimates of streamflow characteristics. The paucity of data in these areas will be remedied as funds become available.

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. The data are collected in cooperation with State and local governments and other Federal agencies. The Geological Survey operates approximately 7,000 continuous-record gaging stations throughout the Nation. Some of these records extend back to the turn of the century. Any activity of long standing, such as the collection of surface-water data, should be reexamined at intervals, if not continuously, because of changes in objectives, technology, or external constraints. The last systematic nationwide evaluation of the streamflow information program was completed in 1970 and is documented by Benson and Carter (1973). The Geological Survey is presently undertaking another nationwide analysis of the streamflow 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.

The first phase of the study identifies the principal uses of the data and relates these uses to funding sources. Streamflow-gaging stations for which data are no longer needed are identified, as are deficient or unmet data needs. In addition, gaging stations are categorized as to whether the data are available to users in a real-time sense, on a provisional basis, or at the end of the water year.

The second phase of the study is to identify less costly methods of furnishing the needed information; among these are flow-routing models and statistical methods. The streamflow-gaging activity no longer is considered a network of observation points, but rather an integrated information system in which data are provided both by observation and synthesis.

The final phase of the study involves the use of Kalman-filtering and mathematical-programming 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 study. A steepest descent optimization program uses these uncertainty functions, information on practical streamflow gaging routes, the various costs associated with streamflow gaging, and the total operating budget to identify the visit frequency for each station that minimizes the overall uncertainty in the streamflow. The streamflow 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 being an introduction to the streamflow gaging activities in West Virginia and to the study itself. The middle three sections each contain discussions of individual steps of the study. Because of the sequential nature of the steps and the dependence of subsequent steps on the previous results, summaries of conclusions are made at the end of each of the middle three sections. The complete study is summarized in the final section.

The report format and most of the discussions of flow-routing models and statistical procedures used in this report were taken wholly or in part from a report, "Cost-Effectiveness of the Stream-Gaging Program in Maine--A Prototype for Nationwide Implementation" by Fontaine and others (1984).

History of the Streamflow-Gaging Program in West Virginia

Systematic streamflow-gaging activities in West Virginia by the U.S. Geological Survey began in the late 1800's when streamflow records were collected at a few selected streamflow-gaging stations. These stations were located on the larger streams that were accessible by rail travel. The number of continuous-record streamflow-gaging stations operated in West Virginia for each year since 1900 is shown in figure 1. The program gradually expanded from early 1900 to the late 1940's, when about 95 streamflow stations were operated. The streamflow-gaging program remained relatively steady from about 1945 until 1964.

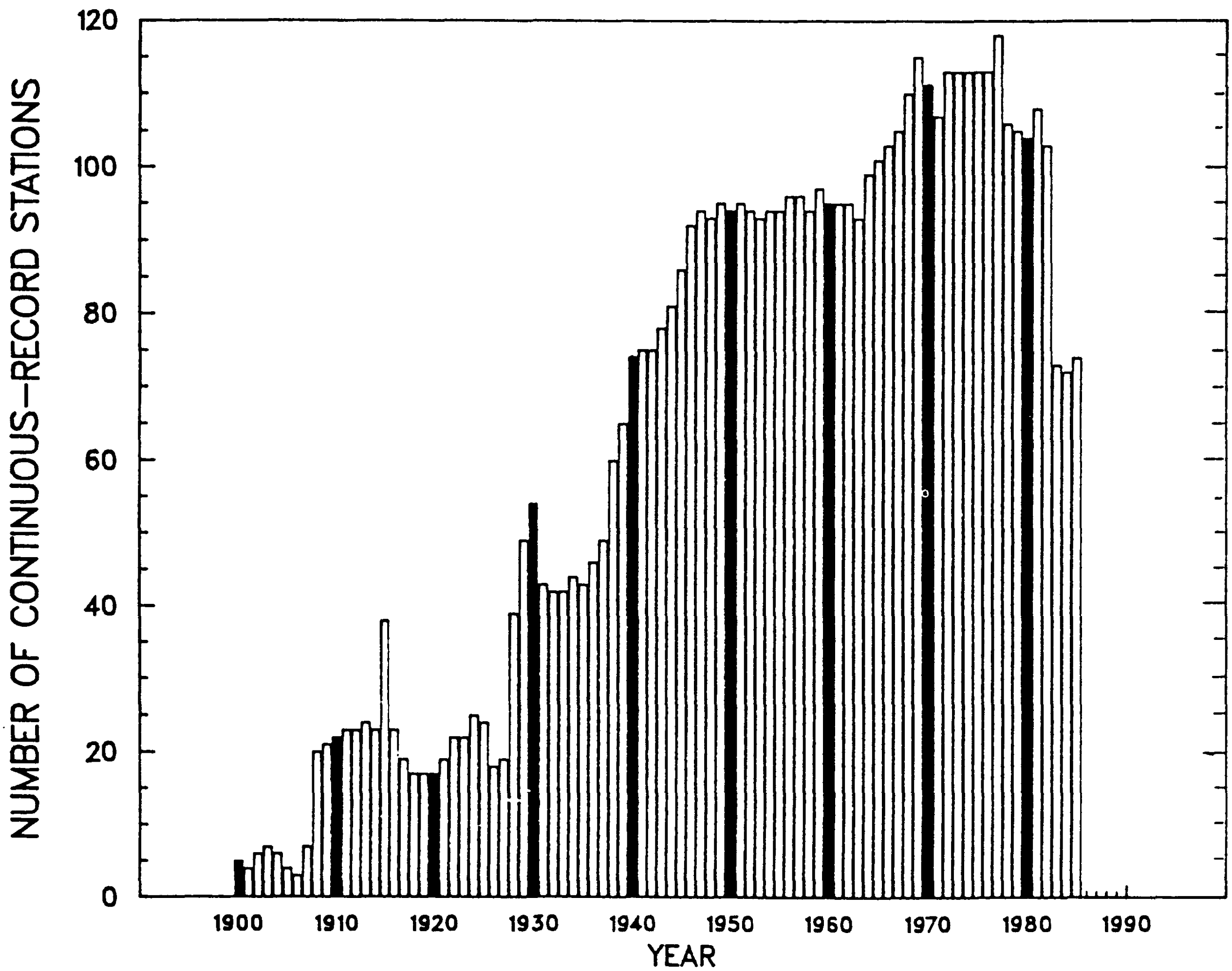

Figure 1.--Continuous-record stream-gaging stations in West Virginia.

A study of peak flows from rural watersheds of less than 10 mi^2 was begun in 1964. To support this program, 15 continuous stage-rainfall stations and 50 high-flow partial-record stations were operated. Although this program was terminated in 1977, the surface-water program in West Virginia continued to expand from 1964 until 1977, when the U.S. Geological Survey operated 118 continuous-record stations in the State.

A study by Frye and Runner (1970) described the surface-water program in West Virginia and proposed a streamflow program to meet the future needs of water-data users. Regression equations developed as part of this study are used to predict streamflow characteristics of West Virginia streams. The study used records from the streamflow gaging stations that had at least 10 years of non-regulated flow.

In 1983 the West Virginia continuous-record streamflow monitoring program was reduced by about 30 percent in response to the redirection of cooperator funding into real-time water-data systems. Eighteen stations supported by the U.S. Army Corps of Engineers were discontinued from the continuous-record program and became partial-record stations where current ratings are maintained. The continuous-record streamflow program continued to decline during 1984 as special-project stations were discontinued. The decline in number of continuous streamflow-gaging stations was halted in 1985 with the construction of two stations for the U.S. Army Corps of Engineers, Pittsburgh District, and three streamflow-gaging stations on the Tug Fork funded by the Federal CBR (collection of basic records) program, as part of a network of streamflow-gaging stations for flood forecasting.

Current West Virginia Stream-Gaging Program

The West Virginia District currently (1985) operates 74 continuous-record streamflow-gaging stations. Eighteen of these stations are continuous-stage stations; a stage-discharge rating is maintained, the mean daily stage for each day of the year is computed, and the maximum discharge for the year is computed. The remaining 60 stations are continuous-discharge stations; a stage-discharge rating is maintained and the mean daily discharge for each day of the year is computed. The District also operates 18 partial-record stations and (or) stage stations where a continuous-record of stage is provided from December through May. Finally, the District operates 10 stations as part of special projects for the collection of runoff quality, sediment, or turbidity data. The funds used to maintain and operate the surface-water program in fiscal year 1985 were approximately $485,000; of this amount, $390,000 was used to operate the 74 continuous-record stations analyzed in this study.

West Virginia is divided into three major physiographic provinces (Fenneman, 1938)--the Blue Ridge, the Ridge and Valley, and the Appalachian Plateau (figure 2). The location of these regions and the location of the 74 continuous-record stream-gaging stations are shown in figure 2. One station is in the Blue Ridge Province, nine stations are in the Ridge and Valley, and the remaining 64 stations are in the Appalachian Plateau. The drainage basins in West Virginia, as defined by the U.S. Geological Survey (1974), are shown on figure 2. There are 10 stations in the Potomac River basin and 64 in the Ohio River basin. There are no streamflow-gaging stations in small, tributary drainage basins along the Ohio River and in the lower Kanawha River drainage basin.

The surface-water program is being expanded in fiscal year 1985. Accurate low-flow data for the lower Kanawha River are important for management of waste discharge by the large manufacturing and chemical industries concentrated around Charleston (Frye and Runner, 1970). An acoustic velocity meter was installed on the Kanawha River at Charleston to provide these data. Three new streamflow-gaging stations are being constructed in the Tug Fork drainage basin as part of the Federal CBR program. They will become part of flood-forecasting network.

Selected hydrologic data, including drainage area, period of record, and mean annual flow, as of 1981, for the 74 stations are given in table 1. Station identification numbers used throughout this report are the map numbers given in table 1 and shown on figure 2. Table 1 also provides the official name for each stream gage and the U.S. Geological Survey's eight-digit downstream-order station number. Subdistrict operation areas, number of stations, and the approximate fiscal year 1985 operational costs are listed in table 2.

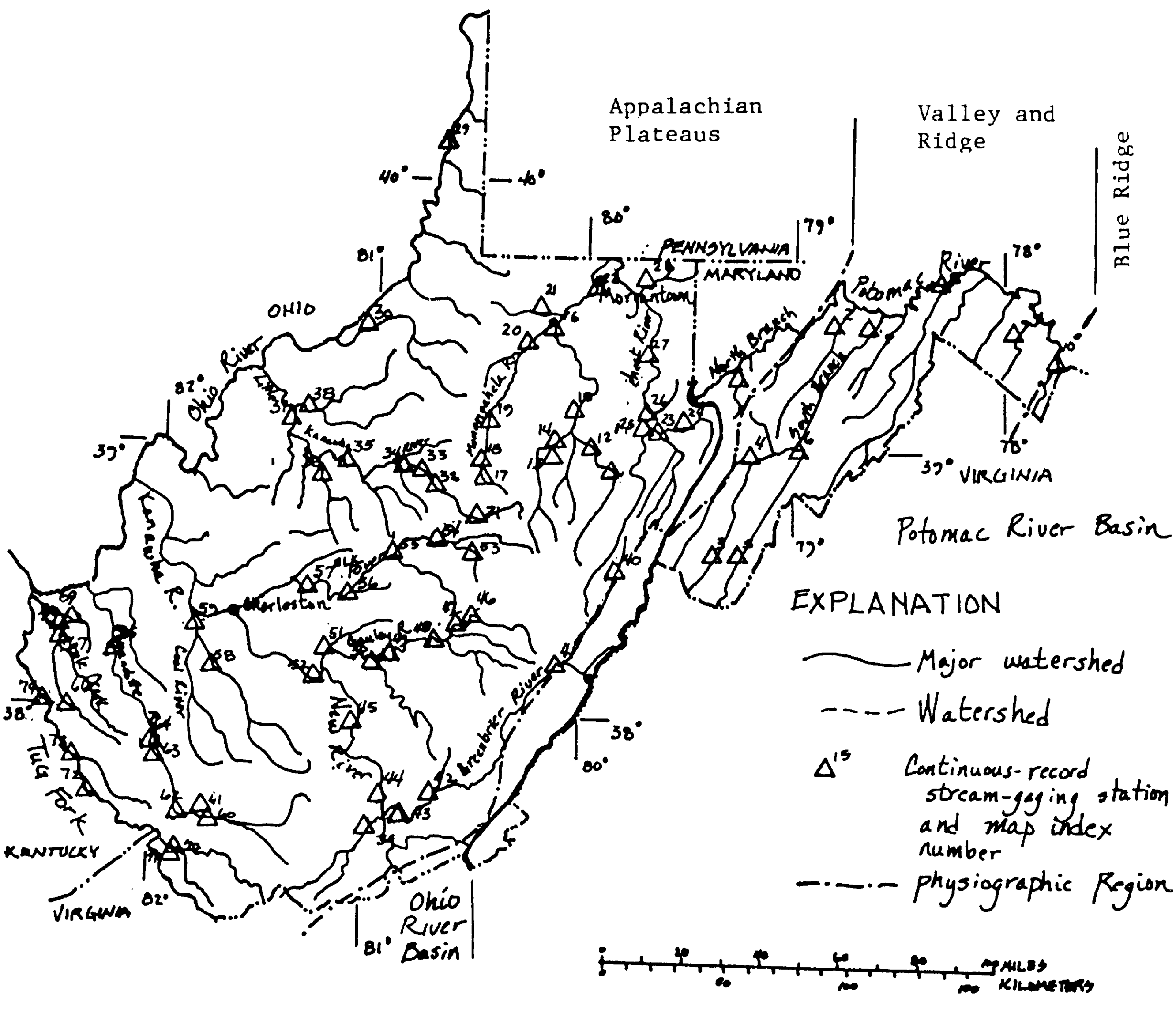

Figure 2.--Location of stream-gaging stations in West Virginia.

Table 1.--Selected hydrologic data for stream-gaging stations the West Virginia surface-water network

Map index number	Station number	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
1	01595200	Stony River near Mt. Storm, W. Va.	48.8	1961-	99.3
2	01604500	Patterson Creek near Headsville, W. Va.	219	1938-	166
3	01605500	South Branch Potomac River at Franklin, W. Va.	182	1940-69 1976-	165
4	01606500	South Branch Potomac River near Petersburg, W. Va.	642	1928-	709
5	01607500	South Fork South Branch Potomac River at Brandywine, W. Va.	102	1943-	99.4
6	01608000	South Fork South Branch Potomac River near Moorefield, W. Va.	283	1928-35 1938-	218
7	01608500	South Branch Potomac River near Springfield, W. Va.	1,471	1900-05 1929-	1,294
8	01611500	Cacapon River near Great Cacapon, W. Va.	677	1923-	586
9	01616500	Opequon Creek near Martinsburg, W. Va.	272	1947-	227
10	01636500	Shenandoah River at Millville, W. Va.	3,040	1895-1909 1928-	2,681
11	03050500	Tygart Valley River near Elkins, W. Va.	272	1944-	537
12	03051000	Tygart Valley River at Belington, W. Va.	408	1908-	811
13	03052500	Sand Run near Buckhannon, W. Va.	14.5	1946-	26.8
14	03053500	Buckhannon River at Hall, W. Va.	277	1915-	596
15	03054500	Tygart Valley River at Philippi, W. Va.	916	1940-	1,866
16	03057000	Tygart Valley River at Colfax, W. Va.	1,366	1939-	2,659
17	03057500	Skin Creek near Brownsville, W. Va.	25.7	1946-	41.4
18	03058000	West Fork River at Brownsville, W. Va.	102	1946-	167
19	03058500	West Fork River at Butcherville, W. Va.	181	1915-	302
20	03061000	West Fork River at Enterprise, W. Va.	759	1932-	1,156
21	03061500	Buffalo Creek at Barrackville, W. Va.	115	1915-24	170
22	03062400	Cobun Creek at Morgantown, W. Va.	10.9	1965-	17.1
23	03065000	Dry Fork at Hendricks, W. Va.	345	1940-	762
24	03066000	Blackwater River at Davis, W. Va.	86.2	1921-	198
25	03069000	Shavers Fork at Parsons, W. Va.	214	1910-26 1940-	552
26	03069500	Cheat River near Parsons, W. Va.	718	1913-	1,692
27	03070000	Cheat River at Rowlesburg, W. Va.	972	1923-	2,280
28	03070500	Big Sandy Creek at Rockville, W. Va.	200	1909-18 1921	424
29	03112000	Wheeling Creek at Elm Grove, W. Va.	282	1940-	338

Table 1.--Selected hydrologic data for stream-gaging stations the West Virginia surface-water network--continued

Map index number	Station number	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
30	03114500	Middle Island Creek at Little, W. Va.	458	1928-	644
31	03151400	Little Kanawha River near Wildcat, W. Va.	112	1973-83 1/1984	237
32	03151520	Little Kanawha River below Burnsville Dam, W. Va.	163	1976-82 1/1983-	311
33	03151600	Little Kanawha River at Burnsville, W. Va.	248	1974-78 1/1979-	390
34	03152000	Little Kanawha River at Glenville, W. Va.	386	1928-	606
35	03153500	Little Kanawha River at Grantsville, W. Va.	913	1928-78 1/1979-	1,327
36	03154000	West Fork Little Kanawha River at Rocksdale, W. Va.	205	1937-75 1/1976-	258
37	03155000	Little Kanawha River at Palestine, W. Va.	1,515	1939-	2,127
38	03155500	Hughes River at Cisco, W. Va.	452	1928-	585
39	03179000	Bluestone River near Pipestem, W. Va.	394	1950-	355
40	03180500	Greenbrier River at Durbin, W. Va.	133	1943-	257
41	03182500	Greenbrier River at Buckeye, W. Va.	540	1929-	872
42	03183500	Greenbrier River at Alderson, W. Va.	1,364	1895-	1,991
43	03184000	Greenbrier River at Hilldale, W. Va.	1,619	1936-	2,245
44	03184500	New River at Hinton, W. Va.	6,256	1936-	7,921
45	03185400	New River at Thurmond, W. Va.	6,687	1981-	
46	03186500	Williams River at Dyer, W. Va.	128	1929-	331
47	03187000	Gauley River at Camden-on-Gauley, W. Va.	236	1910-75 1/1976-	587
48	03189100	Gauley River near Craigsville, W. Va.	529	1964-82 1/1983-	1,470
49	03189600	Gauley River below Summersville Dam, W. Va.	806	1966-82 1/1983	2,156
50	03190400	Meadow River near Mt. Lookout, W. Va.	365	1966-82 1/1983-	774
51	03192000	Gauley River above Belva, W. Va.	1,317	1928	2,728
52	03193000	Kanawha River at Kanawha Falls, W. Va.	8,371	1877-	12,588
53	03194700	Elk River below Webster Springs, W. Va.	266	1959-82 1/1983-	702
54	03195500	Elk River at Sutton, W. Va.	542	1938	1,140
55	03196600	Elk River near Frametown, W. Va.	751	1958-78 1/1979-	1,572
56	03196800	Elk River at Clay, W. Va.	992	1958-78 1/1979-	1,925
57	03197000	Elk River at Queen Shoals, W. Va.	1,145	1928-	2,043
58	03198500	Big Coal River at Ashford, W. Va.	391	1930-	520
59	03200500	Coal River at Tornado, W. Va.	862	1961	1,252

Table 1.--Selected hydrologic data for stream-gaging stations the West Virginia surface-water network--continued

Map index number	Station number	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
60	03202400	Guyandotte River near Baileysville, W. Va.	306	1968	465
61	03202750	Clear Fork at Clear Fork, W. Va.	124	1974	218
62	03202915	Guyandotte River below R. D. Bailey Dam, W. Va.	535	1978-82 1/1983-	800
63	03203000	Guyandotte River at Man, W. Va.	758	1930-62 1/1963-	984
64	03203600	Guyandotte River at Logan, W. Va.	833	1962-	1,216
65	03204000	Guyandotte River at Branchland, W. Va.	1,224	1928-	1,652
66	03206600	East Fork Twelvepole Creek near Dunlow, W. Va.	38.5	1964-83	55.3
67	03206790	East Fork Twelvepole Creek below East Lynn Dam, W. Va.	138	1962-82 1/1983-	177
68	03207020	Twelvepole Creek below Wayne, W. Va.	300	1922-82 1/1983-	349
69	03207057	Beech Fork below Beech Fork Dam, W. Va.	79.2	1976-82 1/1983-	94.5
70	03213000	Tug Fork at Litwar, W. Va.	504	1930-	557
71	03213500	Panther Creek near Panther, W. Va.	31.0	1946-	36.5
72	03213700	Tug Fork at Williamson, W. Va.	936	1967-	1,215
73	03214000	Tug Fork near Kermit, W. Va.	1,188	1934-	1,424
74	03214900	Tug Fork at Glenhayes, W. Va.	1,507	1976-82 1/1983-	2,060

1/ Station converted from a continuous-discharge station to continuous-stage station; mean, daily discharges are not available.

Table 2.--Service areas, number of stream-gaging stations, and operational cost for fiscal year 1985

Subdistrict office	Service area	Number of stations: Continuous record1/	Partial record2/	Project	Approximate cost
Morgantown	Potomac River basin Monongahela River basin Little Kanawha River basin	38	5	5	--
Charleston	Kanawha River basin Guyandotte River basin Tug Fork basin	36	13	5	--
Total		74	18	10	$485,000

1/ Includes continuous-stage stations where a stage-discharge rating is required and maintained.
2/ Includes continuous-stage stations where a stage-discharge rating is not maintained and continuous-record stations that are operated only from December through May.

USES, FUNDING, AND AVAILABILITY OF CONTINUOUS STREAMFLOW DATA

The relevance of a continuous-record streamflow-gaging station is defined by the uses that are made of the data produced from the station. The uses of the data from each station in the West Virginia program were identified by a survey of known data users. The survey documented the importance of each station and identified streamflow-gaging stations that may be considered for discontinuation.

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

Data-Use Classes

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

Regional Hydrology

For data to be useful in defining regional hydrology, a streamflow-gaging station must be largely unaffected by manmade storage or diversion. In this class of use, the effects of man on streamflow are not necessarily small, but the effects are limited to those caused primarily by land-use and climate changes. Large amounts of manmade storage may exist in the basin provided the outflow is uncontrolled. These stations are useful in developing regionally transferable information about the relationship between basin characteristics and streamflow.

Nine stations in the West Virginia network are classified in the regional hydrology data-use category. Two stations are regional index stations. Their records are used to indicate current hydrologic conditions in the State. The locations of gaging stations that provide regional hydrologic information are given in figure 3.

Hydrologic Systems

Stations that can be used for accounting, that is, to define current hydrologic conditions and the sources, sinks, and fluxes of water through hydrologic systems, including regulated systems, are designated as hydrologic system stations. They include diversions and return flow and stations that are useful for defining the interaction of water systems.

Fifteen stations are classified in the hydrologic-systems category. The two index stations are included in this category because they account for current and long-term conditions of the hydrologic systems they gage. Four stations are operated at hydroelectric-generating stations by power companies to fulfill licensing requirements of the Federal Energy Regulatory Commission. The data from these stations are used to determine if the power companies are maintaining required minimum flows downstream of their plants as required by the Federal Energy Regulatory Commission.

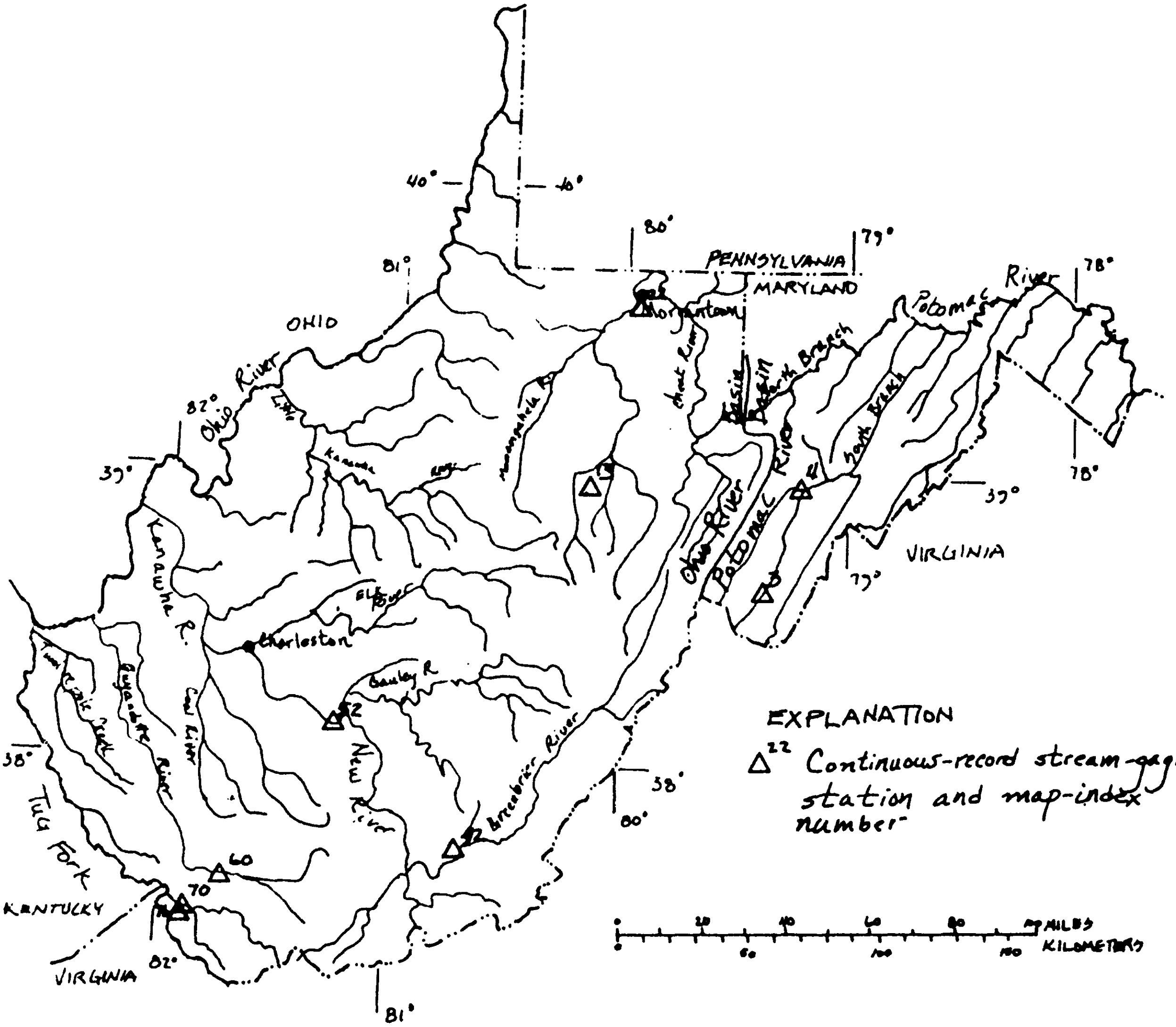

Figure 3.--Location of stream-gaging stations that provide regional hydrological information.

Legal Obligations

Some stations provide records of flows for the verification or enforcement of existing treaties, compacts, and decrees. The legal obligation category contains only those stations that the Geological Survey is required to operate to satisfy a legal responsibility. There are no stations in the West Virginia program that exist to fulfill a legal responsibility of the Geological Survey.

Planning and Design

Gaging stations in this category of data use are used for the planning and design of a specific project (for example, a dam, levee, floodwall, navigation system, water-supply diversion, hydropower plant, or waste-treatment facility) or group of structures. The planning and design category is limited to those stations that were instituted for such purposes and where this purpose is still valid. Currently, six stations in the West Virginia program are being operated for planning or design purposes.

Project Operation

Gaging stations in this category are used, on an ongoing basis, to assist water managers in making operational decisions such as reservoir releases, hydropower operations, or diversions. The project operation use generally implies that the data are routinely available to the operators on a rapid-reporting basis. For projects on large streams, data may only be needed every few days. There are 37 stations in the West Virginia program that are used for project operation.

Hydrologic Forecasts

Gaging stations in this category are regularly used to provide information for hydrologic forecasting. This information might be flood forecasts for a specific river reach, or periodic (daily, weekly, monthly, or seasonal) flow-volume forecasts at a specific site or region. The hydrologic forecast use generally implies that the data are routinely available to the forecasters on a rapid-reporting basis. On large streams, data may only be needed every few days.

Twenty stations in the West Virginia program are included in the hydrologic forecast category. Data from eighteen stations are used by the National Weather Service for flood forecasting, and data from two stations are used by the Corps of Engineers to determine the operation of locks and dams on the Ohio River.

Water-Quality Monitoring

Gaging stations where regular water-quality or sediment-transport monitoring is conducted and where the availability of streamflow data contributes to the utility, or is essential to the interpretation, of water-quality or sediment data, are designated as water-quality-monitoring sites. Forty-two stations are included in this category. The data from 39 stations are used by the West Virginia Department of Natural Resources for statewide water-quality monitoring. Three stations are part of the National Stream Quality Accounting Network (NASQAN). NASQAN is a nationwide network designed to assess water-quality trends of significant streams.

Research

Gaging stations in this category are operated for a particular research or water-investigations study. Typically, these are only operated for a few years. There are no stations in West Virginia that are operated for research purposes.

Other

In addition to the eight data-use classes described above, one station is used to provide streamflow information for recreational planning, primarily for canoeists, rafters, and fishermen. All stations are used in the statewide water quality-assessment program.

Funding

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

1. Federal program.--Funds that have been directly allocated to the Geological Survey.

2. Other Federal Agency (OFA) program.--Funds that have been transferred to the Geological Survey by OFA's.

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

4. Other non-Federal.--Funds that are provided entirely by a non-Federal agency or a private concern under the auspices of a Federal agency. In this study, funding from private concerns was limited to licensing and permitting requirements for hydropower development by the Federal Energy Regulatory Commission. Funds in this category are not matched by Geological 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 or sediment samples, that might be carried out at the site may not necessarily be the same as those identified in table 3. There are nine funding sources for the current West Virginia streamflow gaging program: Federal agencies include the U.S. Geological Survey, U.S. Soil Conservation Service, U.S. Army Corps of Engineers, and National Park Service; participants in the cooperative funding program are the West Virginia Department of Natural Resources, Water Resources Division; the Morgantown Water Commission, and three electric power companies: the Kanawha Valley Power Company, the Virginia Electric Power Company, and the Allegheny Power Service Corporation.

Frequency of Data Availability

Frequency of data availability refers to the periodicity and manner in which streamflow data are furnished to users. Four frequency categories are used. Data can be furnished by direct-access telemetry equipment for immediate use, by periodic release of provisional data, by publication in the annual data reports published by the U.S. Geological Survey for West Virginia (U.S. Geological Survey, 1983) and by request only. These four categories are designated T, P, A, and R, respectively, in table 3. In the current West Virginia program, data for most stations will be made available through the annual water-data report.

Data-Use Presentation

Data-use, funding-type, and data-availability information are presented for each continuous gaging station in table 3.

Table 3.--Data use, funding, and data availability

Map index number	Station number	Uses: Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Funding: Federal program	OFA program	Coop. program	Other program	Data availability
1	01595200					3		2				1	2		A
2	01604500				4		5					4			A
3	01605500	28									29				A
4	01606500	28					5				29				A
5	01607500				4							4			A
6	01608000				4			4				4			A
7	01608500						6					1			A
8	01611500							2					2		A
9	01616500							2					2		A
10	01636500			7		9	5,6	8			29	1	2	7	A,T
11	03050500		*				5	2				1	2		A,T
12	03051000		*				5	2				1	2		A
13	03052500	28									29				A
14	03053500							2					2		A
15	03054500					10		2				1	2		A
16	03057000					10		2				1	2		A
17	03057500				11							1			A
18	03058000				11			2				1			A
19	03058500				11			2				1			A
20	03061000				11			2				1	2		A
21	03061500							2				1	2		A
22	03062400	28						2				1	2,12		A
23	03065000							2					2		A
24	03066000							2					2		A
25	03069000		*					2				1	2		A
26	03069500		*					2			29	1	2		A
27	03070000		*				5	2				1	2		A
28	03070500		*				5	2				1	2		A
29	03112000		*					2				1	2		A
30	03114500		*					2				1	2		A

Table 3.--Data use, funding, and data availability--Continued

Map index number	Station number	Uses: Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Funding: Federal program	OFA program	Coop. program	Other program	Data availability
31	03151400					14						1			26,T
32	03151520					14						1			26,T
33	03151600					14						1			26,T
34	03152000					14	5	2				1	2		A,T
35	03153500					14		2				1	2		26,T
36	03154000					14						1			26,T
37	03155000					15		2,5,8			29	1	2		A,T
38	03155500							2					2		A,T
39	03179000					16		2			29	1			A,T
40	03180500							2					2		A
41	03182500						5	2				1	2		A,T
42	03183500	28	17				5	2				1	2		A,T
43	03184000					16	5				29				A,T
44	03184500					16		2				1	2		A,T
45	03185400		*							19		18			A,T
46	03186500							2		13	*		2		A
47	03187000					20				13		1			26,T
48	03189100					20				13		1			26,T
49	03189600					20				13,19		1			26,T
50	03190400					20				13		1			26,T
51	03192000					20	5	2		13		1	2		A,T
52	03193000	28	17			16,20				13,17		1		21	A,T
53	03194700					22				13		1			26,T
54	03195500					22		2		13		1	2		A,T
55	03196600					22				13		1			26,T
56	03196800					22				13		1			26,T
57	03197000					22		2		13		1	2		A,T
58	03198500		*					2		13		1	2		A
59	03200500					15		2		13		1	2		A,T
60	03202400	28				23				13	*				A,T

Table 3.--Data use, funding, and data availability--Continued

Map index number	Station number	Uses: Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Funding: Federal program	OFA program	Coop. program	Other program	Data availability
61	03202750					23						1			A
62	03202915					23						1			26,T
63	03203000					23						1			26,T
64	03203600					23	5					1			A,T
65	03204000					23	5	8			29	1			A,T
66	03206600					24						1			A
67	03206790					24						1			26,T
68	03207020					24	15					1			26,T
69	03207057					25						1			26,T
70	03213000	28	*				5	2			29	1	2		A
71	03213500	28						2			29		2		A
72	03213700		*				5					1			A,T
73	03214000		*				5,15	2				1	2		A,T
74	03214900						15					1			26,T

1) Station funded by the U.S. Corps of Engineers
2) Station funded by the West Virginia Department of Natural Resources - Division of Water Resources
3) Data used by the Virginia Electric Power Company
4) Station funded by the U.S. Soil Conservation Service
5) Data used by the National Weather service to forecast floods
6) Data used by the National Weather Service to forecast flooding in the Potomac River Basin
7) Station funded by the Allegheny Power Service Corporation
8) Station is part of the National Stream Quality Accounting Network (NASQAN)
9) Data is used for regulation of Bloomington Lake
10) Data is used for regulation of Tygart Lake
11) Data is used for planning the Stonewall Jackson Dam
12) Station is funded by the Morgantown Water Commission
13) Data is used for determining water-quality and low-flow parameters and used in water-use studies
14) Data is used for regulation of Burnsville Lake
15) Data is used to determine the operation of Ohio River locks and dams
16) Data is used for regulating Bluestone Lake
17) Index station of current hydrologic conditions
18) Station is funded by the National Park Service
19) Data is used for recreational planning
20) Data is used for regulating Summersville Lake
21) Station is funded by the Kanawha Valley Power Company
22) Data is used for regulating Sutton Lake
23) Data is used for regulating R. D. Bailey Lake
24) Data is used for regulating East Lynn Lake
25) Data is used for regulating Beech Fork
26) The station was changed to a continuous-record, stage-only.
27) Station operated to comply with a Federal Energy Regulatory Commission (FERC) hydroelectric power plant licensing requirement
28) Station operated primarily to provide information on regional hydrology
29) Station funded by the U.S. Geological Survey

A - Streamflow data published on an annual basis
P - Provisional data provided at specified intervals
T - Data transmitted by telemetry--radio, phone line, or data platform
* - Regional hydrology - Federal funds only.

Conclusions Pertaining to Data Uses

As shown in table 3, most stations have at least two agencies interested in the data and many have three or more. However, not all data users contribute funds to each station where they use the information. No stations were found to be producing data in excess of data-user needs. Long-term index stations in some areas of the State were found to be insufficient to provide valid estimates of streamflow characteristics or to define current hydrologic conditions.

As funds become available, stations should be established on unregulated streams in West Virginia along the Ohio River and the lower Kanawha River. The surface-water gaging stations that were reduced to collection of stage data only or that are operated only from December through May beginning in 1983 FY should be restored to continuous-record station status. Most of these stations are located on unregulated streams and the data are needed for estimating streamflow characteristics on ungaged streams.

New stations established for hydrologic-data or hydrologic surveillance purposes should, if possible, be located on unregulated streams with a drainage area less than 100 mi^2. Hydrologic information of this type would serve to fill data gaps in the West Virginia hydrologic-data base and would be valuable for future studies of flood frequency, low-flow characteristics, regional hydrology, and studies of water as a renewable resource in West Virginia.

ALTERNATIVE METHODS OF DEVELOPING STREAMFLOW INFORMATION

The second step of this study is to investigate alternative methods of providing daily streamflow information in lieu of operating continuous-record streamflow-gaging stations. The objective of the analysis is to identify gaging stations where alternative technology, such as flow-routing or statistical methods, will provide information about daily mean streamflow in a more cost-effective manner than operating a continuous stream gage. No guidelines exist concerning suitable accuracies for particular uses of the data; therefore, judgment is required in deciding whether the accuracy of the estimated daily flows is suitable for the intended purpose. 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 might be a legal obligation to operate an actual gaging station that would preclude utilizing alternative methods. The primary candidates for alternative methods are stations that are operated upstream or downstream of 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 between sites. Similar watersheds, located in the same physiographic and climatic area, also may have potential for alternative methods.

Stations in the West Virginia streamflow-gaging program were categorized as to their potential utilization of alternative methods. Selected alternative methods (regression and flow routing) were applied at 16 stations. The categorization of gaging stations and the application of the specific methods are described in subsequent sections of this report. This section briefly describes the two alternative methods that were used in the West Virginia analysis and documents why these specific methods were chosen.

Desirable attributes of a proposed alternative method are (1) the proposed method should be computer oriented and easy to apply, (2) the proposed method should have an available interface with the Geological Survey WATSTORE Daily Values File (Hutchinson, 1975), (3) the proposed method should be technically sound and generally acceptable to the hydrologic community, and (4) the proposed method should permit easy evaluation of the accuracy of the simulated streamflow records. The desirability of the first attribute above is obvious. Second, the interface with the WATSTORE Daily Values File is needed to easily calibrate the proposed alternative method. Third, the alternative method selected for analysis must be technically sound or it will not be able to provide data of suitable accuracy. Fourth, the alternative method should provide an estimate of the accuracy of the streamflow to judge the adequacy of the simulated data. Because of the short timeframe of this analysis, only two methods were considered--a flow-routing model and multiple-regression analysis.

Description of Flow-Routing Model

Hydrologic flow-routing models use the law of conservation of mass, the law of conservation of momentum, and the relationship between the storage in a reach and the outflow from the reach. The hydraulics of the system are not considered. The method usually requires only the determination of the values of a few parameters and treats the reach in a lumped sense without subdivision. The input to the model is usually a discharge hydrograph at the upstream end of the reach and the output from the model of a discharge hydrograph at the downstream end. Several models use only the law of conservation of mass and the storage-outflow relationship. They include the Muskingum, modified Puls (Lawler, 1964), and storage-continuity method (Doyle and others, 1983). Other models use the laws of conservation of mass and momentum and the storage-outflow relationship. They include the kinematic wave and the diffusion wave methods (Doyle and others, 1983). The unit-response convolution flow-routing method (CONROUT) (Doyle and others, 1983) was the model selected for this analysis. This model uses two methods--storage continuity (Sauer, 1973) or diffusion analogy (Keefer and McQuivey, 1974).

The CONROUT model was selected because it fulfilled the criteria noted above. The CONROUT model can be used to route streamflow from one or more upstream locations to a downstream location. Downstream hydrographs are produced by the convolution of upstream hydrographs with their appropriate unit-response functions. This model can only be applied at a downstream station where an upstream station exists on the same stream. An advantage of this model is that it can be used for regulated stream systems. Reservoir routing techniques are included in the model so flows can be routed through reservoirs if the operating rules are known. Calibration and verification of the flow-routing model are achieved using observed upstream and downstream hydrographs and estimates of tributary inflows.

The CONROUT model treats a stream reach as a linear one-dimensional system in which the system output (downstream hydrograph) is computed by multiplying (convoluting) the ordinates of the upstream hydrograph by the unit-response function and lagging them appropriately. 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 location. Routing can be accomplished using hourly data, but only daily data are used in this analysis.

Three options are available for determining the unit (system) response function: The storage-continuity method, the diffusion-analogy method with single linearization, and the diffusion-analogy method with multiple linearization. In the storage-continuity method (Sauer, 1973), the response function is derived by modifying a translation hydrograph technique developed by Mitchell (1962). A triangular pulse (Keefer and McQuivey, 1974) 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 parameters determine the shape of the resulting response function.

In the diffusion-analogy method, 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 and is analogous to K_s in the storage-continuity method. C_o controls the traveltime and is analogous to W_s in the storage-continuity method if the traveltime is held constant in that method. In the single linearization method, only one value of K_o and C_o is used. In the multiple linearization method, C_o and K_o are varied with discharge.

Selection of the appropriate option for the diffusion-analogy method depends primarily upon the variability of wave celerity and dispersion throughout the range of discharges to be routed. Adequate routing of daily flows can usually be accomplished using a single unit-response function (linearization about a single discharge) to represent the system response. However, if the routing coefficients vary drastically with discharge, linearization about a low-range discharge results in overestimated high flows that arrive late at the downstream site; whereas, linearization about a high-range discharge results in low flows that are underestimated and arrive too soon. A single unit-response function may not provide acceptable results in such cases. 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 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. Determination of the system's response to the input at the upstream end of the reach is not the total solution for most flow-routing problems. The convolution process makes no accounting of flow from the intervening area between upstream and downstream locations. Such flows may be unknown or estimated by some combination of gaged and ungaged flows. An estimating technique that should prove satisfactory in many instances is the multiplication of known flows at an index gaging station by a factor (for example, a drainage-area ratio). Flow-routing techniques were developed for four streams.

Description of Regression Analysis

Simple- and multiple-regression techniques can also be used to estimate daily-flow records. Regression equations can be computed that relate daily flows (or their logarithms) at a single station to daily flows at a combination of upstream, downstream, and (or) tributary stations. This statistical method is not limited, like the flow-routing method, to stations where an upstream station exists on the same stream. The explanatory variables in the regression analysis can be stations from different watersheds, or downstream and tributary 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 several textbooks such as Draper and Smith (1966) and Kleinbaum and Kupper (1978). The application of regression analysis to hydrologic problems is described and illustrated by Riggs (1973) and Thomas and Benson (1970). Only a brief description of regression analysis is provided in this report.

A linear regression model of the following form was used for estimating ing daily mean discharges in West Virginia:

$$y = B_o + \sum_{j=1}^{p} B_j x_j + e_i$$

where

y_i = daily mean discharge at station i (dependent variable),

x_j = daily mean discharges at nearby stations (explanatory) variables),

B_o and B_j = regression constant and coefficients, and

e_i = the random error term.

p = the number of nearby stations

The above equation 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 may be for previous or future days, depending on whether station j is upstream or downstream of station i. Once the equation is calibrated and verified, future values of y_i are estimated using observed values of x_j. The regression constant and coefficients (B_o and B_j) are tested to determine if they are significantly different from zero. A given station j should only be retained in the regression equation if its regression coefficient (B_j) is significantly different from zero. The regression equation should be calibrated using one period of time and then verified or tested on a different period of time 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 j. The equation should be verified by plotting the residuals e_i (difference between simulated and observed discharges) against the dependent and all explanatory variables in the equation, and by plotting the simulated and observed discharges versus time. These tests are intended to determine if the linear model is appropriate or whether some transformation of the variables is needed, and whether 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. In this report those tests indicated that linear model with Yy_i and x_i, in cubic feet per second, was appropriate. The application of linear-regression techniques to selected watersheds in West Virginia 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

An analysis of the data uses presented in table 2 identified 9 stations, listed in table 4, at which alternative methods for providing the needed streamflow information could be applied. Based on the capabilities and limitations of the methods and data availability, flow-routing techniques were developed for 4 stations (see table 4).

Two stations that do not currently provide mean-daily discharge data were included in the analysis. The stream-gaging station on the New River at Bluestone Dam (03180000) was discontinued in 1984 because of budget constraints. The station on the Tug Fork at Glenhayes was converted to a stage-only partial-record station in October 1982. These stations were included in this analysis to determine if the record that had been supplied by these stations could be supplied by an alternative method or if the stations should be reactivated.

Table 4.--Stream-gaging stations selected for alternative methods analysis

Station number	Station name	Model used: CONROUT	Model used: Regression
03180000	New River at Bluestone Dam, W. Va.	x	x
03184000	Greenbrier River at Hilldale, W. Va.		x
03184500	New River at Hinton, W. Va.		x
03185400	New River at Thurmond, W. Va.	x	x
03213000	Tug Fork at Litwar, W. Va.		x
03213500	Panther Creek near Panther, W. Va.		x
03213700	Tug Fork at Williamson, W. Va.	x	x
03214000	Tug Fork near Kermit, W. Va.	x	x
03214900	Tug Fork at Glenhayes, W. Va.	x	

Results of Flow-Routing Analysis

Unit-response, convolution, flow-routing models (CONROUT, Doyle and others, 1983) were developed to route measured daily flows from an upstream station to stations downstream on the New River and the Tug Fork. The diffusion analogy method with single linearization was selected as the most appropriate of the three methods available.

Model parameters C_o, floodwave celerity, and K_o, wave dispersion coefficient, were initially computed from the following equations:

$$C_o = \frac{1}{W_o} \frac{dQ_o}{dY_o} \quad (1)$$

$$K_o = \frac{Q_o}{2 S_o W_o} \quad (2)$$

Where:

W_o = channel width, in feet

S_o = channel slope, in feet per foot (ft/ft),

dQ_o = slope of the stage-discharge relation, in square feet per second,

dY_o = (ft^2/s), and

Q_o = the discharge in cubic feet per second (ft^3/s) for the reach being modeled.

Average values for the model parameters C_o and K_o were used in the first routing trials. The discharge, Q_o, for which the initial values of C_o and K_o were linearized, was the average discharge for the period of record for each station as shown in tables 5 and 8. The channel width, W_o, was calculated as the average for the reach between the streamflow-gaging stations as measured from topographic maps. Channel slope, S_o, was determined by converting the corresponding gage heights of the initial discharge, Q_o, taken from the stage-discharge relationships at each station to a common datum. The difference between these values was then divided by channel length, measured from topographic maps, to obtain a slope, The slope of the stage-discharge discharge relations, dQ_o/dY_o, was determined from the stage-discharge rating curve at each station by using a 1-foot increment that bracketed the annual mean discharge, Q_o. The difference in the discharge through the 1-foot increment, therefore, represents the slope of the function at that point.

Tug Fork

Simulation of daily flows at the station on the Tug Fork at Williamson (03213700) is based on flows routed from the upstream station at Litwar (03213000) and on adjusted flows from the station on Panther Creek near Panther (03213500). Station locations and streamflow data for the stations are given in figures 4 and in table 5, respectively.

The mean daily discharge at Litwar was routed to Williamson using the diffusion analogy method with single linearization. The intervening drainage area between Litwar and Williamson, 432 mi², is 46 percent of the total drainage area above the station at Litwar. To account for the increased discharge from this portion of the drainage basin, the discharge from the Panther Creek station was multiplied by the ratio of drainage areas (432/31 = 13.9) and added to the routed discharge from Litwar. Data for water years 1981 through 1983 were used to calibrate this model. The model parameters determined for this model are given in table 6.

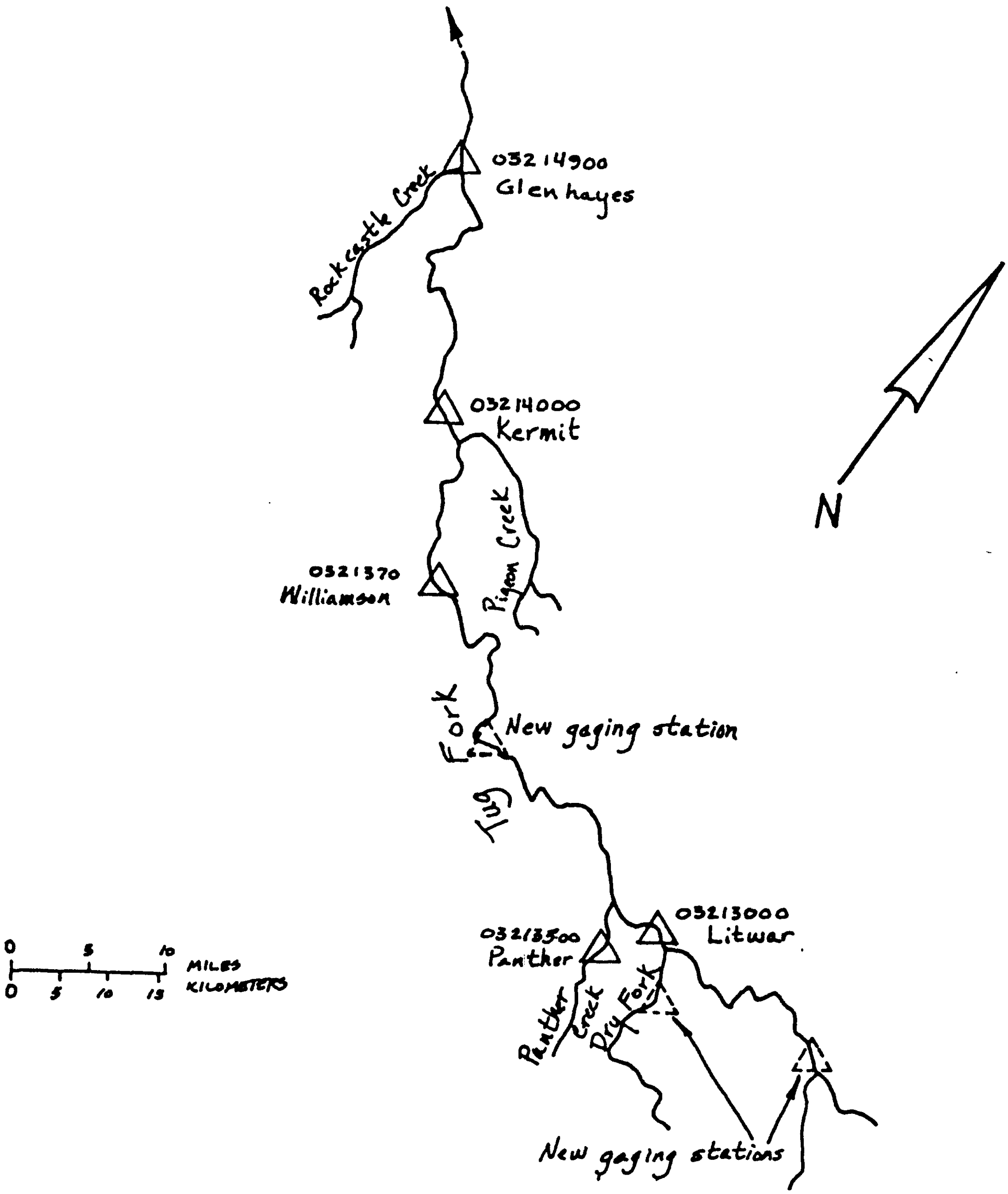

Figure 4.--The Tug Fork study area.

Table 5.--Stream-gaging stations used in the Tug Fork flow-routing study

Station number	Station name	Drainage area (mi^2)	Period of record	Average discharge for period of record through 1983 (ft^3/s)
03213000	Tug Fork at Litwar	504	May 1930-	555
03213500	Panther Creek near Panther	31.0	July 1946-	35.8
03213700	Tug Fork at Williamson	936	October 1967-	1,173
03214000	Tug Fork at Kermit	1,188	July 1934-	1,414
03214900	Tug Fork at Glenhayes	1,507	March 1976-September 1982, 1/October 1982-	1,967

1/ Station converted from a continuous-discharge station to continuous-stage station; the stage-discharge rating is maintained but mean-daily discharges are not available.

Table 6.--Selected reach characteristics used in the Tug Fork flow-routing analysis

Station	Qo (ft^3/s)	Wo (ft)	So (ft/ft)	$\frac{dQo}{dYo}$ (ft^2/s)	Co (ft/s)	Ko_2 (ft^2/s)
Litwar 03213000	555	250	1.2 x 10-3	750	3.00	928
Panther Creek 03213500	35.8	25	5.7 x 10-3	87.5	3.50	128
Williamson 03213700	1,173	200	3.9 x 10-4	415	2.08	7,788
Kermit 03214000	1,414	180	3.0 x 10-4	464	2.58	13,185
Glenhayes 03214900	1,967	250	2.5 x 10-4	530	2.12	15,760

The mean daily discharges at Kermit (03214000) and at Glenhayes (03214900) were simulated by routing the flows for Williamson downstream to Kermit and from Williamson downstream to Glenhayes. Station locations and streamflow data for the stations are given in figure 4 and in table 5, respectively. No adjustments were made for the additional ungaged flow from the drainage area between Kermit and Williamson (252 mi^2, 21 percent of the drainage area above the station at Kermit) and between Glenhayes and Williamson (571 mi^2, 37 percent of the drainage area above the station at Glenhayes). Data from the stations for water years 1981 and 1982 were used to calibrate the models. The model parameters for the models are given in table 6.

Daily hydrographs of simulated and measured mean-daily discharges at Williamson and at Glenhayes are plotted in figures 5 and 6 for a 2-month period. The figures show the best results of the simulations. Summaries of the simulation of mean daily discharges at Williamson, Kermit, and Glenhayes are shown in table 7. A large percentage of the mean daily discharges simulated for Kermit (66 percent) and for Glenhayes (94 percent) were underestimated. All attempts to refine the model fits failed to reduce the errors significantly at the modeled gaging stations.

New River

The streamflow-gaging station on the New River at Bluestone Dam (03180000) was discontinued because of budget constraints in 1984. A flow-routing model was constructed using data from the station on the New River at Hinton (03184500) and the station on the Greenbrier River at Hilldale (03184000) to see if the streamflow-gaging record that was supplied by the station at Bluestone Dam could be replaced without reactivating the station. The location of the stations and streamflow data for the stations are given in figure 7 and table 8, respectively.

The station on the Greenbrier River at Hilldale is located 5.5 miles upstream from its confluence with the New River. The reach is not subject to regulation, and the drainage area between the station at Hilldale and the mouth is 35 mi^2, 7 percent of the drainage area above the mouth. As a result no drainage-area adjustment was applied to the routed Greenbrier River discharges. The mean daily discharge from Hilldale was routed to Hinton and subtracted from the measured mean daily discharge to obtain the simulated discharge at Bluestone Dam. Data from water years 1981 through 1983 were used to calibrate this model. The routing parameters for this model are shown in table 9 and hydrographs of simulated and observed daily flows at Bluestone Dam are shown in figure 8 for April and May 1983. The hydrographs show the best results of the model.

The mean daily discharge at the stream-gaging station on the New River at Thurmond (03185400) was simulated by routing discharges from Hinton. Because the drainage area between Hinton and Thurmond is only 431 mi^2, 6 percent of the drainage area above the station at Thurmond, no drainage area adjustment was made to the routed discharges. Data from water year 1983 was used to calibrate this model. The routing parameters for this model are shown in table 9.

Summary of the simulation of mean daily discharge at Thurmond is shown in table 10.

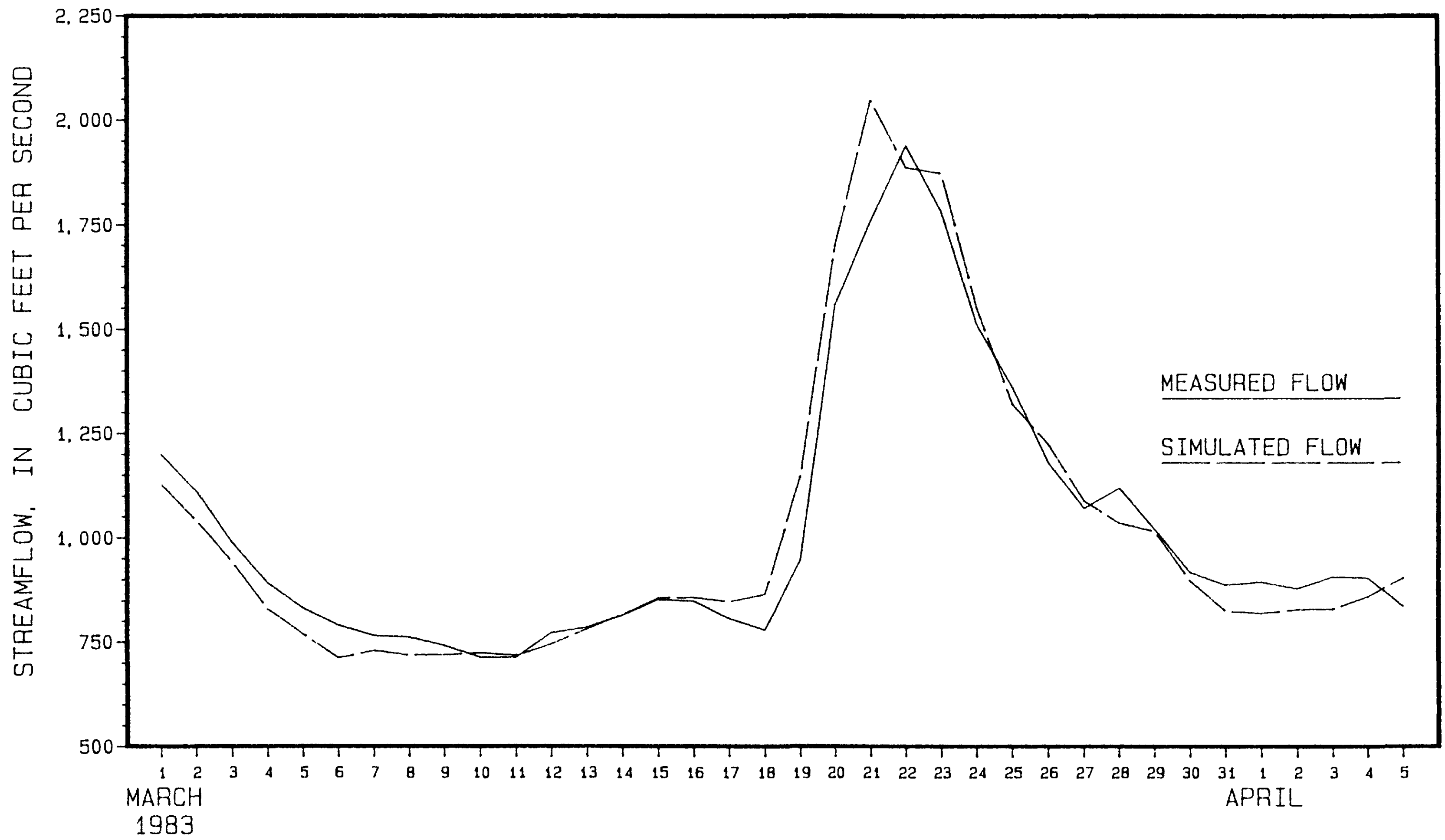

Figure 5.--Measured and simulated daily streamflow at Williamson for March and April 1983.

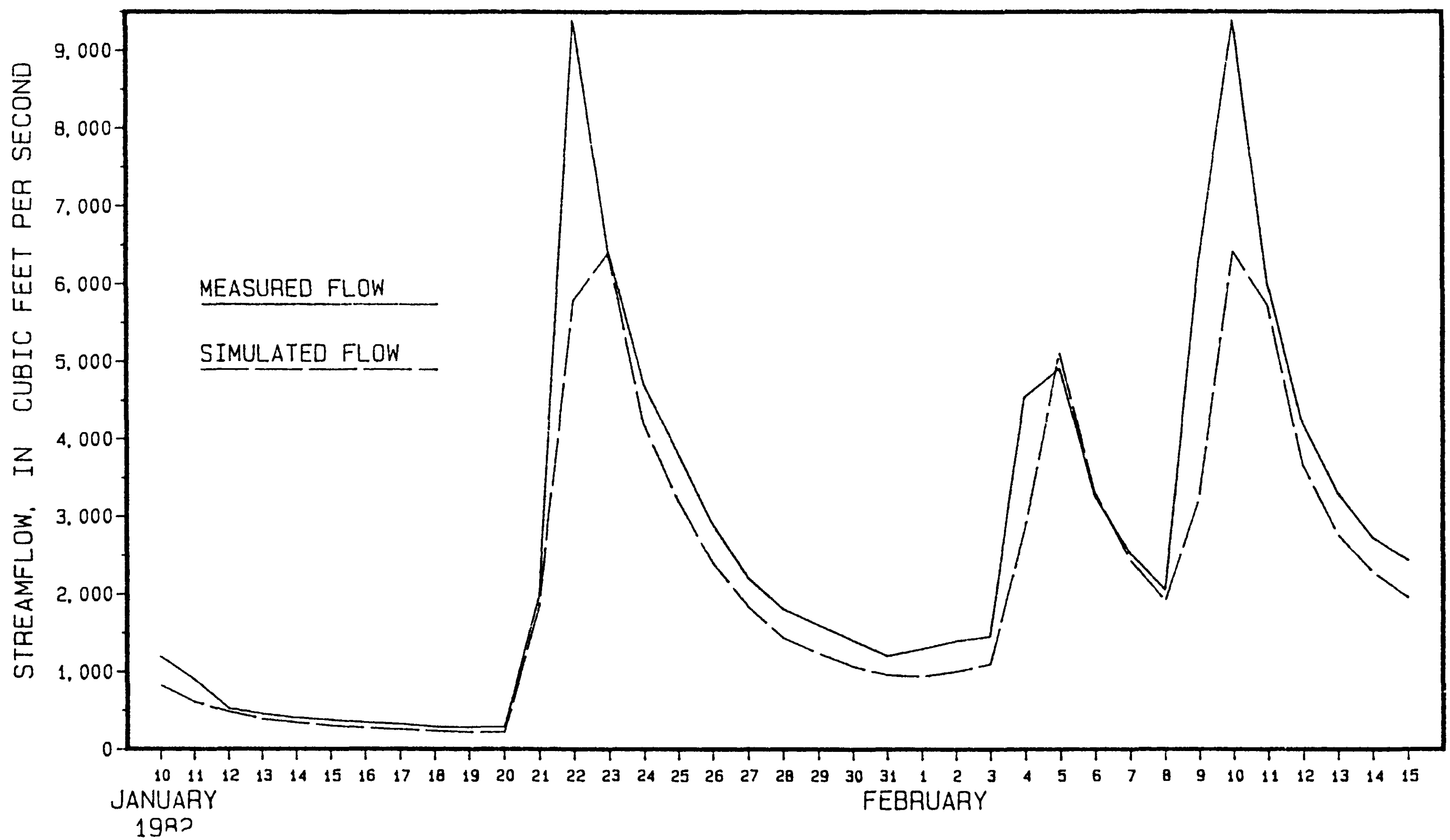

Figure 6.--Measured and simulated daily streamflow for Glenhayes for January and February 1982.

Table 7.--Results of flow-routing models for the Tug Fork

Williamson gaging station (03213700), October 1, 1980 to September 30, 1983

Mean absolute error for 1,095 days	=	13.59 percent
Mean negative error (500 days)	=	-12.83 percent
Mean positive error (595 days)	=	23.54 percent
Total volume error	=	8.28 percent

21 percent of the total observations had errors < 5 percent
42 percent of the total observations had errors < 10 percent
59 percent of the total observations had errors < 15 percent
73 percent of the total observations had errors < 20 percent
79 percent of the total observations had errors < 25 percent
21 percent of the total observations had errors > 25 percent

Kermit gaging station (03214000), October 1, 1980 to September 30, 1982

Mean absolute error for 730 days	=	13.99 percent
Mean negative error (484 days)	=	-12.86 percent
Mean positive error (246 days)	=	16.20 percent
Total volume error	=	-20.73 percent

25 percent of the total observations had errors < 5 percent
50 percent of the total observations had errors < 10 percent
70 percent of the total observations had errors < 15 percent
81 percent of the total observations had errors < 20 percent
88 percent of the total observations had errors < 25 percent
12 percent of the total observations had errors > 25 percent

Glenhayes gaging station (03214900), October 1, 1980 to September 30, 1982

Mean absolute error for 730 days	=	17.92 percent
Mean negative error (684 days)	=	-18.77 percent
Mean positive error (46 days)	=	5.33 percent
Total volume error	=	-19.43 percent

12 percent of the total observations had errors < 5 percent
26 percent of the total observations had errors < 10 percent
44 percent of the total observations had errors < 15 percent
62 percent of the total observations had errors < 20 percent
77 percent of the total observations had errors < 25 percent
23 percent of the total observations had errors > 25 percent

Table 8.--Stream-gaging stations used in the New River flow-routing study

Station number	Station name	Drainage area (mi^2)	Period of record	Average discharge for period of record through 1983 (ft^3/s)
03180000	New River at Bluestone Dam	4,602	October 1923 - September 1969 October 1975 - September 1983 1/	5,602
03184000	Greenbrier River at Hilldale	1,619	June 1936-	2,339
03184500	New River at Hinton	6,256	June 1936-	7,940
03185400	New River at Thurmond	6,687	February 1981-	8,390

1/ Discontinued 1983.

Table 9.--Selected reach characteristics used in the New River flow-routing analysis

Station number	Q_o (ft^3/s)	W_o (ft)	S_o (ft/ft)	$\frac{dQ_o}{dY_o}$ (ft^2/s)	C_o (ft/s)	K_o (ft^2/s)
03183500[1/]	1,994	250	17.4 x 10-4	1,560	6.24	2,292
03184000	2,339	250	95.0 x 10-5	1,360	5.44	4,924
03180000	5,602	800	38.0 x 10-5	4,600	5.75	9,214
03184500	7,940	800	17.0 x 10-4	6,350	7.94	2,919
03185400	8,390	500	17.0 x 10-4	2,750	5.50	5,470

1/ Station Greenbrier River at Alderson used only for estimating C_o and K_o in the analysis.

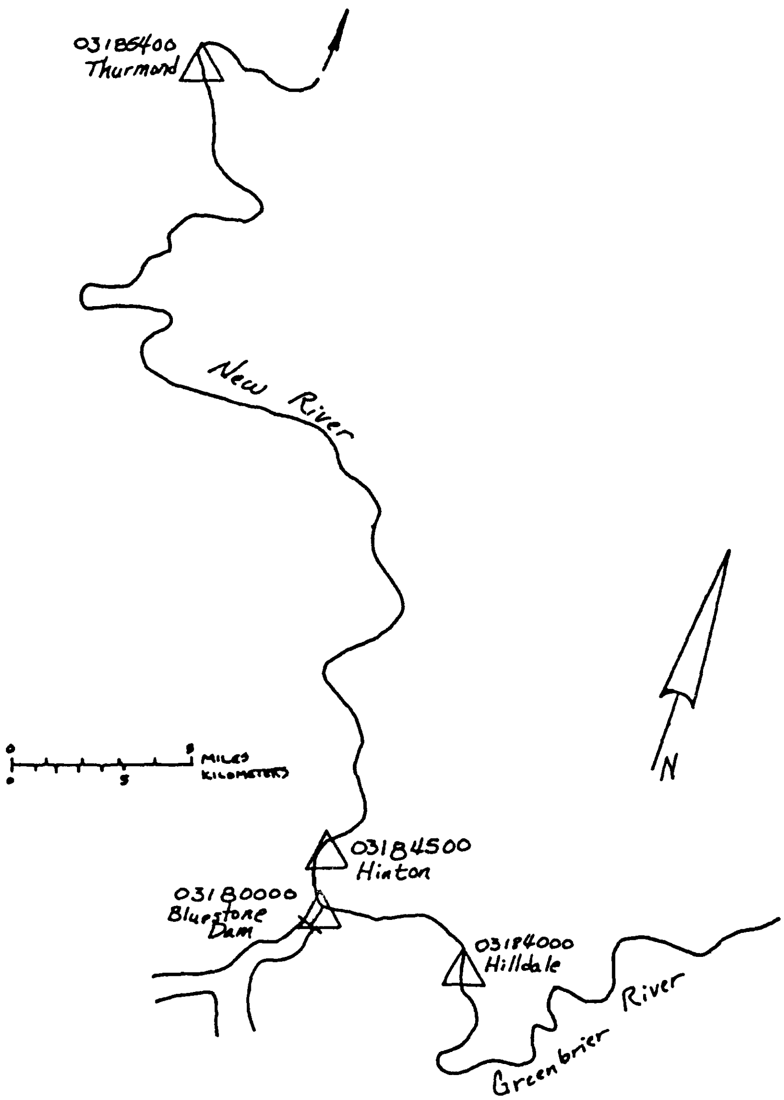

Figure 7.--The New River study area.

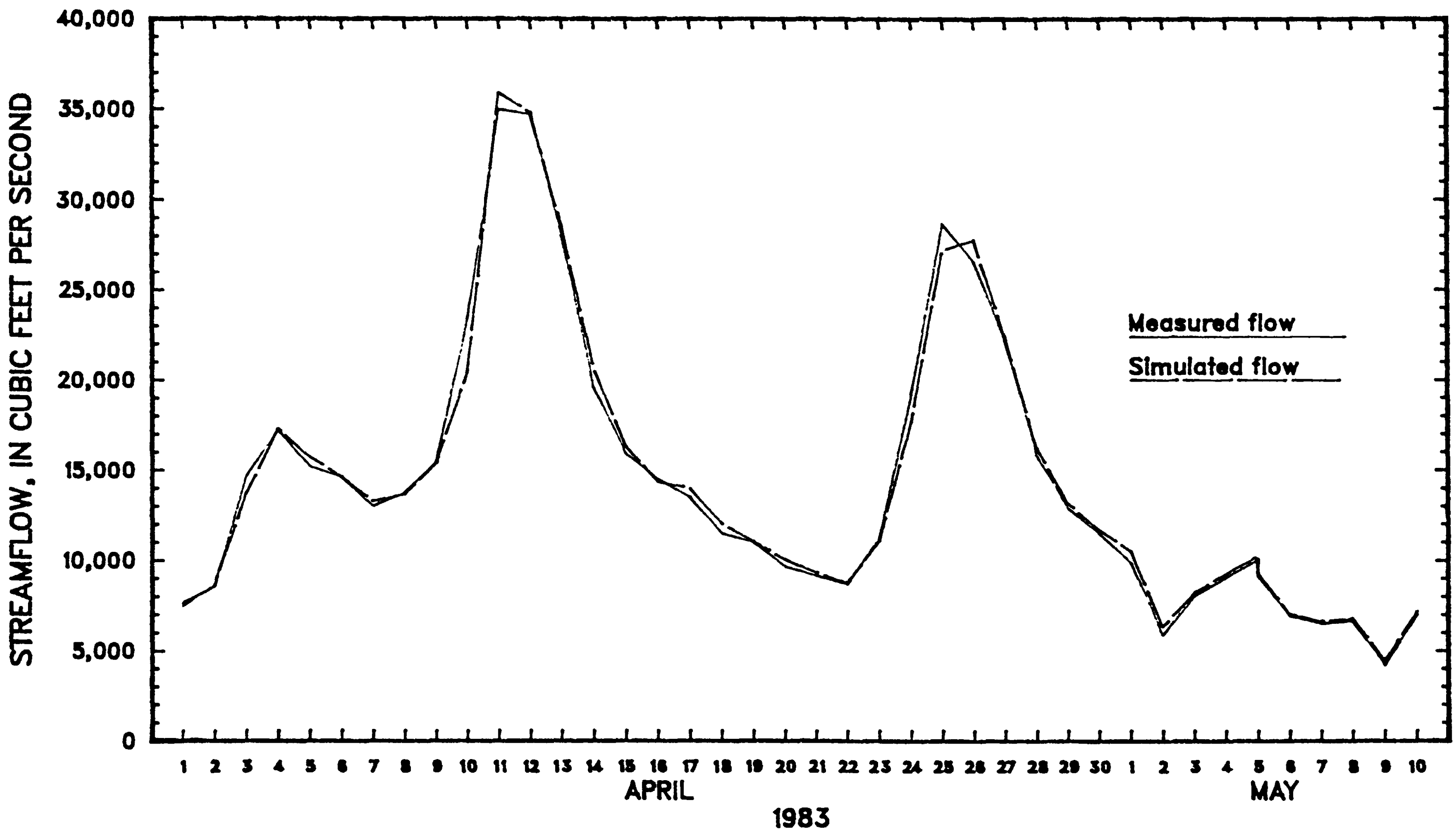

Figure 8.--Measured and simulated daily streamflow at Bluestone Dam for April and May 1983.

Table 10.--Results of flow-routing models for the New River

Thurmond gaging station 03185400, October 1, 1982 to September 30, 1983

Mean absolute error for 365 days	=	8.88 percent
Mean negative error (223 days)	=	-9.26 percent
Mean positive error (142 days)	=	8.28 percent
Total volume error	=	-7.21 percent

39 percent of the total observations had errors < 5 percent
67 percent of the total observations had errors < 10 percent
84 percent of the total observations had errors < 15 percent
90 percent of the total observations had errors < 20 percent
94 percent of the total observations had errors < 25 percent
6 percent of the total observations had errors > 25 percent

Results of Regression Analysis

Linear regression techniques were applied to 4 streamflow-gaging stations in the New River and Tug Fork watersheds. The mean daily discharges for each station, the dependent station, was regressed against the mean daily discharge of nearby stations, the explanatory stations. The dependent station and the explanatory stations selected for each of the regression models are in table 11. An explanatory station was retained in a model only if its inclusion significantly reduced the error of the model. The final regression models, the calibration period, and a summary of the regression results are listed in table 12.

Only the regression model for the station on New River at Bluestone Dam (03180000) out of the 4 regression models simulates the mean daily discharges at the dependent station with sufficient accuracy to satisfy present uses of the data. The mean daily discharges for the stations on the Greenbrier River at Hilldale and on the New River at Hinton were used as the explanatory variables. This regression model simulated the actual record at Bluestone Dam within 10 percent for 90.2 percent of the calibration period and within 5 percent for 67.4 percent of the period (table 12).

Table 11.--Dependent and explanatory stream-gaging stations used in multiple linear-regression models

Dependent stations	Explanatory stations
03180000 (Bluestone Dam)	03184500 (Hinton), 03184000 (Hilldale)
03185400 (Thurmond)	03184500 (Hinton)
03213700 (Williamson)	03213000 (Litwar), 03213500 (Panther Creek)
03214000 (Kermit)	03213700 (Williamson)

Table 12.--Summary of calibration for regression modeling of mean daily streamflow at selected stream-gaging stations in West Virginia

Station number	Model1/	Percent of simulated flow within 5 percent of actual	Percent of simulated flow within 10 percent of actual	Calibration period (water years)
03180000 Bluestone Dam	Q03180000 = 25.7 + 0.99(Q03184500 - Q03184000)	67.4	90.2	1982-83
03185400 Thurmond	Q03185400 = -365 + 1.13(Q03184500)	38.2	63.6	1981-83
03213700 Williamson	Q03213700 = -42 + 2.77(Q03213000) 12.1 (Q03213500)	9.4	20.8	1976-79
03214000 Kermit	Q03214000 = 47.5 + 1.29(Q03213700)	22.4	43.1	1981-83

1/ Discharge Q, in cubic feet per second.

Conclusions Pertaining to Alternative Methods for Data Generation

The results for both the linear-regression and flow-routing models are given in table 13 for the four gaging stations for which models were developed. Because the same period was not used to calibrate the two models for each station, comparisons cannot be made about the accuracy of each model.

The linear-regression model is sufficiently accurate to substitute for the operation of a continuous-record streamflow-gaging station on New River at Bluestone Dam. This station should remain inactive, provided that the stations on the Greenbrier River at Hilldale and on the New River at Hinton continue to remain part of the West Virginia surface-water network.

Because the flow-routing model was not not sufficiently accurate to provide the information that had been supplied by Glenhayes, it should be reactivated as a continuous-discharge gaging station.

Neither the flow-routing nor the linear-regression models are sufficiently accurate to substitute for the operation of the remaining gaging stations. They should remain part of the West Virginia streamflow gaging network and will be included in the next step of this study.

Table 13.--Comparison of the flow-routing model and linear-regression model for four gaging stations

Station	Calibration period water years		Percent of simulated flow within 5 percent of actual		Percent of simulated flow within 10 percent of actual	
	flow-routing	linear regression	flow-routing	linear regression	flow-routing	linear regression
New River at Bluestone Dam	1981-83	1982-83		67		90
New River at Thurmond	1983	1981-83	39	38	67	64
Tug Fork at Williamson	1981-83	1976-79	21	9	42	21
Tug Fork near Kermit	1981-82	1981-83	25	22	50	43

COST-EFFECTIVE RESOURCE ALLOCATION

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

In a study of the cost-effectiveness of a network of stream gages operated to determine water consumption in the Lower Colorado River Basin, a set of techniques called K-CERA was developed (Moss and Gilroy, 1980). Because that study concerned water balance, the network's effectiveness was measured on the extent to which it minimized the sum of variances of errors in estimating annual mean discharges at each site in the network. This measure of effectiveness tends to concentrate streamflow gaging resources on the larger, less stable streams where potential errors are greatest. While such a tendency is appropriate for a water-balance network, in the broader context of the multitude of uses of the streamflow data collected in the USGS's Streamflow Information Program, this tendency causes undue concentration on larger streams. Therefore, the original version of K-CERA was extended to include, as optional measures of effectiveness, the sums of the variances of errors of estimation of the following streamflow variables: annual mean discharge in cubic feet per second, annual mean discharge in percentage, average instantaneous discharge in cubic feet per second, and average instantaneous discharge in percentage. Using percentage errors does not unduly weight activities at large streams to the detriment of records on small streams. In addition, the instantaneous discharge is the basic variable from which all other streamflow data are derived. For these reasons, this study used the K-CERA techniques with the sums of variances of the percentage errors of the instantaneous discharges at all continuously gaged sites to measure the effectiveness of the data-collection activity.

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

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

Description of Mathematical Program

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 is discussed above. The set of decisions available to the manager is the frequency of use (number of times per year) of each of a number of routes that may be used to service the stream gages and to make discharge measurements. The range of options within the program is from zero usage to daily usage for each route.

A route is defined as a set of one or more stream gages and the least-cost travel that takes the hydrographer from his base of operations to each of the gages and back to base. A route will have associated with it an average cost of travel and average cost of servicing each stream gage visited along the way. The first step in this part of the analysis is to define the set of practical routes. This set of routes frequently will contain the path to an individual stream gage with that gage as the lone stop and return to the home base so that the individual needs of a stream gage can be considered in isolation from the other gages.

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

The final step is to use all of the above to determine the number of times, N_i, that the i^{th} route for i = 1, 2, ..., NR, where the NR is the number of practical routes, is used during a year such that (1) the budget for the network is not exceeded, (2) the minimum number of visits to each station is made, and (3) the total uncertainty in the network is minimized. Figure 9 represents this step in the form of a mathematical program. Figure 10 presents a tabular layout of the problem. Each of the NR routes is represented by a row of the table and each of the stations is represented by a column. The zero-one matrix, (ωij), defines the routes in terms of the stations that compose it. A value of one in row i and column j indicates that gaging station j will be visited on route i; a value of zero indicates that it will not. The unit-travel costs, βi, are the per-trip costs of the hydrographer's time and any related per diem and operation, maintenance, and rental costs of vehicles. The sum of the products of βi and N_i for i = 1, 2, ..., NR is the total travel cost associated with the set of decisions $N = (N_i, N_2, \ldots, N_{NR})$.

The unit-visit cost, αj, is composed of the average cost of making a discharge measurement. The set of minimum visit constraints is denoted by the row λj, j = 1, 2 ..., MG, where MG is the number of stream gages. The row of integers M_j, j = 1, 2, ... MG specifies the number of visits to each station. M_j is the sum of the products of ω_{ij} and N_i for all i and must equal or exceed λj for all j if N is to be a feasible solution to the problem.

The total cost expended at the stations is equal to the sum of products of α_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 network. The total cost of operating the network 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, Φj, evaluated at the value of M_j from the row above it, for j = 1, 2, ..., MG.

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

$V \equiv$ 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 9. Mathematical-programming form of the optimization of the routing of hydrographers. (From Fountaine and others, 1984)

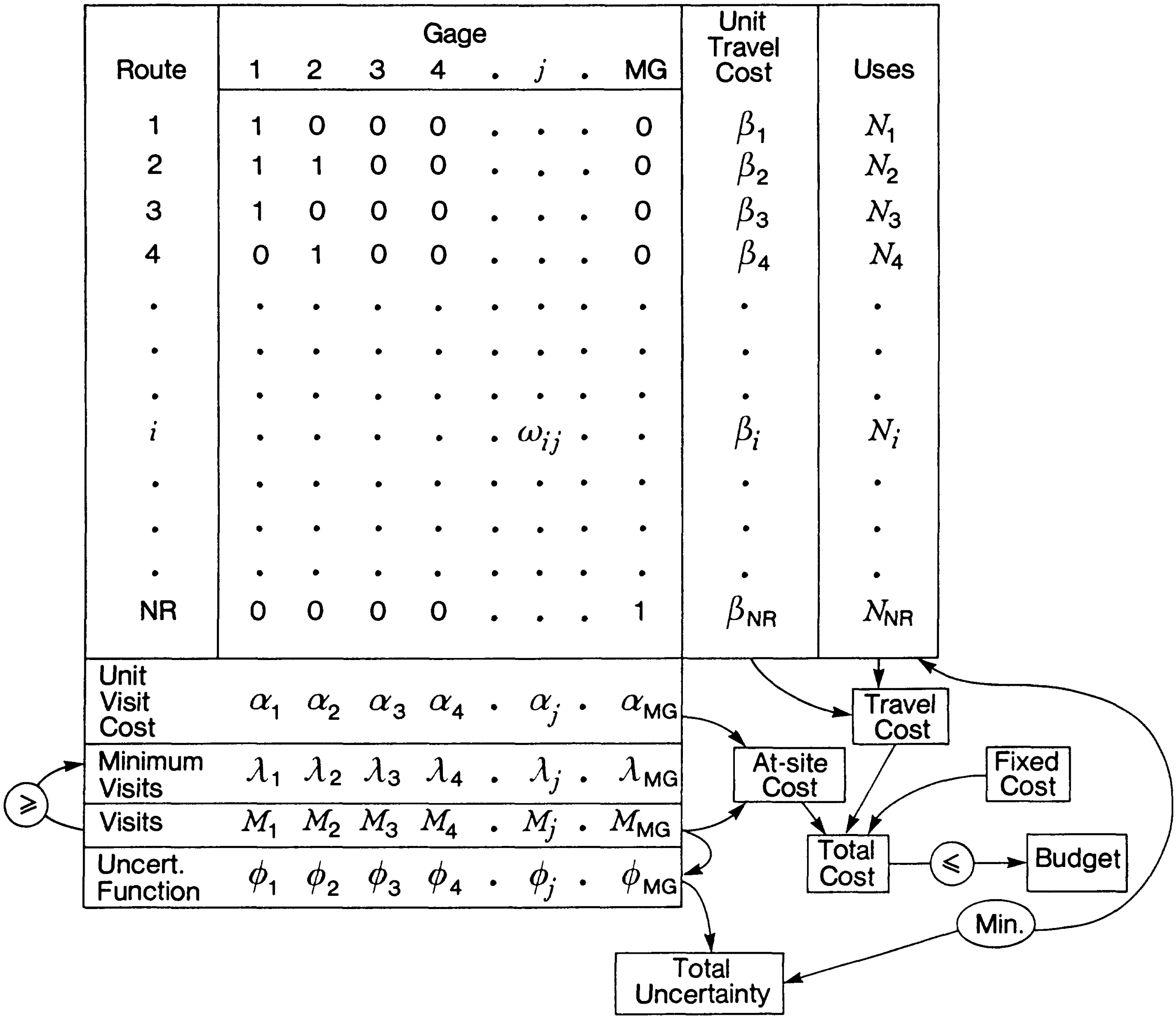

Figure 10. Tabular form of the optimization of the routing of hydrographers. (From Fountaine and others, 1984)

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 N obtained with this technique specify an efficient strategy for operating the network, which may be the true optimum strategy. The true optimum cannot be guaranteed without testing all undominated, feasible strategies.

Description of Uncertainty Functions

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

$$V_T = \epsilon_f V_f + \epsilon_r V_r + \epsilon_e V_e \qquad (3)$$

with

$$1 = e_f + e_r + e_e$$

where

V_T 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 density function is

$$f_\tau = ke^{-k\tau}/(1-e^{-ks}) \tag{4}$$

where

f_τ is the probability density of failure times,
k is a coefficient,

and

e is the base of natural logarithms.

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

$$\epsilon_f = 1-E[d]/s \tag{5}$$

where

d is downtime of the primary recorders,

E[•] is the expected value of the random variable contained within the brackets,

and

s is the interval between visits to the site.

E[d] is derivable from equation 4, as is shown in Fontane and others (1984).

The fraction of time, ϵ_e, for which no records exist at either the primary or the secondary site also can be derived from a bivariate application of equation 4. (See Fontane and others, 1984.) It is assumed that the times to failure at the primary and secondary sites are independent of each other and that they have identical probability density functions for failure times.

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

$$\epsilon_r = 1-\epsilon_f-\epsilon_e. \tag{6}$$

The 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 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 for the gaging station. The measured discharge is the discharge determined by field observations of depths, widths, and velocities. The following variables are defined:

$$x_2(t) = \ln\left[qT(t)\right] - \ln\left[qR(t)\right] \qquad (7)$$

where $x_2(t)$ is the instantaneous difference between the logarithms of the true discharge, $qT(t)$, and the rating-curve discharge $qR(t)$. The variable $x_2(t)$ represents the true variability about the rating curve, but $x_2(t)$ is an unobservable random variable because $qT(t)$ is unobservable. The residuals available to the analyst include measurement errors but also contain information about the structure of $x_2(t)$. These residuals, $z(t)$, are defined as

$$z(t) = x_2(t)+v(t() = \ln\left[qm(t)\right] - \ln\left[qR(t)\right], \qquad (8)$$

where

$v(t)$ is the measurement of error,

and

$qm(t)$ is the measured discharge.

In the Kalman-filter analysis, the time series of $z(t)$ is analyzed to determine three site-specific parameters for each uncertainty function. The Kalman filter used in this study assumes that the difference $x_2(t)$ is a continuous first-order Markovian process that has an underlying Gaussian (normal) probability distribution with a zero mean and a variance (subsequently referred to as process variance) equal to $q/2\beta$. The variable q is the spectral density of the white noise that drives the Markovian process, and β is the reciprocal of the correlation time of the Markovian structure of $x_2(t)$. The 1-day autocorrelation coefficient, p, of $x_2(t)$ is a function of β. The variance of $z(t)$, $\alpha^2{}_z$, is therefore defined as

$$\alpha^2{}_z = q/2\beta+r, \qquad (9)$$

where r is the variance of the measurement error $v(t)$. The three parameters, q, β, and r, are computed by analyzing the statistical properties of the time series of residuals $z(t)$. 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 variance of the errors of estimation of discharge as a function of the number of discharge measurements per year (Moss and Gilroy, 1980).

If the recorder at the primary site fails and no concurrent data are available at other sites to reconstruct the missing record at the primary site, there would be at least two ways of estimating discharges at the primary site. A recession curve could be applied from the time of recorder stoppage until the gage was once again functioning, or the expected value of discharge for the period of missing data could be used as an estimate. The expected-value approach is used in this study to estimate V_e, the error variance during periods when concurrent data are unavailable at nearby sites. If the expected value is used to estimate discharge, the value used should be the expected value of discharge at the time of year for which the record is missing 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, C_v, squared is an estimate of the required error variance V_e. Because C_v varies seasonally and the times of failures cannot be anticipated, a seasonally averaged C_v is used:

$$C_v = 100 \left[\frac{1}{365} \sum_{i=1}^{365} \left(\frac{\sigma_i}{\mu_i} \right)^2 \right]^{1/2} \qquad (10)$$

where

σ_i is the square root of the variance of daily discharges for the i^{th} day of the year,

and

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

The variance, V_r, of the 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 sites. The correlation coefficient, P_c, between the streamflows with seasonal trends removed (detrended) at the site of interest and detrended streamflows at the other sites is a measure of the soundness 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 p_c^2. Thus, the fraction of unexplained variance, that is, the error in reconstructed records at the primary site, is $(1-p_c^2)$. If the error variance is expressed in units of percentage squared, as is the case in this study, an estimate of the potential variance of streamflow for any day of the year is C_v^2 as defined in the paragraph above. Thus, V_r can be estimated as $(1-p_c^2)C_v^2$.

It is assumed in this study that the differences between the logarithms of the computed discharges and the true discharges at each instance are normally (Gaussian) distributed with a mean of zero and a variance of either V_f, V_r, or V_e depending on whether the at-site streamflow recorder was functioning (f), whether the record was reconstructed (r) from another primary source of data, or whether the record was estimated (e) without the aid of other concurrent data. Therefore, the resulting a priori distribution of errors is not normally distributed in terms of the logarithms of discharge data. This lack of normality causes difficulty in interpretation of the resulting errors of estimation, that is, the square root of the uncertainty contained in the streamflow record. If the logarithmic errors were normally distributed, approximately two-thirds of the time the true logarithmic error would be within the range defined by plus and minus one standard error from the mean. The lack of normality caused by the multiple sources of error increases the percentage of errors contained within this range above that of a Gaussian probability distribution of logarithmic errors with the same standard deviation.

To assist in interpreting the results of the analyses, a new parameter, equivalent Gaussian spread (EGS), is introduced. The parameter EGS specifies the range in terms of equal positive and negative logarithmic units from the mean that would encompass errors with the same a priori probability as would Gaussian distribution with a standard deviation equal to EGS; in other words, the range from -1 EGS to +1 EGS contains about two-thirds of the errors. For Gaussian distributions of logarithmic errors, EGS and standard error are equivalent. EGS is reported herein in units of percentage and an approximate interpretation of EGS is "two-thirds of the errors in instantaneous streamflow data will be within plus or minus EGS percent of the reported value."

Application of K-CERA in West Virginia

As a result of the first two parts of this analysis, it has been recommended that the 74 continuous-record gaging stations used in the K-CERA analysis be continued in operation. At 14 of these stations rating curves only are maintained; daily discharges at these stations are not computed or stored. The results of the K-CERA analysis 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, the value of k in the truncated negative exponential probability distribution of times to failure of the equipment. In the representation of f_r as given in equation 4, the average time to failure is 1/k. The value of 1/k will vary from station to station depending upon the type of equipment at the station 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, and the frequency of station visits. The stream-gaging records for water years 1972-83 were used to determine the frequency of lost record. This period was used because there was little change in technology and the gaging stations were visited at a consistent frequency of 8-week intervals (minimum 6 visits per year). The 3-10 percent lost record and a bimonthly visit frequency was used to determine a value of 1/k, which was used to determine ϵf, ϵe, and ϵr for each of the 74 stations as a function of the individual frequencies of visit.

Definition of Cross-Correlation Coefficient and Coefficient of Variation

To compute the values of V_e and V_r of the needed uncertainty functions, daily streamflow records for each of the 74 stations for the last 30 years, or the part of the last 30 years for which daily streamflow values are stored in WATSTORE (Hutchinson, 1975), were retrieved. For each of the stream-gaging stations that had 3 or more complete water years of data, the coefficient of variation (C_v) was computed and various options, based on combinations of other stream gages, were explored to determine the maximum cross-correlation coefficient (ρ_c). For one station that had less than 3 water years of data, values of C_v and ρ_c were estimated subjectively. In addition to other nearby stream gages, some of the stations had other means by which streamflow data could be reconstructed when the primary recorder was malfunctioning. Several stations are equipped with telemetry systems that operate independently from the primary recorder and are routinely queried. In some locations, a local resident is hired as an observer to read and record stage at a station once or twice daily. At several stations, nearby multi-purpose reservoirs have rated their release gates to determine the discharge that passes through them and keep records that can be used for streamflow reconstruction. At reservoir locations, U.S. Army Corps of Engineers personnel inspect the stations on a daily basis. At four sites, an auxiliary recorder provides backup stage record. The set of C_v and ρ_c values for each station and the sources of backup records that gave the highest cross-correlation coefficient for reconstructing missing record are listed in table 14.

Kalman-Filter Definition of Variance

The determination of the variance V_f for each of the 74 stream gages required the execution of three distinct steps: (1) long-term rating analysis and computation of residuals of measured discharges from the long-term rating, (2) time-series analysis of the residuals to determine the input parameters of the Kalman-filter streamflow records, and (3) computation of the error variance, V_f as a function of the time-series parameters, the discharge-measurement-error variance, and the frequency of discharge measurement.

In the West Virginia program analysis, definition of long-term rating functions was based on discharge measurements not significantly affected by backwater due to ice conditions. A review of past rating functions indicated that most ratings were developed for open-water applications. Little data were available to define winter-discharge ratings. The K-CERA procedures were applied under open-water conditions at each site.

Table 14.--Statistics of record reconstruction

Station no.	C_v	p_c	Source of reconstructed records	
01595200	119	0.68	01595000	
01604500	168	.78	01605500	01603000 (Md.)
01605500	118	.76	01606500	
01606500	127	.86	01605500	01608500
01607500	177	.89	01608000	
01608000	177	.88	01607500	01605500
01608500	139	.99	01606500	Telemetry
01611500	164	.78	01616500	
01616500	164	.77	01615000	
01636500	121	.80	Telemetry	01608500
03050500	153	.77	03051000	
03051000	148	.82	03052500	
03052500	166	.83	03053500	03054500
03053500	140	.97	03054500	
03054500	139	.99	03051000	
03057000	113	.97	Corps of Engineers outflow record	
03057500	144	.75	03058000	
03058000	186	.98	03058500	03061000
03058500	175	.98	03058000	03061500
03061000	148	.96	03058000	
03061500	183	.78	03058000	03061000
03062400	151	.82	03052500	03061500
03065000	136	.98	03069000	
03066000	137	.93	03069000	03070500
03069000	123	.96	03069500	
03069500	130	.98	03069000	03065000
03070000	129	.82	03069500	03069000
03070500	146	.76	03070000	01595000
03112000	173	.72	03114500	03061500
03114500	194	.72	03112000	03061500
03151400	121	.46	03194700	03155500
03151520	111	.73	03151600	Telemetry
03151600	107	.69	03152000	Telemetry
03152000	169	.86	03151600	Telemetry
03153500	171	.86	03155000	Telemetry
03154000	187	.82	03153500	Telemetry
03155000	162	.79	03153500	Telemetry
03155500	163	.79	03152000	Telemetry
03179000	137	.80	03177710	Telemetry
03180500	139	.79	03182500	
03182500	145	.87	03183500	Telemetry
03183500	143	.98	03184000	Telemetry
03184000	142	.98	03183500	Telemetry
03184500	85	0.95	03184000	Gate openings at upstream multipurpose reservoir

Station no.	C_v	p_c	Source of reconstructed records	
03185400*	98	.98	03184500	Telemetry
03186500	142	.91	03187000	03189100
03187000	134	.93	03189100	Telemetry
03189100	117	.91	03186500	
03189600	109	.73	Rated valve openings at upstream multi-purpose reservoir	
03190400	112	.71	03189100	Telemetry
03192000	120	.80	03189600	
03193000	88	.87	03185400	Telemetry
03194700	122	.89	03186500	Telemetry
03195500	125	.94	Gate openings at upstream multi-purpose reservoir	
03196600	117	.96	03195500	03196800
03196800	118	.86	03196600	
03197000	126	.68	03196800	Telemetry
03198500	142	.93	03200500	
03200500	108	.82	03198500	Telemetry
03202400	104	.84	03202750	Telemetry
03202750	119	.84	03202400	
03202915	85	.52	Gate ratings at upstream multi-purpose reservoir	
03203000	107	.77	03203600	
03203600	127	.90	03204000	Telemetry
03204000	132	.90	03203600	
03206600	166	.69	Telemetry	
03206790	154	.92	Gate ratings at upstream multi-purpose reservoir	
03207020	152	.80	03206790	Telemetry
03213000	119	.82	03213700	Telemetry
03213500	180	.82	03213000	
03213700	108	.82	03213000	03213700
03214000	133	.81	03213700	Observer
03214900	95	.76	03214000	Telemetry

* Less than 3 water years of data available. Estimates of C_v and p_c are subjective.

The rating function determined for the stations in this analysis is of the form:

$$LQM = B1 + B3 * \ln (GHT - B2), \quad (11)$$

in which:

LQM is the natural logarithm of measured discharge,

GHT is the recorded gage height corresponding to the measured discharge,

B1 is the logarithm of discharge for a flow depth of 1 foot,

B2 is the gage height of zero flow, and

B3 is the slope of the rating curve.

The open-water measurements used for definition of the rating function and computation of the time series of measurement residuals were primarily those made in the period 1972-83. However, some measurements made prior to 1972 were used for those stations with fewer than 50 open-water measurements during the 1972-83 period. The numbers of measurements used for the analysis for each station are tabulated in table 15.

The time series of residuals (in logarithmic units) is used to compute sample estimates of q and β, two of the three parameters required to compute V_f, by using the time series of residuals. Measurement variance, the third parameter, is determined from an assumed constant percentage standard error. For the West Virginia program, all open-water measurements were assumed to have a measurement error of 3 to 8 percent.

As discussed earlier, q and β can be expressed as the process variance of the residuals from the rating curve and the 1-day autocorrelation coefficient of these residuals. Table 12 presents a summary of the autocovariance analysis, expressed in terms of process variance and 1-day autocorrelation, for each station.

The autocovariance parameters, summarized in table 15, and data from the definition of missing record probabilities, summarized in table 14, are used to define uncertainty functions for each gaging station. The uncertainty functions give the relationship of total error variance to the number of visits and discharge measurements. Typical uncertainty functions for two gaging stations in West Virginia are shown in figure 11.

In West Virginia, feasible routes to service the 74 continuous stream gages were determined after consultation with personnel in both subdistrict offices and after review of the uncertainty functions. In summary, 69 routes were selected to service all the stream gages in West Virginia. These routes, included all possible combinations that describe the current operating practice, alternatives that were under consideration as future possibilities, routes that visited certain individual stations, and combinations that grouped proximate gages where the levels of uncertainty indicated more frequent visits might be useful. These routes and the stations visited on each are summarized in table 16.

Table 15.--Summary of autocovariance analysis

Station number	Station name	Number of measurements used	RHO*	Measurement variance (log base e)^2	Process variance (log base e)^2
01595200	Stony River near Mt. Storm	123	0.992	0.0025	0.2813
01604500	Patterson Creek near Headsville	107	.981	.0025	.0732
01605500	South Branch Potomac River at Franklin	44	.976	.0025	.0015
01606500	South Branch Potomac River near Petersburg	99	.965	.0016	.0039
01607500	South Fork South Branch Potomac River at Brandywine	100	.992	.0025	.3562
01608000	South Fork South Branch Potomac River near Moorefield	107	.956	.0025	.0214
01608500	South Branch Potomac River near Springfield	106	.992	.0025	.0243
01611500	Cacapon River near Great Cacapon	103	.932	.0025	.0125
01616500	Opequon Creek near Martinsburg	98	.966	.0025	.0038
01636500	Shenandoah River at Millville	44	.756	.0025	.0012
03050500	Tygart Valley River near Elkins	97	.638	.0025	.0146
03051000	Tygart Valley River at Belington	101	.907	.0025	.0173
03052500	Sand Run near Buckhannon	48	.987	.0036	.1205
03053500	Buckhannon River at Hall	103	.607	.0016	.0188
03054500	Tygart Valley River at Philippi	86	.945	.0025	.0166
03057000	Tygart Valley River at Colfax	69	.972	.0004	.0021
03057500	Skin Creek near Brownsville	144	.967	.0036	.3848
03058000	West Fork River at Brownsville	88	.960	.0036	.2120
03058500	West Fork River at Butcherville	98	.988	.0025	.0299
03061000	West Fork River at Enterprise	66	.970	.0025	.0040
03061500	Buffalo Creek at Barrackville	120	.906	.0016	.0046
03062400	Cobun Creek at Morgantown	132	.317	.0025	.3236
03065000	Dry Fork at Hendricks	97	.622	.0025	.0044
03066000	Blackwater River at Davis	105	.908	.0016	.0519
03069000	Shavers Fork at Parsons	99	.514	.0016	.0066
03069500	Cheat River near Parsons	88	.966	.0025	.0012
03070000	Cheat River at Rowlesburg	92	.375	.0025	.0233
03070500	Big Sandy Creek at Rockville	97	.982	.0025	.0081
03112000	Wheeling Creek at Elm Grove	111	.987	.0036	.1542
03114500	Middle Island Creek at Little	107	.898	.0025	.0870

* One-day autocorrelation coefficient

Table 15.--Summary of autocovariance analysis--Continued

Station number	Station name	Number of measurements used	RHO*	Measurement variance (log base e)^2	Process variance (log base e)^2
03151400	Little Kanawha River near Wildcat	80	0.970	0.0025	0.0613
03151520	Little Kanawha River below Burnsville Dam	23	.981	.0036	.0666
03151600	Little Kanawha River at Burnsville	45	.415	.0036	.4916
03152000	Little Kanawha River at Glenville	61	.577	.0025	.0077
03153500	Little Kanawha River at Grantsville	82	.901	.0036	.0083
03154000	West Fork Little Kanawha River at Rocksdale	89	.902	.0025	.0256
03155000	Little Kanawha River at Palestine	38	.660	.0025	.0097
03155500	Hughes River at Cisco	58	.985	.0036	.0791
03179000	Bluestone River near Pipestem	144	.406	.0025	.0017
03180500	Greenbrier River at Durbin	137	.545	.0025	.0105
03182500	Greenbrier River at Buckeye	101	.603	.0025	.0275
03183500	Greenbrier River at Alderson	123	.959	.0025	.0129
03184000	Greenbrier River at Hilldale	114	.849	.0009	.0042
03184500	New River at Hinton	110	.945	.0009	.0130
03185400	New River at Thurmond	18	.310	.0036	.0379
03186500	Williams River at Dyer	155	.441	.0009	.0172
03187000	Gauley River at Camden-on-Gauley	95	.976	.0025	.1149
03189100	Gauley River near Craigsville	127	.436	.0036	.0275
03189600	Gauley River below Summersville Dam	102	.955	.0036	.0477
03190400	Meadow River near Mount Lookout	86	.773	.0025	.0024
03192000	Gauley River above Belva	153	.623	.0025	.0043
03193000	Kanawha River at Kanawha Falls	57	.890	.0025	.0040
03194700	Elk River below Webster Springs	80	.982	.0025	.0323
03195500	Elk River at Sutton	96	.973	.0025	.0092
03196600	Elk River near Frametown	130	.595	.0025	.0072
03196800	Elk River at Clay	140	.965	.0025	.0029
03197000	Elk River at Queen Shoals	119	.615	.0025	.0162
03198500	Big Coal River at Ashford	159	.994	.0036	.0809
03200500	Coal River at Tornado	83	.500	.0025	.0940
03202400	Guyandotte River near Baileysville	134	.977	.0025	.0306

* One-day autocorrelation coefficient

Table 15.--Summary of autocovariance analysis--Continued

Station number	Station name	Number of measurements used	RHO*	Measurement variance (log base e)^2	Process variance (log base e)^2
03202750	Clear Fork at Clear Fork	9	0.794	0.0036	0.0035
03202915	Guyandotte River below R.D. Bailey Dam	22	.505	.0064	.300
03203000	Guyandotte River at Man	83	.463	.0064	.2703
03203600	Guyandotte River at Logan	91	.396	.0025	.0141
03204000	Guyandotte River at Branchland	110	.510	.0036	.0150
03206600	East Fork Twelvepole Creek near Dunlow	105	.973	.0036	.3217
03206790	East Fork Twelvepole Creek below East Lynn Dam	135	.982	.0025	.0873
03207020	Twelvepole Creek below Wayne	127	.973	.0025	.0322
03207057	Beech Fork below Beech Fork Dam	50	.971	.0036	.0345
03213000	Tug Fork at Litwar	89	.888	.0025	.0118
03213500	Panther Creek near Panther	18	.748	.0025	.0042
03213700	Tug Fork at Williamson	109	.987	.0025	.0095
03214000	Tug Fork near Kermit	113	.906	.0016	.0046
03214900	Tug Fork at Glenhayes	59	.972	.0036	.0146

* One-day autocorrelation coefficient

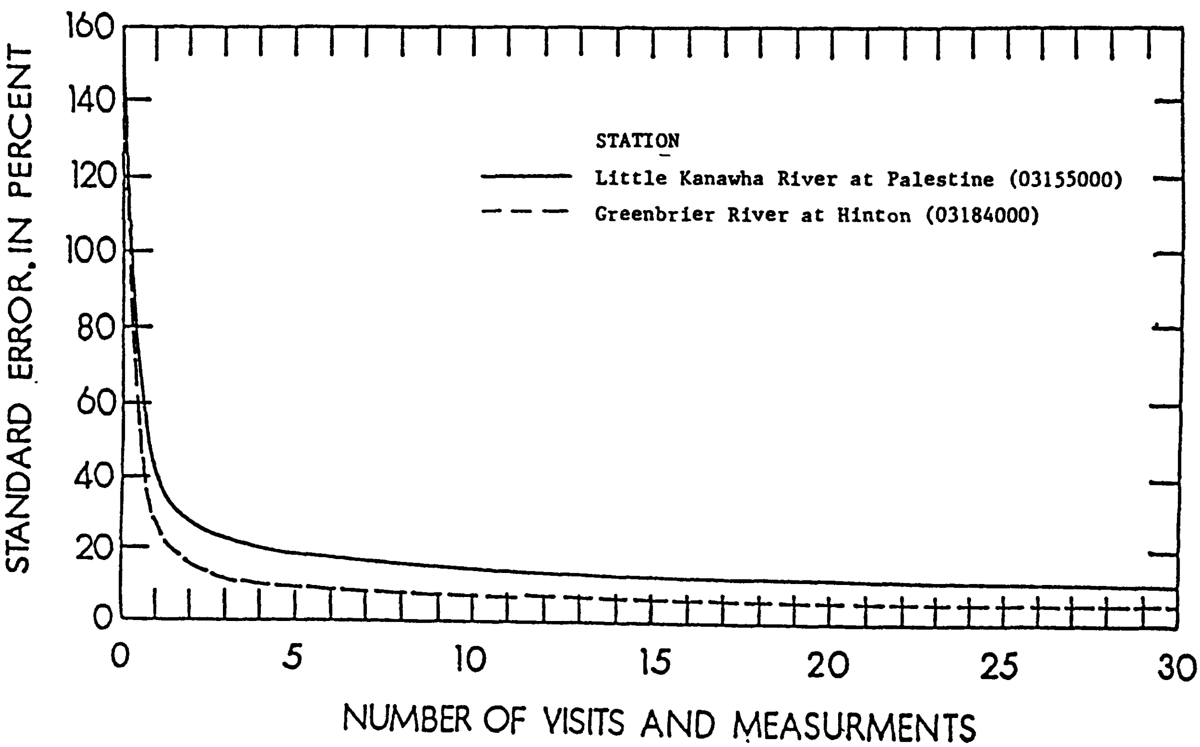

Figure 11. Typical uncertainty function for instataneous discharges.

Table 16.--Summary of routes that may ba used to visit stations in West Virginis

Route number	Ststions sarviced on the route											
1	01636500	01616500	01611500	01608500	01607500	01606500	01605500					
2	01636500	01616500										
3	01604500	01605500	01606500	01607500								
4	01608000	01606500	01608500	01611500								
5	01636500											
6	01607500											
7	01616500	01611500										
8	01595200	03066000	03065000	03069000	03069500							
9	03069500	03069000	03066000									
10	03069500											
11	03066000	03065000										
12	03050500	03053500	03051000	03054500								
13	03050500											
14	03053500											
15	03051000	03054500										
16	03151400	03151520	03151600	03152000	03153500	03154000	03155000	03155500	03058500	03058000	03057500	03052500
17	03058000	03058500										
18	03155000											
19	03151400	03151520	03151600	03152000	03153000							
20	03155500											
21	03057500											
22	03058000											
23	03151600											
24	03155000	03114500	03112000									
25	03114500											
26	03112000											
27	03114500	03112000										
28	03112000											
29	03114500											
30	03061500	03061000	03057000	03062400	03070500							
31	03062400											
32	03070500											
33	03070000											
34	03183500	03193000										
35	03183500											
36	03193000											
37	03192000											
38	03179000	03180500	03182500	03183500	03184000	03184500	03185400					
39	03180500											
40	03184000	03185400										
41	03185400											
42	03179000	03184500										
43	03194700	03195500	03196600	03196800	03197000							
44	03194700											
45	03195500	03197000										
46	03196600	03196800										
47	03186500	03187000	03189100	03190400	03192000							
48	03189600	03190400										
49	03192000											
50	03166500											
51	03193000											
52	03190400											
53	03189600	03189100										
54	03189600											
55	03198500	03200500										
56	03200500											
57	03204000											
58	03207057	03207020	03206790									
59	03204000											
60	03202400	03202750	03202915	03203000	03203600	03213500						
61	03202915											
62	03202400	03202750	03202915	03213000	03213500							
63	03203000	03203600										
64	03203000											
65	03206600	03213700	03214000	03214900								
66	03214900											
67	03206600											
68	03213700	03214000										
69	03214000											

Operational costs for each station were partitioned into annual fixed, visit, and travel costs. All cost estimates were based on monies available for operations in 1985.

Annual fixed costs to operate a station typically include equipment rental, batteries, data processing and storage, computer use, maintenance, miscellaneous supplies, data analysis, publication, and supervisory costs. Costs for auxiliary equipment that is often used for reconstruction of lost record, but which is not necessary for normal streamflow-gaging operations, were excluded from fixed costs. Such equipment includes that associated with satellite telemetry, water-quality activities, or a second recorder installed for project activities.

Visit costs are those associated with paying the hydrographer for the time actually spent at a station making a discharge measurement. These costs vary from station to station and are largely a function of the time required to make the discharge measurement. Average visit times were calculated for each station by reviewing the time hydrographers spend making various measurements. This time was then multiplied by the average hourly salary of hydrographers to determine typical visit costs.

Travel costs include the vehicle cost associated with driving the number of miles it takes to cover the route, vehicle flat rate daily cost, the cost of the hydrographer's time while in transit, servicing the equipment and any per diem associated with the time it takes to complete the trip.

K-CERA Results

The Traveling Hydrographer Program uses the uncertainty functions along with the appropriate cost data and route definitions to compute the most cost-effective way of operating the streamflow-gaging program. In this application, the first step was to simulate the current practice and determine the total uncertainty associated with it. To accomplish this, the number of visits made to each stream gage and the specific routes used to make these visits were specified according to current operating procedures. In West Virginia, current policy is that a discharge measurement be made each time that a station is visited. The resulting average error of estimation for the current policy is 24.6 percent. (See plotted point in figure 12).

The solid line on figure 12 represents the minimum average standard error that can be obtained for a given budget with the existing instrumentation and technology. The line was defined by several runs of the Traveling Hydrographer Program with different budgets. The mild slope of the curve in figure 12 is probably due to many stations being highly correlated. Constraints on the operations other than budget were defined as described below.

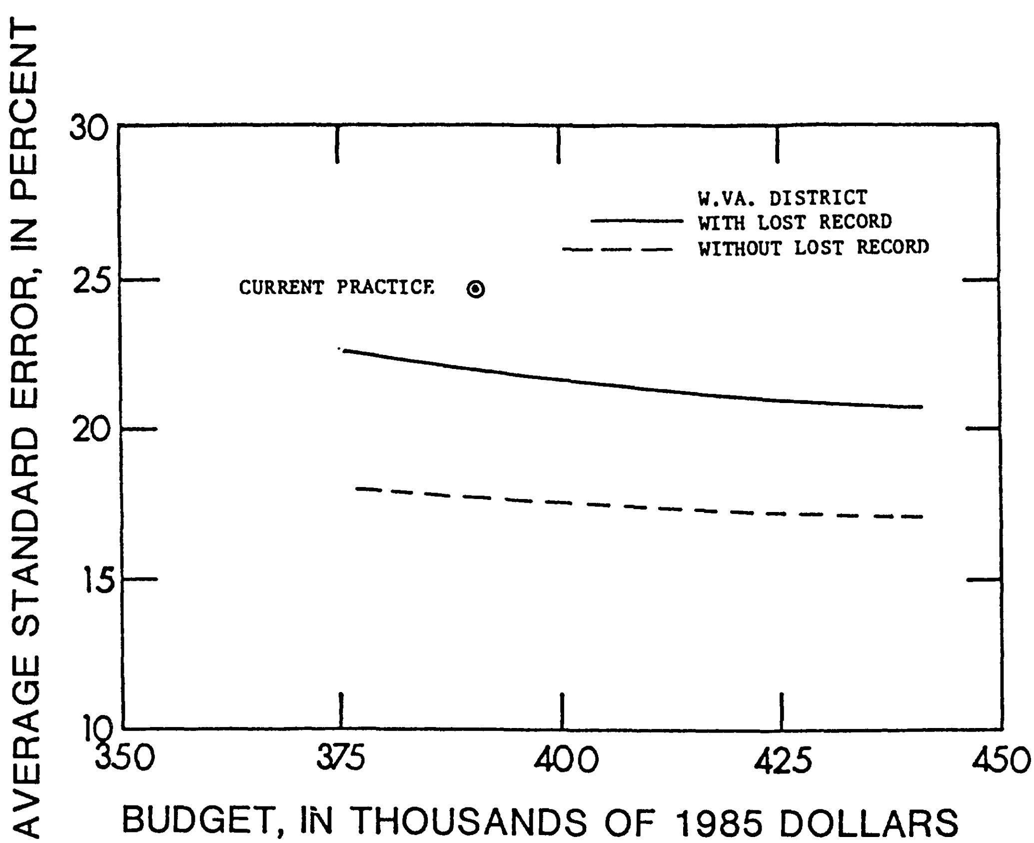

Figure 12. Temporal average standard error per streamflow gage.

To determine the minimum number of times each station must be visited, consideration was given only to the physical limitations of the method used to record data. The effect of visitation frequency on the accuracy of the data and amount of lost record is taken into account in the uncertainty analysis. In West Virginia, required minimum visits per year were calculated and applied to all stations. This requirement was based on present intervals between field trips as imposed by present budget and travel restraints. Minimum visit requirements should also reflect the need to visit stations for special reasons such as water-quality sampling and water-use information.

The results in figure 12 and table 17 summarize the K-CERA analysis and are predicated on a discharge measurement made each time a station is visited. It was felt that this policy would improve the cost-effectiveness of the operation. Ideally, the ratio of measurements to visits would be optimized for each site individually. This step will be accomplished in any future evaluation of the West Virginia program.

It should be emphasized that figure 12 and table 17 are based on various assumptions (stated previously) concerning both the time series of shifts to the stage-discharge relationship and the methods of record reconstruction. Where a choice of assumptions was available, the assumption that would not underestimate the magnitude of the error variances was chosen.

Table 17.--Selected results of K-CERA analysis

Standard error of instantaneous discharge, in percent
[Equivalent Gaussian spread]
(Number of visits per year to site)

Station Number	Current operation	Budget, in thousands of 1985 dollars 375,000	390,000	400,000	420,000	430,000
Average SE per station	24.65	22.48	21.96	21.66	21.33	21.06
EGS for the program	[12.32]	[11.59]	[11.32]	[11.16]	[11.02]	[10.85]
01595200	29.52 [23.85] (6)	22.99 [18.09] (10)	24.23 [19.16] (9)	22.99 [18.09] (10)	21.94 [17.19] (11)	21.05 [16.45] (12)
01604500	28.95 [18.05] (6)	22.83 [14.20] (10)	24.02 [14.98] (9)	22.83 [14.20] (10)	21.83 [13.58] (11)	20.93 [13.00] (12)
01605500	17.58 [3.78] (6)	13.78 [3.36] (10)	14.49 [3.46] (9)	13.78 [3.36] (10)	13.16 [3.28] (11)	12.63 [3.21] (12)
01606500	15.44 [5.16] (6)	12.12 [4.30] (10)	12.75 [4.49] (9)	12.12 [4.30] (10)	11.58 [4.25] (11)	11.11 [4.01] (12)
01607500	32.01 [26.76] (6)	21.15 [17.68] (13)	22.01 [18.48] (12)	21.15 [17.68] (13)	20.37 [16.99] (14)	19.07 [15.85] (16)
01608000	21.86 [12.70] (6)	17.58 [10.79] (10)	18.42 [11.22] (9)	18.42 [11.22] (9)	16.87 [10.44] (11)	16.23 [10.10] (12)
01608500	13.85 [4.88] (6)	10.87 [4.06] (10)	11.43 [4.21] (9)	11.43 [4.21] (9)	10.38 [3.92] (11)	9.96 [3.80] (12)
01611500	25.06 [10.56] (6)	20.04 [9.38] (10)	20.98 [9.60] (9)	20.04 [9.38] (10)	18.47 [8.87] (12)	17.83 [8.66] (13)
01616500	24.01 [5.06] (6)	18.75 [4.23] (10)	19.74 [4.40] (9)	18.75 [4.23] (10)	17.15 [3.95] (12)	16.50 [3.82] (13)
01636500	10.11 [3.52] (6)	8.13 [3.46] (10)	8.49 [3.47] (9)	8.49 [3.47] (9)	7.81 [3.45] (11)	7.54 [3.44] (12)
03050500	23.22 [12.55] (6)	21.96 [12.41] (7)	23.22 [12.55] (6)	21.96 [12.41] (7)	20.95 [12.30] (8)	20.13 [12.21] (9)
03051000	21.05 [12.67] (6)	19.93 [12.41] (7)	21.05 [12.67] (6)	19.93 [12.41] (7)	19.00 [12.14] (8)	18.22 [11.90] (9)
03052500	23.64 [19.17] (6)	16.35 [13.13] (13)	19.55 [15.78] (9)	17.74 [14.27] (11)	15.75 [12.62] (14)	15.25 [12.22] (15)
03053500	15.70 [14.11] (6)	15.34 [13.99] (7)	15.70 [14.11] (6)	15.34 [13.99] (7)	15.05 [13.89] (8)	14.83 [13.80] (9)
03054500	12.30 [11.34] (6)	11.74 [10.94] (7)	12.30 [11.34] (6)	11.74 [10.94] (7)	11.31 [10.64] (8)	10.91 [10.31] (9)
03057000	7.60 [3.52] (6)	7.60 [3.52] (6)	7.60 [3.52] (6)	7.60 [3.52] (6)	7.01 [3.32] (7)	7.01 [3.32] (7)
03057500	50.44 [49.81] (6)	27.83 [27.29] (24)	29.79 [29.23] (21)	28.47 [27.93] (23)	25.77 [25.25] (28)	24.86 [24.35] (30)

Table 17.--Selected results of K-CERA analysis--continued

Standard error of instantaneous discharge, in percent
[Equivalent Gaussian spread]
(Number of visits per year to site)

Station Number	Current operation	Budget, in thousands of 1985 dollars				
		375.000	390.000	400.000	420.000	430.000
03058000	36.40 [36.24] (7)	29.36 [29.25] (13)	32.46 [32.34] (10)	30.32 [30.22] (12)	27.69 [27.59] (15)	26.17 [26.06] (17)
03058500	11.21 [6.74] (7)	8.20 [6.47] (13)	9.36 [7.36] (10)	6.54 [6.73] (12)	7.62 [6.02] (15)	7.37 [5.82] (16)
03061000	10.15 [4.93] (6)	10.15 [4.93] (6)	10.15 [4.93] (6)	10.15 [4.93] (6)	9.42 [4.69] (7)	9.42 [4.69] (7)
03061500	24.44 [6.57] (6)	24.44 [6.57] (6)	24.44 [6.57] (6)	24.44 [6.57] (6)	22.75 [6.43] (7)	22.75 [6.43] (7)
03062400	62.97 [62.38] (6)	62.14 [61.76] (9)	62.97 [62.38] (6)	62.64 [62.14] (7)	61.95 [61.60] (10)	61.77 [61.46] (11)
03065000	9.23 [6.82] (6)	10.75 [7.02] (4)	9.23 [6.82] (6)	9.23 [6.82] (6)	9.23 [6.82] (6)	9.23 [6.82] (6)
03066000	23.18 [21.67] (6)	23.94 [22.16] (5)	20.57 [19.61] (11)	21.48 [20.38] (9)	21.01 [19.98] (10)	21.01 [19.98] (10)
03069000	9.24 [8.21] (6)	10.40 [8.40] (3)	9.24 [8.21] (6)	9.24 [8.21] (6)	9.24 [8.21] (6)	9.24 [8.21] (6)
03069500	6.63 [2.80] (6)	9.90 [3.42] (3)	6.63 [2.80] (6)	6.63 [2.80] (6)	6.63 [2.80] (6)	6.63 [2.80] (6)
03070000	20.33 [15.80] (6)	22.48 [16.14] (4)	20.33 [15.80] (6)	20.33 [15.80] (6)	20.33 [15.80] (6)	20.33 [15.80] (6)
03070500	16.32 [5.80] (6)	16.32 [5.80] (6)	16.32 [5.80] (6)	15.14 [5.46] (7)	14.18 [5.15] (8)	14.18 [5.15] (8)
03112000	28.29 [20.33] (7)	18.90 [13.39] (16)	19.52 [13.84] (15)	18.32 [12.95] (17)	17.84 [12.61] (18)	16.52 [11.66] (21)
03114500	39.01 [28.99] (6)	29.04 [24.07] (16)	30.32 [24.89] (14)	29.04 [24.07] (16)	28.46 [23.68] (17)	26.91 [22.59] (20)
03155000	13.76 [9.60] (12)	13.45 [9.55] (13)	14.98 [9.74] (9)	14.10 [9.64] (11)	13.18 [9.51] (14)	12.94 [9.47] (15)
03155500	26.33 [22.75] (6)	19.62 [17.28] (13)	22.80 [19.97] (9)	21.05 [18.50] (11)	19.03 [16.78] (14)	18.44 [16.26] (15)
03179000	14.94 [4.26] (6)	18.05 [4.36] (4)	14.94 [4.26] (6)	14.94 [4.26] (6)	14.94 [4.26] (6)	14.94 [4.26] (6)
03180500	20.26 [10.68] (6)	20.26 [10.68] (6)	20.26 [10.68] (6)	20.26 [10.68] (6)	19.13 [10.58] (7)	18.24 [10.49] (8)
03182500	23.17 [17.36] (6)	26.12 [17.93] (4)	23.17 [17.36] (6)	23.17 [17.36] (6)	23.17 [17.36] (6)	23.17 [17.36] (6)
03183500	9.23 [7.50] (16)	14.39 [10.36] (6)	11.38 [8.87] (10)	11.38 [8.87] (10)	11.36 [8.87] (10)	11.38 [8.87] (10)
03184000	7.99 [6.40] (6)	9.01 [6.58] (4)	7.99 [6.40] (6)	7.99 [6.40] (6)	7.99 [6.40] (6)	7.99 [6.40] (6)

Table 17.--Selected results of K-CERA analysis--continued

Standard error of instantaneous discharge, in percent
[Equivalent Gaussian spread]
(Number of visits per year to site)

Station Number	Current operation	Budget, in thousands of 1985 dollars 375,000	390,000	400,000	420,000	430,000
03184500	11.13 [10.72] (6)	11.72 [11.09] (4)	11.13 [10.72] (6)	11.13 [10.72] (6)	11.13 [10.72] (6)	11.13 [10.72] (6)
03185400	19.65 [19.57] (6)	19.80 [19.62] (4)	19.65 [19.57] (6)	19.65 [19.57] (6)	19.65 [19.57] (6)	19.65 [19.57] (6)
03186500	15.87 [13.31] (9)	19.42 [13.83] (4)	15.87 [13.31] (9)	15.87 [13.31] (9)	15.67 [13.31] (9)	15.87 [13.31] (9)
03187000	28.97 [28.72] (6)	34.00 [33.47] (2)	26.97 [28.72] (6)	28.97 [28.72] (6)	28.97 [28.72] (6)	28.97 [28.72] (6)
03189100	17.27 [16.76] (6)	18.71 [17.12] (2)	17.27 [16.76] (6)	17.27 [16.76] (6)	17.27 [16.76] (6)	17.27 [16.76] (6)
03189600	20.48 [19.73] (6)	21.68 [20.64] (4)	20.48 [19.73] (6)	20.48 [19.73] (6)	20.48 [19.73] (6)	20.48 [19.73] (6)
03190400	12.32 [4.96] (6)	14.72 [5.05] (4)	12.32 [4.96] (6)	12.32 [4.96] (6)	12.32 [4.96] (6)	12.32 [4.96] (6)
03192000	10.37 [6.52] (8)	13.25 [6.71] (4)	10.37 [6.52] (8)	10.37 [6.52] (8)	10.37 [6.52] (8)	10.37 [6.52] (8)
03193000	7.41 [6.02] (10)	12.0 [6.65] (2)	7.80 [6.12] (8)	7.60 [6.12] (8)	7.80 [6.12] (8)	7.80 [6.12] (8)
03194700	13.31 [11.27] (6)	15.74 [13.18] (4)	13.31 [11.27] (6)	13.31 [11.27] (6)	13.31 [11.27] (6)	13.31 [11.27] (6)
03195500	7.89 [6.93] (6)	7.89 [6.93] (6)	7.89 [6.93] (6)	7.89 [6.93] (6)	7.89 [6.93] (6)	7.89 [6.93] (6)
03196600	9.44 [8.58] (6)	10.45 [8.76] (3)	9.44 [8.58] (6)	9.44 [8.58] (6)	9.44 [8.58] (6)	9.44 [8.58] (6)
03196800	9.21 [4.88] (6)	12.21 [5.23] (3)	9.21 [4.88] (6)	9.21 [4.88] (6)	9.21 [4.88] (6)	9.21 [4.88] (6)
03197000	21.03 [13.09] (6)	21.03 [13.09] (6)	21.03 [13.09] (6)	21.03 [13.09] (6)	20.02 [12.97] (7)	20.02 [12.97] (7)
03198500	14.95 [11.06] (6)	14.95 [11.06] (6)	14.95 [11.06] (6)	14.95 [11.06] (6)	13.77 [10.19] (7)	12.84 [9.51] (8)
03200500	33.09 [31.85] (6)	33.09 [31.85] (6)	33.09 [31.85] (6)	33.09 [31.85] (6)	32.72 [31.66] (6)	32.43 [31.50] (6)
03202400	16.73 [12.38] (6)	15.65 [11.63] (7)	15.65 [12.38] (7)	14.74 [12.38] (8)	13.99 [12.38] (9)	13.99 [12.38] (9)
03202750	16.16 [6.10] (6)	15.05 [6.00] (7)	15.05 [6.00] (7)	14.17 [5.92] (8)	13.45 [5.85] (9)	13.45 [5.65] (9)
03202915	12.83 [1.04] (6)	11.89 [1.03] (7)	11.89 [1.03] (7)	11.13 [1.02] (8)	10.50 [1.02] (9)	10.50 [1.02] (9)
03203000	55.62 [55.57] (6)	56.05 [55.94] (3)	55.62 [55.57] (6)	55.62 [55.57] (6)	55.62 [55.57] (6)	55.62 [55.57] (6)

Table 17.--Selected results of K-CERA analysis--continued

Standard error of instantaneous discharge, in percent
[Equivalent Gaussian spread]
(Number of visits per year to site)

Station Number	Current operation	375,000	390,000	400,000	420,000	430,000
		Budget, in thousands of 1985 dollars				
03203600	14.79 [12.14] (6)	17.46 [12.54] (3)	14.79 [12.14] (6)	14.79 [12.14] (6)	14.79 [12.14] (6)	14.79 [12.14] (6)
03204000	16.96 [12.77] (6)	17.81 [12.90] (5)	16.96 [12.77] (6)	16.96 [12.77] (6)	16.96 [12.77] (6)	16.96 [12.77] (6)
03206600	49.12 [43.65] (6)	28.63 [24.98] (20)	30.98 [27.11] (17)	29.35 [25.63] (19)	26.73 [23.27] (23)	26.73 [23.27] (23)
03206790	19.59 [18.45] (6)	18.37 [17.30] (7)	18.37 [17.30] (7)	18.37 [17.30] (7)	16.44 [15.47] (9)	15.62 [14.69] (10)
03207020	21.05 [15.71] (6)	19.99 [15.18] (7)	19.99 [15.18] (7)	19.99 [15.18] (7)	18.31 [14.23] (9)	17.62 [13.80] (10)
03207057	21.17 [13.98] (6)	19.86 [13.29] (7)	19.86 [13.29] (7)	19.86 [13.29] (7)	17.79 [12.07] (9)	17.79 [12.07] (9)
03213000	13.80 [10.72] (6)	13.32 [10.63] (7)	13.32 [10.63] (7)	12.94 [10.54] (8)	12.63 [10.45] (9)	12.63 [10.45] (9)
03213500	27.45 [6.86] (6)	25.40 [6.74] (7)	25.40 [6.74] (7)	23.78 [6.65] (8)	22.44 [6.57] (9)	22.44 [6.57] (9)
03213700	11.32 [5.52] (6)	13.75 [6.55] (4)	11.32 [5.52] (6)	11.32 [5.52] (6)	11.32 [5.52] (6)	11.32 [5.52] (6)
03214000	12.88 [6.37] (6)	15.24 [6.67] (4)	12.88 [6.37] (6)	12.88 [6.37] (6)	12.88 [6.37] (6)	12.88 [6.37] (6)
03214900	17.64 [11.03] (6)	18.93 [11.46] (5)	17.64 [11.03] (6)	17.64 [11.03] (6)	17.64 [11.03] (6)	17.64 [11.03] (6)

It can be seen that the current policy results in an average standard error of estimate of streamflow of 24.6 percent (table 17). This policy requires a budget of $390,000 to operate the 74-station streamflow-gaging program. The range in standard errors is from a low of 6.6 percent for station 03069500 to a high of 79.2 percent for station 03151600. It is possible to reduce the average standard error by a policy change while maintaining the $390,000 budget. In this case, the average standard error would decrease from 24.6 to 22.0 percent. Extremes of standard errors for individual sites would be from 6.6 to 79.0 percent for stations 03069500 and 03151600, respectively.

A minimum budget of $375,000 is required to operate the 74-station program; a smaller budget would not permit proper service and maintenance of the gages and recorders. Stations would have to be eliminated from the program if the budget fell below this minimum. At the minimum budget, the average standard error is 22.5 percent. The minimum and maximum standard errors for individual stations would be from 7.6 to 78.6 percent for stations 03057000 and 03151600, respectively.

The maximum budget analyzed was $430,000, which resulted in an average standard error of estimate of 21.1 percent. The minimum standard error would remain the same as in the current policy and minimum budget analysis and the maximum would be 78.5 percent at station 03151600. The maximum budget analysis indicates that increasing the current budget by $40,000 in conjunction with policy change would reduce by only 3.5 percent points the average standard error that results from the current policy and current budget. Thus, it is apparent that only modest improvements in accuracy of streamflow records can be obtained if larger budgets become available.

The analysis also was performed under the assumption that no correlative data at a stream gage were lost to estimate the uncertainty added to the streamflow-gaging records because of less than perfect instrumentation. The curve, labeled "Without lost record" on figure 12, shows the average standard errors of estimation of streamflow that could be obtained if perfectly reliable systems were available to measure and record the correlative data. For the minimal operational budget of $375,000, the effects of less than perfect equipment are greatest; average standard errors increase from 17.9 to 22.5 percent.

At the other budgetary extreme of $430,000, under which stations are visited more frequently and the equipment should be more reliable, average standard errors increase from 17.2 percent for ideal equipment to 21.1 percent for the current system of sensing and recording of hydrologic data. Thus, improved equipment can have a positive impact on streamflow uncertainties throughout the range of operational budgets that could be anticipated for the streamflow-gaging program in West Virginia.

Conclusions from the K-CERA Analysis

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

1. The policy for definition of field activities in the stream-gaging program should remain unchanged to maintain the current average standard error of estimate of streamflow records of 24.6 percent with a budget of about $390,000.

2. Data users should evaluate whether the accuracy of gaging flow-station data is sufficient for their needs.

3. The K-CERA analysis should be repeated with the new stations whenever sufficient information about the characteristics of the new stations has been obtained.

4. Schemes for reducing missing record, such as increased use of local gage observers and satellite relay of data, should be evaluated as to their cost-effectiveness in providing streamflow information.

SUMMARY

Currently, 74 continuous stream gages are operated in West Virginia at a cost of $390,000. Eight sources of funding contribute to the program and nine uses were identified for the data from the gages. In spite of the size of the program, some areas of the State lack sufficient streamflow data to provide valid estimates of streamflow characteristics. This paucity of data should be remedied as funds can be made available.

Three stations were identified as having uses specific to short-term studies. These stations should be deactivated at the end of the data-collection phases of the studies, unless their continued operation would be beneficial to the long-term hydrologic network in the State. The remaining stations should be maintained in the program.

The policy for the definition of field activities at the 74-station program should remain unchanged to maintain the current average standard error of estimate (24.6 percent) with a current budget of $390,000. An analysis of changes in field activities with no change in the current budget indicated that the standard error would only be decreased to 22.0 percent.

A major component of the error in streamflow records is caused by loss of primary record (stage or other correlative data) at the stream gages because of malfunctions of sensing and recording equipment. Upgrading equipment and developing strategies to minimize lost record appear to be key actions required to improve the reliability and accuracy of the streamflow data generated in the State.

Future studies of the cost-effectiveness of the streamflow-gaging program should be continued and should include investigation of the optimum ratio of discharge measurements to the total number of site visits for each station. Additionally, investigations of cost-effective ways to reduce missing record are also needed. Changes in data-user interests and in demands for streamflow information will require subsequent addition and deletion of stream gages. Such changes will affect the operation of other stations in the program both because of the dependence of the information that is generated (data redundancy) between stations and because of the dependence of the costs of collecting the data from which the information is derived.

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