COST EFFECTIVENESS OF THE STREAM-GAGING PROGRAM IN OHIO

By Harold L. Shindel and William P. Bartlett, Jr.

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 85-4072

Columbus, Ohio

1986

DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

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

Multiply inch-pound unit	By	To obtain SI units
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square foot per second (ft^2/s)	0.09290	square meter per second (m^2/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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ABSTRACT

This report documents the results of the cost effectiveness of the stream-gaging program in Ohio. Data uses and funding sources were identified for 107 continuous stream gages currently being operated by the U.S. Geological Survey in Ohio with a budget of $682,000; this budget includes field work for other projects and and excludes stations jointly operated with the Miami Conservancy District. No stream gages were identified as having insufficient reason to continue their operation; nor were any stations identified as having uses specifically only for short-term studies. All 107 stations should be maintained in the program for the foreseeable future.

The average standard error of estimation of streamflow records is 29.2 percent at its present level of funding. A minimum budget of $679,000 is required to operate the 107-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 is 31.1 percent. The maximum budget analyzed was $1,282,000, which resulted in an average standard error of 11.1 percent.

A need for additional gages has been identified by other agencies that cooperate in the program. It is suggested that these gages be installed as funds can be made available.

INTRODUCTION

Background

The U.S. Geological Survey is the principal Federal agency collecting surface-water data in the Nation. The collection of these data is a major activity of the Water Resources Division of the Survey. The data are collected in cooperation with state and local governments and other Federal agencies. As of 1983, the Survey operated approximately 8,000 continuous-record gaging stations throughout the Nation. Some of these records extend back to before the turn of the century. Long-standing activities, such as the collection of surface-water data, should be reexamined at intervals because of changes in objectives and technological or external constraints. The last systematic nationwide evaluation of the streamflow information program was completed in 1970 and is documented by Benson and Carter (1973). The Survey is presently (1984) undertaking another nationwide analysis of the stream-gaging program that will be completed over a 5-year period 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. In addition, gaging stations are categorized as to whether the data are available to the users in a real-time sense, on a provisional basis, or at the end of the water year.

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

The final part of the analysis involves the use of Kalman-filtering and mathematical-programming techniques to define strategies for operation of the necessary stations that minimize the uncertainty in the streamflow records for given operating budgets. This work was largely pioneered by Moss and Thomas and reported by Fontaine and others (1983); it is on their work that much of this report is based. Kalman-filtering techniques are used to compute uncertainty functions (relating to standard errors of computation or estimation of streamflow records to the frequencies of visits to the stream gages) for all stations in the analysis. A steepest descent optimization program uses these uncertainty functions, information on practical stream-gaging routes, the various costs associated with stream gaging, and the total-operating budget to identify the visit frequency for each station that minimizes the overall estimate. The stream-gaging program that results from this analysis will meet the expressed water-data needs in the most cost-effective manner.

The standard errors of estimate given in this report are those that would occur if daily discharges were computed through the use of methods described in this study. No attempt has been made to estimate standard errors for discharges that are computed by other means. Such errors could differ 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.

This report is organized into five sections. The first is an introduction to the stream-gaging activities in Ohio and to the study itself. The middle three sections each contain discussions of an individual step of the analysis. Because of the sequential nature of the steps and the dependence of subsequent steps on the previous results, suggestions are made at the end of each of the middle three sections. The study, including all suggestions, is summarized in the final section.

History of Stream-Gaging Program in Ohio

Water resources have been a dominant factor in the economic growth of Ohio. The most important water resource is surface water because of its relative abundance and distribution. The inception and growth of the cooperative streamflow-data program of the U.S. Geological Survey in Ohio have resulted from the ever-increasing demand for appraisal of this valuable resource.

One of the first measurements of streamflow in the United States was made in 1823 on the Sandusky River. Prior to 1898, streamflow data collected in Ohio consisted of river stage readings and occasional discharge measurements. In 1898, the U.S. Geological Survey began cooperative stream-gaging work on the Scioto and Olentangy Rivers at Columbus. The first cooperative stream-gaging station was established on the Scioto River during August of that year and continued in operation for 3 years.

Following the disastrous floods of 1913, the Ohio Legislature in 1914 passed the Conservancy Act of Ohio, which empowered residents of river basins to organize into districts for flood protection and allied purposes. The largest and most notable of the districts is the Miami Conservancy District (MCD) established in 1915 with headquarters in Dayton. Until the establishment of the present cooperative program, the streamflow program of the MCD was by far the most significant hydrologic activity in Ohio.

In July 1921 the State of Ohio and the U.S. Geological Survey cooperatively established the continuous and systematic streamflow program in existence today. From 1921 to 1936 a network of gages, well distributed over the State and numbering more than 100 in 1931, was established and maintained. State cooperation was discontinued from 1936 to 1939 and the network of gages was reduced to a minimum of 52. Since 1939, the streamflow program was gradualy expanded to a maximum of 180 continuous-record stations in 1974 and 1980. The number of continuous record stations remained fairly constant until 1980. Since that time, the network has been reduced to 137 continuous-record stations due to severe economic pressures. Nineteen of these stations are operated jointly with MCD.

The historical number of continuous stream gages operated within the State of Ohio is shown in figure 1.

Current Ohio Stream-Gaging Program

Ohio is divided into five major physiographic regions: The Till plains, the Lake plains, the Lexington Plains, the Glaciated plateau, and the Unglaciated plateau (Ohio Department of Natural Resources, no date). The locations of these regions and the distribution of the 126 stream gages currently operated by the

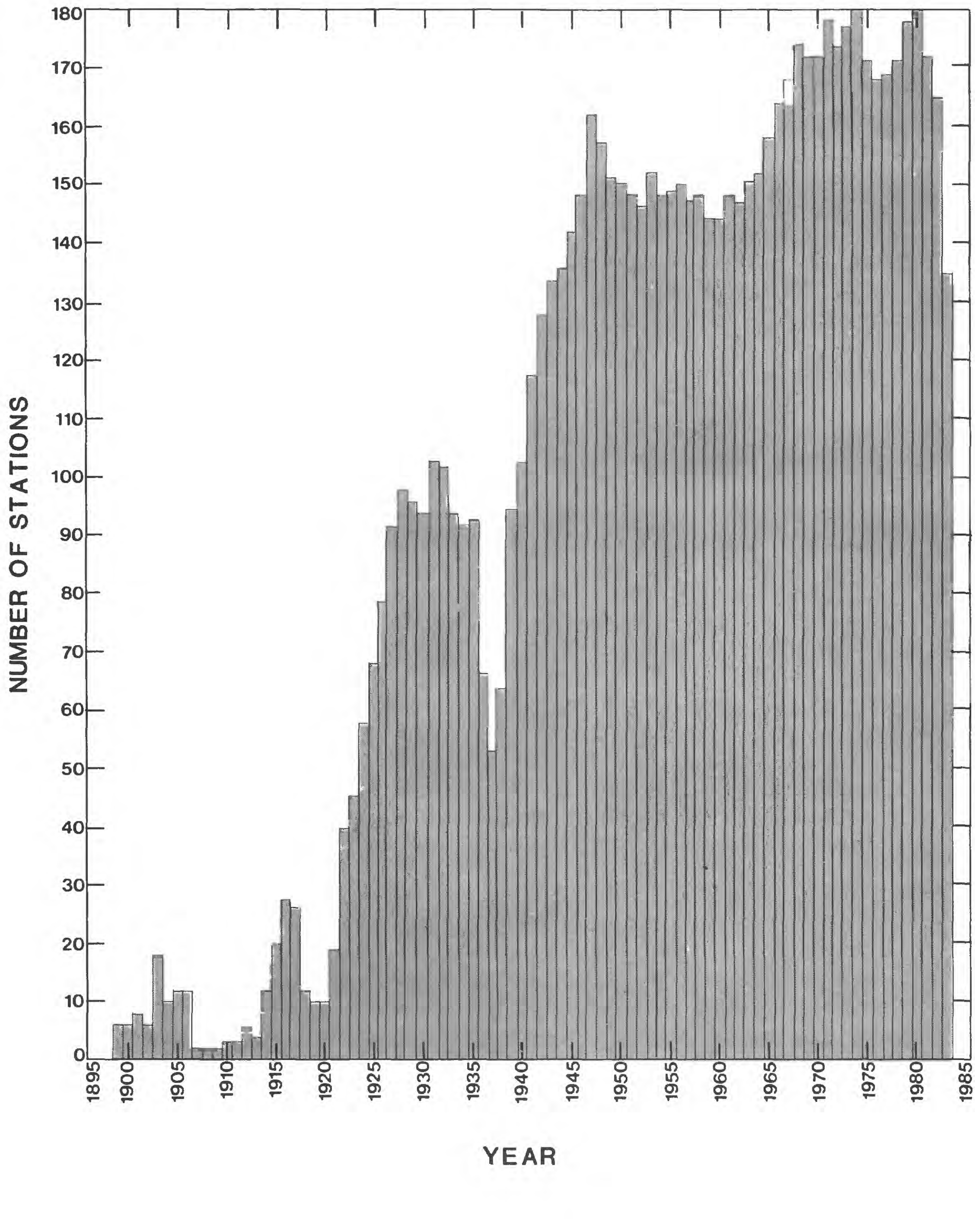


Figure 1.--History of continuous stream gaging in Ohio.

U.S. Geological Survey and MCD are shown in figure 2. There are 53 gages located in the Till plains, 15 in the Lake plains, 1 in the Lexington Plain, 26 in the Glaciated plateau, and 31 in the Unglaciated plateau. It can be seen in figure 2 that the gages are fairly well distributed throughout the State.

In 1984, the cost of operating the 126 stream gages and other related field work was $798,500. The budget for the network without the MCD gages was $682,000.

Selected hydrologic data, including drainage area, period of record, and mean annual flow for the 126 stations are given in table 1. Station identification numbers used throughout this report are U.S. Geological Survey's eight-digit downstream-order station numbers.

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 that are produced from the gage. The uses made of the data from each gage in the Ohio program were identified by a survey of the known data users. This survey documents the importance of each gage and identifies particular gaging stations of lesser importance that may be considered for discontinuation.

The data uses resulting from this survey were categorized into the nine classes defined below. The sources of funding for each gage and the frequency at which data are provided to the user also were compiled. Many of the stations have multiple uses and the gages identified with each category will total considerably more than 126.

Data-Use Classes

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 effect of man on streamflow is not necessarily small, but the effects are limited to those caused primarily by changes in land use and climate. Large amounts of manmade storage may exist in the basin provided that the outflow is uncontrolled. These stations are useful in developing regionally transferable information about the relationship between basin characteristics and streamflow.

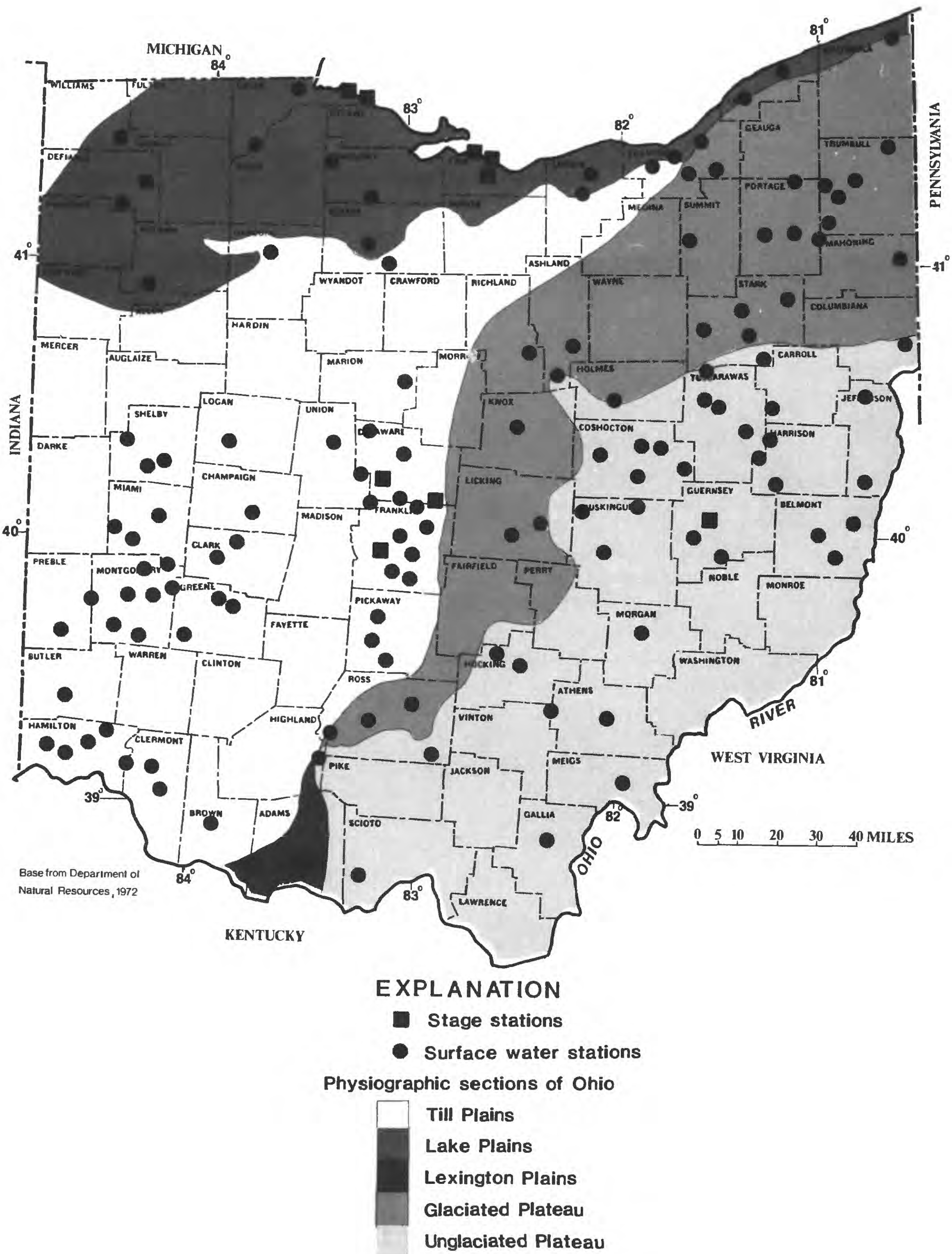


Figure 2a.—Locations of stream gages Statewide.

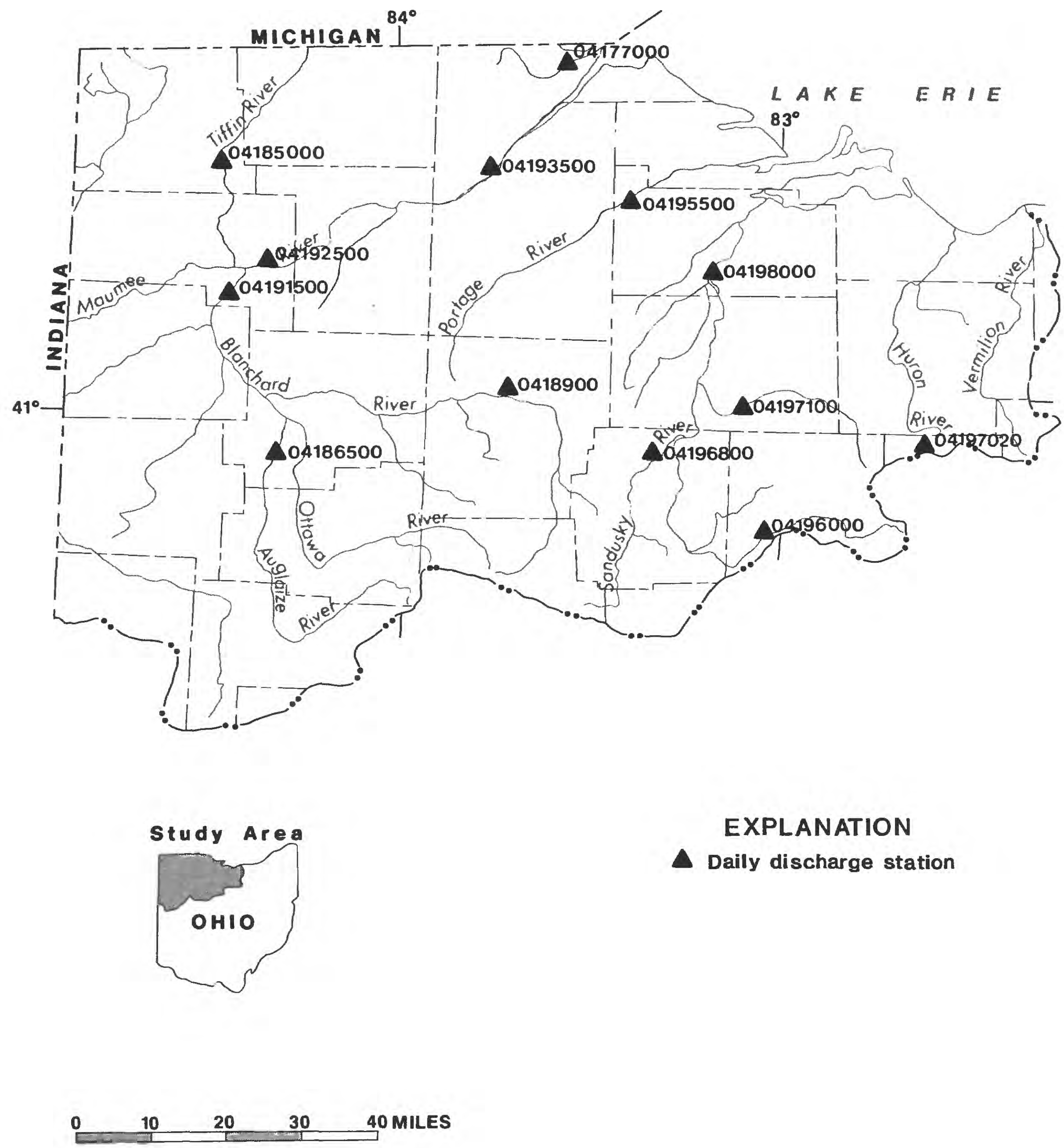


Figure 2b.—Locations of stream gages, northwestern Ohio.

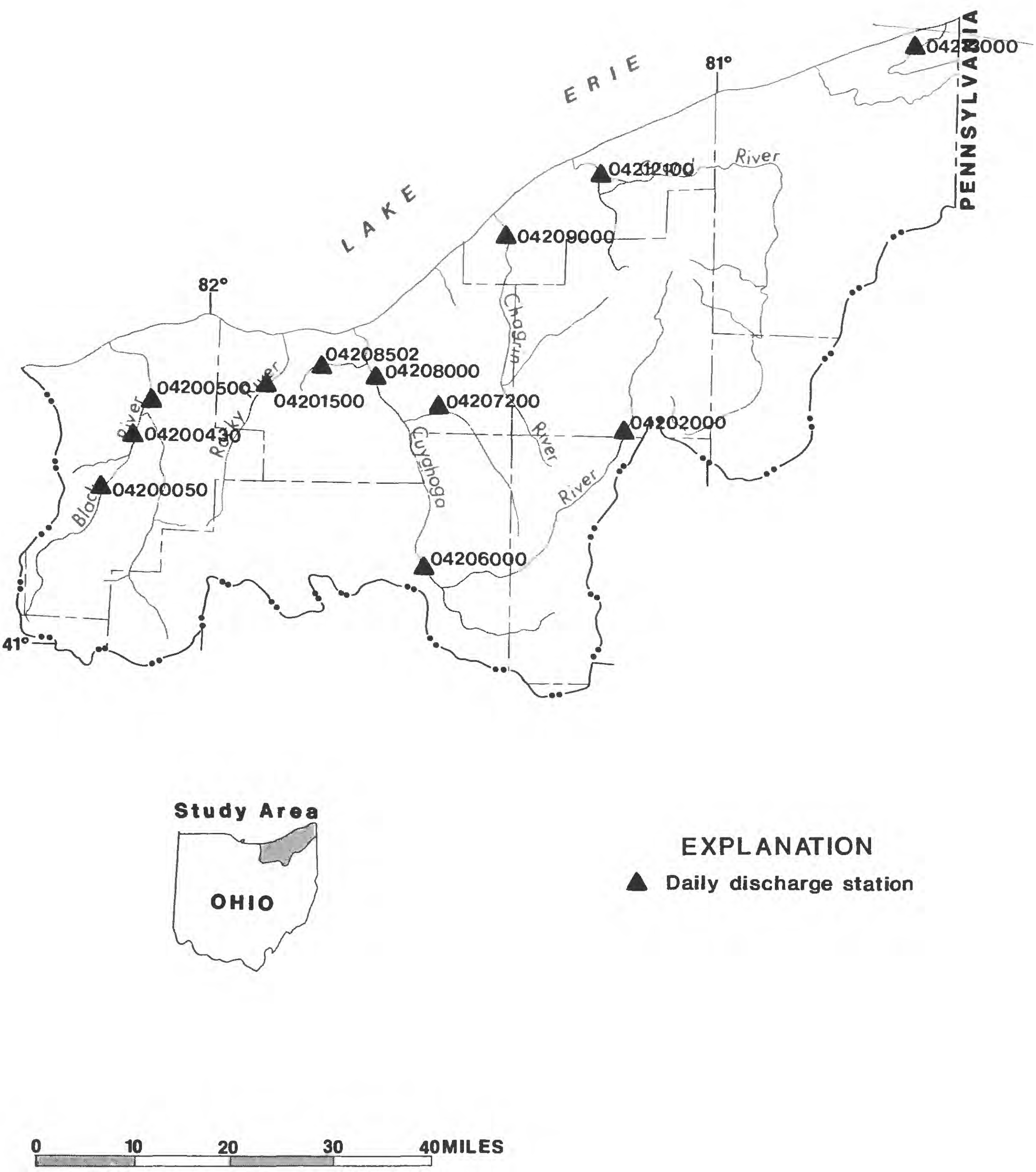


Figure 2c.—Locations of stream gages, northeastern Ohio.

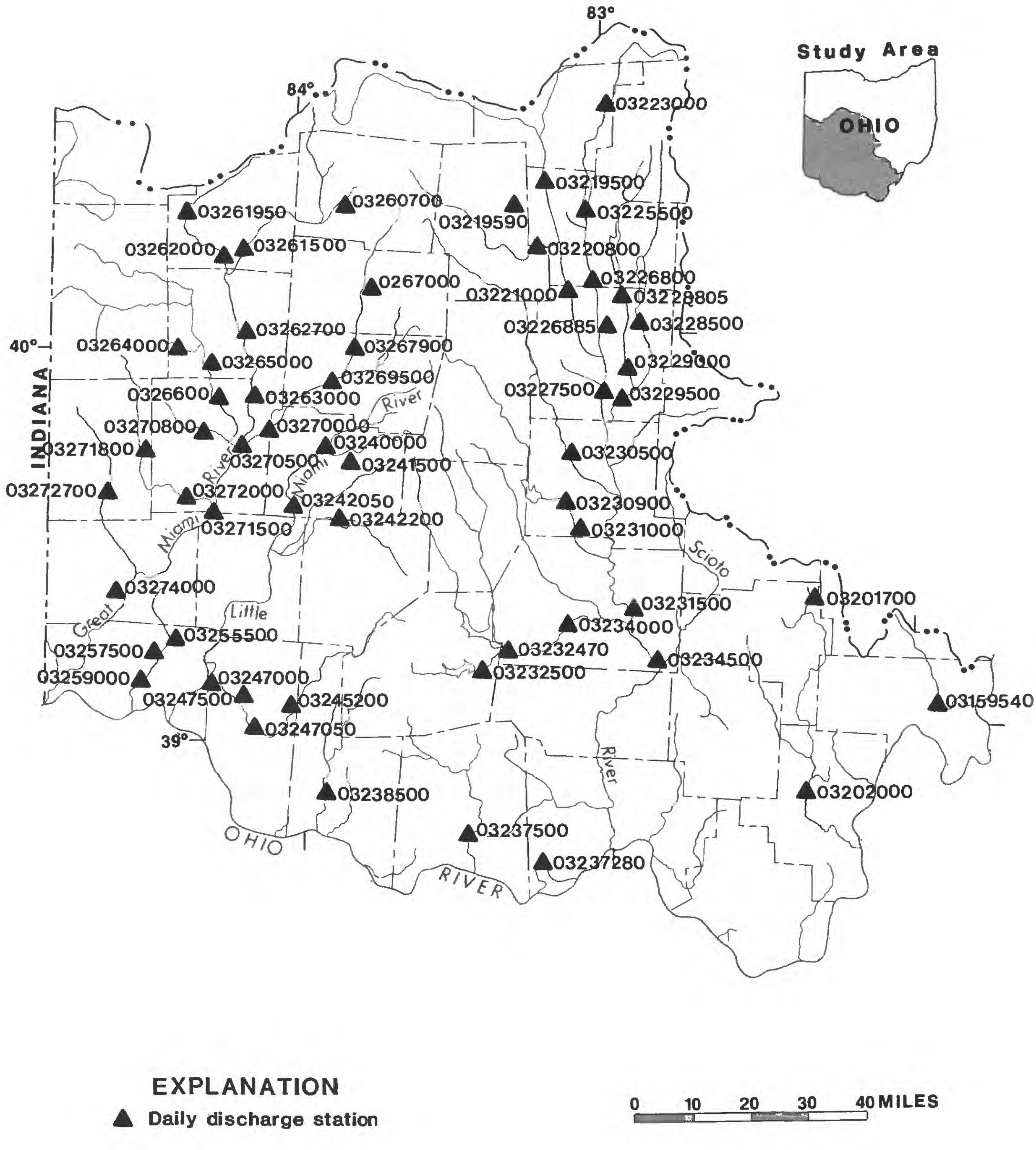


Figure 2d.—Locations of stream gages, southwestern Ohio.

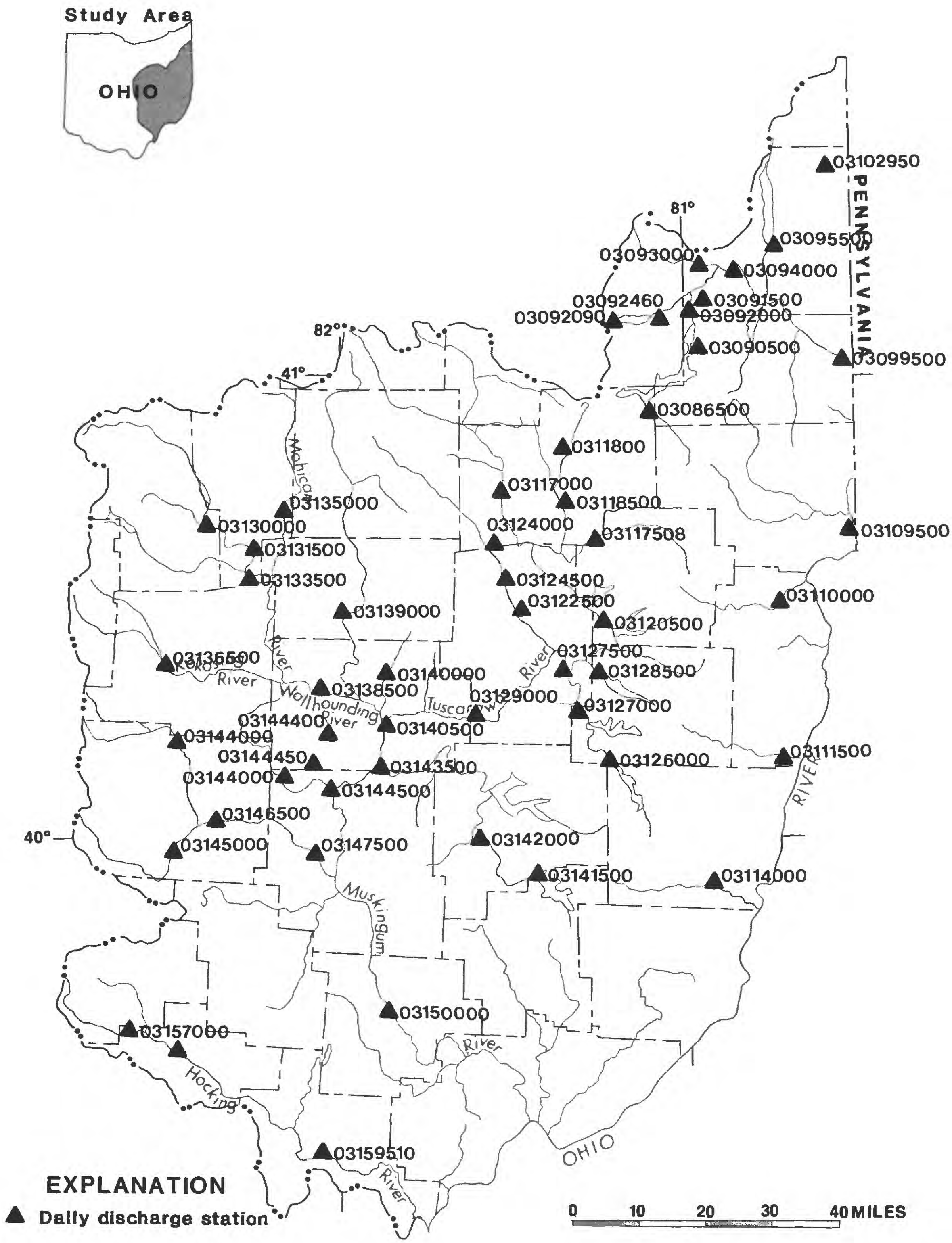


Figure 2e.--Locations of stream gages, southeastern Ohio.

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

[Numbers in parentheses refer to footnotes]

Station number	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
03086500	Mahoning River at Alliance	89.2	1941-	88.5
03090500	Mahoning River near Berlin Center	248	1931-	237
03091500	Mahoning River at Pricetown	273	1929-	259
03092000	Kale Creek near Pricetown	21.9	1941-	23.3
03092090	West Br Mahoning River near Ravenna	21.8	1966-	27.9
03092460	West Br Mahoning River at Wayland	81.7	1969-	105
03093000	Eagle Creek at Phalanx Station	97.6	1926-34, 1938-	109
03094000	Mahoning River at Leavittsburg	575	1941-	577
03095500	Mosquito Creek near Cortland	97.5	1926-29, 1943-	87.0
03099500	Mahoning River at Lowellville	1073	1943-	1099
03102950	Pymatuning Creek at Kinsman	96.7	1966-	124
03109500	Little Beaver Creek near E. Liverpool	496	1915-	523
03110000	Yellow Creek at Hammondsville	147	1941-	162
03111500	Short Creek near Dillonvale	123	1942-	131
03114000	Captina Creek at Armstrongs Mills	134	1926-35, 1959-	167
03117000	Tuscarawas River at Massillon	518	1938-	441
03117500	Sandy Creek at Waynesburg	253	1939-	271
03118000	Middle Br Nimishillen Creek at Canton	43.1	1941-	35.8
03118500	Nimishillen Creek at North Industry	175	1922-	183
03120500	McQuire Creek near Leesville	48.3	1939-	54.0

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

Station number	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
03122500	Tuscarawas River near Dover	1405	1924-	1432
03124000	Sugar Creek near Beach City	300	1939-	277
03124500	Sugar Creek at Strasburg	311	1931-33,1935-39,1962-	316
03126000	Stillwater Creek at Piedmont	122	1939-	139
03127000	Stillwater Creek at Tippecanoe	282	1939-	323
03127500	Stillwater Creek at Uhrichsville	367	1922-	436
03128500	Little Stillwater Creek at Tappan	71.1	1939-	78.0
03129000	Tuscarawas River at Newcomerstown	2443	1921-	2543
03130000	Black Fork near Mifflin	217	1939-	199
03131500	Black Fork at Loudonville	349	1931-	348
03133500	Clear Fork near Perrysville	198	1939-	199
03135000	Lake Fork near Mohicanville	271	1939-	237
03136500	Kokosing River at Mt. Vernon	202	1953-	213
03138500	Walhonding River at Nellie	1505	1910-13(1), 1921-	1508
03139000	Killbuck Creek at Killbuck	464	1931-	413
03140000	Mill Creek near Coshocton	27.2	1937-	29.0
03140500	Muskingum River near Coshocton	4859	1936-	4990
03141500	Seneca Fork near Senecaville	118	1939-	133
03142000	Wills Creek at Cambridge	406	1926-28, 1937-	454
03143500	Wills Creek at Wills Creek	842	1939-	945

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

Station number	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
03144000	Wakatomika Creek near Frazeysburg	140	1936-	155
03144500	Muskingum River at Dresden	5993	1921-	6370
03145000	South Fork Licking River near Hebron	133	1940-48, 1968-	155
03146500	Licking River near Newark	537	1940-	590
03147500	Licking River near Dillon Falls	742	1940-	890(2)
03150000	Muskingum River at McConnelsville	7422	1922-	7585
03157000	Clear Creek near Rockbridge	89.0	1940-	89.6
03157500	Hocking River at Enterprise	459	1931-	462
03159510	Hocking River below Athens	957	1977-	1269
03159540	Shade River near Chester	156	1956,1962-64(3) 1965-	178
03202000	Raccoon Creek at Adamsville	585	1915-35, 1939-	654
03219500	Scioto River near Prospect	567	1925-32, 1940-	455
03219590	Bokes Creek near Warrensburg	83.2	1982-	(X)
03220000	Mill Creek near Bellepoint	178	1943-	154
03221000	Scioto River near Dublin	980	1921-	788
03223000	Olentangy River near Claridon	157	1947-	151
03225500	Olentangy River near Delaware	393	1924-34, 1938-	351
03226800	Olentangy River near Worthington	497	1956-	457
03227500	Scioto River at Columbus	1629	1921-	1393
03228500	Big Walnut Creek at Central College	190	1938-	189

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

Station number	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
03228805	Alum Creek at Africa	122	1962(3) , 1963-	109(4)
03229000	Alum Creek at Columbus	189	1923-35, 1938-	172
03229500	Big Walnut Creek at Rees	544	1921-35, 1939-	521
03230500	Big Darby Creek at Darbyville	534	1921-35, 1938-	454
03230900	Deer Creek near Pancoastburg	277	1964-65(5) , 1966-	272
03231000	Deer Creek at Williamsport	333	1926-35,38-56, (59,61-62(6))1962-	301
03231500	Scioto River at Chillicothe	3849	1913-14(7), 1921-	3444
03232470	Paint Creek near Bainbridge	570	1962-67(3) 1963-67(5), 1968-	590
03232500	Rocky Fork near Barretts Mills	140	1940-	155
03234000	Paint Creek near Bourneville	807	1921-37, 1938-	805(8)
03234500	Scioto River at Higby	5131	1931-	4596
03237280	Upper Twin Creek at McGaw	12.2	1963-	14.0
03237500	Ohio Brush Creek near West Union	387	1926-35, 1940-	458
03238500	Whiteoak Creek near Georgetown	218	1924-35, 1940-	260
03240000	Little Miami River near Oldtown	129	1952-	117
03241500	Massies Creek at Wilberforce	63.2	1952-	62.6
03245500	Little Miami River at Milford	1203	1915-17, 1917-20(9) 1925-36, 1938-	1244
03247050	East Fork Little Miami River near Batavia	352	1965-	(X)

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

Station number	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
03247500	East Fork Little Miami River at Perintown	476	1915-17, 1918-20(9) 1925-	(X)
03255500	Mill Creek at Reading	73.0	10/38-4/39, 6/39-	(X)
03259000	Mill Creek at Carthage	115	1947-	(X)
03260700 *	Bokengehalas Creek near DeGraff	36.0	1958-	32.7
03261500 *	Great Miami River at Sidney	541	1914-	476
03261950 *	Loramie Creek near Newport	152	1965-	130
03262000 *	Loramie Creek at Lockington	257	1916-	208
03262700 *	Great Miami River at Troy	926	1961-62(2), 1963-	797
03263000 *	Great Miami River at Taylorsville	1149	1914-17, 1922	996
03264000 *	Greenville Creek near Bradford	193	10/1930-4/1931-	172
03265000 *	Stillwater River at Pleasant Hill	503	1917-1928, 1935-	444
03266000 *	Stillwater River at Englewood	650	1926-	579
03267000 *	Mad River near Urbana	162	1925-31, 1939-	144
03267900	Mad River at Eagle City	310	1966-	312
03269500 *	Mad River near Springfield	490	1904-06(10), 1914-	490
03270000 *	Mad River near Dayton	635	1915-	629
03270500 *	Great Miami River at Dayton	2511	4-9/1905, 1-9/06, 1/07-12/09(9), 1913-	2143
03270800 *	Wolf Creek at Trotwood	22.7	1963-	22.1

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

Station number	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
03271500 *	Great Miami River at Miamisburg	2711	1916-20, 1924-35, 1953-	2418
03271800 *	Twin Creek near Ingomar	197	1959,61-62(5), 1963-	192
03272000 *	Twin Creek near Germantown	275	1914-23, 1927-	263
03272700 *	Sevenmile Creek at Camden	69.0	1971-	73.0
03274000 *	Great Miami River at Hamilton	3630	1907-09(11), 1910-1918, 1927-	3269(12)
04177000	Ottawa River at Toledo	150	1945-48, 1976-	117
04185000	Tiffin River at Stryker	410	1921-28, 1941-	316
04186500	Auglaize River near Ft. Jennings	332	1921-35, 1941-	284
04189000	Blanchard River near Findlay	346	1924-36, 1941-	249
04191500	Auglaize River near Defiance	2318	1903(9), 1915-	1703
04192500	Maumee River near Defiance	5545	1925-35, 1939-74, 1979-	4110
04193500	Maumee River at Waterville	6330	1898-1901, 1921-35, 1939-	4857
04195500	Portage River at Woodville	428	1928-36, 1940-	313
04196800	Tymochtee Creek at Crawford	229	1961-64(5), 1964-	175
04197020	Honey Creek near New Washington	17.0	1979-	(X)
04197100	Honey Creek at Melmore	149	1961-75(5), 1976-	138
04197170	Rock Creek at Tiffin	34.6	1983-	(X)
04198000	Sandusky River near Fremont	1251	1899-1901(7), 1924-36, 1938-	974
04200430	West Br Black River at Elyria	174	1980-	(X)

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

Station number	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
04200500	Black River at Elyria	396	1945-	324
04201500	Rocky River near Berea	267	1924-35, 1943-	263
04202000	Cuyahoga River at Hiram Rapids	151	1927-36, 1945-	205
04206000	Cuyahoga River at Old Portage	404	1921-35, 1939-	424
04207200	Tinkers Creek at Bedford	83.9	1963-	127
04208000	Cuyahoga River at Independence	707	1903-05(11), 1906(7) 1921-23, 1927-36, 1940-	809
04208502	Big Creek at Cleveland	35.3	1973-	50.7
04208690	Euclid Creek near Euclid	22.6	1977-80, 1983-	(X)
04209000	Chagrin River at Willoughby	246	1925-36, 1940-	330
04212100	Grand River near Painesville	685	1975-	1030
04213000	Conneaut Creek at Conneaut	175	1922-35,1950-	265

(1) Gage heights and discharge measurements only
(2) Occasional low-flow measurements
(3) Occasional low-flow measurements
(4) Mean annual flow based on period 1974-81
(5) Occasional low flow measurements and annual maximum
(6) Annual maximums
(7) Gage heights and discharge measurements only
(8) Mean annual flow based on period 1921-36, 1939-81
(9) Gage heights only
(10) Monthly discharge only
(11) Fragmentary
(12) Annual mean flow based on period 1931-81
(X) Mean not computed because of diversion or insufficient record
(*) Miami Conservancy District

Eighty-five stations in the Ohio network are classified in the regional hydrology data-use category. Five of these stations are special cases, in that they are designated benchmark and (or) index stations. There is one hydrologic benchmark station in Scioto County in southern Ohio that serves as an indicator of hydrologic conditions in watersheds relatively free of manmade alteration. Four index stations located in other parts of the State are used to indicate current hydrologic conditions. The locations of stream gages that provide information about regional hydrology are shown in figure 3.

Hydrologic Systems

Gaging stations 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. Such stations are designated as hydrologic-systems stations. They include stations measuring diversions and return flows and stations that are useful for defining the interaction of water systems.

The benchmark and index stations are included in the hydrologic-systems category because they are accounting for current and long-term conditions of the hydrologic systems that they gage.

Forty-five other stations are included in this category. These stations are operated to insure the compliance with waste-water-treatment plant permits, and to provide data useful for flood-control, low-flow augmentation, water-supply, and recreational purposes.

Legal Obligations

Some stations provide records of flow for the verification of enforcement of existing treaties, compacts, and decrees. This category contains only those stations which the U.S. Geological Survey is required to operate to satisfy a legal responsibility. There are no such stations in the Ohio program.

Planning and Design

Gaging stations in this category are used for planning and design of a specific project (for example, a dam, levee, floodwell, 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 a purpose and where this purpose is still valid.

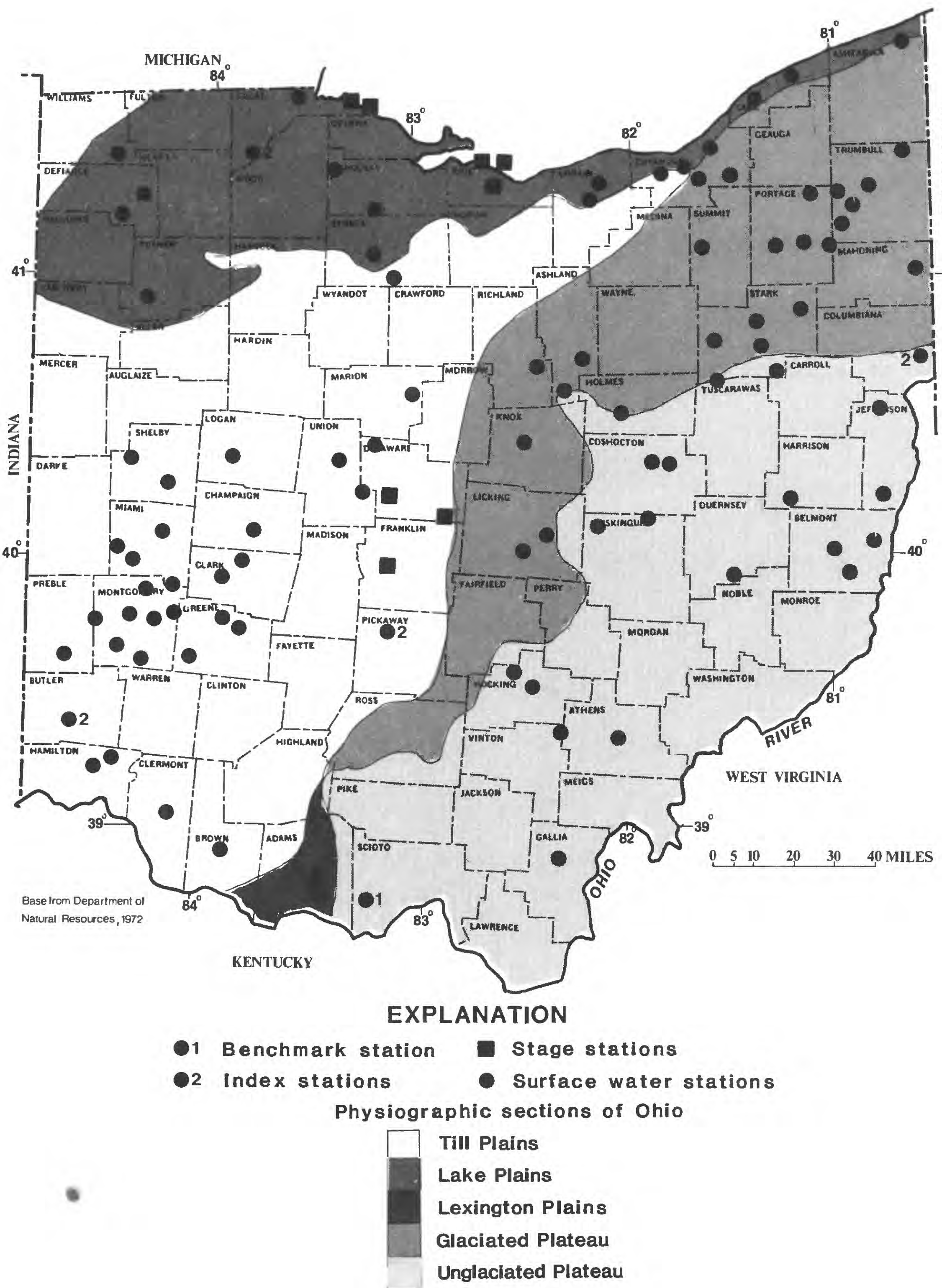


Figure 3.--Locations of regional-hydrology stream gages.

Project Operation

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

There are 65 stations in the Ohio program used in this manner. Fifty-three of these are used to aid operators in the management of reservoirs that are part of the flood-control system. Six are used to assist water plant operators, and six are used to assist wastewater-treatment plant operators to provide current information on the local hydrologic system.

Hydrologic Forecasts

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

Stations in the Ohio program that are included in the hydrologic-forecast category are those used for flood forecasting. ata are used by the National Weather Service River Forecast Center in Cincinatti, and by U.S. Army Corps of Engineers District Offices (Buffalo, N.Y., Huntington, W.Va., Louisville, Ky., and Pittsburgh, Pa.) to predict and regulate flood volumes at downstream sites.

Water-Quality Monitoring

Gaging stations where regular water-quality or sediment-transport monitoring is being conducted and where the availability of streamflow data contributes to the utility or is essential to the interpretation of the water-quality or sediment data are designated as water-quality-monitoring sites.

One such site in the program is a designated benchmark station, nine are National Stream Quality Accounting Network (NASQAN) stations, and five other sites are water-quality sites. Water samples from the benchmark station are used to indicate water-quality characteristics of streams that have been and probably will continue to be relatively free of human influences.

NASQAN stations are part of a countrywide network designed to assess water-quality trends of significant streams. The remaining five water-quality monitoring stations provide data for miscellaneous purposes.

Research

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

Nine stations in the Ohio program are used in support of research activities, including nitrogen- and phosphorus-loading studies and land conservation (no-till farming) studies.

Other

In addition to the eight data-use classes described above, 71 stations are also used to provide streamflow information for recreation planning (primarily fishing and boating) and fish and wildlife studies.

Funding

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

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

2. Other Federal Agency (OFA) programs.--Funds that have been transferred to the USGS by OFAs.

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 the non-Federal agency and are not matched by U.S. Geological Survey cooperative funds.

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

Eleven entities currently are contributing funds to the Ohio stream-gaging program.

Frequency of Data Availability

Frequency of data availability refers to the times at which the streamflow data may be furnished to the users. Data can be furnished by direct-access telemetry equipment for immediate use, by periodic release of provisional data, by National Weather Service observer reports, or in publication format through the annual report published by the Survey for Ohio (Water Resources Data -- Ohio). These four categories are designated T, P, W, and A, respectively, in table 2. In the current Ohio program, data for 126 stations are made available through the annual report, data for 42 stations are available on a real-time basis, and data are released on a provisional basis for 86 stations.

Through close cooperation with the National Weather Service, data are available almost immediately from observers at an additional 23 stations. These stations are designated in table 2.

Data-Use Presentation

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

Conclusions Pertaining To Data Uses

The data program in Ohio has been reduced considerably in recent years because of budget constraints among the U.S. Geological Survey's cooperators. Further, the expected expansion of the network brought about by increasing water problems has not taken place, also because of lack of funds. Various cooperators have expressed strong interest in more data gathering should the funds become available. Appendix 1 gives the responses of our present cooperators to the question "Where and for what reasons would you like to see additional gages if the funding should become available?" As can be seen from appendix 1, the network should be increasing rather than decreasing. From a use standpoint, all of the extraneous gages have already been eliminated mainly because of declining levels of funding. Project, or short-term stations, are currently not handled as parts of regularly scheduled field trips. Therefore, no stations in this analysis will be dropped because of completion of short-term projects. As funding becomes even more difficult to obtain, additional stations will have to be dropped.

ALTERNATIVE METHODS FOR DEVELOPING STREAMFLOW INFORMATION

The next step in the analysis is the investigation of alternate methods of providing daily streamflow information in a more cost-effective way than the traditional continuous-record stream gage. The alternate method should (1) be computerized and easy to

Table 2.--Data-use table

STATION NUMBER	DATA USE: REGIONAL HYDROLOGY	HYDROLOGIC SYSTEMS	LEGAL OBLIGATIONS	PLANNING & DESIGN	PROJECT OPERATION	HYDROLOGIC FORECASTS	WATER-QUALITY MONITORING	RESEARCH	OTHER	FUNDING: FEDERAL PROGRAM	OFA PROGRAM	CO-OP PROGRAM	OTHER NON-FEDERAL	FREQUENCY OF DATA AVAILABILITY
03086500	1,7	2		7	2	7	7				2	1		A
03090500		2			2	7			19		2	1		A
03091500			2		2	7			19		2	1		A,P
03092000	1,7	2			2	7					2			A
03092090	1,7	2			2	7					2	1		A,T
03092460		2			2	7			17		2			A
03093000	1,7	2		7	2,7	7	7				2	1		A
03094000		2	7	7	2,7	2,7,10	7		15		2	7		A,P,T
03095500		2		7	2,7	7	7		17		2	1		A
03099500			7	7	7	7	7		15		7			A,P
03102950	1,7	2			2	7					2			A,P
03109500	1,7		7			7,10	7			*		1		A,W
03110000	1,7					7	7		26			1		A
03111500	1,2,7					7	7		23,26		2	1		A
03114000	1,2,7					7	7		23,26		2	1		A,P
03117000	1,7		7	7	4,7	7	7				4	7		A
03117500	1,7				4	7					4	1		A
03118000	1,7					7						1		A
03118500	1,7		7	7	4,7	7,10	7				4	1		A,W
03120500					4	4,7			22		4	1		A,P
03122500				7	4,7	4,7,10	7		15		4	1		A,P,T
03124000	7			7	4	4,7			17		4	1		A,P
03124500						7			14,17				12	A,P
03126000	7				4	4,7,10			17		4	1		A,P,W
03127000				7	4	4,7,10			17		4	1		A,P,T
03127500					4	4,7,10			17		4	1		A,T
03128500					4	4,7,10			17		4	1		A,P,W
03129000				7	4,7	4,7,10	7		17		4	7		A,T
03130000				7	4	4,7			17		4	1		A,P
03131500				7	4	4,7,10			17		4	7		A,P,W

See footnotes at end of table.

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

STATION NUMBER	DATA USE: REGIONAL HYDROLOGY	HYDROLOGIC SYSTEMS	LEGAL OBLIGATIONS	PLANNING & DESIGN	PROJECT OPERATION	HYDROLOGIC FORECASTS	WATER-QUALITY MONITORING	RESEARCH	OTHER	FUNDING: FEDERAL PROGRAM	OFA PROGRAM	CO-OP PROGRAM	OTHER NON-FEDERAL	FREQUENCY OF DATA AVAILABILITY
03133500					4	4,7			17		4	1		A,P
03135000	7				4	4,7			17		4	1		A,P
03136500	7				4	7,10			17		4	1		A,P,W
03138500					4	4,7			17		4	1		A,P
03139000	1,7			7	4,7	7,10	7				4	7		A,T
03140000	1,7											1		A
03140500				7	4	4,7,10	7		18		4	7		A,P,T
03141500					4	4			17		4	1		A,P
03142000				7	4	4,7,10			17,26		4	1		A,T
03143500					4	4,7,10			18		4	1		A,P,W
03144000	1,7				4	7			26		4	1		A
03144500					4	4,7,10			18		4	7		A,P,T
03145000	1,7			7		7						1		A
03146500	1,7			7	4	4,7,10	7				4	7		A,P,T
03147500					4	4,10			18		4	1		A,P,W
03150000					4	4,7,10			18	*	4			A,P,T
03157000	1,7				4	4,7	7				4	1		A
03157500	7			7	4	7,10	7		17		4	1		A,T
03159510				7	4	4,10			17		4	7		A,P,T
03159540	1,7											1		A
03202000	1,7				4						4	7		A
03219500	1,7					10	7					1		A,P,W
03219590	7							8					8	A
03220000	1,7				4,8		7				4		8	A
03221000		7			4,8	4,10			14,19		4		8	A,P,T
03223000	1,7			7	4	7					4	1		A,P
03225500		7		7	4	4,7,10			18		4	1		A,P,W
03226800					4	4,10	7		17		4	7		A,T
03227500				7	4,8	4,7,10	7		17		4		8	A,P,W
03228500		7		7	8	7			14,19				8	A,P
03228805					4	4,7,10			18		4	1		A,P,T
03229000		7			4	4,7,10			17		4			A,T

See footnotes at end of table.

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

STATION NUMBER	DATA USE: REGIONAL HYDROLOGY	HYDROLOGIC SYSTEMS	LEGAL OBLIGATIONS	PLANNING & DESIGN	PROJECT OPERATION	HYDROLOGIC FORECASTS	WATER-QUALITY MONITORING	RESEARCH	OTHER	FUNDING: FEDERAL PROGRAM	OFA PROGRAM	CO-OP PROGRAM	OTHER NON-FEDERAL	FREQUENCY OF DATA AVAILABILITY
03229500		7		7	8	7,10			17				8	A,P,W
03230500	1,7			7	4	4,7,10	7				4	1		A,W
03230900		7			4	4,7,10			18		4			A,P,W
03231000		7			4	4,10			17		4			A,T
03231500		7		7	4	4,7,10	7		17		4			A,P,T
03232470					4	4,7			18		4			A,P
03232500					4	4,7,10			21		4	1		A,T
03234000				7	4	4,7,10			17		4	1		A,P,T
03234500				7	4	4,7,10	7			*	4			A,T
03237280	1,7								13	*				A
03237500	1,7				4	10					4	1		A,W
03238500	1,7			7		7						1		A
03240000	1,7			7		7						1		A,P
03241500	1,7											1		A,P
03245500	7			7	3	3,7,10	7		17		3	7		A,P,T
03246200	1,7				3		3		24		3			A,P
03247050				7	3	7			17,25		3			A,P
03247500					3	3,10			17		3	7		A,P,W
03255500	1,7			7	3						3	1		A,P,T
03259000					3	7			16		3	7		A,P,T
03260700	1,6,7			7		6,7							6	A,P
03261500	1,7			7		6,7							6	A,P
03261950	1					6			20				6	A,P
03262000		6				6			21				6	A,P
03262700	7	6		7		6,7			20,21				6	A,P
03263000	7	6				6,7	6		21				6	A,P,T
03264000	1,7			7		6,7							6	A,P
03265000	1,7			7		6,7			20				6	A,P,T
03266000	7	6				6,7			21				6	A,P
03267000	1,7			7		6,7							6	A,P
03267900	1,7				3						3	1		A,P,T
03269500	7	6		7	3	6,7,10			17		3		6	A,P,T
03270000	7	6		7		6,7,10			17				6	A,P,T

See footnotes at end of table.

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

STATION NUMBER	DATA USE: REGIONAL HYDROLOGY	HYDROLOGIC SYSTEMS	LEGAL OBLIGATIONS	PLANNING & DESIGN	PROJECT OPERATION	HYDROLOGIC FORECASTS	WATER-QUALITY MONITORING	RESEARCH	OTHER	FUNDING: FEDERAL PROGRAM	OFA PROGRAM	CO-OP PROGRAM	OTHER NON-FEDERAL	FREQUENCY OF DATA AVAILABILITY
03270500	7	6		7	3	6,7,10			17		3		6	A,P,T
03270800	1,7												6	A,P
03271500	7	6		7		6,7	6		17				6	A,P
03271800	1,7					6			20				6	A,P
03272000	7	6		7		6,7			21				6	A,P
03272700	1,7					6,7							6	A,P,T
03274000	7	6		7		3,6,7,10			17		3		6	A,P,T
04177000	1,5,7	7		5	5	7,10	7				5			A,P,W
04185000	1,5,7	5,7				5,7,10	7					1		A,P,T
04186500	1,5,7	5,7				5,7,10	7				5	7		A,P,W
04189000	1,5,7	5,7		5,7		5,7,10	7				5	7		A,P,T
04191500	1,5,7	5,7				5,7,10	7				5	7		A,P,T
04192500	1,5,7	5,7				5,7,10	7				5	7		A,T
04193500	1,5,7	5,7	7			5,7,10	5,7,11	11		*	5			A,P,T
04195500	1,5,7	7	7			7,10	7,11	11				7		A,P,T
04196800	1,5,	7			11	7	7,11	11				1		A,P
04197020	5,7	7				7	5,7,11	11				7		A,P
04197100	1,5,7	7				7	5,7,11	11				11		A,P
04197170	5,7	7				7	7,11	11				11		
04198000	1,5,7	7	7		5,11	7,10	7,11	11			5	7		A,P,W
04200430	5,7	9		7	7		7,9					7		A
04200500	1,5	9		5	5	10	9	5			5			A,W
04201500	1,5,7	9	7	7	7	10	7,9					7		A,P,W
04202000		9					9					1		A
04206000	1,5,7	9		7		5,10	7,9					7		A,P,T
04207200	1,5,7	9		7			7,9					1		A,P
04208000	1,5,7	9	7	7	5,7	5,10	5,7,9,11	11			5			A,P,T
04208502	1,5,7			5	5		7,9				5			A
04208690	5			5							5			A,P
04209000	1,5,7	9	7	7	7	10	7,9					9		A,T
04212100	1,5,7	9	7	7	7	10	7,9					7		A,P,W
04213000	1,5,7					10						1		A,W

See footnotes at end of table.

Table 2.--<u>Data-use table</u>--Continued (footnotes)

A--Data published on annual basis.
P--Provisional data provided as available.
T--Data transmitted by telemetry such as satellite or phone.
W--Observer reports to National Weather Service.
*--Federal.
1--Ohio Department of Natural Resources.
2--Corps of Engineers--Pittsburgh, Pa.
3--Corps of Engineers--Louisville, Ky.
4--Corps of Engineers--Huntington, W.Va.
5--Corps of Engineers--Buffalo, N.Y.
6--Miami Conservancy District.
7--Ohio Environmental Protection Agency.
8--City of Columbus.
9--Northeast Ohio Areawide Coordinating Agency.
10-National Weather Service.
11-Seneca County Soil and Water District
12-City of Canton.
13-Benchmark Station.
14-Water-supply studies.
15-Water-supply, flood-management studies.
16-Water-supply, flood-management, recreation studies.
17-Water-supply, flood-management, recreation, fish and wildlife studies.
18-Water-supply, flood-management, recreation, fish and wildlife, hydropower studies.
19-Water-supply, flood-management, recreation, fish and wildlife, hydropower, dam-safety studies.
20-Dam inflow studies.
21-Water-supply, flood-management, recreation, fish and wildlife, dam-safety studies.
22-Water-supply, flood-management, fish and wildlife studies.
23-Peaks.
24-Model study.
25-Project outflow.
26-Mine drainage

apply, (2) interface with the U.S. Geological Survey's WATSTORE daily-values file (Hutchinson, 1975), (3) be technically sound, and (4) permit evaluation of the accuracy of the simulated streamflow. Two methods, regression analysis and hydrologic flow-routing were identified as meeting these criteria.

The data presented in table 2 provided the information for selecting potential sites where alternative methods could be used. Candidates included all sites where frequency of data availability is annual only. Table 2 shows 24 such sites. Certain data uses also require regular daily stream-gaging stations, and were not considered for the application of alternate methods. These data uses include those operated for legal obligations, project operation, water-quality monitoring, or research. These additional constraints left four sites where alternate methods could potentially provide the needed streamflow information. These sites are Middle Branch Nimishillen Creek at Canton (03118000), Mill Creek near Coshocton (03140000), South Fork Licking River near Hebron (03145000), and Shade River near Chester (03159540). Since none of these sites have stream-gaging stations upstream on the same stream, the routing model cannot be used. However, it was decided that at least one routing should be tried. The pair of stations with the highest coefficient of correlation (0.99) in the State was selected for both routing- and regression-model development. The stations are Sugar Creek below Beach City Dam near Beach City (03124000) and Sugar Creek near Strasburg (03124500).

A total of 11 alternate-method models were developed and tested for acceptance. Originally, the model-acceptance criterion was to produce a record equivalent to a rating of "good" for mean daily flows, which implies that 95 percent of the predicted flows should be within 10 percent of the observed values. Since that rating is a subjective evaluation by the analyzer, it was felt that a more lenient acceptance criterion should be adopted. Therefore, the model acceptance criterion used in this analysis is that the model should be able to predict 85 percent of the mean daily flows within 10 percent of the observed values, and should not show bias.

Description of Regression Analysis

Regression techniques have commonly been used to estimate various streamflow characteristics. Regression equations can be derived which relate the daily flows at one site with the flows at another site. The theory and assumptions of regression analysis can be found in several textbooks such as Draper and Smith (1981) and Montgomery and Beck (1982). The application of regression analysis to hydrologic data is found in Riggs (1973) and Haan (1977).

The linear-regression model used in Ohio for estimating mean daily discharges has the form:

$$Y_i = B_o + \sum_{j=1}^{k} B_j x_j + e_i$$

where

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

x_j = mean daily discharge at k nearby stations (independent variables),

e_i = random error (residual), and

B_o, B_j = regression constant and coefficients

The model was calibrated using observed values of y_i and x_j, which were retrieved from the WATSTORE daily values file. The x_j values can be lagged or advanced depending on the relative response times of the stations with respect to the y_i values. Once the model has been calibrated sucessfully, it should be verified with a data set that was not used for calibration. The errors observed for the verification are a better measure of the model's predictive accuracy. Additional analysis include plotting of residuals versus the dependent and independent variables and plotting of simulated and observed discharges versus time and each other. This will point out any bias or non-linearity of the model. For the application in Ohio, the flow values were also transformed by taking the logarithm (base 10) before being used in the regression analysis.

The use of a regression model for simulating flows tends to reduce the variance of the streamflow, since the effects of extreme outliers are damped out by the averaging affect of the model. Fontaine and others (1983, p. 24) state that "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."

Description of the Flow-Routing Model

A unit-response flow-routing model using the diffusion analogy (Keefer, 1974; Keefer and McQuivey, 1974) was used in the Ohio analysis. This hydrologic-routing method uses the law of conservation of mass and a relation between storage and outflow to route the flows. This method requires only a few parameters and treats the reach as a lumped system. The inputs are the hydrograph at the upstream end of the reach and a method to account for the intervening drainage area; the output is the hydrograph at the downstream end of the reach.

A series of interrelated computer programs has been documented by Doyle and others (1983) and allows retrieval of data from the WATSTORE files and the subsequent calibration of the model. The routing phase of the model has three parameters requiring calibration. The first two are C_0, the floodwave celerity which controls the traveltime, and K_0, the wave-dispersion coefficient, which controls the attenuation of the flows. The third is the intervening-area multiplier (IAM), which accounts for the contribution of the intervening area between the two sites by multiplying values at the upstream site, a tributary site, or a nearby hydrologically similar site by a coefficient based on drainage-area ratios. This multiplier is adjusted during calibration to reduce the total volume error to a minimum.

When the model has been successfully calibrated, a separate verification period should be used to evaluate the predictive ability of the model.

Application of Regression Analysis

Linear-regression analyses were applied to all five of the sites where alternate methods could supply the needed streamflow information. The first step in each modeling process was to examine the correlations between the dependent and independent values with lags of up to 3 days. The pair with the highest correlation coefficient determined the lag to be used in building the regression model. This was done with and without a logarithmic transformation of the data. The mean daily discharges for the selected sites (the dependent variable) were regressed against the corresponding flows at other stations (the independent variable). The model errors, in percent, were calculated for each day to determine if the modeling effort was successful. The results summarized in table 3 show that none of the ten models developed meet the "successful" criteria by simulating 85 percent of the flows within 10 percent of the observed values. Overall, the log-transformed models were slightly better than the nontransformed model, but examination of the distribution and magnitude of the errors showed that all the models, except Sugar Creek, tended to overestimate discharges in the low range of flows. At each site, the station chosen for the independent variable was the one with the highest correlation coefficient for the total concurrent period of record. There were no additional tributary or same-stream sites available for inclusion in the models. The 3-year calibration period selected was October 1, 1976 through September 30, 1979.

The regression model for Middle Branch Nimishillen Creek at Canton (03118000) used flows at Nimishillen Creek at North Industry (03118500) as the independent variable. The estimates from the regression models for 03118000 were within 10 percent of the observed for 28 percent of the time with the arithmetic model and 29 percent of the time with the log-transformed model. The difference in drainage areas (03118000 is 43.1 square miles, 03118500

Table 3.--Summary of regression models of mean daily discharge

[Q, discharge, in cubic feet per second, for station indicated by abbreviated station number in subscript; R^2, coefficient of determination]

Station	Model	R^2	Percentage or modelled flows within the indicated percentage of observed flows: 5%	10%	15%	Calibration period (water years)
03118000 Middle Branch Nimishillen Creek at Canton	$Q_{1180} = -4.18 + 0.196\ (Q_{1185})$	.72	15	28	40	1977-79
	$Q_{1180} = 0.0748\ (Q_{1185})^{1.13}$	.82	16	29	44	
03140000 Mill Creek at Canton	$Q_{1400} = 3.49 + 0.0699\ (Q_{1390})$	.29	3	7	11	1977-79
	$Q_{1400} = 0.0194\ (Q_{1390})^{1.17}$	.76	8	18	25	
031450000 South Fork Licking River near Hebron	$Q_{1450} = 26.6 + 0.225\ (Q_{1465})$	.78	4	7	11	1977-79
	$Q_{1450} = 0.0908\ (Q_{1465})^{1.13}$	.85	8	17	28	
03159540 Shade River near Chester	$Q_{LAG2} = 18.5 + 0.225\ (Q_{2020})$	.51	5	9	14	1977-79
	$Q_{LAG1} = 0.356\ (Q_{2020})^{0.914}$	.79	10	22	30	
03124500 Sugar Creek at Strasburg	$Q_{1245} = 5.72 + 1.04\ (Q_{1240})$	.99	44	72	85	1977-79
	$Q_{1245} = 1.25\ (Q_{1240})^{0.972}$	.99	43	72	86	

is 175 square miles) and man-induced alterations of the low flows at both sites are contributing factors in the failure of the model to meet the accuracy standards. Figure 4 compares the observed and simulated daily discharge for a typical high-flow period and low-flow period.

Mill Creek near Coshocton (03140000) was modeled using Killbuck Creek at Killbuck (03139000) as the independent variable. The arithmetic model predicted 7 percent of the flows within 10 percent, while the log model simulated 18 percent of the flows within 10 percent. One significant problem with the arithmetic model during calibration was that the intercept of 3.59 cubic feet per second combined with the minimum value of 58 cubic feet per second at 03139000 gives a minimum simulated value of 7.54 cubic feet per second; however, over 25 percent (quartile point) of the observed flows were below 5.2 cubic feet per second during the period. Both models exhibit bias at the low end, where the models overestimate, and the high end, where the models underestimate. The failure of both models is probably caused by the large difference in drainage areas (03140000 is 27.2 square miles, 03139000 is 464 square miles). Figure 5 shows the observed and simulated flows furing a spring high-flow period and a late summer low-flow period.

The model for South Fork Licking River at Hebron (03145000) used daily flows for Licking River at Newark (03146500) as the independent variable. The arithmetic and log models predicted 7 percent and 17 percent respectively of the flows within 10 percent of the observed flows. The results are similar to the Mill Creek model, and the drainage area difference (153 square miles versus 537 square miles) is the probable cause. A comparison of observed and simulated flows during high- and low-flow periods is shown in figure 6.

Mean daily flows at Shade River near Chester (03159540) were simulated based on flows at Raccoon Creek at Adamsville (03202000). The best models were found when values for Shade River were lagged by 2 days in the arithmetic model and 1 day in the logarithmic model. Results of 9 percent and 22 percent of predicted values within 10 percent of observed flows for the arithmetic- and log- models, respectively, were not acceptable. Drainage-area difference (156 square miles versus 585 square miles) is again a hinderance, and these sites are in different drainage basins which also contributes to the inability of the models to perform better. Comparison of the observed and simulated flows are shown for two selected periods in figure 7.

The final pair of regression models were developed for Sugar Creek at Strasburg (03144500) using flows at Sugar Creek below Beach City Dam near Beach City (03144000). These sites are on the same stream, have similar drainage areas (311 versus 300 square miles), and have a long-term correlation coefficient of 0.9924. Both models were able to predict 72 percent of the flows within 10 percent of the observed, but this did not meet the alternate method acceptance criteria. The distribution of errors were

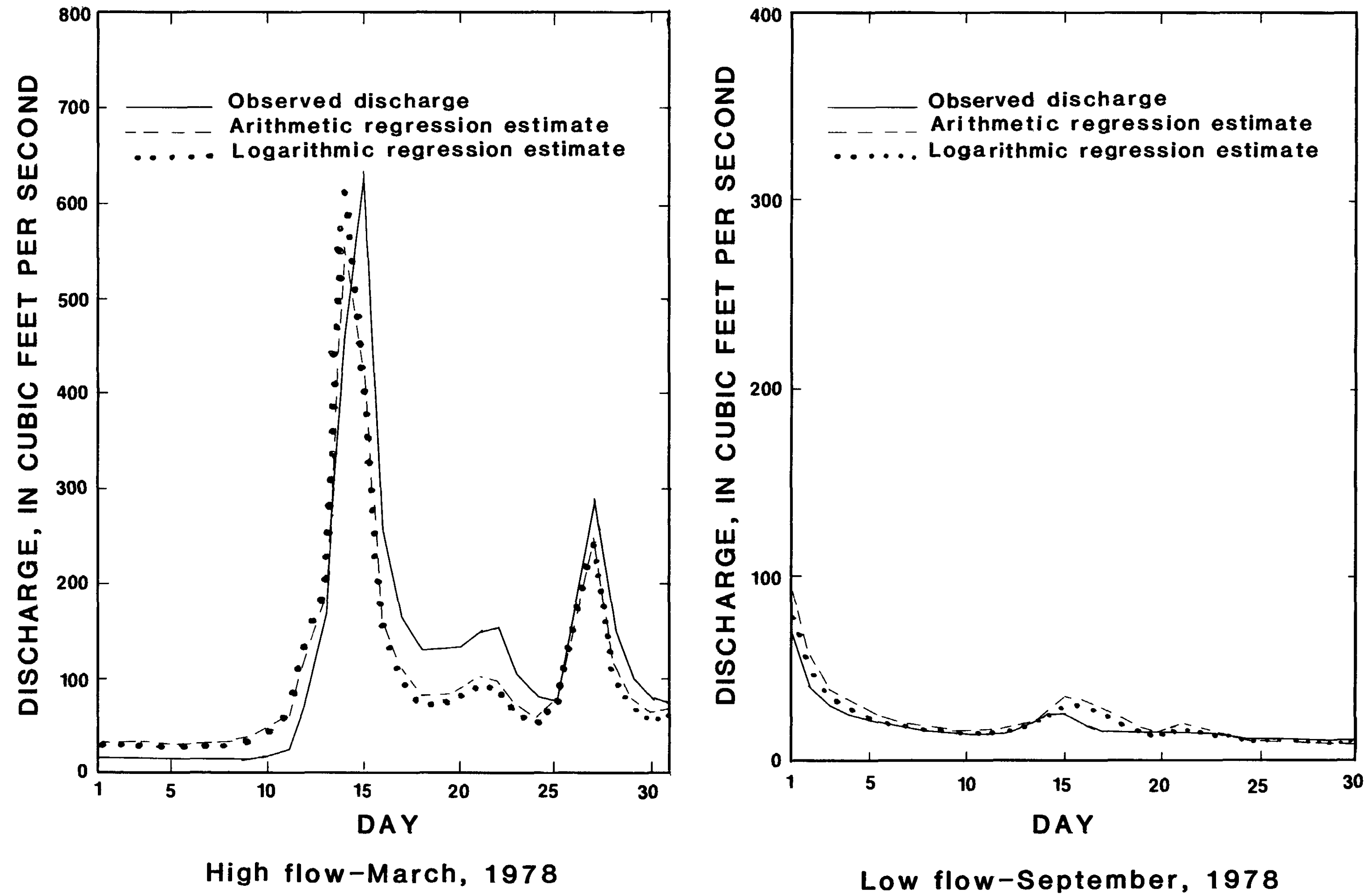


Figure 4.--Daily discharge hydrographs for Middle Branch Nimishillen Creek at Canton.

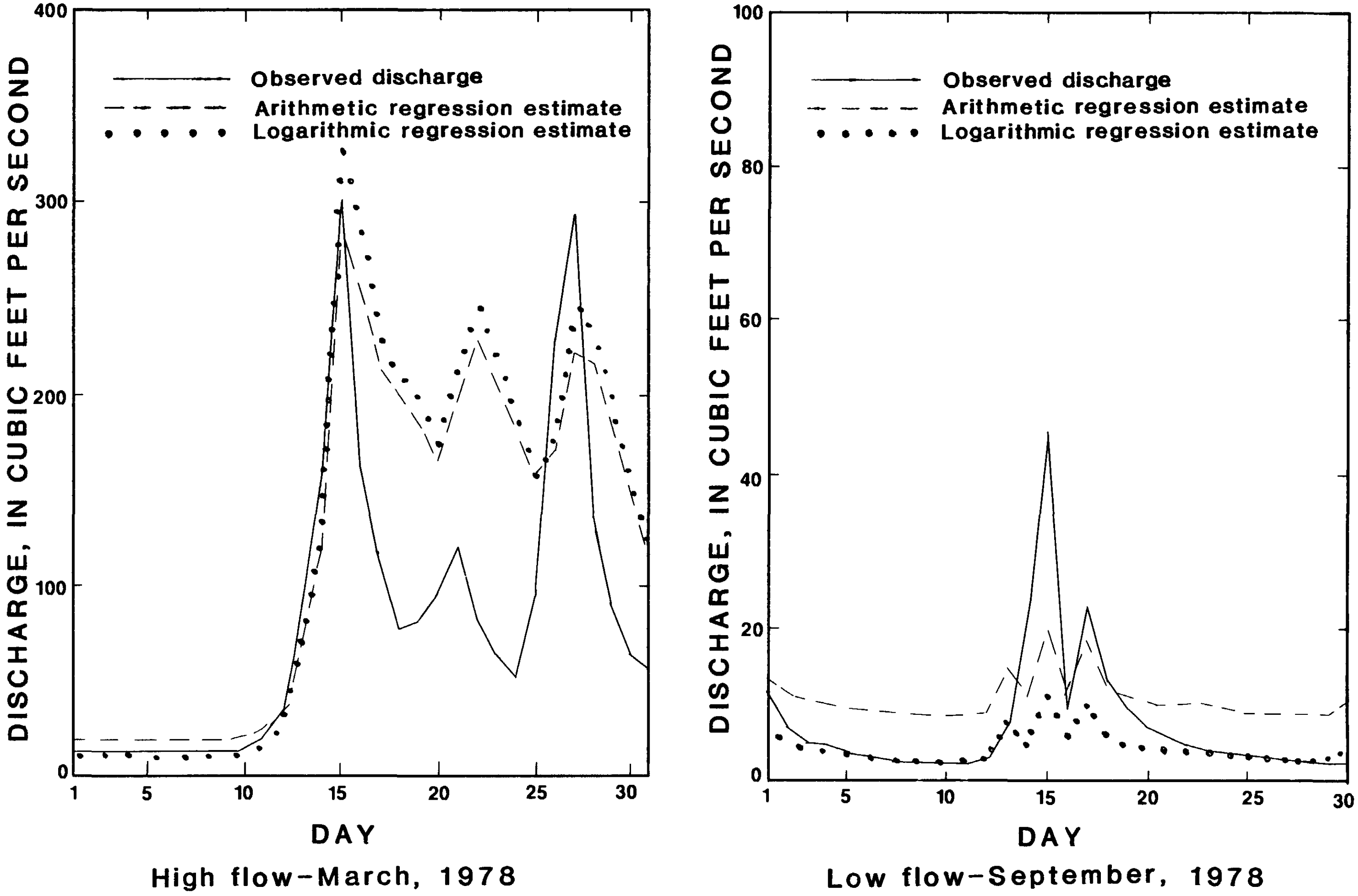


Figure 5.--Daily discharge hydrographs for Mill Creek near Coshocton.

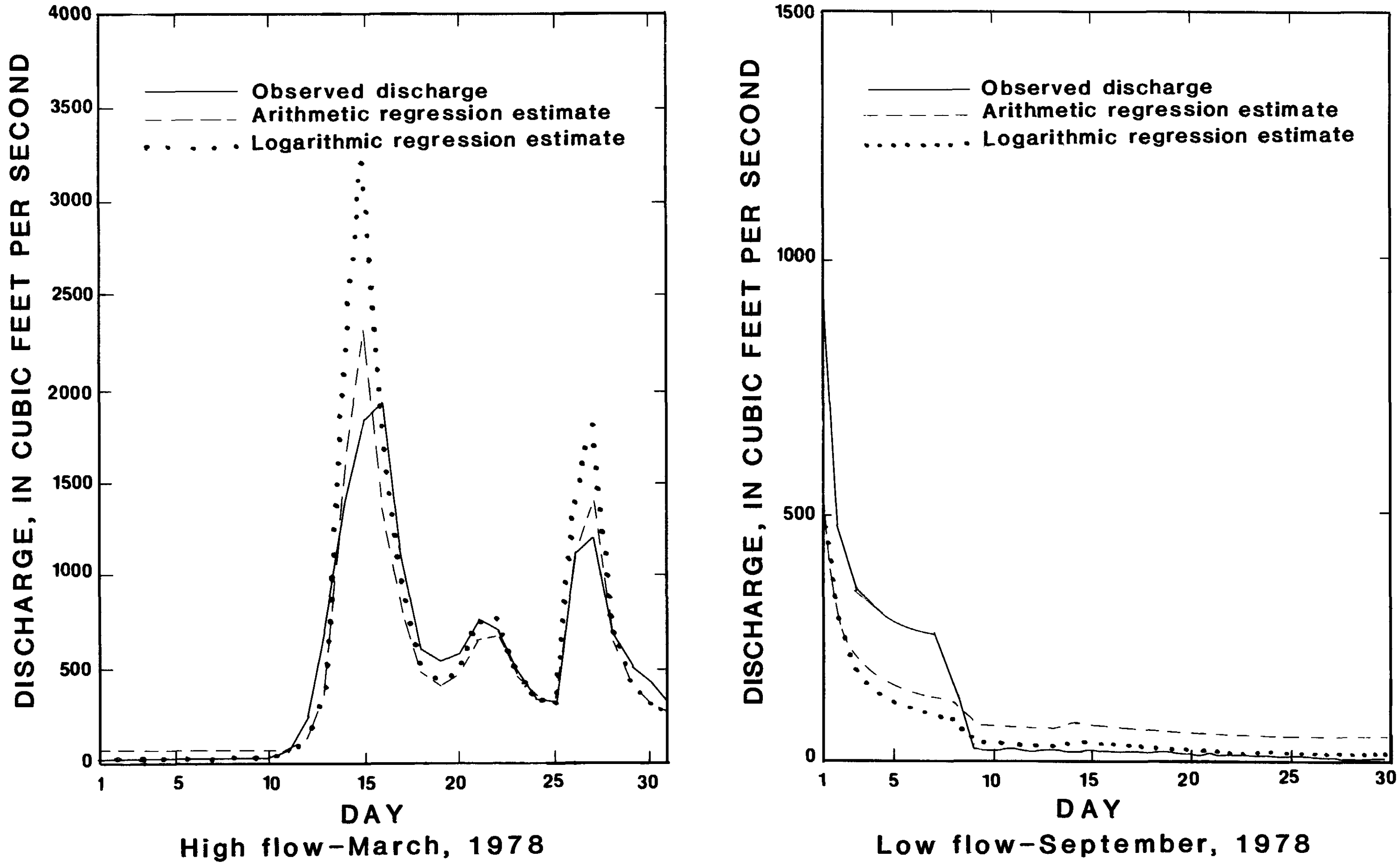


Figure 6.--Daily discharge hydrographs for South Fork Licking River near Hebron.

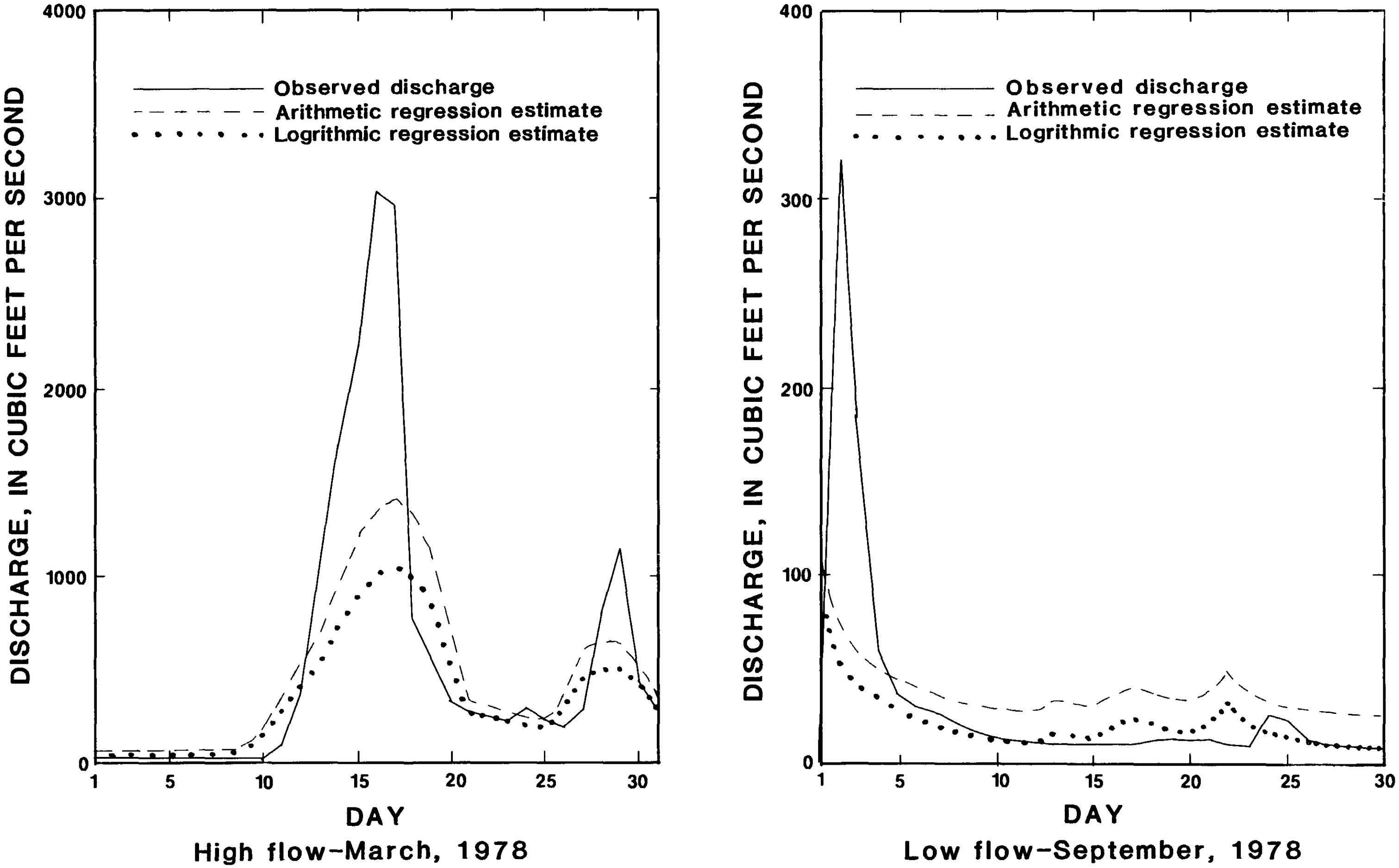


Figure 7.--Daily discharge hydrographs for Shade River near Chester.

evenly distributed throughout the range of flows, and from a statistical viewpoint, these two models were the only ones that did not seriously violate some of the underlying assumptions involved in linear least-squares regression analysis. A comparison of the observed and simulated flows during representative high- and low-flow periods are shown in figure 8.

The investigation of regression analyses as an alternate method for providing streamflows was unsuccessful at the four potential sites. The fifth site, Sugar Creek at Strasburg, with almost ideal conditions for modeling, was also an unsuccessful modeling effort. This indicates that simple linear regression models may not be a viable alternate method for estimating daily flows in Ohio, or the acceptance criteria may be too stringent.

Sugar Creek Flow-Routing Analysis

The flow-routing analysis investigated the potential for using a unit-response, single-linearization routing model to simulate mean daily discharges at Sugar Creek at Strasburg. The inflow station is Sugar Creek below Beach City Dam near Beach City, located 4.75 miles upstream.

The approach involved routing the flows from Beach City to Strasburg using the diffusion-analogy method with a single point of linearization. The 11-square-mile intervening area was simulated by adding an additional percentage of the flow at Beach City to the routed flow.

The flow-routing model had three parameters requiring calibration to achieve a best fit; the intervening-area multiplier (IAM), the wave celerity, C_o, and the wave-dispersion coefficient, K_o. The intervening area multiplier was estimated in two ways, one based on drainage area, the other based on long-term average flows. The coefficients C_o and K_o are theoretically related to the channel width (W_o) in feet, the channel slope (S_o) in feet per feet, the discharge (Q_o) in cubic feet per second, and the slope of the stage-discharge rating (dQ/dy) in square feet per second. The formulas are:

$$IAM = \frac{|X_1 - X_2|}{X_2}$$

where X_1 is the characteristic at the model site,

X_2 is the characteristic at the index site,

$$C_o = \frac{1}{W_o} \frac{\partial Q_o}{\partial y_o}, \text{ and}$$

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

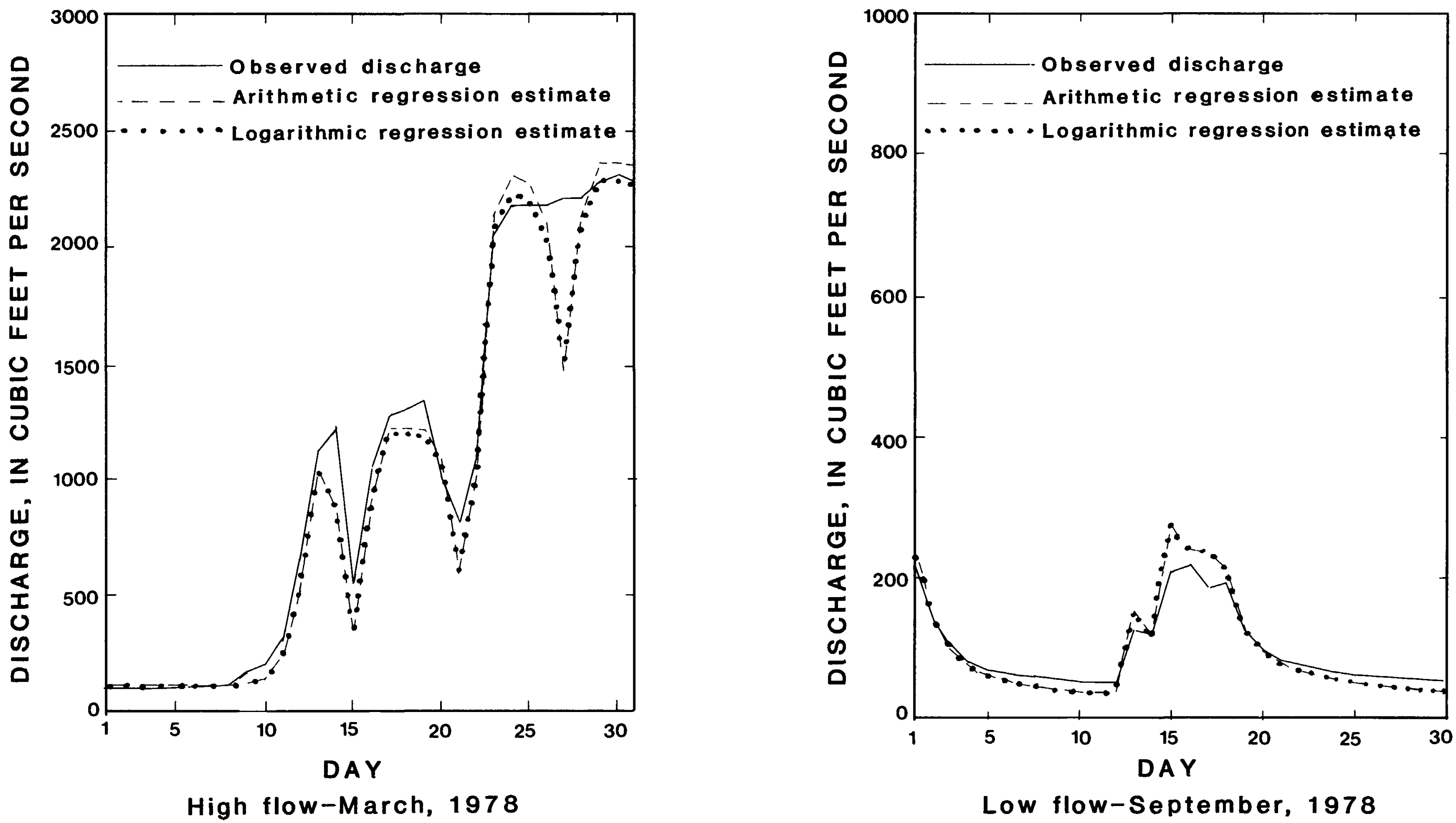


Figure 8.--Daily discharge hydrographs for Sugar Creek at Strasburg.

Initial values for IAM were calculated using published values for the drainage areas and the long-term average discharge at both sites. The results are given in table 4. Initial values for C_o and K_o were determined by measuring the characteristics at the long-term mean daily discharge which was used for Q_o. The channel width (W_o) was based on discharge-measurement notes and topographic maps to get an average for the reach. The channel slope, S_o, was determined by reducing the gage height of the mean flow at each gage to mean sea level datum to determine the elevation difference, and dividing that fall by the river distance between the two gages. The slope of the rating was computed from the rating table by computing the difference in discharge between a point 0.5 foot above and below the gage height of the average discharge. The reach characteristics and model parameters are listed in table 5.

Initially, the reach parameters were determined by averaging the computed values of C_o and K_o, which gives values of 3.30 and 1,625. The routing of hydrographs conserves mass while altering the timing characteristics of the flows. Therefore, the volume errors are controlled by the intervening-area multiplier, which can be adjusted to produce minimum volume error. Five calibrations were done with C_o and K_o fixed while using IAM values of .03, .06, .09, .12, and .15, which covered the expected range. Total volume errors ranged from a high of +8.41 percent when IAM was .15 to a minimum of -.08 percent when IAM equalled .06, which was used in the rest of the calibrations.

The calibration of C_o and K_o was done by doubling and halving the initial values and then trying all combinations of the three values of the two parameters for a total of nine calibration attempts.

The change in the model response was minimal for all nine calibrations, so the initial values were adopted as giving the best fit. It should be noted that the reason for this lack of sensitivity is due to the proximity of two sites, which combined with the daily routing period tended to produce a pure translation of the input hydrographs. The unit response had two values, .90 and .10 in six cases when C_o was 3.30 or 6.60, and about .80 and .20 when C_o was 1.65.

The errors in the routing model were the best of any of the alternate methods attempted, but they were still too high with only about 73 percent of the simulated flows being within 10 percent of the observed flows. This failure to meet acceptance criteria indicates that perhaps the constraints are too severe. The final model and an error summary are shown in table 6. Since the calibration period did not produce an acceptable model, there was no need for model verification. A comparison of observed and simulated flows during typical high- and low-flow periods is shown in figure 9.

Table 4.--Intervening-area multiplier for Sugar Creek flow-routing model

Site	Drainage area (mi2)	Average flow (ft^3/s)	Intervening-area multiplier	
			Drainage area	$\bar{Q}$
03124000	300	277	.04	.14
03124500	311	316		

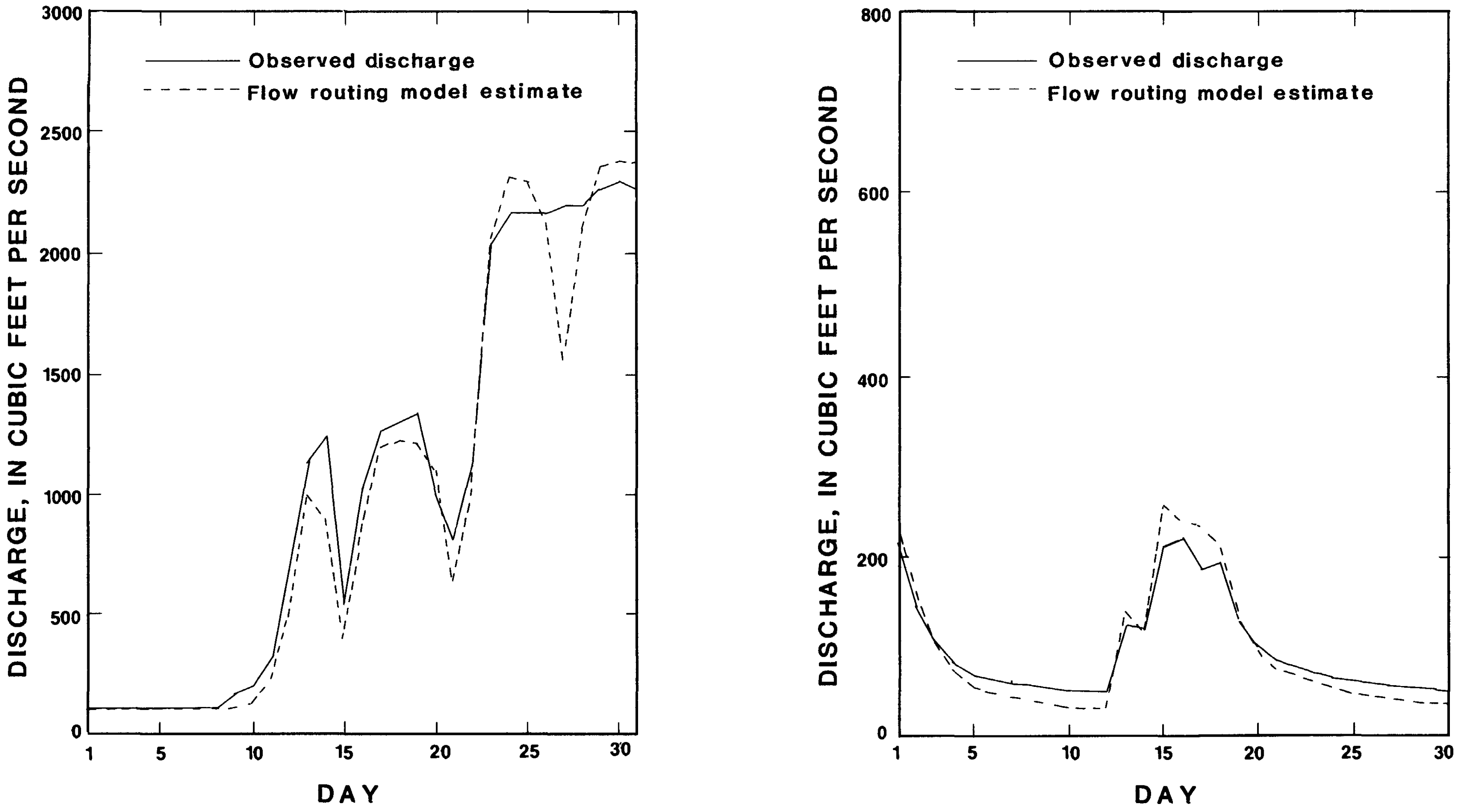
Table 5.--Reach characteristics for Sugar Creek flow-routing model

Site	Q_o (ft^3/s)	W_o (ft)	S_o (ft/ft)	$\frac{dQ_o}{dy_o}$ (ft^2/s)	C_o (ft/s)	K_o (ft^2/s)
031240 Sugar Creek below Beach City Dam near Beach City	277			230	2.88	1520
		80	1.14×10^{-3}			
031245 Sugar Creek at Strasburg	316			300	3.75	1730

Table 6.--Summary of routing model for mean daily discharge

Calibration period -- 10/01/76 to 09/30/79		
Mean error (percent) for 1095 days	=	7.57
Mean - error (percent) for 582 days	=	-8.23
Mean + error (percent) for 518 days	=	6.82
Q_1 volume (second-feet per day)	=	411,955
Q_2 volume (second-feet per day)	=	412,284
Volume error (percent)	=	-0.08
RMS error (percent)	=	10.59

45 percent of total observations had errors	$\leq$	5 percent
73 percent of total observations had errors	$\leq$	10 percent
87 percent of total observations had errors	$\leq$	15 percent
94 percent of total observations had errors	$\leq$	20 percent
96 percent of total observations had errors	$\leq$	25 percent
4 percent of total observations had errors	$>$	25 percent



High flow–March, 1978

Low flow–September, 1978

Figure 9.--Daily hydrographs showing observed discharges and discharges estimated by flow-routing model, Sugar Creek at Strasburg, Ohio.

Conclusions Pertaining to Alternative Methods of Data Generation

Alternative methods of producing mean daily discharges were investigated at five sites in Ohio. Four of the sites had no existing stations upstream from them, therefore, regression analysis was the only method investigated. Two models were developed at each site (arithmetic- and log-transformed); however, none of the models met the overall acceptance criteria by simulating at least 85 percent of the flows within 10 percent of the observed values. Additionally, they all exhibited a bias in the low-flow range where the models tended to overpredict.

The fifth site selected was not a candidate for exclusion from the network, but was thought to be an ideal site for successful regression analysis and flow routing model building. Results were the best of any of the models attempted, but errors were still greater than the specified acceptance criteria.

Overall, alternate methods of providing streamflow data cannot be suggested for any sites in Ohio. The four potential sites will remain in operation and will be included in the next phase of the network analysis.

COST EFFECTIVE RESOURCE ALLOCATION

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

A set of techniques called Kalman filtering for cost effective resource allocation (K-CERA) was developed in a study of the cost effectiveness of a network of stream gages operated to determine water consumption in the lower Colorado River basin (Moss and Gilroy, 1980). Because of the water-balance nature of that study, the measure of effectiveness of the network was chosen to be the minimization of the sum of variances of errors of estimation of annual mean discharges at each site in the network. This measure of effectiveness tends to concentrate stream-gaging resources on the larger, less stable streams where potential errors are greatest.

Although such a tendency is appropriate for a water-balance network, this tendency causes undue concentration on the larger streams considering the broader context of the multitude of uses of the streamflow data collected in the Survey's Streamflow Information Program. Therefore, the original version of K-CERA was extended to include additional variables as optional measures of effectiveness. These variables are the sums of the variances of errors of estimation of 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 of the instantaneous discharges at all continuously gaged sites as the measure of the effectiveness of the data-collection activity.

The original version of the K-CERA 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 application of Kalman filtering (Gelb, 1974) to the determination of the accuracy of a stream-gaging record are presented below. Details on the theory and the applications of K-CERA are presented in Moss and Gilroy (1980) and Gilroy and Moss (1981).

Description of Mathematical Program

The program, called "The Traveling Hydrographer," attempts to allocate among stream gages a predefined budget for the collection of streamflow data in such a manner that the field operation is the most cost-effective possible. The measure of effectiveness is discussed above. The set of decisions available to the manager is the frequency of use (number of times per year) of each of a number of routes that may be used to service the stream gages and to make discharge measurements. The range of options within the program is from zero usage to daily usage for each route. A "route" is defined as a set of one or more stream gages and the least-cost travel that takes the hydrographer from his base of operations to each of the gages and back to base. A route will have associated with it an average cost of travel and average cost of servicing each stream gage visited along the way.

The first step in this part of the analysis is to define the set of practical routes. This set of routes frequently will contain the path to an individual stream gage with that gage as the lone stop and return to the home base so that the individual needs of a stream gage can be considered in isolation from the other gages.

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

The final step is to use all of the above to determine the number of times, N_i , that the i^{th} route for i=1,2,...,NR, where NR is the number of practical routes, is used during a year such that (1) the budget for the network is not exceeded, (2) the minimum number of visits to each station is made, and (3) the total uncertainty in the network is minimized. Figure 10 represents this step in the form of a mathematical program. Figure 11 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, (W_{ij}) defines the routes in terms of the stations that comprise it. A value of one in row i and column j indicates the gaging station 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 the vehicles. The sum of the products, β_i and N_i for i=1,2,..., NR is the total travel cost associated with the set of decisions $\underline{N}=(N_1, N_2,...,N_{NR})$.

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=1, 2, ...,MG specifies the number of visits to each station. M is the sum of the products of ω_{ij} and N_i for all i and must equal or exceed λ_j for all j if $\underline{N}$ is to be a feasible solution to the decision problem.

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

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

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

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

$V \equiv$ total uncertainty in the network

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

$MG \equiv$ number of gages in the network

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

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

Such that

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

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

$F_c \equiv$ fixed cost

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

$NR \equiv$ number of practical routes chosen

$\beta_i \equiv$ travel cost for route i

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

and such that

$$M_j \geq \lambda_j$$

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

Figure 10.--Mathematical-programing form of the optimization of the routing of hydrographers.

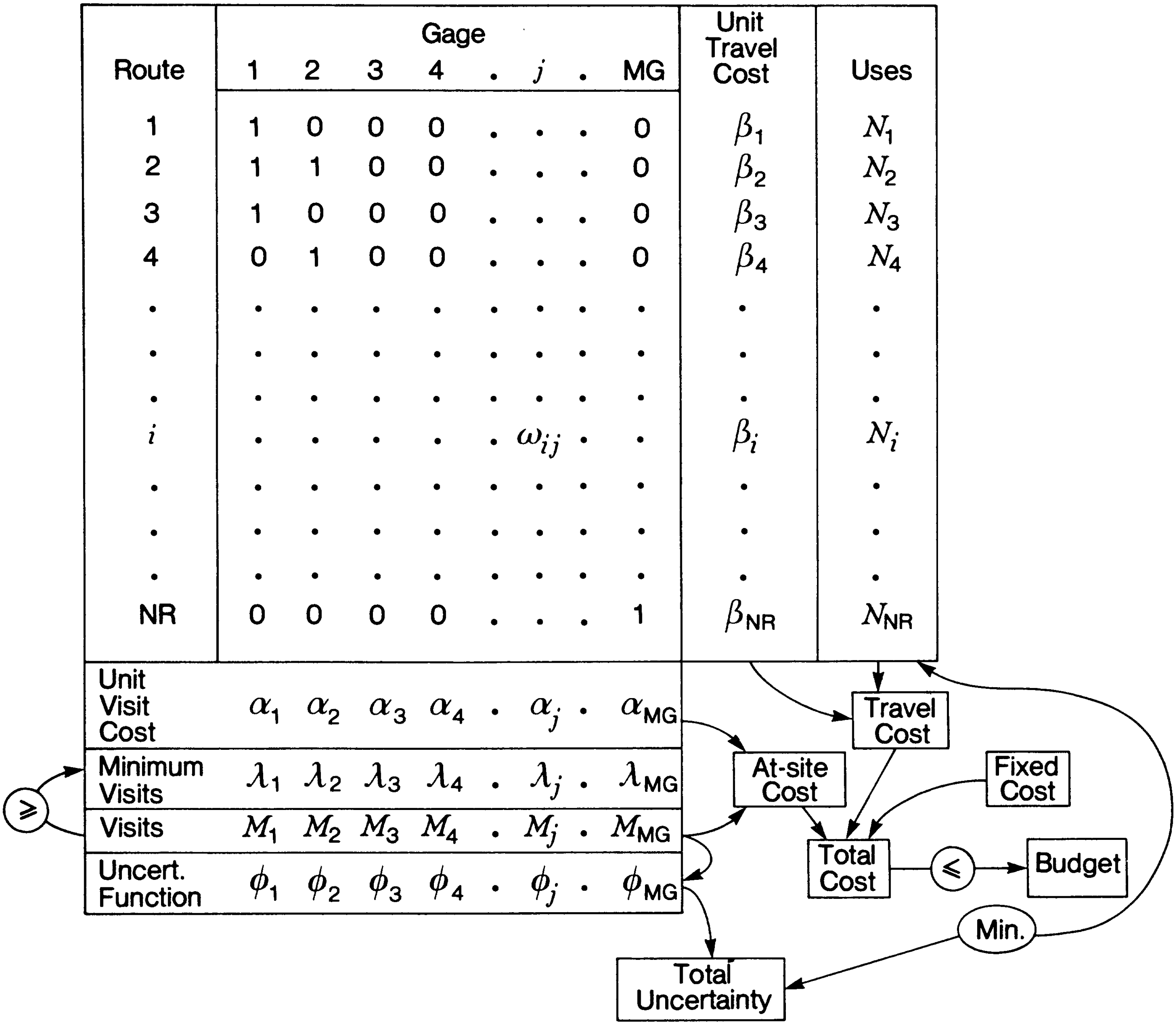


Figure 11.--Tabular form of the optimization of the routing of hydrographers.

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 variance of the estimates of flow that would be employed in each situation were weighted by the fraction of time each situation is expected to occur. Thus the variance would be

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

with $1 = \varepsilon_f + \varepsilon_r + \varepsilon_e$ (3)

where

- $\tilde{V}$ is the average relative variance of the error 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 the time secondary data are available to reconstruct streamflow record given that the primary data are missing,
- V_r is the relative variance of the errors of estimation of flow 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 fraction of the time that each source of error is relevant is a function of the frequency at which the recording equipment is serviced.

The time, t, 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

$$f(t) = ke^{-kt}/(1-e^{-ks}) \quad (4)$$

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,

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

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

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

It then follows that

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

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

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

$$\varepsilon_r = 1 - \varepsilon_f - \varepsilon_e$$

$$= [(1-e^{-ks}) + 0.5\ (1-e^{-2ks})] / (ks) \quad (6)$$

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

Then $$x(t) = \ln q_T(t) - \ln q_R(t) = \ln [q_T(t)/q_R(t)] \quad (7)$$

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 better estimate of the stream's discharge at time t. The difference between the variable $\hat{x}(t)$ which is defined

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

and 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 the measured discharge from the rating curve be z(t) so that

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

where

v(t) is the measurement error, and

$\ln q_m(t)$ is the logarithm of the measured discharge 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 refered to as process variance) equal to p. A second important parameter is β, the recriprocal of the correlation time of the Markovian process giving rise to x(t); the correlation between $x(t_1)$ and $x(t_2)$ is $\exp[-\beta/t_1-t_2/]$. Fontaine and others (1983) also define q, the constant value of the spectral density function of the white noise which drives the Gauss-Markov x-process. The parameters, p, q, and β are related by

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

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

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

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

where

σ_i is the standard deviation of daily discharges for the ith day of the year,

μ_i is the expected value of discharge on the ith day of the year, and

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

The variance V_r of the relative error during periods of reconstructed streamflow records is estimated on the basis of correlation between records at the primary site and records from other nearby sites. The correlation coefficient between the streamflows with seasonal trends removed at the site of interest and determined streamflows at the other sites is a measure of the goodness of their linear relationship. The fraction of the variance of the streamflow at the primary site that is expected by the 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

$$V_r = \left(1-\rho_c^2\right)\bar{C}_v^{\,2} \quad (13)$$

Because errors in streamflow estimates arise from three different sources with widely varying precisions, the resultant distribution of these errors may differ significantly from a normal or log-normal distribution. This lack of normality causes difficulty in interpretation of the resulting average estimation variance. When primary and secondary data are unavailable, the relative error variance V_e may be very large. This could yield correspondingly large values of $\bar{V}$ in equation (3) even if the probability that the 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 analysis. If it is assumed that the various errors arising from the three situations represented in equation (3) are log-normally distributed, the value EGS is determined by the probability statement that

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

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

The Application of K-CERA in Ohio

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 Ohio be continued in operation. All of these stream gages were subjected to the K-CERA analysis with results that are described below. The following sections describe the methodology of some of the input to the program as well as the results.

Definition of Network Boundaries

The Ohio network was divided into 2 parts; (1) those stations run by another agency and (2) those stations for which the U.S. Geological Survey handles the field work.

1. MCD Area.--The Miami Conservancy District (MCD) handles the field work for 19 stations in their area. These stations are independent of the rest of the network. As the network is integrated with MCD's other duties, the stations covered by MCD were not considered in the K-CERA analysis.

2. New Philadelphia and Columbus offices of the U.S. Geological Survey.--The New Philadelphia office handles 52 gages in the eastern part of the State. The gages have been grouped into the first 87 routes for analysis.

3. Columbus.-- The Columbus office covers the rest of the State's 55 gages. The gages have been grouped into 97 routes, numbered 88 to 184 for analysis.

The number of stations and areas handled by the Columbus and New Philadelphia offices of the U.S. Geological Survey are determined both by basin boundaries and the relative overall workload of the individual office. With the reduction of coal-related studies in 1981 some of the stations formerly handled by the Columbus office were given to New Philadelphia. The program emphasis could change; if so, those stations might be given back to the Columbus office. Evaluation of Ohio's gaging-station network must be tempered by workload and management considerations. The network is being analyzed as of June 30, 1984.

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 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. To estimate 1/k in Ohio, a period of actual data collection was used (3 years) in which little change in technology occurred and in which stream gages were visited on a consistent pattern of frequency. During this period, the percent of time a gage malfunctioned or produced poor stage record was noted. Gages varied in the amount of lost record (the overall average was about 8 percent), therefore, values were determined for each station. The percentage of lost record with a bi-monthly visit frequency was used to determine a value of 1/k of 365 days, which was used to determine ε_f, ε_r, and ε_e for each of the stream gages as a function of the individual frequencies of visits.

Definition of Cross-Correlation Coefficient and Coefficient of Variation

To compute the values of V_e and V_r of the needed uncertainty functions, daily streamflow records for each of the 107 stations for the last 30 years or a 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 three 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 P_c. For the three stations that had less than three water years of data, values of C_v and P_c were estimated subjectively. In addition to other nearby stream gages, some of the stations had other means by which streamflow 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 a day. Generally, if a station has telemetry, the P_c was increased. Even with telemetry, however, each gage was modified differently based on the degree of telemetry. A phone line might be queried only infrequently, whereas a GOES (Geostationary Observational Environmental Satellite) station generally has a 3-hour reporting time. Also considered was the "independance" of the telemetry. The telemetry may be hooked directly to the gage (especially if a manometer); when the gage malfunctions, so does the telemetry. At other locations, a local resident is hired to read and record stage at the station once or twice daily. At 45 sites, an auxiliary recorder is operated at the station to provide backup stage record.

Analyses were performed to determine cross correlations, p_c, between daily discharges at sites with one or another of these types of auxiliary recorders. A set of parameters for each station and the auxiliary records that gave the highest cross correlation coeficient are listed in table 7.

Kalman-Filter Definition of Variance

The determination of V_f for each of the 107 stream gages requires the execution of three distinct steps: (1) Long-term rating analysis and computations of residuals of measured discharges from the long-term rating, (2) time-series analysis of the residuals to determine the input parmeters of the Kalman-filter streamflow records, and (3) computation of the error variance, V_f, as a function of the time-series parameters, the discharge-measurement-error variance, and the frequency of discharge measurement.

In the Ohio program analysis, definition of long-term rating functions was complicated by the fact that many stream gages in Ohio are characterized predominantly by open-water periods with relatively short winter backwater ice periods. As a result of these characteristics, a single rating function to define the entire year is not feasible. Of 107 stations included for analysis, most have both an open and ice-backwater period. The rating analysis covers the open periods only. The methodology for accounting for the ice periods are covered under fixed costs.

Most ratings were determined by computer using the form

in which $LQM = B_1 + B_3 * \log (GHT - B_2)$

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

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

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

B2 is the gage height of zero flow, and

B3 is the slope of the rating curve.

Ratings which did not fit the form LQM = B1 + B3 * log (GHT - B2) were fit graphically.

Table 7.--Statistics of record reconstruction

[C_v, coefficient of variance; P_c, cross correlation between independent and dependent stations]

Station number	Percent missing record	C_v	P_c	Source of reconstructed record
03086500	5	1.64	0.735	03117000
03090500	<2	1.10	.93	Supplemental recorder.
03091500	<2	1.02	.93	Supplemental recorder.
03092000	5	2.48	.770	03086500
03092090	<2	1.46	.756	03093000 Telemetry.
03092460	<2	.919	.537	Supplemental recorder.
03093000	<2	1.49	.96	Supplemental recorder, Observer; read weekly.
03094000	6	.932	.80	Observer; Telemetry-weekly.
03095500	<2	1.46	.93	Supplemental recorder.
03099500	5	.883	.929	03094000
03102950	2	1.38	.93	Supplemental recorder.
03109500	<2	1.33	.96	Supplemental recorder, GOES.
03110000	2	1.40	.93	Supplemental recorder.
03111500	20	1.12	.99	Supplemental recorder, Observer; read daily.
03114000	10	1.73	.752	03111500
03117000	2	1.20	.96	Observer; read daily.
03117500	5	1.23	.891	03109500
03118000	10	1.37	.896	03118500
03118500	5	.980	.896	03118000
03120500	<2	1.37	.93	Supplemental recorder.
03122500	5	.897	.93	Telemetry; read daily.
03124000	<2	1.53	.969	Supplemental recorder.

Table 7.--Statistics of record reconstruction--Continued

Station number	Percent missing record	C_v	P_c	Source of reconstructed record
03124500	5	1.43	.969	Supplemental recorder.
03126000	<2	1.25	.93	Supplemental recorder
03127000	<2	1.34	.970	Supplemental recorder, Telemetry.
03127500	<2	1.29	.99	Supplemental recorder, Telemetry; read daily.
03128500	<2	1.61	.93	Supplemental recorder.
03129000	<2	.928	.99	Supplemental recorder, Telemetry; read daily.
03130000	<2	1.29	.93	Supplemental recorder.
03131500	15	.917	.93	Supplemental recorder.
03133500	<2	1.06	.93	Supplemental recorder.
03135000	<2	1.50	.93	Supplemental recorder.
03136500	9	1.38	.796	03223000
03138500	<2	1.03	.93	Supplemental recorder.
03139000	2	1.32	.96	Telemetry; read daily.
03140000	<2	1.79	.93	Supplemental recorder.
03140500	<2	.920	.986	Supplemental recorder, Telemetry; read daily.
03141500	<2	1.65	.93	Supplemental recorder.
03142000	5	1.49	.99	Supplemental recorder, Telemetry; read daily.
03143500	<2	1.35	.93	Supplemental recorder.
03144000	3	1.63	.796	03140000
03144500	5	.945	.986	Telemetry; read daily.
03145000	10	1.45	.841	03146500

Table 7.--Statistics of record reconstruction--Continued

Station number	Percent missing record	C_v	P_c	Source of reconstructed record
03146500	2	1.48	.96	Telemetry; read daily.
03147500	<2	1.36	.96	Supplemental recorder.
03150000	5	.940	.984	Telemetry; read daily.
03157000	24	1.37	.901	03157500
03157500	11	1.41	.901	03157000
03159510	5	1.02	.96	Telemetry; read daily.
03159540	4	1.69	.670	03202000
03202000	3	1.62	.705	03157500
03219500	11	1.81	.940	03221000
03219590*	<2	1.9	.88	03220000
03220000	2	2.19	.782	03221000
03221000	3	1.79	.940	03219500 Telemetry.
03223000	13	1.99	.780	03221000
03225500	3	1.85	.96	Supplemental recorder, Telemetry.
03226800	9	1.68	.919	03225500 Telemetry.
03227500	4	1.44	.925	03221000
03228500	<2	1.36	.747	03229500
03228805	<2	2.08	.99	Supplemental recorder, Telemetry.
03229000	2	1.92	.880	03229500
03229500	19	1.68	.880	03229000
03230500	17	1.72	.865	03231500
03230900	<2	1.44	.96	Supplemental recorder.
03231000	8	1.61	.931	03230900 Telemetry.

Table 7.--Statistics of record reconstruction--Continued

Station number	Percent missing record	C_v	P_c	Source of reconstructed record	
03231500	3	1.31	.99	Supplemental recorder, Telemetry.	
03232470	2	1.49	.884	03234000	
03232500	13	1.58	.804	03234000	Telemetry.
03234000	<2	1.66	.99	Supplemental recorder, Telemetry; read daily.	
03234500	<2	1.26	.976	Telemetry, GOES.	
03237280	4	1.97	.743	03237500	
03237500	3	2.16	.875	03234500	03238500
03238500	9	2.43	.870	03234500	03237500
03240000	7	1.39	.952	03241500	
03241500	9	1.59	.939	03240000	
03245500	<2	1.56	.96	Telemetry; read daily.	
03247050	<2	1.86	.910	03247500	
03247500	<2	2.10	.910	03247050	
03255500	7	1.84	.951	03259000	
03259000	15	1.87	.974	03255500	
03260700	2	1.17	.868	03261500	03261950
03261500	4	1.51	.948	03262000	03262700
03261950	2	2.10	.910	03261500	03262000
03262000	2	2.20	.940	03261500	03261950
03262700	<2	1.55	.949	03263000	
03263000	<2	1.52	.966	03270500	Telemetry.
03264000	3	1.51	.958	03265000	

Table 7.--Statistics of record reconstruction--Continued

Station number	Percent missing record	C_v	P_c	Source of reconstructed record
03265000	2	1.82	.99	Supplemental recorder, Telemetry.
03266000	5	1.72	.927	03265000
03267000	<2	.830	.910	03267900
03267900	<2	.739	.933	03267000 03269500
03269500	11	.910	.96	Telemetry; read daily.
03270000	3	.914	.99	Supplemental recorder, Telemetry; read daily.
03270500	3	1.32	.99	Supplemental recorder, Telemetry; read daily.
03270800	4	1.81	.886	03262000 03271800
03271500	3	1.22	.96	Supplemental recorder.
03271800	4	1.74	.942	03272000 03272700
03272000	9	1.85	.924	03271800
03272700	4	1.39	.868	03271800 Telemetry
03274000	<2	1.21	.99	Supplementary recorder, Telemetry; read daily, GOES.
04177000	32	1.24	.575	04189000
04185000	5	1.50	.96	Telemetry; read daily.
04186500	10	1.93	.844	04191500
04189000	4	2.12	.96	Telemetry; read daily.
04191500	10	1.97	.96	Telemetry; read daily.
04192500	4	1.64	.972	04193500 Telemetry.
04193500	5	1.63	.972	Telemetry; read daily, GOES.

Table 7.--Statistics of record reconstruction--Continued

Station number	Percent missing record	C_v	P_c	Source of reconstructed record
04195500	4	2.18	.804	04198000 Telemetry.
04196800	8	2.00	.857	04198000
04197020	7	1.03	.696	04197100
04197100	10	1.36	.696	04197020
04197170*	11	1.2	.70	04197020
04198000	2	1.94	.857	04196800
04200430*	5	1.8	.93	Supplemental recorder.
04200500	10	2.01	.93	Supplemental recorder. Observer; read weekly.
04201500	5	1.82	.823	04200500
04202000	5	1.01	.842	04206000
04206000	<2	.932	.99	Supplemental recorder, Telemetry; read daily.
04207200	5	1.38	.872	04208000
04208000	2	1.08	.99	Supplemental recorder. Telemetry; read daily.
04208502	8	1.19	.80	Observer; read weekly.
04208690	8	1.19	.80	04208502, 04209000.
04209000	2	1.47	.96	Supplemental recorder, Telemetry; read daily.
04212100	2	1.25	.93	Supplemental recorder.
04213000	10	1.86	.93	Supplemental recorder.

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

Once a base rating curve has been defined for a particular gaging station, the next step is to compute the time series of residuals (difference between the measured and rated discharge) about this curve. Residual data for 4 selected station are presented in tables 8 through 11. The time series of residuals is used to compute sample estimates of Q and B, 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 of standard error. For the Ohio program, all open-water measurements were assumed to have a measurement error of 5 percent.

As discussed earlier, q and β can be expressed as the process variance of the shift from the rating curve and the 1-day autocorrelation coefficient of these shifts. Table 12 presents a summary of the autocovariance analysis expressed in the terms of process variance and 1-day autocorrelation. Typical fits of the covariance functions for selected stations in Ohio are given in figures 12-15.

The autocovariance parameters, summarized in table 12, and data from the definition of missing-record probabilities, summarized in table 7, 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 figures 16. These functions are based on the assumption that a measurement was made during each visit to the station.

Travel

Route Selection and Cost

In Ohio, feasible routes to service the 107 stream gages were determined after consultation with personnel in the hydrologic data section and after review of the uncertainty functions. In summary, 184 routes were selected to service all of the network stations (crest-stage gages, ground-water wells, and monitors) as well as stream gages in Ohio. These routes include all possible combinations that describe the current operating practice, alternatives that were under consideration as future possibilities, routes that visit 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 13.

Table 8.--Residual data for station 03092000, Pricetown

Observation number	Measurement number	Date	Measured discharge (ft^3/s)	Predicted discharge (ft^3/s)	Percent error
1	403	June 11, 1975	4.75	1.57	202.55
..	...				
40	446	June 27, 1980	0.84	.54	55.56
41	447	Aug. 20, 1980	4.37	15.0	-70.86
42	448	Aug. 26, 1980	4.45	5.25	-15.24
43	449	Oct. 28, 1980	4.59	30.8	-85.10
44	450	Dec. 11, 1980	32.0	41.5	-22.89
45	451	Feb. 20, 1981	324	221	46.61
46	452	Feb. 23, 1981	87.7	32.5	169.85
47	453	Apr. 13, 1981	277	152	88.23
48	454	June 10, 1981	70.9	21.0	237.62
49	455	June 18, 1981	5.62	3.06	83.66
50	456	July 29, 1981	4.40	5.36	-17.91
51	457	July 29, 1981	4.50	2.99	50.50
52	458	Sep. 16, 1981	0.34	4.93	93.10
53	459	Oct. 8, 1981	1.91	10.8	-82.31
54	460	Dec. 10, 1981	11.3	25.5	-55.69
55	461	Feb. 25, 1982	28.4	8.32	241.35
56	462	Apr. 15, 1982	11.5	4.32	166.20
57	463	June 23, 1982	2.43	2.05	18.54
58	464	Aug. 10, 1982	0.73	1.48	-50.68
59	465	Oct. 4, 1982	0.28	2.11	-86.73
60	466	Oct. 20, 1982	0.31	2.65	-88.30

Table 9.--Residual data for station 03144500, Dresden

Observation number	Measurement number	Date	Measured discharge (ft^3/s)	Predicted discharge (ft^3/s)	Percent error
1	476	Feb. 1, 1973	9900	9620	2.91
..	...				
40	516	June 1, 1979	14300	14000	2.14
41	517	Aug. 1, 1979	5290	5330	-0.75
42	518	Oct. 1, 1979	18900	18400	2.72
43	519	Dec. 3, 1979	8380	8990	-6.79
44	520	Feb. 1, 1980	3730	3530	5.67
45	521	Apr. 1, 1980	21700	22000	-1.36
46	522	June 3, 1980	22000	23100	-4.76
47	523	Aug. 1, 1980	12000	11900	0.84
48	524	Oct. 2, 1980	2370	2460	-3.66
49	525	Dec. 1, 1980	6410	7000	-8.43
50	526	Dec. 10, 1980	8620	9150	-5.79
51	528	Apr. 1, 1981	4940	5430	-9.02
52	529	June 1, 1981	9980	10400	-4.04
53	530	Aug. 3, 1981	3340	3580	-6.70
54	531	Oct. 1, 1981	1370	1570	-12.74
55	532	Dec. 1, 1981	3160	3270	-3.36
56	533	Feb. 1, 1982	25300	26000	-2.69
57	534	Apr. 1, 1982	13400	13700	-2.19
58	535	June 1, 1982	3700	3860	-4.15
59	536	Aug. 2, 1982	1340	1400	-4.29
60	537	Oct. 4, 1982	1040	1110	-6.31

Table 10.-- Residual data for station 03225500, Delaware

Observation number	Measurement number	Date	Measured discharge (ft^3/s)	Predicted discharge (ft^3/s)	Percent error
1	491	Mar. 8, 1972	231	223	3.59
..	...				
39	532	Nov. 10, 1977	7.80	8.61	-9.41
40	533	Jan. 4, 1978	24.0	22.3	7.62
41	534	Mar. 14, 1978	292	279	4.66
42	535	May 3, 1978	133	141	-5.67
43	536	Aug. 3, 1978	37.2	42.5	-12.47
44	537	Oct. 6, 1978	17.4	19.4	-10.31
45	538	Nov. 3, 1978	19.8	21.1	-6.16
46	539	Dec. 27, 1978	61.2	68.4	-10.53
47	540	Mar. 8, 1979	4460	4420	0.90
48	541	Aug. 15, 1979	37.7	41.4	-8.94
49	542	Oct. 24, 1979	44.6	58.6	-21.48
50	543	Jan. 30, 1980	114	132	-13.64
51	544	June 27, 1980	67.8	66.6	1.80
52	546	Oct. 20, 1980	17.5	18.3	-4.37
53	547	Dec. 22, 1980	55.0	52.5	4.76
54	548	Feb. 3, 1981	1200	1270	-5.51
55	549	Apr. 3, 1981	20.8	19.4	7.22
56	550	June 26, 1981	1130	1180	-4.24
57	551	Aug. 12, 1981	40.7	39.2	3.83
58	552	Oct. 1, 1981	20.2	19.9	1.51

Table 11.--Residual data for station 03237280, McGaw

Observation number	Measurement number	Date	Measured discharge (ft^3/s)	Predicted discharge (ft^3/s)	Percent error
1	210	Sep. 14, 1976	0.30	6.29	-95.23
..	...				
36	250	Dec. 5, 1979	10.9	4.01	171.82
37	251	Jan. 9, 1980	7.73	2.77	179.06
38	253	Mar. 4, 1980	10.9	3.67	197.00
39	254	Apr. 7, 1980	18.9	6.29	200.48
40	255	May 6, 1980	9.24	3.51	163.25
41	256	June 10, 1980	4.14	1.44	187.50
42	257	June 18, 1980	2.95	1.05	180.95
43	258	July 7, 1980	2.24	0.79	183.54
44	259	Aug. 11, 1980	0.54	0.28	92.86
45	260	Sep. 10, 1980	4.64	1.62	186.42
46	261	Oct. 21, 1980	0.03	0.07	-57.14
47	262	Nov. 3, 1980	0.19	0.14	35.71
48	263	Dec. 10, 1980	12.5	4.19	198.33
49	266	Mar. 10, 1981	11.0	3.67	199.73
50	267	Apr. 6, 1981	34.0	12.5	172.00
51	268	May 4, 1981	7.30	2.77	163.54
52	269	June 2, 1981	12.7	4.38	189.95
53	270	July 7, 1981	2.92	1.35	116.30
54	271	Aug. 4, 1981	0.23	0.07	228.57
55	272	Sep. 1, 1981	0.03	0.03	0.00
56	273	Oct. 21, 1981	0.02	0.07	-71.43
57	275	Dec. 9, 1981	0.12	0.16	-25.00

Table 12.--Summary of the autocovariance analysis

Station no.	Station name	Rho*	Measurement variance (log base e)	Process variance (log base e)	Length of period (days)
03086500	Mahoning River at Alliance	0.977	0.0025	0.068	361
03090500	Mahoning River near Berlin Center	.636	.0025	.0059	365
03091500	Mahoning River at Pricetown	.926	.0025	.031	365
03092000	Kale Creek near Pricetown	.985	.0025	1.36	365
03092090	West Br Mahoning River near Ravenna	.992	.0025	.90	320
03092460	West Br Mahoning River at Wayland	.912	.0025	.036	365
03093000	Eagle Creek at Phalanx Statíon	.990	.0025	.140	320
03094000	Mahoning River at Leavittsburg	.821	.0025	.0081	365
03095500	Mosquito Creek near Cortland	.983	.0025	.0081	365
03099500	Mahoning River at Lowellville	.985	.0025	.0037	365
03102950	Pymatuning Creek at Kinsman	.974	.0025	.365	320
03109500	Little Beaver Creek near East Liverpool	.682	.0004	.0021	320
03110000	Yellow Creek at Hammondsville	.993	.0025	.033	320
03111500	Short Creek near Dillonvale	.992	.0025	.180	320
03114000	Captina Creek at Armstrongs Mills	.979	.0025	.060	320
03117000	Tuscarawas River at Massillon	.991	.0025	.0265	346
03117500	Sandy Creek at Waynesburg	.953	.0025	.0048	320
03118000	Middle Br Nimishillen Cr at Canton	.941	.0025	.015	320
03118500	Nimishillen Creek at North Industry	.988	.0025	.010	320
03120500	McQuire Creek near Leesville	.511	.0025	.014	365

Table 12.--Summary of the autocovariance analysis--Continued)

Station no.	Station name	Rho*	Measurement variance (log base e)	Process variance (log base e)	Length of period (days)
03122500	Tuscarawas River near Dover	.980	.0025	.0061	343
03124000	Sugar Creek near Beach City	.987	.0025	.0036	336
03124500	Sugar Creek at Strasburg	.984	.0025	.014	320
03126000	Stillwater Creek at Piedmont	.837	.0025	.017	320
03127000	Stillwater Creek at Tippecanoe	.974	.0025	.016	320
03127500	Stillwater Creek at Uhrichsville	.848	.0025	.106	336
03128500	Little Stillwater Creek at Tappan	.853	.0025	.053	365
03129000	Tuscarawas River at Newcomerstown	.994	.0025	.0025	336
03130000	Black Fork near Mifflin	.946	.0025	.034	350
03131500	Black Fork at Loudonville	.955	.0025	.0013	358
03133500	Clear Fork near Perrysville	.977	.0025	.0036	365
03135000	Lake Fork near Mohicanville	.984	.0025	.028	350
03136500	Kokosing River at Mt. Vernon	.996	.0025	.048	350
03138500	Walhonding River at Nellie	.958	.0004	.00097	336
03139000	Killbuck Creek at Killbuck	.995	.0025	.089	320
03140000	Mill Creek near Coshocton	.779	.0025	.012	320
03140500	Muskingum River near Coshocton	.623	.0001	.0017	336
03141500	Seneca Fork near Senecaville	.985	.0025	.019	365
03142000	Wills Creek at Cambridge	.659	.0025	.067	336
03143500	Wills Creek at Wills Creek	.974	.0025	.0058	343

Table 12.--Summary of the autocovariance analysis--Continued

Station no.	Station name	Rho*	Measurement variance (log base e)	Process variance (log base e)	Length of period (days)
03144000	Wakatomika Creek near Frazeysburg	.934	.0025	.0063	336
03144500	Muskingum River at Dresden	.978	.0025	.00026	346
03145000	South Fork Licking River near Hebron	.976	.0025	.045	328
03146500	Licking River near Newark	.993	.0025	.132	343
03147500	Licking River near Dillon Falls	.974	.0025	.0017	361
03150000	Muskingum River at McConnelsville	.943	.0004	.0016	354
03157000	Clear creek near Rockbridge	.987	.0025	.022	336
03157500	Hocking River at Enterprise	.890	.0025	.0076	314
03159510	Hocking River below Athens	.893	.0025	.018	332
03159540	Shade River near Chester	.988	.0025	.0771	339
03202000	Raccoon Creek at Adamsville	.741	.0025	.0228	347
03219500	Scioto River near Prospect	.879	.0025	.0051	361
03219590	Bokes Creek near Warrensburg	.900	.0025	e .0050	330
03220000	Mill Creek near Bellpoint	.979	.0025	.054	347
03221000	Scioto River near Dublin	.672	.0025	.0082	339
03223000	Olentangy River near Claridon	.979	.0025	.0185	307
03225500	Olentangy River near Delaware	.989	.0025	.0015	361
03226800	Olentangy River near Worthington	.910	.0025	.0278	343
03227500	Scioto River at Columbus	.981	.0025	.0177	350
03228500	Big Walnut Creek at Central College	.825	.0025	.0027	361

Table 12.--Summary of the autocovariance analysis--Continued

Station no.	Station name	Rho*	Measurement variance (log base e)	Process variance (log base e)	Length of period (days)
03228805	Alum Creek at Africa	.980	.0025	.1059	354
03229000	Alum Creek at Columbus	.813	.0025	.0257	354
03229500	Big Walnut Creek at Rees	.990	.0025	.0102	354
03230500	Big Darby Creek at Darbyville	.987	.0025	.0313	336
03230900	Deer Creek near Pancoastburg	.982	.0025	.0231	361
03231000	Deer Creek at Williamsport	.980	.0025	.0124	354
03231500	Scioto River at Chillicothe	.994	.0025	.0065	361
03232470	Paint Creek near Bainbridge	.935	.0025	.0230	361
03232500	Rocky Fork near Barretts Mills	.947	.0025	.0079	350
03234000	Paint Creek near Bourneville	.988	.0025	.0340	336
03234500	Scioto River at Higby	.904	.0025	.0232	361
03237280	Upper Twin Creek at McGaw	.997	.0025	1.237	361
03237500	Ohio Brush Creek near West Union	.969	.0025	.0384	347
03238500	Whiteoak Creek near Georgetown	.927	.0025	.0566	339
03240000	Little Miami River near Oldtown	.985	.0025	.0113	321
03241500	Massies Creek at Wilberforce	.987	.0025	.0450	332
03245500	Little Miami River at Milford	.990	.0025	.0064	350
03247050	East Fork Little Miami R near Batavia	.584	.0025	.1004	354
03247500	East Fork Little Miami R at Perintown	.991	.0025	.0328	361
03255500	Mill Creek at Reading	.984	.0025	.0553	343

Table 12.--Summary of the autocovariance analysis--Continued

Station no.	Station name	Rho*	Measurement variance (log base e)	Process variance (log base e)	Length of period (days)
03259000	Mill Creek at Carthage	.985	.0025	.0509	350
03260700	Bokengehalas Creek near DeGraff	.993	.0025	.1075	336
03261500	Great Miami River at Sidney	.971	.0025	.0018	321
03261950	Loramie Creek near Newport	.976	.0025	.2947	307
03262000	Loramie Creek at Lockington	.658	.0025	.0100	336
03262700	Great Miami River at Troy	.974	.0025	.0371	328
03263000	Great Miami River at Taylorsville	e .90	.0025	1.00	330
03264000	Greenville Creek near Bradford	.992	.0025	.0514	314
03265000	Stillwater River at Pleasant Hill	.994	.0025	.0913	322
03266000	Stillwater River at Englewood	.959	.0025	.0216	328
03267000	Mad River near Urbana	.950	.0025	.0024	328
03267900	Mad River at Eagle City	.992	.0025	.0175	347
03269500	Mad River near Springfield	.593	.0025	.0041	365
03270000	Mad River near Dayton	.993	.0025	.0140	343
03270500	Great Miami River at Dayton	e .90	.0025	1.00	339
03270800	Wolf Creek at Trotwood	.980	.0025	.0902	314
03271500	Great Miami River at Miamisburg	.990	.0025	.0822	354
03271800	Twin Creek near Ingomar	.986	.0025	.0292	325
03272000	Twin Creek near Germantown	.980	.0025	.0161	321
03272700	Sevenmile Creek at Camden	.994	.0025	.3079	321

Table 12.--Summary of the autocovariance analysis--Continued

Station no.	Station name	Rho*	Measurement variance (log base e)	Process variance (log base e)	Length of period (days)
03274000	Great Miami River at Hamilton	.983	.0025	.0011	361
04177000	Ottawa River at Toledo	.981	.0025	.2010	314
04185000	Tiffin River at Stryker	.971	.0025	.0954	321
04186500	Auglaize River near Ft Jennings	.950	.0025	.0417	314
04189000	Blanchard River near Findlay	.955	.0025	.0101	354
04191500	Auglaize River near Defiance	.918	.0025	.0261	332
04192500	Maumee River near Defiance	.587	.0025	.0042	347
04193500	Maumee River at Waterville	.993	.0025	.0160	321
04195500	Portage River at Woodville	.856	.0025	.0281	307
04196800	Tymochtee Creek at Crawford	.936	.0025	.1358	299
04197020	Honey Creek near New Washington	.975	.0025	.1200	347
04197100	Honey Creek at Melmore	.994	.0025	.1739	321
04197170	Rock Creek at Tiffin	e .90	.0025	.1000	303
04198000	Sandusky River near Fremont	.949	.0025	.0131	292
04200430	West Br Black River at Elyria	e .90	.0025	e 1.00	336
04200500	Black River at Elyria	.941	.0025	.0049	330

Table 12.--Summary of the autocovariance analysis--Continued

Station no.	Station name	Rho*	Measurement variance (log base e)	Process variance (log base e)	Length of period (days)
04201500	Rocky River near Berea	.985	.0025	.0434	336
04202000	Cuyahoga River at Hiram Rapids	.926	.0025	.0049	310
04206000	Cuyahoga River at Old Portage	.992	.0025	.0045	358
04207200	Tinkers Creek at Bedford	.997	.0025	.0213	336
04208000	Cuyahoga River at Independence	.987	.0025	.0092	350
04208502	Big Creek at Cleveland	.993	.0025	.2001	336
04208690	Euclid Creek near Euclid	.900	.0025	1.00	292
04209000	Chagrin River at Willoughby	.984	.0025	.0344	310
04212100	Grand River near Painesville	.929	.0025	.0351	310
04213000	Conneaut Creek at Conneaut	.989	.0025	.0273	274

* One-day autocorrelation coefficient
e Estimated

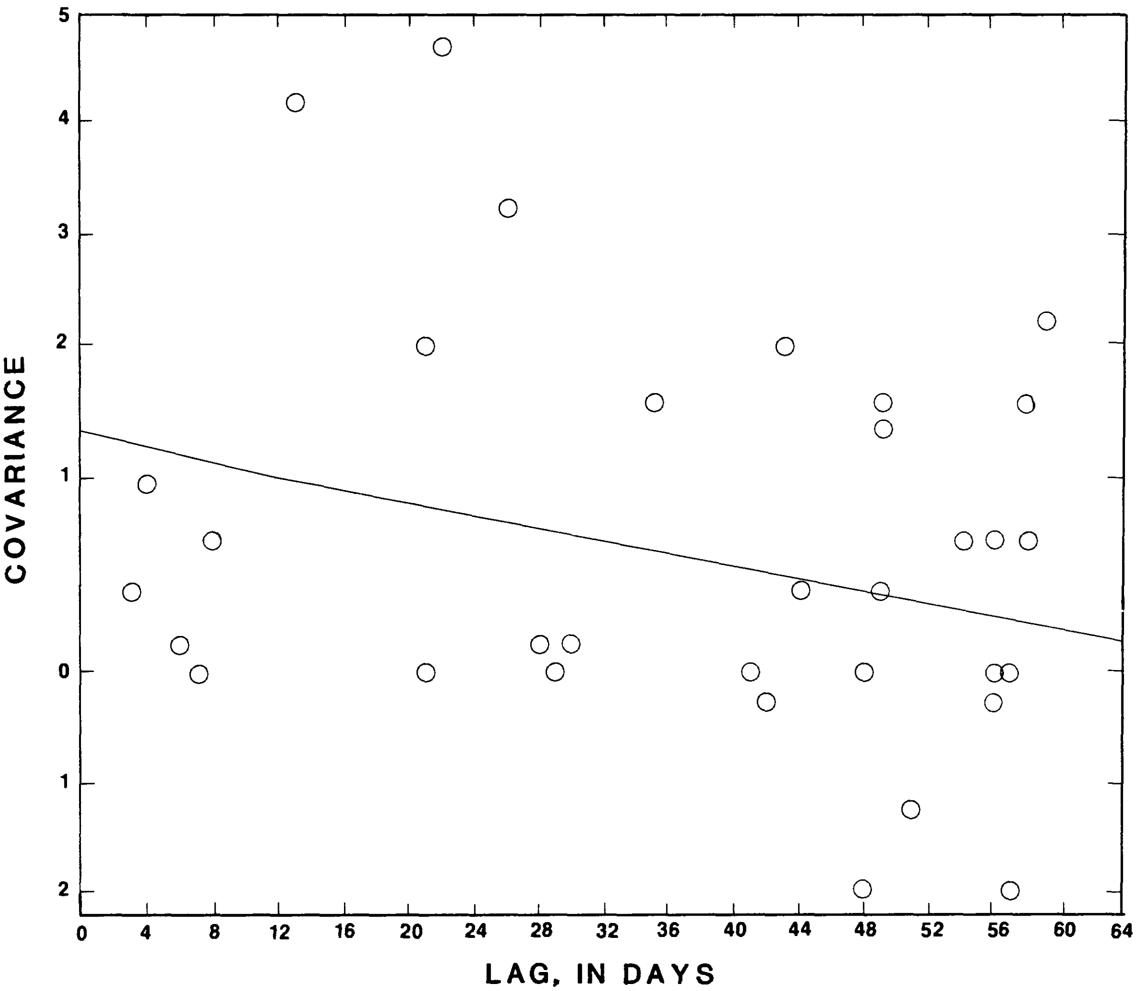


Figure 12.--Autocovariance function for non-ice period for 03092000 Pricetown.

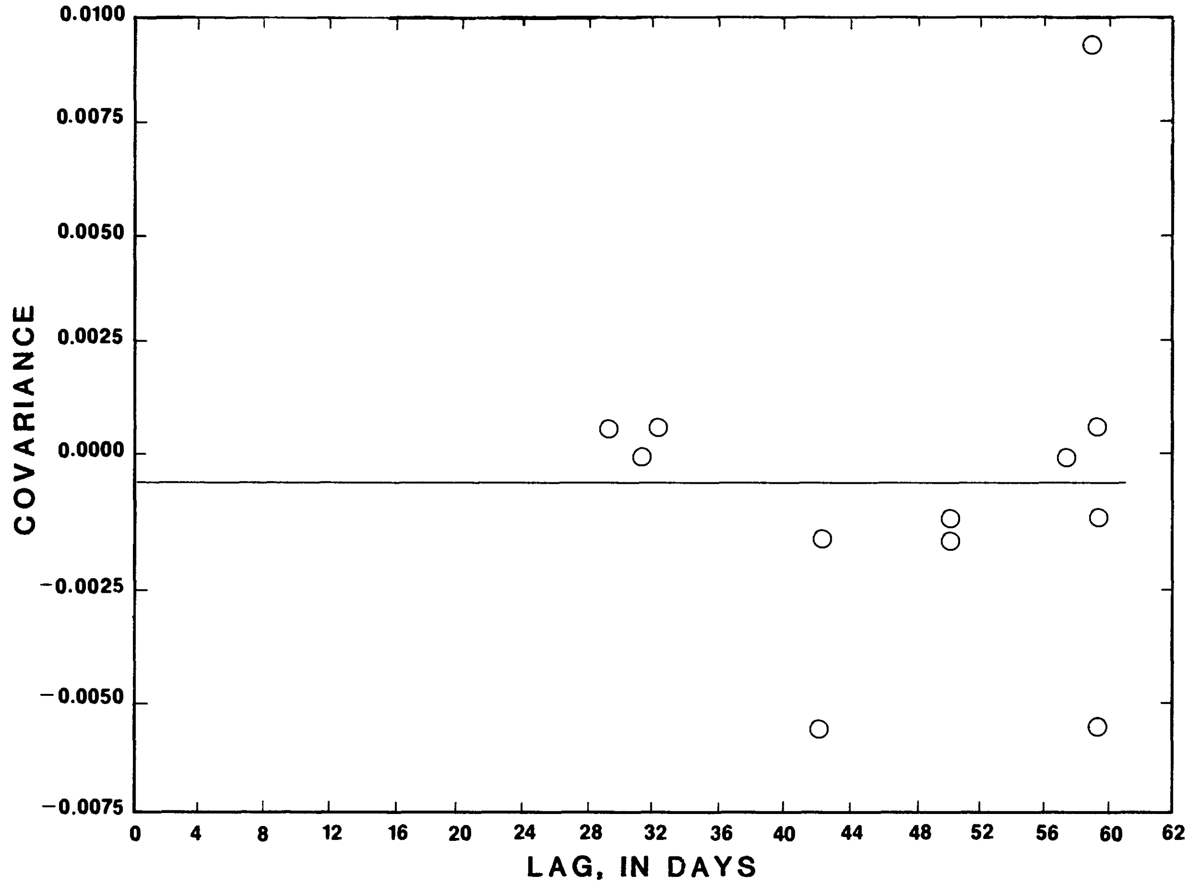


Figure 13.--Autocovariance function for non-ice period for 03144500 Dresden.

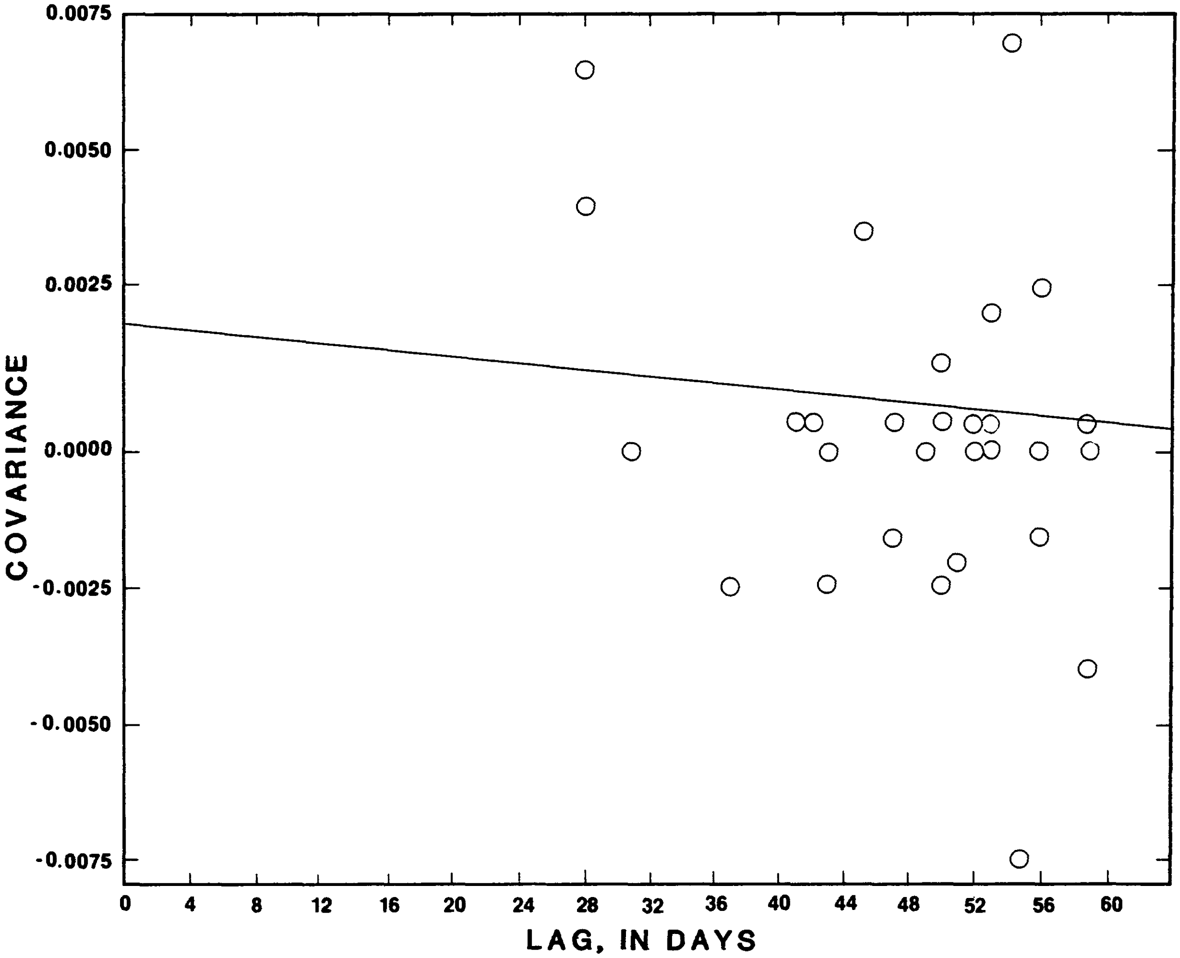


Figure 14.--Autocovariance function for non-ice period for 03225500 Delaware.

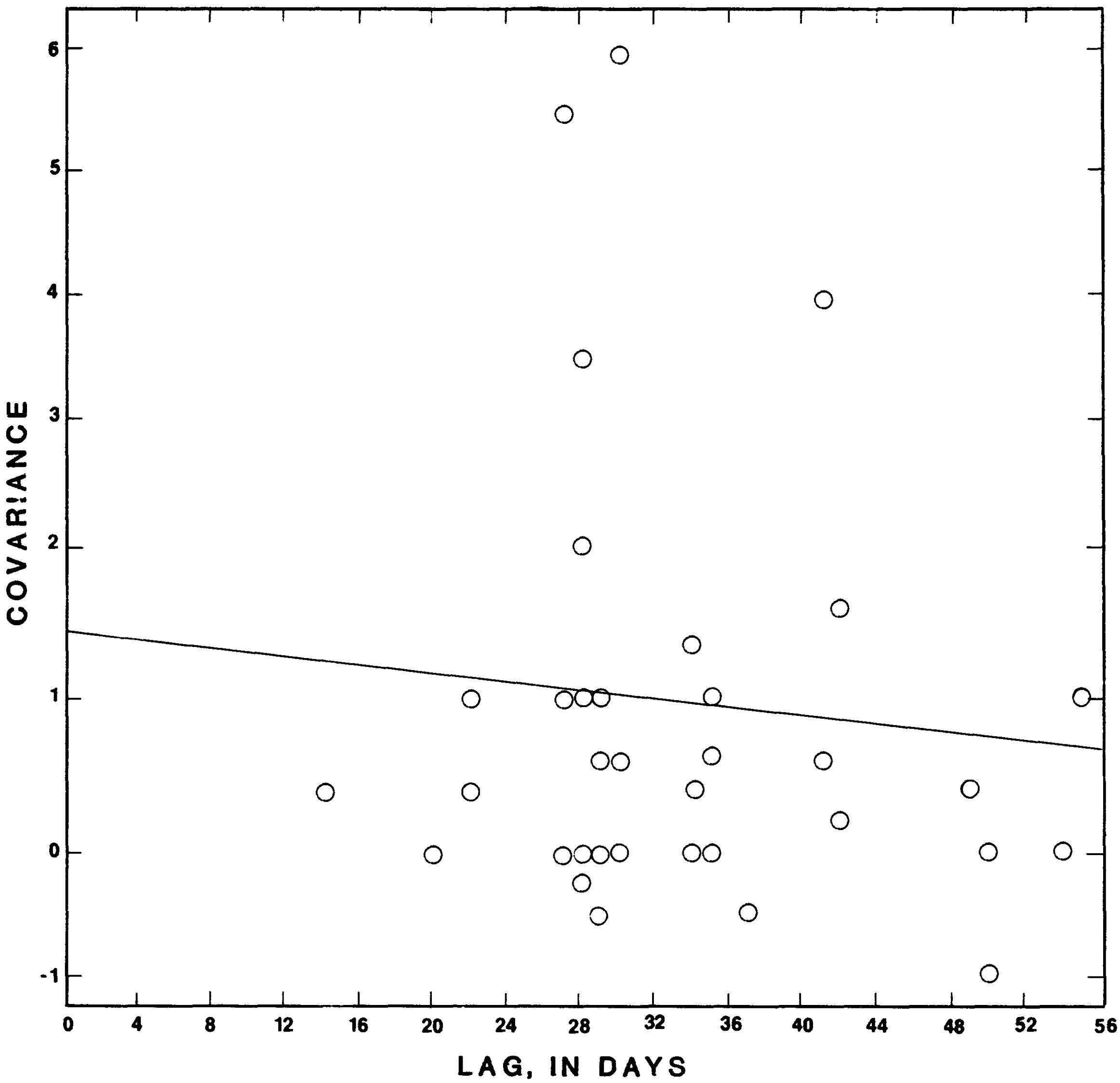


Figure 15.--Autocovariance function for non-ice period for 03237280 McGaw.

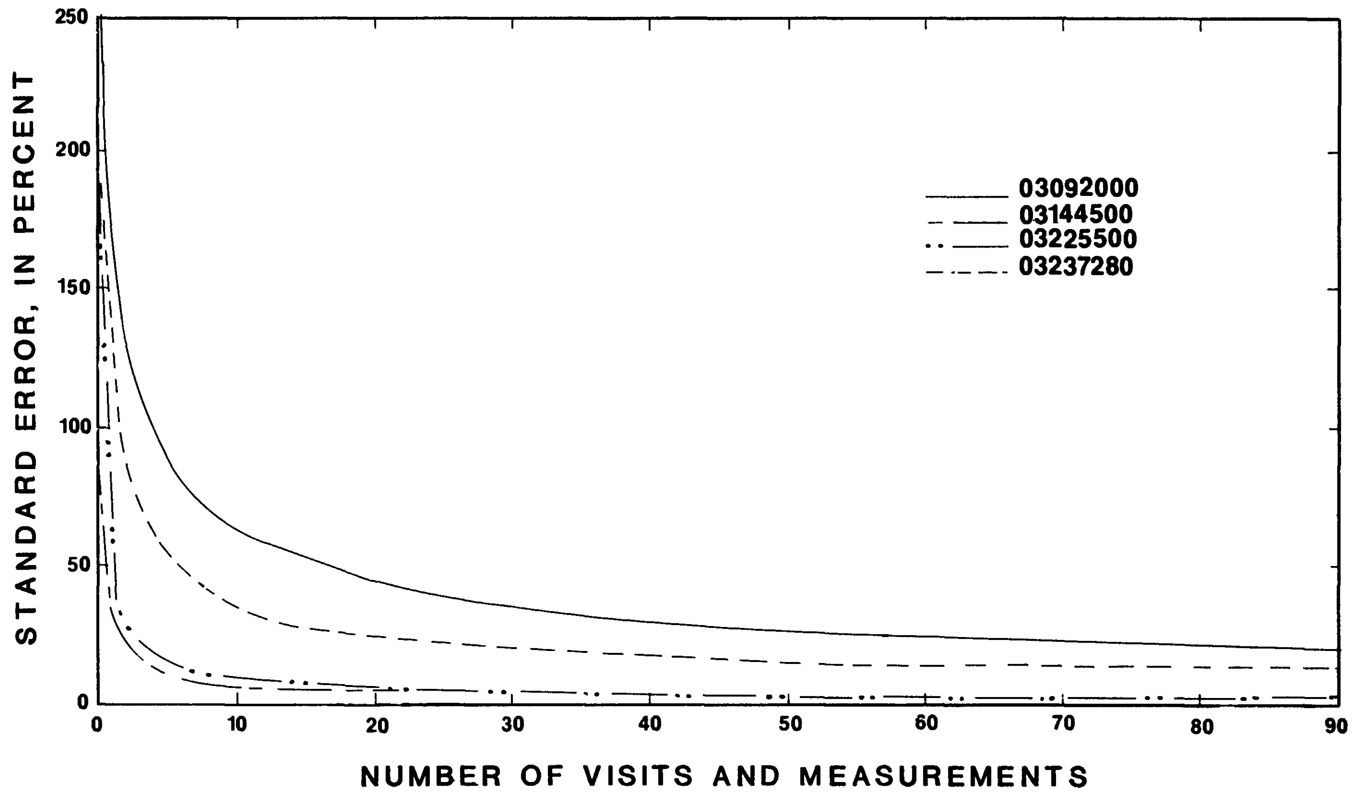


Figure 16.--Typical uncertainty function for instantaneous discharge.

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

[Six-digit numbers are longitude identifiers for observation wells serviced]

Route number	Stations serviced on the route				
1	04209000	04212100	04213000	03102950	04212680
	04202000	03092000	03091500	03095500	03092090
	03091000	04206001	03117100	04208506	04208001
	812215				
2	04209000	04212100	04213000	03102950	04202000
	03092000	03091500	03095500	03092090	04206000
3	04212100	03102950	03092000	03092090	04206000
4	04212100	03102950	04212100		
5	03102950	03092000	03092090		
6	04212100	03091500			
7	03102950	04206000			
8	04209000	04212100	04202000	03092000	03095500
9	03102950	03092000			
10	04209000	04212100	04213000	03102950	03092000
	03092090	04206000			
11	04209000	04212100	03102950	03092000	
12	04209000	03102950	03092000	03092090	04206000
13	04209000	04212100	04213000	03092000	03092090
	04206000				
14	04212100	03102950	03092000	03095500	03092090
	04206000				
15	04213000	03102950	04202000	03095500	03092090
16	04212680				

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

Route number	Stations serviced on the route				
17	03117100				
18	03092000				
19	03128650				
20	03120500				
21	04208502	04220000	04208000	04208001	04208506
	04206001	04206000	04207200		
22	04208502	04220000	04208000	04207200	04206000
23	04208001	04208506	04206001		
24	04208502	04220000			
25	04208502	04208000			
26	04208502	04207200			
27	04208000	04207200			
28	03122500	03118500	03117500	03124000	03124500
	03118000				
29	04208000	04206000			
30	03144500				
31	03091500	03094000	03099500		
32	03111500				
33	03114000				
34	03124500	03124000			
35	03122500	03118500			
36	03117500	03118000			
37	03118000	03118500			

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

Route number	Stations serviced on the route				
38	03143500	03138500	03139000		
39	03099510				
40	03090500	03086500	03092460	03093000	03094000
	03099500	03099510	03117000		
41	03090500	03086500	03092460	03093000	03094000
	03099500	03117000			
42	03090500	03093000			
43	03086500	03093000			
44	03093000				
45	03092460	03093000	03099500		
46	03093000	03117000			
47	03093000	03099500			
48	03090500	03093000	03117000		
49	03094000				
50	03092460	03099500			
51	03094000	03099500			
52	03090500	03086500	03099510	03099500	03094000
53	03092460	03093000	03094000	03099500	03117000
54	03093000	03094000	03099500	03117000	
55	03109500	03110000	03114000		
56	03109500				
57	03110000				
58	03109500	03110000			

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

Route number	Stations serviced on the route				
59	04201500	04200500	04200430	04199160	04199165
	04199170				
60	04201500	04200500	04200430		
61	04200500	04200430			
62	03111450	03127950	03110980	03111470	03111490
	03111540	03111455			
63	03127500	03128500	03111500	03144500	03141500
64	03127500				
65	03144500				
66	03128500	03144500	03141500		
67	03144500	03140500			
68	03127500	03128500			
69	03127500	03128500	03111500		
70	03141500	03142000	03141700	03142290	03126000
	03127000	03129000	03115510	03115410	03115710
	03125400	03115280	03114240		
71	03141500	03142000	03126000	03127000	03129000
72	03142000	03141700	03142290	03115710	03115410
	03115510	03125400	03115280	03114240	
73	03142000	03111548	03113950	03139950	
74	03126000				
75	03126000	03127000			
76	03141500	03142000			

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

Route number	Stations serviced on the route				
77	03129000	03142000			
78	03130000	03133500	03131300	03135000	03131500
	03140000	03139000			
79	03130000	03133500	03131500	03140000	03139000
	03135000				
80	03135000				
81	03139000				
82	03130000				
83	03131500	03133500			
84	03130000	03135000			
85	03139000	03140000			
86	03110980	03111450	03111455	03111470	03111490
	03111540	03127950			
87	03114240	03115280	03115410	03115510	03125400
	03115710				
88	03136500	03144000	03145000	03146500	03147500
	03150000	03148000	03148300	825733	815932
89	03157000	03157500	03159510	03159540	03230900
	03231000	03158220	03159450	03201550	03159500
	03159000	03230700	03236090		
90	03231500	03232470	03232500	03234000	03237280
	03237500	03238500	03245500	03247050	03247500
	03237095	03202000	830151		

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

Route number	Stations serviced on the route				
91	03231500	03232470	03232500	03234000	03234500
	03237280	03237500	03238500	03245500	03247050
	03247500	03237095			
92	03230900	03231000	03231500	03232470	03232500
	03234000	03234500	03237280	03237500	03238500
	03245500	03247050	03247500	03237095	830151
93	03136500	03144000	03145000	03146500	03147500
	03150000				
94	03157000	03157500	03159510	03159540	03230900
	03231000				
95	03231500	03232470	03232500	03234000	03237280
	03237500	03238500	03245500	03247050	03247500
96	03231500	03232470	03232500	03240000	03234500
	03237280	03237500	03240000	03245500	03247050
	03247500	03202000			
97	03230900	03231000	03231500	03232470	03232500
	03234000	03234500	03237280	03237500	03238500
	03245500	03247050	03247500		
98	03202001	03234501			
99	03245501				
100	03136500	03144000			
101	03145000	03146500	03147500		
102	03150000				

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

Route number	Stations serviced on the route				
103	03157000	03157500	03157510		
104	03159540	03202000			
105	03219500	03219590	03220000		
106	03221000	03220200	03221500		
107	03223000	03225500			
108	03225500	03226800			
109	03227500	03228500			
110	03228500	03228805			
111	03229000	03229500	03230500		
112	03230900	03231000			
113	03231500	03232470			
114	03232500	03234000			
115	03234500	03158500			
116	03237280				
117	03237500	03240000			
118	03245500				
119	03247050	03247500			
120	03157000	03157500	03159510	03158220	03159450
	03201550				
121	03236090				
122	03237500	03240000	03237095		
123	03237280	03237095			
124	03157000				

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

Route number	Stations serviced on the route				
125	03159510				
126	03159540				
127	03202000				
128	03219590				
129	03220000				
130	03223000				
131	03226800				
132	03227500				
133	03228805				
134	03229000				
135	03229500				
136	03230500				
137	03230900				
138	03231000				
139	03232470				
140	03234000				
141	03237500				
142	03238500				
143	03247050				
144	03247500				
145	03240000	03241500	03242050		
146	03255500	03257500	03259000	03271510	843933
	841628	03267900			

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

Route number	Stations serviced on the route				
147	03240000	03241500	03242050	03271510	
148	03255500	03257500	03259000		
149	03240000	03241500	03242050	03255500	03257500
	03259000	03271510	843933	841628	
150	03240000	03241500			
151	03255500	03259000			
152	03271510				
153	03240000	03241500	03255500	03259000	03267900
154	03255500	03259000	03245500	03247050	03247500
155	03267900				
156	04177000	04185000	04186500	04189000	04191500
	04192500	04193500	04193490	04194107	04191480
	04185945	835740	832552		
157	04185000	04186500	04189000	04191500	04192500
	04193500				
158	04177000	04185000	04193500		
159	04185000				
160	04177000				
161	04193500				
162	04186500				
163	04195500	04196800	04197020	04197100	04197170
	04198000	830453	831705		
164	04198000				

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

Route number	Stations serviced on the route				
165	04197100	04197170			
166	04197100				
167	04197170				
168	04197020				
169	04189000	04193500	04195500	04198000	04193490
	04194107				
170	04196800	04197100	04197170		
171	04189000	04192500	04193500	04198000	
172	04189000	04192500	04193500	04198000	04193490
173	04193490				
174	04193490	04194107			
175	815932	03148000	03148300		
176	825733				
177	03158220	30159450	03201550	03159500	03159000
178	03230700	830151	03237095		
179	03202001	03236090			
180	04191480	832552			
181	04185945	835740			
182	831705				
183	843933	841628			
184	831453				

Route and Station Costs

The cost associated with the particular routes must be determined. Although the gross cost per station is presently (1984) $5,320-$5,660 (depending on the cooperator) and the budget for the gaging network analyzed is $600,000; not all the money is available for routine gaging trips.

Station cost can be divided into three categories:

(1) Overhead costs, which include the Ohio District and Washington operational costs. For the stream-gaging network these costs are approximately 51.3 percent of the total budget.

(2) Fixed costs for each station vary with the station, and include such items as recorder rental, batteries, electricity, computer charges, maintenance, and publication cost; and for the purpose of this study, analysis and record interpretation, supervision, ice measurements, flood work, contracted services, and, anything else that is not a part of a routine gaging trip. In order to simplify the analysis, all costs except for the ice cost were considered to be equal for all stations. This is a reasonable assumption as the "fixed" cost for a station will vary considerably from year to year depending on a number variables including areal distribution of floods, difficulty in working the records, vandalism, major construction, and a host of other factors. The fixed cost for all stations is $1,875 plus ice-measurement costs.

In order to allow for measurements during the ice period, money was added under fixed costs. Each station was classified as to whether one or two ice measurements were needed annually to estimate the record and the money was added. The station input card was also adjusted to show the percentage of open water where the main rating and the associated variability would be in effect.

(3) The final cost for the program is the cost of running the route and the visit cost.

Visit costs are those associated with the paying of the hydrographer for the time actually spent at a station servicing the equipment and making a discharge measurement. Average visit times were calculated for each station and are a function of the difficulty and time required to make a discharge measurement. Average visit times were calculated for each station based on an analysis of discharge measurement data available. This time was then multiplied by the average hourly salary of a hydrologic-technician GS-9/1 to determine total visit cost. By fixing the salary at this grade/step the variable of different wages is removed from the program.

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.

Budget

The gaging budget covers the financing of the gaging network. When computing the budget, a few assumptions were made. First, the amount of money necessary for running the MCD network ($115,000) was subtracted from the gross budget.

Defining a budget is more complicated for those districts running integrated field trips. In Ohio the field man generally services four types of gages during his gaging trip: Discharge stations, crest-stage stations, ground-water wells, and water-quality monitors. As sediment stations are run with a discharge station or as part of a special high-water run they were not considered.

A fixed amount was added for the other networks' cost to cover the field-data gathering. The total amount for both offices is $82,000. Therefore an initial total budget of $682,000 would have $600,000 for the gaging network. As an example, if the cost of the gages is doubled to $1,200,000, the entire network cost becomes $1,282,000.

CONCLUSIONS FROM THE K-CERA ANALYSIS

The "Traveling-Hydrographer Program" utilizes the uncertainty functions in conjunction 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 specific routes that are being used to make these visits were fixed. The current practice in Ohio is to make discharge measurements each time a station is visited. The exceptions to this practice are stations visited for additional purposes such as month-end or concurrent monitor operation.

This current-practice value was determined as an average and applied to the open-water period. To counterbalance the winter period--which was handled separately under fixed cost and has a variable, undefined, uncertainty--the number of required field trips was reduced appropriately. The resulting error of estimation for the current practice in Ohio, plotted as a point in figure 17, is 29.2 percent.

The solid line in figure 17 represents the minimum level of average uncertainty that can be obtained for a given budget and the existing 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.

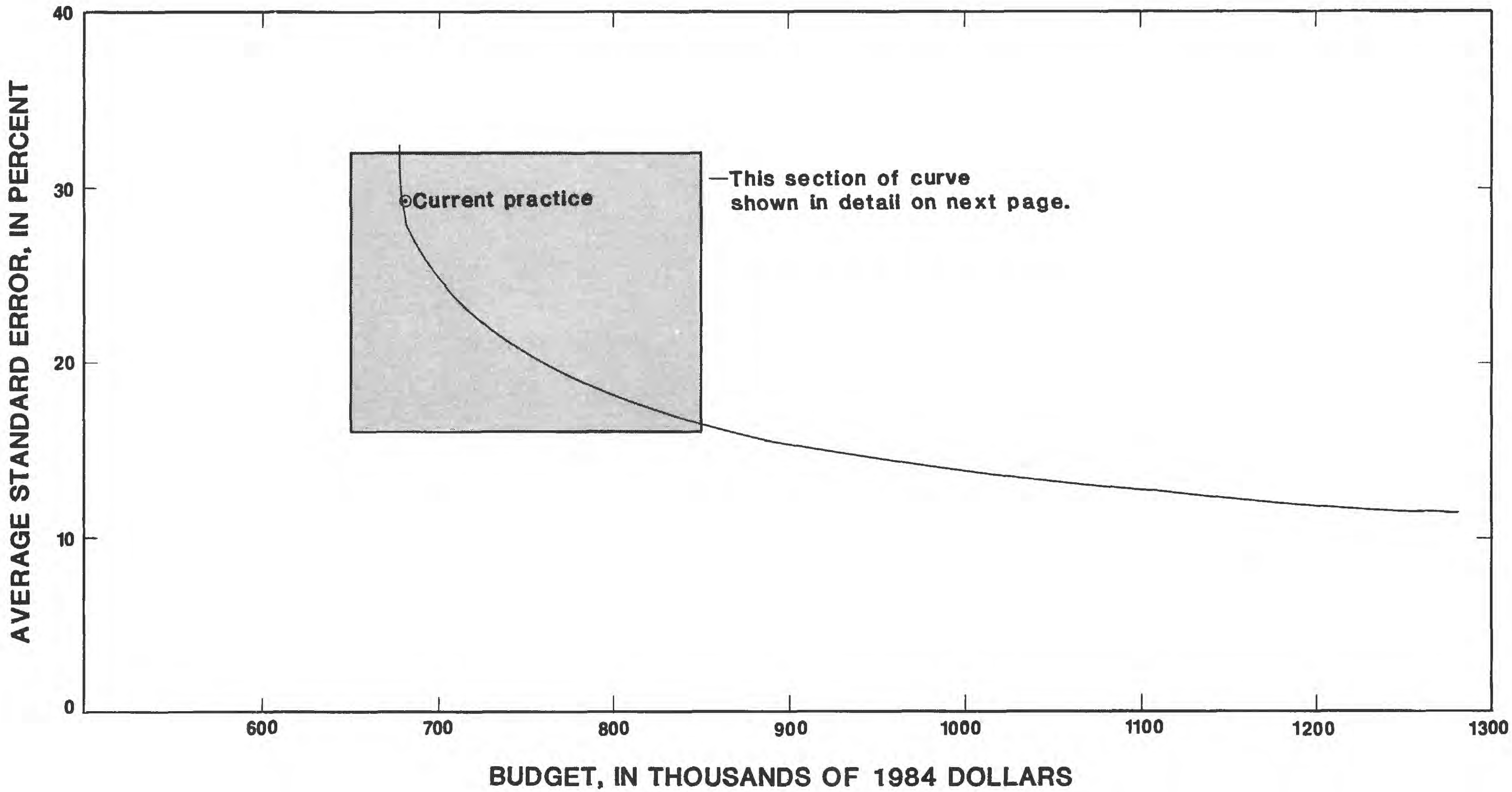


Figure 17.—Temporal average standard error per stream gage.

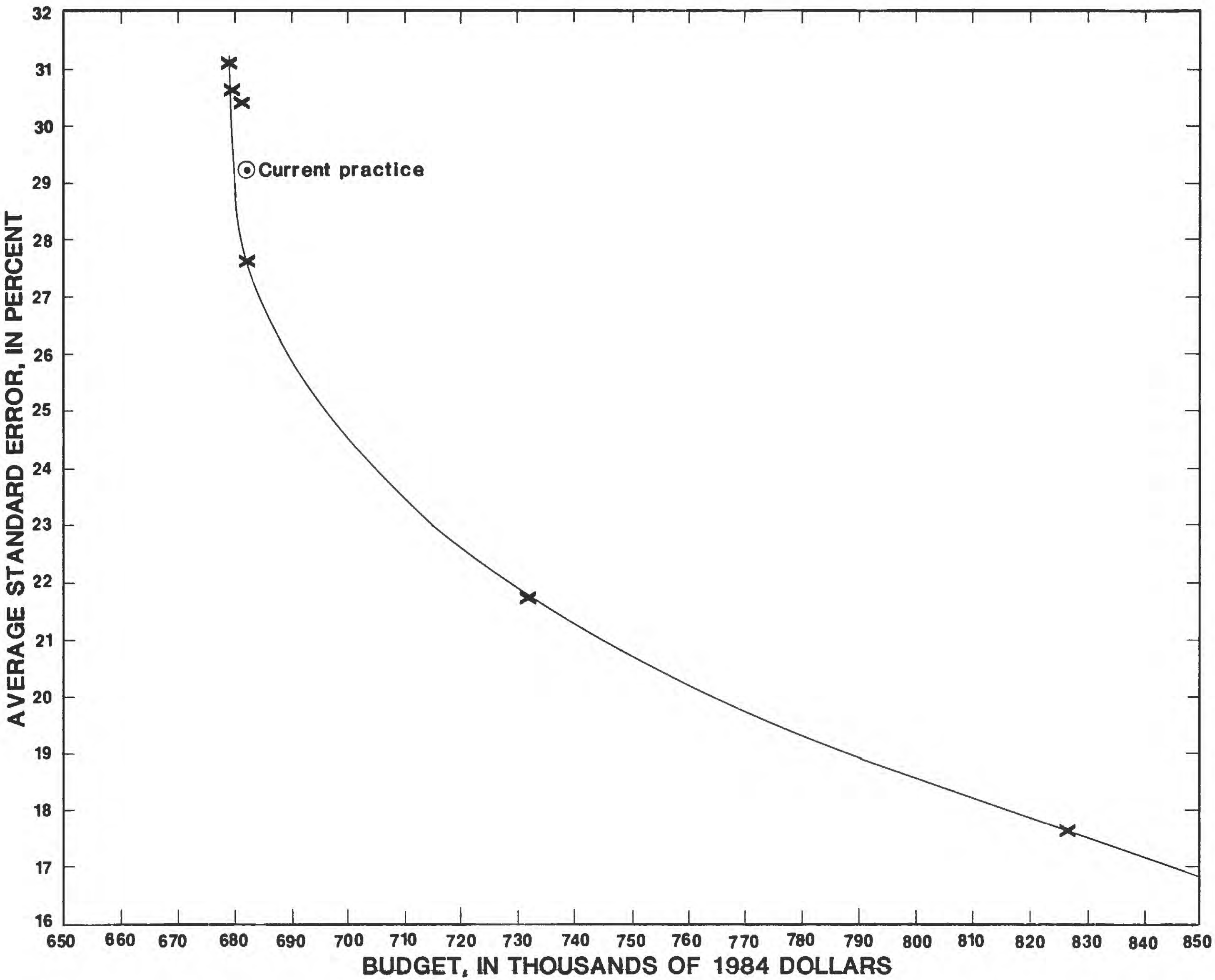


Figure 17.--Temporal average standard error per stream gage (Continued).

To determine the minimum number of times each station must be visited, consideration was given only to the physical limitations of the method used to record data. The effect of visitation frequency on the accuracy of the data and amount of lost record is taken into account in the uncertainty analysis. In Ohio, a minimum requirement of four visits per year was calculated and applied to all stations. In general, at least one of these visits would be during the winter period which would leave a minimum of three visits for the open-water period. This value was based on limitations of the batteries used to drive recording equipment, capacities of uptake spools on the digital recorders, and the need to protect gages from freezing winter conditions.

Minimum visit requirements should also reflect the need to visit stations for special reasons such as water-quality sampling. This problem was handled by adjusting the percentage of time a station was measured even if visited more often for water-quality and monthend data. Special water-quality trips also were set up even though the water-quality stations are adjacent to the gaging station.

The results in figure 17 and table 14 summarize the K-CERA analysis, and, unless otherwide adjusted, are predicated on a discharge measurement being made each time that a station is visited.

It should be emphasized that figure 17 and table 14 are based on various assumptions (stated previously) concerning both the time series of shifts to the stage-discharge relationship and the methods of record reconstruction. Where a choice of the assumptions was available, the assumption that would not underestimate the magnitude of the error variances was chosen.

It can be seen that the current operation results in an average standard error of estimate of streamflow of 29.2 percent. This requires a budget of $682,000 to operate the 107-station stream-gaging program. The range in standard errors is from a low of 2.6 percent for station 03129000 (Newcomerstown), to a high of 112.3 percent at station 04200430 (West Branch Black River). It may be possible to obtain this same average standard error with a reduced budget, but this reduction would be negligable (less than $1,000, or 0.1 percent).

It would also be possible to reduce the average standard error by rescheduling visits while maintaining the same budget of $682,000. This might be done by abandoning the bimonthly field trips, using a minimum visit constraint of 3, and concentrating on the "poorer" stations. In this case, the average would decrease from 29.2 to 27.6 percent. Extremes of standard errors for individual sites would be 2.6 and 106 percent for stations 03129000 and 04220000, Tuscarawas River and Euclid Creek, respectively.

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

Identification	Standard error of instantaneous discharges, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1984 dollars				
		679	682	816	1047	1282
Average per station	29.2	31.1	27.6	17.6	13.1	11.1
03086500	30.7	33.4	28.5	20.3	15.3	12.7
Mahoning	[17.9]	[19.4]	[16.7]	[12.0]	[8.9]	[7.5]
Alliance	(6)	(5)	(7)	(14)	(25)	(36)
03090500	8.7	9.1	8.6	8.6	8.3	7.9
Mahoning R	[7.6]	7.7	[7.6]	[7.6]	[7.5]	[7.4]
Berlin Center	(6)	(5)	(7)	(7)	(9)	(14)
03091500	17.4	17.1	17.4	17.4	16.9	15.4
Mahoning R	[17.0]	[17.0]	[17.0]	[17.0]	[16.6]	[15.2]
Pricetown	(12)	(14)	(12)	(12)	(16)	(32)
03092000	81.8	62.6	66.2	37.7	26.8	21.7
Kale Cr	[76.4]	[57.3]	[60.8]	[33.4]	[23.5]	[18.9]
Pricetown	(6)	(10)	(9)	(26)	(50)	(76)
03092090	39.6	32.0	34.1	19.2	13.9	11.7
W Br Mahoning R	[38.9]	[31.3]	[33.3]	[18.7]	[13.5]	[11.3]
Ravenna	(6)	(9)	(8)	(24)	(46)	(66)
03092460	19.2	21.6	19.8	19.8	16.0	13.4
W Br Mahoning R	[17.6]	[18.7]	[17.9]	[17.9]	[15.2]	[12.8]
Wayland	(6)	(3)	(5)	(5)	(14)	(24)
03093000	17.2	23.6	18.8	12.2	7.8	6.5
Eagle Cr	[16.8]	[23.1]	[18.3]	[11.9]	[7.5]	[6.3]
Phalanx Sta.	(6)	(3)	(5)	(12)	(30)	(43)
03094000	19.0	19.0	19.0	17.8	15.1	12.8
Mahoning R	[9.7]	[9.7]	[9.7]	[9.5]	[9.1]	[8.7]
Leavittsburg	(12)	(12)	(12)	(14)	(21)	(34)
03095500	8.2	7.1	8.2	7.1	5.1	4.1
Mosquito Cr	[5.6]	[5.0]	[5.6]	[5.0]	[3.7]	[2.9]
Cortland	(6)	(8)	(6)	(8)	(16)	(26)

Table 14.--Selected results of K-CERA analysis--Continued

Identification	Current operation	679	682	816	1047	1282
	Standard error of instantaneous discharges, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
		Budget, in thousands of 1984 dollars				
03099500 Mahoning R Lowellville	12.8 [5.0] (12)	12.8 [5.0] (12)	12.8 [5.0] (12)	11.7 [4.7] (14)	9.2 [4.0] (21)	6.7 [3.1] (37)
03102950 Pymatuning Cr Kinsman	42.4 [42.2] (6)	34.2 [34.0] (10)	37.8 [37.6] (8)	23.2 [23.0] (22)	16.1 [15.8] (46)	13.1 [12.9] (68)
03109500 Little Beaver Cr E. Liverpool	6.5 [4.5] (6)	8.4 [4.7] (3)	8.4 [4.7] (3)	8.4 [4.7] (3)	6.5 [4.5] (6)	5.8 [4.5] (9)
03110000 Yellow Cr Hammondsville	11.5 [7.2] (6)	16.8 [10.1] (3)	16.8 [10.1] (3)	11.5 [7.2] (6)	8.3 [5.3] (11)	6.9 [4.4] (16)
03111500 Short Cr Dillonvale	38.0 [18.8] (6)	43.1 [21.0] (5)	43.1 [21.0] (5)	19.5 [11.5] (15)	13.8 [8.9] (11)	11.0 [7.7] (33)
03114000 Captina Cr Armstrong Mills	54.5 [19.3] (6)	54.5 [19.3] (6)	50.3 [17.5] (7)	27.7 [9.0] (22)	19.7 [6.3] (43)	16.4 [5.3] (62)
03117000 Tuscarawas R Massillon	9.6 [7.2] (6)	13.8 [10.4] (3)	10.5 [8.2] (5)	10.5 [8.2] (5)	6.2 [5.0] (14)	5.1 [4.1] (21)
03117500 Sandy Cr Waynesburg	15.2 [6.0] (6)	22.3 [7.1] (3)	18.9 [6.7] (4)	10.2 [4.6] (13)	8.0 [3.8] (21)	6.6 [3.2] (31)
03118000 M Branch Nimishillen Cr Canton	26.1 [11.8] (6)	32.8 [13.3] (4)	28.9 [12.4] (5)	16.6 [8.7] (14)	11.8 [6.6] (27)	9.6 [5.4] (41)
03118500 Nimishillen Cr N. Industry	12.2 [5.3] (6)	15.2 [6.5] (4)	13.4 [5.8] (5)	8.7 [4.0] (11)	5.8 [2.7] (24)	4.7 [2.2] (36)

Table 14.--Selected results of K-CERA analysis--Continued

Identification	Current operation	679	682	816	1047	1282
	Standard error of instantaneous discharges, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
		Budget, in thousands of 1984 dollars				
03120500 McGuire Cr Leesville	13.0 [11.9] (6)	14.4 [12.1] (3)	14.4 [12.1] (3)	13.7 [12.0] (4)	12.6 [11.8] (8)	12.2 [11.6] (12)
03122500 Tuscarawas R Dover	12.7 [5.5] (6)	19.6 [7.4] (3)	16.3 [6.5] (4)	9.3 [4.3] (10)	6.7 [3.3] (18)	5.5 [2.8] (26)
03124000 Sugar Cr Beach City	5.4 [3.3] (6)	7.8 [4.3] (3)	6.7 [3.8] (4)	4.2 [2.6] (10)	3.1 [2.0] (18)	2.6 [1.7] (26)
03124500 Sugar Cr Strasburg	14.1 [7.1] (6)	22.8 [9.7] (3)	18.6 [8.6] (4)	10.2 [5.6] (10)	7.2 [4.2] (18)	5.8 [3.5] (26)
03126000 Stillwater Cr Piedmont	13.2 [12.5] (6)	14.5 [13.0] (3)	13.2 [12.5] (6)	13.2 [12.5] (5)	12.4 [12.0] (10)	11.3 [11.0] (18)
03127000 Stillwater Cr Tippecanoe	9.3 [8.6] (6)	11.7 [10.6] (3)	9.3 [8.6] (6)	9.3 [8.6] (6)	7.5 [7.1] (10)	5.8 [5.5] (18)
03127500 Stillwater Cr Uhrichsville	31.4 [31.3] (6)	32.4 [31.2] (3)	32.4 [32.2] (3)	26.6 [26.6] (21)	18.1 [18.1] (64)	14.7 [14.7] (100)
03128500 L Stillwater Cr Tappan	22.9 [22.3] (6)	24.5 [23.1] (3)	24.5 [23.1] (3)	21.5 [21.1] (11)	14.4 [14.2] (52)	12.2 [12.1] (76)
03129000 Tuscarawas R Newcomerstown	2.6 [2.0] (6)	3.9 [2.7] (3)	2.6 [2.0] (6)	2.6 [2.0] (6)	2.6 [2.0] (6)	2.6 [2.0] (6)
03130000 Black Fork Mifflin	16.4 [15.8] (6)	16.4 [15.8] (6)	16.4 [15.8] (6)	16.4 [15.8] (6)	12.8 [12.4] (14)	10.1 [9.9] (25)

Table 14.--Selected results of K-CERA analysis--Continued

Identification	Current operation	Budget, in thousands of 1984 dollars: 679	682	816	1047	1282
	Standard error of instantaneous discharges, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
03131500 Black Fork Loudonville	21.6 [3.8] (6)	21.6 [3.8] (6)	21.6 [3.8] (6)	16.4 [3.2] (9)	11.3 [2.4] (16)	9.2 [2.1] (22)
03133500 Clear Fork Perrysville	6.0 [4.2] (6)	6.0 [4.2] (6)	6.0 [4.2] (6)	5.0 [3.6] (9)	3.9 [2.8] (16)	3.3 [2.5] (22)
03135000 Lake Fork Mohicanville	11.2 [9.7] (6)	11.2 [9.7] (6)	11.2 [9.7] (6)	11.2 [9.7] (6)	7.6 [6.6] (14)	5.9 [5.2] (23)
03136500 Kokosing R Mt. Vernon	15.9 [14.3] (6)	40.3 [11.7] (3)	27.6 [7.5] (6)	20.0 [5.3] (11)	14.3 [3.9] (21)	11.7 [3.2] (31)
03138500 Walhonding Nellie	4.8 [2.5] (6)	6.6 [2.9] (3)	6.6 [2.9] (3)	6.6 [2.9] (3)	4.8 [2.5] (6)	3.8 [2.2] (10)
03139000 Killbuck Cr Killbuck	8.0 [6.9] (12)	9.3 [7.9] (9)	9.3 [7.9] (9)	9.3 [7.9] (9)	7.5 [6.4] (14)	6.0 [5.2] (22)
03140000 Mill Cr Coshocton	12.9 [10.7] (6)	12.9 [10.7] (6)	12.9 [10.7] (6)	12.9 [10.7] (6)	12.2 [10.5] (8)	11.3 [10.2] (12)
03140500 Muskingum R Coshocton	4.9 [4.1] (6)	5.5 [4.2] (4)	4.7 [4.1] (7)	4.7 [4.1] (7)	4.7 [4.1] (7)	4.7 [4.1] (7)
03141500 Seneca Fork Senecaville	10.5 [8.0] (6)	14.2 [10.4] (3)	9.7 [7.5] (7)	9.1 [7.1] (8)	7.0 [5.5] (14)	5.7 [4.5] (21)
03142000 Wills Cr Cambridge	27.5 [25.6] (6)	25.8 [25.1] (11)	27.5 [25.6] (6)	26.9 [25.5] (7)	25.0 [24.7] (16)	20.1 [20.1] (64)

Table 14.--Selected results of K-CERA analysis--Continued

Identification	Standard error of instantaneous discharges, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1984 dollars				
		679	682	816	1047	1282
03143500 Wills Cr Wills Creek	7.6 [5.4] (6)	10.1 [6.5] (3)	10.1 [6.5] (3)	10.1 [6.5] (3)	7.6 [5.4] (6)	6.1 [4.5] (10)
03144000 Wakatomika Cr Frazeysburg	19.6 [7.2] (6)	27.4 [8.1] (3)	19.6 [7.2] (6)	14.7 [6.2] (11)	10.8 [5.1] (21)	9.0 [4.3] (31)
03144500 Muskingum R Dresden	6.4 [1.9] (12)	6.4 [1.9] (12)	6.4 [1.9] (12)	6.4 [1.9] (12)	6.4 [1.9] (12)	6.0 [1.9] (13)
03145000 S F Licking R Hebron	29.9 [15.7] (6)	43.0 [21.3] (3)	29.9 [15.7] (6)	21.8 [11.7] (11)	15.6 [8.4] (21)	12.8 [6.9] (31)
03146500 Licking R Newark	15.9 [14.3] (6)	22.7 [20.3] (3)	15.9 [14.3] (6)	11.7 [10.6] (11)	8.5 [7.7] (21)	7.0 [6.4] (31)
03147500 Licking R Dillon Falls	5.0 [3.0] (6)	7.0 [3.6] (3)	5.0 [3.0] (6)	3.8 [2.4] (11)	2.8 [1.8] (21)	2.3 [1.5] (31)
03150000 Muskingum R McConnelsville	7.2 [3.6] (6)	11.7 [4.1] (3)	7.2 [3.6] (6)	7.2 [3.6] (6)	5.6 [3.2] (9)	4.7 [3.0] (12)
03157000 Clear Cr Rockbridge	50.9 [12.7] (6)	46.2 [11.0] (7)	42.5 [9.8] (8)	20.7 [4.2] (25)	14.8 [3.3] (44)	11.9 [2.7] (64)
03157500 Hocking R Enterprise	27.0 [9.3] (6)	34.4 [10.3] (4)	27.0 [9.3] (6)	18.3 [7.8] (12)	13.1 [6.4] (23)	10.7 [5.5] (34)
03159510 Hocking R Athens	15.4 [12.9] (6)	17.8 [13.6] (4)	15.4 [12.9] (6)	12.6 [11.5] (12)	10.3 [9.7] (23)	8.9 [8.4] (34)

Table 14.--Selected results of K-CERA analysis--Continued

Identification	Current operation	679	682	816	1047	1282
	Standard error of instantaneous discharges, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
		Budget, in thousands of 1984 dollars				
03159540 Shade R Chester	31.6 [14.8] (6)	44.3 [21.0] (3)	31.6 [14.8] (6)	21.5 [9.9] (13)	15.5 [7.1] (23)	13.2 [6.0] (35)
03202000 Raccoon Cr Adamsville	24.5 [15.3] (6)	31.7 [16.1] (3)	24.5 [15.3] (6)	20.4 [14.6] (11)	16.6 [13.5] (24)	14.3 [12.2] (40)
03219500 Scioto R Prospect	33.3 [8.0] (6)	37.8 [8.4] (5)	33.3 [8.0] (6)	17.8 [6.3] (16)	15.6 [5.9] (20)	15.6 [5.9] (20)
03219590 Bokes Cr Warrensburg	28.7 [7.1] (6)	31.9 [7.4] (5)	28.7 [7.1] (6)	17.0 [5.7] (16)	12.8 [4.7] (28)	10.3 [4.0] (43)
03220000 Mill Cr Bellepoint	24.2 [15.3] (6)	26.3 [16.4] (5)	24.2 [15.3] (6)	15.1 [9.8] (16)	13.6 [8.8] (20)	13.6 [8.8] (20)
03221000 Scioto R Dublin	14.5 [9.2] (6)	14.5 [9.2] (6)	14.5 [9.2] (6)	14.5 [9.2] (6)	12.6 [9.0] (9)	11.3 [8.8] (13)
03223000 Olentangy R Claridon	50.6 [10.1] (6)	50.6 [10.1] (6)	46.5 [9.3] (7)	24.8 [4.9] (23)	17.8 [3.6] (44)	14.2 [2.8] (68)
03225500 Olentangy R Delaware	11.0 [2.1] (6)	14.3 [2.5] (4)	17.4 [2.8] (3)	10.0 [2.0] (7)	7.2 [1.5] (12)	5.9 [1.3] (17)
03226800 Olentangy R Worthington	32.8 [17.2] (6)	32.8 [17.2] (6)	32.8 [17.2] (6)	18.1 [12.3] (20)	13.1 [9.3] (39)	10.9 [7.9] (57)
03227500 Scioto R Columbus	14.7 [8.7] (6)	21.3 [11.3] (3)	21.3 [11.3] (3)	12.6 [7.6] (8)	9.1 [5.7] (15)	7.2 [4.6] (24)

Table 14.--Selected results of K-CERA analysis--Continued

Identification	Current operation	679	682	816	1047	1282
	Standard error of instantaneous discharges, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
		Budget, in thousands of 1984 dollars				
03228500 Big Walnut Cr Central College	10.3 [5.0] (6)	13.8 [5.2] (3)	13.8 [5.2] (3)	11.1 [5.1] (5)	8.8 [4.9] (9)	7.7 [4.7] (13)
03228805 Alum Cr Africa	20.9 [20.8] (6)	26.4 [26.0] (3)	26.4 [26.0] (3)	14.8 [14.7] (13)	10.5 [10.5] (26)	8.7 [8.7] (38)
03229000 Alum Cr Columbus	20.2 [15.8] (6)	24.8 [16.5] (3)	18.9 [15.5] (8)	17.3 [14.9] (12)	13.6 [12.5] (33)	11.2 [10.4] (58)
03229500 Big Walnut Cr Rees	46.5 [6.6] (6)	42.3 [5.9] (7)	38.9 [5.4] (8)	21.2 [2.9] (22)	15.2 [2.2] (40)	12.1 [1.7] (61)
03230500 Big Darby Cr Darbyville	52.5 [12.6] (6)	44.1 [10.2] (8)	41.1 [9.5] (9)	22.7 [5.1] (25)	15.7 [3.6] (49)	12.9 [3.0] (71)
03230900 Deer Cr Pancoastburg	10.3 [9.5] (6)	13.3 [12.0] (3)	10.3 [9.5] (6)	9.6 [8.9] (7)	7.3 [6.8] (13)	6.2 [5.8] (18)
03231000 Deer Cr Williamsport	22.2 [7.9] (6)	28.8 [9.4] (4)	22.2 [7.9] (6)	14.6 [5.7] (12)	10.4 [4.2] (22)	8.3 [3.5] (33)
03231500 Scioto R Chillicothe	6.3 [3.3] (6)	10.6 [4.6] (3)	6.3 [3.3] (6)	5.6 [3.1] (7)	3.4 [2.1] (15)	2.4 [1.6] (28)
03232470 Paint Cr Bainbridge	16.7 [13.6] (6)	20.5 [14.9] (3)	16.7 [13.6] (6)	16.0 [13.2] (7)	12.1 [10.6] (16)	9.6 [8.5] (28)
03232500 Rocky Fork Barretts Mills	38.5 [9.0] (6)	48.1 [10.6] (4)	38.5 [9.0] (6)	25.4 [6.7] (13)	17.8 [4.9] (26)	14.2 [4.0] (40)

Table 14.--Selected results of K-CERA analysis--Continued

Identification	Standard error of instantaneous discharges, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1984 dollars				
		679	682	816	1047	1282
03234000 Paint Cr Bourneville	9.6 [9.3] (6)	11.6 [11.1] (4)	9.6 [9.3] (6)	6.7 [6.5] (14)	4.8 [4.7] (26)	3.9 [3.8] (40)
03234500 Scioto R Higby	14.3 [14.1] (6)	14.3 [14.1] (6)	14.3 [14.1] (6)	14.3 [14.1] (6)	14.3 [14.1] (6)	12.9 [12.8] (12)
03237280 Upper Twin Cr McGaw	47.7 [31.4] (6)	58.7 [40.3] (4)	47.7 [31.4] (6)	28.9 [18.0] (16)	20.8 [12.8] (31)	16.8 [10.3] (48)
03237500 Ohio Brush Cr West Union	24.8 [15.0] (6)	34.3 [18.3] (3)	24.8 [15.0] (6)	20.5 [12.9] (9)	14.7 [9.5] (18)	11.8 [7.7] (28)
03238500 Whiteoak Cr Georgetown	48.4 [23.8] (6)	53.2 [25.0] (5)	48.4 [23.8] (6)	29.2 [17.2] (17)	21.1 [13.0] (33)	16.8 [10.4] (52)
03240000 L Miami R Oldtown	19.6 [6.6] (6)	16.2 [5.7] (8)	19.6 [6.6] (6)	10.8 [4.1] (15)	7.8 [3.1] (26)	6.7 [2.8] (34)
03241500 Massies Cr Wilberforce	27.7 [12.5] (6)	25.1 [11.4] (7)	27.7 [12.5] (6)	17.0 [8.1] (13)	12.2 [6.1] (23)	9.8 [5.0] (34)
03245500 L Miami R Milford	7.9 [4.0] (6)	11.8 [5.4] (3)	7.9 [4.0] (6)	7.2 [3.7] (7)	4.8 [2.6] (15)	3.4 [1.9] (30)
03247050 E Fk L Miami R Batavia	32.9 [32.2] (6)	34.2 [32.8] (3)	32.9 [32.2] (6)	32.7 [32.1] (7)	31.5 [31.3] (15)	28.1 [28.0] (49)
03247500 E Fk L Miami R Perintown	12.7 [8.3] (6)	17.9 [11.4] (3)	12.7 [8.3] (6)	11.8 [7.8] (7)	8.0 [5.4] (15)	5.5 [3.8] (32)

Table 14.--Selected results of K-CERA analysis--Continued

Identification	Standard error of instantaneous discharges, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1984 dollars				
		679	682	816	1047	1282
03255500	27.3	27.3	22.8	14.0	10.4	8.7
Mill Cr	[14.8]	[14.8]	[12.8]	[8.4]	[6.4]	[5.4]
Reading	(6)	(6)	(8)	(18)	(31)	(43)
03259000	44.2	44.2	35.8	19.4	13.3	10.7
Mill Cr	[15.7]	[15.7]	[13.2]	[8.2]	[6.2]	[5.2]
Carthage	(6)	(6)	(8)	(18)	(31)	(43)
03267900	6.5	7.8	6.5	6.5	5.6	4.8
Mad R	[5.8]	[6.9]	[5.8]	[5.8]	[5.0]	[4.3]
Eagle City	(6)	(4)	(6)	(6)	(8)	(11)
04177000	76.1	85.4	76.1	51.2	18.4	18.4
Ottawa R	[61.8]	[70.4]	[61.8]	[44.0]	[6.5]	[6.5]
Toledo	(6)	(4)	(6)	(25)	(98)	(98)
04185000	25.3	30.0	25.3	19.2	14.7	11.7
Tiffin R	[22.6]	[25.8]	[22.6]	[17.6]	[13.5]	[10.7]
Stryker	(6)	(4)	(6)	(11)	(19)	(30)
04186500	43.7	48.1	43.7	27.2	19.7	15.5
Auglaize R	[19.2]	[20.6]	[19.2]	[13.2]	[9.8]	[7.7]
Ft. Jennings	(6)	(5)	(6)	(15)	(28)	(45)
04189000	19.7	31.0	19.7	13.8	10.3	8.1
Blanchard R	[8.7]	[10.3]	[8.7]	[7.2]	[5.8]	[4.7]
Findlay	(6)	(3)	(6)	(11)	(19)	(30)
04191500	34.9	55.5	34.9	24.1	17.8	14.0
Auglaize R	[16.5]	[20.2]	[16.5]	[14.0]	[11.6]	[9.7]
Defiance	(6)	(3)	(6)	(11)	(19)	(30)
04192500	10.0	14.1	10.0	8.2	7.2	6.6
Maumee R	[6.6]	[6.8]	[6.6]	[6.4]	[6.2]	[6.0]
Defiance	(6)	(3)	(6)	(11)	(19)	(30)
04193500	13.6	18.2	13.6	9.1	6.5	5.0
Maumee R	[5.3]	[6.5]	[5.3]	[3.9]	[3.0]	[2.4]
Waterville	(6)	(4)	(6)	(11)	(19)	(30)

Table 14.--Selected results of K-CERA analysis--Continued

Identification	Standard error of instantaneous discharges, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1984 dollars				
		679	682	816	1047	1282
04195500 Portage R Woodville	29.2 [16.5] (6)	39.2 [17.8] (3)	29.2 [16.5] (6)	23.3 [15.2] (11)	18.4 [13.2] (21)	15.0 [11.3] (35)
04196800 Tymochtee Cr Crawford	44.4 [34.2] (6)	47.6 [35.8] (5)	44.4 [34.2] (6)	25.5 [21.0] (23)	18.4 [15.1] (45)	14.3 [11.7] (74)
04197020 Honey Cr New Washington	31.4 [25.6] (6)	40.8 [33.0] (3)	31.4 [25.6] (6)	21.5 [17.3] (14)	15.3 [12.1] (28)	12.2 [9.6] (44)
04197100 Honey Cr Melmore	38.0 [16.8] (6)	41.7 [18.9] (5)	38.0 [16.8] (6)	19.3 [7.8] (23)	13.8 [5.6] (45)	10.8 [4.5] (74)
04197170 Rock Cr Tiffin	30.9 [29.5] (6)	31.8 [30.2] (5)	30.9 [29.5] (6)	22.0 [21.4] (23)	16.6 [16.1] (35)	13.0 [12.7] (74)
04198000 Sandusky R Fremont	15.9 [9.4] (6)	21.4 [10.8] (3)	15.9 [9.4] (6)	12.2 [7.8] (11)	9.1 [6.1] (21)	7.1 [4.8] (35)
04200430 W Br Black R Elyria	112.3 [111.3] (6)	102.3 [101.9] (10)	91.3 [91.1] (15)	43.8 [43.8] (73)	30.9 [30.8] (140)	25.3 [25.3] (204)
04200500 Black R Elyria	33.3 [6.9] (6)	24.0 [5.8] (10)	18.7 [5.0] (15)	7.8 [2.5] (73)	5.5 [1.8] (140)	4.6 [1.5] (204)
04201500 Rocky R Berea	28.0 [12.3] (6)	28.0 [12.3] (6)	28.0 [12.3] (6)	21.5 [9.5] (10)	15.9 [7.1] (18)	12.93 [5.8] (27)
04202000 Cuyahoga R Hiram Rapids	14.4 [6.5] (6)	13.4 [6.3] (7)	14.4 [6.5] (6)	12.6 [6.1] (8)	9.1 [5.0] (16)	7.3 [4.2] (26)

Table 14.--Selected results of K-CERA analysis--Continued

Identification	Standard error of instantaneous discharges, in percent [Equivalent Gaussian spread] (Number of visits per year to site)					
	Current operation	Budget, in thousands of 1984 dollars				
		679	682	816	1047	1282
04206000	4.6	4.6	4.6	3.9	3.0	2.6
Cuyahoga R	[4.1]	[4.1]	[4.1]	[3.5]	[2.8]	[2.4]
Old Portage	(12)	(12)	(12)	(17)	(29)	(39)
04207200	17.7	19.6	16.2	12.1	9.5	8.2
Tinkers Cr	[4.2]	[4.6]	[3.9]	[2.9]	[2.3]	[2.1]
Bedford	(6)	(5)	(7)	(12)	(19)	(25)
04208000	10.1	10.1	10.1	10.1	7.7	6.6
Cuyahoga R	[7.0]	[7.0]	[7.0]	[7.0]	[5.9]	[5.2]
Independence	(12)	(12)	(12)	(12)	(19)	(25)
04208502	29.5	36.4	25.4	11.0	8.9	8.9
Big Cr	[19.0]	[24.3]	[16.1]	[6.8]	[5.5]	[5.5]
Cleveland	(6)	(4)	(8)	(42)	(65)	(65)
04208690	109.0	116.1	106.3	54.6	43.4	43.4
Euclid Cr	108.1	[114.0]	[105.6]	[54.5]	[43.3]	[43.2]
Euclid	(6)	(3)	(7)	(42)	(65)	(65)
04209000	12.1	19.9	11.2	9.0	7.5	5.8
Chagrin R	[10.4]	[8.6]	[9.7]	[7.8]	[6.6]	[5.1]
Willoughby	(6)	(9)	(7)	(11)	(16)	(27)
04212100	18.2	18.2	18.2	18.2	17.6	16.2
Grand R	[17.7]	[17.7]	[17.7]	[17.7]	[17.2]	[16.0]
Painesville	(12)	(12)	(12)	(12)	(16)	(27)
04213000	27.7	23.0	27.7	20.0	15.1	11.5
Conneaut Cr	[8.2]	[7.0]	[8.2]	[6.2]	[4.8]	[3.8]
Conneaut	(6)	(8)	(6)	(10)	(16)	(26)

A minimum budget of $679,000 is required to operate the 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 31.1 percent. The minimum standard error of 3.9 percent would be for 03129000 (Newcomerstown), whereas the maximum of 102.3 percent would be for 04200430 (West Branch Black River).

The maximum budget analized was $1,282,000, which resulted in an average standard error of estimate of 11.1 percent. Thus, nearly doubling the budget in conjunction with schedule changes would more than halve the average standard error that would result from the current schedule and current budget. For the $1,282,000 budget, the extremes of standard error are a minimum of 2.3 percent for station 03147500 (Licking River near Dillon Falls) and a maximum of 43.4 percent at 04220000 (Euclid Creek). Thus, it is apparent that significant improvements in the accuracy of streamflow records can be obtained if larger budgets become available.

SUMMARY

Currently, there are 107 continuous stream gages and other gages being operated in Ohio at a cost of $682,000. Eleven separate sources of funding contribute to this program and seven separate uses were identified for the data from a single gage. In spite of the size of the program, there are areas for which additional coverage would be beneficial. The paucity of data in these areas should be remedied as funds can be made available.

In an analysis of the uses that are made of the data, no stations were identified that had insufficient reason to continue their operation. Stations identified as having uses specific only to short-term studies are generally not handled under the gaging network and were not considered in this analysis. All stations now in the network should be maintained in the program for the foreseeable future.

The current plan for operation of the 107-station program (including other field work) would require a budget of $682,000 per year. It was shown that the overall level of accuracy of the record at these 107 sites could not be maintained with a lesser budget. It is suggested that alteration take place to increase the accuracy within the present budget by changing the frequency of some visits.

Studies of the cost-effectiveness of the sream-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 loss-correlative data. Future studies also will be required because of changes in demand for streamflow information and the subsequent addition and deletion of stream gages. Such changes will affect the operation of other stations in the program in terms of data redundancy and cost.

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Appendix 1.--Data Requested by Cooperators for which no funds are available.

In recent years, the stream-gaging network has been reduced considerably for a number of reasons, the main reason being a lack of funding. Further, the expected expansion of the network in response to constantly increasing water problems has not occured.

Various cooperators expressed strong interest in additional gages should funds become available. The additional stations are listed below by coooperator and use.

Miami Conservancy District

To better define flow of tributaries for water management:

1.--Wolf Creek near Dayton downstream from Trotwood gage: to include flow from North Fork tributary.

2.--Honey Creek in Miami and Clark County; a high-yield stream in an area of residential development.

Northeast Ohio Areawide Coordinating Agency

To enhance ability to better manage areawide water-quality objectives:

1.--Each Branch Rocky River above Baldwin Lake.
2.--Chagrin River near Chagrin Falls.
3.--East Branch Chagrin River at mouth.
4.--Tinkers Creek near Hudson.
5.--Beaver Creek at mouth (between Black and Rocky Rivers).
6.--Cuyahoga River at Brecksville Road (SR 82).
7.--West Branch Rocky River at Sprague Road.

Ohio Envirementa1 Protection Agency

For (1) better water-quality monitoring, (2) planning and design, (3) legal obligations, and (4) regional hydrology:

1.--Black River below Elyria, (1, 2).
2.--Grand River at Painesville, (1, 2).
3.--Ashtabula River at Ashtabula, (1, 2, 3, 4).
4.--Hocking River at Lancaster, (1)
5.--Mohican River at Greer, (1)
6.--Hocking River below Lancaster, (1)
7.--Ottawa River at Allentown, (1, 3).

Ohio Department of Natural Resources

For regional hydrology purposes in such studies as dam safety, hydropower, watershed management, recreation, flood-plain management, fish and wildlife habitat, and erosion and sediment studies.

1.--Reestablish recently discontinued stations.
   a.--Huron River at Milan.
   b.--Ottawa River at Allentown.
   c.--Sandusky River near Mexico.
   d.--Chippewa Creek at Easton.
   e.--Mohican River at Greer.
   f.--Licking River at Utica.
   g.--Little Muskingum River at Bloomfield.

2.--Establish new daily record gages.
   a.--Feeder Canal above Buckeye Lake.
   b.--Outlet Channel below Buckeye Lake.
   c.--Beaver Creek below Grand Lake at St. Marys.
   d.--Gages upstream and downstream from a number of other non-Federal lakes.
   e.--Additional gages on unregulated streams in the upper reaches of tributary streams, particulary in the northwestern and southeastern parts of Ohio.

3.--Expand urban hydrology program.

Seneca County Soil and Water District

To further research associated with gross erosion between watersheds and sediment transportation.

1.--Reestablish discontinued stations
   a.--Broken Sword Creek at Nevada.
   b.--East Branch Wolf Creek near Bettsville.
   c.--West Branch Wolf Creek near Bettsville.

Department of the Army
Corps of Engineers, Buffalo District

Additional gages to be used for (1) regional hydrology, (2) hydrologic systems, and (3) hydrologic forecasts.

1.--Maumee River at Napoleon (1, 2, 3).
2.--Maumee River at Grand Rapids (1, 2, 3).
3.--Blanchard River at Ottawa (1, 2, 3).
4.--St. Joseph River at Mountpelier (1, 2, 3).
5.--Swan Creek at Toledo (1, 3).
6.--Vermilion River at Vermilion (1, 3).
7.--Sandusky River at Tiffin (1, 3).

U.S. Department of Commerce

National Oceanic and Atmospheric Administration

Stations to be added for River Forecast Center to better cover hydrologic forecasts for the State.

1.--Huron River at Milan.
2.--Vermilion River at Vermilion.
3.--St. Marys River at Rockford.
4.--Ottawa River at Allentown.
5.--Maumee River at Antwerp.

U.S. GOVERNMENT PRINTING OFFICE: 1986-648-551/41714