COST-EFFECTIVENESS OF THE STREAM-GAGING PROGRAM IN NORTH CAROLINA

By Robert R. Mason and N. Macon Jackson, Jr.

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FACTORS FOR CONVERTING INCH-POUND TO METRIC (SI) UNITS

Multiply inch-pound units	by	To obtain SI units
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	Kilometer (km)
	Area	
Square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow	
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 study of the cost-effectiveness of the stream-gaging program in North Carolina. Data uses and funding sources were identified for the 146 continuous stream gages currently being operated in North Carolina with a budget of $777,600. Nine stations were identified as being operated solely to provide data for developing regional relations and having 20 years or more of record; seven of these stations were nominated for discontinuance. Data collected at fourteen stations were identified as having uses specific only to short-term studies; four of these stations are scheduled for discontinuance, and five for downgrading from recording to partial-record status. The remaining 130 stations should be maintained in the program.

Large parts of North Carolina's Coastal Plain were identified as having sparse streamflow data. This sparsity should be remedied as funds are made available. Efforts should also be directed toward defining the effects of drainage improvements on local hydrology and streamflow characteristics.

The average standard error of estimation of streamflow records in North Carolina is 18.6 percent. The overall level of accuracy of the 146 station network could be improved under the present budget if the number of visits in excess of the minimum required to service recording equipment were targeted to stations where additional measurements would most reduce the uncertainty of the network. The average standard error could be reduced to about 12 percent if there were no lost record due to equipment failure or other cause. Likewise, this says that streamflow records based on actual stage data have a standard error of 12 percent.

A minimum budget of $762,000 is required to operate the 146-gage program; a budget less than this does not permit proper service and maintenance of the gages and recorders. At the minimum budget, and with the optimum allocation of field visits, the average standard error is 17.6 percent. The maximum budget analyzed was $972,000, which resulted in an average standard error of 11.8 percent.

The standard errors of estimate given in this report are those that would occur if daily discharges were computed through the use of methods described in this study. No attempt has been made to estimate standard errors for discharges that are computed by other means. Such errors could differ greatly from the errors computed in the report. The magnitude and direction of the differences would be a function of methods used to account for shifting controls and for estimating discharges during periods of missing record.

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 U.S. Geological Survey. The data are collected in cooperation with State and local governments and other Federal agencies. The Survey is presently (1984) operating approximately 8,000 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 Survey is presently (1984) undertaking another nationwide analysis of the stream-gaging program that will be completed over a 5-year period; 20 percent of the program is analyzed each year. The objective of this analysis is to define and document the most cost-effective means of furnishing streamflow information.

For every continuous-record gaging station, the analysis identifies the principal uses of the data and relates these uses to funding sources. Gaging stations for which data are no longer needed are identified, as are deficient or unmet data demands. In addition, 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 aspect of the analysis is to identify less costly alternative methods of furnishing the needed information; among these are flow-routing models and statistical methods. The stream-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 part of the analysis 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 analysis. A steepest descent optimization program uses these uncertainty functions, information on practical stream-gaging routes, the various costs associated with stream gaging, and the total operating budget to identify the visit frequency for each station that minimizes the overall uncertainty in the streamflow. The stream-gaging program that results from this analysis will meet the expressed water-data needs in the most cost-effective manner.

This report is organized into five sections; the first being an introduction to the stream-gaging activities in North Carolina and to the study itself. The middle three sections each contain discussions of an individual step of the analysis. Because of the sequential nature of the steps and the dependence of subsequent steps on the previous results, conclusions are drawn at the end of each of the middle three sections. The complete study is summarized in the final section.

History of the Stream-Gaging Program in North Carolina

The streamflow data-collection program has evolved through the years as the Federal and State interests in surface-water resources have increased and funds for operating the stream-gaging network have become available. Cooperative agreements between the U.S. Geological Survey and the State of North Carolina for the systematic collection of streamflow records began in 1895 and continued until 1909. After a lapse of 9 years, State cooperation resumed in October 1918, and has continued to date without interruption. This cooperative program, together with agreements with other Federal agencies, principally the U.S. Army Corps of Engineers and the Tennessee Valley Authority, and with many municipalities and other agencies, permitted the gradual expansion of the network of streamflow stations to a total of 177 in 1969. A study by Goddard and others (1970) described the development of North Carolina's surface-water program and proposed a program to meet the future needs of water-data users. Sixty-five stations were recommended for discontinuance and five new stations were proposed. After consultation with cooperative agencies, the network was reduced and the total number of active stations has remained in the 140 to 155 range since that time. Currently, there are 146 active stations in the network and continuous records are available for various periods of time at 203 discontinued stations. The number of continuous stream gages historically operated within the state of North Carolina is given in figure 1.

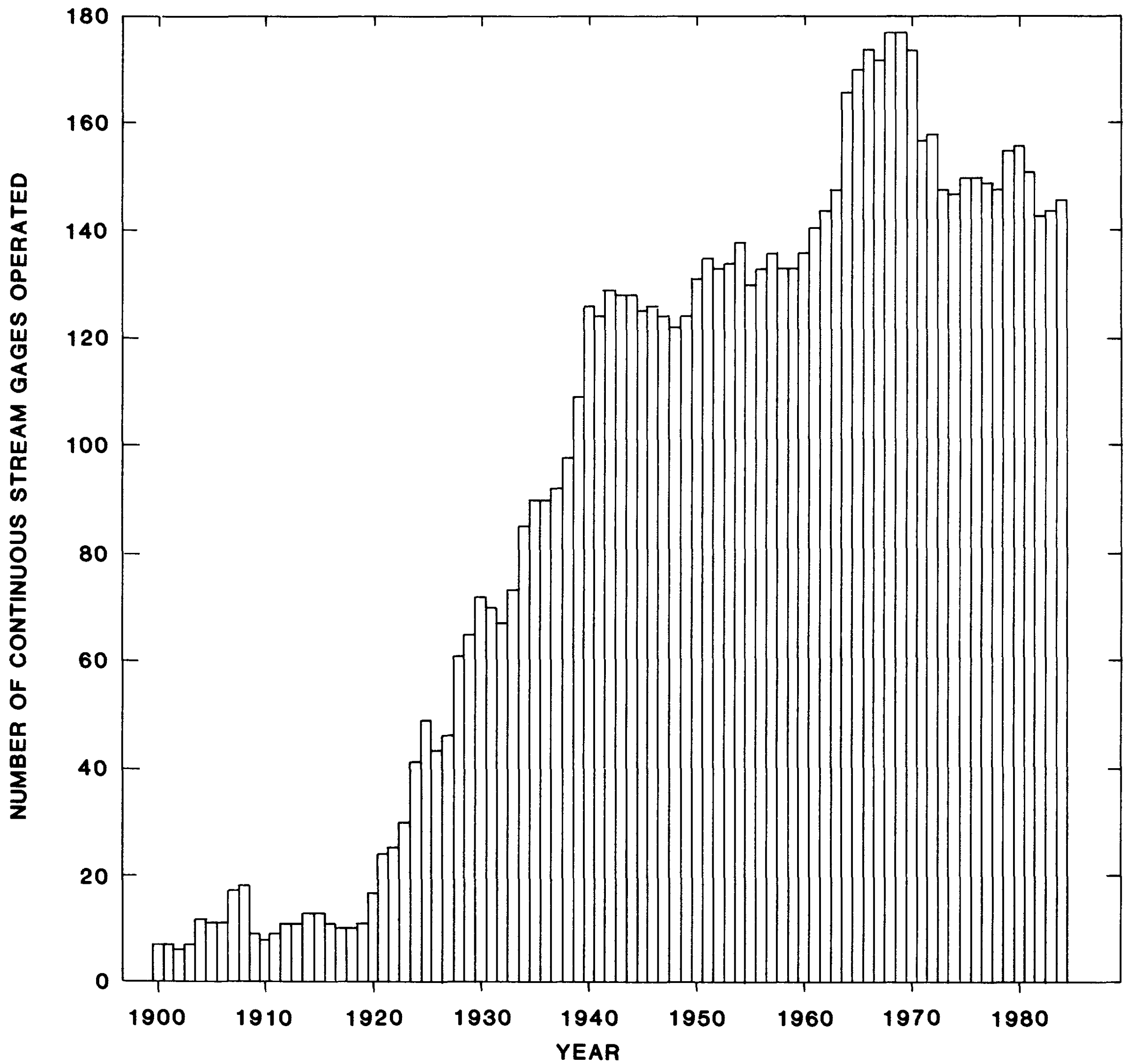

Figure 1.--History of recording stream gaging in North Carolina, 1900-84.

Prior to about 1950, gaging stations were established mainly to: (1) meet needs for planning or managing developments along streams, such as hydroelectric or flood control reservoirs, and (2) achieve some degree of areal hydrologic sampling. Most gages were located on larger streams; little was known about the flow characteristics of smaller streams draining less than about 50 square miles.

In the late 1940's, network operations were expanded to include "low-flow, partial-record" stations. Stations in the low-flow network were routinely replaced after several years of operation during which time active low-flow stations increased from about 100 in the mid-fifties to 225 in 1964. About 200 stations were in operation when the program was discontinued in 1968. Currently, data are available for approximately 515 low-flow partial-record stations.

In 1968 network operations were further expanded to provide time-of-sample discharges, at more than a thousand sites, where ambient water quality conditions were to be defined. Currently, this part of the network contains 212 stations, including 101 located at existing continuous-record stations.

Discharge measurements are made at miscellaneous sites during extreme floods and droughts, or to obtain data for a special need. The number of measured sites vary from a few in "normal" years to a large number in flood or drought years, such as 1954. One or more discharge measurements have been made at more than 3,300 miscellaneous sites across the state.

A network of 120 high-flow partial-record stations, located on predominately small, rural streams, was established during the period 1952-54. Most of these stations were discontinued in 1971, after sufficient data was collected to define flood-frequency distributions.

A study of the effects of urban development on flood magnitude and frequency was started in 1962. An initial network, consisting of four continuous-record and seven high-flow partial-record stations in Charlotte was expanded in 1966-67 to cover the Piedmont Province; 35 additional stations were established in the cities of Charlotte, Winston-Salem, Durham, Lenoir, and Morganton. All of these stations were discontinued in 1970, except for five continuous-record stations in Charlotte. Currently, five urban stations in several cities in the Coastal Plain are operated to obtain data to develop areal-flood relations for developing areas in the Coastal Plain.

Current North Carolina Stream-Gaging Program

North Carolina has three major physiographic Provinces--the Blue Ridge, the Piedmont, and the Coastal Plain. The locations of these Provinces and continuous record stations in operation (1984) are shown on figure 2. Twenty-six stations are in Blue Ridge, 80 are in the Piedmont, and 40 are in the Coastal Plain. Areal distribution of stations is generally even across most areas of the Provinces, except the eastern Coastal Plain, where few stations exist.

The cost of operating the 146 stations in 1984 is $777,600.

Selected hydrologic data including drainage area, period of record, and mean annual flow, for active stations are listed in table 1 in downstream order. Mean annual flows are not listed in table 1 for stations having less than 5 years record.

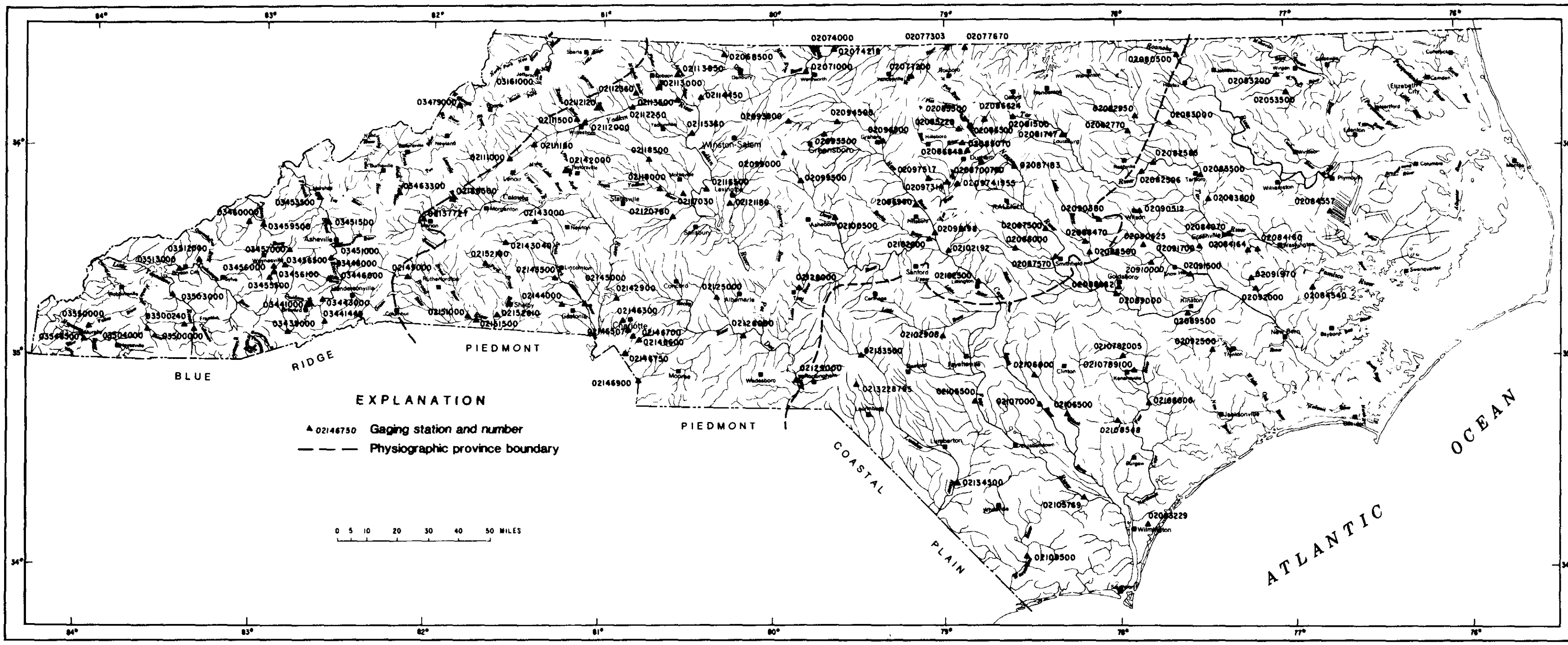

Figure 2.--Location of recording stream gages in North Carolina.

Table 1.--Selected hydrologic data for active stations in the North Carolina surface-water program, 1984

Station no.	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
02053200	Potecasi Creek near Union	225	1/Mar. 1958 -	234
02053500	Ahoskie Creek at Ahoskie	63.3	Jan. 1950 -	63.4
02068500	Dan River near Francisco	129	2/Aug. 1924 -	190
02071000	Dan River near Wentworth	1053	3/Oct. 1939 -	1212
02074000	Smith River at Eden	538	Oct. 1939 -	4/617
02074218	Dan River near Mayfield	1778	Oct. 1976 -	2077
02077200	Hyco Creek near Leasburg	45.9	July 1964 -	44.3
02077303	Hyco River below Afterbay Dam near McGehees Mill	202	Oct. 1973 -	193
02077670	Mayo Creek near Bethel Hill	53.5	Aug. 1977 -	40.3
02080500	Roanoke River at Roanoke Rapids	8386	Dec. 1911 -	5/8065
02081500	Tar River near Tar River	167	2/Oct. 1939 -	154
02081747	Tar River at U.S. 401 at Louisburg	427	6/Oct. 1963 -	422

1/Occasional low-flow measurement, water years 1953-57.
2/Monthly discharge only for some periods.
3/Monthly discharge only for October 1939.
4/Mean flow adjusted for storage in Philpott Lake.
5/Mean flow adjusted for storage in Kerr Lake.
6/Prior to October 1972, medium and high discharges only.

Table 1.--Selected hydrologic data for active stations in the North Carolina surface-water program (continued)

Station no.	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
02082506	Tar River below Tar River Reservoir near Rocky Mount	777	Aug. 1972 -	811
02082585	Tar River at N.C. 97 at Rocky Mount	925	Aug. 1976 -	860
02082770	Swift Creek at Hilliardston	166	July 1963 -	146
02082950	Little Fishing Creek near White Oak	177	Oct. 1959 -	161
02083000	Fishing Creek near Enfield	526	Oct. 1923 -	487
02083500	Tar River at Tarboro	2183	July 1896-Dec. 1900, Oct. 1931 -	2213
02083800	Conetoe Creek near Bethel	78.1	Dec. 1956 -	82.7
02084070	Green Mill Run at Arlington Boulevard at Greenville	9.1	Mar. 1980 -	--
02084160	Chicod Creek at SR 1760 near Simpson	45	Oct. 1975 -	47.5
02084164	Juniper Branch near Simpson	7.5	Oct. 1975 -	7.31
02084540	Durham Creek at Edward	26.0	7/ 1950-1954, 1956-1965, Aug. 1965 -	37.7
02084557	Van Swamp near Hoke	23.0	May 1977 -	27.0

7/ Occasional low-flow measurements, water years 1950-54, 1956-65.

Table 1.--Selected hydrologic data for active stations in the North Carolina surface-water program (continued)

Station no.	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
02085070	Eno River near Durham	141	8/ 1955, 1963 -	125
02085220	Little River near Orange Factory	80.4	9/ 1930, 1954-59, Sept. 1961 -	71.4
02085500	Flat River at Bahama	149	July 1925 -	142
02086500	Flat River below Dam near Bahama	168	Aug. 1927-Sept. 1959, Aug. 1961-Sept. 1963, Oct. 1982 -	154
02086624	Knap of Reeds Creek near Butner	43.0	1954-55, Sept. 1982 -	--
02086849	Ellerbe Creek near Gorman	21.9	Oct. 1982 -	--
0208700780	Little Lick Creek near Durham	10.1	Sept. 1982 -	--
02087183	Neuse River near Falls	772	July 1970 -	808
02087500	Neuse River near Clayton	1150	July 1927 -	1171
02087570	Neuse River at Smithfield	1206	10/ Oct. 1959 -	1331
02088000	Middle Creek near Clayton	83.5	3/ Oct. 1939 -	90.5
02088470	Little River near Kenly	191	July 1964 -	184

3/ Monthly discharge only for October 1939.
8/ Occasional low-flow measurements, water year 1955.
9/ Occasional low-flow measurements, water years 1930, 1954-59, 1961.
10/ Prior to October 1970, medium and high discharges only.

Table 1.--Selected hydrologic data for active stations in the North Carolina surface-water program (continued)

Station no.	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
02088500	Little River near Princeton	232	[2]Feb. 1930 -	250
02088682	Big Ditch at Retha Street at Goldsboro	2.17	Feb. 1980 -	--
02089000	Neuse River near Goldsboro	2399	Feb. 1930 -	2497
02089500	Neuse River at Kinston	2692	Feb. 1930 -	2865
02090380	Contentnea Creek near Lucama	161	Sept. 1964 -	149
02090512	Hominy Swamp at Phillips Street at Wilson	8.2	Aug. 1978 -	--
02090625	Turner Swamp near Eureka	2.1	June 1968 -	2.29
02091000	Nahunta Swamp near Shine	80.4	[2]Apr. 1954 -	86.1
02091500	Contentnea Creek at Hookerton	729	Nov. 1928 -	759
02091700	Little Contentnea Creek near Farmville	93.3	[11]Oct. 1956 -	116
02091970	Creeping Swamp near Vanceboro	27	Mar. 1971 -	35.6
02092000	Swift Creek near Vanceboro	182	Jan. 1950 -	207
02092500	Trent River near Trenton	168	Jan. 1951 -	198

[2] Monthly discharge only for some periods.
[11] Occasional low-flow measurements, water years 1952-54, 1956.

Table 1.--Selected hydrologic data for active stations in the North Carolina surface-water program (continued)

Station no.	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
02093229	Hewletts Creek at SR 1102 near Wilmington	1.98	Nov. 1976 -	3.76
02093800	Reedy Fork near Oak Ridge	20.6	Oct. 1955 -	23.4
02094500	Reedy Fork near Gibsonville	131	Sept. 1928 -	100
02095500	North Buffalo Creek near Greensboro	37.1	Aug. 1928 -	54.9
02096500	Haw River at Haw River	606	Oct. 1928 -	574
02096960	Haw River near Bynum	1275	Oct. 1973 -	1337
02097314	New Hope Creek near Blands	75.9	Oct. 1982 -	--
020974955	Northeast Creek near Genlee	21.1	Oct. 1982 -	--
02097517	Morgan Creek near Chapel Hill	41.0	Oct. 1982 -	--
02098198	Haw River below B. Everett Jordan Dam near Moncure	1689	Oct. 1965 -	12/1593
02099000	East Fork Deep River near High Point	14.8	July 1928 -	16.5
02099500	Deep River near Randleman	125	Oct. 1928 -	125
02100500	Deep River at Ramseur	349	Nov. 1922 -	352
02102000	Deep River at Moncure	1434	July 1930 -	1452

12/Adjusted for storage in B. Everett Jordan Lake.

Table 1.--Selected hydrologic data for active stations in the North Carolina surface-water program (continued)

Station no.	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
02102192	Buckhorn Creek near Corinth	76.3	June 1972 -	68.0
02102500	Cape Fear River at Lillington	3464	Dec. 1923 -	3368
02102908	Flat Creek near Inverness	7.63	June 1968 -	12.6
02105500	Cape Fear River at William O. Huske Lock near Tarheel	4852	Oct. 1937 -	4957
02105769	Cape Fear River at Lock 1 near Kelly	5255	July 1969 -	5753
02106000	Little Coharie Creek near Roseboro	92.8	Jan. 1950 -	116
02106500	Black River near Tomahawk	676	Oct. 1951 -	784
02107000	South River near Parkersburg	379	Oct. 1951 -	418
0210782005	Nahunga Creek at N.C. Highway 11	8.3	Aug. 1982 -	--
0210789100	Grove Creek at Kenansville	22.5	Aug. 1982 -	--
02108000	Northeast Cape Fear River near Chinquapin	599	July 1940 -	725
02108548	Little Róckfish Creek at Wallace	7.8	Sept. 1976 -	10.4
02109500	Waccamaw River at Freeland	680	July 1939 -	706
02111000	Yadkin River at Patterson	28.8	2/ Oct. 1939 -	49.6

2/ Monthly discharge only for some periods.

Table 1.--Selected hydrologic data for active stations in the North Carolina surface-water program (continued)

Station no.	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
02111180	Elk Creek at Elkville	48.1	Oct. 1965 -	104
02111500	Reddies River at North Wilkesboro	89.2	2/ Oct. 1939 -	144
02112000	Yadkin River at Wilkesboro	504	Apr. 1903-1909, Oct. 1920 -	13/ 824
02112120	Roaring River near Roaring River	128	14/ 1925, 1947, 1949-56, 1963, Apr. 1964 -	193
02112250	Yadkin River at Elkin	869	Apr. 1964 -	13/ 1434
02112360	Mitchell River near State Road	78.8	15/ 1952-58, 1963, Apr. 1964 -	128
02113000	Fisher River near Copeland	128	Oct. 1931 -	183
02113500	Yadkin River at Siloam	1226	Oct. 1976 -	13/ 2015
02113850	Ararat River at Ararat	231	Apr. 1964 -	312
02114450	Little Yadkin River at Dalton	42.8	Aug. 1960 -	46.5
02115360	Yadkin River at Enon	1694	July 1964 -	13/ 2566
02116500	Yadkin River at Yadkin College	2280	July 1928 -	2974

2/ Monthly discharge only for some periods.
13/ Mean flow adjusted for storage in W. Kerr Scott Reservoir.
14/ Occasional low-flow measurements, water years 1925, 1947, 1949-56, 1963.
15/ Occasional low-flow measurements, water years 1952-58, 1963.

Table 1.--Selected hydrologic data for active stations in the North Carolina surface-water program (continued)

Station no.	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
02118000	South Yadkin River near Mocksville	306	Oct. 1938 -	342
02118500	Hunting Creek near Harmony	155	[2/]Oct. 1950 -	205
02120780	Second Creek near Barber	118	[16/]1949-57, 1961-63, Apr. 1979	--
02121180	North Potts Creek at Linwood	9.62	May 1979 -	--
02125000	Big Bear Creek near Richfield	55.6	May 1954 -	56.9
02126000	Rocky River near Norwood	1372	Oct. 1929 -	1331
02128000	Little River near Star	106	[17/]1949-54, Apr. 1954 -	110
02129000	Pee Dee River near Rockingham	6863	Aug. 1906-Jan. 1912, Oct. 1927 -	[18/]8012
0213228795	Jordan Creek at Silver Hill	.10	Oct. 1983 -	--
02133500	Drowning Creek near Hoffman	183	Oct. 1939 -	259
02134500	Lumber River at Boardman	1228	Sept. 1929 -	1325
02137727	Catawba River near Pleasant Gardens	126	[19/]1963, 1970-73, 1975, Oct. 1980 -	--

[2/]Monthly discharge only for some periods.
[16/]Occasional low-flow measurements, water years 1949-57, 1961-63.
[17/]Occasional low-flow measurements, water years 1949-54.
[18/]Mean flow based on water years 1906-11, 1927-82.
[19/]Occasional low-flow measurements, water years 1963, 1970-73.

Table 1.--Selected hydrologic data for active stations in the North Carolina surface-water program (continued)

Station no.	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
02138500	Linville River near Nebo	66.7	20/ June 1922 -	148
02142000	Lower Little River near All Healing Springs	28.2	21/ Oct.-Dec. 1952, Jan. 1953 -	37.9
02142900	Long Creek near Paw Creek	16.4	June 1965 -	17.8
02143000	Henry Fork near Henry River	83.2	July 1925 -	133
02143040	Jacob Fork at Ramsey	25.7	22/ 1960-61, Oct. 1961 -	50.1
02143500	Indian Creek near Laboratory	69.2	Aug. 1951 -	90.3
02144000	Long Creek near Bessemer City	31.8	2/ Oct. 1952 -	35.8
02145000	South Fork Catawba River at Lowell	628	Jan. 1942-Sept. 1971, Oct. 1982 -	796
02146300	Irwin Creek near Charlotte	30.7	May 1962 -	43.4
02146507	Little Sugar Creek at Archdale Drive at Charlotte	42.6	Oct. 1977 -	75.2
02146600	McAlpine Creek at Sardis Road near Charlotte	39.6	Apr. 1962 -	40.3

2/ Monthly discharge only for some periods.
20/ May 1907 to August 1980 fragmentary.
21/ October to December 1952, monthly discharge only.
22/ Occasional low-flow measurements, water years 1960-61.

Table 1.--Selected hydrologic data for active stations in the North Carolina surface-water program (continued)

Station no.	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
02146700	McMullen Creek at Sharon View Road near Charlotte	6.95	Apr. 1962 -	7.82
02146750	McAlpine Creek below McMullen Creek near Pineville	92.4	Apr. 1974 -	129
02146900	Twelve Mile Creek near Waxhaw	76.5	23/ 1949-60, Oct. 1960 -	72.2
02149000	Cove Creek near Lake Lure	79.0	24/ 1949-50, Oct. 1950 -	135
02151000	Second Broad River at Cliffside	220.0	June 1925 -	312
02151500	Broad River near Boiling Springs	875	June 1925 -	1507
02152100	First Broad River near Casar	60.5	25/ 1949-56, Mar. 1959 -	94.0
02152610	Sugar Branch near Boiling Springs	1.42	26/ 1954-68, June 1968 -	2.21
03161000	South Fork New River near Jefferson	205	2/ Oct. 1924 -	429
03439000	French Broad River at Rosman	67.9	2/ May 1907-June 1909, Oct. 1935 -	240
03441000	Davidson River near Brevard	40.4	2/ Oct. 1920 -	130

2/ Monthly discharge only for some periods.
23/ Occasional low-flow measurements, water years 1949-60.
24/ Occasional low-flow measurements, water years 1949-50.
25/ Occasional low-flow measurements, water years 1949-56.
26/ Annual maximum, water years 1954-68.

Table 1.--Selected hydrologic data for active stations in the North Carolina surface-water program (continued)

Station no.	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
03441440	Little River above High Falls near Cedar Mountain	26.8	Oct. 1962 -	108
03443000	French Broad River at Blantyre	296	2/ Oct. 1920 -	993
03446000	Mills River near Mills River	66.7	2/ Sept. 1924-26, Oct. 1933 -	169
03448000	French Broad River at Bent Creek	676	2/ Oct. 1933 -	1694
03451000	Swannanoa River at Biltmore	130	2/ Oct. 1920-Sept. 1926, May 1934 -	162
03451500	French Broad River at Asheville	945	2/ Oct. 1895 -	2090
03453500	French Broad River at Marshall	1332	Oct. 1942 -	2462
03455500	West Fork Pigeon River above Lake Logan, near Hazelwood	27.6	Feb. 1954 -	104
03456100	West Fork Pigeon River at Bethel	58.4	Jan. 1981 -	--
03456500	East Fork Pigeon River near Canton	51.5	Mar. 1954 -	144
03457000	Pigeon River at Canton	130	2/ May 1907-June 1909, Oct. 1928 -	322
03459500	Pigeon River near Hepco	350	July 1927 -	676

2/ Monthly discharges only for some periods.

Table 1.--Selected hydrologic data for active stations in the North Carolina surface-water program (continued)

Station no.	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
03460000	Cataloochee Creek near Cataloochee	49.2	2/Oct. 1933-Sept. 1952, Oct. 1962 -	110
03463300	South Toe River near Celo	43.3	July 1957 -	148
03479000	Watauga River near Sugar Grove	92.1	2/Oct. 1939 -	176
03500000	Little Tennessee River near Prentiss	140	2/Oct. 1943 -	393
03500240	Cartoogechaye Creek near Franklin	57.1	27/1944, 1947, 1953-55, 1960, 1961 -	147
03503000	Little Tennessee River at Needmore	436	Oct. 1943-Sept. 1981, Oct. 1983 -	1087
03504000	Nantahala River near Rainbow Springs	51.9	Oct. 1940 -	205
03512000	Oconaluftee River at Birdtown	184	July 1945-Sept. 1946, July 1948 -	520
03513000	Tuckasegee River at Bryson City	655	July 1945-Sept. 1946, July 1948-Sept. 1981, Oct. 1983 -	524

2/Monthly discharge only for some periods.
27/Occasional low-flow measurements, water years 1944, 1947, 1953-55, 1960.

Table 1.--Selected hydrologic data for active stations in the North Carolina surface-water program (continued)

Station no.	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
03458500	Hiwassee River above Murphy	406	28/ June 1896-Aug. 1897, Oct. 1897 -	29/ 921
03550000	Valley River at Tomotla	104	June 1904-Dec. 1909, Jan. 1914-Apr. 1917, Oct. 1918 -	257

28/ June 1896 to August 1897, gage heights only.
29/ Adjusted for storage.

USES, FUNDING, AND AVAILABILITY OF CONTINUOUS STREAMFLOW DATA

The relevance of a station is defined by the uses that are made of its data. The uses of the data for each active station were identified through discussions with known data users. Results of these discussions were used as an aid in evaluating the relative importance of each station; those that may be considered for discontinuation were identified.

Data uses for active stations are listed in table 2 by sources of funding and the frequency at which data are provided. Nine data uses and 4 funding categories are provided.

Data-Use Classes

Data-use classes include regional hydrology, hydrologic systems, legal obligations, planning and design, project operation, hydrologic forecast, water quality monitoring, research and other. Definitions for each data class are provided below. It should be noted that these classes are not mutually exclusive. Data from most stations has multiple uses.

Regional Hydrology

For data to be useful in defining regional hydrology, a stream gage must be largely unaffected by manmade storage or diversion. In this class of uses, 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. For example, large amounts of manmade storage may exist in the basin providing the outflow is uncontrolled. These stations are useful in developing regionally transferable information about the relationship between basin characteristics and streamflow.

One hundred fifteen stations fall under regional hydrology; ten of these are hydrologic bench-mark or index stations. One of these stations is located in a watershed relatively free of manmade alteration; the other nine stations are located in different regions of the State, and are used to monitor long-term hydrologic trends.

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 systems stations. They include diversions and return flows and stations that are useful for defining the interaction of water systems.

Twenty-nine stations are in this category. Hydrologic bench-mark and index stations are included because they account for current and long-term conditions of the hydrologic systems they gage. Six Federal Energy Regulatory Commission (FERC) stations are also included. FERC stations monitor the compliance of control structures to downstream flow requirements.

The U.S. Army Corps of Engineers uses ten stations to define hydrologic conditions of the systems gaged.

The remaining three hydrologic system stations have other primary uses, but are included in this category because they offer information on either the hydrologic conditions of a system or its interaction with other systems.

Legal Obligations

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

Planning and Design

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, 12 stations are being operated for planning or design purposes. Seven of these stations are used by the U.S. Army Corps of Engineers in ongoing studies. The other five are used for water-supply planning by municipalities.

Project Operation

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.

Thirty-seven stations are used for project operations. Twenty-one of these stations aid operators managing flood control structures; eleven are used to monitor the effluents of industrial operators or steam generating plants. Eight stations are used to aid operators of hydropower structures, while three are used by municipal water-supply operators.

Hydrologic Forecasts

Stations in this category are regularly used to provide information for hydrologic forecasting, such as flood forecasts for a specific river reach, or periodic (daily, weekly, monthly, or seasonal) flow-volume forecasts for 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-five stations are in this category. Data produced by these stations are used by the U.S. National Weather Service (NWS) to predict floods at downstream sites.

Water-Quality Monitoring

Stations where regular water-quality or sediment-transport monitoring is being conducted, and where the availability of streamflow data contribute to the utility or is essential to the interpretation of the water-quality or sediment data, are designated as water-quality-monitoring sites. One hundred nine stations are used for water-quality monitoring; eleven of these are national network stations.

National network stations include one bench-mark, eight National Stream Quality Accounting Network (NASQAN), one sediment-transport, and one national trends network. Bench-mark stations monitor water-quality characteristics of streams that have been and will continue to be relatively free from manmade influence. NASQAN stations are used to assess water-quality trends. Sediment-transport stations provide sediment transport and sediment loading data for planning and management programs. National trend network stations monitor acid deposition.

One hundred and one stations are used by the North Carolina Department of Natural Resources and Community Development to monitor the ambient water-quality of streams. Four stations monitor the water quality of major streams and detect changes and trends in quality. Four stations, are used to monitor water-quality changes resulting from stream channel restoration and modification. Eight stations monitor nutrient loads of inflow to two lakes.

Research

Twenty stations are included in this category; they support a particular area of research and special studies to determine various hydrologic relations. Typically, research stations are only operated for a few years.

Nine stations monitor the effects of urban development on flood magnitude and frequency. Four stations monitor the effects of stream channel modification on flow characteristics and one station supports a long-term national study of the effects of atmospheric deposition on stream quality. Six stations monitor the quality of water flowing into two major reservoirs.

Funding

The sources of funding for the streamflow program are The U.S. Geological Survey Federal program, other Federal agencies (OFA), U.S. Geological Survey Federal-State cooperative program, and other non-Federal entities. Each source is discussed below:

1. Federal program.--Funds directly appropriated to the Survey, Federal program.

2. Other Federal Agencies (OFA).--Funds provided to the Survey by other Federal agencies, such as the U.S. Army Corps of Engineers, Tennessee Valley Authority, and so forth.

3. U.S. Geological Survey Federal-State Cooperative Program (Coop program)--Funds provided from Survey cooperative-designated funding and from non-Federal cooperating agencies. Contribution of a non-Federal cooperating agency may be in the form of direct services or cash, or both.

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

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

Twenty-one entities currently are contributing funds to the North Carolina stream-gaging program.

Frequency of Data Availability

Frequency of data availability refers to the times at which the streamflow data may be furnished to the users. In this category, four distinct possibilities exist. Data are available by direct-access telemetry equipment for immediate use, by periodic release of provisional data, in publication format through the annual data report published by the Survey for North Carolina (U.S. Geological Survey, 1983), or obtained directly by on-site observers. Data for all currently active stations are published annually; data for 41 stations are available on a real-time basis, and data for 73 stations are released on a provisional basis.

Data-Use Presentation

Data-use and ancillary information are presented for each active station in table 2, which is replete with footnotes to expand the information conveyed.

Data-Use Conclusions

A review of the data-use and funding information presented in table 2 indicates that most stations have multiple data uses and are currently funded. However, 13 regional hydrology stations are operated only for developing regional relations. Goddard (1970) illustrated that the accuracy of streamflow characteristics at a station is little improved with records longer than 20 years and proposed that stations operated to collect regional hydrology information be discontinued after 20 years operation. The following nine regional hydrology stations have 20 or more years of record and should be considered for discontinuance:

Station No.	Station
02084540	Durham Creek near Edward
02099000	East Fork Deep River near High Point
02112360	Mitchell River near State Road
02114450	Little Yadkin River near Dalton
02125000	Big Bear Creek near Richfield
02142000	Lower Little River near All Healing Springs
02149000	Cove Creek near Lake Lure
03448000	French Broad River at Bent Creek
03500240	Cartoogechaye Creek near Franklin

Conetoe Creek near Bethel was channelized before the gage was installed, and Durham Creek near Edward is in the eastern Coastal Plain in an area of large ground-water withdrawals. These stations provide current information about the impacts of development in the Coastal Plain. Very little long-term hydrologic information exists in these situations. Therefore, operations of these stations should continue.

Table 2.--Data-Use Table

STATION NUMBER	DATA USE: REGIONAL HYDROLOGY	DATA USE: HYDROLOGIC SYSTEMS	DATA USE: LEGAL OBLIGATIONS	DATA USE: PLANNING AND DESIGN	DATA USE: PROJECT OPERATION	DATA USE: HYDROLOGIC FORECASTS	DATA USE: WATER-QUALITY MONITORING	DATA USE: RESEARCH	DATA USE: OTHER	FUNDING: FEDERAL PROGRAM	FUNDING: OFA PROGRAM	FUNDING: COOP PROGRAM	FUNDING: OTHER NON-FEDERAL	FREQUENCY OF DATA AVAILABILITY
02 0532 00	*						1					1		A
02 0535 00	*						1					1		A
02 0685 00	*						1					1		A P
02 0710 00	*			2			1				3			A P
02 0740 00		4			5		1				3	1		A P
02 0742 18		4			7	6	1 7					1		ATP
02 0772 00	*				8		8					1		A observer
02 0773 03					9		1 9					1		A observer
02 0776 70					10							1		A observer
02 0805 00		12			13	6	1 11				3		13	ATP
02 0815 00	*						1				3	1		A P
02 0817 47	*					6	1				3			ATP
02 0825 06					14	6	1					14		ATP
02 0825 85					14	6	1					14		ATP
02 0827 70	*						1				3			A P
02 0829 50	*						1					1		A P
02 0830 00	*	15				6	1			15				A P observer
02 0835 00	*					6	1 11			11	3	1		ATP
02 0838 00	*											1		A
02 0840 70	*							16				16		A
02 0841 60	*						17	17			17			A
02 0841 64	*						17	17			17			A
02 0845 40	*											1		A
02 0845 57	*											1		A
02 0850 70	*			18	19		1 20	20			3	18		AT

1. State of North Carolina, Department of Natural Resources and Community Development.
2. South Boston, Virginia, Flood Control Study.
3. U.S. Army Corps of Engineers, Wilmington, N.C. District.
4. Dan River, Roanoke River System.
5. Operation of Philpott Lake.
6. U.S. National Weather Service, Flood Forecasting.
7. Duke Power Company, Dan River Steam Electric Generating Plant Operation.
8. Carolina Power & Light Company, Hyco Lake Operation.
9. Carolina Power & Light Company, Roxboro Steam Electric Generating Plant Operation.
10. Carolina Power & Light Company, Mayo Steam Electric Generating Plant Reservoir Operation.
11. National Stream Quality Accounting Network.
12. Federal Energy Regulatory Commission, Hydropower License Requirement.
13. Virginia Electric & Power Company, Hydropower System Operation.
14. City of Rocky Mount, N.C., Tar River Reservoir Operation.
15. Long-Term Index Gaging Station.
16. State of North Carolina, Department of Transportation, Urban Flood Hydrology.
17. Soil Conservation Service, Hydrologic Effects of Channelization.
18. City of Durham, Public Water Supply Planning.
19. Operation of Falls Lake.
20. Water Quality of Inflow to Falls Lake.

* Station used for regional hydrology purposes.
A Data available through annual data report published by the Survey for North Carolina
P Data available through periodic release of provisional data.
T Data available by direct-access telemetry.

observer - Data obtained by direct observer readings.

Table 2.--Data-Use Table (continued)

STATION NUMBER	DATA USE: REGIONAL HYDROLOGY	HYDROLOGIC SYSTEMS	LEGAL OBLIGATIONS	PLANNING AND DESIGN	PROJECT OPERATION	HYDROLOGIC FORECASTS	WATER-QUALITY MONITORING	RESEARCH	OTHER	FUNDING: FEDERAL PROGRAM	OFA PROGRAM	COOP PROGRAM	OTHER NON-FEDERAL	FREQUENCY OF DATA AVAILABILITY
02 0852 20	*			18	19		20	20			3	18		AT
02 0855 00	*			18								18		A
02 0865 00					19		20	20			3			AT
02 0866 24	*						1 20	20			3			A P
02 0868 49	*						1 20	20			3			A P
02 0870 0780	*						1 20	20			3			A P
02 0871 83					19 21		1 22				3	21		AT
02 0875 00					19		1 22				3	1		ATP
02 0875 70					19	6	1				3			ATP
02 0880 00	*						1					1		A P
02 0884 70	*			23			1				3			A P
02 0885 00	*			23			1				3	1		A
02 0886 82	*							16				16		A
02 0890 00						6	1					1		AT
02 0895 00	*					6	1 11			11	3	1		A observer
02 0903 80							1					1		A
02 0905 12	*						1	16				16		A
02 0906 25	*						1					1		A
02 0910 00	*						1					1		A
02 0915 00	*	15		23			1 11			15	3	1		A
02 0917 00	*						1					1		A
02 0919 70	*											1		A
02 0920 00	*						1				3			A
02 0925 00	*	15					1			15				A
02 0932 29	*							16				16		A

1. State of North Carolina, Department of Natural Resources and Community Development.
3. U.S. Army Corps of Engineers, Wilmington, N.C. District.
6. U.S. National Weather Service, Flood Forecasting.
11. National Stream Quality Accounting Network.
15. Long-Term Index Gaging Station.
16. State of North Carolina, Department of Transportation, Urban Flood Hydrology.
18. City of Durham, Public Water Supply Planning.
19. Operation of Falls Lake.
20. Water Quality of Inflow to Falls Lake.
21. City of Raleigh, Public Water Supply Operation.
22. Water Quality Accounting Station.
23. Neuse River Basin, Flood Control Study.

* Station used for regional hydrology purposes.
A Data available through annual data report published by the Survey for North Carolina
P Data available through periodic release of provisional data.
T Data available by direct-access telemetry.

observer - Data obtained by direct observer readings.

Table 2.--Data-Use Table (continued)

STATION NUMBER	DATA USE: REGIONAL HYDROLOGY	HYDROLOGIC SYSTEMS	LEGAL OBLIGATIONS	PLANNING AND DESIGN	PROJECT OPERATION	HYDROLOGIC FORECASTS	WATER-QUALITY MONITORING	RESEARCH	OTHER	FUNDING: FEDERAL PROGRAM	OFA PROGRAM	COOP PROGRAM	OTHER NON-FEDERAL	FREQUENCY OF DATA AVAILABILITY
02 0938 00	*			24			1					24		A P
02 0945 00				24			1					24		A P
02 0955 00	*						1					1		A P
02 0965 00	*				25		1				3	1		ATP
02 0969 60	*				25		1 22				3			ATP
02 0973 14	*						1 26				3			A P
02 0974 1955	*						1 26				3			A P
02 0975 17	*						26				3			A P
02 0981 98					25		1 22				3	1		ATP
02 0990 00	*											1		A
02 0995 00	*			27			1				3	1		A P
02 1005 00	*			27			1				3	1		A P
02 1020 00	*	15			25		1				3	1		ATP
02 1021 92		28					1					1		A P
02 1025 00					25		1				3	1		ATP
02 1029 08	*						1					1		A P
02 1055 00		29				6	1				3	1		A P observer
02 1057 69		29 30				6	1 11				3	1		ATP
02 1060 00	*						1					1		A P
02 1065 00	*						1					1		A P
02 1070 00	*						1					1		A P
02 1078 2005	*							31				31		A
02 1078 9100	*							31				31		A
02 1080 00	*	30					1				3			A P
02 1085 48	*											1		A

1. State of North Carolina, Department of Natural Resources and Community Development.
3. U.S. Army Corps of Engineers, Wilmington, N.C. District.
6. U.S. National Weather Service, Flood Forecasting.
11. National Stream Quality Accounting Network.
15. Long-Term Index Gaging Station.
22. Water Quality Accounting Station.
24. City of Greensboro, Public Water Supply Planning.
25. Operation of B. Everett Jordan Dam.
26. Water Quality of Inflow to B. Everett Jordan Lake.
27. Randleman Lake.
28. Carolina Power & Light Company, Shearon Harris Lake Reservoir Operation.
29. Cape Fear River Basin.
30. Wilmington Harbor.
31. State of North Carolina, Department of Human Resources, Grove Creek Project.

* Station used for regional hydrology purposes.
A Data available through annual data report published by the Survey for North Carolina
P Data available through periodic release of provisional data.
T Data available by direct-access telemetry.

observer - Data obtained by direct observer readings.

Table 2.--Data-Use Table (continued)

STATION NUMBER	DATA USE: REGIONAL HYDROLOGY	HYDROLOGIC SYSTEMS	LEGAL OBLIGATIONS	PLANNING AND DESIGN	PROJECT OPERATION	HYDROLOGIC FORECASTS	WATER-QUALITY MONITORING	RESEARCH	OTHER	FUNDING: FEDERAL PROGRAM	OFA PROGRAM	COOP PROGRAM	OTHER NON-FEDERAL	FREQUENCY OF DATA AVAILABILITY
02 1095 00	*	32					1				3	1		A P
02 1110 00	*				33	6					3	1		ATP
02 1111 80	*				33	6					3			AT
02 1115 00	*										3	1		A
02 1120 00		33			33	6					3			ATP
02 1121 20	*						1				3			A P
02 1122 50		33			33	6	1				3			ATP
02 1123 60	*										3			A
02 1130 00	*	15								15		1		A
02 1135 00		33					1				3			A P
02 1138 50	*			35		6	1				3			A P observer
02 1144 50	*											1		A
02 1153 60		33			33	6	1				3			ATP
02 1165 00		12				6	1 11				3		34	ATP
02 1180 00	*	15			34		1			15		1		ATP
02 1185 00	*						1				3	1		A P
02 1207 80	*						1					1		A P
02 1211 80	*						1					1		A P
02 1250 00	*											1		A
02 1260 00	*					6	1				3			A P observer
02 1280 00	*	15					1					1		A P
02 1290 00		12					1 11			11		1	36	A P
02 1322 8795	*						37	37		38	37			A
02 1335 00	*						1				3	1		A P
02 1345 00	*						1					1		A P

1. State of North Carolina, Department of Nstursl Resources and Community Development.
3. U.S. Army Corps of Engineers, Wilmington, N.C. District.
6. U.S. National Weather Service, Flood Forecasting.
11. National Stream Quality Accounting Network.
12. Federsl Energy Regulatory Commission, Hydropower License Requirement.
15. Long-Term Index Gaging Station.
32. Waccamaw River Basin Study.
33. W. Kerr Scott Reservoir Operation.
34. Yadkin, Inc., Hydropower System Operation.
35. Mt. Airy Flood Control Study.
36. Carolina Power & Light Company, Hydropower System Operation.
37. Environmental Protection Agency, Effects of Acid Deposition on Water Quality.
38. National Trends Network.

* Station used for regional hydrology purposes.
A Data available through annual data report published by the Survey for North Carolina
P Data available through periodic release of provisional data.
T Data available by direct-access telemetry.

observer - Data obtained by direct observer readings.

Table 2.--Data-Use Table (continued)

STATION NUMBER	DATA USE									FUNDING				FREQUENCY OF DATA AVAILABILITY
	REGIONAL HYDROLOGY	HYDROLOGIC SYSTEMS	LEGAL OBLIGATIONS	PLANNING AND DESIGN	PROJECT OPERATION	HYDROLOGIC FORECASTS	WATER-QUALITY MONITORING	RESEARCH	OTHER	FEDERAL PROGRAM	OFA PROGRAM	COOP PROGRAM	OTHER NON-FEDERAL	
02 1377 27	*	12					1						39	A
02 1385 00	*	12					1						39	A P
02 1420 00	*											1		A
02 1429 00	*											1		A
02 1430 00	*						1					1		A P
02 1430 40	*						1					1		A
02 1435 00	*	15					1					1		A
02 1440 00	*						1					1		A
02 1450 00	*						40						40	A P
02 1463 00	*						1	41				41		A P
02 1465 07	*						1	41				41		A P
02 1466 00	*						1	41				41		A P
02 1467 00	*							41				41		A
02 1467 50	*						1	41				41		A P
02 1469 00	*						1					1		A P
02 1490 00	*											1		A
02 1510 00							1					1		A
02 1515 00	*				42							1		ATP
02 1521 00	*						1					1		A
02 1526 10	*						1					1		A
03 1610 00	*						1					1		A P
03 4390 00	*					6	1				43	1		AT
03 4410 00	*				44		1					1		A P observer
03 4414 40	*				45							1		A P
03 4430 00	*					6	1					1		AT

1. State of North Carolina, Department of Natural Resources and Community Development.
6. U.S. National Weather Service, Flood Forecasting.
12. Federal Energy Regulatory Commission, Hydropower License Requirement.
15. Long-Term Index Gaging Station.
39. Duke Power Company, Hydropower System Operation.
40. Duke Power Company, Biological Study of Lake Wylie.
41. City of Charlotte, Charlotte-Mecklenburg County Urban Hydrology Study.
42. Duke Power Company, Broad River Steam Plant Operation.
43. Tennessee Valley Authority.
44. Olin Corporation, Paper Mill Operation.
45. E. I. du Pont de Nemours, plant operations.

* Station used for regional hydrology purposes.
A Data available through annual data report published by the Survey for North Carolina
P Data available through periodic release of provisional data.
T Data available by direct-access telemetry.

observer - Data obtained by direct observer readings.

Table 2.--Data-Use Table (continued)

STATION NUMBER	DATA USE: REGIONAL HYDROLOGY	DATA USE: HYDROLOGIC SYSTEMS	DATA USE: LEGAL OBLIGATIONS	DATA USE: PLANNING AND DESIGN	DATA USE: PROJECT OPERATION	DATA USE: HYDROLOGIC FORECASTS	DATA USE: WATER-QUALITY MONITORING	DATA USE: RESEARCH	DATA USE: OTHER	FUNDING: FEDERAL PROGRAM	FUNDING: OFA PROGRAM	FUNDING: COOP PROGRAM	FUNDING: OTHER NON-FEDERAL	FREQUENCY OF DATA AVAILABILITY
03 4460 00	*						1					1		A
03 4480 00	*											1		A
03 4510 00	*					6						1		AT
03 4515 00	*	15				6	1			15				ATP
03 4535 00	*					6	1 11					1		AT
03 4555 00	*				46							1		ATP
03 4561 00					46							1		AT
03 4565 00	*				46							1		AT
03 4570 00					46		1					1		AT
03 4595 00		12			36						43		36	AT
03 4600 00	*	47					1 47			47				A
03 4633 00	*						1					1		A
03 4790 00	*				48		1				43			AT
03 5000 00	*						1				43	1		A
03 5002 40	*											1		A
03 5030 00		49			49						43			AT
03 5040 00	*						1					1		A
03 5120 00	*				49						43	1		AT
03 5130 00		49			49						43			AT
03 5485 00	*						1					1		A
03 5500 00	*						1					1		A

1. State of North Carolina, Department of Natural Resources and Community Development.
6. U.S. National Weather Service, Flood Forecasting.
11. National Stream Quality Accounting Network.
12. Federal Energy Regulatory Commission, Hydropower License Requirement.
15. Long-Term Index Gaging Station.
36. Carolina Power & Light Company, Hydropower System Operation.
43. Tennessee Valley Authority.
46. Champion International, Canton Plant Operations.
47. Bench-mark Station.
48. Watauga Reservoir Operations.
49. Fontana Reservoir Operations.

* Station used for regional hydrology purposes.
A Data available through annual data report published by the Survey for North Carolina
P Data available through periodic release of provisional data.
T Data available by direct-access telemetry.

observer - Data obtained by direct observer readings.

Fourteen stations currently support short-term hydrologic research projects. Four of these stations, Juniper Branch near Simpson (02084164), Chicod Creek at Secondary Road 1760 near Simpson (02084160), Nahunga Creek at SR 1301 near Warsaw (0210782005), and Grove Creek near Kenansville (0210789100), support research on the hydrologic effects of stream channelization. Continuation of these stations after the short-term project objectives have been met is desirable to assess the long-term impact of channelization on streamflow characteristics. Green Mill Run at Greenville (02084070), Big Ditch at Goldsboro (02088682), Hominy Swamp at Wilson (02090512), and Hewletts Creek at SR 1102 near Wilmington (02093229), are operated to assess the effect of urban development on the magnitude and frequency of floods in the Coastal Plain province and are tentatively scheduled for discontinuance September 30, 1984.

Five stations previously used in the urban flood hydrology study in the City of Charlotte continue in operation. These stations, Irwin Creek at Charlotte (02146300), Little Sugar Creek at Archdale Drive at Charlotte (0214650), McAlpine Creek at Sardis Road near Charlotte (02146600), McMullen Creek at Sharon View Road near Charlotte (02146700), and McAlpine Creek below McMullen Creek near Pineville (02146750), could be converted to high-flow partial-record stations and meet project objectives at a lower cost.

Jordan Creek near Silver Hill (0213228795), used in a long-term national study of the effects of atmospheric deposition on water quality, will be operated until project objectives are met.

Collection of additional streamflow data is needed in a number of areas across the state. The most important area is the eastern Coastal Plain where almost all stream channels have been altered to some degree by drainage projects and data availability and transferability are limited. The few long-term stations in the Coastal Plain are on larger rivers and most were installed after 1950. Current short-term stations operated as part of channelization projects are insufficient for developing regional relations for estimating streamflow characteristics. If the regional hydrology stations listed above are discontinued, the funding could be shifted to new stations in the Coastal Plain sited to collect the information for better definition of the impacts of development.

ALTERNATIVE METHODS OF DEVELOPING STREAMFLOW INFORMATION

The second step of the stream-gaging program analysis is to investigate alternative methods of providing daily streamflow information in lieu of operating continuous-flow 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.

A flow-routing model and multiple-regression analysis were selected as alternative methods of analysis for developing streamflow information using the following criteria. The alternative should be: (1) computer oriented and easy to apply, (2) have an available interface with the USGS WATSTORE Daily Values File (Hutchinson, 1975), (3) technically sound and generally acceptable to the hydrologic community, and (4) permit easy evaluation of the accuracy of the simulated streamflow records.

All stations were categorized as to their potential utilization of the selected methods; six stations were identified for study. The categorization of gaging stations and the application of the specific methods are described in subsequent sections of this report.

Description of Flow-Routing Model

The flow-routing model uses the law of conservation of mass and the relationship between the storage in a reach and the outflow from the reach. The hydraulics of the system are not considered. The model usually requires only a few parameters and treats the reach in a lumped sense without subdivision. The input is usually a discharge hydrograph at the upstream end of the reach and the output, a discharge hydrograph at the downstream end. The model uses the unit-response flow-routing method. This method uses two techniques--storage continuity (Sauer, 1973) and diffusion analogy (Keefer, 1974; Keefer and McQuivey, 1974).

The unit-response method routes 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 method can only be applied for stream reaches having streamflow hydrographs at the beginning and end of the study reach. The method can be used for regulated stream systems; reservoir routing techniques allow routing of flow through reservoirs if the operating rules are known. Calibration and verification of the flow-routing model is achieved using observed streamflow hydrographs and (estimates of) tributary inflows.

The convolution process 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. In this study upstream hydrographs are routed to downstream points using daily streamflow data.

Three options are available for determining the unit (system) response function. Selection of the appropriate option depends primarily upon the variability of wave celerity (traveltime) and dispersion (channel storage) 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-range 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.

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 the upstream and downstream locations. Such flows may be totally 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 upstream hydrograph ordinates by a factor such as a ratio of drainage areas of the downstream to upstream sites.

The objective in either the storage-continuity or diffusion analogy flow-routing method is to calibrate two parameters that describe the storage-discharge relationship in a given reach and the traveltime of flow passing through the reach. In the storage-continuity method, a response function is derived by modifying a translation hydrograph technique developed by Mitchell (1962) to apply to open channels. A triangular pulse (Sauer, 1973) is routed through reservoir-type storage and then transformed by a summation curve technique to a unit response of desired duration. The two parameters that describe the routing reach are K_s, a storage coefficient which is the slope of the storage-discharge relation, and W_s, the translation hydrograph time base. These two parameters determine the shape of the resulting unit-response function.

In the diffusion analogy theory (Keefer and McQuirey, 1974), the two parameters requiring calibration in this method are K_o, a wave dispersion or damping coefficient, and C_o, the floodwave celerity. K_o controls the spreading of the wave (analogous to K_s in the storage-continuity method) and C_o controls the traveltime (analogous to W_s in the storage-continuity method). In the single linearization method, only one K_o and C_o value are used. In the multiple linearization method, C_o and K_o are varied with discharge so a table of wave celerity (C_o) versus discharge (Q) and a table of dispersion coefficient (K_o) versus discharge (Q) are used.

In both the storage-continuity and diffusion-analogy methods, the two parameters are calibrated by trial and error. The analyst must decide if suitable parameters have been derived by comparing the simulated discharge to the observed discharge.

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 developed for estimating daily mean discharges:

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

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_o = the random error term.

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 i. The equation should be verified by (1) plotting the residuals e_i (difference between simulated and observed discharges) against the dependent and all explanatory variables in the equation, and (2) plotting the simulated and observed discharges versus time. These tests are intended to identify if: (1) the linear model is appropriate or whether some transformation of the variables is needed, and (2) 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 these tests indicated that a linear model with y_i and x_j, in cubic feet per second, was appropriate. The application of linear-regression techniques to six watersheds in North Carolina 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

All stations or station groups were considered for the use of alternative methods to provide the needed streamflow information and each was ranked in order of the greatest perceived chance that alternative methods might apply. Three station groupings, as shown in table 3, were considered to have excellent potential for the use of alternative methods, and both the flow-routing and regression techniques were tested.

Table 3.--Gaging stations included in the alternative-methods analysis

Station no.	Station name	Drainage area (mi^2)	Period of record
02 0875 00	Neuse River near Clayton	1150	July 1927 -
02 0875 70	Neuse River at Smithfield	1206	October 1970 -
02 0880 00	Middle Creek near Clayton	83.5	October 1939 -
02 0884 70	Little River near Kenly	191	July 1964 -
02 0885 00	Little River near Princeton	232	February 1930 -
03 4515 00	French Broad River at Asheville	945	October 1895 -
03 4535 00	French Broad River at Marshall	1332	October 1942 -

The accuracy requirements of any data depend upon the intended use of that data. For many uses a level of accuracy substantially less than actual streamflow records is satisfactory. However, the purpose of this analysis is to test the feasibility of using alternative methods in lieu of operating a station. Consequently, the accuracy level for acceptance must remain high to protect most, if not all, uses. For the purpose of this report, acceptance criteria for an alternative method will be for that method to generate a streamflow record within $\pm$ 10 percent of the gaged record 95 percent of the time.

Neuse River Flow-Routing Analysis

The purpose of the Neuse River Flow-Routing Analysis was to evaluate the unit-response model for simulating daily mean discharges at Neuse River at Smithfield (02087570). A best-fit model for the entire flow range was desired.

A schematic diagram of the Neuse River study reach is shown in figure 3. The Smithfield gage is located 14 miles downstream from the next upstream gage, Neuse River near Clayton (02087500). In this reach there are no major impoundments. However, the city of Smithfield diverts an average of about 3.5 ft^3/s for municipal water supply, most of which returns downstream as sewage effluent. This diversion is negligible except during extreme low flow. The intervening drainage area between the gages is 56 mi^2 or about 5 percent of the total drainage area contributing to the Smithfield gage. There are no stream gages in the intervening area. Streamflow for the intervening area was estimated using data from a gage on a nearby, hydrologically similar basin, Middle Creek near Clayton (02088000).

Daily streamflows were routed downstream from Clayton to Smithfield. The streamflow contributed by the intervening area was estimated using daily discharge data for Middle Creek, adjusted by a ratio of the intervening area to the drainage area of the Middle Creek gage. Thus, the total daily discharge at Smithfield is the sum of the routed daily discharges for Clayton and the adjusted daily discharge for Middle Creek.

Eleven years of record are available for the Smithfield station; water years with the highest and lowest daily mean flows at Smithfield were used to calibrate the model.

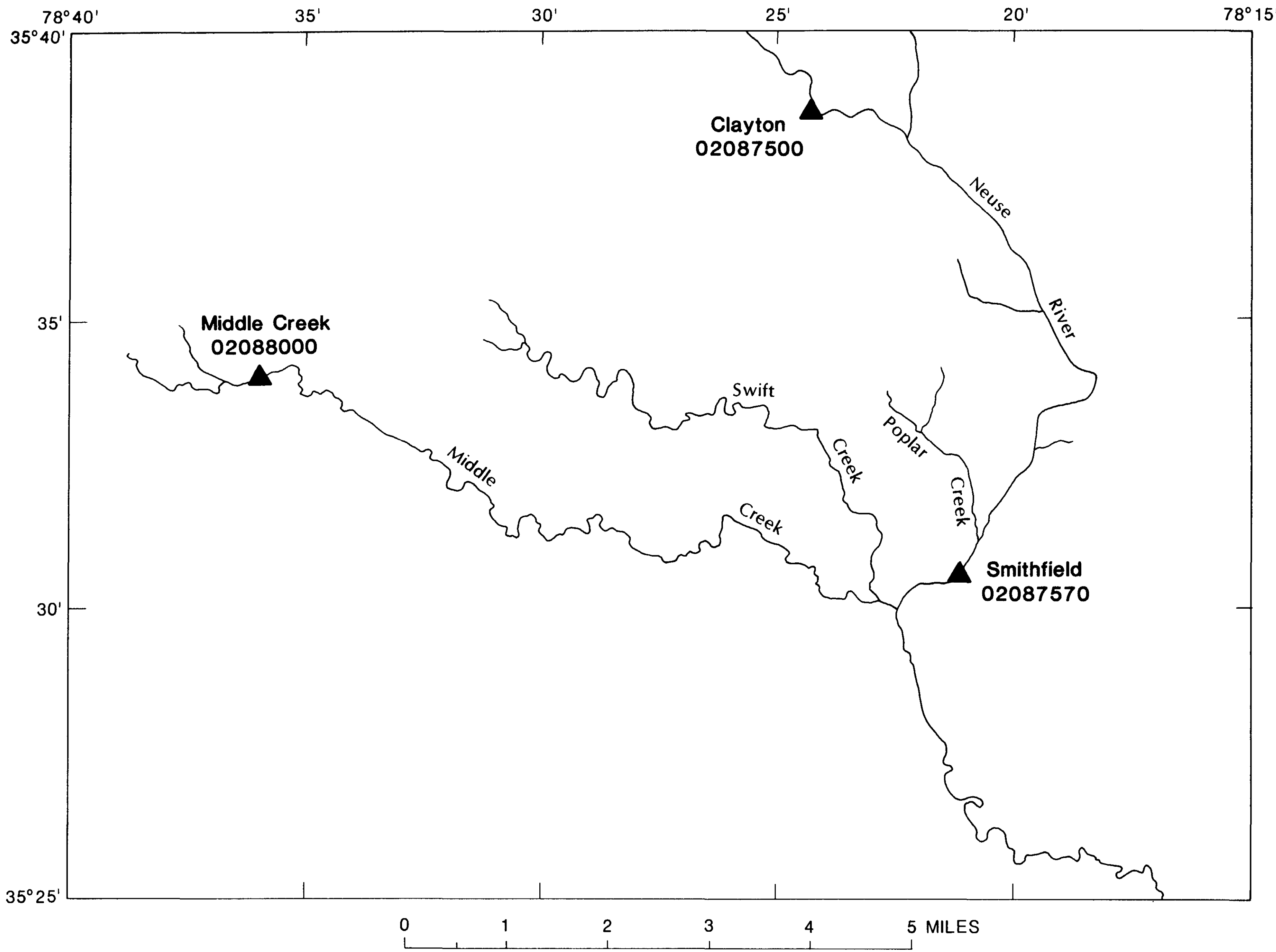

Figure 3.--The Neuse River study area.

Model parameters C_o, the floodwave celerity, and K_o, the wave dispersion coefficient were estimated using equations 2 and 3. The coefficients C_o and K_o are functions of channel width (W_o) in feet, channel slope (S_o) in feet per foot, the slope of the stage discharge relation (dQ_o/dY_o) in square feet per second and the discharge (Q_o) in cubic feet per second representative of the reach. The parameters are determined as follows:

$$C_o = \frac{1}{W_o} \frac{dQ_o}{dY_o} \tag{2}$$

$$K_o = \frac{Q_o}{2\, S_o\, W_o}. \tag{3}$$

The discharge, Q_o, for which initial values of C_o and K_o were linearized was the annual mean discharge for the Clayton and Smithfield gages for the 1982 water year (U.S. Geological Survey, 1982). The channel width, W_o, was calculated by averaging stream widths during flows approximating the annual mean discharge, Q_o. Channel slope, S_o, was determined by converting the corresponding gage heights of the discharges, Q_o, taken from the stage-discharge relationships at each gage, to a common datum. The difference between these values divided by channel length, is slope. The slope of the stage discharge relations, dQ_o/dY_o, was determined from the rating curves at each gage by using a 1-foot increment that bracketed the mean discharge, Q_o. The difference in the discharge through the 1-foot increment then represents the slope of the function at that point. The resulting model parameters as determined above are listed in table 4.

Table 4.--Selected reach characteristics used in the Neuse River flow-routing study

Site	Q_o (ft³/s)	W_o (ft)	S_o (ft/ft)	$\frac{dQ_o}{dY_o}$ (ft²/s)	C_o (ft/s)	K_o (ft²/s)
Clayton	1,171	131	$3.37 \mathrm{x} 10^{4}$	600	4.50	13,060
Smithfield	1,206			350	2.69	13,765

For the first routing trial, average values for the model parameters, C_o of 3.60 and K_o of 13, 412, were used. Using the water year with the highest instantaneous flow, 1973, and the water year with the lowest instantaneous flow, 1977, as a calibration data set, several trials were made adjusting both the values of C_o, K_o, and the drainage area adjustment factors. The model proved quite insensitive to adjustment of C_o and K_o. The best fit, single-linearization model was determined to be that with C_o = 1.70, K_o = 2000, and a drainage area adjustment factor of 0.74. Daily mean discharge at Smithfield was simulated for the entire 11 years (1971-82) of observed data using the best fit parameters.

A summary of the simulation of mean daily discharges at Smithfield for the 11 water years (1971-82) is given in table 5.

Table 5.--Results of routing model for Smithfield

Mean absolute error for 4383 days	= 8.64 percent
Mean negative error (1939 days)	= 7.95 percent
Mean positive error (2444 days)	= 9.19 percent
Total volume error	= -0.40 percent

13 percent of the total observations had errors	$\leq$ 1 percent
44 percent of the total observations had errors	$\leq$ 5 percent
72 percent of the total observations had errors	$\leq$ 10 percent
86 percent of the total observations had errors	$\leq$ 15 percent
93 percent of the total observations had errors	$\leq$ 20 percent
95 percent of the total observations had errors	$\leq$ 25 percent

Overall, simulated and observed discharges match fairly well; peak flows and recessions are generally underestimated and low flows are overestimated. The hydrographs of simulated and observed flows at Smithfield for the fall of 1974 shown in figure 4 are typical for the model results.

Little River Flow-Routing Analysis

The purpose of this analysis was to evaluate the unit-response model for simulating daily mean discharges at Little River near Princeton (02088500). A best-fit model for the entire flow range was desired. Streamflow data available for this analysis are summarized in table 3.

A diagram of the Little River study reach is shown in figure 5. The Princeton gage is located 12 miles downstream from the next upstream gage, Little River near Kenly (02088470). There are no impoundments in this reach. The intervening drainage area between Kenly and Princeton is 41 mi^2, or 18 percent of the total drainage area contributing to the Princeton site. There are no stream gages located within this 41 mi^2 area. The discharge record for Kenly is the shorter with 18 years.

Often during late summer and early fall, the upstream Kenly gage indicates greater flow than the downstream Princeton gage. Discharge measurements during the months of Nov. 1975, Oct. 1976, and Aug. 1980, confirm the phenomenon. No satisfactory explanation for the phenomenon has ever been documented, and no attempt to account for its effects was included in this analysis.

The approach used in the model was to route the flow downstream from Kenly to Princeton. There are no stations gaging the area between Princeton and Kenly and no stations are close enough to use in estimating the ungaged contribution to streamflow. Consequently, the intervening drainage area was not taken into account. The routing parameters C_o and K_o were determined using the same techniques applied in the Neuse River analysis and are summarized in table 6. Average values for the model parameters, $C_o = 1.76$ and $K_o = 3948$, were used for the first routing trial. Refinement of the model determined the best fit values of C_o and K_o as 4.50 and 5000, respectively.

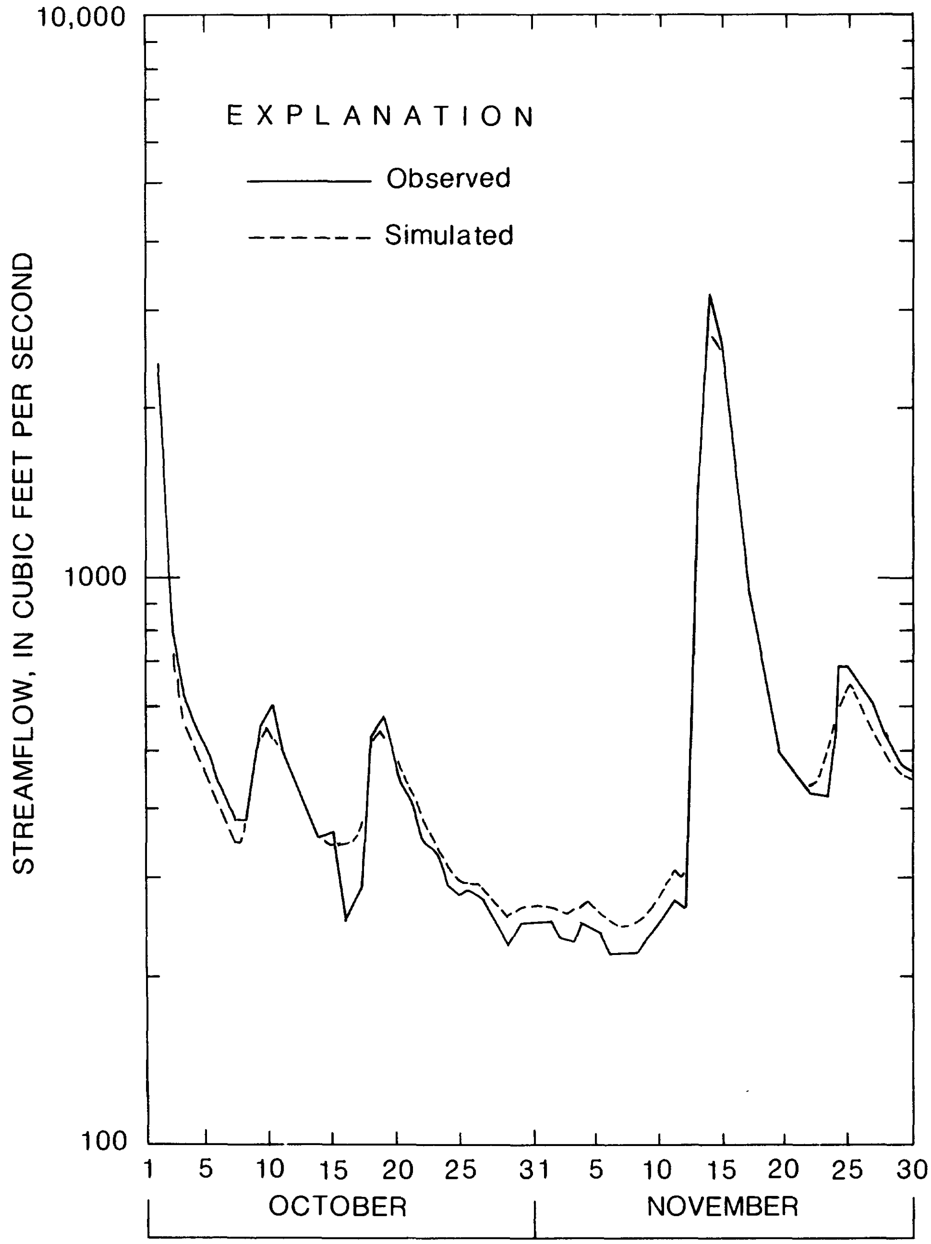

Figure 4.--Simulated and observed streamflow hydrographs for Neuse River at Smithfield, October-November, 1974.

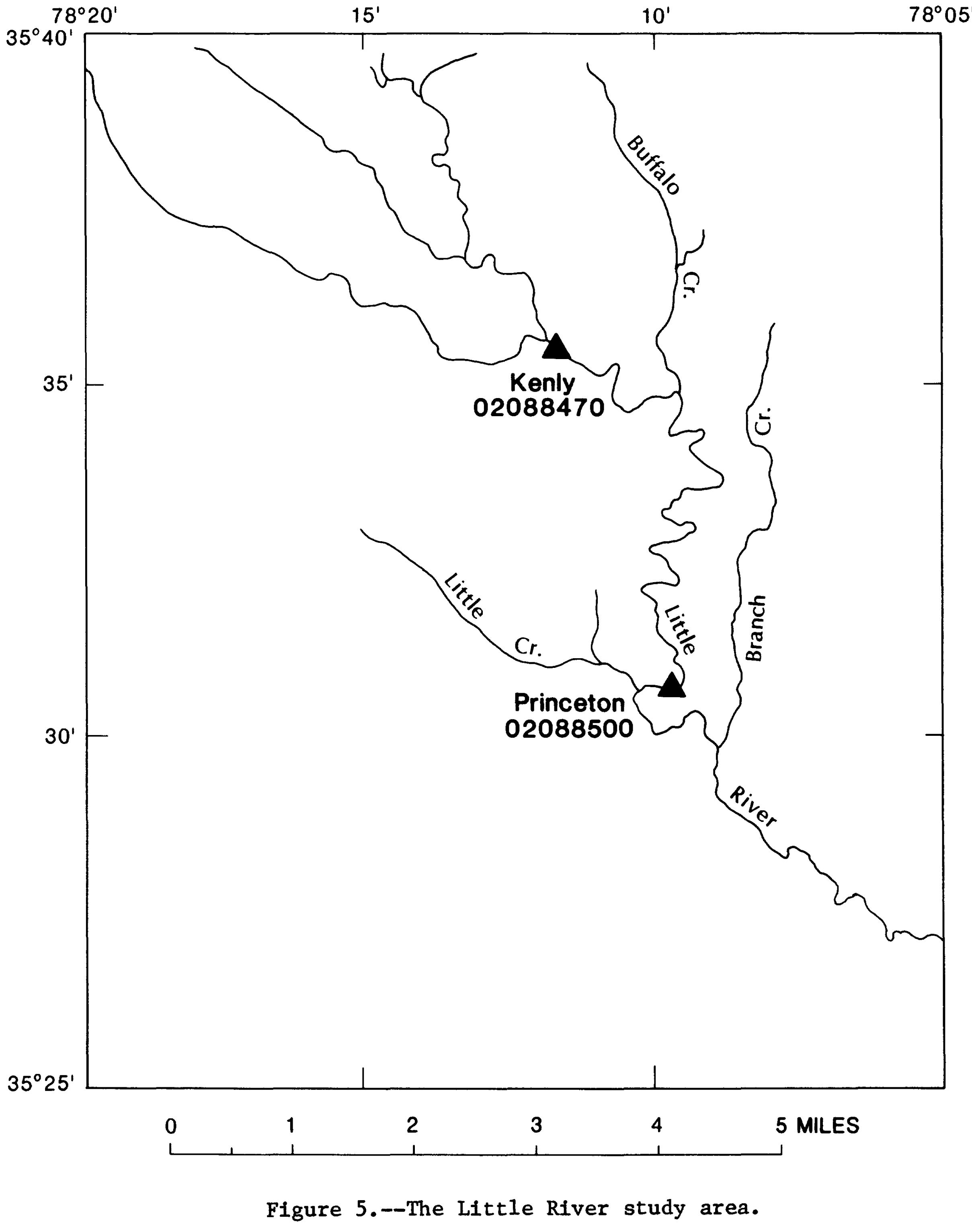

Figure 5.--The Little River study area.

Table 6.--Selected reach characteristics used in the Little River flow-routing study

Site	Q_o (ft³/s)	W_o (ft)	S_o (ft/ft)	$\frac{dQ_o}{dY_o}$ (ft²/s)	C_o (ft/s)	K_o (ft²/s)
Kenly	184	72	3.8×10^{4}	95	1.48	3783
Princeton	250			163	2.04	4112

Concurrent flow records are available for Kenly and Princeton for 1965-82. Data for the 1965 and 1969 water years were used for calibration. These years contained the highest and lowest flows for the Princeton gage during the period of concurrent flow records. Daily mean discharges at Princeton were simulated for the period, (1965-82), using the best fit parameters.

A summary of the simulation of mean daily discharge at Princeton for the water years 1965 through 1982 is given in table 7.

Table 7.--Results of routing model for Little River near Princeton

Mean absolute error for 6574 days	=	17.88 percent
Mean negative error (4076 days)	=	-14.32 percent
Mean positive error (2498 days)	=	23.69 percent
Total volume error	=	1.40 percent

25 percent of the total observations had errors ≤ 5 percent
45 percent of the total observations had errors ≤ 10 percent
62 percent of the total observations had errors ≤ 15 percent
74 percent of the total observations had errors ≤ 20 percent
81 percent of the total observations had errors ≤ 25 percent

Simulated and observed streamflow hydrographs of Princeton during a typical early fall period are shown in figure 6. In general, the model appears to slightly underestimate through much of the middle and high range of flows but overestimates low flows.

French Broad River Flow-Routing Analysis

The purpose of this analysis was to evaluate the unit-response model for simulating daily mean discharges at French Broad River at Marshall (03453500). A best fit model for the entire flow range was desired. Streamflow data available for this analysis are summarized in table 3.

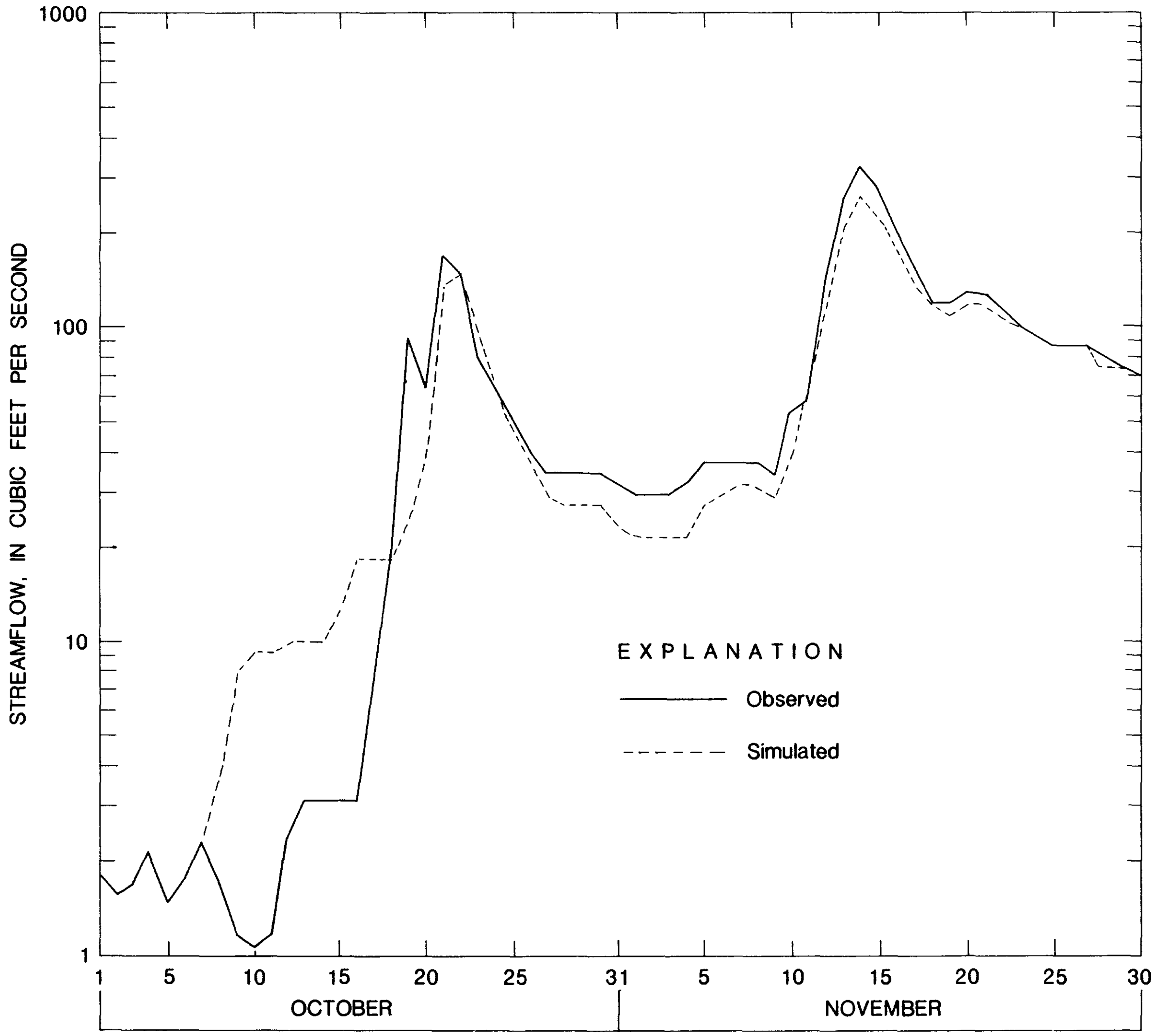

Figure 6.--Simulated and observed streamflow hydrographs for Little River near Princeton, October-November, 1974.

A schematic diagram of the French Broad River study reach is shown in figure 7. The Marshall gage is located 31 miles downstream from the next upstream gage, French Broad River at Asheville (03451500). There are two run-of-the-river impoundments in this reach. Under normal circumstances they discharge approximately the inflow they receive. Even during low flow, they have minor effects on the flow at Marshall. The intervening drainage area between Asheville and Marshall is 387 mi^2 or approximately 29 percent of the drainage area contributing to the Marshall site.

For this analysis, streamflow was routed downstream from Asheville to Marshall. There are no stations gaging the area between Asheville and Marshall and no stations are close enough to use in estimating the ungaged contribution to streamflow. Consequently, the intervening drainage area was not accounted for in this analysis.

The routing parameters C_o and K_o were determined using the techniques applied during the Neuse River analysis and are summarized in table 8.

Table 8.--Selected reach characteristics used in the French Broad flow-routing study

Site	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)
Asheville	2,090	290	1.85×10^{-3}	1,450	5.00	1,950
Marshall	2,462	320		1,750	5.50	2,100

For the first routing trial, average values for the model parameters C_o = 5.25 and K_o = 2025 were used; final values of C_o = 6.00 and K_o = 2169 were found to be the best-fit model.

Concurrent flow records are available for Asheville and Marshall for 1943-82. Data for the 1970 and 1978 water years were used for calibration. These years contain the highest and lowest daily flows at the Asheville station for the period of concurrent flow records.

A summary of the simulated daily mean discharge at Marshall for the water years 1964 through 1982 is shown in table 9.

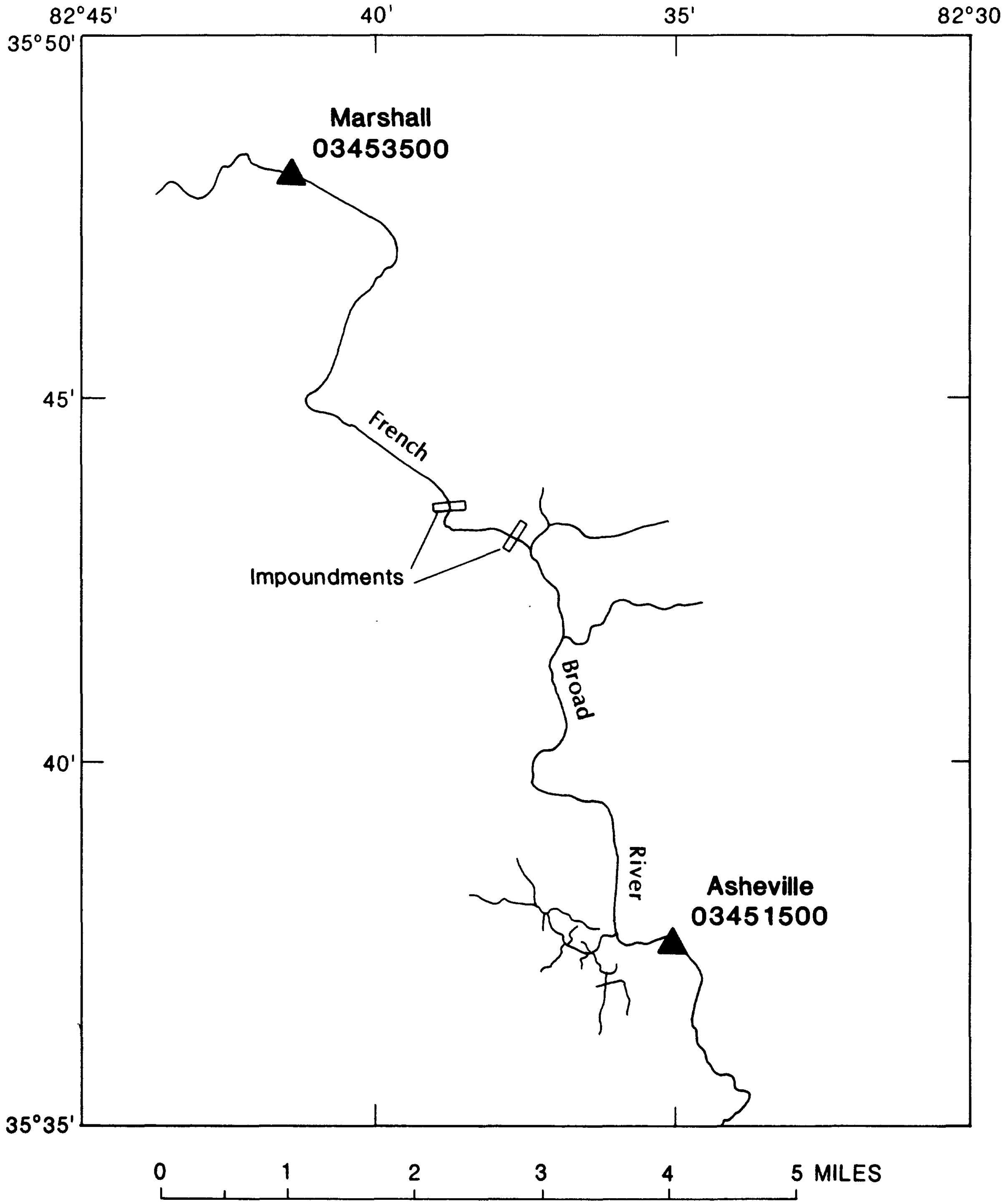

Figure 7.--The French Broad River study area.

Table 9.--Results of routing model for Marshall

Mean absolute error for 6940 days	= 6.42
Mean negative error (3008 days)	= 4.85
Mean positive error (3932 days)	= 7.61
Total volume error	= 1.12 percent

58.5 percent of the total observations had errors $\leq$ 5 percent
83.8 percent of the total observations had errors $\leq$ 10 percent
93.3 percent of the total observations had errors $\leq$ 15 percent
97.1 percent of the total observations had errors $\leq$ 20 percent
98.8 percent of the total observations had errors $\leq$ 25 percent

In general, simulated and observed streamflows showed good agreement; however, the model underestimates many peaks and recessions. Hydrographs of simulated and observed discharges at Marshall during a typical summer period are shown in figure 8.

Regression Analysis Results

Linear regression techniques were also applied to stations used in the flow-routing study. The streamflow record for each station considered for simulation, Smithfield, Princeton, and Marshall (the dependent variables), was regressed against streamflow records at respective upstream stations (explanatory variables) during a given period of record (the calibration period). "Best fit" linear regression models were developed and used to provide a daily streamflow record that was compared to the observed streamflow record. The percent difference between the simulated and actual record for each day was calculated. The results of the regression analysis for each site are summarized in table 10.

The regression model for Smithfield (02087570) did not reproduce streamflows with an acceptable degree of accuracy. Simulated data were within 10 percent of the observed data only 60.8 percent of the time. These results were obtained using logarithm transformation of the daily discharge. Three other models were evaluated that lagged Clayton discharge by one, two, and three days. The lagged discharge values account for the travel time between the two sites. None of the three lagged models produced better results than the logarithm transformation model.

The regression model for Princeton (02088500) yielded the poorest results of the three studies. The simulated record at Princeton was within 10 percent of the observed record only 36 percent of the time. The best model required two explanatory variables; Kenly discharge lagged by one and by two days. Several other models utilizing other explanatory variables, such as logarithm transformed data, were developed but no improvement in accuracy was obtained.

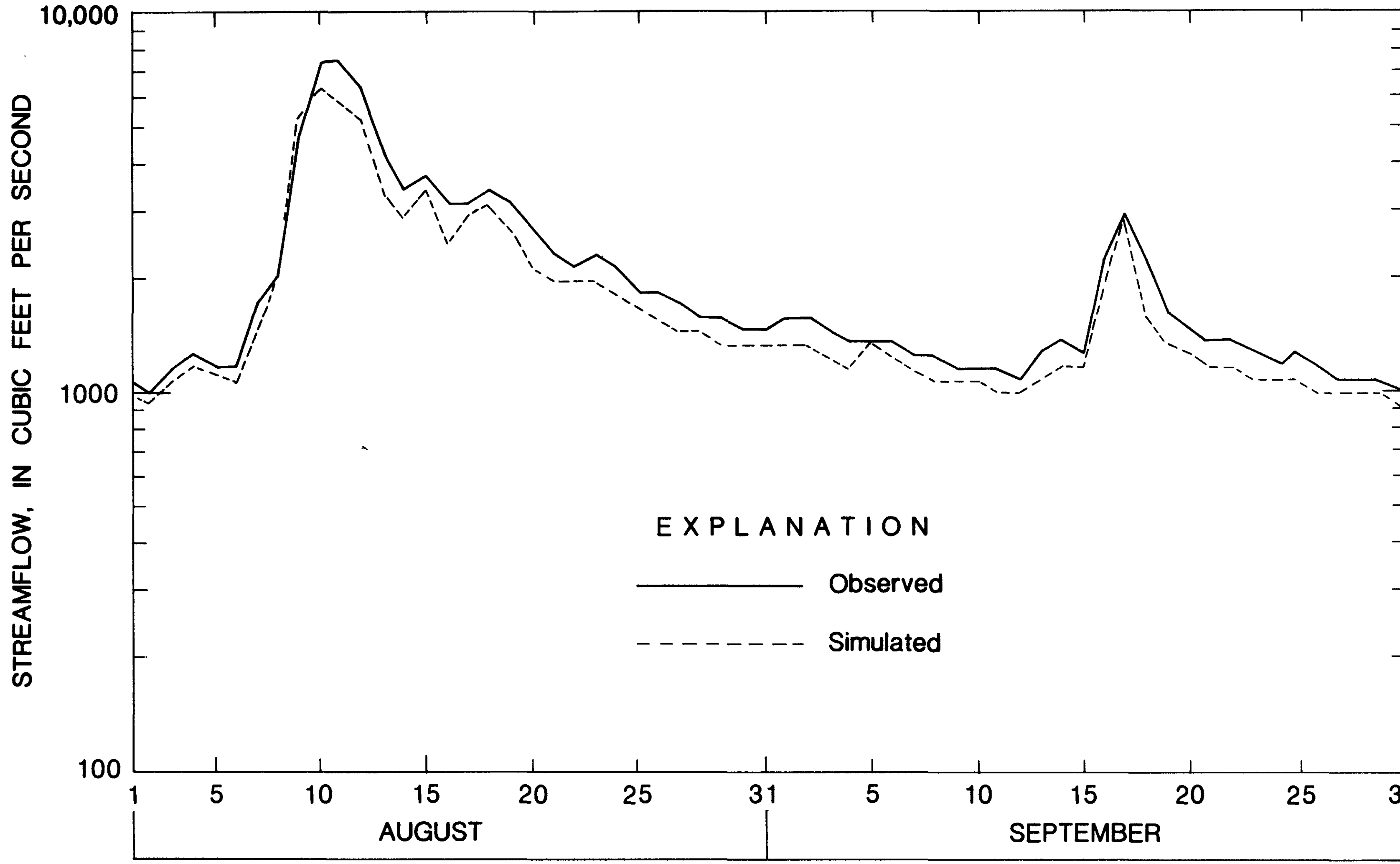

Figure 8.--Simulated and observed streamflow hydrograph for French Broad River at Marshall, August-September, 1978.

Table 10.--Summary of calibration for regression modeling of daily mean streamflow at selected gage sites in North Carolina

Station	Model	Percentage of simulated flow within 5% of actual	Percentage of simulated flow within 10% of actual	Calibration period (water years)
Neuse River at Smithfield (02087570)	Smithfield = 1.07 $(\text{Clayton})^{1.01}$	34.6	60.8	1973, 1977
Little River nr. Princeton (02088500	Princeton = 3.1 + 0.94 (Kenly LAG1) + 0.33 (Kenly LAG2)	19.7	36.0	1965, 1969
French Broad R. at Marshall (03453500)	Marshall = 200 + 1.12 Asheville	42.6	75.9	1956, 1965

The regression model for Marshall (03453500) was the most reliable of any developed for reaches studied. The model uses unlagged, untransformed daily mean streamflow for Asheville. Simulated and observed flows for Marshall are within 10 percent 75.9 percent of the time.

None of the regression models developed produced simulated streamflow record of acceptable accuracy. Considerable improvement may be obtained if average discharge data for time periods, other than a day, were readily available as input to calibrate the model. The regression model for Marshall is the most reliable one developed; a factor may be that time of travel between Asheville and Marshall is the shortest (a few hours) of any stream reach modeled.

Conclusions of Alternative-Methods Analysis

The simulated data from both the flow routing and regression models are not sufficiently accurate to use those methods in lieu of operating any of the stations tested. Simulated streamflow records could not be used to replace stations in the present network without significant loss of records accuracy. Therefore, all of the stations considered thus far as part of the network will remain in operation and will be included in the next section of this analysis.

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 were developed (Moss and Gilroy, 1980). Because of the water-balance nature of that study, the measure of effectiveness of the network was chosen to be the minimization of the sum of variances of errors of estimation of annual mean discharges at each site in the network. This measure of effectiveness tends to concentrate stream-gaging resources on the larger, less stable streams where potential errors are greatest. While such a tendency is appropriate for a water-balance network, in the broader context of the multitude of uses of the streamflow data collected in the Geological Survey's Streamflow Information Program, this tendency causes undue concentration on larger streams. Therefore, the original version of K-CERA was extended to include 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, or average instantaneous discharge in percentage. The use of percentage errors does not unduly weight activities at large streams to the detriment of records on small streams. In addition, the instantaneous discharge is the basic variable from which all other streamflow data are derived. For these reasons, this study used the KCERA techniques with the sums of the variances of the percentage errors of the instantaneous discharges at all continuously gaged sites as the measure of the effectiveness of the data-collection activity.

The original version of K-CERA also did not account for error contributed by missing stage or other correlative data that are used to compute streamflow data. 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 the determination of the accuracy of a stream-gaging record are presented below. For more detail on either the theory or the applications of K-CERA, see Moss and Gilroy (1980) 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 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 comprise 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 travel time and any related per diem and operation, maintenance, and rental costs of vehicles. The sum of the products of βi and Ni for i = 1, 2, ..., NR is the total travel cost associated with the set of decisions $\underline{N}$ = (N1, N2, ..., N_{NR}).

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

$V \equiv$ total uncertainty in the network

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

$MG \equiv$ number of gages in the network

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

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

Such that

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

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

$F_c \equiv$ fixed cost

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

$NR \equiv$ number of practical routes chosen

$\beta_i \equiv$ travel cost for route i

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

and such that

$$M_j \geq \lambda_j$$

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

Figure 9.--Mathematical-programming form of the optimization of the routing of hydrographers.

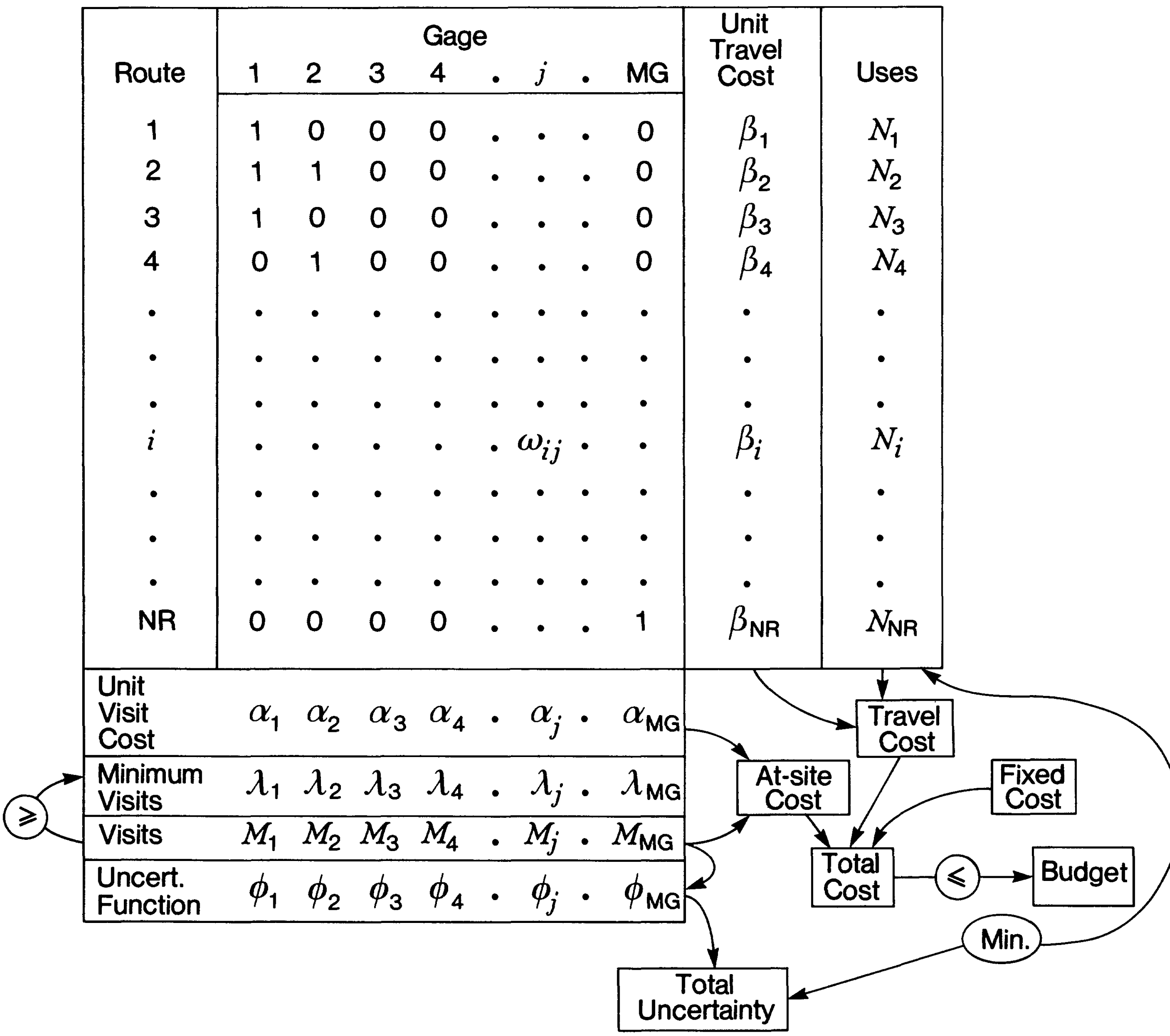

Figure 10.--Tabular form of the optimization of the routing of hydrographers.

The unit-visit cost, α_j, is comprised of the average service and maintenance costs incurred on a visit to the station plus the average cost of making a discharge measurement. The set of minimum visit constraints is denoted by the row λ_j, j = 1, 2, ... MG, where MG is the number of 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 λ_j for all j if $\underline{N}$ is to be a feasible solution to the decision problem.

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

As pointed out in Moss and Gilroy (1980), the steepest descent search used to solve this mathematical program does not guarantee a true optimum solution. However, the locally optimum set of values for $\underline{N}$ obtained with this technique specify an efficient strategy for operating the 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

$$\bar{V} = \varepsilon_f V_f + \varepsilon_r V_r + \varepsilon_e V_e \tag{4}$$

with

$$1 = \varepsilon_f + \varepsilon_r + \varepsilon_e \tag{5}$$

where

$\bar{V}$ is the average relative variance of the errors of streamflow estimates,

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

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

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

V_r is the relative variance of the errors of estimation of flows reconstructed from secondary data,

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

V_e is the relative error variance of the third situation.

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

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

$$f(\tau) = ke^{-k\tau}/(1-e^{-ks}) \tag{6}$$

where

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

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

$$\varepsilon_f = (1-e^{-ks})/(ks) \tag{7}$$

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

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

$$\varepsilon_e = 1 - [2(1-e^{-ks}) + 0.5(1-e^{-2ks})]/(ks) \tag{8}$$

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

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

$$\begin{aligned} \varepsilon_r &= 1 - \varepsilon_f - \varepsilon_e \\ &= [(1-e^{-ks}) + 0.5(1-e^{-2ks})]/(ks). \end{aligned} \tag{9}$$

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

$$x(t) = \ln q_T(t) - \ln q_R(t) = \ln [q_T(t)/q_R(t)] \tag{10}$$

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

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

$$\hat{x}(t) = \ln q_c(t) - \ln q_R(t) \tag{11}$$

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

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

$$z(t) = x(t) + v(t) = \ln q_m(t) - \ln q_R(t), \tag{12}$$

where

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

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

In the Kalman-filter analysis, the $z(t)$ time series was analyzed to determine three site-specific parameters. The Kalman filter used in this study assumes that the time residuals $x(t)$ arise from a continuous first-order Markovian process that has a Gaussian (normal) probability distribution with zero mean and variance (subsequently referred to as process variance) equal to p. A second important parameter is β, the reciprocal of the correlation time of the Markovian process giving rise to $x(t)$; the correlation between $x(t_1)$ and $x(t_2)$ is $\exp\,[-\beta|t_1-t_2|]$. Fontaine and others (1983) also define q, the constant value of the spectral density function of the white noise which drives the Gauss-Markov x-process. The parameters, p, q, and β are related by

$$\mathrm{Var}[x(t)] = p = q/(2\beta). \tag{13}$$

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

$$\mathrm{Var}[z(t)] = p + r, \tag{14}$$

where r is the variance of the measurement error $v(t)$.

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

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

$$\bar{C}_v = \left[\frac{1}{365} \sum_{i=1}^{365} \left(\frac{\sigma_i}{\mu_i} \right)^2 \right]^{\frac{1}{2}} , \tag{15}$$

where

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

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

$\bar{C}_v^2$ is used as an estimate of V_e.

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

$$V_r = (1-\rho_c{}^2)\ \bar{C}_v{}^2 . \tag{16}$$

Because errors in streamflow estimates arise from three different sources with widely varying precisions, the resultant distribution of those errors may differ significantly from a normal or log-normal distribution. This lack of normality causes difficulty in interpretation of the resulting average estimation variance. When primary and secondary data are unavailable, the relative error variance V_e may be very large. This could yield correspondingly large values of $\overline{V}$ in equation (4) even if the probability that primary and secondary information are not available, ε_e, is quite small.

A new parameter, the equivalent Gaussian spread (EGS), is introduced here to assist in interpreting the results of the analyses. If it is assumed that the various errors arising from the three situations represented in equation (4) are normally distributed, the value of EGS was determined by the probability statement that

$$\text{Probability } [e^{-EGS} \leq (q_c(t)/q_T(t)) \leq e^{+EGS}] = 0.683. \qquad (17)$$

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

The Application of K-CERA in North Carolina

In the first part of this anaylsis, seven stations operated to define regional hydrology were nominated for discontinuance and five stations, part of the Charlotte urban hydrology project, were suggested for conversion to high-flow partial-record stations. Final determinations on these proposals have not been made; therefore, all 146 stations currently in operation were subjected to the K-CERA analysis.

Definition of Missing Record Probabilities

As described earlier, the statistical characteristics of missing stage or other correlative data for computation of streamflow records can be defined by a single parameter. This parameter is the value of k in the truncated negative exponential probability distribution of times to failure of the equipment. In the representation of $f(\tau)$ as given in equation 6, the average time to failure is 1/k. The value of 1/k varies from site to site depending upon the type of equipment at the site and upon its exposure to natural elements and vandalism. The value of 1/k can be changed by advances in the technology of data collection and recording.

The most recent 10 years of record for each of the 146 stations were analyzed to estimate 1/k. Historically, the element most influencial on the amount of lost record in North Carolina is the presence or absence of backup recorders. Accordingly, the streamflow records were separated into two groups. One group consisted of records produced where backup recorders were installed, the other, of records produced without backup recorders. The percentage of lost record was then computed and averaged for each group. For the group with backup records, a period of lost record was defined to have occurred only when data for the period were absent from both records.

The results revealed that on the average a station without a backup recorder malfunctioned approximately 3.5 percent of the time. Where a backup recorder was available, the down-time percentage fell to 0.5 percent. These percentages determine a 1/k of 580 and 4,000 days, respectively. These values were then used to calculate ε_f, ε_e, and ε_r for each station as a function of individual frequencies of visits.

Definition of Cross-Correlation Coefficient and Coefficient of Variation

To compute the values of V_e and V_r of the uncertainty functions, daily streamflow records for each of the 146 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 gages with 3 or more complete water years of data, the value of C_v was computed and various options, based on combinations of other stream gages, were explored to determine the maximum ρ_c. For the 14 stations that had less than 3 water years of data, values of C_v and ρ_c were estimated subjectively.

At several sites, nearby hydropower plants have rated their turbines to monitor the discharge that passes through them and keep flow records that can be used for streamflow reconstruction. For these sites, a worst-case situation, Hiwassee River above Murphy (03548500), was analyzed. This site had the largest intervening flow between the gage and the power plant of all stations in this category. The ρ_c developed between Hiwassee station and the power plant was 0.61. This value was applied at Hiwassee and a second similar site, Tuckasegee River at Bryson City (03513000). For Roanoke River at Roanoke Rapids (02080500), the hydrographs compare much better than a ρ_c of 0.61 would indicate. Therefore, a subjective estimate of 0.98 was assumed for this station.

The set of parameters for each station and the auxiliary records that gave the highest cross correlation coefficient are listed in table 11.

Table 11.--Statistics of record reconstruction

Station no.	Coefficient of variation	Coefficient of cross correlation	Source of reconstructed records	
02 0532 00	1.75	.766	2053500	
02 0535 00	2.01	.766	2053200	
02 0685 00	.802	.772	0271000	
02 0710 00	1.12	.772	2068500	
02 0740 00	.886	.771	2074218	
02 0742 18	.784	.761	2071000	
02 0772 00	1.89	.577	2077303	2077670
02 0773 03	1.46	.559	2077200	2077670
02 0776 70	1.42	.490	2077303	2077200
02 0805 00	.756	.98	Upstream hydropower plant.	
02 0815 00	2.22	.889	2081747	2085500
02 0817 47	1.33	.788	2081500	2085500
02 0825 06	1.23	.874	2083000	2082585
02 0825 85	.957	.662	2083000	2083500
02 0827 70	1.24	.838	2082950	
02 0829 50	1.58	.838	2082770	
02 0830 00	1.60	.617	2091700	
02 0835 00	1.29	.828	2082585	2083000
02 0838 00	1.60	.617	2091700	
02 0840 70	1.5*	.74*		
02 0841 60	1.50	.829	2084164	
02 0841 64	1.20	.829	2084160	
02 0845 40	1.66	.672	2091970	
02 0845 57	1.34	.679	2091970	2084540
02 0850 70	1.62	.882	2085220	
02 0852 20	1.81	.882	2085070	
02 0855 00	1.8*	.88*		
02 0865 00	1.50	.622	2085500	
02 0866 24	1.8*	.88*		
02 0868 49	1.8*	.88*		
02 08700780	1.8*	.88*		
02 0871 83	1.62	.920	2087500	2087570
02 0875 00	1.39	.902	2087183	2087570
02 0875 70	1.27	.931	2087183	2087500
02 0880 00	1.59	.587	2090380	

Table 11.--Statistics of record reconstruction (continued)

Station no.	Coefficient of variation	Coefficient of cross correlation	Source of reconstructed records	
02 0884 70	1.34	.914	2088500	
02 0885 00	1.55	.914	2088470	
02 0886 82	1.6*	.96*		
02 0890 00	1.16	.962	2089500	
02 0895 00	1.04	.975	2089500	2089000
02 0903 80	1.48	.587	2088000	
02 0905 12	1.25	.543	2090380	
02 0906 25	1.19	.724	2091000	
02 0910 00	1.46	.724	2090625	
02 0915 00	1.24	.837	2089000	2089500
02 0917 00	1.81	.617	2083800	
02 0919 70	1.70	.769	2084540	2092000
02 0920 00	1.82	.788	2091970	2084540
02 0925 00	1.64	.524	2105769	
02 0932 29	.864	.464	2092500	
02 0938 00	1.36	.851	2094000	209900
02 0945 00	1.95	.522	2099000	
02 0955 00	1.42	.624	2096500	
02 0965 00	1.48	.624	2095500	
02 0969 60	1.17	.797	2096500	
02 0973 14	1.2*	.75*		
02 09741955	1.2*	.75*		
02 0975 17	1.2*	.75*		
02 0981 98	1.26	.766	2102500	
02 0990 00	1.97	.810	2093800	2094500
02 0995 00	1.83	.898	2100500	
02 1005 00	1.84	.898	2099500	
02 1020 00	1.76	.511	2098198	
02 1021 92	1.52	.567	2102908	
02 1025 00	1.55	.958	2105769	2105500
02 1029 08	.755	.567	2102192	
02 1055 00	1.19	.854	2102500	2105769
02 1057 69	1.00	.899	2105500	2102500
02 1060 00	1.18	.592	2107000	
02 1065 00	1.03	.866	2108000	

Table 11.--Statistics of record reconstruction (continued)

Station no.	Coefficient of variation	Coefficient of cross correlation	Source of reconstructed records		
02 1070 00	1.16	.592	2106000		
02 10782005	1.2*	.53*			
02 10789100	1.2*	.53*			
02 1080 00	1.35	.866	2106500		
02 1085 48	1.27	.360	2092500		
02 1095 00	1.28	.699	2134500		
02 1110 00	.932	.928	2111500	2111180	
02 1111 80	.973	.910	2111000		
02 1115 00	.828	.903	2111180	2111000	
02 1120 00	.806	.933	2112250	2113500	
02 1121 20	.789	.915	2112360	2113000	
02 1122 50	.743	.948	2112000	2113500	
02 1123 60	.757	.941	2112120	2113000	
02 1130 00	1.02	.901	2113850	2114450	
02 1135 00	.634	.828	2112250	2115360	
02 1138 50	.825	.901	2114450	2113000	
02 1144 50	1.38	.709	2115360	2113500	
02 1153 60	.791	.935	2113500	2116500	
02 1165 00	.901	.866	2115360	2113500	
02 1180 00	1.05	.853	2118500	2117030	
02 1185 00	1.08	.845	2117030		
02 1207 80	.714	.767	2121180		
02 1211 80	.692	.767	2120780		
02 1250 00	2.46	.697	2146900		
02 1260 00	1.95	.780	2133500	2128000	
02 1280 00	1.80	.759	2133500	2126000	
02 1290 00	.949	.694	2116500		
02 13228795	2.0*	.66*			
02 1335 00	.731	.658	2129000	2102908	
02 1345 00	.811	.699	2109500		
02 1377 27	.86*	.88*			
02 1385 00	1.19	.886	2143000	3479000	
02 1420 00	1.12	.692	2138500		
02 1429 00	1.64	.800	2146507	2146300	
02 1430 00	1.09	.909	2138500	2143040	2152100

Table 11.--Statistics of record reconstruction (continued)

Station no.	Coefficient of variation	Coefficient of cross correlation	Source of reconstructed records		
02 1430 40	1.10	.915	2143000	2152100	
02 1435 00	1.26	.862	2143000	2144000	
02 1440 00	1.41	.838	2143500	2142900	
02 1450 00	1.26	.57	2143500		
02 1463 00	1.54	.884	2142900	2146700	
02 1465 07	.897	.689	2142900	2146900	2146750
02 1466 00	1.88	.821	2146900	2146750	
02 1467 00	2.28	.896	2146500	2146600	
02 1467 50	1.46	.793	2146900	2146600	
02 1469 00	2.13	.697	2125000		
02 1490 00	.863	.825	2143040	2152100	
02 1510 00	.992	.925	2151000		
02 1515 00	.802	.925	2151000		
02 1521 00	.972	.802	2149000		
02 1526 10	1.17	.711	2143040	2143500	2152100
03 1610 00	.767	.871	3479000		
03 4390 00	.786	.956	3441000	3441440	3443000
03 4410 00	.858	.952	3439000	3441440	
03 4414 40	.884	.879	3439000	3441000	
03 4430 00	.765	.956	3439000	3441000	
03 4460 00	.806	.950	3441000	3451000	
03 4480 00	.751	.993	3443000	3451500	3453500
03 4510 00	1.05	.860	3446000	3441000	
03 4515 00	.762	.997	3448000	3453500	
03 4535 00	.732	.988	3451500		
03 4555 00	1.05	.894	3441000	3456500	
03 4561 00	1.0*	.89*			
03 4565 00	1.01	.897	3455500	3460000	
03 4570 00	.966	.985	3459500	3456500	
03 4595 00	.812	.952	3457000		
03 4600 00	.732	.884	3512000		
03 4633 00	1.08	.794	3479000	3460000	
03 4790 00	1.17	.893	3463300	3161000	
03 5000 00	.728	.910	3500240	3504000	
03 5002 40	.706	.930	3504000	3500000	

Table 11.--Statistics of record reconstruction (continued)

Station no.	Coefficient of variation	Coefficient of cross correlation	Source of reconstructed records	
03 5030 00	.725	.972	3500000	3500240
03 5040 00	.688	.926	3500240	3550000
03 5120 00	.747	.905	3560000	3504000
03 5130 00	.616	.61	Upstream hydropower plant.	
03 5485 00	.679	.61	Upstream hydropower plant.	
03 5500 00	.846	.841	3500240	3504000

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

Kalman-Filter Definition of Variance

The determination of the variance, V_f, for each of the 146 stations required the execution of three distinct steps: (1) long-term rating analysis and computation of residuals of measured discharge from the long-term rating, (2) time-series analysis of the residuals to determine the parameters of the Kalman-filter streamflow records, and (3) computation of the error variances, V_f, as a function of the time-series parameters, the discharge-measurement-error variance, and the frequency of discharge measurement.

Definition of the long-term rating for each station was accomplished by employing either of two methods. The first method was to develop a rating function by non-linear regression of the last 75 to 100 streamflow measurements at each station. The rating function for the non-linear regression was of the form:

$$LQM = B1 + B3 * \text{Log}\ (GHT - B2) \tag{18}$$

in which

LQM is the logarithmic (base e) value of the discharge measured in cubic feet per second,

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

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

B2 is the gage height, in feet, of zero flow, and

B3 is the slope of the rating curve.

This method proved too inaccurate to develop a meaningful time-series of residuals for all but a few on the 146 stations. A second, more successful method was to plot the last 75 to 100 measurements on logarithmic paper and draw a best fit curve.

At several stations, backwater or rate-of-change-of-stage-relations are used to supplement discharge ratings. Most of these relations are quite stable and once developed change little. Therefore, no effort was made to develop a long-term backwater or rate-of-change-of-stage relation for any station. Instead, if a backwater relation was in use at a station, the measured discharge was adjusted by that existing backwater relation before the measured discharge was used in the rating analysis.

In areas heavily influenced by winter ice, ice ratings are often necessary to supplement the open water ratings. In North Carolina, only stations located in the mountains are affected by ice every year, and, except under extreme conditions, these effects usually last for only brief durations; therefore, no seasonal ratings are in use in the State and none are necessary for this analysis.

The mean long-term ratings developed were used to compute the time series of residuals (measured discharge minus rating discharge) for analysis to determine the input parameters of the Kalman-filter streamflow records.

The time series of residuals was used to compute sample estimates of q and β, two of the three parameters required to compute V_f, by determining a best fit autocovariance function to the time series of residuals. Measurement variance, the third parameter, was determined from an assumed constant percentage standard error. All streamflow measurements were assumed to have a measurement error of 5 percent. This assumption produced unexpected results for nine stations in the Blue Ridge and western Piedmont Provinces. The total variance calculated from the time series of residuals for these stations was actually less than 5 percent. This low value probably typified the strong, stable controls of these stations. Still, since the measuring conditions at these stations (rocky, irregular bottoms and turbulent flow) are not ideal, the 5 percent measurement error did not appear too conservative. This value was maintained and applied to all nine stations and the total variance set to 0.0027, the lowest positive variance determined for any of the stations. Three stations, North Buffalo Creek near Greensboro (02095500), South Fork Catawba River near Lowell (02145000), and Swannanoa River at Biltmore (03451000), all produced this value.

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

The length of record for several stations was too short to establish reliable estimates of their process variance and autocorrelation coefficients. Parameters for these stations were estimated from values for nearby streams. Estimated autocorrelation and process variances are footnoted in table 12. In a few instances the values of the autocorrelation coefficient and process variance, as determined in the autocovariance analysis, did not accurately model conditions at the station. This was especially true for stations on small streams. For these stations, substitute parameters were estimated. These estimates are also footnoted.

Table 12.--Summary of autocovariance analysis

Station no.	Station name	RHO	Process variance (log base e)^2
02 0532 00	Potecasi Creek near Union	1/ .98	.2515
02 0535 00	Ahoskie Creek at Ahoskie	.995	.3541
02 0685 00	Dan River near Francisco	.982	.0036
02 0710 00	Dan River near Wentworth	.975	.0058
02 0740 00	Smith River at Eden	.986	.0024
02 0742 18	Dan River near Mayfield	.987	.0027
02 0772 00	Hyco Creek near Leasburg	.975	1/ .3
02 0773 03	Hyco River below Afterbay Dam near McGehees Mill	.990	.1658
02 0776 70	Mayo Creek near Bethel Hill	1/ .97	.2174
02 0805 00	Roanoke River at Roanoke Rapids	0	.0050
02 0815 00	Tar River near Tar River	.915	.0231
02 0817 47	Tar River at U.S. 401 at Louisburg	.974	.0347
02 0825 06	Tar River below Tar River Reservoir near Rocky Mount	.959	.0075
02 0825 85	Tar River at N.C. 97 at Rocky Mount	.958	.0084
02 0827 70	Swift Creek at Hilliardston	.962	.0298
02 0829 50	Little Fishing Creek near White Oak	.988	.0558
02 0830 00	Fishing Creek near Enfield	.569	.0102
02 0835 00	Tar River at Tarboro	.551	.0037
02 0838 00	Conetoe Creek near Bethel	.557	.0495
02 0840 70	Green Mill Run at Arlington Boulevard at Greenville	2/ .56	2/ .05

1/ These values are subjective estimates. The values determined by the autocovariance analysis for this station do not model the hydraulic conditions of this gage.

2/ Sufficient measurements were not available for autocovariance analysis at this gage. A subjective estimate was substituted.

Table 12.--Summary of autocovariance analysis (continued)

Station no.	Station name	RHO	Process variance (log base e)^2
02 0841 60	Chicod Creek at SR 1760 near Simpson	.983	.3788
02 0841 64	Juniper Branch near Simpson	.876	.0672
02 0845 40	Durham Creek at Edward	.939	.0894
02 0845 57	Van Swamp near Hoke	.926	.1835
02 0850 70	Eno River near Durham	.962	.0601
02 0852 20	Little River near Orange Factory	.978	.1192
02 0855 00	Flat River at Bahama	.967	.0099
02 0865 00	Flat River below Dam near Bahama	.710	.0189
02 0866 24	Knap of Reeds Creek near Butner	2/ .97	2/ .01
02 0868 49	Ellerbe Creek near Gorman	2/ .97	2/ .01
02 08700780	Little Lick Creek near Durham	2/ .97	2/ .01
02 0871 83	Neuse River near Falls	.992	.1082
02 0875 00	Neuse River near Clayton	.974	.0031
02 0875 70	Neuse River at Smithfield	.984	.0146
02 0880 00	Middle Creek near Clayton	.976	1/ .14
02 0884 70	Little River near Kenly	.981	.1640
02 0885 00	Little River near Princeton	.964	.1424
02 0886 82	Big Ditch at Retha Street at Goldsboro	.340	.0716
02 0890 00	Neuse River near Goldsboro	.970	.0054
02 0895 00	Neuse River at Kinston	.975	.0020
02 0903 80	Contentnea Creek near Lucama	.808	.0245
02 0905 12	Hominy Swamp at Phillips Street at Wilson	.971	.0745

1/ These values are subjective estimates. The values determined by the autocovariance analysis for this station do not model the hydraulic conditions of this gage.

2/ Sufficient measurements were not available for autocovariance analysis at this gage. A subjective estimate was substituted.

Table 12.--Summary of autocovariance analysis (continued)

Station no.	Station name	RHO	Process variance (log base e)^2
02 0906 25	Turner Swamp near Eureka	.525	.0461
02 0910 00	Nahunta Swamp near Shine	.987	.0195
02 0915 00	Contentnea Creek at Hookerton	.630	.0044
02 0917 00	Little Contentnea Creek near Farmville	.970	.1028
02 0919 70	Creeping Swamp near Vanceboro	.934	.2107
02 0920 00	Swift Creek near Vanceboro	.959	.0890
02 0925 00	Trent River near Trenton	.946	.0763
02 0932 29	Hewletts Creek at SR 1102 near Wilmington	.960	.0797
02 0938 00	Reedy Fork near Oak Ridge	.969	.0082
02 0945 00	Reedy Fork near Gibsonville	.960	.0508
02 0955 00	North Buffalo Creek near Greensboro	.940	.0002
02 0965 00	Haw River at Haw River	.969	.0039
02 0969 60	Haw River near Bynum	.985	.0012
02 0973 14	New Hope Creek near Blands	2/ .96	2/ .05
02 09741955	Northeast Creek near Genlee	2/ .96	2/ .05
02 0975 17	Morgan Creek near Chapel Hill	2/ .96	2/ .05
02 0981 98	Haw River below B. Everett Jordan Dam near Moncure	.873	.1844
02 0990 00	East Fork Deep River near High Point	.973	.0008
02 0995 00	Deep River near Randleman	.992	.0108
02 1005 00	Deep River at Ramseur	.981	.0074
02 1020 00	Deep River at Moncure	.983	.0060

2/ Sufficient measurements were not available for autocovariance analysis at this gage. A subjective estimate was substituted.

Table 12.--Summary of autocovariance analysis (continued)

Station no.	Station name	RHO	Process variance (log base e)[2]
02 1021 92	Buckhorn Creek near Corinth	.978	1/ .14
02 1025 00	Cape Fear River at Lillington	2/ .98	2/ .006
02 1029 08	Flat Creek near Inverness	.997	.0132
02 1055 00	Cape Fear River at William O. Huske Lock near Tarheel	2/ .98	2/ .006
02 1057 69	Cape Fear River at Lock 1 near Kelly	2/ .98	2/ .006
02 1060 00	Little Coharie Creek near Roseboro	.989	.0391
02 1065 00	Black River near Tomahawk	.982	.0045
02 1070 00	South River near Parkersburg	.967	.0033
02 10782005	Nahunga Creek at SR 1301 near Warsaw	2/ .98	2/ .04
02 10789100	Grove Creek at Kenansville	2/ .98	2/ .04
02 1080 00	Northeast Cape Fear River near Chinquapin	.977	.0281
02 1085 48	Little Rockfish Creek at Wallace	.940	.3130
02 1095 00	Waccamaw River at Freeland	.948	.0146
02 1110 00	Yadkin River at Patterson	.988	.0114
02 1111 80	Elk Creek at Elkville	.988	.0033
02 1115 00	Reddies River at North Wilkesboro	.984	.0147
02 1120 00	Yadkin River at Wilkesboro	.990	.0045
02 1121 20	Roaring River near Roaring River	.988	.0064
02 1122 50	Yadkin River at Elkin	.973	.0005

1/ These values are subjective estimates. The values determined by the autocovariance analysis for this station do not model the hydraulic conditions of this gage.

2/ Sufficient measurements were not available for autocovariance analysis at this gage. A subjective estimate was substituted.

3/ Subjective estimate based upon lowest positive process variance calculated for the analysis.

Table 12.--Summary of autocovariance analysis (continued)

Station no.	Station name	RHO	Process variance (log base e)^2
02 1123 60	Mitchell River near State Road	.585	3/ .0002
02 1130 00	Fisher River near Copeland	.959	.0011
02 1135 00	Yadkin River at Siloam	.985	.0109
02 1138 50	Ararat River at Ararat	.974	.0032
02 1144 50	Little Yadkin River at Dalton	.968	.0083
02 1153 60	Yadkin River at Enon	.994	.0011
02 1165 00	Yadkin River at Yadkin College	.979	.0020
02 1180 00	South Yadkin River near Mocksville	.979	.0013
02 1185 00	Hunting Creek near Harmony	.988	.0235
02 1207 80	Second Creek near Barber	.989	.0056
02 1211 80	North Potts Creek at Linwood	.930	.0086
02 1250 00	Big Bear Creek near Richfield	.570	.0564
02 1260 00	Rocky River near Norwood	.540	.0014
02 1280 00	Little River near Star	.986	.0476
02 1290 00	Pee Dee River near Rockingham	.973	.0036
02 13228795	Jordan Creek at Silver Hill	2/ .98	2/ .005
02 1335 00	Drowning Creek near Hoffman	.983	.0052
02 1345 00	Lumber River at Boardman	.630	.0064
02 1377 27	Catawba River near Pleasant Gardens	.973	3/ .0002
02 1385 00	Linville River near Nebo	.997	.0597
02 1420 00	Lower Little River near All Healing Springs	.983	.0064

2/ Sufficient measurements were not available for autocovariance analysis at this gage. A subjective estimate was substituted.

3/ Subjective estimate based upon lowest positive process variance calculated for the analysis.

Table 12.--Summary of autocovariance analysis (continued)

Station no.	Station name	RHO	Process variance (log base e)^2
02 1429 00	Long Creek near Paw Creek	.943	.0381
02 1430 00	Henry Fork near Henry River	.576	3/ .0002
02 1430 40	Jacob Fork at Ramsey	.969	.0053
02 1435 00	Indian Creek near Laboratory	.954	.0031
02 1440 00	Long Creek near Bessemer City	.964	.0013
02 1450 00	South Fork Catawba River near Lowell	0	.002
02 1463 00	Irwin Creek near Charlotte	.978	.0109
02 1465 07	Little Sugar Creek at Archdale Drive at Charlotte	.549	.0935
02 1466 00	McAlpine Creek at Sardis Road near Charlotte	.941	.0154
02 1467 00	McMullen Creek at Sharon View Road near Charlotte	.672	.0316
02 1467 50	McAlpine Creek below McMullen Creek near Charlotte	.525	.0026
02 1469 00	Twelve Mile Creek near Waxhaw	.967	.0297
02 1490 00	Cove Creek near Lake Lure	.981	.0012
02 1510 00	Second Broad River at Cliffside	.973	.0007
02 1515 00	Broad River near Boiling Springs	.939	.0019
02 1521 00	First Broad River near Casar	.982	.0064
02 1526 10	Sugar Branch near Boiling Springs	.907	.0339
03 1610 00	South Fork New River near Jefferson	.986	.0017
03 4390 00	French Broad River at Rosman	.456	3/ .0002

3/ Subjective estimate based upon lowest positive process variance calculated for the analysis.

Table 12.--Summary of autocovariance analysis (continued)

Station no.	Station name	RHO	Process variance $(\log \text{ base } e)^2$
03 4410 00	Davidson River near Brevard	.992	.0020
03 4414 40	Little River above High Falls near Cedar Mountain	.988	.0018
03 4430 00	French Broad River at Blantyre	.986	.0037
03 4460 00	Mills River near Mills River	.949	.0005
03 4480 00	French Broad River at Bent Creek	.546	3/ .0002
03 4510 00	Swannanoa River at Biltmore	.914	.0002
03 4515 00	French Broad River at Asheville	.991	.0273
03 4535 00	French Broad River at Marshall	0	3/ .0002
03 4555 00	West Fork Pigeon River above Lake Logan, near Hazelwood	.987	.0482
03 4561 00	West Fork Pigeon River at Bethel	0	3/ .0002
03 4565 00	East Fork Pigeon River near Canton	.975	.0112
03 4569 91	Pigeon River above Canton	.978	.0012
03 4570 00	Pigeon River at Canton	.978	.0012
03 4595 00	Pigeon River near Hepco	.976	3/ .0002
03 4600 00	Cataloochee Creek near Cataloochee	.971	3/ .0002
03 4633 00	South Toe River near Celo	.958	.0011
03 4790 00	Watauga River near Sugar Grove	.988	.0034
03 5000 00	Little Tennessee River near Prentiss	.336	3/ .0002
03 5002 40	Cartoogechaye Creek near Franklin	.986	.0048
03 5030 00	Little Tennessee River at Needmore	.986	.0013

3/ Subjective estimate based upon lowest positive process variance calculated for the analysis.

Table 12.--Summary of autocovariance analysis (continued)

Station no.	Station name	RHO	Process variance (log base e)^2
03 5040 00	Nantahala River near Rainbow Springs	.986	.0024
03 5120 00	Oconaluftee River at Birdtown	.978	.0013
03 5130 00	Tuckasegee River at Bryson City	.974	3/ .0002
03 5485 00	Hiwassee River above Murphy	.973	3/ .0002
03 5500 00	Valley River at Tomotla	.980	.0016

3/ Subjective estimate based upon lowest positive process variance calculated for the analysis.

The autocovariance parameters, summarized in table 12, and data from the definition of missing record probabilities, summarized in table 11, were used to define uncertainty functions for each gaging station. The uncertainty functions relate total error variance to the number of visits and discharge measurements. Three stations which present typical examples of uncertainty functions are shown in figure 11. These functions are based on the assumption that a measurement was made during each visit to the station.

Feasible routes to service the 146 stream gages were determined in consultation with field office personnel after review of the uncertainty functions. Water-quality monitoring stations and ground-water observation wells are serviced by the same personnel who service the streamflow stations. The routes used in this analysis incorporated this practice.

In summary, 121 routes were selected to service all the streamflow stations. These routes included current operations. Alternative routes that visited certain key individual stations and that grouped proximate stations where more frequent visits might be useful were also included. These routes and the stations visited on each are summarized in table 13.

The costs associated with the routes must be determined. Three major cost categories are distinguishable; visit, route, and fixed costs.

Visit costs are those associated with paying the hydrographer for the time actually spent at a station servicing the equipment and making a discharge measurement. These costs vary from station to station and are a function of the difficulty and time required to make the discharge measurement. Average visit times were calculated for each station based on an analysis of discharge measurement data available. This time was then multiplied by the average hourly salary of hydrographers to determine total visit costs. Route costs include the vehicle cost associated with driving the number of miles it takes to cover the route, the cost of the hydrographer's time while in transit, and any per diem associated with the time it takes to complete the trip. The fixed costs to operate a gage typically includes equipment rental, batteries, electricity, data processing and storage, computer charges, maintenance and miscellaneous supplies, and analysis and supervisory charges. An average fixed cost was applied to all of the stations in the program.

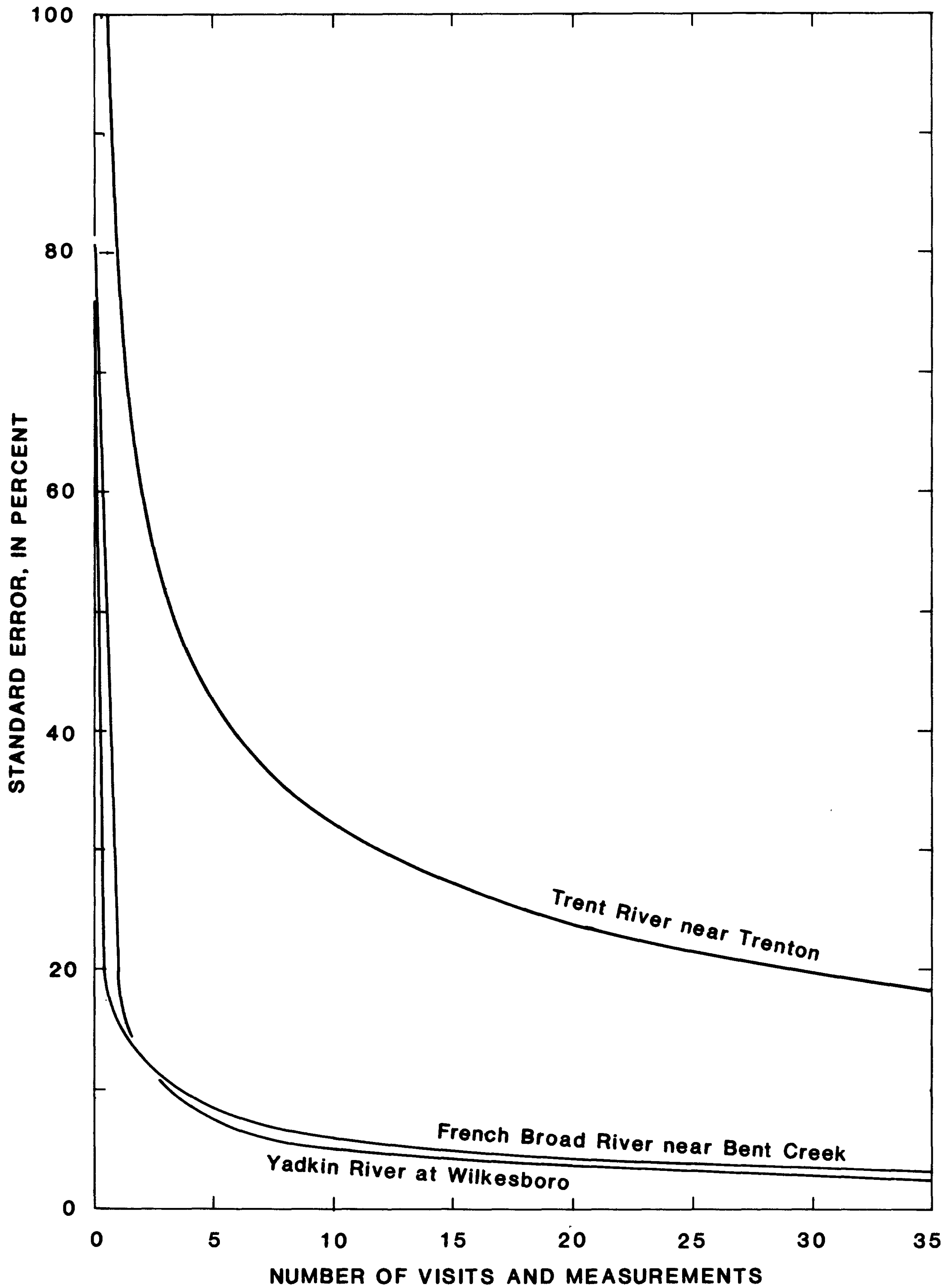

Figure 11.--Typical uncertainty functions for instantaneous discharge.

Table 13.--Summary of the routes that may be used to visit stations in North Carolina

Route number	Stations serviced on the route					
1	2081747	2082750	2082770	2083000	2082585	2082506
	NC-72	2083432	NC-43	NC-32	2081096	2053652
	2053633	NC-86	NC-141	NC-143	NC-78	NC-58
	NC-30	NC-31	NC-54	2053244	NC-82	2050160
	NC-81	NC-55	2053573	2053500	2053200	NC-27
	2085302	2077227	2077200	207527050	2077303	2077348
	2077670	Hyco Lake	2081500	2079717	2079264	207920940
	2079101	2082950	2077670			
2	2085302	2077227	2077200	20752705	2077303	2077348
	2077670	Hyco Lake				
3	2081500	2079717	2079264	207920940	2079101	
4	2081747	2082950	2082770	2083000	2082585	2082506
	NC-72	2083432	NC-43	NC-32	2081096	2053652
	2053633	NC-86	NC-141	NC-143	NC-78	NC-58
	NC-30	NC-31	NC-54	2053244	NC-82	2050160
	NC-81	2053500	2053200			
5	2087183	2087007	208725100	209741955	2097203	2097299
	2097521	2097360	2097203	2097577	NC-126	2085070
	2086849	2086500	2086624	2086224	2097521	2097203
	2097521	2097360				
6	2087007	2086849	208725100			
7	2097419	2097314	2097299			
8	2097299	2097521	2097360	2097203		
9	2085070	2086849	2086500	2086624		
10	2097517	NC-126	2097521	2097360	2097203	209741955
	2097314	2097299	2085070	2086849		
11	NC-58	NC-85	2108000	2108000	2108548	2093000
	2108500	Grove Creek	2107820	2107891	NC-24	NC-69
	2106000	2106681	2106760	2080500	2081000	2097299
	2081500	Du-107	Du-109	Du-111	Du-113	Du-117
	Du-116	Du-122	Du-124	210787855	NC-52	
12	NC-24	NC-69	2108000	2106000	2108548	NC-52
	NC-85	2093000	Grove Creek	2107820	2107891	2108500
	2080500	2081000	2097299			
13	NC-24	NC-69	2108000	2106000		
14	Du-107	Du-109	Du-111	Du-113	Du-117	Du-116
	Du-122	Du-124	2107891	210782005	210787855	2108000
	NC-52	NC-85	2081500			

Table 13.--Summary of the routes that may be used to visit stations in North Carolina (continued)

Route number	Stations serviced on the route					
15	2103000	2102908	2104279	2105500	2134297	2134338
	2104380	2102500	2108800	2087500	2107000	2106500
	2105769	NC-26	2093229	NC-20	NC-22	2109500
	2109821	2133624	2133691	2132394	2134500	2134623
16	2107000	2106500	2105769	NC-26	2093229	NC-20
	NC-22	2109500	2109821	2134495	2134500	2134495
	2132394	2133691	2133624	2134623	2105500	2104500
	2104380	2104274	2104000	2102908	2103000	
17	2107000	2106500	2105769	NC-26	2093229	NC-20
	NC-22	2109500	2109821	2134500	2132394	2105500
	2104000	2102908	2102500	2088000	2087500	
18	2107000	2106500	2105769	2093229	2109500	2134500
	2105500	2104000	2102908	2102500	2088000	2087500
19	2109821	2134623	2134495	2132394	2133691	2133624
	2134297	2104500	2104380	2104279	2103000	
20	2102500	2102908	2134500	2105500	2134500	2109500
	NC-22	NC-20	2093229	NC-26	2105769	2106500
	2107000	2088000	2087500			
21	2084160	2084164	NC-14	2091970	2092000	NC-137
	NC-138	Pitt Wells	NC-16	2084540	2084557	2084070
	208400	2091700	NC-139	NC-73	2083500	2083800
	20810513	2089500	2091500	NC-128	2092500	20918190
	NC-44	NC-51	NC-48	NC-15	NC-75	NC-13
22	2084000	2084070	2084164	2084160	2084148	2084158
	NC-14	Pitt Wells	NC-137	NC-138	NC-16	2091970
	2091700	2084557	NC-75	NC-15	NC-13	2084540
	2083500	2077303	NC-73	NC-44	NC-48	2092500
	NC-46	20918190	2089000	2091500	NC-128	2083500
	2083800	20810513				
23	2083500	2152610	2084557	2113000	2071000	2093800
	2112120	2071000	2100500	2053500	2084164	
24	2084148	2084158	Pitt Wells	NC-137	NC-138	NC-16
	2091970	2092000	2084540	NC-14	2084557	NC-75
	NC-15	NC-13				
25	2084160	2084164	NC-14	2084148	2084158	2091970
	2092000	NC-137	NC-138	Pitt Wells	2084540	2084557
	2084070	2084000	2091700	2083500		
26	2083500	2083800	20810513	2089500	2091500	NC-128
	2092500	20918190	NC-44	NC-51	NC-48	

Table 13.--Summary of the routes that may be used to visit stations in North Carolina (continued)

Route number	Stations serviced on the route					
27	2087570	2088500	2088470	2090512	2090380	2090634
	2090625	2091000	2088682	20918190	2089000	Wa-154
	2088332	2088270	2102192	2098000	2098198	2096960
	2085500	2085220	2102000			
28	2085220	2085500	2098000	2102192	2098198	2102000
	2096960	2088682	2089000	NC-25	2088270	2088332
	Wa-154	2088500	2090625	2090634	2091000	2090380
	2090512	2088470	2087570			
29	2087570	2088500	2088470			
30	Wa-154	2088270	2088332	NC-25	2088682	2089000
	2091000	2090625	2090512	2090634	2090380	
31	2102192	2102000	2098000			
32	2098198	2096960				
33	2087570	2088470				
34	2091000	2090625	2090634	2090512	2090380	2088470
	2088500	Wa-154	2088270	2088332	2088682	2089000
	NC-25	2087570	2102192	2102000	2098198	2085220
	2085500	2098000	2096960			
35	2068500	2069000	2071000	2074000	2074218	2074360
	2093248	2093800	2094500	2095091	2095500	2095554
	2095681	2096500	2096879	2099484	2099000	2099500
	2100500					
36	2125128	2125000	2135000	2128000	NC-35	NC-122
	2133581	2133500	2132269	2132172	212955844	2129341
	2129000	2126000	2125588	2124401	2125128	2124374
37	2142900	2146300	2146507	2146700	2146750	2146600
	2146900	2126000	2129000	2133500	2128000	2125000
38	2068500	2071000	2074000	2074218	2093800	2094500
	2095500	2096500	2099000	2099500	2100500	
39	2142000	2112000	2111500	3162500	3162850	3161361
	3162500	3161000	2111180	2111000	2118500	
40	2099000	2099500	2095500	2096500	2094500	2093800
	2071000	2074000	2074218	2068500		
41	2112120	2112250	2112360	2113000	2113850	2114450
	2115360	2113500	2121180	2120780		
42	2120780	2121180	2121360	2121500	212147355	2115860
	2116500	2117022	2120640	2121360		

Table 13.--Summary of the routes that may be used to visit stations in North Carolina (continued)

Route number	Stations serviced on the route					
43	2125000	2126000	2129000	2133500	2128000	2100500
	2121180	2116500	2120780			
44	2142900	2146300	2146507	2146700	2146750	2146600
	2146900	2125482				
45	2142900	2146300	2146507	2146700	2146750	2146600
	2146900					
46	2118000	NC-142	2117022	2120640	2116500	
47	2120780	2121180	2121360	2121500	212147355	2115860
48	2142000	2112000	2111500	3161000	2111180	2111000
49	2120780	2121180	2116500	2118000	2118500	
50	2125000	2128000	2133500	2129000	2126000	
51	3161000	3162500	3161361	3162951	2097521	3162850
52	2118000	2116500				
53	2112000	2111500	2118500			
54	2111000	2111180	2142000			
55	2116500					
56	2111500	2118500				
57	2112120	2112250				
58	2112360	2113000				
59	2113850	2114450				
60	2115360	2113500				
61	2120780	2121180				
62	3161000					
63	2112000					
64	2118000					
65	2096500					
66	2112250					

Table 13.--Summary of the routes that may be used to visit stations in North Carolina (continued)

Route number	Stations serviced on the route					
67	2115360					
68	2116500					
69	2129000					
70	2137727	2138500	2143000	2143500	2145000	2144000
	2143040	2152100	2149000			
71	2151000	2151500	2152610	2144000	2143500	2143000
	2143040	2152100	2138500	2137727		
72	3512000	3550000	3548500	3504000	3500240	3500000
73	3513000	3503000				
74	3463300	3479000	2138500	2143000	2143500	2144000
	2143040	2152100	2149000	2137727		
75	2137727	2138500				
76	3463300	3479000				
77	2143000	2143500	2144000			
78	2143040	2152100	2149000			
79	2152610	2151500	2151000			
80	3439000	3441000	3446000	3448000		
81	3441440	3443000	NC-144	NC-127		
82	3453500	3451500	3451000			
83	3457000	3456100	3455773	3455500	3456500	NC-40
	3456991					
84	3459500	3460000				
85	3500000	3500240	3504000			
86	3512000	3550000	3548500			
87	2080500	2081000				
88	2080500					
89	2084160					
90	2088000	2088500	2088470			

Table 13.--Summary of the routes that may be used to visit stations in North Carolina (continued)

Route number	Stations serviced on the route			
91	2102192	2098198		
92	2091970			
93	2132200			
94	2107891	2107820		
95	2074218			
96	2088000			
97	2089500	2090380	2090625	2092000
98	2097517			
99	2090625			
100	2149000			
101	3451500			
102	2145000			
103	2102908			
104	2087500			
105	210782005			
106	2121360	2121500	212147355	2115860
107	2087500			
108	2090625			
109	2102908			
110	2118500			
111	2149000			
112	2145000			
113	2077670	2079101		
114	NC-15	NC-75	NC-13	
115	2084540			
116	2097521	2097299		
117	2125482			

Table 13.--Summary of the routes that may be used to visit stations in North Carolina (continued)

Route number	Stations serviced on the route					
118	2135000	NC-35	NC-122	2133581	2132269	2132172
	212955844	2129341	2125588	2124401	2125128	2124374
	3162500					
119	2121360	2121500	212147355	2115860		
120	3439000					
121	3161361	3162500	2121360	2121500		

K-CERA Results

The "Traveling Hydrographer Program" utilizes the uncertainty functions along with the appropriate cost data and route definitions to compute the most cost-effective way of operating the stream-gaging program. In this application, the first step was to simulate the current practice and determine the total uncertainty associated with it. Current operations depend largely on routine field schedules where stations are visited at fixed intervals. This routine schedule is supplemented by special visits required to measure and document extreme floods and droughts or when other conditions, such as large shifts in a rating curve, warrant. The unpredictable nature of these visits preclude their inclusion in this analysis. Only the routine schedule, which was more easily defined, was subjected to the Traveling Hydrographer Program. It should be noted that standard error of estimate of streamflow as computed in this report may not be the best estimate of error of the daily-discharge record published by the U.S. Geological Survey. The additional measurements not included in the routine schedule, plus the use of stage discharge rating shifts, should produce a variance somewhat less than that calculated by the autocovariance analysis. However, the relative magnitude of this estimate, from station to station, can be used for comparative purposes to determine a more cost-effective operation of the stream-gaging program.

To simulate the routine field schedule, constraints on the operations other than budget had to be defined. The number of visits being made to each stream gage, the specific routes that are being used to make these visits, and the probability of making a discharge measurement during a visit were determined. The probability (of making a discharge measurement during a visit) was determined in cooperation with field office personnel and was based upon past experience.

The minimum visit requirement for each station was determined on a case by case basis. Consideration was given to the physical limitations of the method used to record the data. The physical limitations include the durability of batteries used to drive recording equipment, the capacities of the uptake spools on the digital recorders, and the length of analog strip charts.

Minimum visit requirements should also reflect the need to visit stations for special reasons such as water-quality sampling. Because some stations house quality-of-water and precipitation recorders, consideration was given to the physical limitations and maintenance requirements of these recorders. Sampling frequencies specified in cooperative agreements and the cooperator's need for provisional data were also considered.

The results of the K-CERA analysis are based on various assumptions (stated previously) concerning both the time series of shifts of 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 variance was chosen. For a few stations, consistent application of these principles resulted in overestimation of some error variances and their associated standard errors. Several variances of questionable accuracy are based upon subjective estimates of their autocorrelation and process variances. Yet, no better substitute for these estimates are available. For these reasons, efforts to modify or improve the results produced by the Traveling Hydrographer Program were not attempted. However, the presence of a few erroneous values does not negate the applicability of the results to the network as a whole.

For stations where the standard error appeared overly large, an effort was made to identify the cause. This problem was most severe for stations on small streams. Two of the highest standard errors, those for Van Swamp near Hoke (02084557) and Little Rockfish Creek at Wallace (02108548), are especially troublesome. The low-water controls for these gages should provide a much stronger, and more stable rating than respective calculated errors, (40.7 and 50.9 percent), suggest. A number of low-flow measurements were used in the analysis of both stations. Very low flow is difficult to measure. Even slight measurement errors cause large residual errors and may be responsible for the large standard error.

The standard errors for 25 stations were based upon subjective estimates of either their autocorrelation coefficient or process variance, or both, as noted previously. Standard errors for the following stations are much larger than expected: Potecasi Creek near Union (02053200), Hyco Creek near Leasburg (02077200), Mayo Creek near Bethel Hill (02077670), Chicod Creek at Secondary Road 1760 near Simpson (02084160), Middle Creek near Clayton (02088000), and Buckhorn Creek near Corinth (02102192).

The results of the K-CERA analyses are summarized in figure 12 and table 14. The solid line on figure 12 represents the minimum level of average uncertainty that can be obtained for a given budget with the existing instrumentation and technology. The line was defined by several runs of the "Traveling Hydrographer Program" with different budgets. The routine stream gaging schedule results in an average standard error of estimate of instantaneous streamflow of 18.6 percent. This schedule requires a budget of $777,600 to operate the 146-station stream-gaging program. The range in standard errors is from a low of 1.5 percent for French Broad River at Bent Creek (03448000), to a high of 50.9 percent, at Little Rockfish Creek at Wallace (02108548).

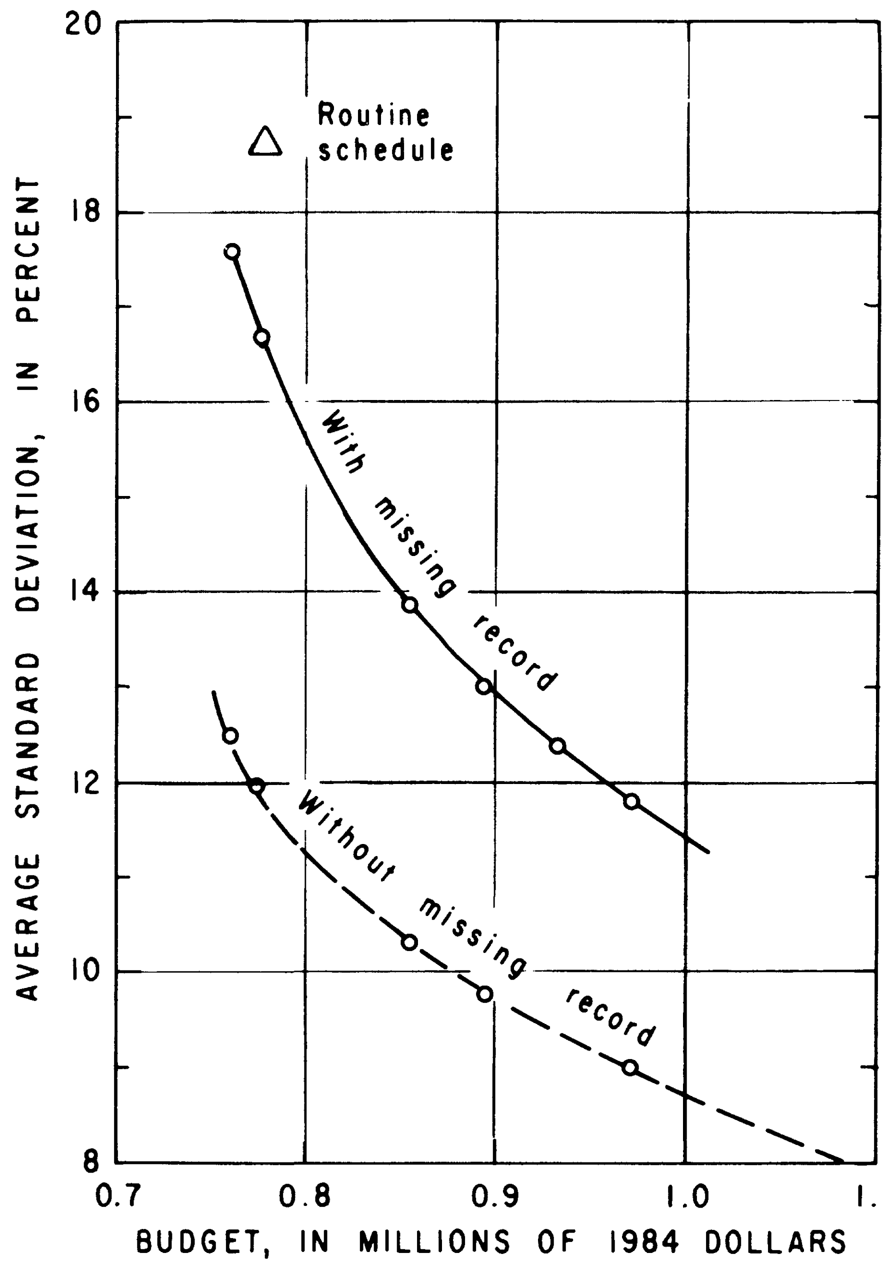

Figure 12.--Temporal average standard error per stream gage.

Table 14.--Selected results for K-CERA analysis

Station number	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)						
	Current operation	Budget, in thousands of 1984 dollars					
		762.0	777.6	855.0	894.2	933.3	972.0
Average per station [1]	18.6	17.6	16.7	13.9	13.0	12.4	11.8
2053200	34.6 [28.4] (9)	32.90 [27.0] (10)	30.1 [24.6] (12)	24.0 [19.5] (19)	21.3 [17.2] (24)	20.5 [16.5] (26)	19.1 [15.4] (30)
2053500	29.4 [16.7] (9)	25.4 [14.2] (12)	23.5 [13.3] (14)	19.7 [11.0] (20)	17.7 [9.9] (25)	16.6 [9.2] (28)	15.3 [8.5] (33)
2068500	4.8 [3.2] (9)	5.8 [3.8] (6)	5.7 [3.8] (6)	4.8 [3.2] (9)	4.6 [3.1] (10)	4.4 [2.9] (11)	4.1 [2.8] (13)
2071000	6.8 [4.7] (9)	6.5 [4.5] (10)	6.6 [4.5] (10)	6.3 [4.3] (11)	6.1 [4.2] (12)	5.4 [3.8] (15)	4.9 [3.5] (19)
2074000	4.8 [2.7] (9)	5.9 [3.2] (6)	5.9 [3.2] (6)	4.9 [2.8] (9)	4.6 [2.7] (10)	4.4 [2.5] (11)	4.1 [2.4] (13)
2074218	9.2 [3.4] (12)	9.0 [3.4] (12)	9.0 [3.4] (12)	9.0 [3.4] (12)	9.0 [3.4] (12)	9.0 [3.4] (12)	8.7 [3.3] (13)
2077200	45.9 [37.5] (9)	36.4 [29.5] (15)	34.3 [27.7] (17)	26.8 [21.5] (28)	25.5 [20.4] (31)	23.9 [19.1] (35)	22.1 [17.6] (41)
2077303	28.5 [18.2] (9)	20.8 [12.9] (17)	19.7 [12.2] (19)	15.4 [9.5] (31)	14.8 [9.1] (34)	13.4 [8.2] (41)	12.5 [7.7] (48)
2077670	37.8 [31.5] (9)	37.8 [31.5] (9)	33.3 [27.6] (12)	26.8 [22.1] (19)	24.0 [19.7] (24)	23.0 [18.9] (26)	21.4 [17.5] (30)
2080500	7.7 [7.2] (12)	7.7 [7.2] (12)	7.7 [7.2] (12)	7.4 [7.1] (20)	7.3 [7.1] (25)	7.3 [7.1] (28)	7.2 [7.1] (30)

[1] Square root of the quotient of the total network variance divided by the number of stations in the network.

Table 14.--Selected results for K-CERA analysis (continued)

Station number	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)						
	Current operation	Budget, in thousands of 1984 dollars					
		762.0	777.6	855.0	894.2	933.3	972.0
2081500	24.2 [13.7] (9)	24.2 [13.7] (9)	21.4 [12.8] (12)	17.4 [11.5] (19)	15.7 [10.3] (24)	15.2 [10.0] (26)	14.2 [9.4] (30)
2081747	19.4 [11.8] (9)	18.4 [11.3] (10)	16.9 [10.4] (12)	13.5 [8.4] (19)	12.0 [7.4] (24)	11.6 [7.2] (26)	10.8 [6.7] (30)
2082506	13.4 [6.5] (9)	12.8 [6.3] (10)	11.7 [5.9] (12)	9.3 [4.9] (19)	8.3 [4.4] (24)	8.0 [4.3] (26)	7.4 [4.0] (30)
2082585	15.1 [6.9] (9)	14.4 [6.7] (10)	13.2 [6.3] (12)	10.6 [5.2] (19)	9.5 [4.7] (24)	9.2 [4.6] (26)	8.5 [4.3] (30)
2082770	17.9 [12.6] (9)	17.0 [12.2] (10)	15.7 [11.3] (12)	12.7 [9.3] (19)	11.4 [8.3] (24)	11.0 [8.0] (26)	10.2 [7.5] (30)
2082950	19.7 [10.6] (9)	18.62 [10.0] (10)	17.0 [9.2] (12)	13.4 [7.3] (19)	11.9 [6.5] (24)	11.4 [6.2] (26)	10.7 [5.8] (30)
2083000	25.7 [10.4] (9)	24.6 [10.3] (10)	22.8 [10.2] (12)	19.0 [9.9] (19)	17.4 [9.7] (24)	16.9 [9.6] (26)	16.0 [9.5] (30)
2083500	15.3 [6.3] (9)	13.5 [6.1] (12)	13.0 [6.1] (13)	11.4 [6.0] (18)	10.6 [6.0] (22)	9.7 [5.8] (28)	9.1 [5.7] (33)
2083800	32.2 [22.9] (9)	33.3 [23.1] (8)	32.2 [22.9] (9)	28.9 [22.3] (14)	27.2 [22.0] (18)	26.6 [21.8] (20)	25.8 [21.6] (23)
2084070	29.1 [23.0] (9)	29.1 [23.0] (9)	27.4 [22.6] (12)	24.5 [21.8] (22)	23.7 [21.4] (27)	23.1 [21.1] (32)	22.7 [20.9] (35)
2084160	35.6 [33.8] (12)	31.0 [29.3] (16)	29.3 [27.6] (18)	23.0 [21.5] (29)	21.2 [19.9] (34)	19.8 [18.5] (39)	18.6 [17.4] (44)

Table 14.--Selected results for K-CERA analysis (continued)

Station number	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)						
	Current operation	Budget, in thousands of 1984 dollars					
		762.0	777.6	855.0	894.2	933.3	972.0
2084164	26.75 [24.45] (9)	25.7 [23.7] (11)	24.4 [22.7] (14)	21.3 [20.2] (23)	20.0 [18.9] (28)	18.7 [17.7] (34)	17.9 [17.0] (38)
2084540	33.3 [25.2] (9)	26.0 [20.4] (17)	25.4 [19.9] (18)	19.1 [15.1] (34)	18.3 [14.5] (37)	17.0 [13.4] (43)	16.0 [12.6] (49)
2084557	40.7 [37.8] (9)	38.5 [36.0] (11)	35.8 [33.5] (14)	29.8 [28.0] (23)	27.4 [25.7] (28)	25.1 [23.6] (34)	23.9 [22.4] (38)
2085070	20.1 [15.9] (12)	18.8 [15.0] (14)	17.7 [14.1] (16)	13.8 [11.0] (27)	13.3 [10.7] (29)	12.3 [9.8] (34)	11.3 [9.1] (40)
2085220	25.6 [20.1] (9)	23.2 [18.3] (11)	22.3 [17.5] (12)	16.8 [13.2] (21)	15.1 [11.9] (26)	14.1 [11.0] (30)	13.4 [10.5] (33)
2085500	18.4 [7.0] (9)	16.5 [6.4] (11)	15.8 [6.2] (12)	11.9 [4.9] (21)	10.6 [4.4] (26)	9.9 [4.1] (30)	9.4 [4.0] (33)
2086500	23.3 [13.8] (12)	22.1 [13.7] (14)	21.2 [13.5] (16)	18.0 [13.0] (27)	17.9 [12.9] (28)	17.0 [12.7] (33)	16.3 [12.5] (39)
2086624	16.1 [7.0] (12)	14.9 [6.6] (14)	13.9 [6.2] (16)	10.7 [5.0] (27)	10.5 [4.9] (28)	9.7 [4.6] (33)	8.9 [4.2] (39)
2086849	16.1 [7.0] (12)	14.9 [6.6] (14)	13.9 [6.2] (16)	10.5 [4.9] (28)	9.8 [4.6] (32)	8.9 [4.2] (39)	8.4 [4.0] (44)
2087007	16.1 [7.0] (12)	15.5 [6.8] (13)	15.5 [6.8] (13)	13.1 [5.9] (18)	11.9 [5.4] (22)	11.1 [5.2] (25)	10.5 [4.9] (28)
2087183	16.3 [12.3] (12)	15.6 [11.8] (13)	15.6 [11.8] (13)	13.6 [10.2] (17)	12.8 [9.7] (19)	12.5 [9.4] (20)	11.4 [8.6] (24)

Table 14.--Selected results for K-CERA analysis (continued)

Station number	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)						
	Current operation	Budget, in thousands of 1984 dollars					
		762.0	777.6	855.0	894.2	933.3	972.0
2087500	11.0 [3.7] (12)	11.0 [3.7] (12)	11.0 [3.7] (12)	8.9 [3.2] (18)	8.2 [3.0] (21)	8.0 [2.9] (22)	8.0 [2.9] (22)
2087570	11.5 [6.2] (9)	10.3 [5.7] (11)	9.8 [5.4] (12)	7.3 [4.2] (21)	6.5 [3.7] (26)	6.1 [3.5] (30)	5.8 [3.4] (33)
2088000	33.7 [23.1] (9)	26.5 [18.7] (14)	24.2 [17.0] (17)	18.9 [13.1] (28)	17.6 [12.3] (32)	16.6 [11.5] (36)	15.1 [10.4] (44)
2088470	23.8 [21.9] (9)	18.6 [17.0] (15)	17.4 [16.0] (17)	13.1 [11.9] (30)	12.2 [11.1] (35)	11.1 [10.1] (42)	10.4 [9.5] (47)
2088500	28.7 [26.7] (9)	23.1 [21.6] (15)	21.8 [20.3] (17)	16.6 [15.4] (30)	15.4 [14.3] (35)	14.0 [13.0] (42)	13.3 [12.3] (47)
2088682	28.3 [27.4] (9)	27.9 [27.2] (11)	27.8 [27.2] (12)	27.0 [26.7] (21)	26.7 [26.5] (26)	26.5 [26.3] (30)	26.3 [26.2] (33)
2089000	9.1 [5.7] (9)	7.6 [5.0] (13)	7.2 [4.9] (14)	5.5 [3.9] (24)	5.0 [3.6] (29)	4.5 [3.3] (36)	4.3 [3.1] (40)
2089500	6.7 [3.2] (9)	6.2 [3.1] (10)	6.2 [3.1] (10)	5.1 [2.7] (14)	4.6 [2.5] (17)	4.2 [2.4] (20)	4.2 [2.5] (21)
2090380	26.9 [15.5] (9)	22.5 [14.7] (15)	22.5 [14.6] (15)	19.1 [13.5] (24)	18.0 [13.0] (28)	16.5 [12.2] (36)	16.2 [12.0] (38)
2090512	27.9 [20.9] (9)	25.8 [19.4] (11)	24.8 [18.7] (12)	19.3 [14.7] (21)	17.5 [13.3] (26)	16.3 [12.4] (30)	15.6 [11.8] (33)
2090625	9.2 [4.2] (9)	24.0 [21.4] (15)	23.8 [21.4] (16)	22.5 [20.8] (24)	22.1 [20.6] (28)	21.3 [20.1] (36)	21.0 [19.9] (40)

Table 14.--Selected results for K-CERA analysis (continued)

Station number	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)						
	Current operation	Budget, in thousands of 1984 dollars					
		762.0	777.6	855.0	894.2	933.3	972.0
2091000	20.2 [6.5] (9)	18.3 [5.9] (11)	17.5 [5.7] (12)	13.2 [4.3] (21)	11.9 [3.9] (26)	11.1 [3.7] (30)	10.5 [3.5] (33)
2091500	14.8 [6.8] (9)	15.6 [6.8] (8)	14.8 [6.8] (9)	12.3 [6.5] (14)	11.1 [6.4] (18)	10.7 [6.4] (20)	10.2 [6.3] (23)
2091700	33.7 [21.4] (9)	33.6 [21.4] (9)	29.5 [18.8] (12)	22.0 [14.1] (22)	19.9 [12.7] (27)	18.3 [11.6] (32)	17.5 [11.1] (35)
2091970	43.3 [39.8] (9)	36.7 [24.0] (15)	33.6 [31.1] (19)	26.0 [24.1] (34)	24.4 [22.5] (39)	22.5 [20.8] (46)	21.4 [20.0] (51)
2092000	20.3 [22.4] (9)	27.8 [20.7] (11)	25.8 [19.3] (13)	20.2 [15.2] (22)	18.6 [14.1] (26)	16.9 [12.7] (32)	16.6 [12.5] (33)
2092500	33.8 [22.6] (9)	35.4 [23.4] (8)	23.8 [22.6] (9)	28.2 [19.4] (14)	25.2 [17.8] (18)	24.1 [16.8] (20)	22.6 [15.8] (23)
2093229	24.5 [20.9] (9)	23.4 [20.1] (10)	21.8 [18.6] (12)	17.9 [15.3] (19)	16.7 [14.2] (22)	16.3 [13.9] (23)	16.3 [13.9] (23)
2093800	7.8 [5.7] (9)	8.2 [6.2] (8)	8.1 [6.2] (8)	7.5 [5.7] (10)	7.2 [5.5] (11)	6.7 [5.2] (13)	6.1 [4.8] (16)
2094500	19.9 [16.2] (9)	23.1 [18.3] (6)	23.1 [18.3] (6)	16.2 [32.2] (9)	19.1 [15.6] (10)	18.4 [15.1] (11)	17.2 [14.2] (13)
2095500	8.0 [1.2] (9)	9.7 [1.3] (6)	9.7 [1.3] (6)	7.9 [1.2] (9)	7.6 [1.2] (10)	7.2 [1.2] (11)	6.6 [1.1] (13)
2096500	9.2 [4.2] (9)	11.1 [4.7] (6)	11.1 [4.7] (6)	9.2 [4.2] (9)	8.7 [4.0] (10)	8.3 [3.9] (11)	7.7 [3.6] (13)

Table 14.--Selected results for K-CERA analysis (continued)

Station number	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)						
	Current operation	Budget, in thousands of 1984 dollars					
		762.0	777.6	855.0	894.2	933.3	972.0
2096960	13.9	12.5	12.0	9.0	8.1	7.2	7.0
	[2.5]	[2.3]	[2.2]	[1.7]	[1.6]	[1.4]	[1.4]
	(9)	(11)	(12)	(21)	(26)	(33)	(34)
2097314	21.0	19.8	17.8	13.8	13.1	12.4	11.3
	[17.0]	[16.2]	[14.7]	[11.4]	[10.8]	[10.3]	[9.4]
	(12)	(14)	(18)	(32)	(36)	(40)	(49)
2097419	21.0	19.8	17.8	13.8	13.0	12.4	11.3
	[17.0]	[16.2]	[14.7]	[11.4]	[10.8]	[10.3]	[9.4)
	(12)	(14)	(18)	(32)	(36)	(40)	(49)
2097517	21.0	21.0	21.0	17.8	17.0	15.4	14.7
	[17.0]	[17.0]	[17.0]	[14.7]	[14.1]	[12.8]	[12.2]
	(12)	(12)	(12)	(18)	(20)	(25)	(28)
2098198	42.7	42.2	41.4	33.7	31.6	28.4	27.2
	[47.6]	[42.1]	[41.4]	[33.7]	[31.6]	[28.5]	[27.2]
	(9)	(11)	(14)	(46)	(57)	(76)	(85)
2099000	12.6	14.9	14.9	12.6	12.1	11.6	10.7
	[9.7]	[11.1]	[11.1]	[9.7]	[9.3]	[9.0]	[8.3]
	(9)	(6)	(6)	(9)	(10)	(11)	(13)
2099500	6.9	8.4	8.4	6.9	6.5	6.2	5.7
	[3.8]	[4.6]	[4.6]	[3.8]	[3.6]	[3.5]	[3.2]
	(9)	(6)	(6)	(9)	(10)	(11)	(13)
2100500	7.5	10.8	10.8	9.8	9.0	8.4	7.9
	[4.8]	[6.4]	[6.4]	[5.9]	[5.5]	[5.2]	[5.0]
	(9)	(4)	(4)	(5)	(6)	(7)	(8)
2102000	28.7	22.3	21.0	18.4	17.0	15.8	15.1
	[4.3]	[3.4]	[3.2]	[2.8]	[2.6]	[2.4]	[2.3]
	(9)	(15)	(17)	(22)	(26)	(30)	(33)
2102192	31.5	24.6	21.9	14.0	12.7	11.3	10.5
	[22.1]	[17.1]	[15.1]	[9.6]	[8.7]	[7.7]	[7.2]
	(9)	(15)	(19)	(47)	(57)	(73)	(84)
2102500	11.6	10.9	9.8	7.7	7.1	6.9	6.9
	[5.8]	[5.6]	[5.2]	[4.3]	[4.1]	[4.0]	[4.0]
	(9)	(10)	(12)	(19)	(22)	(23)	(23)

Table 14.--Selected results for K-CERA analysis (continued)

Station number	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)						
	Current operation	Budget, in thousands of 1984 dollars					
		762.0	777.6	855.0	894.2	933.3	972.0
2102908	12.2 [3.6] (9)	11.6 [3.4] (10)	11.0 [3.2] (11)	8.6 [2.5] (18)	8.0 [2.4] (21)	7.8 [2.3] (22)	7.8 [2.3] (22)
2105500	13.4 [5.8] (9)	12.7 [5.6] (10)	11.6 [5.2] (12)	9.2 [4.3] (19)	8.6 [4.1] (22)	8.4 [4.0] (23)	8.4 [4.0] (23)
2105769	10.5 [5.8] (9)	9.9 [5.6] (10)	9.1 [5.2] (12)	7.3 [4.3] (19)	6.8 [4.1] (22)	6.6 [4.0] (23)	6.6 [4.0] (23)
2106000	19.7 [8.7] (9)	19.7 [8.7] (9)	17.9 [7.8] (11)	13.3 [5.8] (20)	11.9 [5.2] (25)	11.3 [4.9] (28)	10.9 [4.8] (30)
2106500	10.8 [3.7] (9)	10.2 [3.6] (10)	9.3 [3.3] (12)	7.3 [2.7] (19)	6.8 [2.5] (22)	6.7 [2.4] (23)	6.7 [2.4] (23)
2107000	18.1 [4.1] (9)	17.2 [3.9] (10)	15.7 [3.6] (12)	12.5 [3.0] (19)	11.6 [2.8] (22)	11.4 [2.7] (23)	11.4 [2.8] (23)
2107820	19.7 [9.9] (12)	19.0 [9.5] (13)	17.1 (8.6] (16)	14.0 (7.0] (24)	13.2 [6.6] (27)	12.0 [6.0] (33)	11.2 [5.6] (38)
2107891	19.7 [9.9] (12)	19.0 [9.5] (13)	16.6 [8.4] (17)	13.8 [6.9] (25)	13.2 [6.6] (27)	12.0 [6.0] (33)	11.2 [5.6] (38)
2108000	16.5 [10.1] (9)	16.4 [10.1] (9)	14.3 [8.8] (12)	10.8 [6.7] (21)	9.9 [6.2] (25)	9.3 [5.9] (28)	9.0 [5.7] (30)
2108548	50.9 [48.0] (9)	52.6 [49.5] (8)	47.9 [45.1] (11)	38.2 [35.9] (20)	34.6 [32.5] (25)	32.9 [30.9] (28)	31.8 [29.8] (30)
2109500	11.3 [9.4] (9)	10.9 [9.1] (10)	10.2 [8.6] (12)	8.5 [7.3] (19)	8.0 [6.9] (22)	7.9 [6.8] (23)	7.9 [6.8] (23)

Table 14.--Selected results for K-CERA analysis (continued)

Station number	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)						
	Current operation	Budget, in thousands of 1984 dollars					
		762.0	777.6	855.0	894.2	933.3	972.0
2111000	4.9 [4.3] (9)	5.2 [4.5] (8)	5.2 [4.5] (8)	5.2 [4.5] (8)	5.2 [4.5] (8)	5.2 [4.5] (8)	4.9 [4.3] (9)
2111180	4.5 [3.5] (9)	4.7 [3.6] (8)	4.7 [3.6] (8)	4.7 [3.6] (8)	4.7 [3.6] (8)	4.7 [3.6] (8)	4.5 [3.5] (9)
2111500	6.5 [6.0] (9)	7.7 [7.1] (6)	7.7 [7.1] (6)	7.7 [7.2] (6)	6.8 [6.3] (8)	6.2 [5.7] (10)	5.7 [5.3] (12)
2112000	3.7 [3.3] (12)	3.8 [3.3] (12)	3.8 [3.3] (12)	3.8 [3.3] (12)	3.8 [3.3] (12)	3.8 [3.3] (12)	3.8 [3.3] (12)
2112120	4.3 [3.7] (9)	5.1 [4.3] (6)	4.8 [4.1] (7)	5.5 [4.7] (5)	5.6 [4.7] (5)	4.8 [4.1] (7)	4.8 [4.1] (7)
2112250	2.3 [1.6] (9)	2.5 [1.7] (8)	2.5 [1.7] (8)	2.5 [1.7] (8)	2.5 [1.7] (8)	2.5 [1.7] (8)	2.5 [1.7] (8)
2112360	5.7 [1.5] (9)	6.1 [1.5] (8)	6.1 [1.5] (8)	6.1 [1.5] (8)	5.7 [1.5] (9)	5.4 [1.4] (10)	5.4 [1.4] (10)
2113000	9.4 [2.8] (9)	8.9 [2.7] (10)	8.9 [2.7] (10)	9.4 [2.8] (9)	8.9 [2.7] (10)	8.1 [2.5] (12)	7.8 [2.5] (13)
2113500	8.9 [6.0] (9)	9.4 [6.3] (8)	9.4 [6.3] (8)	9.4 [6.3] (8)	9.4 [6.3] (8)	9.4 [6.3] (8)	9.4 [6.3] (8)
2113850	4.3 [3.5] (9)	5.9 [4.5] (4)	5.9 [4.5] (4)	5.1 [4.0] (6)	4.8 [3.8] (7)	4.3 [3.5] (9)	4.1 [3.4] (10)
2114450	9.2 [6.1] (9)	12.8 [7.7] (4)	12.8 [7.7] (4)	10.9 [6.9] (6)	10.2 [6.6] (7)	9.2 [6.1] (9)	8.8 [5.9] (10)

Table 14.--Selected results for K-CERA analysis (continued)

Station number	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)						
	Current operation	Budget, in thousands of 1984 dollars					
		762.0	777.6	855.0	894.2	933.3	972.0
2115360	2.5 [1.5] (9)	2.7 [1.6] (8)	2.7 [1.6] (8)	2.7 [1.6] (8)	2.7 [1.6] (8)	2.7 [1.6] (8)	2.7 [1.6] (8)
2116500	5.0 [3.9] (9)	5.2 [4.0] (8)	5.2 [4.0] (8)	5.2 [4.0] (8)	5.2 [4.0] (8)	5.2 [4.0] (8)	5.2 [4.0] (8)
2118000	4.0 [2.2] (12)	4.0 [2.2] (12)	4.0 [2.2] (12)	4.0 [2.2] (12)	4.0 [2.2] (12)	4.0 [2.2] (12)	4.0 [2.2] (12)
2118500	7.9 [6.8] (9)	8.3 [7.1] (8)	8.3 [7.1] (8)	8.3 [7.1] (8)	7.9 [6.8] (9)	7.5 [6.4] (10)	6.9 [5.9] (12)
2120780	4.5 [3.3] (9)	4.9 [3.4] (8)	4.9 [3.5] (8)	4.9 [3.4] (8)	4.6 [3.3] (9)	4.0 [2.9] (12)	3.7 [2.7] (14)
2121180	11.7 [8.4] (9)	12.2 [8.6] (8)	12.2 [8.6] (8)	12.2 [8.6] (8)	11.7 [8.4] (9)	10.6 [7.9] (12)	10.0 [7.6] (14)
2125000	26.6 [23.7] (9)	26.6 [23.7] (9)	26.6 [23.7] (9)	25.7 [23.5] (12)	25.5 [23.4] (13)	25.3 [23.3] (14)	24.7 [23.1] (17)
2126000	23.8 [3.9] (9)	23.8 [3.9] (9)	23.8 [3.9] (9)	20.6 [3.8] (12)	19.8 [3.8] (13)	19.1 [3.8] (14)	17.4 [3.7] (17)
2128000	13.0 [10.0] (9)	13.0 [10.0] (9)	13.0 [10.0] (9)	11.3 [8.8] (12)	10.9 [8.4] (13)	10.5 [8.2] (14)	9.5 [7.4] (17)
2129000	6.6 [5.2] (12)	6.6 [5.2] (12)	6.6 [5.2] (12)	6.6 [5.2] (12)	6.5 [5.1] (13)	6.3 [5.0] (14)	5.9 [4.8] (17)
2132200	24.9 [3.7] (12)	24.9 [3.6] (12)	24.9 [3.7] (12)	21.6 [3.2] (16)	19.8 [3.0] (19)	18.4 [2.8] (22)	16.9 [2.6] (26)

Table 14.--Selected results for K-CERA analysis (continued)

Station number	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)						
	Current operation	Budget, in thousands of 1984 dollars					
		762.0	777.6	855.0	894.2	933.3	972.0
2133500	5.4 [3.8] (9)	5.4 [3.8] (9)	5.4 [3.8] (9)	4.8 [3.4] (12)	4.6 [3.3] (13)	4.4 [3.2] (14)	4.0 [2.9] (17)
2134500	13.5 [8.1] (9)	10.7 [7.7] (19)	10.1 [7.6] (23)	8.9 [7.2] (37)	8.6 [7.1] (43)	8.5 [7.0] (45)	8.5 [7.0] (45)
2137727	2.6 [.81] (12)	2.6 [.81] (12)	2.6 [.81] (12)	2.6 [.81] (12)	2.6 [.81] (12)	2.5 [.80] (13)	2.4 [.74] (15)
2138500	11.7 [7.1] (12)	11.7 [7.1] (12)	11.7 [7.1] (12)	11.7 [7.1] (12)	11.7 [7.1] (12)	11.2 [6.8] (13)	10.4 [6.3] (15)
2142000	7.1 [4.2] (9)	7.5 [4.4] (8)	7.5 [4.4] (8)	7.5 [4.4] (8)	7.5 [4.4] (8)	7.5 [4.4] (8)	7.1 [4.2] (9)
2142900	25.0 [17.1] (9)	22.4 [15.9] (12)	21.1 [15.2] (14)	21.7 [15.5] (23)	15.7 [11.8] (28)	14.6 [11.0] (33)	14.0 [10.5] (36)
2143000	3.5 [1.4] (9)	3.5 [1.4] (9)	3.5 [1.4] (9)	3.5 [1.4] (9)	3.5 [1.4] (9)	3.5 [1.4] (9)	3.2 [1.4] (11)
2143040	10.7 [5.7] (9)	10.7 [5.7] (9)	10.7 [5.7] (9)	10.7 [5.7] (9)	10.7 [5.7] (9)	10.7 [5.7] (9)	9.6 [5.3] (11)
2143500	6.5 [4.6] (9)	6.5 [4.6] (9)	6.5 [4.6] (9)	6.5 [4.6] (9)	6.5 [4.6] (9)	6.5 [4.6] (9)	6.0 [4.4] (11)
2144000	6.0 [2.5] (9)	6.0 [2.5] (9)	6.0 [2.5] (9)	6.0 [2.5] (9)	6.0 [2.5] (9)	6.0 [2.5] (9)	5.5 [2.4] (11)
2145000	18.8 [1.5] (9)	18.8 [1.5] (9)	17.8 [1.5] (10)	14.1 [1.4] (16)	13.0 [1.4] (19)	12.3 [1.4] (21)	11.6 [1.4] (24)

Table 14.--Selected results for K-CERA analysis (continued)

Station number	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)						
	Current operation	Budget, in thousands of 1984 dollars					
		762.0	777.6	855.0	894.2	933.3	972.0
2146300	15.9 [6.9] (9)	13.4 [6.2] (12)	12.6 [5.7] (14)	9.8 [4.6] (23)	8.8 [4.2] (28)	8.2 [3.9] (33)	7.8 [3.7] (36)
2146507	32.7 [31.5] (9)	32.1 [31.2] (12)	31.8 [31.0] (14)	30.8 [30.3] (23)	30.4 [29.9] (28)	30.0 [29.6] (33)	30.0 [29.4] (36)
2146600	23.4 [11.0] (9)	20.5 [10.2] (12)	19.1 [9.8] (14)	15.2 [8.3] (23)	13.8 [7.7] (28)	12.8 [7.2] (33)	12.3 [6.9] (36)
2146700	26.8 [18.2] (9)	24.5 [17.9] (12)	23.5 [17.7] (14)	20.8 [17.1] (23)	19.9 [16.8] (28)	19.2 [16.5] (33)	18.8 [16.3] (36)
2146750	7.1 [5.1] (9)	6.6 [5.0] (12)	6.4 [5.0] (14)	5.8 [4.9] (23)	5.6 [4.9] (28)	5.5 [4.8] (33)	5.4 [4.8] (36)
2146900	31.7 [13.2] (9)	27.6 [11.9] (12)	25.6 [11.2] (14)	20.1 [9.0] (23)	18.3 [8.2] (28)	16.9 [7.6] (33)	16.1 [7.3] (36)
2149000	3.9 [1.9] (9)	4.4 [2.1] (7)	4.4 [2.1] (7)	4.4 [2.1] (7)	4.7 [2.2] (6)	5.2 [2.3] (5)	4.7 [2.2] (6)
2151000	3.2 [1.7] (9)	3.6 [1.9] (7)	3.6 [1.9] (7)	2.9 [1.6] (11)	2.9 [1.6] (11)	2.7 [1.5] (13)	2.5 [1.4] (15)
2151500	4.3 [3.8] (9)	4.7 [4.0] (7)	4.7 [4.0] (7)	4.3 [3.8] (9)	4.1 [3.6] (11)	2.7 [1.5] (13)	3.7 [3.4] (15)
2152100	6.5 [5.0] (9)	5.0 [4.0] (16)	4.8 [3.8] (18)	4.0 [3.2] (27)	3.7 [3.0] (31)	3.5 [2.8] (35)	3.4 [2.7] (38)
2152610	22.9 [17.6] (9)	22.9 [17.6] (9)	22.9 [17.6] (9)	22.2 [17.4] (10)	21.1 [16.9] (12)	19.8 [16.2] (15)	18.8 [15.6] (18)

Table 14.--Selected results for K-CERA analysis (continued)

Station number	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)						
	Current operation	Budget, in thousands of 1984 dollars					
		762.0	777.6	855.0	894.2	933.3	972.0
3161000	3.4 [2.0] (9)	4.9 [2.8] (4)	4.9 [2.8] (4)	4.9 [2.8] (4)	4.9 [2.8] (4)	4.9 [2.8] (4)	4.9 [2.8] (4)
3439000	2.2 [1.4] (9)	2.5 [1.4] (6)	2.5 [1.4] (6)	2.5 [1.4] (6)	2.5 [1.4] (6)	2.5 [1.4] (6)	2.5 [1.4] (6)
3441000	2.6 [1.8] (9)	3.2 [2.1] (6)	3.2 [2.1] (6)	3.2 [2.1] (6)	3.2 [2.1] (6)	3.2 [2.1] (6)	3.2 [2.1] (6)
3441440	8.9 [2.8] (9)	8.9 [2.8] (9)	8.9 [2.8] (9)	8.9 [2.8] (9)	8.9 [2.8] (9)	8.9 [2.8] (9)	8.0 [2.6] (11)
3443000	3.9 [3.6] (9)	3.9 [3.6] (9)	3.9 [3.6] (9)	3.9 [3.6] (9)	3.9 [3.6] (9)	3.9 [3.6] (9)	3.6 [3.3] (11)
3446000	2.6 [1.8] (9)	3.0 [2.0] (6)	3.0 [2.0] (6)	3.0 [2.0] (6)	3.0 [2.0] (6)	3.0 [2.0] (6)	3.0 [2.0] (6)
3448000	1.5 [1.4] (9)	1.7 [1.4] (6)	1.7 [1.4] (6)	1.7 [1.4] (6)	1.7 [1.4] (6)	1.7 [1.4] (6)	1.7 [1.4] (6)
3451000	10.7 [1.3] (9)	14.8 [1.4] (5)	12.3 [1.4] (7)	10.7 [1.3] (9)	9.6 [1.2] (11)	8.8 [1.2] (13)	8.4 [1.2] (14)
3451500	7.5 [7.5] (12)	7.5 [7.5] (12)	7.5 [7.5] (12)	7.5 [7.5] (12)	7.5 [7.5] (12)	7.3 [7.3] (13)	7.0 [7.0] (14)
3453500	1.7 [1.4] (9)	1.9 [1.4] (5)	1.8 [1.4] (7)	1.7 [1.4] (9)	1.6 [1.4] (11)	1.6 [1.4] (13)	1.6 [1.4] (14)
3455500	10.2 [9.7] (9)	10.2 [9.7] (9)	10.2 [9.7] (9)	10.2 [9.7] (9)	10.2 [9.7] (9)	9.3 [8.8] (11)	8.6 [8.1] (13)

Table 14.--Selected results for K-CERA analysis (continued)

Station number	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)						
	Current operation	Budget, in thousands of 1984 dollars					
		762.0	777.6	855.0	894.2	933.3	972.0
3456100	3.6 [1.4] (9)	3.6 [1.4] (9)	3.6 [1.4] (9)	3.6 [1.4] (9)	3.6 [1.4] (9)	3.2 [1.4] (11)	3.0 [1.4] (13)
3456500	7.1 [6.4] (9)	7.1 [6.4] (9)	7.1 [6.4] (9)	7.1 [6.4] (9)	7.1 [6.4] (9)	6.5 [5.9] (11)	6.1 [5.5] (13)
3457000	2.7 [2.3] (9)	2.7 [2.3] (9)	2.7 [2.3] (9)	2.7 [2.3] (9)	2.7 [2.3] (9)	2.4 [2.2] (11)	2.3 [2.0] (13)
3459500	2.0 [.92] (9)	2.0 [.92] (9)	2.0 [.92] (9)	2.0 [.92] (9)	2.0 [.92] (9)	2.0 [.92] (9)	2.0 [.92] (9)
3460000	2.7 [1.0] (9)	2.7 [1.0] (9)	2.7 [1.0] (9)	2.7 [1.0] (9)	2.7 [1.0] (9)	2.7 [1.0] (9)	2.7 [1.0] (9)
3463300	5.4 [2.7] (9)	5.4 [2.7] (9)	5.4 [2.7] (9)	5.4 [2.7] (9)	5.4 [2.7] (9)	5.4 [2.7] (9)	5.4 [2.7] (9)
3479000	4.6 [2.7] (9)	4.6 [2.7] (9)	4.6 [2.7] (9)	4.6 [2.7] (9)	4.6 [2.7] (9)	4.6 [2.7] (9)	4.6 [2.7] (9)
3500000	2.5 [1.4] (9)	2.6 [1.4] (9)	2.6 [1.4] (9)	2.6 [1.4] (9)	2.6 [1.4] (9)	2.6 [1.4] (9)	2.6 [1.4] (9)
3500240	6.8 [4.2] (9)	6.8 [4.2] (9)	6.8 [4.2] (9)	6.8 [4.2] (9)	6.8 [4.2] (9)	6.8 [4.2] (9)	6.8 [4.2] (9)
3503000	2.2 [1.8] (9)	3.1 [2.4] (4)	3.1 [2.4] (4)	3.1 [2.4] (4)	3.1 [2.4] (4)	3.1 [2.4] (4)	3.1 [2.4] (4)
3504000	3.4 [2.8] (9)	3.4 [2.8] (9)	3.4 [2.8] (9)	3.4 [2.8] (9)	3.4 [2.8] (9)	3.4 [2.8] (9)	3.4 [2.8] (9)

Table 14.--Selected results for K-CERA analysis (continued)

Station number	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)						
	Current operation	Budget, in thousands of 1984 dollars					
		762.0	777.6	855.0	894.2	933.3	972.0
3512000	3.1 [2.1] (9)	3.7 [2.5] (6)	3.7 [2.5] (6)	3.7 [2.5] (6)	3.7 [2.5] (6)	3.7 [2.5] (6)	3.7 [2.5] (6)
3513000	3.6 [.90] (9)	5.3 [1.1] (4)	5.3 [1.1] (4)	5.3 [1.1] (4)	5.3 [1.1] (4)	5.3 [1.1] (4)	5.3 [1.1] (4)
3548500	3.9 [1.0] (9)	4.8 [1.1] (6)	4.8 [1.1] (6)	4.8 [1.1] (6)	4.8 [1.1] (6)	4.8 [1.1] (6)	4.8 [1.1] (6)
3550000	4.0 [2.3] (9)	4.8 [2.7] (6)	4.8 [2.7] (6)	4.8 [2.7] (6)	4.8 [2.7] (6)	4.8 [2.7] (6)	4.8 [2.7] (6)

Reduction of the average standard error from 18.6 to 16.5 percent would be possible if all visits allowed by the current budget were made to optimize the reduction in uncertainty. Extremes of standard errors for individual sites would be 1.7 and 47.9 percent for French Broad River at Bent Creek (03448000) and Little Rockfish Creek at Wallace (02108548), respectively.

A minimum budget of $762,000 is required to operate the 146-station program; a budget less than this does not meet all of the minimum visit constraints. These constraints were imposed to permit proper service and maintenance of gages and recorders and to assure cooperators of timely submission of preliminary data as discussed previously. Either cooperators would have to make do with less frequent data submissions or stations would have to be eliminated from the program if the budget fell below this minimum. At $762,000, the average standard error is 17.6 percent. The minimum standard error of 1.7 percent would occur at French Broad River at Bent Creek and the maximum of 52.6 percent would occur at Little Rockfish Creek at Wallace.

The maximum budget analyzed was $972,000. This budget resulted in an average standard error of estimate of 11.8 percent. Thus, increasing the budget by 25 percent in conjunction with policy change would reduce the average standard error by one third of the error that would result from the current policy and current budget. For the $972,000 budget, the extremes of standard error are 1.6 percent for station French Broad River at Marshall (03453500), and 31.8 percent at Little Rockfish Creek at Wallace (02108548). It is apparent that significant improvements in accuracy of streamflow records can be obtained if larger budgets become available.

A second analysis was performed to estimate the uncertainty that was added to the stream-gaging records because of lost record. The dashed line curve, labeled "without missing record" on figure 12, shows the average standard error of estimation of streamflow that could be obtained with perfect data. For the minimal operational budget of $762,000, lost record as experienced increased average standard error from 12.5 to 17.6 percent; for a maximum budget of 972,000, the increase is from 9.0 percent to 11.8 percent. Another interpretation of the dashed curve in figure 12 is that it represents the standard error applicable to that part of the streamflow data that does not contain missing record.

Conclusions from the K-CERA Analysis

The Traveling Hydrographer Program minimizes the network uncertainty by scheduling an optimum frequency of visits and streamflow measurements at each station for a given budget. A redeployment of station visits as indicated in table 14 would reduce the standard error of estimate from 18.6 to 16.7 percent for the current budget. The 10 percent reduction in these two error estimates is not considered significant, considering possible analytical errors from use of estimated input data. However, the station errors and number of visits in table 14 show definite regional bias or patterns. Errors are consistently higher for stations in the Coastal Plain and in the vicinity of the City of Charlotte indicating some shifting of field visits are warranted.

Additional measurements should be considered for most Coastal Plain stations and those with large errors in the City of Charlotte area. This increase could be funded from reductions of measurements at stations in the northern Piedmont and Blue Ridge provinces where errors are small. Increasing the number of measurements at stations in the Coastal Plain and around the City of Charlotte by two, while reducing the measurements elsewhere by the same amount, reduces the average standard error of estimate from 18.6 to 18.1 percent for the present budget. This reduction is about a fourth of that achieved by the Traveling Hydrographer program, but the changes could be made without organizational changes or transfer of personnel. In addition, use of additional satellite relay or telemark equipment would allow daily or twice-daily interrogation of stations and possibly reduce the amount of lost record and thereby the standard errors.

The K-CERA analysis might be helpful in evaluating potential new locations for relocating field offices, or establishment of new ones, by developing estimates of the cost of field operations and uncertainties associated with each alternative location and could suggest reassignment of gaging sites between existing field offices. Periodic review and updating of the K-CERA results will be necessary to allow these uses and to insure the cost-effectiveness of future stream-gaging programs.

The K-CERA analysis does not allow detection of differing magnitudes of variance at different gage heights along a stage-discharge rating. In reality, most ratings exhibit varying degrees of stability at different ranges of stage. Stability differences are important in determining the relative worth of a measurement at a station during a particular visit and in applying rating shifts to calculate a discharge record. The present K-CERA analysis determines only one lumped value for the variance of streamflow measurements about the entire rating. Some evidence, noted earlier, suggests that the variance at low stages may dominate the variance for other sections of the rating. A more accurate and useful version of the K-CERA analysis might weight the variance at different stages by the percentage of time a particular range in stage would be expected. This area of study remains open.

SUMMARY

Currently, there are 146 continuous stream gages being operated in North Carolina at a cost of $777,600. Twenty-one separate sources of funding contribute to this program and eight separate uses were identified for data from a single station. In spite of the size of the program, there is a large part of Coastal Plain in which streamflow data are too sparse to provide valid estimates of streamflow characteristics, especially where drainage projects have altered local hydrology. This paucity should be remedied as funds can be made available.

In an analysis of the uses that are made of the data, seven stations, operated solely to collect data for regional hydrology, were nominated for discontinuance. Fourteen stations were identified as having uses specific to short-term projects. Five of these stations could be converted to high-flow partial-record stations, and four discontinued at the end of the data collection phase of the studies.

The current policy for routine operation of the 146-station program requires a budget of $777,600 per year. The overall level of accuracy of data collected at the 146 stations could be maintained with a budget of $762,000, if current field operations were designed for the sole purpose of reducing inaccuracy of the records. However, obtaining these savings would require organizational changes and capital expenditures. A more feasible alternative might be to make approximately two additional measurements per year at stations in the Coastal Plain and at stations near the City of Charlotte with an accompanying reduction in measurements at selected stations elsewhere. The present budget would remain approximately the same but there would be an improvement in the overall accuracy of the streamflow records.

A major component of the error in streamflow records is caused by loss of primary record (stage or other correlative data) at the station because of malfunctions of sensing and recording equipment and human errors. The percentage of record lost is very low; however, upgrading of equipment and development of maintenance strategies to minimize lost record appear to be key actions required to improve the reliability and accuracy of the streamflow data.

Studies of the cost-effectiveness of the stream-gaging program should be continued and should include investigation of the optimum ratio of discharge measurements to total site visits for each station, as well as investigation of cost-effective ways of reducing the probabilities of lost correlative data. Future studies also will be required because of changes in demands for streamflow information with subsequent addition and deletion of stream gages. Such changes will impact the operation of other stations in the program both because of the dependence between stations of the information that is generated (data redundancy) and because of the dependence of the costs of collecting the data from which the information is derived.

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