COST-EFFECTIVENESS OF THE
STREAM-GAGING PROGRAM IN NEW JERSEY

By Robert D. Schopp and Randy L. Ulery

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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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By R. D. Schopp and R. L. Ulery

ABSTRACT

This report documents the results of a study of the cost-effectiveness of the stream-gaging program in New Jersey. Data uses and funding sources are identified for the 101 continuous (daily discharge) stream gages and 73 crest-stage and stage-only gages currently operated in New Jersey. Two gaging stations were identified that could be converted to crest-stage gages. Two gaging stations, operated for special studies, could be discontinued when the project, for which they supply data is completed. The remaining 170 stations need to be maintained in the program for the forseeable future.

The current 174-station stream-gaging program in New Jersey operates on a budget of $569,000 per year. The average standard error of estimation of continuous streamflow records is 24.9 percent. This overall level of accuracy could be maintained with a budget of approximately $554,000 if the gaging resources were redistributed among the gages.

A minimum budget of $548,000 is required to operate the 174-gage program; a budget less than this does not permit proper service and maintenance of the gages and recorders. At the minimum budget, the average standard error of estimate increases to 27.6 percent. The maximum budget analyzed was $650,000, which resulted in an average standard error of estimate of 17.8 percent.

INTRODUCTION

The U.S. Geological Survey is the principal Federal agency collecting 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 U.S. Geological Survey operates approximately 8,000 continous-record gaging stations throughout the Nation. Some of the older records extend back to the turn of the century. Any activity of long standing, such as the collection of surface-water data, needs to reexamined at intervals, if not continuously, because of changes in objectives, technology, or external constraints. The latest systematic nationwide evaluation of the streamflow-information program of the U.S. Geological Survey was completed in 1970 and is documented by Benson and Carter (1973). The U.S. Geological Survey is presently undertaking another nationwide analysis of the stream-gaging program that will be completed over a 5-year period with 20 percent of the program being analyzed each year. The objective of this analysis is to define and document the most cost-effective means of furnishing streamflow information.

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

The second goal 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 is no longer 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 operating the minimum number of needed to stations minimize 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. The standard errors of estimate given in the 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 a recomputed by other means. Such errors could differ 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. 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 information. 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 is an introduction to the stream-gaging activities in New Jersey and to the study itself. The middle three sections each contain discussions of individual steps of the analysis. Because of the sequential nature of the steps and the dependence of subsequent steps on the previous results, conclusions are made at the end of each of the three middle sections. The complete study, including all conclusions, is summarized in the final section.

History of the Stream-Gaging Program in New Jersey

The stream-gaging program of the U.S. Geological Survey in New Jersey evolved as Federal, State, and local interests in surface-water resources increased and as funds for operating the stream-gaging station network became available. There are now 101 daily discharge stations in the network, 6 stage-only stations and 70 crest-stage gages. Of the stage-only stations, 3 are tidal and were not included in this analysis because they are not serviced on the regular field trips.

The earliest known streamflow records in New Jersey began in 1877 on the Passaic River from Little Falls to Dundee Dam collected by private organizations; later, the data were reviewed and published (monthly totals) in the 1894 Annual Report of the State Geologist (Vermeule, 1894). The level of Lake Hopatcong was recorded daily beginning in 1887 by the Morris Canal and Banking Company. The City of Newark began collecting records of flow on the Pequannock River at Macopin Intake Dam in 1892. Other stations were added gradually by various Federal, State, or local agencies.

In 1921, the U.S. Geological Survey began operating a stream-gaging program in cooperation with the State of New Jersey. This agreement resulted in the establishment of 72 additional daily-discharge stations by the beginning of World War II. The rapid expansion of the stream-gaging program during the 1920's and 1930's was influenced by the need for data for planning, designing, and operating of the Wanaque Reservoir and other proposed reservoirs to meet the geometrically increasing water demands of northeastern New Jersey and the Trenton-Camden region. The extended severe drought of the early 1930's and major floods of 1936 and 1938, also added impetus to this program of documenting the extremes of streamflow.

The streamflow measurement program grew in response to the need for information. However, in about 1954 it became evident that the increasing costs for operating gaging stations and the need for a greater variety of hydrologic information made it imperative that a more specific and systematic plan for data collection be devised. Statistical analyses and application of the then relatively new "information theory" (Langbein and Hardison, 1955) showed that the cost effectiveness (amount of information per dollar spent) of operating gaging stations could be improved by selectively eliminating some stations from the network. The plan that was developed and implemented in 1957, by agreement between the New Jersey Division of Water Policy and Supply and the U.S. Geological Survey, was the primary/secondary water-management and partial-record-station network concept. That concept was described in detail by McCall (1961) and included a comparison of the stream-gaging networks in the various states of the U.S. Geological Survey and in other countries of the world, and dealt with the changes in our national network in the first few years since 1957.

A study by McCall and Lendo (1970) described the development of New Jersey's surface-water program and proposed a program to meet the future needs of water-data users. At the time of the study, the New Jersey program had 91 continuous gaging stations and 49 crest-stage partial-record stations. Three gages were discontinued and four new gages were installed in the Coastal Plain based on the study recommendations. A historical account of the number of continuous stream gages operated within the State of New Jersey is given in figure 1.

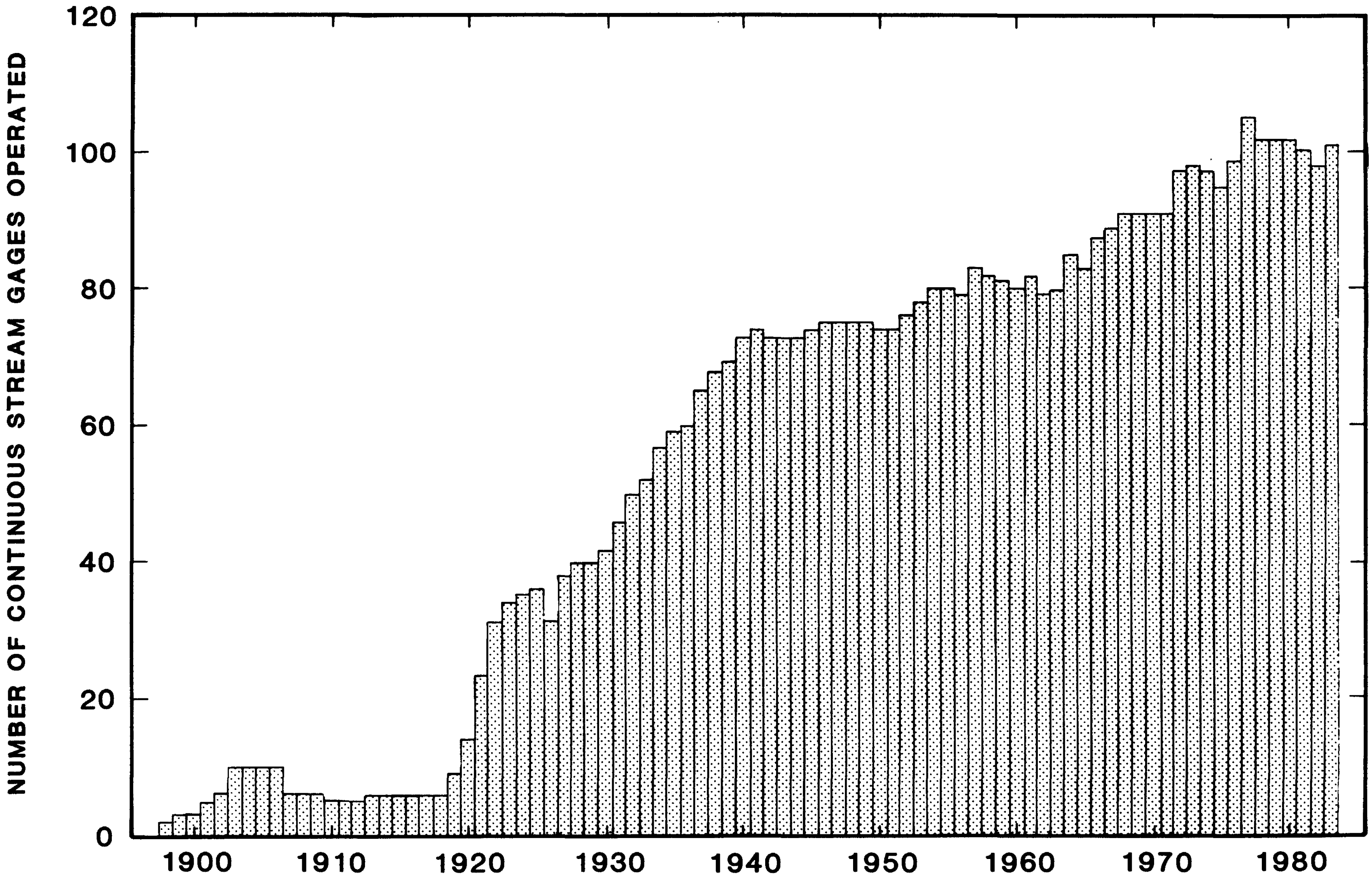
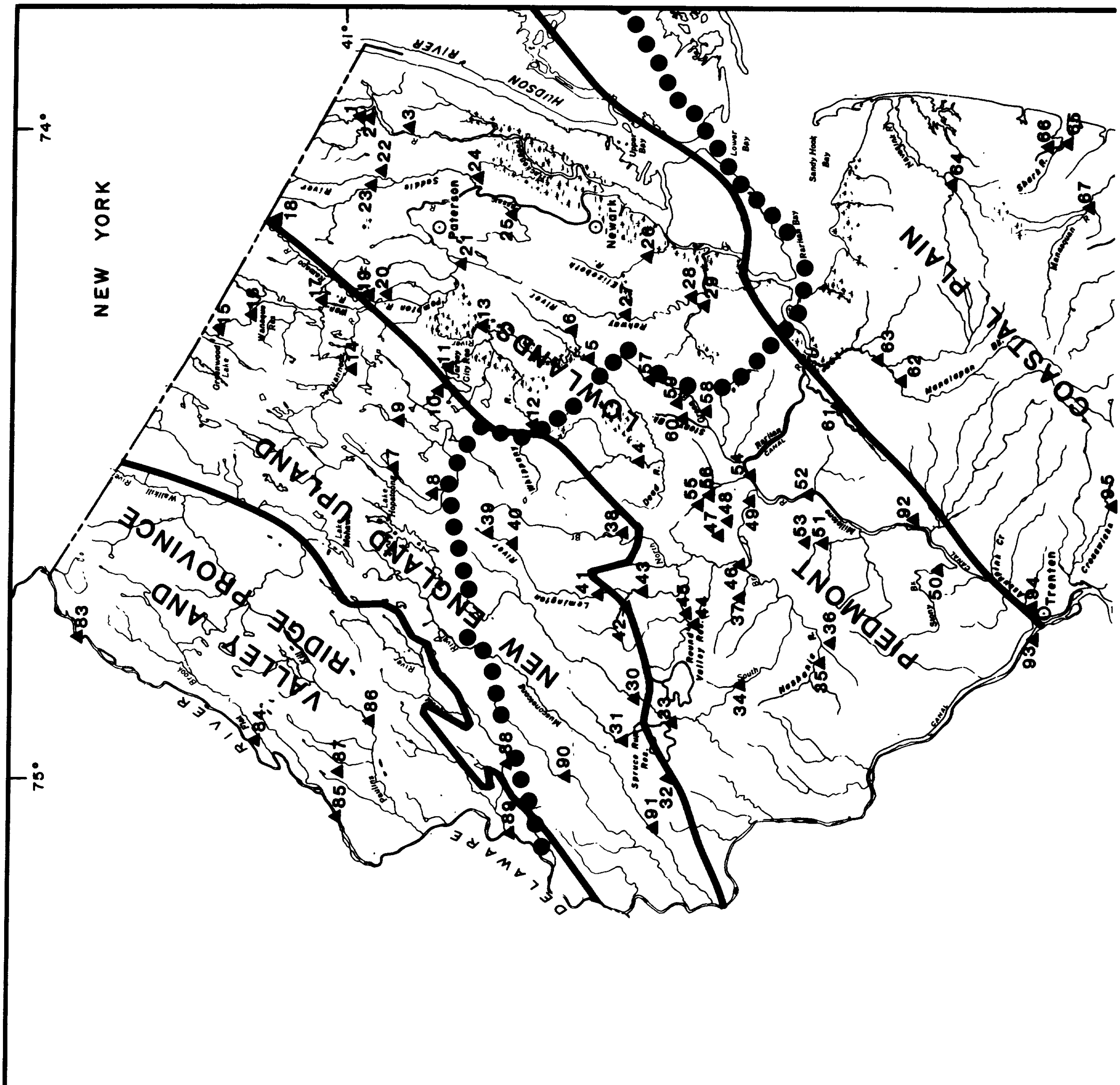


Figure 1.--Duration and extent of continuous stream gaging in New Jersey by the U.S. Geological Survey


NEW YORK
HUDSON RIVER
DELAWARE RIVER
VALLEY AND RIDGE PROVINCE
NEW ENGLAND UPLAND
PIEDMONT LOWLANDS
COASTAL PLAIN
Paterson
Newark
Trenton
74°
75°
41°

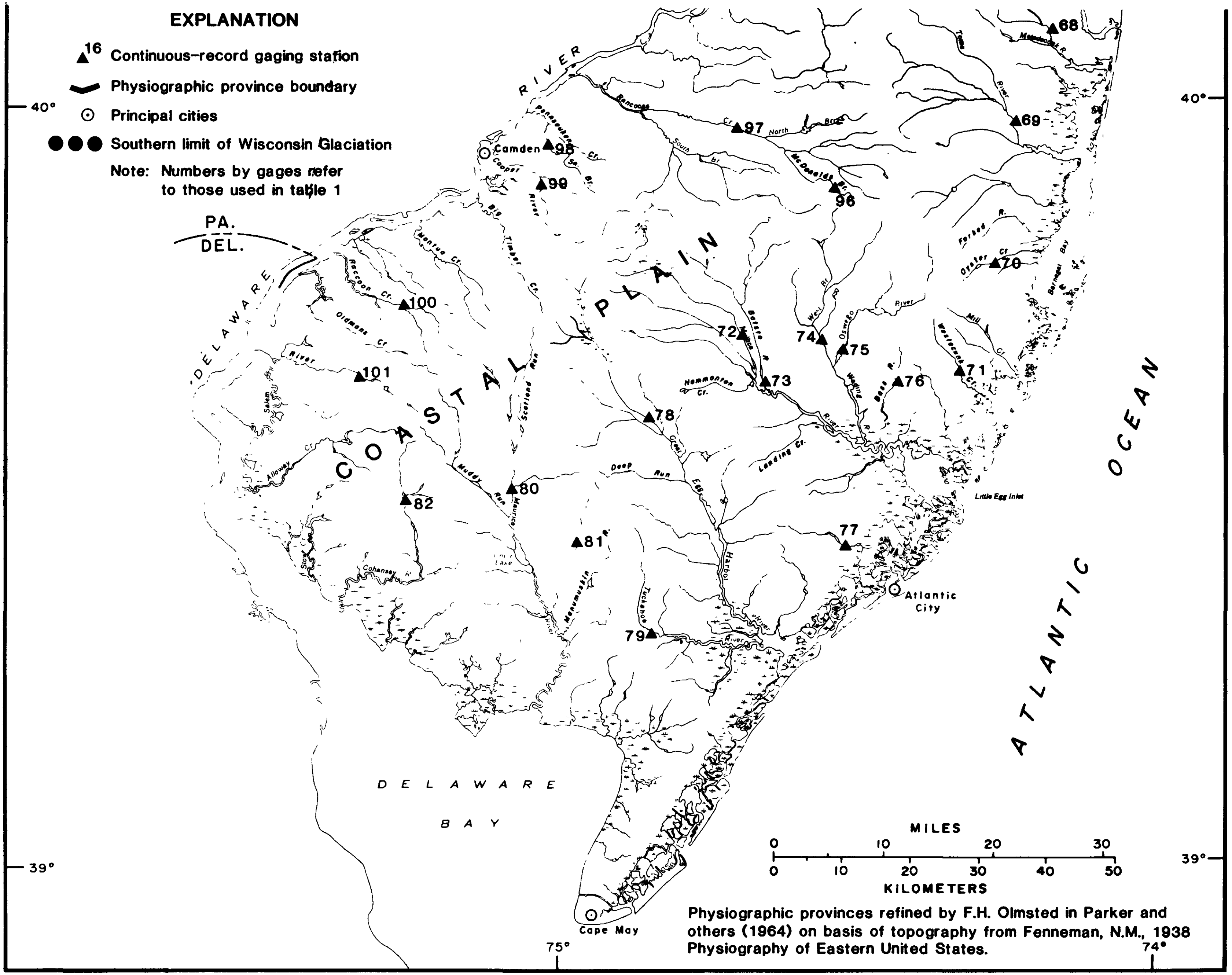


Figure 2.--Location of gaging stations, drainage network and physiographic provinces in New Jersey

Table 1.--Selected hydrologic data for gaging stations in the New Jersey surface-water program

Map Index number	Station number	Station name	Drainage area (mi²)	Period of record	Mean annual flow (ft³/s)	Physiographic province
1	01377000	Hackensack River at Rivervale, NJ	58.0	1942-	89.0	PL(G)
2	01377500	Pascack Brook at Westwood, NJ	29.6	1935-	55.0	PL(G)
3	01378500	Hackensack River at New Milford, NJ	113	1922-	103	PL(G)
4	01379000	Passaic River near Millington, NJ	55.4	1904-06, 1922-	89.7	NE,PL
5	01379500	Passaic River near Chatham, NJ	100	1903-12, 1938-	170	PL,NE(G)
6	01379530	Canoe Brook near Summit, NJ	11.0	1930-	a	PL(G)
7	01379773	Green Pond Brook at Picatinny Arsenal, NJ	7.65	1983-	b	NE(G)
8	01379790	Green Pond Brook at Wharton, NJ	12.6	1983-	b	NE(G)
9	01380000	Beaver Brook at outlet of Splitrock Pond, NJ	5.50	1926-46, 1958-	15.2	NE(G)
10	01380500	Rockaway River above reservoir at Boonton, NJ	116	1938-	223	NE(G)
11	01381000	Rockaway River below reservoir at Boonton, NJ	119	1903-04, 1906-	136	NE,PL(G)
12	01381500	Whippany River at Morristown, NJ	29.4	1921-	52.0	NE,PL
13	01381900	Passaic River at Pine Brook, NJ	349	1963-69[c], 73[c], 1966-75[d], 1978-79[d], 1980-	b	NE,PL(G)
14	01382500	Pequannock River at Macopin Intake Dam, NJ	63.7	1898-	50.8	NE(G)
15	01383500	Wanaque River at Awosting, NJ	27.1	1919-	53.6	NE(G)
16	01384000	Wanaque River at Monks, NJ	40.4	1935-	81.9	NE(G)
17	01387000	Wanaque River at Wanaque, NJ	90.4	1904-06, 1912-15, 1919-	77.9	NE(G)
18	01387500	Ramapo River near Mahwah, NJ	118	1903-07, 1922-	229	NE,PL(G)
19	01388000	Ramapo River at Pompton Lakes, NJ	160	1922-	301	NE,PL(G)
20	01388500	Pompton River at Pompton Plains, NJ	355	1903-05, 1940-	478	NE,PL(G)
21	01389500	Passaic River at Little Falls, NJ	762	1898-	1,160	NE,PL(G)
22	01390500	Saddle River at Ridgewood, NJ	21.6	1955-74, 1975-77[d], 1978-	35.5	PL(G)
23	01391000	Hohokus Brook at Hohokus, NJ	16.4	1954-73, 1974-77[d], 1978-	32.0	PL(G)
24	01391500	Saddle River at Lodi, NJ	54.6	1923-	99.8	PL(G)
25	01392210	Third River at Passaic, NJ	11.8	1977-	b	PL(G)
26	01393450	Elizabeth River at Ursino Lake, at Elizabeth, NJ	16.9	1922-	25.6	PL(G)
27	01394500	Rahway River near Springfield, NJ	25.5	1938-	28.2	PL(G)
28	01395000	Rahway River at Rahway, NJ	40.9	1908-15, 1922-	46.7	PL(G)
29	01396001	Robinsons Branch at Maple Ave, at Rahway, NJ	21.6	1939-	25.0	PL(G)
30	01396500	South Branch Raritan River near High Bridge, NJ	65.3	1919-	121	NE
31	01396580	Spruce Run at Glen Gardner, NJ	12.3	1978-	b	NE
32	01396660	Mulhockaway Creek at Van Syckel, NJ	11.8	1973-77; 1977-	b	NE,PL
33	01396800	Spruce Run at Clinton, NJ	41.3	1959-	60.5	NE,PL
34	01397000	South Branch Raritan River at Stanton, NJ	147	1903-07, 1919-	241	NE,PL
35	01398000	Neshanic River at Reaville, NJ	25.7	1930-	35.9	PL

See footnotes at end of table.

Table 1.--Selected hydrologic data for gaging stations in the New Jersey surface-water program--Continued

Map Index number	Station number	Station name	Drainage area (mi²)	Period of record	Mean annual flow (ft³/s)	Physio-graphic province
36	01398045	Back Brook tributary near Ringoes, NJ	1.98	1978-	b	PL
37	01398107	Holland Brook at Readington, NJ	9.51	1978-	b	PL
38	01398500	North Branch Raritan River near Far Hills, NJ	26.2	1922-75, 1976-77[d], 1978-	47.6	NE
39	01399190	Lamington (Black) River at Succasunna, NJ	7.37	1977	11.2	NE
40	01399200	Lamington (Black) River near Ironia, NJ	10.9	1976-	20.8	NE
41	01399500	Lamington (Black) River near Pottersville, NJ	32.8	1922-	55.8	NE
42	01399510	Upper Cold Brook near Pottersville, NJ	2.18	1973-	3.82	NE
43	01399525	Lamington tributary No. 2 near Pottersville, NJ	1.22	1978-	b	PL
44	01399690	SB Rockaway Creek at Whitehouse, NJ	13.2	1964-67[c], 1977-	b	PL,NE
45	01399700	Rockaway Creek at Whitehouse, NJ	37.1	1959-65[c],73[c], 1977-	b	PL,NE
46	01400000	North Branch Raritan River near Raritan, NJ	190	1923-	303	NE,PL
47	01400300	Peters Brook near Raritan, NJ	4.19	1978	b	PL
48	01400350	Macs Brook at Somerville, NJ	0.77	1982-	b	PL
49	01400500	Raritan River at Manville, NJ	490	1903-07, 1908-15[e], 1921-	758	NE,PL
50	01401000	Stony Brook at Princeton, NJ	44.5	1954-	63.5	PL
51	01401650	Pike Run at Belle Mead, NJ	5.36	1980-	b	PL
52	01402000	Millstone River at Blackwells Mills, NJ	258	1903-05[e], 1921-	375	PL,CP PL
53	01402600	Royce Brook tributary near Belle Mead, NJ	1.20	1967-74, 1980-	2.29	PL
54	01403060	Raritan River below Calco Dam at Bound Brook, NJ	785	1903-09, 1944-	1,274f	MIX
55	01403150	West Branch Middle Brook near Martinsville, NJ	1.99	1979-	b	PL
56	01403160	West Branch Middle Brook near Somerville, NJ	3.83	1982-	b	PL
57	01403400	Green Brook at Seeley Mills, NJ	6.23	1959-64[c], 69[c], 1969-78[d], 1979-	b	PL(G)
58	01403500	Green Brook at Plainfield, NJ	9.75	1938-	12.6	PL(G)
59	01403535	East Branch Stony Brook at Best Lake, at Watchung, NJ	1.57	1980-	b	PL
60	01403540	Stony Brook at Watchung, NJ	5.51	1975-	10.5	PL
61	01405000	Lawrence Brook at Farrington Dam, NJ	34.4	1927-	38.9	PL,CP
62	01405400	Manalapan Brook at Spotswood, NJ	40.7	1957-	65.5	CP
63	01405500	South River at Old Bridge, NJ	94.6	1939-	140	CP
64	01407500	Swimming River near Red Bank, NJ	48.5	1922-	80.6	CP
65	01407705	Shark River near Neptune City, NJ	9.96	1967-	14.7	CP
66	01407760	Jumping Brook near Neptune City, NJ	6.46	1967-	134	CP
67	01408000	Manasquan River at Squankum, NJ	43.4	1931-	75.4	CP
68	01408120	North Branch Metedeconk River near Lakewood, NJ	34.9	1973-	65.9	CP
69	01408500	Toms River near Toms River, NJ	124	1929-	216	CP
70	01409095	Oyster Creek near Brookville, NJ	7.43	1965-	28.8	CP

See footnotes at end of table.

Table 1.--Selected hydrologic data for gaging stations in the New Jersey surface-water program--Continued

Map Index number	Station number	Station name	Drainage area (mi²)	Period of record	Mean annual flow (ft³/s)	Physio-graphic province
71	01409280	Westecunk Creek at Stafford Forge, NJ	16	1969-73[c], 1974-	34.2	CP
72	01409400	Mullica River near Batsto, NJ	46.1	1957-	110	CP
73	01409500	Batsto River at Batsto, NJ	70.5	1928-	125	CP
74	01409810	West Branch Wading River near Jenkins, NJ	84.1	1975-	155	CP
75	01410000	Oswego River at Harrisville, NJ	72.5	1931-	88.4	CP
76	01410150	East Branch Bass River near New Gretna, NJ	8.11	1969-74[c], 1978-	b	CP
77	01410500	Absecon Creek at Absecon, NJ	16.6	1924-29, 1933-39, 1946-	26.8[f]	CP
78	01411000	Great Egg Harbor River at Folsom, NJ	56.3	1925-	86.5	CP
79	01411300	Tuckahoe River at Head of River, NJ	30.8	1970-	45.3	CP
80	01411500	Maurice River at Norma, NJ	112	1932-	168	CP
81	01412000	Menantico Creek near Millville, NJ	23.3	1931-57, 1978-	37.7	CP
82	01412800	Cohansey River at Seeley, NJ	28.0	1978-	b	CP
83	01438500	Delaware River at Montague, NJ	3,480	1936-39, 1940-	5,874	MIX(G)
84	01440000	Flat Brook near Flatbrookville, NJ	64.0	1923-	109	VR(G)
85	01440200	Delaware River Bl Tocks I nr Del Water Gap, PA	3,850	1964-	6,448	MIX(G)
86	01443500	Paulins Kill at Blairstown, NJ	126	1922-76, 1978-	193	VR(G)
87	01443900	Yards Creek near Blairstown, NJ	5.34	1967-	10.9	VR(G)
88	01445500	Pequest River at Pequest, NJ	106	1922-	153	VR,NE(G)
89	01446500	Delaware River at Belvidere, NJ	4,535	1923-	7,913	MIX(G)
90	01455160	Brass Castle Creek near Washington, NJ	2.34	1963-	48.0	NE(G)
91	01457000	Musconetcong River near Bloomsbury, NJ	141	1903-07, 1921-	233	NE(G)
92	01460500	Delaware and Raritan Canal at Kingston, NJ	--	1947-	76.4	-
93	01463500	Delaware River at Trenton, NJ	6,780	1913-	11,692	MIX(G)
94	01464000	Assunpink Creek at Trenton, NJ	90.6	1923-	128	PL,CP
95	01464500	Crosswicks Creek at Extonville, NJ	81.5	1940-52, 1953-	135	CP
96	01466500	McDonalds Branch in Lebanon State Forest, NJ	2.35	1953-	2.32	CP
97	01467000	North Branch Rancocas Creek at Pemberton, NJ	118	1921-	172	CP
98	01467081	South Branch Pennsauken Creek at Cherry Hill, NJ	8.98	1968-76, 1978-	18.4	CP
99	01467150	Cooper River at Haddonfield, NJ	17.0	1964-	35.5	CP
100	01477120	Raccoon Creek near Swedesboro, NJ	26.9	1966-	42.0	CP
101	01482500	Salem River at Woodstown, NJ	14.6	1940, 1942-	19.1	CP

a No mean discharge determined, incomplete record.
b No mean discharge published, less than 5 years of streamflow record.
c Operated as low-flow partial-record station.
d Operated as crest-stage partial-record station.
e Gage heights only.
f Flow adjusted for diversions, or changes in storage.

Physiographic Province Codes

CP Coastal Plain
NE New England Upland
PL Piedmont Lowland
VR Valley and Ridge
MIX More than two provinces drained.
(G) All or part of basin has been glaciated.

Current (1983) New Jersey Stream-Gaging Program

As noted by Parker and others (1964), New Jersey can be divided into four major physiographic regions--the Coastal Plain, the Piedmont Lowlands, the New England Uplands, and the Valley and Ridge Province. The Piedmont Lowlands and the New England Uplands can be further subdivided into glaciated and unglaciated sections. The location of these regions and the distribution of the 101 stream gages currently operated by the New Jersey District office of the U.S. Geological Survey is shown in figure 2. Of these, 28 gages are located in the Coastal Plain, 27 are in the Piedmont Lowlands, 15 are in the New England Uplands, 3 are in the Valley and Ridge Province, and the remaining gaged streams drain two or more provinces.

The cost of operating these 101 stream gages and 73 crest-stage and stage-only gages in fiscal year 1983 was $569,000. Three tide stage-only stations were not included in this analysis because they are not serviced on regular field trips.

Selected hydrologic data, for the 101 stations including drainage area, period of record, mean annual flow and physiographic provinces drained, are given in table 1. Station identification numbers used throughout this report are the U.S. Geological Survey's eight-digit downstream-order station number.

USES, FUNDING, AND AVAILABILITY OF CONTINUOUS STREAMFLOW DATA

The relevance of a stream gage is defined by the uses that are made of the data it produces. The uses made of the data from each gage in the New Jersey program were identified and confirmed by a survey of known data users. This data-use survey documented the importance of each gage and identified particular gaging stations of lesser importance that may be considered for discontinuation or downgrading to partial-record stations.

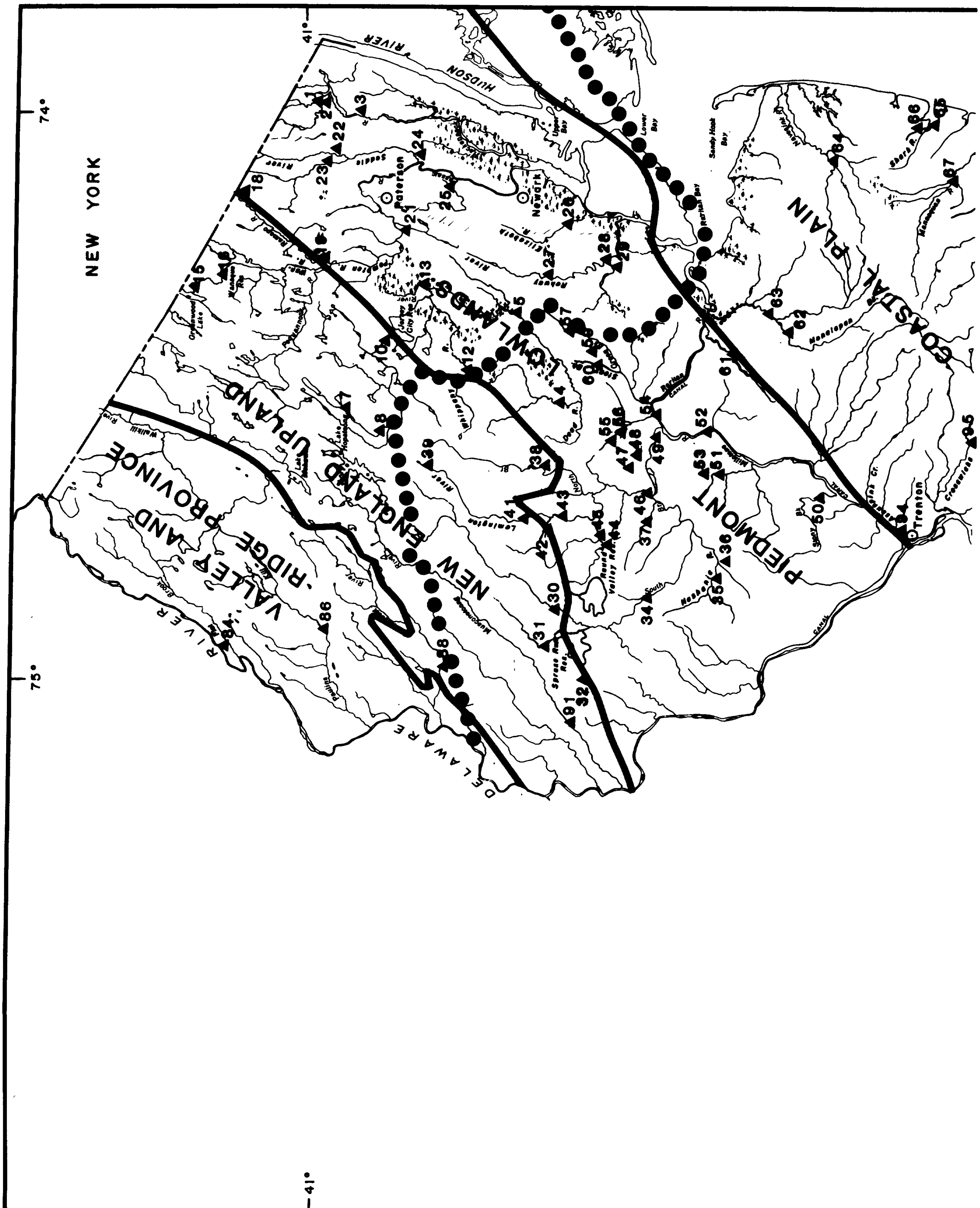
The data uses resulting from this survey were categorized into nine classes, defined below. The sources of funding for each gage and the frequency at which data are provided to the users were also compiled.

Data-Use Classes

The following definitions were used to categorize each known use of streamflow data for each continuous stream gage.

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. Large


NEW YORK
NEW ENGLAND UPLAND
PIEDMONT
LOWLANDS
COASTAL PLAIN
VALLEY AND RIDGE PROVINCE
HUDSON RIVER
DELAWARE RIVER
Paterson
Newark
Trenton
74°
75°
41°

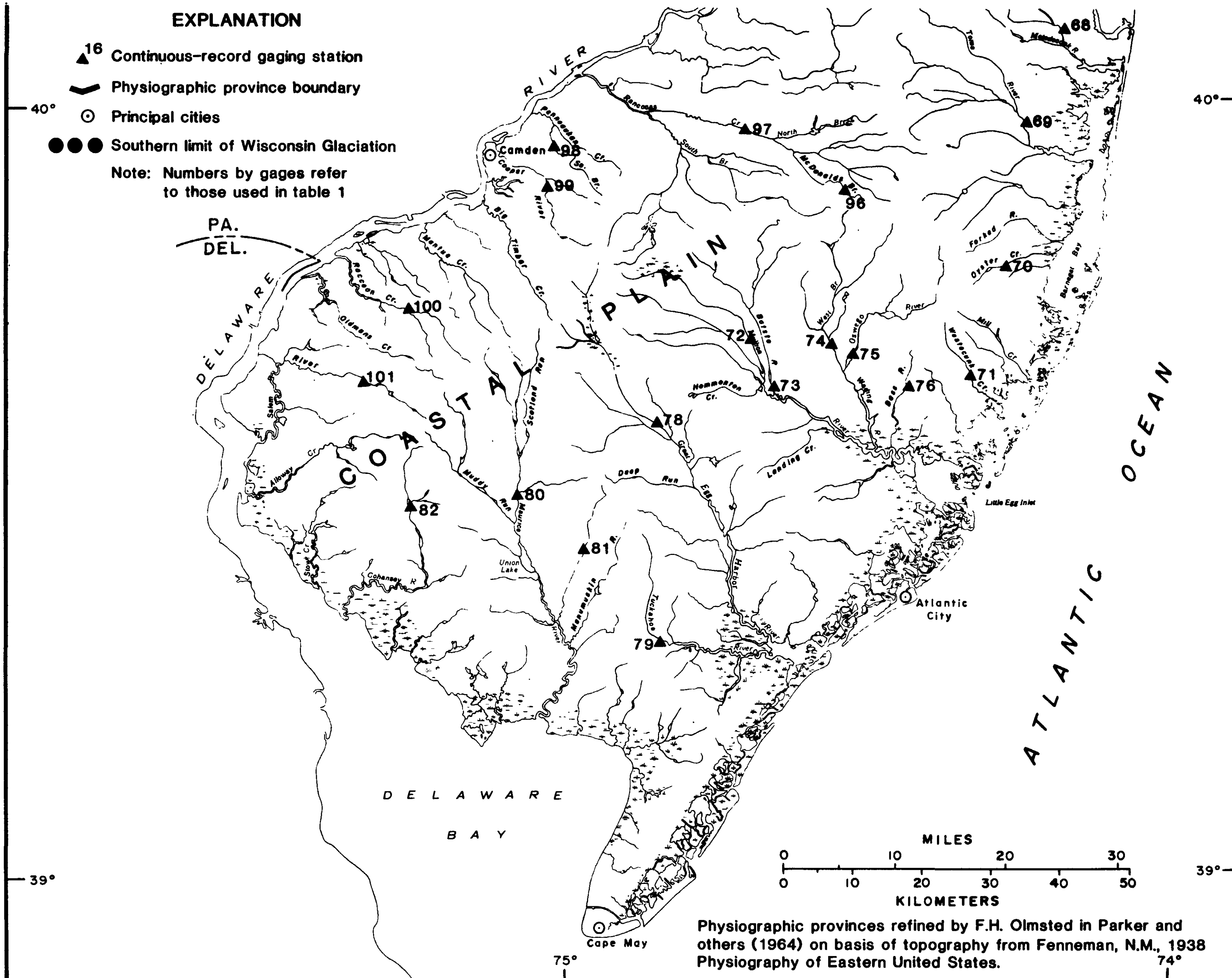


Figure 3.--Location of regional hydrology gaging stations, drainage network and physiographic provinces in New Jersey

amounts of manmade storage may exist in the basin provided that the outflow is uncontrolled. The stations are useful in developing regionally transferable information about the relationship between basin characteristics and streamflow. By the use of footnotes, the usefulness of the station in defining regionally transferable information for low-flow, mean-flow, and flood magnitude and frequency is noted.

Eighty-eight stations in the New Jersey network are classified in this data-use category for low flow and/or mean flow and/or high flow. Three of these stations are special cases in that they are designated bench-mark and index stations. Hydrologic bench-mark stations, of which there is one in New Jersey, were established nationwide to serve as indicators of hydrologic conditions in watersheds that have remained relatively free of cultural alteration. (See Cobb and Biesecker, 1971.) Two regional index stations are used to indicate current hydrologic conditions in the State. The locations of stream gages that provide information on regional high- or low-flow surface water hydrology are given in figure 3.

Hydrologic Systems

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

Bench-mark and index stations are included in this category because they account for current and long-term conditions of the hydrologic systems they gage. One Federal Energy Regulatory Commission (FERC) stations also are included. The data collected at the FERC site is used to monitor the compliance of control structures to downstream flow requirements determined by FERC.

Twenty-five other stations in this class are operated for the State to insure compliance to State-issued diversion permits or regulations. Twelve others serve to document operation of various regulated systems.

Legal Obligations

Some stations provide records of flows for the verification or enforcement of existing treaties, compacts, and decrees. This category contains only those stations that the U.S. Geological Survey is required to operate to satisfy a legal responsibility. There are three stations in the New Jersey program that fulfill a legal responsibility of the U.S. Geological Survey.

Planning and Design

Gaging stations in this category 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. This category is limited to those stations that were instituted for such purposes and where this purpose is still valid. Currently, nine stations in the New Jersey program are operated for planning or design purposes.

Project Operation

Gaging stations in this category are used, on an ongoing basis, to assist water managers in making operational decisions on such activities as reservoir releases, hydropower operations, or diversions. This use generally implies that the data are routinely available to the operators on a rapid-reporting basis. For projects on large streams, data may only be needed every few days. There are 38 stations in the New Jersey program that are used to aid operators in the management of reservoirs and control structures that are part of water-supply systems.

Hydrologic Forecasts

Gaging 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. This use generally implies that the data are routinely available to the forecasters on a rapid-reporting basis. For large streams, data may only be needed every few days.

Stations in the New Jersey program that are included in this category are those used for flood forecasting. Data are used by the U.S. National Weather Service (NWS) as well as by several State and county agencies to predict floodflows at downstream sites. Currently, 33 stations in the New Jersey program are used for hydrologic forecasting.

Water-Quality Monitoring

Gaging stations where regular water-quality or sediment-transport monitoring is conducted and where the availability of streamflow data contributes to the usefullness of the data or is essential to the interpretation of the water-quality or sediment data are designated as water-quality-monitoring sites. A total of 41 stations are included in this category.

One such station in the program is a designated benchmark station and six are National Stream Quality Accounting Network (NASQAN) stations. Water-quality samples from benchmark stations are used to indicate water-quality characteristics of streams that have been and probably will continue to be relatively free of manmade influence. NASQAN stations are part of a national wide network designed to assess water-quality trends of significant streams. (See Ficke and Hawkinson, 1975.)

Research

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

Twenty stations in the New Jersey program are used in the support of research activities, including a rainfall-runoff modeling study and a ground-water movement project. The State of New Jersey Department of Environmental Protection, Rutgers University, Trenton State College, Princeton University, and New Jersey Institute of Technology use the data from several sites for research activities that involve phosphorus loading, sediment transport, waste-load allocation, water-quality, detention basins and river systems modeling.

Other

In addition to the eight data-use classes described above, two stations are used incidentally to provide streamflow information for recreational planning, primarily for canoeists, rafters, and fishermen.

Funding

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

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

2. OFA program.--Funds that have been transferred to the U.S. Geological Survey by other Federal agencies (OFA).

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

4. Other non-Federal.--Funds that are provided entirely by a non-Federal agency and are not matched by U.S. Geolgical 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, are not necessarily the same as those identified herein. Fourteen entities currently contribute funds to the New Jersey stream-gaging program.

Frequency of Data Availability

Frequency of data availability refers to the frequency at which the streamflow data may be furnished to the users. Data can be furnished by direct-access telemetry equipment for immediate use, by periodic release of provisional data, by weekly observer readings, or in publication format through the annual data report published by the U.S. Geological Survey for New Jersey (Bauersfeld and others, 1983). These four subcategories are designated T, P, O, and A, respectively, in table 2. In the current New Jersey program, data for 98 of the 101 stations are made available through the annual water resources data report of the U.S. Geological Survey (published annually for each State), data for 32 stations are available on a real-time basis, and data for 9 stations are routively released on a provisional basis.

Data-Use Presentation

Data-use and ancillary information is presented for each continuous gaging station in table 2, which includes footnotes to expand the information conveyed.

Conclusions Pertaining to Data Uses

A review of the data-use and funding information presented in table 2 indicates that 11 stations are currently operated to support short-term hydrologic studies. Of these, two stations on Green Pond Brook (01379773 and 01379790) are operated as part of a study of the geohydrology of Picatinny Arsenal area and nine stations (01398107, 01398500, 01400300, 01401650, 01402600, 01403150, 01403160, 01403400, and 01403435) are operated as part of a rainfall-runoff study.

Based on current and future data collection needs, several gages could be converted. The upstream gage on Green Pond Brook at Picatinny Arsenal (01379793) should be continued for nine more years in as much as the Brook is only slightly regulated and data on small drainage basins in that area are needed. The downstream gage on Green Pond Brook will not be needed after the completion of the project and could be discontinued. Of the nine rainfall-runoff stations in Somerset County, all except one (01403160) could be continued after the end of the project for flood warning and regional hydrology studies. The gage at West Branch Middle Brook near Somerville (01403160) could be discontinued or downgraded to a crest-stage gage once sufficient peaks have been recorded for modeling, probably in September 1985. Table 2, as well as results of K-CERA (described later in this report), indicate that two gages (01403500 and 01482500) could be downgraded to crest-stage gages.

Table 2.--Gaging-station data use, funding, and data availability

Map index number	Station number	USES: Regional hydrology	USES: Hydrologic systems	USES: Legal obligations	USES: Planning and design	USES: Project operation	USES: Hydrologic forecasts	USES: Water-quality monitoring	USES: Research	USES: Other	FUNDING: Federal program	FUNDING: OFA program	FUNDING: Coop program	FUNDING: Other non-Federal	Data availability
1	01377000	1	50	--	--	5	--	4	--	--	--	--	4	--	AO
2	01377500	1,2	50	--	--	5	--	--	--	--	--	--	--	6	AO
3	01378500	1	7,50	--	--	5	--	--	--	--	--	--	--	4	AO
4	01379000	1,2	7	--	--	--	--	4	--	--	--	--	--	4	A
5	01379500	1,2	7	--	13	--	8	4	--	--	--	9	--	--	AT
6	01379530	--	7	--	--	--	--	--	--	--	--	--	--	4	P
7	01379773	1,2,3	--	--	--	--	--	--	10	--	--	11	--	--	A
8	01379790	1,2	--	--	--	--	--	--	10	--	--	11	--	--	A
9	01380000	--	7	--	--	12	--	--	--	--	--	--	--	4	OP
10	01380500	1,2,3	--	--	--	12	8	--	--	--	--	--	4	--	AO
11	01381000	--	7	--	--	12	8	--	--	--	--	--	--	4	ATO
12	01381500	1,2,3	--	--	--	--	--	4	--	--	--	--	4	--	A
13	01381900	1	--	--	13	--	--	--	--	--	--	9	--	--	A
14	01382500	--	7	--	--	14	8	--	--	--	--	--	--	4	T
15	01383500	1,2	7	--	--	15	--	--	--	--	--	--	--	4	A
16	01384000	1,2	--	--	16	15	--	--	--	--	--	--	--	15	A
17	01387000	--	7,50	--	--	15	8	4	--	--	--	--	15	--	AT
18	01387500	1,2,3	--	--	--	15	8	4	--	--	--	--	4	--	AOT
19	01388000	1,2	7,50	--	--	15	8	--	--	--	--	--	4	--	AT
20	01388500	1	7,50	--	13	17	8	4	--	--	--	9	--	--	AT
21	01389500	1	7,50	--	--	17	8	18	--	--	--	--	17	--	AT
22	01390500	1,2,3	--	--	--	--	--	--	--	--	--	--	4	--	A
23	01391000	1,2,3	--	--	--	--	--	--	--	--	--	--	4	--	A
24	01391500	1,2	7	--	--	5	8	4	--	--	--	--	--	4	AT
25	01392210	1,2,3	--	--	13	--	--	--	--	--	--	9	--	--	A

See footnotes at end of table.

Table 2.--Gaging-station data use, funding, and data availability--Continued

Map index number	Station number	USES: Regional hydrology	USES: Hydrologic systems	USES: Legal obligations	USES: Planning and design	USES: Project operation	USES: Hydrologic forecasts	USES: Water-quality monitoring	USES: Research	USES: Other	FUNDING: Federal program	FUNDING: OFA program	FUNDING: Coop program	FUNDING: Other non-Federal	Data availability
26	01393450	1,2,3	--	--	13	--	--	4	--	--	--	--	4	--	A
27	01394500	1,2	--	--	--	--	8,19	4	--	--	--	--	4	--	AT
28	01395000	1	7	--	--	20	--	4	--	--	--	--	--	4	AO
29	01396001	1,2,3	7	--	--	21	--	--	--	--	--	--	--	4	A
30	01396500	1,2,3,48	48	--	--	22	8	--	--	--	23	--	--	4	APT
31	01396580	1,2,3	--	--	--	22	--	--	--	--	--	--	4	--	AO
32	01396660	1,2,3	--	--	--	22	--	4	--	--	--	--	4	--	A
33	01396800	2	50	--	--	22	8	4	--	--	--	--	4	--	AT
34	01397000	1,2,3	7,50	--	--	22,28	8	--	--	--	--	--	4	--	AT
35	01398000	1,2,3	--	--	--	--	--	4	--	--	--	--	4	--	A
36	01398045	1,2,3	--	--	--	--	--	--	--	--	--	--	4	--	A
37	01398107	1,2,3	--	--	--	--	8,25	--	24	--	--	--	25	--	AT
38	01398500	1,2,3	--	--	--	--	8,25	--	24	--	--	--	25	--	AT
39	01399190	1,2,3	--	--	--	--	--	--	--	--	--	--	26	--	A
40	01399200	--	50	--	--	--	--	4	--	--	--	--	26	26	A
41	01399500	1,2,3	--	--	--	--	--	4	--	--	--	--	4	--	A
42	01399510	1,2,3	--	--	--	--	--	--	--	--	--	--	4	--	A
43	01399525	1,2,3	--	--	--	--	--	--	--	--	--	--	4	--	A
44	01399690	1	50	--	--	22	--	--	--	--	--	--	4	--	A
45	01399700	1	50	--	--	22	--	4	--	--	--	--	4	--	AT
46	01400000	1,2,3	50	--	--	22,28	8	--	--	--	--	--	4	--	AT
47	01400300	1,2,3	--	--	--	--	8,25	--	24,49	--	--	--	25	--	AT
48	01400350	1,2,3	--	--	--	--	--	--	49	--	--	--	--	25	A
49	01400500	1,2	7,50	--	--	22,27,28	8	4	--	--	--	--	4	--	AT
50	01401000	1,2,3	--	--	--	--	--	4	--	--	--	--	4	--	A

See footnotes at end of table.

Table 2.--Gaging-station data use, funding, and data-availability--Continued

Map index number	Station number	USES: Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	FUNDING: Federal program	OFA program	Coop program	Other non-Federal	Data availability
51	01401650	1,2,3	--	--	--	--	8,25	--	24	--	--	--	25	--	AT
52	01402000	1,2	50	--	--	22,28	8	--	--	--	--	--	4	--	AT
53	01402600	1,2,3	--	--	--	--	8,25	--	24	--	--	--	25	--	AT
54	01403060	1,2	7,50	--	--	22,27,28	8	18,41	--	--	--	--	4	--	AT
55	01403150	1,2,3	--	--	--	--	8,25	29	24,49	--	--	--	25	--	AT
56	01403160	1,2,3	--	--	--	--	--	29	49	--	--	--	--	29	A
57	01403400	1,2,3	--	--	30	--	8,25	--	24	--	--	9	25	--	AT
58	01403500	--	50	--	--	--	--	--	--	--	--	--	4	--	A
59	01403535	1,2,3	--	--	--	--	8,25	--	24	--	--	--	25	--	AT
60	01403540	1,2,3	--	--	30	--	--	--	--	--	--	9	--	--	A
61	01405000	1,2	7	--	--	31	--	--	--	--	--	--	--	4	AO
62	01405400	1,2	--	--	--	32	--	--	--	--	--	--	4	--	AO
63	01405500	1,2	--	--	--	32	--	--	--	--	--	--	4	--	AO
64	01407500	1,2	7	--	--	33	--	--	--	--	--	--	--	4	AP
65	01407705	1	7	--	--	33	--	4	--	--	--	--	--	4	A
66	01407760	1	7	--	--	33	--	4	--	--	--	--	--	4	P
67	01408000	1,2,3	--	--	--	--	--	--	--	--	--	--	4	--	A
68	01408120	1,2,3	--	--	--	--	--	--	--	--	--	4	4	--	A
69	01408500	1,2,3	45	--	--	--	--	18	--	--	--	--	4	--	A
70	01409095	1,2,3	45	--	--	--	--	--	--	--	--	--	4	--	A
71	01409280	1,2,3	45	--	--	--	--	--	--	--	--	--	4	--	A
72	01409400	1,2,3	45	--	--	--	--	--	--	--	--	--	4	--	A
73	01409500	1,2,3	45	--	--	--	--	4	--	--	--	--	4	--	A
74	01409810	1,2,3	45	--	--	--	--	18	--	--	--	--	4	--	A
75	01410000	1,2,3	45	--	--	--	--	4	--	--	--	--	4	--	A

See footnotes at end of table.

Table 2.--Gaging-station data use, funding, and data availability--Continued

Map index number	Station number	USES: Regional hydrology	USES: Hydrologic systems	USES: Legal obligations	USES: Planning and design	USES: Project operation	USES: Hydrologic forecasts	USES: Water-quality monitoring	USES: Research	USES: Other	FUNDING: Federal program	FUNDING: OFA program	FUNDING: Coop program	FUNDING: Other non-Federal	Data availability
76	01410150	1,2,3	45	--	--	--	--	4	--	--	--	--	4	--	AO
77	01410500	2	7,45	--	--	--	--	--	--	--	--	--	--	4	A
78	01411000	1,2,3,47	45,47	--	--	--	--	--	46	--	23	--	4	--	APT
79	01411300	1,2,3	45	--	--	--	--	--	--	--	--	--	4	--	A
80	01411500	1,2,3	45	--	--	--	--	18	--	--	--	--	4	--	A
81	01412000	1,2,3	--	--	--	--	--	--	--	--	--	--	4	--	A
82	01412800	1,2,3	--	--	--	--	--	4	--	--	--	--	4	--	A
83	01438500	--	--	34	--	35	8	--	36	44	23	--	--	--	APT
84	01440000	1,2,3	--	--	--	--	--	--	--	--	--	--	4	--	AO
85	01440200	--	--	--	36	37	8	--	--	44	--	37	--	--	AT
86	01443500	1,2,3	--	--	--	--	--	4	--	--	--	--	4	--	AO
87	01443900	2	38	--	--	--	--	--	--	--	--	38	--	--	AP
88	01445500	1,2,3	--	--	--	--	--	--	--	--	--	--	4	--	A
89	01446500	--	--	--	--	--	8	--	--	--	--	--	4	--	AT
90	01455160	--	7	--	--	--	--	--	--	--	--	--	--	4	P
91	01457000	1,2,3	--	--	--	--	--	--	--	--	--	--	4	--	A
92	01460500	--	50	34	--	22,27,35,36	--	--	--	--	23	--	--	--	AT
93	01463500	--	--	--	--	35,36,37,39,40	8,36	7,18,36, 37,42	46	--	--	37	--	--	AT
94	01464000	1,2	7	34	--	--	8	--	46	--	--	--	4	--	AT
95	01464500	1,2,3	--	--	--	--	--	4	46	--	--	--	4	--	A
96	01466500	1,2,3,43	23,45	--	--	--	--	42,43	--	--	23	--	--	--	A
97	01467000	1,2,3	45	--	--	--	8	4	46	--	--	--	4	--	AT
98	01467081	1,2,3	--	--	--	--	--	4	--	--	--	--	4	--	A
99	01467150	1,2	--	--	--	--	8,37	--	46	--	--	37	4	--	AT
100	01477120	1,2,3	--	--	--	--	--	4	--	--	--	--	4	--	A
101	01482500	1,2,3	--	--	--	--	--	4	46	--	--	--	4	--	A

See footnotes at end of table.

Table 2.--Gaging station data use, funding, and data availability--Continued

COOPERATOR, USER AND USE CODES

1--Used for flood-magnitude and frequency-regionalization studies.
2--Used for mean annual discharge regionalization studies.
3--Used for low-flow regionalization studies.
4--New Jersey Department of Environmental Protection, Division of Water Resources.
5--Hackensack Water Company.
6--Bergen County, Department of Public Works.
7--Records used to verify compliance with state diversion permits or State law.
8--National Weather Service flood forecasting station.
9--Corps of Engineers-New York District.
10--Operated as a part of Picatinny Arsenal ground-water-movement study.
11--Picatinny Arsenal-U.S. Army.
12--Jersey City, Bureau of Water.
13--Passaic River Flood Control Study by Corps of Engineers, New York District.
14--City of Newark, Division of Water Supply.
15--North Jersey District Water Supply Commission.
16--Monksville Dam Project of North Jersey District Water Supply Commission.
17--Passaic Valley Water Commission.
18--National stream quality accounting network station. (NASQAN)
19--Cranford Township, Office of Township Engineer.
20--City of Rahway, Water Department.
21--Commonwealth Water Company.
22--New Jersey Water Supply Authority.
23--Federally funded station.
24--Operated as a part of Somerset County rainfall-runoff and flood-warning study.
25--Somerset County, Office of County Engineer.
26--Morris County Municipal Utilities Authority.
27--Elizabethtown Water Company.
28--Lederle Laboratories, a division of American Cyanamid Company.
29--Bridgewater Township Environmental Commission.
30--Green Brook Flood Control Study by Corps of Engineers, New York District.
31--City of New Brunswick, Water Department.
32--Duhernal Water Company.
33--Monmouth Consolidated Water Company.
34--Required under U.S. Supreme Court decree in New Jersey Vs. New York, 347 U.S. 995 (1954).
35--Delaware River Master.
36--Data used by Delaware River Basin Commission for reservoir-outflow simulation studies.
37--Corps of Engineers-Philadelphia District.
38--Jersey Central Power and Light Co.-Federal Energy Regulatory Commission Licensee.
39--City of Philadelphia, Water Department.
40--City of Trenton, Water Department.
41--Pesticide program station.
42--Radiochemical program station.
43--Hydrologic benchmark station.
44--Provides information for recreational needs.
45--Data used by Pinelands Commission (Pinelands National Reserve) for hydrologic assessment.
46--Data used by Delaware River Basin Commission in Salinity Intrusion Model for the Delaware Estuary.
47--Hydrologic index station, Coastal Plain.
48--Hydrologic index station, Non-Coastal Plain.
49--Data used by Bridewater Township to assess effects of development on the hydrologic regime.
50--Data used by New Jersey Department of Environmental Protection, Division of Water Resources to define sources and sinks in regulated hydrologic systems.

Table 2.--Gaging-station data use, funding, and data availability--Continued

DATA AVAILABILITY CODES

A--Data published in annual data report.
O--Station visited weekly or daily by observer.
P--Provisional data provided at specified intervals, usually on a monthly basis.
T--Data transmitted by telephone telemetry.

ALTERNATIVE METHODS OF DEVELOPING STREAMFLOW INFORMATION

The second step of the analysis of the stream-gaging program is to investigate alternative methods of developing 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 develop 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 for a station will influence whether a site has potential for application of 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 a high redundancy of flow information. Similar watersheds, located in the same physiographic and climatic area, also may have potential for using alternative methods.

All stations in the New Jersey stream-gaging program were categorized as to their potential for use of alternative methods, and selected methods were applied at four stations. The categorization of gaging stations and the application of the methods are described in subsequent sections of this report. This section briefly describes the two alternative methods that were used in the New Jersey analysis and documents why these specific methods were chosen.

Because of the short timeframe of this analysis, only two methods were considered. Desirable attributes of a proposed alternative method are (1) it should be computer oriented and easy to apply, (2) it should have an available interface with the U.S. Geological Survey WATSTORE Daily Values File (Hutchinson, 1975), (3) it should be technically sound and generally acceptable to the hydrologic community, and (4) it should permit easy evaluation of the accuracy of the simulated streamflow records. These requirement were used to select two methods--a flow-routing model and multiple-regression analysis.

Description of Flow-Routing Model

Hydrologic flow-routing methods use the law of conservation of mass and the relationship between the inflow to a reach, the storage in a reach and the outflow from the reach. The hydraulics of the system are not considered. The method 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. Several different types of hydrologic routing are available such as Muskingum, Modified Puls, Kinematic Wave, and the unit-response flow-routing method. The last method was selected for this analysis. This method uses two techniques--storage continuity (Sauer, 1973) and diffusion analogy (Keefer, 1974; Keefer and McQuivey, 1974). These concepts are discussed below.

The unit-response method was selected because it fulfilled the criteria noted above. Computer programs for the unit-response method can be used to route streamflow from one or more upstream locations to a downstream location. Downstream hydrographs are produced by the convolution of upstream hydrographs with their appropriate unit-response functions. This method can only be applied at a downstream station where an upstream station exists on the same stream. An advantage of this model is that it can be used for regulated stream systems. Reservoir-routing techniques are included in the model so flows can be routed through reservoirs if the operating rules are known. Calibration and verification of the flow-routing model is achieved with observed upstream and downstream hydrographs and estimates of tributary inflows. The convolution model treats a stream reach as a linear one-dimensional system in which the system output (downstream hydrograph) is computed by multiplying (convoluting) the ordinates of the upstream hydrograph by the unit-response function and lagging them appropriately. The model has the capability of combining hydrographs, multiplying a hydrograph by a ratio, and changing the timing of a hydrograph. Routing can be accomplished with hourly data, but only daily data are used in this flow-routing analysis.

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 with 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. In order to handle this problem, the option of multiple linearization is available (Keefer and McQuivey, 1974), which uses a family of unit-response functions to represent the system response.

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 known flows at an index gaging station by a factor--for example, a drainage-area ratio.

The objective in either the storage-continuity or diffusion analogy flow-routing method is to calibrate two characteristics 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 (Keefer and McQuivey, 1974) is routed through reservoir-type storage and then transformed by a summation curve technique to a unit response of desired duration. The two parameters that describe the routing reach are K_s, a storage coefficient which is the slope of the storage-discharge relation, and W_s, the translation-hydrograph time base. These two parameters determine the shape of the resulting unit-response function.

In the diffusion analogy theory, 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 one 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) verses discharge (Q) is used.

In both the storage-continuity and diffusion-analogy methods, the two parameters Ko and Co, 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. See Doyle and others (1983) for a more detailed discussion of streamflow routing by convolution methods.

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 indexes 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 those of Draper and Smith (1966) and Kleinbaum and Kupper (1978). The application of regression analysis to hydrologic problems is described and illustrated by Riggs (1973) and Thomas and Benson (1970). Only a brief description of regression analysis is provided in this report.

A linear-regression model of the following form was developed for estimating daily mean discharges in New Jersey:

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

where

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

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

B_o and B_j = regression constant and coefficients, and

e_i = the random error term.

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 discharges 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 with 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 at a different period of time to obtain a measure of the true predictive accuracy. Both the calibration and verification periods should represent the range of flows that could occur at station i. The equation needs to 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 as a function of time. These tests are intended to determine whether (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, or 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_i, in cubic feet per second, was appropriate. The application of linear-regression techniques to four watersheds in New Jersey 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

Based on a review by W. Harry Doyle, Jr. (written communication, 1983) and the authors, five stations were identified at which alternative methods for providing the needed streamflow information could be applied. These five stations are Chatham (01379500), Pottersville (01399500), Plainfield (01403500), Tocks Island damsite (01440200) and Belvidere (01446500). Based on the capabilities and limitations of the methods and data availability, flow-routing techniques were used only at the Chatham, Tocks Island damsite and Belvidere gaging stations. Regression methods were applied to all five sites.

Passaic River Flow-Routing Analysis

The purpose of this flow-routing analysis is to investigate the potential for use of the unit-response model for streamflow routing to simulate daily mean discharges of Passaic River near Chatham, New Jersey (01379500). A map of the Passaic River study area is presented in figure 4. In this application, a best fit model for the entire flow range is the desired product. Streamflow data available for this analysis are summarized in table 3.

The Chatham gage is located 13.5 miles downstream from the next upstream stream gage, Millington (01379000). The intervening drainage area between Millington and Chatham is 44.6 mi^2 or 44.6 percent of the total drainage area contributing to the Chatham site. No stream gages are located within this area and the area is moderately developed. This development sometimes causes dual peaking hydrographs at Chatham that are not in evidence at Millington.

When attempting to simulate the daily mean discharges, the approach was to route the flow from Millington to Chatham by the diffusion analogy method with a single linearization. The intervening drainage area was accounted for by using data from stations at Millington (01379000) and Rahway River near Springfield (01394500) adjusted by drainage-area ratios. The total discharge

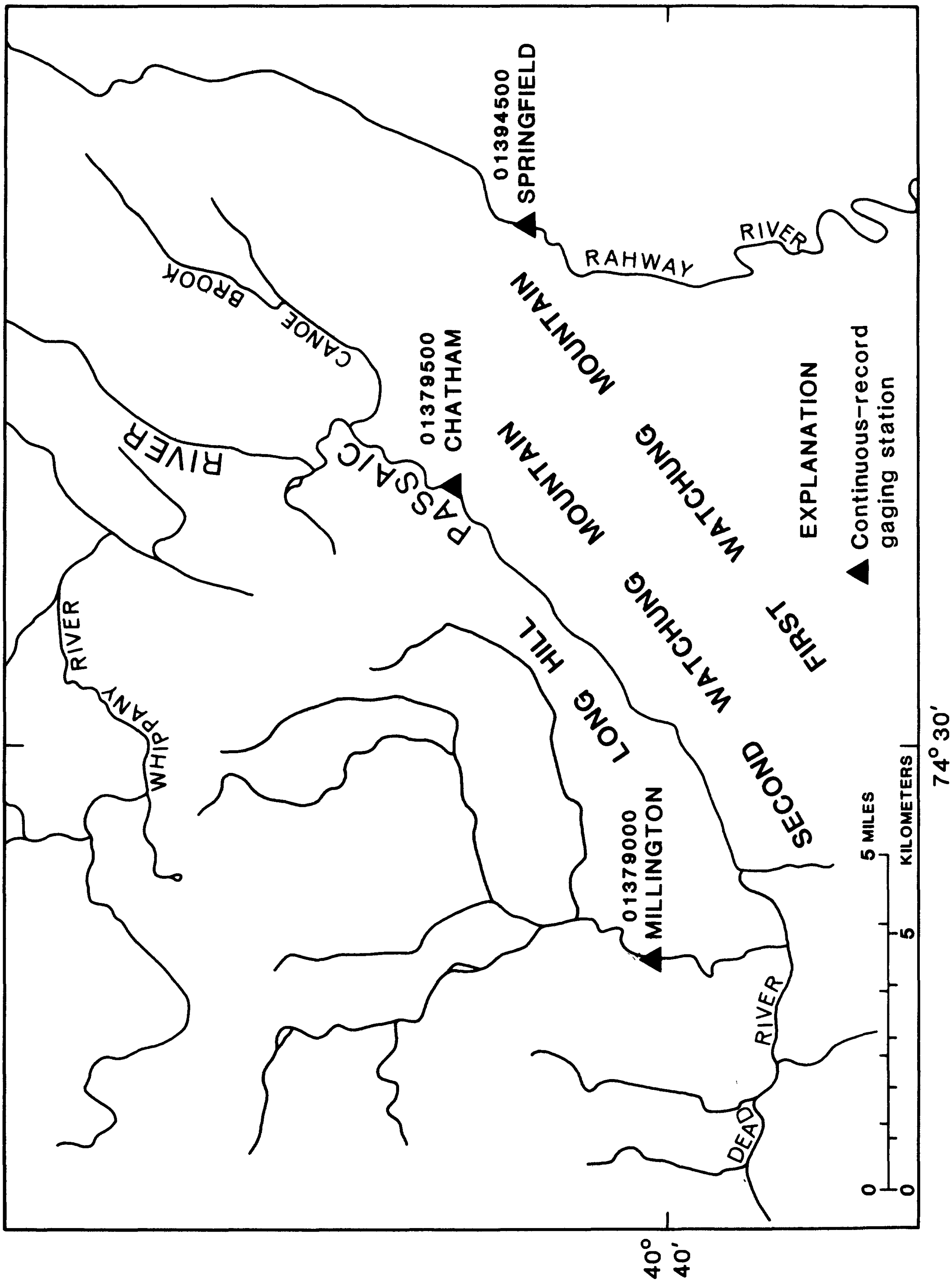


Figure 4.--Passaic River study area

Table 3.--Gaging stations used in the Passaic River flow-routing study

Station number	Station name	Drainage area (mi^2)	Period of record
01379000	Passaic River near Millington, N.J.	55.4	Nov 1903 -Jun 1906, Oct 1921 - present
01379500	Passaic River near Chatham, N.J.	100	Feb 1903 - Dec 1911, Oct 1937 - present
01394500	Rahway River near Springfield, N.J.	25.5	July 1938 - present

at Chatham was the sum of the routed discharge from Millington and adjusted discharges from Millington and Springfield. The period, water years[1] 1974-76, was used to calibrate the model.

When attempting to route flow from Millington to Chatham, it was necessary to determine the model parameters C_o (floodwave celerity) and K_o (wave dispersion coefficient). The coefficients C_o and K_o are functions of channel width (W_o) in feet, channel slope (S_o) in feet per foot (ft/ft), the slope of the stage discharge relation (dQ_o/dY_o) in square feet per second (ft^2/s), and the discharge (Q_o) in cubic feet per second representative of the reach in question and are determined as follows:

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

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

The discharge, Q_o, for which initial values of C_o and K_o were linearized, was the mean daily discharge for the Millington and Chatham gages as published for the 1982 water year (Bauersfeld and others, 1983). The channel width, W_o, was calculated as the average for the 13.5-mile reach between the sites and was determined from topographic maps and discharge-measurement notes. Channel slope, S_o, was determined by converting the corresponding gage heights of the initial discharges, Q_o, taken from the stage-discharge relationships at each gage, to a common datum. The difference between these values was then divided by channel length to obtain a 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 model parameters as determined above are listed in table 4.

For the first routing trial, average values for the model parameters C_o = 3.30 and K_o = 2,930 were used. In order to simulate the intervening drainage area of 44.6 mi^2, an analysis was made of the general characteristics of the basins involved. These characteris-tics were then compared to those of the stream gages at Millington and Springfield. It was noted that the Passaic River above Millington contains a large percentage of lakes and swamps (19.1 percent), whereas Chatham has a smaller percentage (12.2 percent). The Millington data were selected to represent half of the swampier intervening ungaged inflow and the Springfield to represent the urbanized half of the ungaged inflow.

[1] A water year begins on October 1 of the previous calendar year and ends on September 30.

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

Site	Qo (ft^3/s)	Wo (ft)	So (ft/ft)	$\frac{dQo}{dYo}$ (ft^2/s)	Co (ft/s)	Ko (ft^2/s)
Millington	87	65	3.245×10^{-4}	173	2.47	2,473
Chatham	165			295	4.21	3,390

With data for the 3 water years 1980-82 for Chatham as a calibration data set, several trials were made with adjustment made to the values of C_o, K_o, and the drainage area adjustment factors. The best-fit single linearization model used $C_o = 3.00$, $K_o = 2,000$ and 63 percent of Millington and 25 percent of Springfield flow. Other stations were used to simulate intervening drainage but none of provided a better model for the calibration data set.

Data for water years 1967-69 were used to verify the resulting model. The results of the calibration and verification are presented in table 5. As shown, the mean error increased by 1.65 percentage points from 14.37 to 16.02 percent and the volume error increased about 8 percentage points. The reason for this increase in error may be changes in sewage inflows and ground- and surface-water diversions over time. The model cannot be considered verified for use during in other time periods.

Figure 5 is a comparison of the observed and simulated discharge for the Chatham gage during a summer high-water event. The fit for this period is judged fair.

Delaware River Flow-Routing Analysis

A map of the Delaware River study area is presented in figure 6. Gaging-station data available for this analysis are summarized in table 6. The Tocks Island damsite gage (01440200) is 30.2 mi downstream from the next upstream stream gage on the Delaware River at Montague (01438500). The intervening drainage area between Montague and Tocks Island damsite is 370 mi^2, or 9.6 percent of the total drainage area contributing to the Tocks Island damsite site. There are two gaged tributaries between these stations. Bush Kill Creek at Shoemakers, Pennsylvania (01439500) and Flat Brook near Flatbrookville, New Jersey (01440000).

Another gaging station on the Delaware River, located at Belvidere, (01446500) is 18.4 mi downstream from the Tocks Island gage and 48.6 mi downstream from the Montague gage. The intervening drainage area between Tocks Island damsite and Belvidere is 685 mi^2, or 15 percent of the total drainage area upstream from Belvidere. There are three gaged tributaries between these two gages. They are Brodhead Creek at Minisink Hills, Pennsylvania (01442500), Paulins Kill at Blairstown, New Jersey (01443500) and Pequest River at Pequest, New Jersey (01445500).

In this analysis, flow was routed downstream from Montague to Tocks Island damsite, Tocks Island damsite to Belvidere, and Montague to Belvidere by the diffusion analogy method with single linearization. The intervening drainage area would be accounted for by using a station or stations from those listed in table 6, adjusted by proper drainage-area ratios, to account for the difference in size.

Table 5.--Results of routing model for Passaic River

	Calibration	Verification
Period (water years)	1974-76	1967-69
Mean absolute error for 1,096 days	14.37	16.02 percent
Mean negative error	-13.26	-15.18 percent
Mean positive error	15.25	17.07 percent
Days with negative error	485	613
Days with positive error	611	483
Total volume error	- 0.09	-8.00 percent
Percent of observations having errors <= 5 percent	25	19
Percent of observations having errors <= 10 percent	46	41
Percent of observations having errors <= 15 percent	62	60
Percent of observations having errors <= 20 percent	76	73
Percent of observations having errors <= 25 percent	84	83
Percent of observations having errors >= 25 percent	16	17

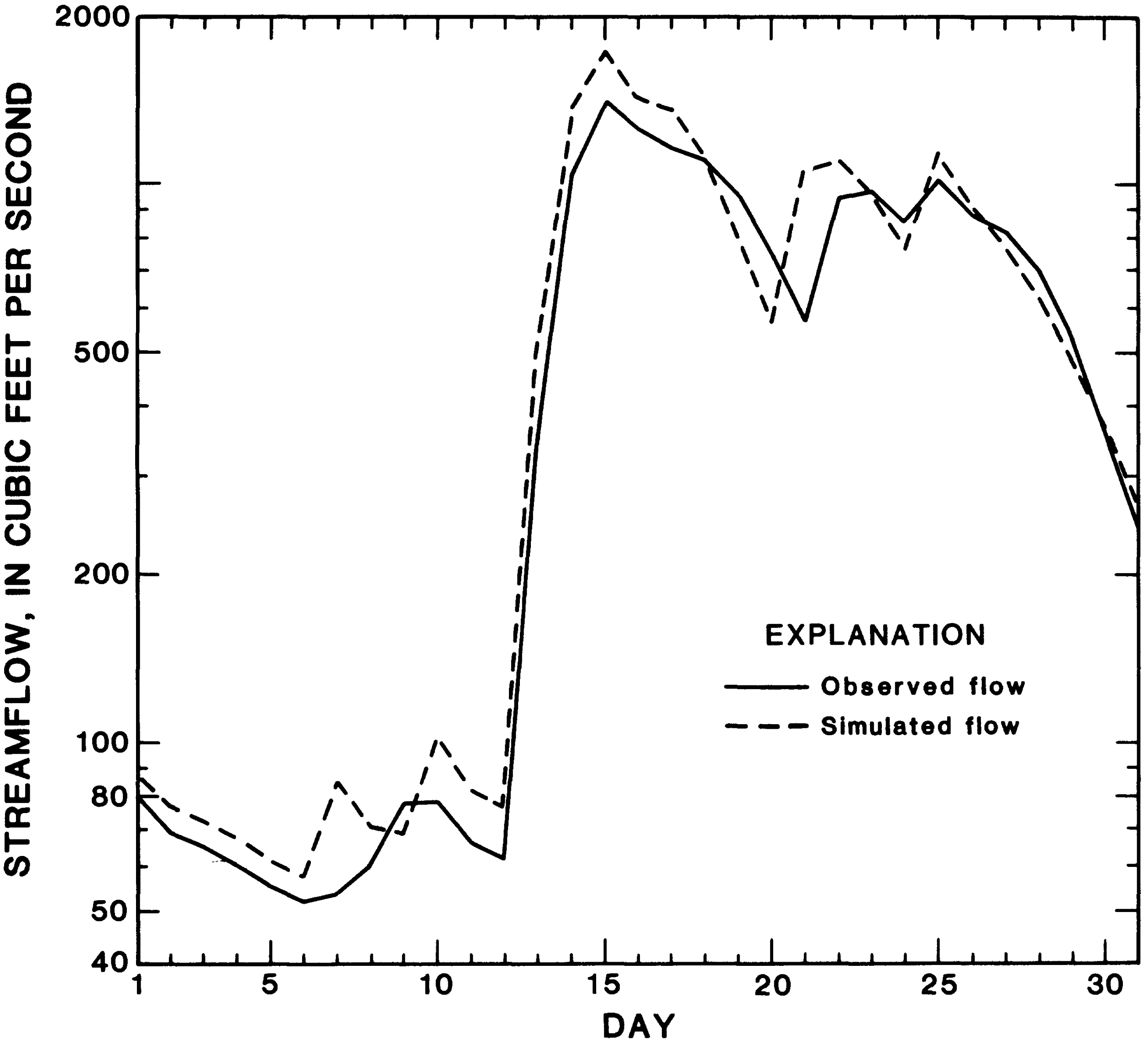


Figure 5.--Daily hydrograph of Passaic River near Chatham, N.J., July 1975

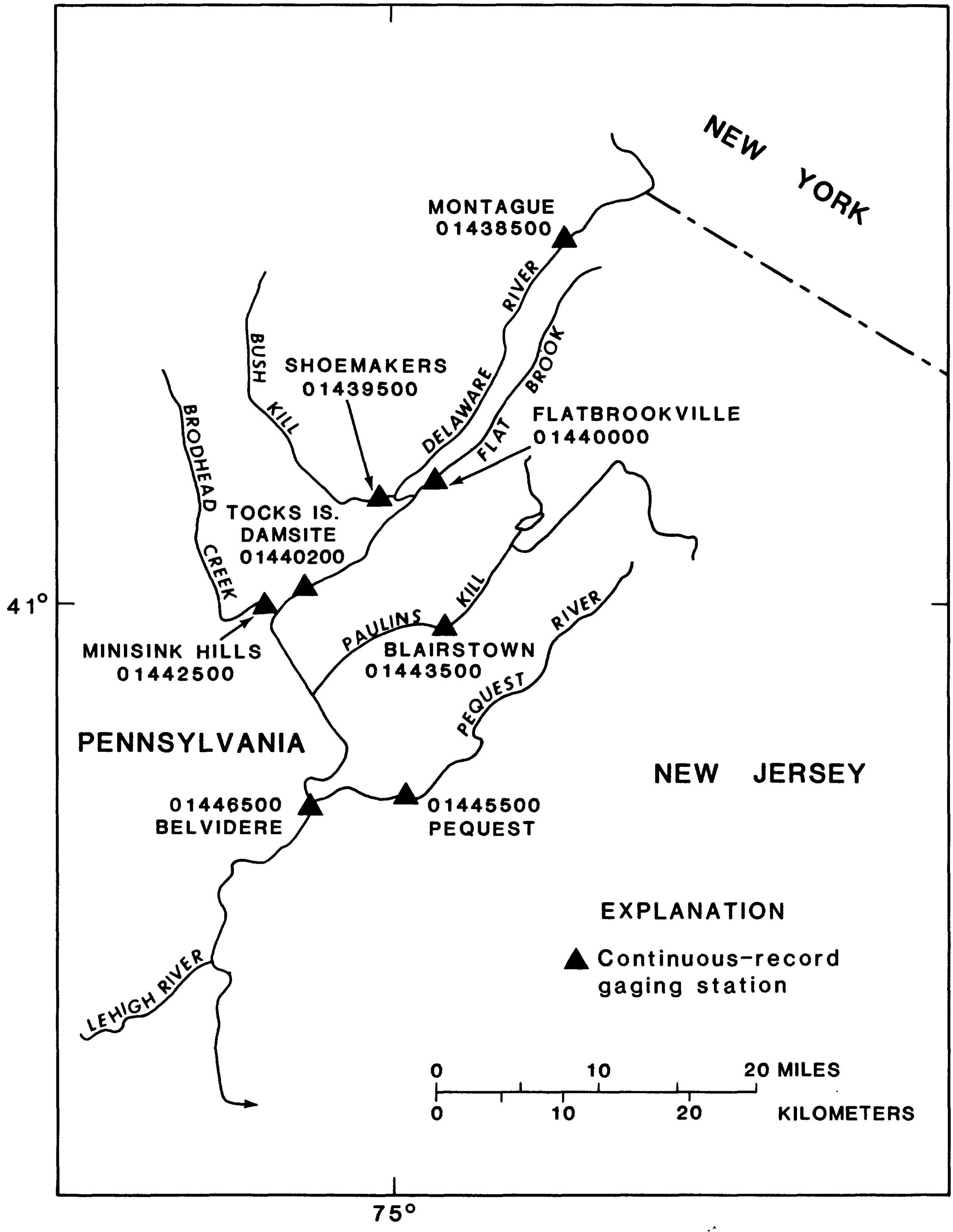


Figure 6.--Delaware River study area

Table 6.--Gaging stations used in the Delaware River flow-routing study

Station number	Station name	Drainage area (mi^2)	Period of record
01438500	Delaware River at Montague, N.J.	3,480	Oct 1939 to present
01439500	Bush Kill at Shoemakers, PA.	117	Oct 1908 to present
01440000	Flat Brook near Flatbrookville, N.J.	64.0	Jul 1923 to present
01440200	Delaware River below Tocks Island damsite, near Delaware Water Gap, PA.	3,850	May 1964 to present
01442500	Brodhead Creek at Minisink Hills, PA.	259	Nov 1950 to present
01443500	Paulins Kill at Blairstown, N.J.	126	Oct 1921 to Sep 1976, Oct 1977 to present
01445500	Pequest River at Pequest, N.J.	106	Oct 1921 to present
01446500	Delaware River at Belvidere, N.J.	4,535	Oct 1922 to Present

The routing parameters C_o and K_o were determined by using the techniques used in the analysis, which are summarized in table 7.

For the first routing trial from Montague to Tocks Island, average values (see table 7) for the model parameters $C_o = 5.0$ and $K_o = 10,000$ were used. In order to simulate the intervening drainage, each of the stations on Bush Kill and Flat Brook was used individually and adjusted. Water years 1974 through 1976 were used as a cali-bration data set. The best-fit model from this analysis was based on the Bush Kill station adjusted by a ratio of 2.10, and the Flat Brook station adjusted by a ratio of 2.86 to simulate intervening drainage (figure 7) and best-fit values for C_o and K_o of 6.00 and 10,000, respectively.

A summary of the simulation of mean daily discharge at Delaware River at Tocks Island damsite for the calibration water years 1974-76 and verification water years 1967-69 is given in table 8. As can be seen, the mean error increased by 0.75 percent, from 6.12 to 6.87 percent as verification, and the volume error increased from -0.16 to -0.91 percent. These changes are small and the model can be considered verified.

For the first routing trial from Tocks Island damsite to Belvidere, average values (see table 7) for the model parameters $C_o = 6.00$ and $K_o = 10,000$ were used. In order to simulate the intervening drainage, the stations Brodhead Creek (01442500), Paulins Kill (01443500), and Pequest River (01445500) were used individually and adjusted. Water years 1974 through 1976 were used as a calibration data set. The best-fit model from this analysis was based on the Brodhead station adjusted by a ratio of 0.9, the Paulins Kill station adjusted by a ratio of 2.6, and the Pequest station adjusted by a ratio of 1.6 to simulate intervening drainage (fig. 8). Further refinement of this model showed the best fit values of C_o and K_o to be 6.0 and 6,000 respectively.

A summary of the simulation of mean daily discharge at Belvidere for the calibration water years, 1974-76, and verification is given in table 9.

For the first routing trial from Montague to Belvidere, average values (see table 7) for the model parameters $C_o = 6.0$ and $K_o = 10,000$ were used. To simulate the intervening drainage, the gages on Flat Brook (01440000), Paulins Kill (01443500), and Pequest River (01445500) were used individually and adjusted. Water years 1974 through 1976 were used as a calibration data set. The best-fit model from this analysis was based on the Flat Brook station adjusted by a ratio of 4.5; Flat Brook station was lagged one day and adjusted by a ratio of 4.8; Paulins Kill station, adjusted by a ratio of 2.3, and Pequest station, adjusted by 3.4 to simulate intervening drainage. Further refinement of this model resulted in best-fit values for C_o and K_o of 6.0 and 10,000 respectively (fig. 8). Added use of Bush Kill and Brodhead Creek, for inflow, would probably improve the model further.

Table 7.--Selected reach characteristics used in the Delaware River flow-routing study

Site	Qo (ft^3/s)	Wo (ft)	So (ft/ft)	$\frac{dQo}{dYo}$ (ft^2/s)	Co (ft/s)	Ko (ft^2/s)
Montague	5900			2800	5.19	11,407
		630	4.789×10^{-3}			
Tocks Island	6400			3640	5.05	9,281
		630	7.045×10^{-3}			
Belvidere	7900			3670	6.80	10,238

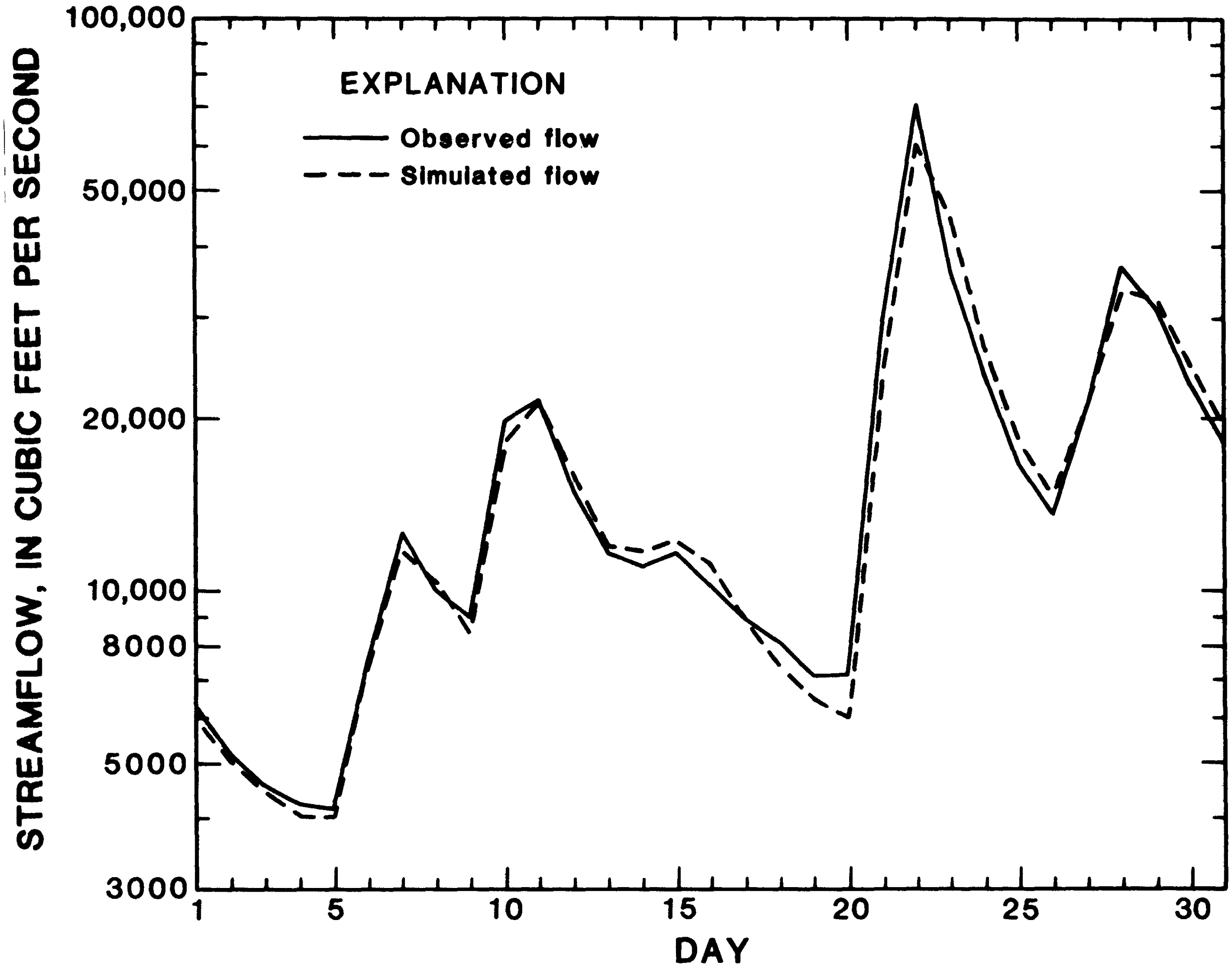


Figure 7.--Daily hydrograph of Delaware River at Tocks Island damsite, at Delaware Water Gap, Pa., December 1973

Table 8.--Results of routing model for Delaware River, Montague to Tocks Island damsite

	Calibration	Verification
Period (water years)	1974-76	1967-69
Mean absolute error for 1,096 days	6.12	6.87 percent
Mean negative error	-5.69	-7.67 percent
Mean positive error	6.51	5.91 percent
Days with negative error	521	598
Days with positive error	575	498
Total volume error	- 0.16	-0.91 percent
Percent of observations having errors <= 5 percent	59	45
Percent of observations having errors <= 10 percent	84	76
Percent of observations having errors <= 15 percent	91	91
Percent of observations having errors <= 20 percent	95	97
Percent of observations having errors <= 25 percent	96	99
Percent of observations having errors >= 25 percent	4	1

Table 9.--Results of routing model for Delaware River, Tocks Island damsite to Belvidere

	Calibration	Verification
Period (water years)	1974-76	1967-69
Mean absolute error for 1,096 days	4.88	5.32 percent
Mean negative error	-3.97	-4.32 percent
Mean positive error	5.73	6.23 percent
Days with negative error	526	520
Days with positive error	570	576
Total volume error	- 0.04	-0.57 percent
Percent of observations having errors <= 5 percent	66	59
Percent of observations having errors <= 10 percent	89	86
Percent of observations having errors <= 15 percent	95	94
Percent of observations having errors <= 20 percent	97	97
Percent of observations having errors <= 25 percent	98	98
Percent of observations having errors >= 25 percent	2	2

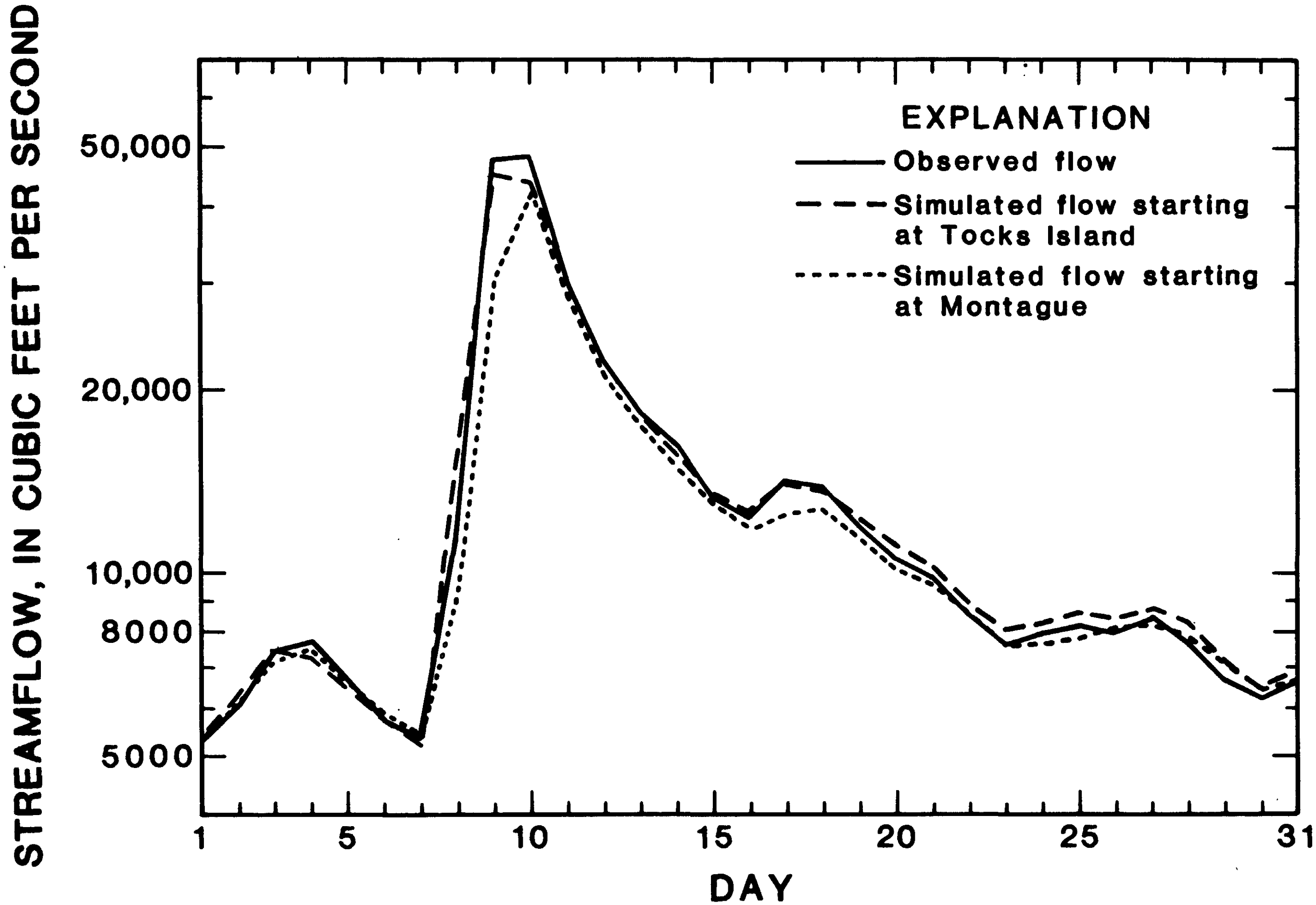


Figure 8.--Daily hydrograph of Delaware River at Belvidere, N.J., December 1974

A summary of the simulation of mean daily discharge at Belvidere for the calibration water years 1974-76 and verification water years 1967-69 is given in table 10.

Regression Analysis Results

Linear-regression techniques were applied to all five of the selected sites. The streamflow record for each station considered for simulation (the dependent variable) was regressed against streamflow records at other stations (explanatory or independent 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 percentage of 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 11.

The streamflow record at Passaic River near Chatham (01379500) was not reproduced with an acceptable degree of accuracy using regression techniques. The Chatham-simulated data were within 10 percent of the actual record only 37.8 percent of the time during the calibration period. These results occurred when lagged and unlagged daily mean discharges for Passaic River near Millington (01379000) and Rahway River near Springfield (01394500) were used as the explanatory variables. Special explanatory variables specified as LAG1 Q were created by lagging the discharges by 1 day. The interaction in a regression of the lagged and unlagged values for a given streamflow record acts to route the flow statistically from an upstream to a downstream site. The lagged discharge values account for the traveltime between the two sites.

The streamflow record at Lamington River at Pottersville (01399500) was not reproduced with an acceptable degree of accuracy with regression techniques. The Pottersville-simulated data were within 10 percent of the actual record only 51.6 percent of the time during the calibration period. These results occurred when lagged daily mean discharges at Ironia (01399200), the mean daily discharge at Succasunna (01399190), and the mean daily and lagged discharge for Far Hills (01398500) were used as the independent variables. A logarithmic transformation of the data gave the best regression results. The record collected at Ironia has been rated fair to poor for the last few years and probably has inflated the error figures given herein. A large swamp between the Ironia and Pottersville gage changes the streamflow characteristics of the Lamington River.

The streamflow record reproduced for Green Brook at Plainfield (01403500), using Green Brook at Seeley Mills (01403400), was not within an acceptable degree of accuracy with regression techniques. Heavy ground-water pumpage from the glacial outwash aquifer between the two gages probably explains the poor accuracy obtained.

Table 10.--Results of routing model for Delaware River, Montague to Belvidere

	Calibration	Verification
Period (water years)	1974-76	1967-69
Mean absolute error for 1,096 days	4.80	6.32 percent
Mean negative error	-4.10	-6.34 percent
Mean positive error	5.30	6.31 percent
Days with negative error	453	572
Days with positive error	643	524
Total volume error	- 0.02	-0.46 percent
Percent of observations having errors <= 5 percent	70	51
Percent of observations having errors <= 10 percent	88	80
Percent of observations having errors <= 15 percent	94	92
Percent of observations having errors <= 20 percent	97	97
Percent of observations having errors <= 25 percent	98	98
Percent of observations having errors >= 25 percent	2	2

Table 11.--Summary of calibration for regression modeling of mean daily streamflow at selected gage sites in New Jersey

Station	Model	Percentage of simulated flow within 5% of actual	Percentage of simulated flow within 10% of actual	Calibration period (water years)
01379500 Passaic River near Chatham, N.J.	Q3790=12.06+0.665(Q3790)+0.835(Lag1 Q3790)+0.476(Q3945)	18.8	37.8	1978-80
01399500 Lamington River at Pottersville, N.J.	For Q3995 < 200 cfs: $Q3995=2.451(Q399190)^{0.368} * (Lag1\ Q3992)^{0.283} * (Q3985)^{0.438} * (Lag1\ Q3985)^{-0.067}$ For Q3995 > 200 cfs: $Q3995=1.042(Q399190)^{0.898} * (Lag1\ Q3992)^{0.245} * (Q3985)^{0.333} * (Lag1\ Q3985)^{-0.117}$	26.8	51.6	1978-80
01403500 Green Brook at Plainfield, N.J.	Q4035=0.137+0.869(Q4034)+0.069(Lag1 Q4034)+0.106(Q3945)	11.2	20.7	1979-81
01440200 Delaware River below Tocks Island damsite near Delaware Water Gap, PA.	Q4402=-207.9+0.897(Q4385)+0.101(Lag1 Q4385)+1.983(Q4400)+3.889(Lag1 Q4400) +2.828(Lag1 Q4395)	42.6	69.7	1979-81
01446500 Delaware River at Belvidere, N.J.	Q4465=354.0+0.156(Lag1 Q4402) + 0.851 (Q4402) + 3.600(Q4435) + 0.372(Lag1 Q4425) + 0.517(Q4425) - 2.092(Q4455)	34.1	66.4	1979-81

The most successful simulations of streamflow records from regressions were on the Delaware River at Tocks Island damsite (01440200) and Belvidere (01446500). Accuracies obtained were about 25 percent worse than those obtained by flow-routing techniques. This difference indicates that peak attenuation is important in this case and must be accounted for.

The regression model for Tocks Island damsite (01440200) includes five explanatory variables. The flow at Tocks Island damsite was regressed against the lagged and unlagged flow at Montague (01438500), the nearest upstream station on the mainstem. The flow in the Delaware River is regulated by numerous reservoirs in Pennsylvania and New York State. Two tributary sites, stations 01439500 (Bush Kill lagged flow only) and 01440000 (Flat Brook, lagged and unlagged) served as indicators of inflow upstream from the Tocks Island station.

The estimates from the regression model for Tocks Island simulated the actual record within 10 percent for 69.7 percent of the calibration period and within 5 percent for 42.6 percent of the period.

The streamflow record for the Delaware River at Belvidere station (01446500) was simulated with a regression model that includes, as explanatory variables, the streamflow at station 01440200 (Tocks Island damsite, lagged and unlagged), 01442500 (Brodhead Creek, lagged and unlagged), 01443500 (Paulins Kill), and 01445500 (Pequest River).

The simulated data for Belvidere were within 10 percent of the actual flows for 66.4 percent of the calibration period and within 5 percent for 34.1 percent of the period.

Conclusions Pertaining to Alternate Methods of Data Generation

The simulated data from both the flow-routing and regression methods for the Chatham stream gage were not sufficiently accurate to suggest these methods in lieu of operating a continuous-flow stream gage. The same was true for the regression results for Pottersville and Plainfield. All three stations should remain in operation as part of the New Jersey stream-gaging program. For the Tocks Island damsite and the Belvidere stream gage, both the flow-routing and regression methods provided streamflow estimates that would be rated fair to poor by accuracy standards U.S. Geological Survey for daily discharge record. Operation of these stream gages should continue unless fair to poor records would fulfill cooperator's needs.

In summary, all five stations considered in this section will remain in operation and will be included in the next step 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 was developed (Moss and Gilroy, 1980). Because of the water-balance nature of that study, the measure of effectiveness of the network was chosen to minimize the sum of error variances in 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. Although 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 U.S. 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 K-CERA techniques with the sums of the variances of the percentage errors in instantaneous discharge 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 commonly will contain the path to an individual stream gage as the lone stop and return to the home base so that the needs of an individual stream gage can be considered in separately from the other gages.

The second 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 on the minimum number of visits to each gage.

The final step is to use all of the above factors 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 presents the mathematical programming form of the problem. 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, (ω_{ij}), 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, β_i, are the per-trip costs of the hydrographer's traveltime and any related per diem and operation, maintenance, and rental costs of vehicles. The sum of the products of β_i and N_i for i = 1, 2, ..., NR is the total travel cost associated with the set of decisions $\underline{N} = (N_1, N_2, \ldots, N_{NR})$.

The unit-visit cost, α_j, is comprised of the average service and maintenance costs incurred on a visit to the station plus the average cost of making a discharge measurement. The set of minimum visit constraints is denoted by the row λ_j, j = 1, 2, ... MG, where MG is the number of 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 compu-

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

V ≡ total uncertainty in the network

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

MG ≡ number of gages in the network

M_j ≡ annual number of visits to station j

ϕ_j ≡ function relating number of visits to uncertainty at station j

Such that

Budget $\geq T_c$ ≡ 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 ≡ fixed cost

α_j ≡ unit cost of visit to station j

NR ≡ number of practical routes chosen

β_i ≡ travel cost for route i

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

and such that

$$M_j \geq \lambda_j$$

λ_j ≡ minimum number of annual visits to station j

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

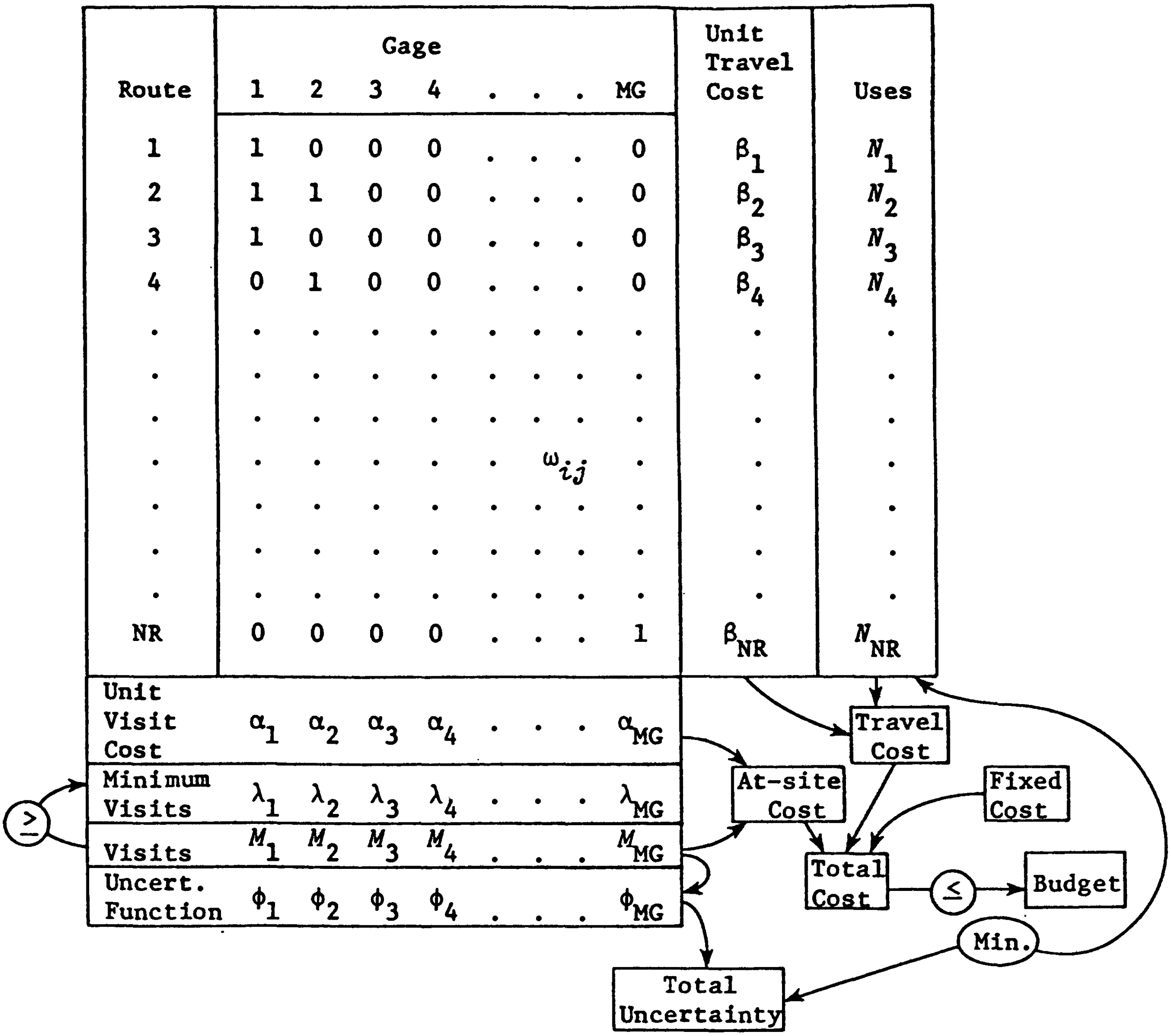


Figure 10.--Tabular form of the optimization of the routing of hydrographers

tation, documentation, and publication is assumed to be negligibly influenced by the number of visits to the station and is included along with overhead in the fixed cost of oprating 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 error variances of the estimates of flow that would be used in each situation were weighted by the fraction of time each situation is expected to occur. Thus, the average relative variance would be

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

with (3)

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

where

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

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

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

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

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

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

V_e is the relative error variance of the third situation.

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

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

where

k is the failure rate in units of $(\text{day})^{-1}$,
e is the base of natural logarithms, and

s is the interval between visits to the site in days.

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

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

(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 assumed that the time between failures at both sites are independent and have negative exponential distributions with the same rate constant. It then follows that

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

(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

$$\varepsilon_r = 1 - \varepsilon_f - \varepsilon_e. \qquad (6)$$
$$= [(1-e^{-ks}) + 0.5(1-e^{-2ks})]/(ks)$$

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

$$x(t) = \log_{10} q_T(t) - \log_{10} q_R(t) = \log_{10} [q_T(t)/q_R(t)] \qquad (7)$$

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

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

$$\hat{x}(t) = \log_{10} q_c(t) - \log_{10} q_R(t) \qquad (8)$$

and $\hat{x}(t)$ 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 either. 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

$$z(t) = x(t) + v(t) = \log_{10} q_m(t) - \log_{10} q_R(t) \qquad (9)$$

where

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

$\log_{10} q_m(t)$ is the logarithm of the measured discharge equal to $\log_{10} q_T(t)$ plus v(t).

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

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

The variance of the observed residuals z(t) is

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

where r is the variance of the measurement error v(t). The three parameters, p, β, and r, are computed by analyzing the statistical properties of the z(t) time series. These three site-specific parameters are needed to define this component of the uncertainty relationship. The Kalman filter uses 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 also is no concurrent data at other sites that can be used to reconstruct the missing record at the primary site, there would be at least two ways of estimating discharges at the primary site. A recession curve could be applied from the time of recorder stoppage until the gage was once again functioning or the expected value of discharge for the period of missing data could be used as an estimate. The expected-value approach is used in this study to estimate V_e, the relative error variance during periods of no concurrent data at nearby sites. 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 variation, squared $(C_v)^2$ is an estimate of the required relative error variance V_e. Because C_v varies seasonally and the times of failures cannot be anticipated, a seasonally averaged value of C_v is used:

$$\overline{C}_v = \left[100 \frac{1}{365} \sum_{i=1}^{365} \left(\frac{\sigma_i}{\mu_i}\right)^2\right]^{1/2} \quad (12)$$

where

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

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

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

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

$$V_r = (1-\rho_C^2)\ \overline{C}_v^2 \quad (13)$$

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

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

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

Thus, if the residuals log 10 $q_c(t)$ - log 10 $q_T(t)$ were normally distributed, $(EGS)^2$ would be their variance. Here EGS is reported in percentage units 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 New Jersey

In New Jersey many gaging stations have concrete weirs which act as control structures. It has been the practice in New Jersey to scrape or clean these weirs after measurements. This scraping destroys most "memory" the site may have, that is the variation in the stage-discharge relation evidenced by one measurement has no relation to the following measurements. Since the K-CERA programs cannot handle this problem a ρc of 0.00 was assigned at 30 stations (table 16) which were regularly scraped (more than 10 percent of the visits) during the past 7 years. It should be noted that this assumption will cause the error characteristics for these stations to be overestimated.

In New Jersey, between 50 and 60 discharge measurements were used for the analysis of each gaging station. These generally covered the period 1975-82. Measurements made under ice conditions, flood flow, or unusual backwater conditions were usually deleted from the final data set.

As a result of the first two parts of this analysis, it has been recommended that all of the currently existing stream gages in the State of New Jersey be continued in operation for the coming year. These stream gages were subjected to the K-CERA analysis with results that are described below.

Definition of Missing Record Probabilities

As was described earlier, the statistical characteristics of missing stage or other correlative data for computation of streamflow records can be defined by a single parameter, the value of k in the truncated negative exponential probability distribution of times to failure of the equipment. In the representation of f_τ as given in equation 4, the average time to failure is 1/k. The value of 1/k will vary 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. In order to estimate 1/k in New Jersey, a period of actual data collection of 7 years duration in which little change in technology occurred and in which stream gages were visited on a consistent pattern of 6 week frequency was used. During this 7-year period, a gage could be expected to be malfunctioning an average of 6.2 percent of the time. The actual percentage of lost record and a 6-week visit frequency were used to determine a value of 1/k, which was used to determine ε_f, ε_e, and ε_r for each of the stream gages.

Definition of Cross-Correlation Coefficient and Coefficient of Variation

In order to compute the values of V_e and V_r of the needed uncertainty functions, daily streamflow records for each of the

101 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 that had 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 six stations that had less than 3 water years of data, values of C_v and ρc were subjectively estimated. In addition to other nearby stream gages, some of the stations had other means by which streamflow data could be reconstructed when the primary recorder was malfunctioning. Some stations are equipped with telemetry systems that operate independently from the primary recorder and are routinely queried either once or twice per day. At other locations, a local resident is hired to read and record stage at a station daily or weekly. Based on the ρ_c determined for several stations with high C_v and independent telemetry or an observer, a value of 0.96 was chosen for all stations with observers or independent telemetry. Because the high C_v indicates a relatively flashy stream, these values of ρ_c were assumed to be worst cases.

The set of parameters for each station and the auxiliary records that gave the highest cross-correlation coefficient are listed in table 12.

Kalman-Filter Definition of Variance

The determination of the variance V_f for each of the 101 stream gages required the execution of three distinct steps: (1) long-term rating analysis and computation of residuals of measured discharges from the long-term rating, (2) time-series analysis of the residuals to determine the input parameters of the Kalman-filter streamflow records, and (3) computation of the error variance, V_f, as a function of the time-series parameters, the discharge-measurement-error variance, and the frequency of discharge measurement.

For New Jersey, almost all rating functions are of the same form. It was necessary at many stations to develop a low-and a high-water equation. An example is the rating function for the Passaic River at Little Falls (01389500) which was of the form:

$$\text{If } GHT<4.5 \quad LQM = B1 + B3 * \log_{10}(GHT - B2) \qquad (15)$$

$$\text{If } GHT>4.5 \quad LQM = B1 + B3 * \log_{10}(GHT - B2)$$

in which

LQM is the logarithmic (base 10) value of the measured discharge,

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

Table 12.--Statistics of record reconstruction

Station Number	+ C(v)	++ Rho(c)	Source of reconstructed record		
01377000	97.9	0.75	01377500	01378500	
01377500	92.8	0.87	01391500	01377000	
01378500	255	0.79	01377500	01391500	01377000
01379000	160	0.97	01381500	01396500	01379500
01379500	153	0.97	01380500	01381500	01379000
01379530	170	0.81	01381500	01394500	01379500
01379773 ***	100	0.80			
01379790 ***	100	0.80			
01380000	100	0.48	01382500	01381500	01380500
01380500	109	0.96	Observer; read daily.		
01381000	196	0.96	Observer; read daily.		
01381500	107	0.85	01389500*	01379000	01380500
01381900	75.6	0.60	01379500	01381000	01381500
01382500	240	0.80	01388500	01389500	01381000
01383500	141	0.93	01384000		
01384000	150	0.93	01385000		
01387000	167	0.96	Independent telemetry; read daily.		
01387500	134	0.95	01377500	01384000	
01388000	136	0.97	01388500		
01388500	141	0.94	01387500		
01389500	135	0.97	01379500**	01381000**	01388500
01390500	115	0.92	01391000		
01391000	110	0.92	01390500		
01391500	112	0.92	01391000	01390500	
01392210	88.3	0.65	01390500		
01393450	172	0.62	01391000		
01394500	207	0.90	01395000		
01395000	215	0.90	01394500		
01396001	223	0.86	01395000		
01396500	99.0	0.92	01397000		
01396580	83.4	0.87	01396660		
01396660	79.6	0.87	01396580		
01396800	115	0.96	Observer; read daily.		
01397000	108	0.96	Observer; read daily.		
01398000	210	0.79	01396500		
01398045	146	0.65	01398000		
01398107	102	0.64	01398045		
01398500	115	0.88	01399500		
01399190	65.4	0.90	01399200		
01399200	70.0	0.90	01399190		

Footnotes at end of table.

Table 12.--Statistics of record reconstruction--Continued

Station Number	+C(v)	++Rho(c)	Source of reconstructed record		
01399500	91.0	0.90	01396500		
01399510	91.0	0.80	01399500		
01399525	115	0.16	01399510		
01399690	99.8	0.34	01396500		
01399700	82.9	0.62	01400000		
01400000	135	0.96	Independent telemetry; read daily.		
01400300	127	0.70	01403150		
01400350 ***	100	0.90			
01400500	139	0.98	01400000	01397000	01403060
01401000	204	0.87	01398000		
01401650 ***	100	0.90			
01402000	156	0.96	Independent telemetry; read daily.		
01402600	169	0.68	01401000		
01403060	156	0.99	01402000	01400500	
01403150	98.7	0.70	01400300		
01403160 ***	100	0.90			
01403400	86.7	0.75	01403150		
01403500	189	0.89	01394500		
01403535 ***	100	0.70			
01403540	120	0.67	01394500		
01405000	140	0.86	01402000		
01405400	93.0	0.93	01405500		
01405500	117	0.93	01405400		
01407500	138	0.84	01408000		
01407705	116	0.80	01407760		
01407760	126	0.80	01407705		
01408000	89.6	0.84	01407500		
01408120	67.8	0.77	01408000		
01408500	56.5	0.83	01410000		
01409095	36.6	0.75	01410000	01408500*	01409280
01409280	37.8	0.79	01409095		
01409400	75.9	0.93	01409500		
01409500	66.1	0.92	01409400		
01409810	72.6	0.83	01410000		
01410000	65.4	0.85	01409500		
01410150	45.7	0.73	01410000		
01410500	89.9	0.71	01410150		
01411000	61.2	0.93	01409400		
01411300	64.6	0.81	01411500		
01411500	61.6	0.92	01411000		

Footnotes at end of table.

Table 12.--Statistics of record reconstruction--Continued

Station Number	+ C(v)	++ Rho(c)	Source of reconstructed record	
01412000	57.8	0.72	01411300	
01412800	54.4	0.72	01412000	
01438500	95.4	0.96	Long-distance recorder.	
01440000	117	0.91	01443500	
01440200	85.6	0.94	01446500	
01443500	110	0.93	01445500	
01443900	128	0.65	01443500	
01445500	94.3	0.93	01443500	
01446500	94.3	0.98	01445500	01438500
01455160	101	0.76	01457000	
01457000	83.9	0.91	01445500	
01460500	29.2	0.96	Observer; read daily.	
01463500	90.2	0.96	Long-distance recorder.	
01464000	106	0.86	01401000	
01464500	105	0.84	01408000	
01466500	52.4	0.84	01467000	
01467000	68.5	0.86	01409500	
01467081	123	0.87	01467150	
01467150	101	0.87	01467081	
01477120	95.0	0.80	01482500	
01482500	136	0.80	01477120	

\+ C(v) = coefficient of variation
++ Rho(c)= correlation coefficient
* Succeeding day's daily discharge used
** Preceeding day's daily discharge used
*** Less than 3 years of data are available. Estimates of C(v) and Rho(c) are subjective

B1 is the logarithm of effective discharge for a flow depth of 1 foot, for that portion of the rating curve,

B2 is the effective gage height of zero flow, for that portion of the rating curve, and

B3 is the slope of a portion of the rating curve.

The values of B1, B2, and B3 for this station were determined to be 1.77, -0.72, and 2.35, respectively below gage height 4.5 feet and 1.90, -1.10 and 2.07 respectively above gage height 4.5 feet.

A tabular presentation of the residuals of the measured discharges about the rating curve (log base 10 of measured discharge minus log base 10 of rated discharge) for Passaic River at Little Falls is given in table 13.

Some stations were analyzed with a single linear rating function. An example is the general linear rating function at Pequest River at Pequest, New Jersey (01445500) which is given by the single equation

$$LQM = 2.01 + 2.06 * \log10(GHT - 0.68) \quad (16)$$

where

LQM is the logarithmic (base 10) value of the measured discharge in cubic feet per second,

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

A tabular presentation of the residuals of the measured discharges about the rating curve (log base 10 of measured discharge minus log base 10 of rated discharge) for Pequest River at Pequest is given in table 14.

Some stations are affected by variable backwater, and two gage heights must be included in the analyses. An example is the general linear rating function at Delaware and Raritan Canal at Kingston (01460500) which is given by the formula

$$\text{If } GHT > 57.00 \quad LQM = 1.84 + 1.71 * \log 10\ (GHTA - 7.00) - .039 * \log10\ (GHTA-7.00/GHTB-57.00) \quad (17)$$

$$\text{If } GHT < 57.00 \quad LQM = 1.84 + 0.043 * \log 10\ (GHT-7.00)$$

Where

LQM is the logarithmic (base 10) value of the measured discharge in cubic feet per second,

GHTA is the gage height above the weir

Table 13.--Residual data for Passaic River at Little Falls, N.J.

Observation	Measurement Number	Date	Measured Discharge (ft^3/s)	Residual (log base 10 ft^3/s)	Percent Error
1	161	01/06/76	1503.0	-0.028933	-6.889
2	162	02/11/76	1064.0	-0.010952	-2.554
3	163	04/07/76	2000.0	-0.027173	-6.457
4	164	05/26/76	435.0	-0.022624	-5.347
5	165	06/25/76	514.0	0.008132	1.855
6	166	08/25/76	142.0	-0.042038	-10.163
7	167	09/29/76	535.0	-0.006668	-1.547
8	168	11/12/76	415.0	-0.064137	-15.914
9	169	12/27/76	328.0	0.015850	3.584
10	170	02/09/77	221.0	0.029697	6.609
11	171	04/11/77	3060.0	-0.000572	-0.132
12	172	05/26/77	275.0	0.016663	3.764
13	173	07/06/77	143.0	-0.025454	-6.036
14	174	08/31/77	103.0	-0.036470	-8.760
15	175	09/21/77	292.0	-0.024621	-5.833
16	176	11/03/77	235.0	-0.001709	-0.394
17	177	12/16/77	2220.0	-0.010269	-2.393
18	178	02/16/78	739.0	0.000135	0.031
19	179	03/30/78	9360.0	0.000050	0.012
20	180	05/01/78	565.0	-0.006468	-1.500
21	181	06/19/78	370.0	-0.003990	-0.923
22	182	08/03/78	199.0	-0.062568	-15.496
23	183	09/14/78	289.0	0.006755	1.543
24	184	10/30/78	179.0	-0.097086	-25.051
25	185	03/20/79	1660.0	0.016717	3.776
26	186	03/27/79	2120.0	-0.015082	-3.534
27	187	05/21/79	1300.0	0.010463	2.380
28	188	07/19/79	477.0	0.000513	0.118
29	189	09/10/79	2590.0	-0.020135	-4.745
30	190	11/06/79	1590.0	0.003028	0.695
31	191	12/12/79	786.0	0.013103	2.972
32	192	02/13/80	381.0	0.041779	9.172
33	193	04/24/80	1260.0	0.013598	3.083
34	194	05/15/80	1639.0	0.013696	3.104
35	195	06/18/80	231.0	-0.003503	-0.810
36	196	08/05/80	191.0	-0.003335	-0.771
37	197	09/12/80	55.9	0.001638	0.377
38	198	10/23/80	57.9	-0.003741	-0.865
39	199	12/08/80	72.8	-0.001692	-0.390
40	200	01/21/81	105.0	0.051551	11.193
41	201	03/02/81	1417.0	0.028736	6.403
42	202	06/05/81	626.0	0.049738	10.821
43	203	08/03/81	124.0	0.027904	6.223
44	204	09/22/81	165.0	0.029904	6.654
45	205	11/13/81	195.0	0.018054	4.072
46	206	12/03/81	1370.0	0.022251	4.995
47	207	01/05/82	4190.0	-0.001070	-0.247
48	208	02/04/82	3670.0	0.001592	0.366
49	209	03/19/82	1050.0	0.016217	3.665
50	210	05/04/82	2140.0	-0.004418	-1.022
51	211	06/10/82	1270.0	0.028324	6.314
52	212	07/20/82	258.0	0.022043	4.949
53	213	09/01/82	166.0	0.025782	5.764
54	214	10/06/82	162.0	-0.011357	-2.659
55	215	11/23/82	314.0	0.022141	4.970

Table 14.--Residual data for Pequest River at Pequest, N.J.

Observation	Measurement Number	Date	Measured Discharge (ft^3/s)	Residual (log base 10 ft^3/s)	Percent Error
1	214	10/14/75	217.0	0.003247	0.745
2	215	11/21/75	265.0	-0.016183	-3.797
3	216	01/08/76	254.0	0.005227	1.196
4	217	02/25/76	294.0	0.001521	0.350
5	218	04/14/76	147.0	-0.016213	-3.804
6	219	05/25/76	80.5	-0.012462	-2.911
7	220	07/02/76	117.0	-0.013489	-3.155
8	221	08/12/76	130.0	-0.047089	-11.452
9	222	10/13/76	78.7	-0.012267	-2.865
10	223	11/11/76	88.5	-0.000708	-0.163
11	224	02/18/77	66.3	0.054839	11.862
12	225	04/22/77	181.0	-0.003818	-0.883
13	226	06/01/77	78.5	0.017366	3.920
14	227	06/28/77	63.2	-0.011948	-2.789
15	228	08/08/77	39.8	0.030389	6.758
16	229	09/27/77	151.0	0.017944	4.048
17	230	11/09/77	215.0	-0.007017	-1.629
18	231	12/19/77	329.0	0.003072	0.705
19	232	02/15/78	191.0	0.026351	5.887
20	233	05/25/78	535.0	-0.014846	-3.478
21	234	06/21/78	109.0	0.006979	1.594
22	235	08/16/78	121.0	0.017863	4.030
23	236	11/07/78	48.3	0.003922	0.899
24	237	12/07/78	76.4	0.016075	3.634
25	238	02/13/79	179.0	-0.008643	-2.010
26	239	03/29/79	283.0	0.012358	2.805
27	240	06/15/79	231.0	-0.012417	-2.900
28	241	08/07/79	45.3	-0.010835	-2.526
29	242	09/20/79	55.5	0.001531	0.352
30	243	11/08/79	180.0	-0.006224	-1.443
31	244	01/24/80	119.0	-0.014388	-3.368
32	245	03/05/80	71.2	-0.014538	-3.404
33	246	04/17/80	358.0	0.029580	6.584
34	247	06/03/80	127.0	0.005684	1.300
35	248	08/04/80	47.0	-0.020832	-4.914
36	249	09/11/80	24.0	-0.010864	-2.533
37	250	10/28/80	77.3	0.000312	0.072
38	251	12/18/80	36.3	-0.009588	-2.232
39	252	02/02/81	113.0	-0.011844	-2.765
40	253	04/01/81	92.1	0.016609	3.752
41	254	06/02/81	205.0	-0.002462	-0.569
42	255	08/19/81	48.1	0.002120	0.487
43	256	10/08/81	38.5	-0.012972	-3.032
44	257	11/20/81	67.5	-0.016368	-3.841
45	258	01/07/82	315.0	0.020755	4.667
46	259	02/12/82	200.0	0.012786	2.901
47	260	03/29/82	157.0	-0.002321	-0.536
48	261	05/05/82	182.0	-0.014899	-3.490
49	262	06/08/82	188.0	-0.007474	-1.736
50	263	07/21/82	123.0	0.016567	3.743
51	264	09/03/82	114.0	0.026457	5.910
52	265	10/15/82	53.5	0.022704	5.093
53	266	10/15/82	49.9	-0.007549	-1.754
54	267	12/06/82	105.0	-0.009258	-2.155
55	268	01/04/83	86.0	-0.022740	-5.376

GHTB is the gage height below the weir.

A tabular presentation of the residuals of the measured discharges about the rating curve for Delaware and Raritan Canal is given in table 15.

The time series of residuals is used to compute sample estimates of q and β, two of the three parameters required to compute V_f, by determining a best fit autocovariance function to the time series of residuals. Measurement variance, the third parameter, is determined from an assumed constant percentage standard error. For the New Jersey program, all open-water measurements were assumed to have a measurement error of 2.5 percent.

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 16 presents a summary of the autocovariance analysis expressed in terms of process variance and 1-day autocorrelation. Typical fits of the covariance functions for selected stations in New Jersey are given in figures 11-13.

The autocovariance parameters, summarized in table 16, and data from the definition of missing record probabilities, summarized in table 10, are used jointly to define uncertainty functions for each gaging station. The uncertainty functions give the relationship of total error variance to the number of visits and discharge measurements. The stations for which graphical fits of the autocovariance functions were previously given present typical examples of uncertainty functions and are given in figure 14. These functions are based on the assumption that a measurement was made during each visit to the station.

In New Jersey, feasible routes to service the 174 stream gages were determined after consultation with personnel in the Hydrologic Records Section of the New Jersey District and after review of the uncertainty functions. In summary, 136 routes were selected to service all the stream gages in New Jersey. These routes included all possible combinations that describe the current operating practice, alternatives that were under consideration as future possibilities, routes that visited certain key individual stations, and combinations that grouped proximate gages where the levels of uncertainty indicated more frequent visits might be useful. These routes and the stations visited on each are summarized in table 17.

Table 15.--Residual data for Delaware and Raritan Canal at Kingston, N.J.

Observation	Measurement Number	Date	Measured Discharge (ft^3/s)	Residual (log base 10 ft^3/s)	Percent Error
1	41	07/03/67	102.0	-0.037556	-9.033
2	42	12/14/67	103.0	-0.070052	-17.504
3	45	01/19/68	95.8	-0.009478	-2.206
4	46	02/01/68	97.2	-0.025318	-6.003
5	57	04/01/70	118.0	0.018392	4.147
6	64	02/11/71	108.0	0.043839	9.602
7	65	03/24/71	120.0	0.051828	11.249
8	68	07/28/71	111.0	-0.005123	-1.187
9	73	01/03/72	109.0	0.014807	3.352
10	74	01/21/72	103.0	0.012652	2.871
11	80	01/15/73	92.2	0.014269	3.232
12	86	11/08/73	95.3	-0.003802	-0.879
13	88	02/21/74	111.0	0.024732	5.536
14	89	05/07/74	95.0	-0.019770	-4.657
15	92	10/02/74	96.6	-0.018998	-4.471
16	93	12/05/74	107.0	-0.004008	-0.927
17	94	01/03/75	99.4	-0.011655	-2.720
18	95	03/06/75	61.1	-0.029081	-6.925
19	96	04/24/75	103.0	0.004266	0.977
20	97	06/12/75	98.2	-0.010485	-2.444
21	98	07/30/75	82.4	-0.019787	-4.662
22	99	08/28/75	94.7	0.013310	3.018
23	100	11/03/75	79.2	-0.036989	-8.890
24	101	12/08/75	82.5	0.001913	0.439
25	102	01/14/76	100.0	-0.014854	-3.480
26	103	04/23/76	104.0	0.008462	1.930
27	104	07/15/76	88.6	0.004793	1.098
28	106	11/24/76	97.3	0.018396	4.147
29	107	03/03/77	100.0	-0.021085	-4.975
30	108	04/22/77	94.2	-0.008844	-2.057
31	109	08/02/77	85.5	-0.010674	-2.488
32	110	08/27/77	92.8	0.018046	4.070
33	111	10/22/77	81.2	-0.019167	-4.512
34	112	12/06/77	100.0	0.009157	2.086
35	113	02/16/78	92.8	-0.002169	-0.501
36	114	04/24/78	108.0	0.012339	2.801
37	115	06/08/78	91.1	0.009074	2.068
38	116	07/20/78	67.7	0.040425	8.888
39	117	12/13/78	57.8	-0.050639	-12.367
40	119	03/30/79	112.0	0.015279	3.457
41	120	05/30/79	83.7	0.001673	0.384
42	121	07/24/79	71.6	0.017401	3.927
43	122	09/26/79	81.0	-0.011936	-2.786
44	123	11/01/79	89.8	-0.029499	-7.028
45	124	12/10/79	98.8	-0.024798	-5.876
46	125	03/04/80	108.0	-0.012134	-2.833
47	127	05/02/80	130.0	0.029747	6.620
48	128	05/02/80	123.0	0.005709	1.306
49	129	06/20/80	75.7	0.001239	0.285
50	130	08/07/80	75.7	0.008968	2.044
51	131	09/17/80	75.9	0.013732	3.113
52	132	11/04/80	89.3	0.050768	11.032
53	133	11/06/80	85.9	0.019452	4.380

Table 15.--Residual Data for Delaware and Raritan Canal at Kingston, N.J --continued

Observation	Measurement Number	Date	Measured Discharge (ft^3/s)	Residual (log base 10 ft^3/s)	Percent Error
54	134	11/19/80	62.4	0.005021	1.149
55	135	12/19/80	60.9	0.011570	2.629
56	136	03/16/81	93.0	0.018883	4.255
57	137	04/28/81	90.2	0.004651	1.065
58	138	05/12/81	87.6	-0.080127	-20.262
59	139	06/29/81	72.3	-0.003524	-0.815
60	140	08/06/81	36.9	-0.031174	-7.442
61	141	10/14/81	30.5	-0.033019	-7.899
62	142	02/11/82	45.8	0.030521	6.787
63	143	03/31/82	54.7	0.028151	6.276
64	144	05/11/82	67.1	0.068530	14.598
65	145	06/24/82	70.4	0.034246	7.583
66	146	08/03/82	13.0	-0.031141	-7.434
67	147	08/31/82	25.9	0.000649	0.149

Table 16.--Summary of autocovariance analysis

Station Number	Station name	**Rho	Variance: Measurement (a)	Variance: Process (b)
01377000	HACKENSACK RIVER AT RIVERVALE NJ	0.963	0.00017	0.00025
01377500	PASCACK BROOK AT WESTWOOD NJ	0.977	0.00017	0.00058
01378500	HACKENSACK RIVER AT NEW MILFORD NJ	0.971	0.00017	0.00149
01379000	PASSAIC RIVER NEAR MILLINGTON NJ	0.981	0.00017	0.00083
01379500	PASSAIC RIVER NEAR CHATHAM NJ	*0.000	0.00017	0.00272
01379530	CANOE BROOK NEAR SUMMIT NJ	0.963	0.00017	0.01105
01379773	GREEN POND BROOK AT PICATINNY ARSENAL NJ	0.841	0.00017	0.00053
01379790	GREEN POND BROOK AT WHARTON NJ	0.962	0.00017	0.00027
01380000	BEAVER BROOK AT OUTLET OF SPLITROCK POND NJ	0.308	0.00017	0.00306
01380500	ROCKAWAY RIVER ABOVE RESERVOIR AT BOONTON NJ	0.984	0.00017	0.00085
01381000	ROCKAWAY RIVER BELOW RESERVOIR AT BOONTON NJ	0.966	0.00017	0.00137
01381500	WHIPPANY RIVER AT MORRISTOWN NJ	0.965	0.00017	0.00064
01381900	PASSAIC RIVER AT PINE BROOK NJ	0.984	0.00017	0.00311
01382500	PEQUANNOCK RIVER AT MACOPIN INTAKE DAM NJ	0.949	0.00017	0.06911
01383500	WANAQUE RIVER AT AWOSTING NJ	*0.000	0.00017	0.00164
01384000	WANAQUE RIVER AT MONKS NJ	0.956	0.00017	0.00302
01387000	WANAQUE RIVER AT WANAQUE NJ	0.992	0.00017	0.00113
01387500	RAMAPO RIVER NEAR MAHWAH NJ	0.990	0.00017	0.03343
01388000	RAMAPO RIVER AT POMPTON LAKES NJ	0.699	0.00017	0.00191
01388500	POMPTON RIVER AT POMPTON PLAINS NJ	0.983	0.00017	0.02301
01389500	PASSAIC RIVER AT LITTLE FALLS NJ	0.658	0.00017	0.00057
01390500	SADDLE RIVER AT RIDGEWOOD NJ	0.983	0.00017	0.00832
01391000	HOHOKUS BROOK AT HOHOKUS NJ	*0.000	0.00017	0.00036
01391500	SADDLE RIVER AT LODI NJ	0.972	0.00017	0.00092
01392210	THIRD RIVER AT PASSAIC NJ	0.986	0.00017	0.00264
01393450	ELIZABETH RIVER AT URSINO LAKE AT ELIZABETH NJ	*0.000	0.00017	0.00190
01394500	RAHWAY RIVER NEAR SPRINGFIELD NJ	0.990	0.00017	0.02716
01395000	RAHWAY RIVER AT RAHWAY NJ	*0.000	0.00017	0.01509
01396001	ROBINSONS BRANCH AT MAPLE AVE AT RAHWAY NJ	0.968	0.00017	0.00357
01396500	SB RARITAN RIVER NEAR HIGH BRIDGE NJ	*0.000	0.00017	0.00207
01396580	SPRUCE RUN AT GLEN GARDNER NJ	0.987	0.00017	0.00899
01396660	MULHOCKAWAY CREEK AT VAN SYCKEL NJ	0.972	0.00017	0.00368
01396800	SPRUCE RUN AT CLINTON NJ	0.967	0.00017	0.00651
01397000	SB RARITAN RIVER AT STANTON NJ	0.988	0.00017	0.00163
01398000	NESHANIC RIVER AT REAVILLE NJ	*0.000	0.00017	0.00929

Footnotes at end of table.

Table 16.--Summary of autocovariance analysis --Continued

Station Number	Station name	**Rho	Variance Measurement (a)	Variance Process (b)
01398045	BACK BROOK TRIB NEAR RINGOES NJ	0.985	0.00017	0.23406
01398107	HOLLAND BROOK AT READINGTON NJ	0.982	0.00017	0.04046
01398500	NB RARITAN RIVER NEAR FAR HILLS NJ	0.899	0.00017	0.01305
01399190	LAMINGTON (BLACK) RIVER AT SUCCASUNNA NJ	0.984	0.00017	0.00342
01399200	LAMINGTON (BLACK) RIVER NEAR IRONIA NJ	0.971	0.00017	0.04024
01399500	LAMINGTON (BLACK) RIVER NEAR POTTERSVILLE NJ	*0.000	0.00017	0.00089
01399510	UPPER COLD BROOK NEAR POTTERSVILLE NJ	*0.000	0.00017	0.00238
01399525	LAMINGTON RIVER TRIB NO.2 NEAR POTTERSVILLE NJ	0.999	0.00017	0.05330
01399690	SB ROCKAWAY CREEK AT WHITEHOUSE NJ	0.986	0.00017	0.01139
01399700	ROCKAWAY CREEK AT WHITEHOUSE NJ	0.000	0.00017	0.00367
01400000	NB RARITAN RIVER NEAR RARITAN NJ	*0.000	0.00017	0.00167
01400300	PETERS BROOK NEAR RARITAN NJ	0.988	0.00017	0.04777
01400350	MACS BROOK AT SOMERVILLE NJ	0.975	0.00017	0.00487
01400500	RARITAN RIVER AT MANVILLE NJ	0.981	0.00017	0.01059
01401000	STONY BROOK AT PRINCETON NJ	*0.000	0.00017	0.00372
01401650	PIKE RUN AT BELLE MEAD NJ	0.662	0.00017	0.03059
01402000	MILLSTONE RIVER AT BLACKWELLS MILLS NJ	*0.000	0.00017	0.00080
01402600	ROYCE BROOK TRIB NEAR BELLE MEAD NJ	*0.000	0.00017	0.03612
01403060	RARITAN RIVER BELOW CALCO DAM AT BOUND BROOK NJ	0.927	0.00017	0.00046
01403150	WB MIDDLE BROOK NEAR MARTINSVILLE NJ	0.989	0.00017	0.08527
01403160	WB MIDDLE BROOK NEAR SOMERVILLE NJ	0.869	0.00017	0.00065
01403400	GREEN BROOK AT SEELEY MILLS NJ	0.987	0.00017	0.00791
01403500	GREEN BROOK AT PLAINFIELD NJ	*0.000	0.00017	0.01110
01403535	EB STONY BROOK AT BEST LAKE AT WATCHUNG NJ	0.587	0.00017	0.00608
01403540	STONY BROOK AT WATCHUNG NJ	0.986	0.00017	0.01279
01405000	LAWRENCE BROOK AT FARRINGTON DAM NJ	0.569	0.00017	0.08936
01405400	MANALAPAN BROOK AT SPOTSWOOD NJ	0.964	0.00017	0.00234
01405500	SOUTH RIVER AT OLD BRIDGE NJ	0.950	0.00017	0.00345
01407500	SWIMMING RIVER NEAR RED BANK NJ	0.994	0.00017	0.00799
01407705	SHARK RIVER NEAR NEPTUNE CITY NJ	*0.000	0.00017	0.00415
01407760	JUMPING BROOK NEAR NEPTUNE CITY NJ	*0.000	0.00017	0.00226
01408000	MANASQUAN RIVER AT SQUANKUM NJ	*0.000	0.00017	0.00078
01408120	NB METEDECONK RIVER NEAR LAKEWOOD NJ	0.977	0.00017	0.00079
01408500	TOMS RIVER NEAR TOMS RIVER NJ	0.985	0.00017	0.00010
01409095	OYSTER CREEK NEAR BROOKVILLE NJ	0.991	0.00017	0.00631

Footnotes at end of table.

Table 16.--Summary of autocovariance analysis--Continued

Station Number	Station name	**Rho	Variance: Measurement (a)	Variance: Process (b)
01409280	WESTECUNK CREEK AT STAFFORD FORGE NJ	0.990	0.00017	0.00615
01409400	MULLICA RIVER NEAR BATSTO NJ	0.988	0.00017	0.00061
01409500	BATSTO RIVER AT BATSTO NJ	0.990	0.00017	0.00048
01409810	WEST BRANCH WADING RIVER NEAR JENKINS NJ	0.979	0.00017	0.00438
01410000	OSWEGO RIVER AT HARRISVILLE NJ	0.930	0.00017	0.00035
01410150	EB BASS RIVER NEAR NEW GRETNA NJ	0.973	0.00017	0.00317
01410500	ABSECON CREEK AT ABSECON NJ	*0.000	0.00017	0.00163
01411000	GREAT EGG HARBOR RIVER AT FOLSOM NJ	*0.000	0.00017	0.00046
01411300	TUCKAHOE RIVER AT HEAD OF RIVER NJ	0.965	0.00017	0.01085
01411500	MAURICE RIVER AT NORMA NJ	0.981	0.00017	0.00054
01412000	MENANTICO CREEK NEAR MILLVILLE NJ	*0.000	0.00017	0.00428
01382800	COHANSEY RIVER AT SEELEY NJ	0.976	0.00017	0.00362
01438500	DELAWARE RIVER AT MONTAGUE NJ	0.980	0.00017	0.00055
01440000	FLAT BROOK NEAR FLATBROOKVILLE NJ	*0.000	0.00017	0.00041
01440200	DELAWARE RIVER NEAR DELAWARE WATER GAP PA	0.961	0.00017	0.00042
01443500	PAULINS KILL AT BLAIRSTOWN NJ	*0.000	0.00017	0.00017
01443900	YARDS CREEK NEAR BLAIRSTOWN NJ	*0.000	0.00017	0.01227
01445500	PEQUEST RIVER AT PEQUEST NJ	*0.000	0.00017	0.00008
01446500	DELAWARE RIVER AT BELVIDERE NJ	0.989	0.00017	0.01706
01455160	BRASS CASTLE CREEK NEAR WASHINGTON NJ	*0.000	0.00017	0.01518
01457000	MUSCONETCONG RIVER NEAR BLOOMSBURY NJ	*0.000	0.00017	0.00040
01460500	DELAWARE AND RARITAN CANAL AT KINGSTON NJ	0.976	0.00017	0.00054
01463500	DELAWARE RIVER AT TRENTON NJ	0.961	0.00017	0.00016
01464000	ASSUNPINK CREEK AT TRENTON NJ	0.973	0.00017	0.00026
01464500	CROSSWICKS CREEK AT EXTONVILLE NJ	*0.000	0.00017	0.00035
01466500	MCDONALDS BRANCH IN LEBANON STATE FOREST NJ	*0.000	0.00017	0.02029
01467000	NB RANCOCAS CREEK AT PEMBERTON NJ	0.977	0.00017	0.00124
01467081	SB PENNSAUKEN CREEK AT CHERRY HILL NJ	0.989	0.00017	0.03013
01467150	COOPER RIVER AT HADDONFIELD NJ	*0.000	0.00017	0.00280
01477120	RACCOON CREEK NEAR SWEDESBORO NJ	0.981	0.00017	0.00684
01482500	SALEM RIVER AT WOODSTOWN NJ	*0.000	0.00017	0.01961

*Rho of 0.000 assumed due to regular cleaning of weir, invalidating assumptions of computer program.
**One-day autocorrelation coefficient.

(a) Measurement variance (log base 10) squared
(b) Process variance (log base 10) squared

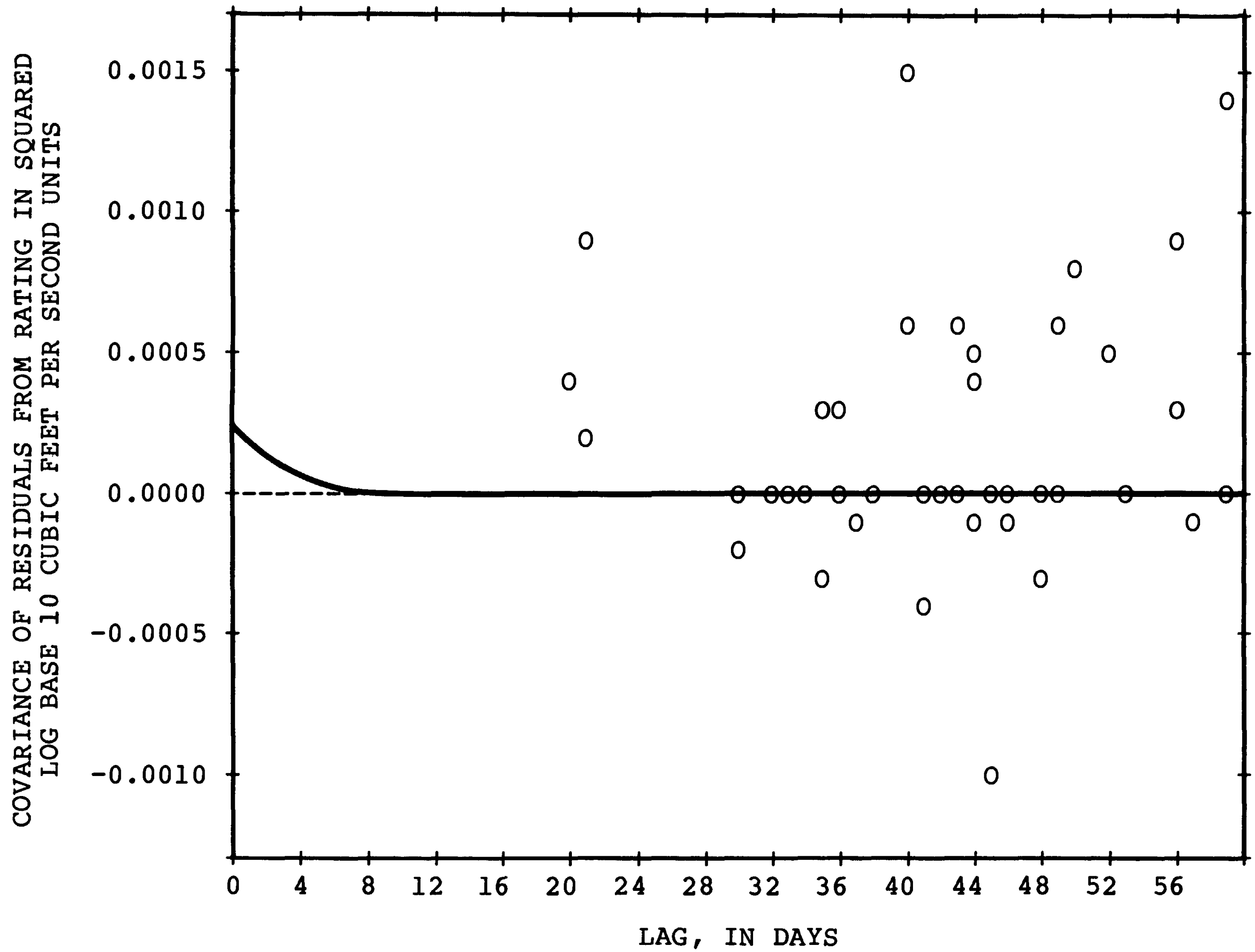


Figure 11.--Autocovariance function for Passaic River at Little Falls, N.J.

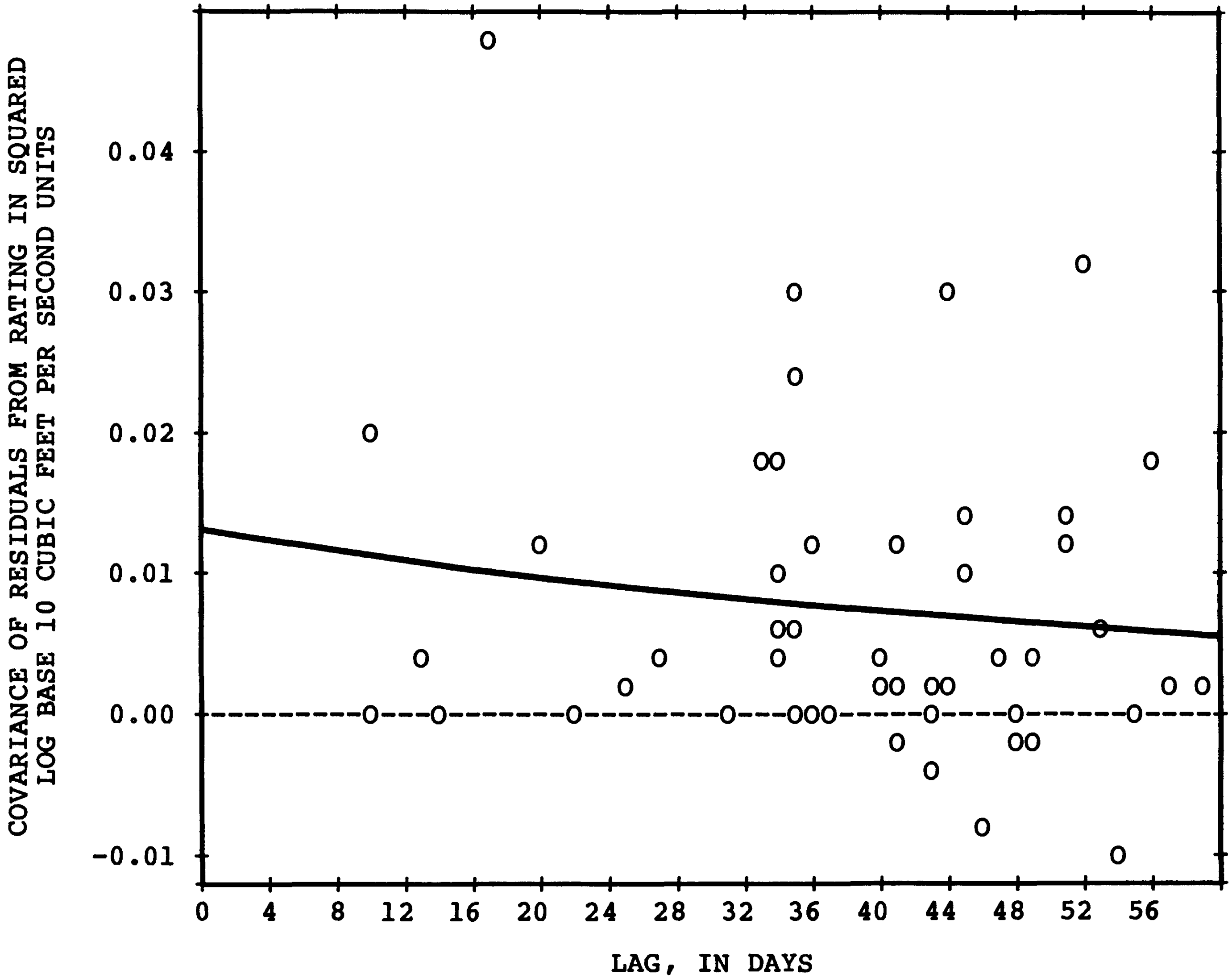


Figure 12.--Autocovariance function for Stony Brook at Watchung, N.J.

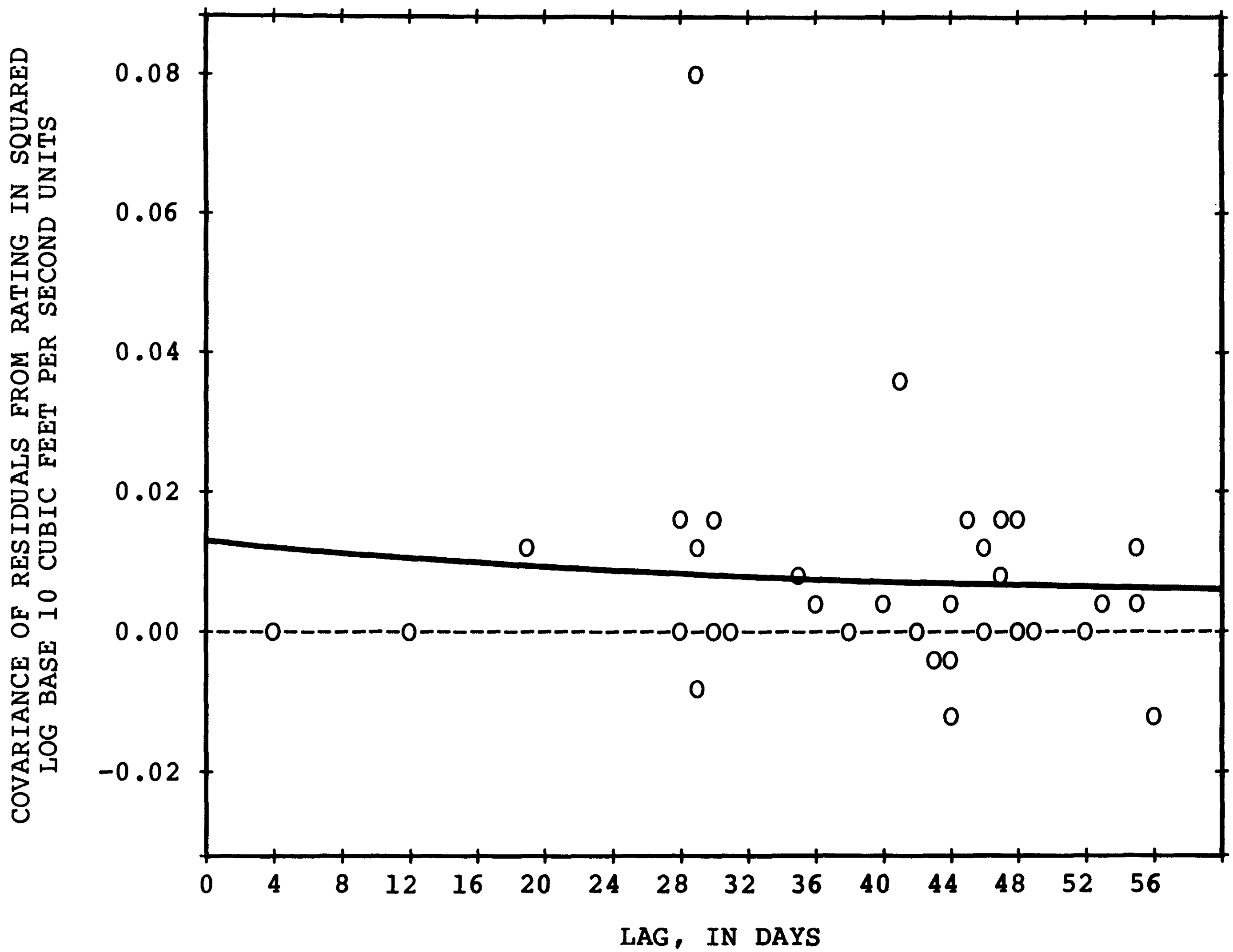


Figure 13.--Autocovariance function for South Branch Pennsauken Creek at Cherry Hill, N.J.

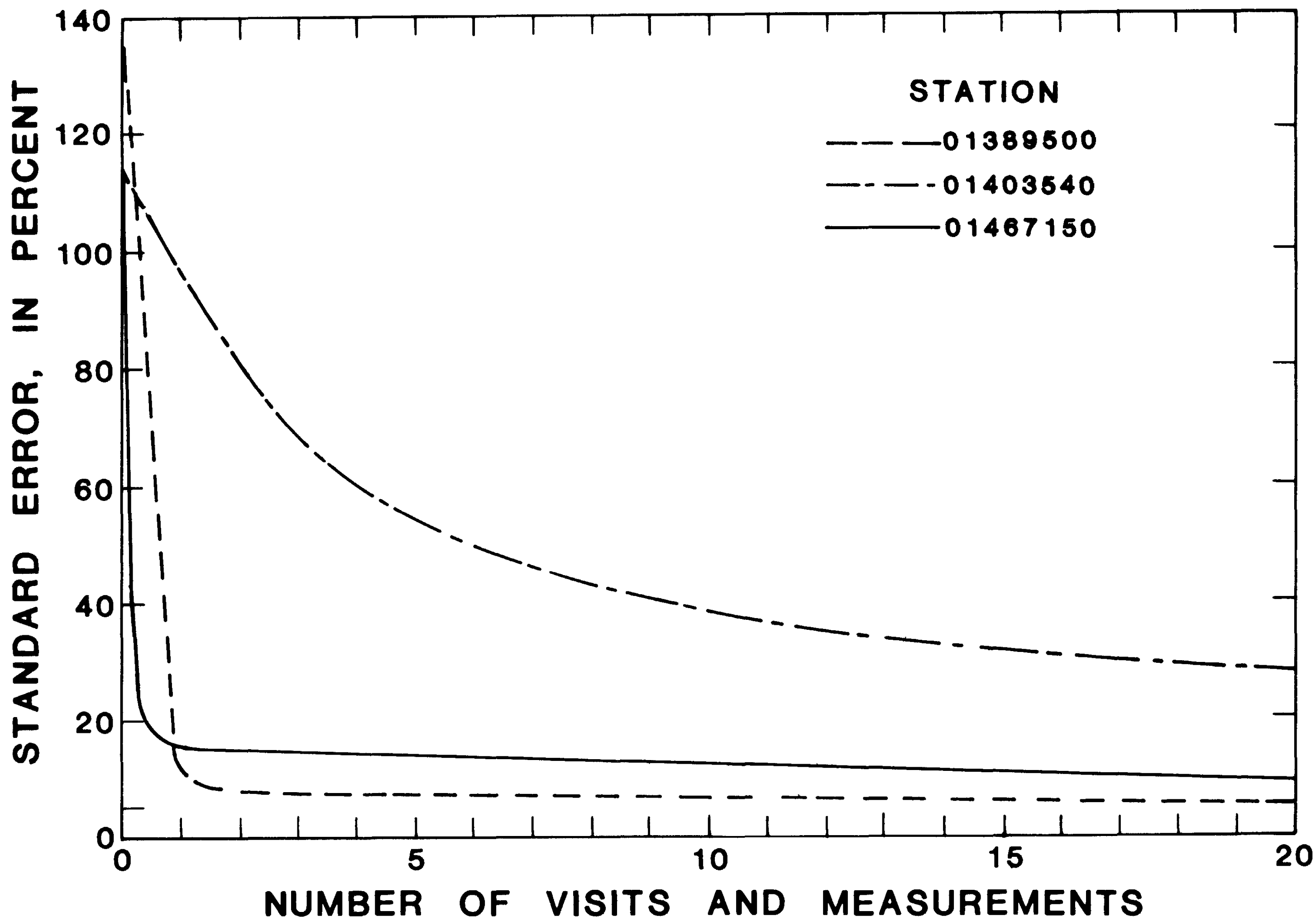


Figure 14.--Typical uncertainty function for instantaneous discharge

Table 17.--Summary of routes that may be used to visit stations in New Jersey

Route number	Stations serviced on route
1	01379000 01379500 01379530
2	01400500 01403060
3	01396660 01457000
4	01396800 01399690 01399700
5	01396500 01396580 01398045
6	01399500 01399510 01399525
7	01397000 01398000
8	01402000
9	01379773 01379790 01399190 01399200
10	01381500 01381900
11	01380000 01380500 01381000
12	01440000 01440200 01443500 01443900
13	01445500 01455160
14	01440000 01440200 01443500 01443900 01445500 01446500 01455160
15	01379773 01379790 01380000 01380500 01381000 01381500 01399190
	01399200 01381900
16	01446500 01457500 01455400
17	01438500
18	01464000 01464500
19	01408000 01408120 01408500
20	01401000
21	01405400 01405500
22	01407500 01407705 01407760
23	01405000
24	01377000 01377500 01378500
25	01382500 01388000 01388500
26	01383500 01384000 01387000 01383000
27	01387500 01390500 01391000
28	01391500 01392210
29	01389500
30	01395000 01396001
31	01393450 01394500
32	01409400 01409500
33	01409810 01410000 01410150
34	01411500 01412800 01477120 01482500
35	01411300 01412000
36	01467000 01467081 01467150
37	01409095 01409280 01466500
38	01411000
39	01403160 01403150
40	01403540 01403535
41	01403500 01403400
42	01402600 01401650
43	01398500 01400300 01400000 01400350

Table 17.--Summary of routes that may be used to visit stations in New Jersey--Continued

Route number	Stations serviced on route
44	01379530
45	01396500
46	01396660
47	01396800
48	01399690
49	01400500
50	01378500
51	01382500
52	01384000
53	01387500
54	01388500
55	01394500
56	01405400
57	01407500
58	01381000
59	01381500
60	01381900
61	01399190
62	01399200
63	01409095
64	01409280
65	01409810
66	01410150
67	01411300
68	01467081
69	01463500
70	01460500
71	01400300
72	01403150
73	01403400
74	01403540
75	01400350
76	01398500
77	01398107
78	01410500
79	01396660 01457000 01457500 01397500
80	01396800 01399690 01399700 01399830
81	01402000 01401870 01401595 01401600 01401520 01401301
82	01464000 01464500 01464515 01464530 01464538 01464582
83	01408000 01408120 01408500 01407830 01408015 01408030 01464400
84	01401000 01401160 01401200 01401301 01400822 01400730 01400775
	01400630
85	01467000 01467081 01467150 01465850 01465880 01467057 01467069
86	01377000 01377500 01378500

Table 17.--Summary of routes that may be used to visit stations in New Jersey--Continued

Route number	Stations serviced on route
87	01382500 01388000 01388500 01382800
88	01383500 01384000 01387000 01387880 01383000
89	01387500 01390500 01391000
90	01391500 01392210 01390810 01390450 01390900
91	01389500 01389900 01389765 01389030 01389534
92	01403500 01403400 01403395
93	01379000 01379530 01379845
94	01445000 01455200 01455500 01456000 01455400 01446000
95	01377475 01377490 01378590 01378385 01378615 01378690
96	01409400 01409500 01409510
97	01409810 01410000 01410150
98	01411500 01412800 01477120 01482500 01412500 01477480 01477110
99	01409095 01409280 01466500 01475000 01475019
100	01410500 01467160 01467305 01467317 01467351
101	01409375 01409403 01409409 01410810 01467330
102	01445430 01400900 01400930 01400950 01407290 01409000
103	01389534 01389900 01392500 01391500 01392210
104	01382800 01384000 01387000
105	01389765 01389030 01382500 01383500
106	01390450 01390810 01390900 01387500 01390500
107	01377475 01377490 01387880 01377000 01377500
108	01378385 01378590 01378615 01389500
109	01378690 01381500 01381900
110	01379845 01380000 01380500 01381000
111	01445000 01445430 01455500 01456000 01445500 01443900 01443500
112	01446000 01455200 01446500
113	01393450 01395000 01396001
114	01407830 01408015 01408030 01408000 01408120 01408500
115	01400630 01400730 01400775 01400822 01401160 01401200 01401000
	01460500 01401301
116	01464530 01464538 01464582 01405000 01405400
117	01412500 01411500 01412800 01482500 01412000
118	01467330 01467351 01475000 01475019 01477110 01477120
119	01409500 01467057 01467069 01467160 01467305 01467317
120	01446500
121	01463610 01464000 01464500
122	01400630 01400730 01400775 01400822 01401160 01401200 01464515
	01465850 01465880 01463610
123	01391500 01392210 01392500
124	01467057 01467069 01467160 01467305 01467317 01467351
125	01407290 01409000 01407830 01408015 01408030
126	01397500 01401520 01401595 01400900 01400930 01400950
127	01467160 01467305 01467317 01467351
128	01398000 01398045
129	01399510 01399525
130	01440200
131	01440000 01443500 01443900
132	01396580 01396660 01396800
133	01402000 01460500 01401301
134	01379000 01379530 01379845 01379500
135	01396660 01457000 01397000
136	01398045

The costs associated with the practical routes were determined. Fixed costs to operate a gage typically include equipment rental, batteries, electricity, telephone, data processing and storage, computer charges, flood measurements, levels, maintenance and miscellaneous supplies, land rental, and analysis and supervisory charges. For New Jersey, average values were applied to each station in the program for all the above categories except data analysis, electricity, telephone, and land rental costs. The cost of data analysis is a large percentage of the cost at each station and can vary widely. The costs were determined on a station-by-station basis from past experience.

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 time was calculated for each station based on an analysis of discharge-measurement data available. This time was then multiplied by the average hourly salary of hydrographers in the New Jersey office 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.

K-CERA Results

The "Traveling Hydrographer Program" uses the uncertainty functions along with the appropriate cost data and route definitions to compute the most cost-effective way of operating the stream-gaging program. In this application, the first step was to simulate the current practice and determine the total uncertainty associated with it. To accomplish this, the number of visits being made to each stream gage and the specific routes that are being used to make these visits were fixed. In New Jersey, current practice dictates that discharge measurements are made each time that a station is visited. The average error of estimation for the current practice in New Jersey, plotted as a point in figure 15, is 24.9 percent.

The solid line in figure 15 represents the minimum level of average uncertainty that can be obtained for a given budget with available instrumentation and technology. The line was defined by several runs of the "Traveling Hydrographer Program" with different budgets. Constraints on the operations other than budget were defined as described below.

Consideration was given only to the physical limitations of the method used to record data in order to determine the minimum number of times each station must be visited. The effect of visitation frequency on the accuracy of the data and amount of lost record is taken into account in the uncertainty analysis. In

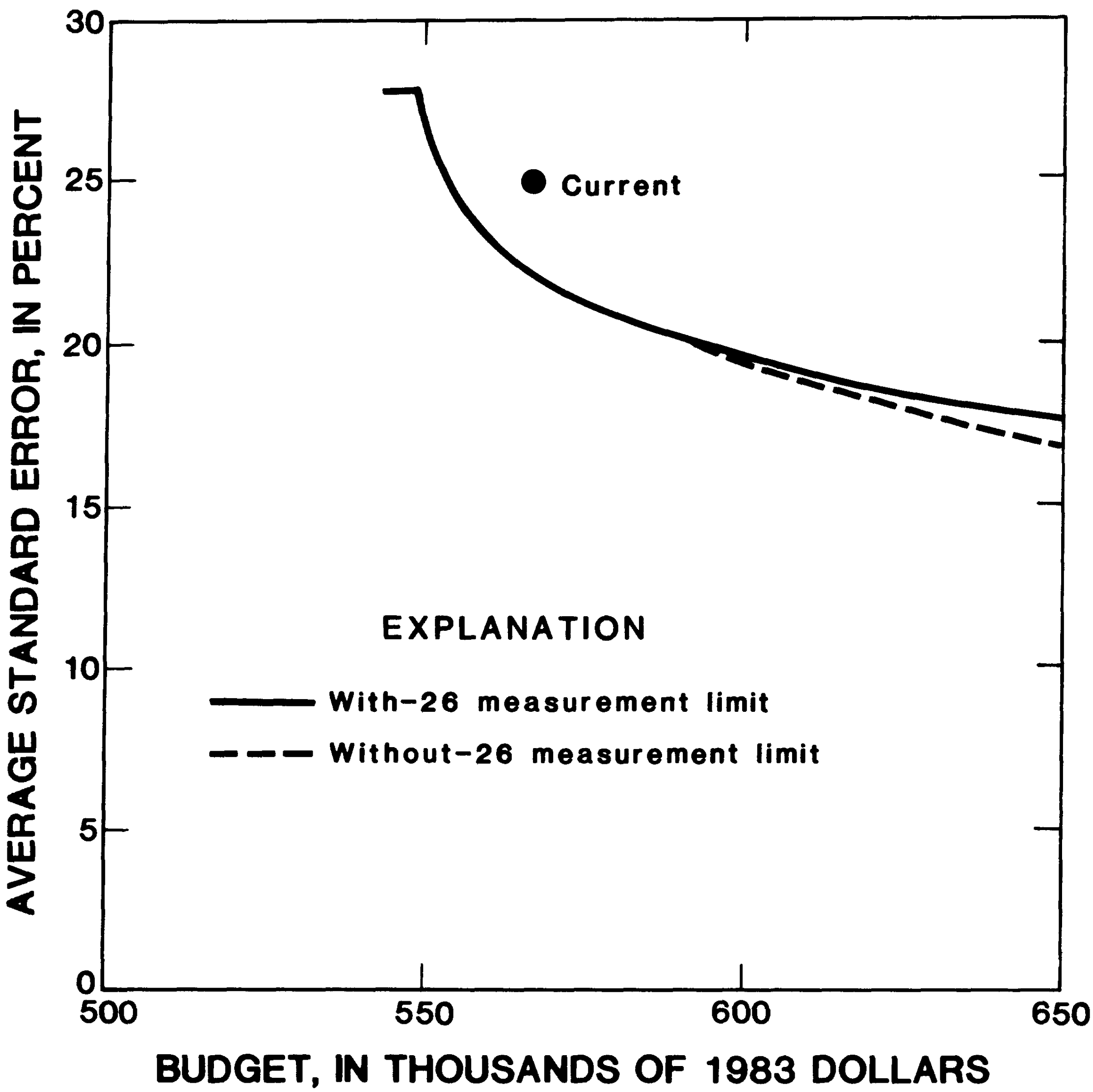


Figure 15.--Temporal average standard error per stream gage

New Jersey, a minimum requirement of four visits per year was applied to all stations. This value was based on limitations of the batteries used to power the recording equipment, capacities of the uptake spools on the digital recorders, and the need to protect gages from freezing winter conditions in New Jersey.

Minimum visit requirements should also reflect the need to visit stations for special reasons such as water-quality sampling. However, in New Jersey, all water-quality work is being done on separate trips not integrated with the surface-water fieldwork and, therefore, did not influence minimum visit requirements.

The "Travel Hydrographer Program", when given a more than minimum budget, tends to concentrate the visits on the stations with the largest improvement in variance per additional measurement. These stations generally have the largest variance. The resulting program may call for 100 to 200 visits to some stations. Some of the assumptions made in determining the costs for each station would no longer be valid under these extreme conditions (for example, data-analysis cost would be higher with 200 measurements than with 10), therefore, it was decided to restrict visits to a maximum of 26. The program achieves an upper limit by flattening the uncertainty curve above the limit for the desired stations. The analysis was run both with and without this limit and the two resulting curves are shown in figure 15. It can be seen that use of this upper limit has an effect only on the larger budget runs.

The results in figure 15 and table 18 summarize the K-CERA analysis and are predicated on a discharge measurement being made each time that a station is visited. Ideally, the ratio of measurements to visits would be optimized for each site individually. This step will be accomplished in a future evaluation of the New Jersey program.

It should be emphasized that figure 15 and table 18 are based on various assumptions (stated previously) concerning both the time series of shifts to the stage-discharge relationship and the methods of record reconstruction. If a choice of assumptions were available, the assumption that would not underestimate the magnitude of the error variances was chosen.

It can be seen that the current policy results in an average standard error of estimate of streamflow of 24.9 percent. This policy requires a budget of $569,000 to operate the crest-stage and streamgaging program in New Jersey. The range in standard errors is from a low of 2.4 percent for station 01463500, at Delaware River at Trenton, to a high of 76.2 percent at station 01405000, Lawrence Brook at Farrington Dam. It is possible to obtain this same average standard error with a reduced budget of about $554,000 with a change of policy in the field activities of

Table 18.--Selected results of K-CERA analysis with maximum visit constraint of 26

	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operat-ion	Budget, in thousands of 1983 dollars 548	554	569	600	650
Average per station 1/	24.9	27.6	24.9	22.0	19.4	17.8
Average per station 2/	24.9	27.6	24.9	22.0	19.0	16.6
01377000 Hackensack River at Rivervale, N.J.	3.3 [2.6] (8)	4.3 [3.1] (4)	4.3 [3.1] (4)	4.3 [3.1] (4)	3.9 [3.0] (5)	3.1 [2.5] (10)
01377500 Pascack Brook at Westwood, N.J.	8.6 [3.5] (8)	12.2 [4.6] (4)	12.2 [4.6] (4)	12.2 [4.6] (4)	10.9 [4.2] (5)	7.6 [3.2] (10)
01378500 Hackensack River at New Milford, N.J.	8.7 [7.2] (8)	10.5 [8.1] (4)	10.5 [8.1] (4)	10.5 [8.1] (4)	9.9 [7.9] (5)	8.1 [6.8] (10)
01379000 Passaic River near Millington, N.J.	19.6 [4.2] (8)	33.2 [6.1] (4)	24.4 [4.9] (6)	17.9 [4.0] (9)	14.5 [3.4] (12)	10.5 [2.7] (19)
01379500 Passaic River near Chatham, N.J.	17.6 [12.7] (8)	25.1 [13.5] (4)	20.0 [13.0] (6)	16.8 [12.6] (9)	15.4 [12.5] (12)	13.9 [12.3] (19)
01379530 Canoe Brook near Summit, N.J.	44.9 [20.7] (8)	48.1 [22.0] (7)	34.9 [16.3] (13)	28.7 [13.4] (19)	24.4 [11.3] (26)	24.4 [11.3] (26)
01379773 Green Pond Brook at Picatinny Arsenal, N.J.	15.0 [5.3] (8)	21.2 [5.9] (4)	18.9 [5.7] (5)	15.0 [5.3] (8)	11.5 [4.9] (14)	10.1 [4.6] (19)
01379790 Green Pond Brook at Wharton, N.J.	14.4 [3.0] (8)	20.9 [3.8] (4)	18.5 [3.5] (5)	14.4 [3.0] (8)	10.8 [2.4] (14)	9.2 [2.1] (19)
01380000 Beaver Brook at outlet of Splitrock Pond, N.J.	13.0 [12.7] (8)	13.3 [12.8] (4)	13.3 [12.8] (4)	13.3 [12.8] (4)	13.1 [12.8] (6)	12.8 [12.6] (12)

Footnotes at end of table.

Table 18.--Selected results of K-CERA analysis with maximum visit constraint of 26--Continued

	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1983 dollars 548	554	569	600	650
01380500 Rockaway River above Reservoir at Boonton, N.J.	7.2 [3.7] (8)	11.0 [4.9] (4)	11.0 [4.9] (4)	11.0 [4.9] (4)	8.5 [4.2] (6)	5.7 [3.1] (12)
01381000 Rockaway River below Reservoir at Boonton, N.J.	11.8 [6.2] (8)	17.6 [7.6] (4)	17.6 [7.6] (4)	17.6 [7.6] (4)	13.9 [6.8] (6)	9.5 [5.3] (12)
01381500 Whippany River at Morristown, N.J.	17.0 [4.5] (8)	25.1 [6.0] (4)	25.1 [6.0] (4)	18.3 [4.8] (7)	14.3 [4.0] (11)	9.9 [2.9] (22)
01381900 Passaic River at Pine Brook, N.J.	21.0 [7.2] (8)	29.5 [10.3] (4)	29.5 [10.3] (4)	22.5 [7.7] (7)	18.0 [6.1] (11)	12.8 [4.3] (22)
01382500 Pequannock River at Macopin Intake Dam, N.J.	60.6 [52.7] (8)	70.8 [60.2] (5)	53.9 [47.2] (11)	41.8 [36.6] (20)	36.9 [32.2] (26)	36.9 [32.2] (26)
01383500 Wanaque River at Awosting, N.J.	13.2 [9.6] (8)	16.9 [9.9] (4)	16.9 [9.9] (4)	16.9 [9.9] (4)	13.7 [9.7] (7)	11.5 [9.5] (14)
01384000 Wanaque River at Monks, N.J.	13.4 [9.9] (8)	18.0 [11.7] (4)	18.0 [11.7] (4)	18.0 [11.7] (4)	14.2 [10.3] (7)	10.5 [8.1] (14)
01387000 Wanaque River at Wanaque, N.J.	7.3 [3.0] (8)	10.2 [4.1] (4)	10.2 [4.1] (4)	10.2 [4.1] (4)	7.8 [3.2] (7)	5.5 [2.3] (14)
0137500 Ramapo River at Mahwah, N.J.	17.4 [17.3] (8)	20.0 [20.0] (6)	17.4 [17.3] (8)	14.8 [14.8] (11)	11.9 [11.9] (17)	9.6 [9.5] (26)

Footnotes at end of table.

Table 18.--Selected results of K-CERA analysis with maximum visit constraint of 26--Continued

	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1983 dollars 548	554	569	600	650
01388000 Ramapo River at Pompton Lakes, N.J.	11.6 [10.0] (8)	14.1 [10.4] (4)	12.4 [10.2] (6)	11.1 [9.9] (10)	10.6 [9.7] (13)	10.2 [9.5] (17)
01388500 Pompton River at Pompton Plains, N.J.	22.7 [19.4] (8)	32.1 [26.4] (4)	26.3 [22.2] (6)	20.3 [17.4] (10)	17.7 [15.2] (13)	14.5 [12.4] (19)
01389500 Passaic River at Little Falls, N.J.	6.0 [5.4] (8)	6.7 [5.5] (4)	6.7 [5.5] (4)	6.7 [5.5] (4)	6.7 [5.5] (4)	6.7 [5.5] (4)
01390500 Saddle River at Ridgewood, N.J.	25.1 [13.0] (8)	30.0 [15.3] (6)	25.1 [13.0] (8)	20.7 [10.8] (11)	15.9 [8.4] (17)	12.4 [6.7] (26)
01391000 Hohokus Brook at Hohokus, N.J.	19.7 [5.1] (8)	31.0 [6.1] (4)	26.7 [5.7] (5)	19.7 [5.1] (8)	14.1 [4.8] (14)	11.0 [4.6] (22)
01391500 Saddle River at Lodi, N.J.	13.0 [4.9] (8)	15.4 [5.6] (6)	17.2 [6.0] (5)	12.1 [4.7] (9)	9.4 [3.8] (14)	6.7 [2.9] (26)
01392210 Third River at Passaic, N.J.	29.3 [7.6] (8)	33.7 [10.0] (6)	36.7 [11.2] (5)	27.6 [7.0] (9)	22.2 [5.2] (14)	16.2 [3.6] (26)
01393450 Elizabeth River at Ursino Lake, at Elizabeth, N.J.	45.7 [6.0] (8)	57.6 [8.1] (5)	37.3 [4.7] (12)	28.9 [3.5] (20)	25.3 [3.1] (26)	25.3 [3.1] (26)
01394500 Rahway River near Springfield, N.J.	27.0 [16.5] (8)	39.8 [24.0] (4)	31.7 [19.3] (6)	25.3 [15.5] (9)	19.9 [12.2] (14)	14.4 [8.7] (26)

Footnotes at end of table.

Table 18.--Selected results of K-CERA analysis with maximum visit constraint of 26--Continued

	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1983 dollars 548	554	569	600	650
01395000 Rahway River at Rahway, N.J.	32.5 [29.6] (8)	32.5 [29.6] (8)	31.8 [29.4] (10)	30.6 [29.2] (16)	30.0 [29.1] (24)	30.0 [29.1] (26)
01396001 Robinsons Branch, at Maple Avenue, at Rahway, N.J.	45.2 [16.4] (8)	45.2 [16.4] (8)	10.1 [15.8] (10)	31.7 [15.0] (16)	26.5 [14.6] (24)	25.7 [14.6] (26)
01396500 South Branch Raritan River near High Bridge, N.J.	7.5 [7.2] (8)	7.5 [7.2] (8)	7.5 [7.2] (8)	7.5 [7.2] (8)	7.5 [7.2] (8)	6.9 [6.7] (10)
01396580 Spruce Run at Glen Gardner, N.J.	17.4 [11.3] (8)	22.4 [14.7] (5)	22.4 [14.7] (5)	18.7 [12.2] (7)	14.0 [9.0] (12)	10.4 [6.7] (21)
01396660 Mulhockaway Creek at Van Syckel, N.J.	13.8 [9.8] (8)	13.8 [9.8] (8)	13.8 [9.8] (8)	13.0 [9.2] (9)	10.5 [7.6] (14)	7.7 [5.6] (26)
01396800 Spruce Run at Clinton, N.J.	16.1 [14.3] (8)	21.1 [17.1] (4)	19.3 [19.3] (5)	15.4 [13.8] (9)	11.4 [10.4] (18)	9.6 [8.8] (26)
01397000 South Branch Raritan River at Stanton, N.J.	9.1 [4.5] (8)	14.2 [6.3] (4)	14.2 [6.3] (4)	12.3 [5.7] (5)	9.1 [4.5] (8)	6.2 [3.3] (15)
01398000 Neshanic River at Reaville, N.J.	41.8 [24.4] (8)	41.7 [24.4] (8)	33.7 [23.4] (15)	30.8 [23.2] (21)	29.9 [23.1] (24)	29.4 [23.0] (26)
01398045 Back Brook tributary near Ringoes, N.J.	64.6 [62.2] (8)	50.3 [47.4] (13)	40.2 [37.1] (20)	35.1 [32.0] (26)	35.1 [32.0] (26)	35.1 [32.0] (26)

Footnotes at end of table.

Table 18.--Selected results of K-CERA analysis with maximum visit constraint of 26--Continued

	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operat-ion	Budget, in thousands of 1983 dollars 548	554	569	600	650
01398107 Holland Brook near Readington, N.J.	33.4 [27.5] (8)	44.8 [38.2] (4)	33.4 [27.5] (8)	26.6 [21.2] (13)	21.0 [16.4] (21)	18.9 [14.6] (26)
01398500 North Branch Raritan near Far Hills, N.J.	25.9 [24.4] (8)	25.9 [24.4] (8)	25.9 [24.4] (8)	25.3 [24.0] (9)	21.0 [20.3] (19)	19.0 [18.3] (26)
01399190 Lamington (Black) River at Succasunna, N.J.	9.9 [7.4] (8)	14.1 [10.1] (4)	12.6 [9.2] (5)	9.9 [7.4] (8)	7.5 [5.6] (14)	6.4 [4.8] (19)
01399200 Lamington (Black) River near Ironia, N.J.	32.1 [31.3] (8)	40.1 [38.4] (4)	37.6 [36.3] (5)	29.4 [28.8] (10)	22.0 [21.5] (19)	18.9 [18.4] (26)
01399500 Lamington (Black) River near Pottersville, N.J.	14.4 [7.5] (8)	14.4 [7.5] (8)	14.4 [7.5] (8)	13.6 [7.4] (9)	11.3 [7.2] (14)	10.2 [7.1] (19)
01399510 Upper Cold Brook near Pottersville, N.J.	18.5 [12.2] (8)	18.5 [12.2] (8)	18.5 [12.2] (8)	16.4 [11.9] (12)	14.6 [11.6] (19)	13.8 [11.5] (26)
01399525 Lamington tributary #2 near Pottersville, N.J.	30.6 [8.4] (8)	30.6 [8.4] (8)	30.6 [8.4] (8)	24.8 [6.5] (12)	19.6 [5.0] (19)	16.7 [4.3] (26)
01399690 South Branch Rockaway Creek at Whitehouse, N.J.	33.9 [13.8] (8)	42.0 [18.5] (5)	33.9 [13.8] (8)	25.2 [9.5] (15)	20.5 [7.5] (23)	19.3 [7.0] (26)
01399700 Rockaway Creek at Whitehouse, N.J.	19.4 [14.8] (8)	23.7 [15.5] (4)	22.1 [15.2] (5)	19.4 [14.8] (8)	17.8 [14.5] (12)	17.1 [14.4] (15)

Footnotes at end of table.

Table 18.--Selected results of K-CERA analysis with maximum visit constraint of 26--Continued

	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1983 dollars 548	554	569	600	650
01400000 North Branch Raritan River near Raritan, N.J.	13.2 [9.8] (8)	13.2 [9.8] (8)	13.7 [9.8] (8)	12.7 [9.8] (9)	10.8 [9.6] (19)	10.5 [9.6] (25)
01400300 Peters Brook near Raritan, N.J.	27.2 [23.5] (8)	27.2 [23.4] (8)	27.2 [23.5] (8)	23.2 [19.9] (11)	17.6 [14.7] (19)	15.1 [12.6] (26)
01400350 Macs Brook at Somerville, N.J.	14.8 [10.7] (8)	14.8 [10.6] (8)	14.8 [10.6] (8)	13.9 [10.1] (9)	9.6 [7.0] (19)	8.3 [6.1] (25)
01400500 Raritan River at Manville, N.J.	21.8 [14.2] (8)	34.8 [19.4] (4)	26.4 [16.3] (6)	20.1 [13.4] (9)	15.0 [10.7] (14)	10.5 [7.9] (25)
01401000 Stony Brook at Princeton, N.J.	39.9 [16.1] (8)	39.9 [16.1] (8)	35.6 [15.7] (10)	28.6 [15.1] (16)	24.0 [14.8] (25)	23.6 [14.7] (26)
01401650 Pike Run at Belle Mead, N.J.	41.5 [41.1] (8)	41.5 [41.1] (8)	41.5 [41.5] (8)	41.2 [40.9] (9)	39.5 [39.4] (18)	38.1 [38.1] (26)
01402000 Millstone River at Blackwells Mills, N.J.	7.0 [6.5] (8)	7.0 [6.5] (8)	7.0 [6.5] (8)	7.0 [6.5] (8)	7.0 [6.5] (8)	7.0 [6.5] (8)
01402600 Royce Brook tributary near Belle Mead, N.J.	49.1 [46.8] (8)	49.1 [46.8] (8)	49.1 [46.8] (8)	48.7 [46.7] (9)	47.4 [46.4] (18)	47.0 [46.2] (26)
01403060 Raritan River below Calco Dam, at Bound Brook, N.J.	9.8 [4.4] (8)	16.8 [5.1] (4)	16.8 [5.1] (4)	14.0 [4.8] (5)	9.8 [4.4] (8)	7.1 [3.9] (23)

Footnotes at end of table.

Table 18.--Selected results of K-CERA analysis with maximum visit constraint of 26--Continued

	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operat-ion	Budget, in thousands of 1983 dollars 548	554	569	600	650
01403150 West Branch Middle Brook near Martinsville, N.J.	35.8 [31.4] (8)	44.7 [40.4] (5)	33.8 [29.4] (9)	27.2 [23.0] (14)	21.2 [17.5] (23)	19.9 [16.4] (26)
01403160 West Branch Middle Brook near Somerville, N.J.	19.0 [5.8] (8)	26.3 [6.5] (4)	19.0 [5.8] (8)	15.7 [5.4] (12)	12.7 [4.9] (19)	11.9 [4.7] (22)
01403400 Green Brook at Seeley Mills, N.J.	20.4 [10.4] (8)	20.4 [10.4] (8)	20.4 [10.4] (8)	16.6 [8.3] (12)	13.2 [6.5] (19)	11.2 [5.6] (26)
01403500 Green Brook at Plainfield, N.J.	41.0 [27.4] (8)	41.0 [27.4] (8)	41.0 [27.4] (8)	35.5 [26.4] (12)	31.4 [25.7] (19)	29.5 [25.4] (26)
01403535 East Branch Stony Brook at Best Lake, at Watchung, N.J.	23.3 [18.6] (8)	26.3 [19.3] (5)	23.3 [18.6] (8)	22.2 [18.3] (10)	20.2 [17.7] (17)	19.5 [17.4] (21)
01403540 Stony Brook at Watchung, N.J.	43.1 [16.6] (8)	49.5 [20.7] (6)	36.8 [13.2] (11)	29.6 [10.0] (17)	23.8 [7.7] (26)	23.8 [7.7] (26)
01405000 Lawrence Brook at Farrington Dam, N.J.	76.2 [76.0] (8)	77.8 [77.1] (4)	77.0 [77.1] (4)	76.2 [76.0] (8)	71.7 [71.7] (26)	71.7 [71.7] (26)
01405400 Manalapan Brook at Spotswood, N.J.	9.9 [8.2] (8)	9.9 [8.2] (8)	9.9 [8.2] (8)	9.9 [8.2] (8)	8.4 [7.0] (12)	6.2 [5.3] (23)
01405500 South River at Old Bridge, N.J.	13.9 [11.0] (8)	18.4 [13.0] (4)	18.4 [13.0] (4)	18.4 [13.0] (4)	13.9 [11.0] (8)	9.7 [8.1] (19)

Footnotes at end of table.

Table 18.--Selected results of K-CERA analysis with maximum visit constraint of 26--Continued

	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1983 dollars 548	554	569	600	650
01407500 Swimming River near Red Bank, N.J.	18.6 [7.0] (8)	18.6 [7.0] (8)	18.6 [7.0] (8)	16.5 [6.2] (10)	12.5 [4.7] (17)	10.0 [3.8] (26)
01407705 Shark River near Neptune City, N.J.	29.2 [17.0] (8)	29.2 [17.0] (8)	29.2 [17.0] (8)	26.8 [16.6] (10)	22.4 [15.9] (17)	20.0 [15.5] (26)
01407760 Jumping Brook near Neptune City, N.J.	21.1 [11.7] (8)	21.1 [11.7] (8)	21.1 [11.7] (8)	19.4 [11.6] (10)	16.3 [11.3] (17)	14.7 [11.2] (26)
01408000 Manasquan River at Squankum, N.J.	16.2 [7.1] (8)	16.2 [7.1] (8)	16.2 [7.1] (8)	16.2 [7.1] (8)	14.6 [7.0] (10)	11.5 [6.7] (18)
01408120 North Branch Metedeconk River near Lakewood, N.J.	11.4 [4.3] (8)	11.4 [4.3] (8)	11.4 [4.3] (8)	11.4 [4.3] (8)	10.2 [3.9] (10)	7.6 [2.9] (18)
01408500 Toms River near Toms River, N.J.	8.3 [1.7] (8)	8.3 [1.7] (8)	8.3 [1.7] (8)	8.3 [1.7] (8)	7.4 [1.5] (10)	5.4 [1.2] (18)
01409095 Oyster Creek near Brookville, N.J.	8.2 [7.4] (8)	8.2 [7.4] (8)	8.2 [7.4] (8)	8.2 [7.4] (8)	8.2 [7.4] (8)	7.0 [6.3] (11)
01409280 Westecunk Creek at Stafford Forge, N.J.	11.2 [8.4] (8)	11.2 [8.4] (8)	11.2 [8.4] (8)	11.2 [8.4] (8)	11.2 [8.4] (8)	9.6 [7.0] (11)
01409400 Mullica River near Batsto, N.J.	14.2 [3.2] (8)	14.2 [3.2] (8)	14.2 [3.2] (8)	14.2 [3.2] (8)	14.2 [3.2] (8)	9.5 [2.2] (15)

Footnotes at end of table.

Table 18.--Selected results of K-CERA analysis with maximum visit constraint of 26--Continued

	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operat- ion	Budget, in thousands of 1983 dollars 548	554	569	600	650
01409500 Batsto River at Batsto, N.J.	9.3 [2.4] (8)	7.3 [2.0] (12)	7.3 [2.0] (12)	7.3 [2.0] (12)	7.3 [2.0] (12)	5.7 [1.6] (18)
01409810 West Branch Wading River near Jenkins, N.J.	11.4 [9.2] (8)	15.2 [12.1] (4)	15.2 [12.1] (4)	13.9 [11.1] (5)	11.4 [9.2] (8)	7.9 [6.4] (17)
01410000 Oswego River at Harrisville, N.J.	11.8 [4.1] (8)	17.2 [5.0] (4)	17.2 [5.0] (4)	15.2 [4.7] (5)	11.8 [4.1] (8)	7.9 [3.2] (17)
01410150 East Branch Bass River near New Gretna, N.J.	10.0 [8.6] (8)	13.0 [11.0] (4)	13.0 [11.0] (4)	12.0 [10.3] (5)	10.0 [8.6] (8)	7.2 [6.2] (17)
01410500 Absecon Creek at Absecon, N.J.	33.4 [12.7] (8)	33.4 [12.7] (8)	33.4 [12.7] (8)	28.7 [11.6] (11)	23.6 [10.7] (17)	19.7 [10.2] (26)
01411000 Great Egg Harbor River at Folsom, N.J.	7.1 [5.2] (8)	7.1 [5.2] (8)	7.1 [5.2] (8)	7.1 [5.2] (8)	7.1 [5.2] (8)	6.8 [5.1] (9)
01411300 Tuckahoe River at Head of River, N.J.	18.3 [17.4] (8)	22.4 [21.2] (4)	22.4 [21.2] (4)	22.4 [21.2] (4)	20.1 [19.1] (6)	13.8 [13.1] (16)
01411500 Maurice River at Norma, N.J.	5.3 [3.2] (8)	5.3 [3.2] (8)	5.3 [3.2] (8)	5.3 [3.2] (8)	5.3 [3.2] (8)	3.8 [2.3] (16)
01412000 Menantico Creek near Millville, N.J.	16.6 [15.6] (8)	16.6 [15.6] (8)	16.6 [15.6] (8)	16.6 [15.6] (8)	16.6 [15.6] (8)	15.9 [15.4] (16)

Footnotes at end of table.

Table 18.--Selected results of K-CERA analysis with maximum visit constraint of 26--Continued

	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1983 dollars				
		548	554	569	600	650
01412800 Cohansey River at Seeley, N.J.	12.0 [9.0] (8)	12.0 [9.0] (8)	12.0 [9.0] (8)	12.0 [9.0] (8)	12.0 [9.0] (8)	8.7 [6.5] (16)
01438500 Delaware River at Montague, N.J.	3.1 [2.9] (10)	3.4 [3.2] (8)	3.4 [3.2] (8)	3.4 [3.2] (8)	3.4 [3.2] (8)	3.4 [3.2] (8)
01440000 Flat Brook near Flatbrookville, N.J.	18.8 [5.3] (8)	18.8 [5.3] (8)	18.8 [5.3] (8)	16.5 [5.1] (10)	12.4 [4.9] (17)	10.1 [4.8] (26)
01440200 Delaware River at Tocks Is. Damsite, Delaware Water Gap, PA.	16.4 [4.9] (8)	26.3 [6.4] (4)	26.4 [6.4] (4)	22.6 [5.8] (5)	15.2 [4.7] (9)	11.4 [4.0] (14)
01443500 Paulins Kill at Blairstown, N.J.	15.4 [3.3] (8)	15.4 [3.3] (8)	15.4 [3.3] (8)	13.4 [3.3] (10)	9.9 [3.2] (17)	8.0 [3.1] (26)
01443900 Yards Creek near Blairstown, N.J.	41.2 [29.C] (8)	41.2 [29.0] (8)	41.2 [29.0] (8)	38.6 [28.4] (10)	33.9 [27.3] (17)	31.4 [27.0] (26)
01445500 Pequest River at Iequest, N.J.	14.2 [2.3] (8)	14.2 [2.3] (8)	14.2 [2.3] (8)	14.2 [2.3] (8)	11.7 [2.3] (11)	8.0 [2.2) (21)
01446500 Delaware River at Belvidere, N.J.	13.6 [13.2] (8)	18.9 [18.1] (4)	18.9 [18.1] (4)	18.9 [18.1] (4)	15.6 [15.1] (6)	11.1 [10.7] (12)
01455160 Brass Castle Creek near Washington, N.J.	33.5 [30.5] (8)	33.5 [30.5] (8)	33.5 [30.5] (8)	33.5 [30.5] (8)	32.3 [30.1] (11)	30.7 [29.6] (21)

Footnotes at end of table.

Table 18.--Selected results of K-CERA analysis with maximum visit constraint of 26--Continued

	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1983 dollars				
		548	554	569	600	650
01457000 Musconetcong River near Bloomsbury, N.J.	12.1 [5.1] (8)	12.1 [5.1] (8)	12.1 [5.1] (8)	12.1 [5.1] (8)	12.1 [5.1] (8)	8.9 [4.8] (15)
01460500 Delaware and Raritan Canal at Kingston, N.J.	4.7 [3.6] (8)	6.9 [4.7] (4)	6.9 [4.7] (4)	6.9 [4.7] (4)	6.9 [4.7] (4)	5.0 [3.8] (7)
01463500 Delaware River at Trenton, N.J.	2.4 [2.3] (8)	2.9 [2.6] (4)	2.9 [2.6] (4)	2.9 [2.6] (4)	2.9 [2.6] (4)	2.9 [2.6] (4)
01464000 Assunpink Creek at Trenton, N.J.	5.4 [2.4] (8)	5.4 [2.4] (8)	5.4 [2.4] (8)	5.4 [2.4] (8)	5.4 [2.4] (8)	4.5 [2.1] (12)
01464500 Crosswicks Creek at Extonville, N.J.	9.4 [4.4] (8)	9.4 [4.4] (8)	9.4 [4.4] (8)	9.4 [4.4] (8)	9.4 [4.4] (8)	8.1 [4.4] (12)
01466500 McDonalds Branch in Lebanon State Forest, N.J.	33.6 [33.4] (8)	33.6 [33.4] (8)	33.6 [33.4] (8)	33.6 [33.4] (8)	33.6 [33.4] (8)	33.6 [33.5] (11)
01467000 North Branch Rancocas Creek at Pemberton, N.J.	9.5 [5.2] (8)	9.5 [5.2] (8)	9.5 [5.2] (8)	9.5 [5.2] (8)	9.5 [5.2] (8)	7.4 [4.2] (13)
01467081 South Branch Pennsauken Creek at Cherry Hill, N.J.	21.6 [18.0] (8)	21.6 [18.0] (8)	21.6 [18.0] (8)	21.6 [18.0] (8)	16.3 [13.3] (14)	11.9 [9.6] (26)
01467150 Cooper River at Haddonfield, N.J.	12.7 [12.3] (8)	12.7 [12.3] (8)	12.7 [12.3] (8)	12.7 [12.3] (8)	12.7 [12.3] (8)	12.5 [12.3] (13)

Footnotes at end of table.

Table 18.--Selected results of K-CERA analysis with maximum visit constraint of 26--Continued

	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operat-ion	Budget, in thousands of 1983 dollars				
		548	554	569	600	650
01477120 Raccoon Creek near Swedesboro, N.J.	21.0 [11.8] (8)	29.9 [16.8] (4)	29.9 [16.8] (4)	26.7 [15.0] (5)	19.8 [11.1] (9)	11.5 [6.3] (26)
01482500 Salem River at Woodstown, N.J.	36.2 [34.1] (8)	36.2 [34.1] (8)	36.2 [34.1] (8)	36.2 [34.1] (8)	36.2 [34.1] (8)	34.1 [33.4] (26)

1/ Visits limited to 26 per year.
2/ No limits on number of visits.

the stream-gaging program. This policy and budget change would result in an increase in standard error from 2.4 to 2.9 percent for station 01463500, while the standard error for station 01405000 would increase from 76.2 to 77.7 percent.

It also would be possible to reduce the average standard error by a policy change while maintaining the same budget of $569,000. In this case, the average would decrease from 24.9 to 22.0 percent. Extremes of standard errors for individual sites would be 2.9 and 76.2 percent for stations 01463500 and 01405000 respectively.

A minimum budget of $548,000 is required to operate the 174-station program; a budget less than this does not permit proper service and maintenance of the gages and recorders. Stations would have to be eliminated from the program if the budget fell below this minimum. At the minimum budget, the average standard error is 27.6 percent. The minimum standard error, 2.9 percent, would be for station 01463500, and the maximum of 77.8 percent would be for 01405000.

The maximum budget analyzed with the 26-trip limit was $650,000, which resulted in an average standard error of estimate of 17.8 percent. Thus, increasing the budget by one quarter in conjunction with policy change would reduce by 30 percent the average standard error that would result from the current budget and current operating policy. With a budget of $650,000, the extremes of standard error are 2.9 percent for station 01463500 and 71.7 percent for station 01405000. Thus, it is apparent that significant improvements in accuracy of streamflow records can be obtained if larger budgets become available.

The analysis also was performed with no upper limit, for comparison purposes. The curve, labeled "Without 26-measurement limit" in figure 15, shows the average standard errors of estimation of streamflow that could be obtained if no upper limit were placed on the number of visits. For the minimal operational budget of $548,000 there would be no impact of the upper limit. At the other budgetary extreme of $650,000, with no upper limit to visits, average standard errors decreased from 17.8 percent for 26-visit upper limit to 16.6 percent for no upper limit. With no upper limit, eight stations had more than 40 visits per year called for, and one called for 182 visits.

Conclusions Based on Results of K-CERA Analysis

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

1. The policy for the definition of field activities in the stream-gaging program should be altered to maintain the current average standard error of estimate of streamflow records of 24.9 percent with a budget of approximately $554,000. This shift would result in

some increases and some decreases in accuracy of records at individual sites.

2. The amount of funding for stations with accuracies that are not acceptable for the data uses should be renegotiated with the data users.

3. The funding made available by implementation of the first two conclusions should be used to establish one or more new stream gages on unregulated small streams in the glaciated section of the Piedmont Lowlands region of New Jersey for which unregulated data are scarce.

4. The K-CERA analysis should be rerun with new stations included when sufficient information about the characteristics of the new stations has been obtained.

5. Schemes for reducing the probabilities of missing record, for example increased use of local gage observers, additional telemetry, more reliable equipment, gage electrification, and satellite relay of data, should be explored and evaluated as to their cost-effectiveness in providing streamflow information.

SUMMARY AND CONCLUSIONS

Currently, 101 continuous stream gages and 73 crest-stage or stage-only gages are being operated in New Jersey at a cost of $569,000. Four separate sources of funding contribute to this program and eight separate uses were identified for data from a single gage. In the glaciated section of the Piedmont Lowlands in northeastern New Jersey there are no gaging stations on unregulated streams. This deficiency should be remedied as funds are made available.

In an analysis of the uses that are made of the data, two stations were identified that had insufficient reason to continue their operation. Operation of these stations could be converted to crest-stage gages. Two other stations were identified as having uses specific only to short-term studies; these stations should also be deactivated at the end of the data-collection phases of the studies. The remaining 97 stations should be maintained in the program for the foreseeable future.

The current policy for operation of the 174-station program would require a budget of $569,000 per year. It was shown that the overall level of accuracy of the records at these 174 sites could be maintained with approximately a $554,000 budget, if the allocation of gaging resources among gages were altered. It is suggested that this alteration be implemented and that the remainder of the currently available money for stream gaging in New Jersey be applied to establishing gaging stations in the northeastern part of the state, in the glaciated Piedmont Lowlands.

A major component of the error in streamflow records is the loss of primary record (stage or other correlative data) at the stream gages due to malfunction of sensing and recording equipment. Upgrading of equipment and development of strategies to minimize lost record are key actions required in order to improve the reliability and accuracy of the streamflow data generated in New Jersey.

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 useful because of changes in demands for streamflow information with the subsequent addition and deletion of stream gages. Such changes will affect the operation of other stations in the program both because of the dependence among 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. Future studies could also explore the possibility of using telemetry to give real-time data in order to allow the scheduling of measurements on the basis of need for data in a specific discharge range, rather than on a fixed time interval. Possibly a real-time computer program could be written to set up optimum field trips on a weekly basis using the previous week's telemetered stages.

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