COST EFFECTIVENESS OF THE U.S. GEOLOGICAL SURVEY'S STREAM-GAGING PROGRAMS IN NEW HAMPSHIRE AND VERMONT

By Joseph A. Smath and Frank E. Blackey

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CONVERSION FACTORS AND ABBREVIATIONS

For the convenience of readers who may prefer to use metric (International System) units rather than the inch-pound units used in this report, values may be converted by using the following factors:

Multiply inch-pound units	by	To obtain SI units
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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ABSTRACT

This report documents the results of a study of the cost effectiveness of the stream-gaging programs in New Hampshire and Vermont. Data uses and funding sources were identified for the 73 continuous stream gages currently (1984) being operated. Eight stream gages were identified as having insufficient reason to continue their operation. Parts of New Hampshire and Vermont were identified as needing additional hydrologic data. New gages should be established in these regions as funds become available.

Alternative methods for providing hydrologic data at the stream-gaging stations currently being operated were found to lack the accuracy that is required for their intended use.

The current policy for operation of the stream gages requires a net budget of $297,000 per year. The average standard error of estimation of the streamflow records is 17.9 percent. This overall level of accuracy could be maintained with a budget of $285,000 if resources were redistributed among gages. Cost-effective analysis indicates that with the present budget, the average standard error could be reduced to 16.6 percent.

A minimum budget of $278,000 is required to operate the present stream-gaging program. Below this level, the gages and recorders would not receive the proper service and maintenance. At the minimum budget, the average standard error would be 20.4 percent.

The loss of correlative data is a significant component of the error in streamflow records, especially at lower budgetary levels.

INTRODUCTION

The U.S. Geological Survey is the principal Federal agency collecting surface-water data in the Nation. The collection of these data is a major activity of the Water Resources Division of the U.S. Geological Survey. The data are collected in cooperation with State and local governments and other Federal agencies. In 1983, the U.S. Geological Survey was operating approximately 8,000 continuous-record gaging stations throughout the Nation. Some of these records extend back to the turn of the century. Any activity of long standing, such as the collection of surface-water data, should be reexamined at intervals, if not continuously, because of changes in objectives, technology, or external constraints. The last systematic nationwide evaluation of the U.S. Geological Survey's streamflow information program was completed in 1970 and is documented by Benson and Carter (1973).

Purpose and Scope

In 1983, the U.S. Geological Survey began another nationwide study of its stream-gaging program to be completed over a 5-year period with 20 percent of the program being analyzed each year. The objective of this study is to define and document the most cost-effective means of furnishing streamflow information. The first step of the study is to identify the principal uses of the data collected at every continuous-record gaging station and to relate these uses to funding sources. Gaged sites for which data are no longer needed and areas requiring additional data are identified. In addition, gaging stations are categorized as to whether the data are available to users in a real-time sense, on a provisional basis, or at the end of the water year.

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

The final step of the study involves the use of Kalman-filtering and mathematical-programming techniques to define strategies for operation of the necessary stations that minimize the uncertainty in the streamflow records for given operating budgets. Kalman-filtering techniques are used to compute uncertainty functions (relating the standard errors of computation or estimation of streamflow records to the frequencies of visits to the stream gages) for all stations in the analysis. A steepest descent optimization program uses these uncertainty functions, information on practical stream-gaging routes, the various costs associated with stream gaging, and the total operating budget to identify the visit frequency for each station that minimizes the overall uncertainty in the streamflow. The stream-gaging program that results from this analysis will meet the expressed water-data needs in the most cost-effective manner.

The standard errors of estimate given in the report are those that would occur if daily discharges were computed through the use of methods described in this study. No attempt has been made to estimate standard errors for discharges that 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 being an introduction to the stream-gaging activities in New Hampshire and Vermont 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, findings are reported at the end of each of the middle three sections. The study, including all findings, is summarized in the final section.

History of the Stream-Gaging Programs in New Hampshire and Vermont

The stream-gaging programs in New Hampshire and Vermont began modestly in 1886 when a gage was established on the Pemigewasset River at Plymouth, New Hampshire. The programs gradually expanded to 20 gages in the two states by 1927 with stream-gaging efforts concentrated on major rivers. Flooding during 1927 and interest in the development of reservoir sites led to further growth of the programs. Hydropower companies became more interested in using the U.S. Geological Survey network of gages to supplement their own streamflow records. By 1935, there were 53 gages in the two states, many funded through cooperative agreements with various state agencies.

In response to floods during 1936 and 1938, the U.S. Army Corps of Engineers became involved in the stream-gaging programs. The Corps needed streamflow data at sites being considered for flood-control control structures. After construction of these projects, many gages were left in place to monitor outflows. At the present time, the Corps is funding 16 gaging stations.

Interest in the streamflow characteristics of small drainage basins (less than 10 square miles) prompted the establishment of 20 continuous-record stations beginning in 1962. Eleven of these stations were discontinued from 1975 to 1979. The nine remaining stations were absorbed into the New Hampshire stream-gaging program.

The stream-gaging programs peaked during 1965-67 when 109 stations were operated in the two-state region. Reviews of data-needs and reductions in funding led to a decrease in the number of gages in recent years. The current programs consist of a total of 73 stream gages.

The number of continuous stream gages historically operated by the U.S. Geological Survey within New Hampshire and Vermont is given in figures 1 and 2.

Current New Hampshire and Vermont Stream-Gaging Programs

Selected hydrologic data, including standard USGS station number, drainage area, period of record, and mean annual flow, for the 73 stream gages of the New Hampshire and Vermont stream-gaging programs are given in table 1. Station identification numbers used elsewhere in this report are

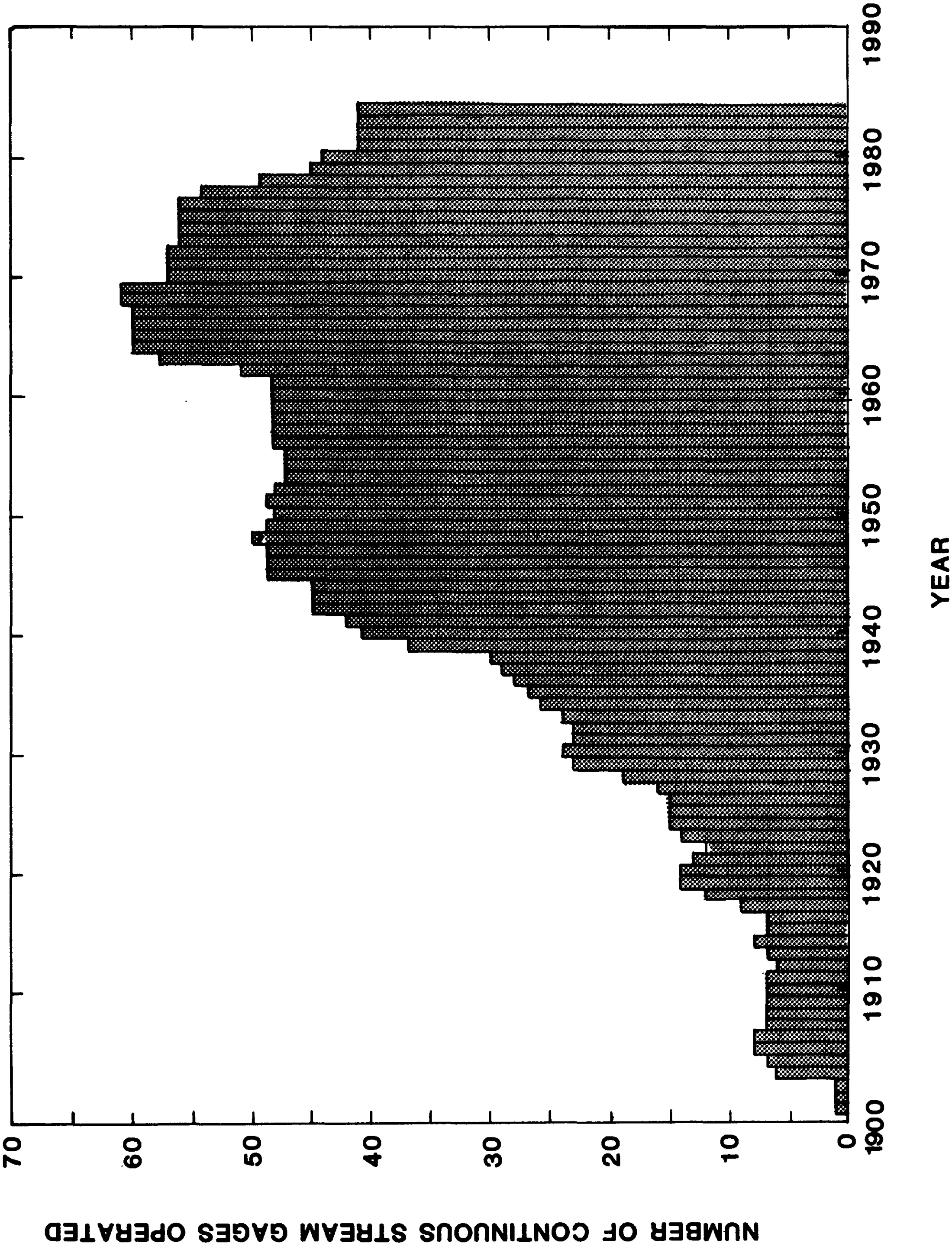

Figure 1.--History of continuous stream gaging in New Hampshire.

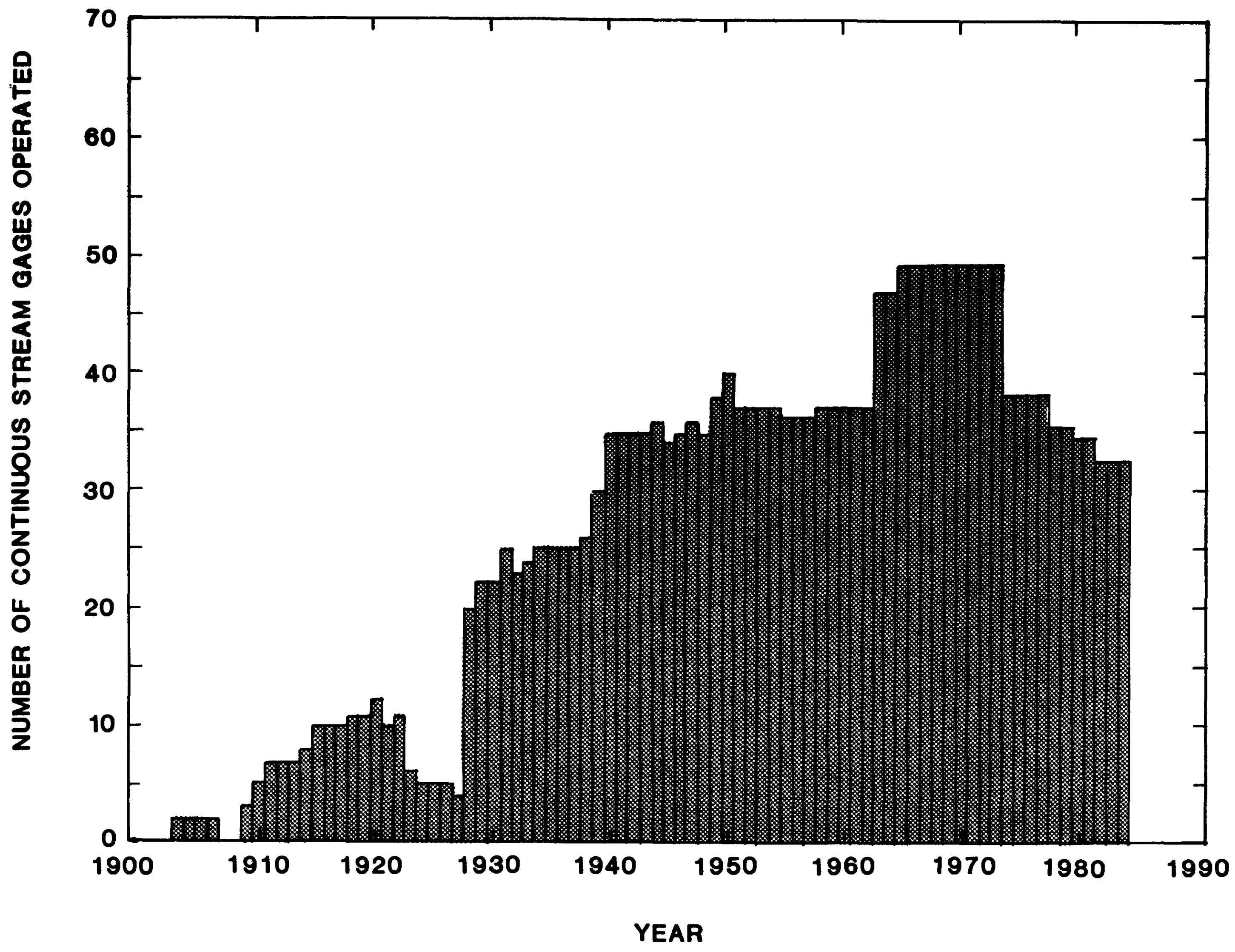

Figure 2.--History of continuous stream gaging in Vermont.

Table 1.--Selected hydrologic data for stations in the New Hampshire-Vermont stream-gaging programs

Footnotes are at end of table

Station no.	Station name (Abbreviated name)	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
01052500	Diamond River near Wentworth Location, N.H. (Diamond)	152	Jul 1941-	349
01053500	Androscoggin River at Errol, N.H. (Errol)	1,046	Jan 1905-1/	1,905
01054000	Androscoggin River near Gorham, N.H. (Gorham)	1,361	Oct 1913- 2/	2,465
01064300	Ellis River near Jackson, N.H. (Ellis)	10.9	Dec 1963-	33.6
01064400	Lucy Brook near North Conway, N.H. (Lucy)	4.68	Jun 1964-	11.0
01064500	Saco River near North Conway, N.H. (Saco)	385	Aug 1903- 3/ Dec 1909 Jan 1910- 3,4/ Jun 1912 Feb 1929-	931
01065000	Ossipee River at Effingham Falls,N.H. (Ossippee)	330	Sep 1942-	689
01072100	Salmon Falls River at Milton, N.H. (Salmon Falls)	108	Oct 1968-	198
01073000	Oyster River near Durham, N.H. (Oyster)	12.1	Oct 1934-5/	19.3

Table 1.--Selected hydrologic data for stations in the New Hampshire-Vermont stream-gaging programs--Continued

Station no.	Station name (Abbreviated name)	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
01073500	Lamprey River near Newmarket, N.H. (Lamprey)	183	Jul 1934-	280
01073600	Dudley Brook near Exeter, N.H. (Dudley)	4.97	May 1962-	6.98
01075800	Stevens Brook near Wentworth, N.H. (Stevens)	2.94	May 1963-	4.79
01076500	Pemigewasset River at Plymouth, N.H. (Plymouth)	622	Oct 1903-	1,358
01077000	Squam River at Ashland, N.H. (Squam)	57.6	Aug 1939-	88.2
01078000	Smith River near Bristol, N.H. (Smith)	85.8	May 1918-	143
01080500	Lake Winnipesaukee Outlet at Lakeport, N.H. (Lakeport)	363	Jan 1860- [6/] Dec 1911 Jun 1933-	534
01081000	Winnipesaukee River at Tilton, N.H. (Tilton)	471	Jan 1937-	702
01083000	Nubanusit Brook near Peterborough, N.H. (Nubanusit)	46.9	Oct 1920- Sep 1931 Jul 1945-	84.3
01085500	Contoocook River below Hopkinton Dam at West Hopkinton, N.H. (West Hopkinton)	427	Aug 1903- [7/] Apr 1907 Aug 1963-	699

Table 1.--Selected hydrologic data for stations in the New Hampshire-Vermont stream-gaging programs--Continued

Station no.	Station name (Abbreviated name)	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
01085800	West Branch Warner River near Bradford, N.H. (Bradford)	5.75	May 1962-	11.4
01087000	Blackwater River near Webster, N.H. (Blackwater)	129	May 1918- Sep 1920 Feb 1927-	212
01089000	Soucook River near Concord, N.H. (Soucook)	76.8	Oct 1951-	111
01090800	Piscataquog River below Everett Dam near East Weare, N.H. (Everett Dam)	63.1	Mar 1963-	95.0
01092000	Merrimack River near Goffs Falls below Manchester, N.H. (Goffs Falls)	3,092	Oct 1936-	5,260
01093800	Stony Brook Tributary near Temple, N.H. (Stony)	3.60	May 1963-	6.97
01127880	Big Brook near Pittsburg, N.H. (Big Brook)	6.36	Dec 1963-	16.0
01128500	Connecticut River at First Connecticut Lake near Pittsburg, N.H. (First Connecticut Lake)	83.0	Apr 1917-	197

Table 1.--Selected hydrologic data for stations in the New Hampshire-Vermont stream-gaging programs--Continued

Station no.	Station name (Abbreviated name)	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
01129200	Connecticut River below Indian Stream near Pittsburg, N.H. (Indian Stream)	254	Oct 1956-	571
01129300	Halls Stream near East Hereford, Quebec, Canada (Halls Stream)	85	Oct 1948- 8/	170
01129500	Connecticut River at North Stratford, N.H. (North Stratford)	799	Aug 1930-	1,583
01130000	Upper Ammonoosuc River near Groveton, N.H. (Groveton)	232	Aug 1940- Nov 1980 Oct 1982-	473
01131500	Connecticut River near Dalton, N.H. (Dalton)	1,514	Mar 1927- 9/	2,907
01134500	Moose River at Victory, Vt. (Victory)	75.2	Jan 1947-	142
01135000	Moose River at St. Johnsbury, Vt. (St. Johnsbury)	128	Aug 1928-	220
01135500	Passumpsic River at Passumpsic, Vt. (Passumpsic)	436	Oct 1928- 10/	737
01137500	Ammonoosuc River at Bethlehem Jct., N.H. (Bethlehem Jct.)	87.6	Aug 1939-	208

Table 1.--Selected hydrologic data for stations in the New Hampshire-Vermont stream-gaging programs--Continued

Station no.	Station name (Abbreviated name)	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
01138500	Connecticut River at Wells River, Vt. (Connecticut at Wells)	2,644	Oct 1949- 11/	4,715
01139000	Wells River at Wells River, Vt. (Wells at Wells)	94.4	Aug 1940-	141
01139800	East Orange Branch at East Orange, Vt. (East Orange)	8.95	Jun 1958-	15.7
01141500	Ompompanoosuc River at Union Village, Vt. (Ompompanoosuc)	130	Sep 1940-	194
01141800	Mink Brook near Etna, N.H. (Mink)	4.60	Aug 1962-	7.39
01142500	Ayers Brook at Randolph, Vt. (Ayers)	30.5	Jul 1939- Sep 1975 Jun 1976-	46.4
01144000	White River at West Hartford, Vt. (White)	690	Jun 1915- 12/	1,183
01144500	Connecticut River at West Lebanon, N.H. (West Lebanon)	4,092	Oct 1911- 13/ Nov 1976 Nov 1978-	7,133
01150500	Mascoma River at Mascoma, N.H. (Mascoma)	153	Aug 1923-	215

Table 1.--Selected hydrologic data for stations in the New Hampshire-Vermont stream-gaging programs--Continued

Station no.	Station name (Abbreviated name)	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
01151500	Ottauquechee River at North Hartland, Vt. (Ottauquechee)	221	Oct 1930-	396
01152500	Sugar River at West Claremont, N.H. (Sugar)	269	May 1928- 14/	404
01153000	Black River at North Springfield,Vt. (North Springfield)	158	Oct 1929-	290
01153500	Williams River at Brockways Mills, Vt. (Williams)	103	Jun 1940-	172
01154500	Connecticut River at North Walpole, N.H. (North Walpole)	5,493	Mar 1942-	9,363
01155500	West River at Jamaica, Vt. (Jamaica)	179	Oct 1946-	365
01156000	West River at Newfane, Vt. (Newfane)	308	Sep 1919- Sep 1923 Oct 1928-	627
01158000	Ashuelot River below Surry Mountain Dam near Keene, N.H. (Surry Mountain)	101	Sep 1945-	174
01158600	Otter Brook below Otter Brook Dam near Keene, N.H. (Otter Brook)	47.2	May 1958-	78.7

Table 1.--Selected hydrologic data for stations in the New Hampshire-Vermont stream-gaging programs--Continued

Station no.	Station name (Abbreviated name)	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
01161000	Ashuelot River at Hindsdale, N.H. (Hindsdale)	420	Mar 1907- Dec 1911 Jul 1914-	670
01329000	Batten Kill at Arlington, Vt. (Batten Kill)	152	Oct 1928-	339
01334000	Walloomsac River near North Bennington, Vt. (Bennington)	111	Jun 1931-	221
04280000	Poultney River below Fair Haven, Vt. (Poultney)	187	Oct 1928-	251
04282000	Otter Creek at Center Rutland, Vt. (Center Rutland)	307	May 1928-	550
04282500	Otter Creek at Middlebury, Vt. (Middlebury)	628	Apr 1903- Apr 1907 Oct 1910- Jan 1920 Oct 1928-	986
04284000	Jail Branch at East Barre, Vt. (Jail Branch)	38.9	Aug 1920- Sep 1923 Oct 1933-	54.7
04285500	North Branch Winooski River at Wrightsville, Vt (North Branch Winooski)	69.2	Oct 1933-	134

Table 1.--Selected hydrologic data for stations in the New Hampshire-Vermont stream-gaging programs--Continued

Station no.	Station name (Abbreviated name)	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
04286000	Winooski River at Montpelier, Vt. (Winooski)	397	May 1909- Jun 1914 Jul 1914- Sep 1923 Aug 1928- 15/	588
04287000	Dog River at Northfield Falls, Vt. (Dog)	76.1	Oct 1934-	122
04288000	Mad River near Moretown, Vt. (Mad)	139	Jul 1910- Nov 1910 Oct 1928-	255
04289000	Little River near Waterbury, Vt. (Little River)	111	Jul 1910- 4/ Oct 1910 Oct 1935- 16/	240
04290500	Winooski River near Essex Jct., Vt. (Essex Jct.)	1,044	Oct 1928-	1,700
04292000	Lamoille River at Johnson, Vt. (Johnson)	310	Jul 1910- Dec 1910 Jun 1911- 17/ Dec 1913 Sep 1928-	534
04292500	Lamoille River at East Georgia, Vt. (East Georgia)	686	Aug 1929- 18/	1,236
04293000	Missiquoi River near North Troy, Vt. (North Troy)	131	Aug 1931-	271

Table 1.--Selected hydrologic data for stations in the New Hampshire-Vermont stream-gaging programs--Continued

Station no.	Station name (Abbreviated name)	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
04293500	Missiquoi River near East Berkshire, Vt. (East Berkshire)	479	Jul 1911-Sep 1923 Oct 1928- 19/	924
04296000	Black River at Coventry, Vt. (Coventry)	122	Oct 1951-	200
04296500	Clyde River at Newport, Vt. (Clyde)	142	May 1909-Sep 1919 May 1920-Aug 1922 Oct 1922-Sep 1924 20/ Nov 1928-May 1936 Sep 1938-	259

Footnotes for Table 1

1/ October 1922 to November 1943, monthly discharge only.

2/ October 1922 to February 1929, monthly discharge only.

3/ Prior to 1912 published as "at Center Conway".

4/ Gage heights only.

5/ October and November 1934, monthly discharge only.

6/ January 1860 to December 1911, monthly gage heights only.

Footnotes for Table 1--Continued

7/ August 1903 to April 1907, no winter record.

8/ October 1948 to September 1962, operated by Water Survey of Canada, Dept. of the Environment.

9/ Prior to 1935 published as "at Waterford, Vt.".

10/ October 1928, monthly discharge only.

11/ October and November 1949, monthly discharge only.

12/ October 1927 to September 1928, monthly discharge only.

13/ Prior to 1976 published as "at White River Jct., Vt.".

14/ Prior to October 1928 published as "at Claremont".

15/ Fragmentary record.

16/ Prior to 1962 published as "Waterbury River near Waterbury, Vt.".

17/ Monthly discharge only.

18/ Prior to 1937 published as "near Milton".

19/ Prior to October 1977 published as "near Richford".

20/ Prior to November 1928 published as "at West Derby".

abbreviated to the last six digits of the standard USGS eight-digit downstream-order station number. Table 1 also provides the full name of each stream gage, as well as an abbreviated version of each name; abbreviated names will be used in the remainder of this report unless otherwise indicated.

New Hampshire and Vermont can be divided into nine major physiographic regions based upon a scheme modified from Denny (1982) -- the Coastal Lowlands, the Southern and Northern Highlands, the White Mountains, the Connecticut Valley, the Green Mountain Highlands, the Champlain Lowlands, the Vermont Valley, and a portion of the Taconic Highlands. The locations of these regions and the 73 stations are shown on figure 3. Five gages are located in the Coastal Lowlands, 16 are located in the Southern Highlands, five gages are in the White Mountains region, and 18 are in the Northern Highlands. The Connecticut Valley contains 9 gages, the Green Mountain Highlands has 15 gages, and the Vermont Valley and Taconic Highlands each have two gages. There is one gage located in the Champlain Lowlands. Figure 3 illustrates that there is a good geographical distribution of gages in all regions except the Champlain Lowlands.

The combined cost of the New Hampshire and Vermont programs in fiscal year 1984 was $347,000.

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 collected at the gaging station. The uses of the data from each gage in the New Hampshire and Vermont programs were identified after discussions with the principal agencies that cooperate in funding the stream-gaging programs. These discussions indicated the importance of each gage and identified gaging stations that may be considered for discontinuation.

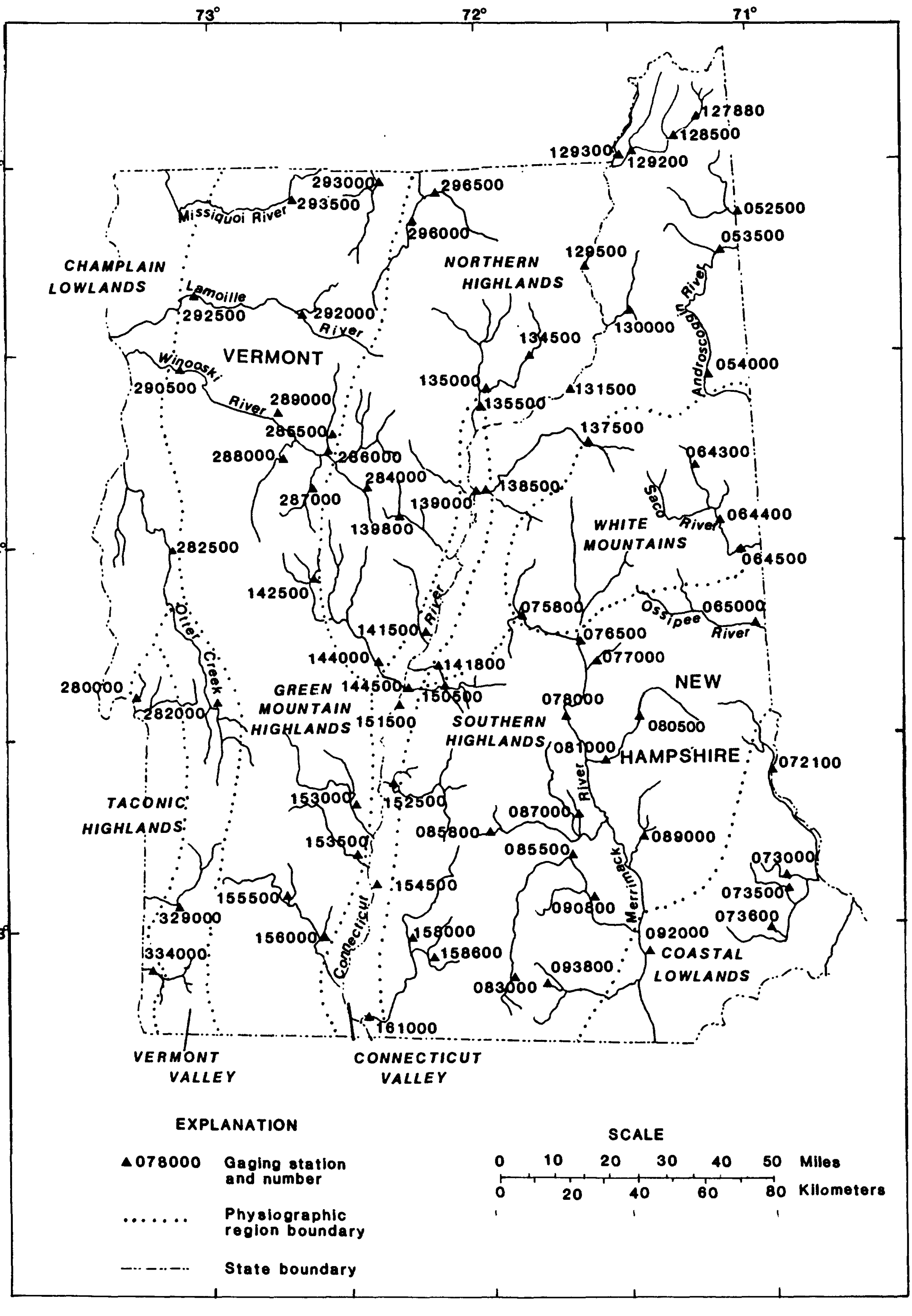

Figure 3.—Location of stream gages.

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

Data-Use Classes

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

Regional Hydrology

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

Thirty-five stations in New Hampshire and Vermont are classified in the regional hydrology category. Two of the stations are special cases in that they are designated index stations. These stations, one in each state, are used to indicate current hydrologic conditions. Four other stations have been designated as long-term-trend stations (Johnson, 1970). These stations are operated for the purpose of collecting a long-term record of streamflow data for regions of differing drainage area, physiographic, and climatic characteristics. Such data can be used to detect long-term changes in streamflow which could occur from a variety of factors. These stations have been proposed for indefinite operation. The locations of stream gages that provide information about regional hydrology are given in figure 4.

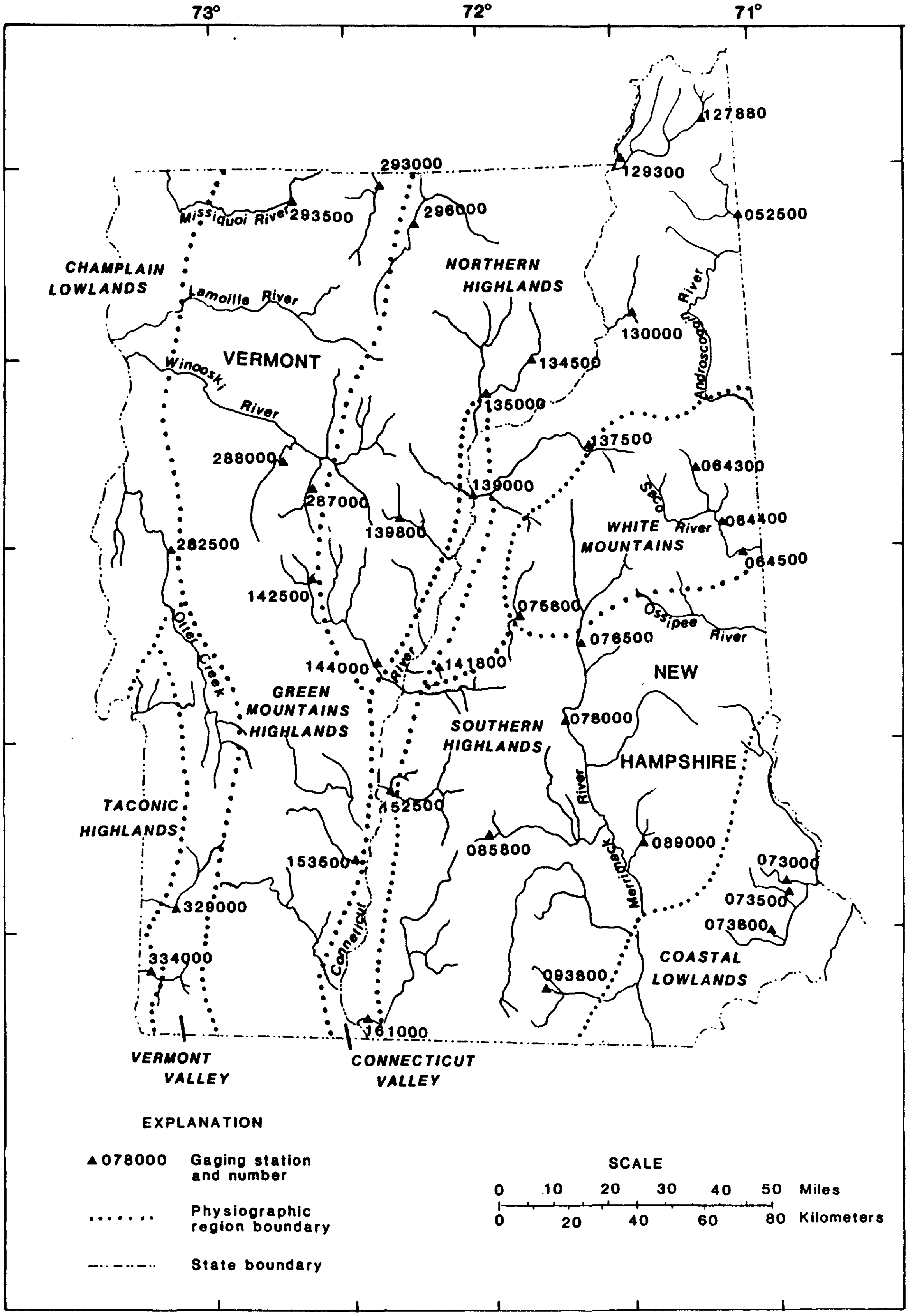

Figure 4.--Location of regional hydrology stream gages.

The thirty-five regional hydrology stations are distributed in such a manner that some regions of New Hampshire and Vermont are well represented while others are not. Those areas which are sparsely covered by regional hydrology gages include the Ossipee River drainage in the southern highlands, the western portion of the White Mountains region, and portions of the Green Mountain Highlands, Taconic Highlands and the Champlain lowlands. The other regions are either well-covered or have few non-regulated streams.

Hydrologic Systems

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

The two 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. Federal Energy Regulatory Commission (FERC) stations and an international gaging station located on Halls Stream along the New Hampshire-Canadian border also are included. The Halls Stream station provides data for the proper management of potentially conflicting uses of the river's resources by both countries. The data collected at the three FERC stations are used to monitor the compliance of control structures to downstream flow requirements determined by FERC.

Seven stations in Vermont are operated to provide streamflow data used for intra-basin streamflow management.

Legal Obligations

Some stations provide records of flows for the verification or enforcement of existing treaties, compacts, and decrees. The legal obligation category contains only those stations that the U.S. Geological Survey is required to operate to satisfy a legal responsibility. International gaging stations are not included in this category.

There are no stations in the New Hampshire or Vermont programs that are operated to fulfill a legal responsibility of the U.S.Geological Survey.

Planning and Design

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

Currently, no stations in the New Hampshire and Vermont programs are being operated for planning or design purposes.

Project Operation

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

There are 34 stations in New Hampshire and Vermont that are used in this manner. The data from these stations assist operators in the management of reservoirs and control structures, many of which are part of hydropower production systems.

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. The method of transmission may range in sophistication from direct-access telemetry to a dam operator travelling to a nearby station to read the gage. On large streams, data may only be needed every few days.

Twenty seven stations in the New Hampshire and Vermont programs are included in the hydrologic forecasts category. They are used for flood forecasting by the U.S. National Weather Service and for forecasting inflows to reservoirs that are part of hydropower generating systems.

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.

There are three stations that are designated NASQAN stations. NASQAN (National Stream Quality Accounting Network) stations are part of a nationwide network designed to assess water-quality trends of significant streams.

Research

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

Seven stations are used in the support of research activities. Data are collected on the Sugar River at West Claremont for use in river-ice research programs conducted by the Cold Regions Research and Environmental Laboratory of the U.S. Army Corps of Engineers. Streamflow data for the Saco River and Lucy Brook near North Conway are being used in a study of the Saco River valley aquifer conducted by the U.S. Geological Survey. Low-flow data collected at several gaging sites in Vermont are used for a variety of regional water-resource studies.

Other

In addition to the eight data-use classes described above, two stations are used to monitor streamflow below flood-retention basins and one station is used for instructional use by the University of New Hampshire.

Funding

The four sources 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) program.--Funds that have been transferred to the U.S. Geological Survey by OFA's.

3. Coop program.--Funds that come jointly from U. S. Geological Survey cooperative-designated funding and from a non-Federal cooperating agency. Cooperating agency funds may be in the form of direct services or cash.
4. Other non-Federal.--Funds that are provided entirely by a non-Federal agency or a private concern under the auspices of a Federal agency. In this study, funding from private concerns was limited to licensing and permitting requirements for hydropower development by the Federal Energy Regulatory Commission. Funds in this category are not matched by 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 activities, particularly collection of water-quality samples, that might be carried out at the site may not necessarily be the same as those identified herein.

Funding for stations not included in the federal program is derived from a variety of cooperating and other agencies. Federal agencies (other than the U.S. Geological Survey) that support stream-gaging activities in New Hampshire and Vermont include the U.S. Army Corps of Engineers and the International Joint Commission. These two agencies fund the operation of 22 stream gages. Non-federal agencies contribute to the operation of 54 stream gages. They include the New Hampshire State Water Resources Board, the Vermont State Department of Water Resources, the Maine Geological Survey and two hydropower companies.

Frequency of Data Availability

Frequency of data availability refers to the times at which the streamflow data may be furnished to the users. In this category, three distinct possibilities exist. Data can be furnished by direct-access telemetry equipment for immediate use, by periodic release of provisional data, or in publication format through the annual data report published by the U.S. Geological Survey for New Hampshire and Vermont (U.S. Geological Survey, 1982). These three categories are designated T, P, and A, respectively, in Table 2. In the current programs of New Hampshire and Vermont, data for all 73 stations are made available through the annual report, data from 22 stations are available on a real-time basis, and data are released on a provisional basis at 3 stations.

Data-Use Presentation

Data-use and supplemental information are presented for each continuous gaging station in Table 2. The entry of an asterisk in the table indicates that the station is used by the U.S. Geological Survey for regional hydrology purposes, and (or) the station is operated from Federal funds appropriated directly to the U.S. Geological Survey.

Conclusions Pertaining to Data Uses

One of the most important functions of the national stream-gaging program of the U.S. Geological Survey is to collect regional hydrologic data that is transferrable to non-gaged sites. As previously discussed, such regional hydrology stations should be located on unregulated basins and they should be spatially located to provide information within geographic regions of similar structure and climate.

Table 2.--Data-use table

Asterisk (*) indicates explanation of data use or funding is given in text; footnotes are at end of table

STATION NUMBER	DATA USE									FUNDING				DATA AVAILABILITY
	REGIONAL HYDROLOGY	HYDROLOGIC SYSTEMS	LEGAL SYSTEMS	PLANNING & DESIGN	PROJECT OPERATION	HYDROLOGIC FORECASTS	WATER-QUALITY MONITORING	RESEARCH	OTHER	FEDERAL PROGRAM	OFA PROGRAM	CO-OP PROGRAM	OTHER NON FEDERAL	
052500	*				1	1						2		A,T
053500		3			1	1							1	A
054000		3			1	1							1	A
064300	*											4		A
064400	*							6				4		A
064500	*					5		6				2		A
065000					7							4		A
072100					7							4		A,T
073000	*								8			4		A
073500	*											4		A,T,P
073600	*											4		A
075800	*											4		A
076500	9	9				10				*				A,T,P
077000					7	7						4		A
078000	11				12	12				*				A
080500					7	7						4		A
081000					7	7						4		A,T
083000					12						13			A
085500					12						13			A
085800	*											4		A

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

STATION NUMBER	DATA USE									FUNDING				DATA AVAILABILITY
	REGIONAL HYDROLOGY	HYDROLOGIC SYSTEMS	LEGAL SYSTEMS	PLANNING & DESIGN	PROJECT OPERATION	HYDROLOGIC FORECASTS	WATER-QUALITY MONITORING	RESEARCH	OTHER	FEDERAL PROGRAM	OFA PROGRAM	CO-OP PROGRAM	OTHER NON FEDERAL	
087000					12						13			A
089000	*					12				*				A,T
090800					12						13			A
092000					7							4		A,T
093800	*											4		A
127880	*											4		A
128500					7,14							4		A
129200					7,14	7,14						4		A,T
129300	*	15									16			A
129500					7,14	10,14						4		A,T
130000	11				14	14						4		A,T
131500					7,14	14						4		A,T
134500	*							17				18		A
135000	*											18		A
135500					14	10,14						18		A,T
137500	*					10,14					13,19			A,T
138500					7	10,14	20					4		A,T
139000	11							17				18		A
139800	*											18		A
141500					12						13			A

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

STATION NUMBER	DATA USE: REGIONAL HYDROLOGY	HYDROLOGIC SYSTEMS	LEGAL SYSTEMS	PLANNING & DESIGN	PROJECT OPERATION	HYDROLOGIC FORECASTS	WATER-QUALITY MONITORING	RESEARCH	OTHER	FUNDING: FEDERAL PROGRAM	OFA PROGRAM	CO-OP PROGRAM	OTHER NON FEDERAL	DATA AVAILABILITY
141800	*											4		A
142500	*							21			13,19	18		A
144000	*				14	10,14						18		A,T
144500					12	12,14				*				A,T
150500					7							4		A
151500					12						13	18		A,T
152500	*							21			13,19			A
153000					12						13			A
153500	*											18		A
154500					7,14 22	10,14 22	20					4		A,T
155500					12						13			A
156000					12	10					13	18		A,T
158000					12	12					13			A
158600					12	12					13			A
161000	*				14,22	10,22						4		A
329000	*											18		A
334000	*							17				18		A
280000		23										18		A
282000		23				10						18		A,T
282500	*											18		A

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

STATION NUMBER	DATA USE									FUNDING				DATA AVAILABILITY
	REGIONAL HYDROLOGY	HYDROLOGIC SYSTEMS	LEGAL SYSTEMS	PLANNING & DESIGN	PROJECT OPERATION	HYDROLOGIC FORECASTS	WATER-QUALITY MONITORING	RESEARCH	OTHER	FEDERAL PROGRAM	OFA PROGRAM	CO-OP PROGRAM	OTHER NON FEDERAL	
284000									24		13,19			A
285500									24		13,19			A
286000		23				10						18		A
287000	9	9										18		A,P
288000	*											18		A
289000		3										18	25	A
290500		23								*				A
292000		23										18		A
292500		23										18		A
293000	*											18		A
293500	11											18		A
296000	*					10	20			*				A,T
296500		23										18		A

Footnotes for Table 2

1. Union Water Power Co. hydropower system operation.
2. State of Maine, Maine Geological Survey, program coordinator for most state agencies.
3. Federal Energy Regulatory Commission hydropower licensing requirements

Footnotes for Table 2--Continued

4. New Hampshire State Water Resources Board, program co-ordinator for most state agencies.
5. Flood forecasting, U.S. National Weather Service (proposed).

6. Saco River valley aquifer study.
7. New Hampshire Water Resources Board reservoir regulation and downstream flow management.
8. Instructional use and research, University of New Hampshire.
9. Long-term index gaging station.
10. Flood forecasting, U.S. National Weather Service.

11. Long-term trend station.
12. U.S. Army Corps of Engineers, New England Division reservoir regulation and downstream flow management.
13. U.S. Army Corps of Engineers, New England Division.
14. New England Power hydropower system operation.
15. International gaging station, Boundary Waters Treaty of 1909.

16. International Joint Commission (State Dept.).
17. Low-flow data collection for regional water-resource studies, State of Vermont.
18. Vermont State Department of Water Resources, program co-ordinator for most state agencies.
19. U.S. Army Corps of Engineers Replacement funds.
20. NASQAN station.

21. Data collection for river-ice research and other studies, U.S. Army Corps of Engineers, New England Division.
22. Northeast Utilities hydropower system operation.
23. Intra-basin flow management, regional streamflow surveys.
24. Streamflow monitoring below flood-retention basin.
25. Citizen's Utility Company.

Several of the physiographic regions in New Hampshire and Vermont are adequately represented by regional hydrology gages and no changes are suggested for them. Figure 4 indicates that the Coastal Lowlands and Northern Highlands are well covered by regional hydrology stations. The Connecticut Valley and Vermont Valley regions are the valleys of highly regulated river systems. No additional regional hydrology stations are suggested for these areas.

The other regions are not as well covered by regional hydrology gages and additional gages are suggested for them. In the Southern Highlands, it is suggested that a regional hydrology stream gage be established in the Ossipee River drainage basin. This area has the geographic feature of the Ossipee Hills and is located to the east of Lake Winnepesaukee, the largest lake wholly within the New Hampshire-Vermont region. In the White Mountains region, small drainage basins in the western area are not represented by a USGS-operated regional hydrology gage. Such a gage could be located in the unregulated headwater region of the Pemigewasset River or along the Mad River. The U.S. Forest Service also operates gages on several small drainage basins in this region as part of their Hubbard Brook watershed studies. The Green Mountain Highlands have only marginal representation of regional hydrology in their north-central and south-central areas. One gage could be added in each of these areas. Suggested locations are the Lamoille drainage in the north and the Deerfield drainage in the south. The Taconic Highlands could be represented by a stream gage on the Mettawee River drainage. It is further suggested that a gage be established in the Champlain Lowlands on an unregulated stream in the Dead Creek or Lemon Creek drainage basins.

The Lamprey (073500), St. Johnsbury (135000), Williams (153500), Batten Kill (329000), Middlebury (282500), Mad (288000), and North Troy (293000) stations are used only for regional hydrologic information and have at least 30 years of record. Because many streamflow characteristics for a site can be estimated with a reasonable degree of accuracy from such a period of record, it is suggested that the stream-gaging effort at these sites be relocated to supply needed regional hydrologic information for other areas. The Lakeport station (080500) will be discontinued after the 1984 water year based upon lack of need by the known users of the record.

Based on the preceeding discussion, the Lamprey, St. Johnsbury, Williams, Batten Kill, Middlebury, Mad, North Troy, and Lakeport stations will not be considered further in this report.

Funding for the stations Diamond (052500), Errol (053500), and Gorham (054000) are derived from sources in the State of Maine and they are operated by the Maine Office of the U.S. Geological Survey, WRD. Information on the contribution of these stations to the cost-effectiveness of the stream-gaging program in Maine can be found in Fontaine and others (1983). In addition, the funding and operation of the station Saco (064500) was transferred to the Maine office on October 1, 1983. These stations will not be considered further in this report.

ALTERNATIVE METHODS OF DEVELOPING STREAMFLOW INFORMATION

The second step of the study of the stream-gaging program is to investigate alternative methods of providing daily streamflow information in lieu of operating continuous-flow gaging stations. The objective of the second step is to identify gaging stations where alternative technology, such as flow-routing or statistical methods, can be used to determine daily mean streamflow in a more cost-effective manner than operating a continuous stream gage. No guidelines exist concerning suitable accuracies for particular uses of the data; therefore judgment is required in deciding whether the accuracy of the estimated daily flows is suitable for the intended purpose. The data uses at a station will influence whether a site has potential for alternative methods. For example, stations for which flood hydrographs are required in a real-time sense, such as hydrologic forecasts and project operation, are not candidates for the alternative methods. Likewise, there might be a legal obligation to operate an actual gaging station that would preclude utilizing alternative methods. The primary candidates for alternative methods are stations operated upstream or downstream of other stations on the same stream. The accuracy of the estimated streamflow at these sites may be suitable because of the high redundancy of flow information between sites. Similar watersheds, located in the same physiographic and climatic area, also may have potential for alternative methods.

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

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

Description of Flow-Routing Model

Computer model CONROUT (Doyle and others, 1983) was selected to route streamflow from one or more upstream locations to a downstream location by the unit-response convolution method. Downstream hydrographs are produced by the convolution of upstream hydrographs with their appropriate unit-response functions. The unit response functions were defined using the diffusion analogy method (Keefer, 1974; Keefer and McQuivey, 1974).

The convolution procedure treats a stream reach as a linear one-dimensional system in which the system output (downstream hydrograph) is computed by multiplying (convoluting) the ordinates of the upstream hydrograph by the unit-response function and lagging them appropriately. This model can only be applied at a downstream station when there is an upstream station on the same stream. An advantage of this model is that it can be used for regulated stream systems. Reservoir-routing techniques are included in the model so flows can be routed through reservoirs if the operating rules are known. Calibration and verification of the flow-routing model are achieved using observed upstream and downstream hydrographs and estimates of tributary inflows. The model has the capability of combining hydrographs, multiplying hydrographs by a ratio, and changing the timing of a hydrograph. In this analysis, the model is only used to route an upstream hydrograph to a downstream location. Routing can be accomplished using any equal-interval streamflow data; only daily streamflow data are used in this analysis.

Determination of the system's response to the input at the upstream end of the reach is not the total solution for most flow-routing problems. The convolution procedure makes no accounting of flow from the intervening area between the upstream and downstream locations. Such flows may be unknown or estimated by some combination of gaged and ungaged flows. An estimating technique that is satisfactory in many instances is the multiplication of known flows at an index gaging station by a factor (for example, a drainage-area ratio).

In the diffusion analogy method, the two parameters required to define the unit-response function are K_o, a wave dispersion or damping coefficient, and C_o, the flood wave celerity. K_o controls the spreading of the wave and C_o controls the traveltime. In the single linearization method, only one K_o and C_o value are used to define one unit-response function (linearization about a single discharge).

Adequate routing of daily flows can usually be accomplished using the single linearization method to represent the system response. However, if the routing coefficients vary drastically with discharge, linearization about a low-range discharge results in overestimated high flows that arrive late at the downstream site; whereas, linearization about a high-range discharge results in low-range flows that are underestimated and arrive too soon. A single unit-response function may not provide acceptable results in such cases. Therefore, the option of multiple linearization (Keefer and McQuivey, 1974), which uses a family of unit-response functions to represent the system response, is available. In the multiple linearization method, C_o and K_o are varied with discharge so a table of wave celerity (C_o) versus discharge (Q) and a table of dispersion coefficient (K_o) versus discharge (Q) are used.

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

Description of Regression Analysis

Simple- and multiple-regression techniques can also be used to estimate daily flow records. Application of such techniques result in regression equations that relate daily flows (or their logarithms) at a single station to daily flows at a combination of upstream, downstream, and (or) tributary stations. Regression techniques are not limited in application, like the flow-routing model, to stations where an upstream station exists on the same stream. The explanatory variables in the regression analysis can be stations from different watersheds, or downstream and tributary watersheds. The regression method has many of the same attributes as the flow-routing model in that it is easy to apply, provides indices of accuracy, and is generally accepted as a good tool for estimation. The theory and assumptions of regression analysis are described in several textbooks such as Draper and Smith (1966) and Kleinbaum and Kupper (1978). The application of regression analysis to hydrologic problems is described and illustrated by Riggs (1973) and Thomas and Benson (1970). Only a brief description of regression analysis is provided in this report.

A linear regression model of the following form was developed for estimating daily mean discharges in New Hampshire and Vermont:

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

where

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

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

B_o and B_j = regression constant and coefficients, and

e_i = the random error term, and

p = the number of explanatory variables.

The above equation is calibrated (B_o and B_j are estimated) using observed values of Y_i and x_j. These observed daily mean discharges can be retrieved from the WATSTORE Daily Values File. The values of x_j may be discharges observed on the same day as discharges at station i or may be for previous or future days, depending on whether station j is upstream or downstream of station i. Once the equation is calibrated and verified, future values of Y_i are estimated using observed values of x_j. The regression constant and coefficients (B_o and B_j) are tested to determine if they are significantly different from zero. A given station j should only be retained in the regression equation if its regression coefficient (B_j) is significantly different from zero. The regression equation should be calibrated using one period of time and then verified or tested on a different period of time to obtain a measure of the true predictive accuracy. Both the calibration and verification period should be representative of the range of flows that could occur at station i. The equation should be verified by plotting the residuals e_i (difference between simulated and observed discharges) against the dependent and all explanatory variables in the equation, and plotting the simulated and observed discharges versus time. These tests are intended to identify if the linear model is appropriate or whether some transformation of the variables is needed, and whether there is any bias in the equation such as overestimating low flows. These tests might indicate, for example, that a logarithmic transformation is desirable, that a nonlinear regression equation is appropriate, or that the regression equation is biased in some way. In this report these tests indicated that a linear model with Y_i and x_j, in cubic feet per second, was appropriate. The application of linear-regression techniques to four gaging stations in New Hampshire and Vermont is described in a subsequent section of this report.

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

Identification of Stream Gages Used to Evaluate Alternative Methods

An analysis of the data uses presented in table 2 identified four stations at which alternative methods for providing the needed streamflow information could be applied. These four stations are Dalton, East Georgia, Ayers, and Smith. Based on the capabilities and limitations of the methods and data availability, flow-routing techniques were used only at the Dalton and East Georgia gaging stations. Regression methods were applied to all four sites.

Flow-Routing Analysis Results

The U.S. Geological Survey computer model, CONROUT (Doyle and others, 1983), was used to simulate daily mean disharges at Dalton (131500) and East Georgia (292500).

A map of the Dalton study area is presented in Figure 5. The Dalton gage is located on the Connecticut River 43.5 miles downstream from the next upstream gage, North Stratford (129500). There is a small mill dam upstream from the Dalton gage which has a minor regulatory influence on the streamflow. The characteristics of the streamflow at both sites are affected by regulation at the Connecticut Lakes and Lake Francis, approximately 40 miles upstream from North Stratford. The intervening drainage area between Dalton and North Stratford is 715 mi^2, 47 percent of the total drainage area contributing to the Dalton site. There is one stream gage, Groveton (130000),

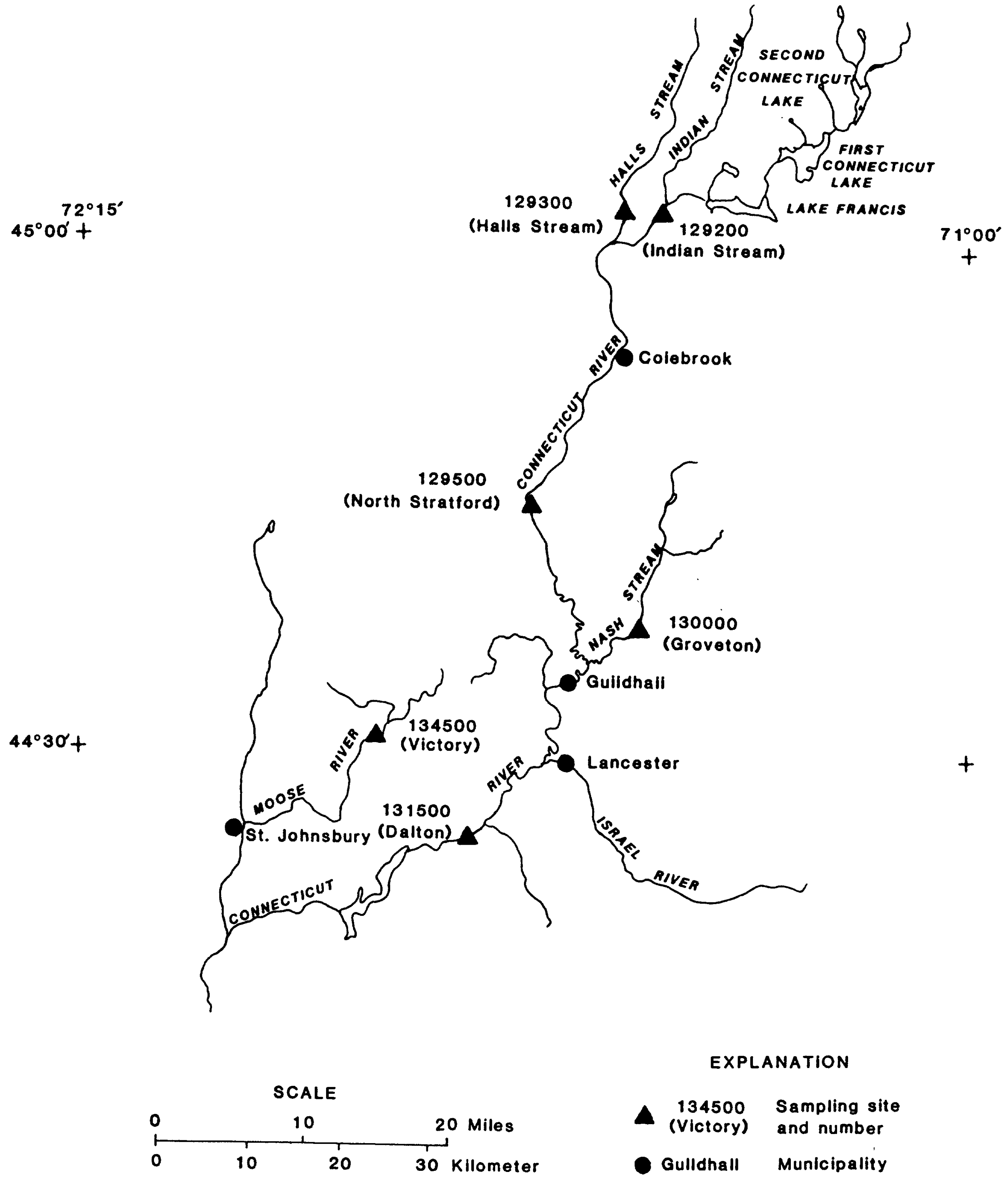

Figure 5.--The Dalton study area.

located within this intervening drainage area. Another stream gage, Victory (134500), is located on a downstream tributary to the Connecticut River. The Victory basin is adjacent to the intervening drainage area.

Mean daily streamflow at Dalton was simulated by routing the flow from North Stratford using the single linearization, diffusion-analogy method. The intervening drainage area was accounted for by using streamflow record from Groveton and Victory adjusted by drainage area adjustment factors. The total discharge at Dalton was the summation of the routed discharge from North Stratford and the adjusted discharges from Groveton and Victory.

It was necessary to determine the model parameters C_o (flood wave celerity) and K_o (wave dispersion coefficient) to route flow from North Stratford to Dalton. The coefficients C_o and K_o are functions of channel width (W_o) in feet, channel slope (S_o) in feet per foot (ft/ft), the slope of the stage-discharge relation (dQ_o/dY_o) in square feet per second (ft²/s), and the discharge (Q_o) in cubic feet per second (ft³/s). These parameters should be representative of the reach in question and are determined as follows:

$$C_o = \frac{1}{W_o} \frac{dQ_o}{dY_o} \qquad (2)$$

$$K_o = \frac{Q_o}{2 S_o W_o} \qquad (3)$$

The discharges, Q_o, for which initial values of C_o and K_o were linearized was the mean annual discharge for the Dalton and North Stratford gages. The channel width, W_o, was calculated as the average for the reach between the sites and was measured from topographic maps. Channel slope, S_o, was determined by subtracting the gage heights, converted to a common datum, which correspond to the mean annual discharges as given by the stage-discharge relation at each gage. This value was then divided by the reach length to obtain slope. The slope of the stage-discharge relation, dQ_o/dY_o, was determined from the rating curve at each gage by using a 1-foot increment that bracketed the mean discharge, Q_o. The difference in the discharge through the 1-foot increment then approximates the slope of the rating curve at the mean annual discharge. The model parameters as determined above are listed in table 3.

For the first routing trial, average values for the model parameters, C_o = 4.90 and K_o = 13,200, were used. The streamflow record from the Groveton gage (drainage area 232 mi^2) was used to simulate the intervening drainage along the east side of the Connecticut River (approximately 465 mi^2) using a drainage area adjustment factor of 2.0 (465 mi^2 divided by 232 mi^2). The streamflow record from the Victory gage (drainage area 75.2 mi^2) was used to simulate the intervening drainage along the west side of the Connecticut River (approximately 250 mi^2) using a factor of 3.32 (250 divided by 75.2).

The routing model was calibrated using actual streamflow record for Dalton for the period of water years 1977 through 1980. Using the calibration data set, several trials were made adjusting both the values of C_o, K_o, and the drainage area adjustment factors. The best fit single linearization model was determined to be that with a C_o = 4.65, K_o = 17,100, and the originally determined drainage area adjustment factors. Comparison of the observed and simulated hydrographs did not reveal any consistent trends that would indicate the need for multiple linearization.

A summary of the simulation of daily mean discharge at Dalton for the calibration period is given in table 4. The routing model simulated the Dalton streamflow within 10 percent of observed streamflow for 57 percent of the calibration period

Table 3.--Selected reach characteristics used in the Dalton flow-routing study

Station	Q_o (ft^3/s)	W_o (ft)	S_o (ft/ft)	dQ_o/dY_o (ft^2/s)	C_o (ft/s)	K_o (ft^2/s)
North Stratford	1,580	260	3.26×10^{-4}	1,360	5.23	9,330
Dalton	2,900			1,210	4.65	17,100

Table 4.--Results of Dalton flow-routing model

Mean absolute error for 1,461 days	=	13.2 percent
Mean negative error (696 days)	=	-9.3 percent
Mean positive error (765 days)	=	16.8 percent
Total volume error	=	5.0 percent

31 percent of the total observations had errors ≤ 5 percent
57 percent of the total observations had errors ≤ 10 percent
71 percent of the total observations had errors ≤ 15 percent
81 percent of the total observations had errors ≤ 20 percent
87 percent of the total observations had errors ≤ 25 percent
13 percent of the total observations had errors > 25 percent

and within 5 percent for 31 percent of the period. The average difference between simulated and observed streamflow was 13.2 percent. The lack of better conformance between the simulated and observed streamflow may be attributed to some minor regulation between Dalton and North Stratford and the proportionately large area of intervening flow between the two sites.

CONROUT was also used to simulate streamflow at East Georgia (292500), a station on the Lamoille River. A map of the East Georgia study area is presented in figure 6. The East Georgia gage is located 31.2 miles downstream from Johnson (292000). There is some minor regulation between the two sites. The intervening drainage area is 376 mi^2, 55 percent of the total drainage area contributing to the East Georgia site. There are no other stream gages in the Lamoille River basin.

In order to simulate daily mean discharge at East Georgia, the flow at Johnson was routed downstream using the single linearization, diffusion-analogy method. Intervening flow was simulated with the discharge record from East Berkshire (293500) and Coventry (296000), stations located in adjacent basins (figure 3). The calibration period used was water years 1977 through 1980.

The routing parameters C_o and K_o were determined by using the techniques applied to the Dalton flow-routing analysis and are summarized in table 5. For the first routing trial, average values for the model parameters $C_o = 4.70$ and $K_o = 2,330$ were used. The streamflow record from Coventry adjusted by a factor based on drainage areas was used to simulate the intervening drainage contributed by the Gihon River. The adjustment factor was 0.61, the ratio of the Gihon River drainage area (75 mi^2) and the drainage area at Coventry (122 mi^2). Drainage from the remaining 301-mi^2 intervening area was simulated by adjusting the East Berkshire streamflow record by a factor of 0.63, the ratio of the remaining intervening area (301 mi^2) and the drainage area at East Berkshire (479 mi^2).

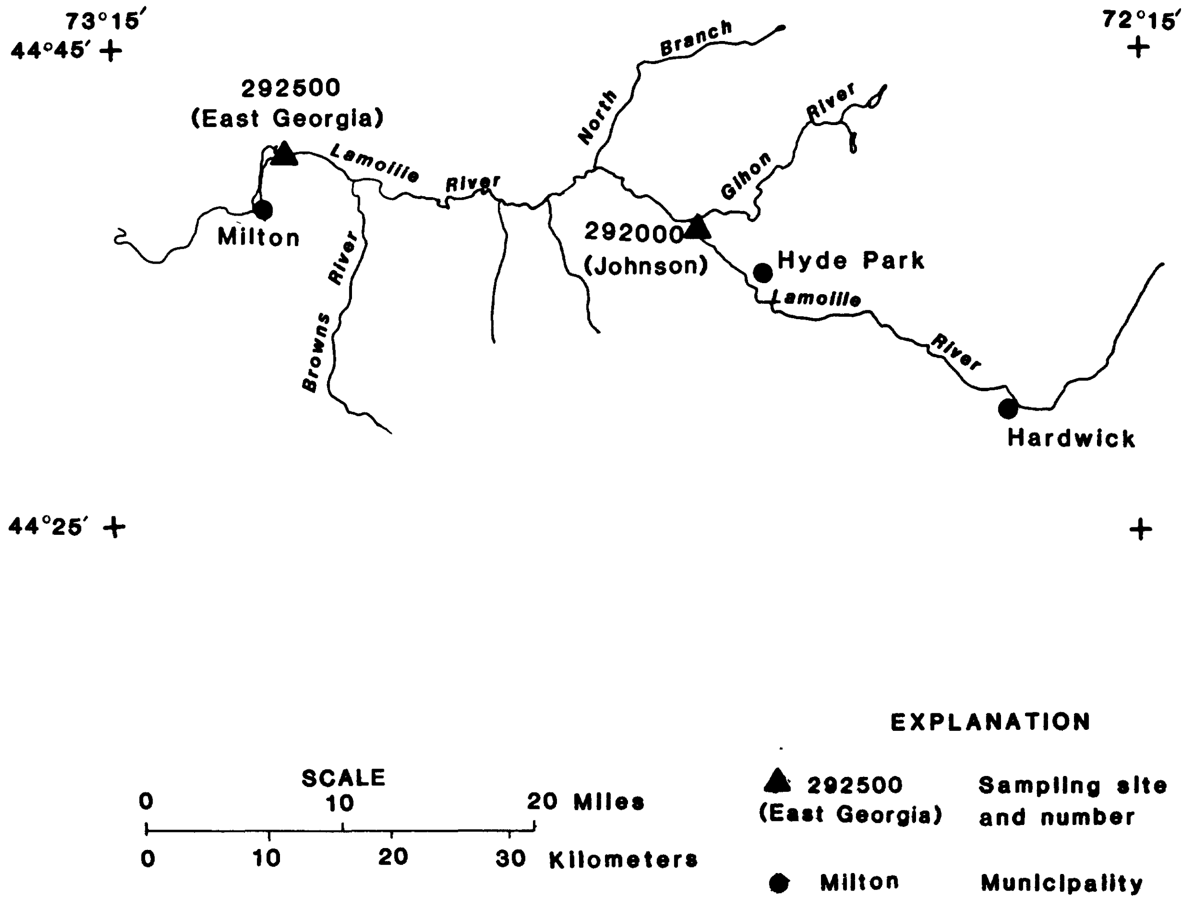

Figure 6.--The East Georgia study area.

Table 5.--Selected reach characteristics used in the East Georgia flow-routing study

Station	Q_o (ft^3/s)	W_o (ft)	S_o (ft/ft)	dQ_o/dY_o (ft^2/s)	C_o (ft/s)	K_o (ft^2/s)
Johnson	534	150	1.27×10^{-3}	478	3.19	1,400
East Georgia	1,240			919	6.13	3,250

The best model for this study was found to be the one using the initial model parameters as described above. Attempts were made to adjust the parameters C_o, K_o, and the drainage area adjustment factors, but none gave better results. Multiple linearization was determined to be unnecessary based upon inspection of the observed and simulated hydrographs.

The results from the East Georgia flow-routing analysis are summarized in table 6. the East Georgia streamflow was simulated within 10 percent of the actual streamflow for 39 percent of the calibration period and within 5 percent of actual during 21 percent of the period. The average simulation error for the period was 16.6 percent. The poor simulation by the model may be attributed to the minor regulation between East Georgia and Johnson, the proportionately large area of intervening flow between the two sites, and the lack of any regional hydrology gages within the Lamoille River basin which could be used to simulate the intervening flow.

Because of the poor results obtained during the calibration of the flow-routing models, no attempt was made to verify them.

Regression Analysis Results

Linear regression techniques were applied to all four of the selected sites. The streamflow record for each station considered for simulation (the dependent variable) was regressed against streamflow records at other stations (explanatory variables) during a given period of record (the calibration period). "Best fit" linear regression models were developed and used to provide a daily streamflow record that was compared to the observed streamflow record. The percent difference between the simulated and observed streamflow for each day was calculated. A summary of the models used for the station simulations and the coefficients of determination are presented in table 7. The coefficient of determination is a measure of how

Table 6.--Results of East Georgia flow-routing model

Mean absolute error for 1,461 days	=	16.6 percent
Mean negative error (946 days)	=	-16.9 percent
Mean positive error (515)days)	=	16.1 percent
Total volume error	=	-4.0 percent

21 percent of the total observations had errors ≤ 5 percent
39 percent of the total observations had errors ≤ 10 percent
54 percent of the total observations had errors ≤ 15 percent
66 percent of the total observations had errors ≤ 20 percent
77 percent of the total observations had errors ≤ 25 percent
23 percent of the total observations had errors > 25 percent

Table 7.--Summary of regression models of mean daily streamflow at selected gage sites in New Hampshire and Vermont

Q_{078000} : Daily mean streamflow for indicated station
LAG1 Q_{129500} : Previous day mean streamflow for indicated station

Station	Model	Coefficient of Determination	Calibration Period (water years)
Smith 078000	$Q_{078000} = 12.6 + 0.0544(Q_{076500}) + 7.79(Q_{141800})$	0.829	1978-1982
Dalton 1131500	$Q_{131500} = 89.6 + 1.23(\text{LAG1 } Q_{129500}) + 3.33(Q_{134500}) + 0.673(Q_{130000})$	0.957	1978-1980
Ayers 142500	$Q_{142500} = 5.40 + 0.0264(Q_{144000}) + 0.94(Q_{139800}) + 0.0604(Q_{287000})$	0.921	1978-1982
East Georgia 292500	$Q_{292500} = 103 + 1.20(Q_{292000}) + 0.378(\text{LAG1 } Q_{292000}) + 0.379(Q_{293500})$	0.938	1978-1982

well a regression model accounts for the variation of the dependent variable. A coefficient of determination of one indicates that the model perfectly predicts every value of the dependent variable. Conversely, a coefficient of determination of zero indicates that none of the variation in the dependent variable is explained by the model. The results from the application of these models are summarized in table 8.

The streamflow records at Ayers (142500) and Smith (078000) were not reproduced with an acceptable degree of accuracy using regression techniques. The simulated streamflow record at Ayers were within 10 percent of the actual record 28 percent of the time during the calibration period. At Smith, the simulated record was within 10 percent of the actual record during 19 percent of the calibration time period.

Both of these simulations involved multiple regression against streamflow records at stations with similar basin and hydrographic characteristics. There were no other stations located within the basins of the stations being simulated. Apparently, differences in basin characteristics and climatic differences were great enough to result in unsatisfactory simulations.

Better simulations were obtained for Dalton (131500) and East Georgia (292500). These simulations involved multiple regression against streamflow records at stations within the basins of the stations being simulated. The streamflow at both of these stations experience some degree of regulation. The dependent streamflow records were regressed against upstream records on the mainstem of the rivers as well as unregulated tributaries to the main stem. Special explanatory variables, specified as LAG1 Q, were created by lagging the appropriate discharge record by one day. The interaction in a regression of the lagged and unlagged values for a given streamflow record acts to statistically route the flow from an upstream site. The lagged discharges account for the traveltime between the two sites.

Table 8.--Results of regression models

Smith (078000)

Mean absolute error for 1,826 days	=	39.0 percent
Mean negative error (566 days)	=	-21.8 percent
Mean positive error (1260 days)	=	46.7 percent
Total volume error	=	0.0 percent

10 percent of the total observations had errors < 5 percent
19 percent of the total observations had errors < 10 percent
28 percent of the total observations had errors < 15 percent
38 percent of the total observations had errors < 20 percent
62 percent of the total observations had errors ≥ 20 percent

Dalton (131500)

Mean absolute error for 1,095 days	=	13.1 percent
Mean negative error (443 days)	=	-10.2 percent
Mean positive error (652 days)	=	15.0 percent
Total volume error	=	0.0 percent

24 percent of the total observations had errors < 5 percent
50 percent of the total observations had errors < 10 percent
70 percent of the total observations had errors < 15 percent
84 percent of the total observations had errors < 20 percent
16 percent of the total observations had errors ≥ 20 percent

Ayers (142500)

Mean absolute error for 1,826 days	=	30.8 percent
Mean negative error (631 days)	=	-14.7 percent
Mean positive error (1195 days)	=	39.4 percent
Total volume error	=	0.0 percent

15 percent of the total observations had errors < 5 percent
28 percent of the total observations had errors < 10 percent
43 percent of the total observations had errors < 15 percent
56 percent of the total observations had errors < 20 percent
44 percent of the total observations had errors ≥ 20 percent

East Georgia (292500)

Mean absolute error for 1,825 days	=	16.6 percent
Mean negative error (663 days)	=	-11.6 percent
Mean positive error (1162 days)	=	19.4 percent
Total volume error	=	0.0 percent

21 percent of the total observations had errors < 5 percent
40 percent of the total observations had errors < 10 percent
58 percent of the total observations had errors < 15 percent
72 percent of the total observations had errors < 20 percent
28 percent of the total observations had errors ≥ 20 percent

The regression model for Dalton includes three explanatory variables. The flow at Dalton was regressed against one-day lagged flow at North Stratford (129500), the nearest upstream station on the Connecticut River. Two tributary sites within the Connecticut River basin, Groveton (130000) and Victory (134500), served as indicators of unregulated inflow between Dalton and North Stratford. The stations used in this regression model are the same as those used for the Dalton flow-routing model as explained in a preceding section.

The estimates from the regression model for Dalton simulated the actual record within 10 percent for 50 percent of the calibration period and within 5 percent for 24 percent of the period. The average percent error for the period is 13.1 percent. There is some minor regulation just upstream from Dalton at a small mill dam. This fact and the proportionately large area of intervening flow between the two sites (47 percent of the total drainage area of Dalton) precluded better results from this simulation.

The streamflow record for East Georgia (292500) was simulated with a regression model that includes, as explanatory variables, the lagged and unlagged streamflow at Johnson (292000), and the streamflow at East Berkshire (293500). Johnson is located upstream from East Georgia on the Lamoille River and East Berkshire is an unregulated site located on the Missiquoi River, outside of the Lamoille River basin. The stations used in this regression model are similar to the ones used for the East Georgia flow-routing analysis, explained earlier.

The estimates from this regression model were within 10 percent of the observed streamflow for 40 percent of the calibration period and within 5 percent for 21 percent of the period. The average percent error for the period is 16.6 percent. These poor results can be attributed to some minor regulation between East Georgia and Johnson, the proportionately large area of intervening flow between these two sites (55 percent of the total drainage area of East Georgia), and the fact that intervening drainage had to be simulated using an out-of-basin streamflow record.

Because of the poor results obtained from all of the regression analyses, no attempt was made to verify the models.

Conclusions Pertaining to Alternative Methods of Data Generation

The simulated data from both the flow-routing and regression methods used for the Dalton and East Georgia stations and the regression methods used for Ayers and Smith were not sufficiently accurate to substitute these methods for the operation of a continuous-flow stream gage. These stations should remain in operation and are included in the next step of this analysis.

COST-EFFECTIVE RESOURCE ALLOCATION

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

In a study of the cost effectiveness of a network of stream gages operated to determine water consumption in the Lower Colorado River Basin, a set of techniques called K-CERA were developed (Moss and Gilroy, 1980). Because of the water-balance nature of that study, the measure of effectiveness of the network was chosen to be the minimization of the sum of variances of errors of estimation of annual mean discharges at each site in the network. This measure of effectiveness tends to concentrate stream-gaging resources on the larger, less stable streams, where potential errors are greatest. While such a tendency is appropriate for a water-balance network, in the broader context of the multitude of uses of the streamflow data collected in the USGS's Streamflow Information Program, this tendency causes undue concentration on larger streams. Therefore, The original version of K-CERA was extended to include as optional measures of effectiveness the sums of the variances of errors of estimation of the following streamflow variables: annual mean discharge in cubic feet per second, annual mean discharge in percent, average instantaneous discharge in cubic feet per second, and average instantaneous discharge in percent. 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 continously gaged sites as the measure of the effectiveness of the data-collection activity.

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

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

Description of Mathematical Program

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

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

The final step is to use all of the above to determine the number of times, N_i, that the i^{th} route (for i = 1, 2,..., NR, where NR is the number of practical routes), is used during a year such that (1) the budget for the network is not exceeded, (2) the minimum number of visits to each station is made, and (3) the total uncertainty in the network is minimized. Figure 7 represents this step in the form of a mathematical program. Figure 8 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,

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

$V \equiv$ 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 7.--Mathematical-programming form of the optimization of the routing of hydrographers.

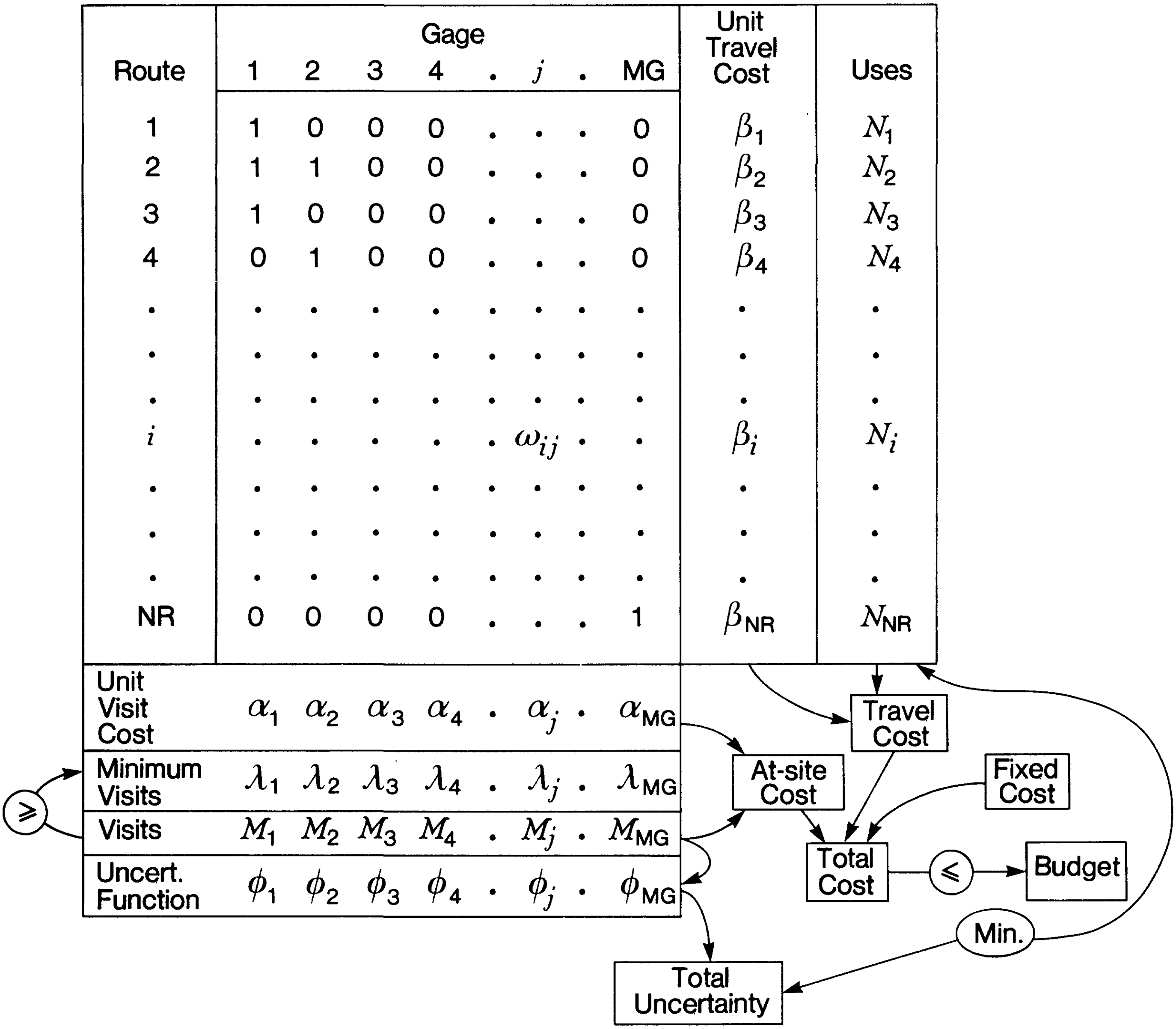

Figure 8.--Tabular form of the optimization of the routing of hydrographers.

(ω_{ij}), defines the routes in terms of the stations that comprise it. A value of one in row i and column j indicates that gaging station j will be visited on route i; a value of zero indicates that it will not. The unit travel costs, B_i, are the per-trip costs of the hydrographer's travel time and any related per diem and operation, maintenance, and rental costs of vehicles. The sum of the products of B_i and N_i for i=1, 2, ..., NR is the total travel cost associated with the set of decisions $N = (N_1, N_2, \ldots, N_{NR})$.

The unit-visit cost, α_j, is comprised of the average service and maintenance costs incurred on a visit to the station plus the average cost of making a discharge measurement. The set of minimum visit constraints is denoted by the row λ_j, j = 1, 2, ..., MG, where MG is the number of stream gages. The row of intergers M_j, j=1,2,...MG specifies the number of visits to each station. M_j is the sum of the products of ω_{ij} and N_i for all i and must equal or exceed λ_j for all j if N is to be a feasible solution to the 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 N obtained with this technique specify an efficient strategy for operating the network, which may be the true optimum strategy. The true optimum cannot be guaranteed without testing all undominated, feasible strategies.

Description of Uncertainty Functions

As noted earlier, uncertainty in streamflow records is measured in this study as the average relative variance of estimation of instantaneous discharges. The accuracy of a streamflow estimate depends on how that estimate was obtained. Three situations are considered in this study: (1) streamflow is estimated from measured discharge and correlative data using a stage-discharge relation (rating curve), (2) the streamflow record is reconstructed using secondary data at nearby stations because primary correlative data, such as stage, are missing, and (3) primary and secondary data are unavailable for estimating streamflow. The variances of the errors of the estimates of flow that would be employed in each situation were weighted by the fraction of time each situation is expected to occur. Thus the average relative variance would be

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

with

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

where

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

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

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

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

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

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

V_e is the relative error variance during periods of no concurrent data at nearby stations.

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

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

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

where

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

e is the base of natural logarithms, and

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

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

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

(Fontaine and others, 1984, eq. 21).

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

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

(Fontaine and others, 1984, eqs. 23 and 25).

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

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

$$= [(1-e^{-ks}) - 0.5(1-e^{-2ks})]/(ks) \qquad (9)$$

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

$$x(t) = \ln q_T(t) - \ln q_R(t) = \ln[q_T(t)/q_R(t)] \qquad (10)$$

is the instantaneous difference between the natural 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 (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

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

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

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

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

where

v(t) is the measurement error, and

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

In the Kalman-filter analysis, the z(t) time series was analyzed to determine three site-specific parameters. The Kalman filter used in this study assumes that the time residuals x(t) arise from a continuous first order Markovian process that has a Gaussian (normal) probability distribution with zero mean and variance (subsequently referred to as process variance) equal to p. A second important parameter is β, the reciprocal of the correlation time of the Markovian process giving rise to x(t); the correlation between $x(t_1)$ and $x(t_2)$ is $\exp[-\beta|t_1 - t_2|]$. The 1-day auto correlation coefficient, RHO, of x(t) is a function of β. Fontaine and others (1984) also define q, the constant value of the spectral density function of the white noise which drives the Gauss-Markov x-process. The parameters, p, q, and β are related by

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

The variance of the observed residuals z(t) is

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

where r is the variance of the measurement error v(t). The three parameters, p, β, and r, are computed by analyzing the statistical properties of the z(t) time series. These three site-specific parameters are needed to define this component of the uncertainty relationship. The Kalman filter utilizes these three parameters to determine the relative variance of the errors of flow estimates from a primary recorder, V_f, as a function of the number of discharge measurements per year (Moss and Gilroy, 1980).

If the recorder at the primary site fails and there are no concurrent data at other sites that can be used to reconstruct the missing record at the primary site, there are at least two ways of estimating discharges at the primary site. A recession curve could be applied from the time of recorder stoppage until the gage was once again functioning or the expected value of discharge for the period of missing data could be used as an estimate. The expected-value approach is used in this study to estimate V_e, the relative error variance during periods of no concurrent data at nearby stations. If the expected value is used to estimate discharge, the value that is used should be the expected value of discharge at the time of year of the missing record because of the seasonality of the streamflow processes. The variance of streamflow, which also is a seasonally varying parameter, is an estimate of the error variance that results from using the expected value as an estimate. Thus, the coefficient of variation, C_v squared 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:

$$\bar{C}_v = \left[\frac{1}{365} \sum_{i=1}^{365} \left(\frac{\sigma i}{\mu i}\right)^2\right]^{1/2} \qquad (15)$$

where

$\overline{C}_v$ is the seasonally-averaged coefficient of variation,

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

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

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

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

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

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

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

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

Thus, if the residuals $\ln q_c(t) - \ln q_T(t)$ were normally distributed, (EGS) would be their variance. Here EGS is reported in units of percent becuase 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.

Application of K-CERA in New Hampshire and Vermont

As a result of the first two parts of this analysis, it has been recommended that 61 of the currently existing stream gages in the States of New Hampshire and Vermont be continued in operation. These 61 stream gages were subjected to the K-CERA analysis with results that are described below. One stream gage, Halls stream (01129300) was not subjected to the Kalman-filter definition of variance because the streamflow record at this site is largely maintained by the Water Survey of Canada. This gage was included in the subsequent cost-effective analysis, however, because it is part of the total funding of the surface-water program and it requires several visits per year by U.S. Geological Survey hydrographers.

Definition of Missing Record Probabilities

As was described earlier, the statistical characteristics of missing stage or other correlative data for computation of streamflow records can be defined by a single parameter, the value of k in the truncated negative exponential probability distribution of times to failure of the equipment. In the representation of f_τ as given in equation 6, 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. A period of actual data collection of 5 years duration was used to estimate 1/k in New Hampshire and Vermont. The stations were divided into two groups to reflect differences in equipment. During the estimation period, stations which are equipped with manometer-type water-stage sensors were found to have an average of 8.1 percent missing record. All other stations were found to be malfunctioning an average of 3.6 percent of the time. These values of percentage missing record and a visit frequency of 9 per year were used to determine values of 1/k of 237 days for manometer stations and 550 days for the other stations. These values of 1/k were used to determine ε_f, ε_e, and ε_r for each of the stream gages as a function of the individual frequencies of visit. Tables 9 and 10 indicate how the missing-record functions vary with visit frequency.

Table 9.--Summary of missing-record probabilities for manometer-type gaging stations

ε_f: Fraction of time that primary recorders are functioning.

ε_r: Fraction of time that secondary source of information is available to reconstruct streamflow records.

ε_e: Fraction of time that primary recorders are not functioning and secondary source of information is unavailable.

Number of visits per year	ε_f	ε_r	ε_e
0	0.000	0.000	1.000
1	.510	.200	0.290
2	.697	.187	.116
4	.830	.133	.037
6	.882	.100	.018
8	.910	.080	.011
9	.919	.072	.009
10	.927	.066	.007
12	.938	.057	.005
15	.950	.046	.003
20	.962	.036	.002
24	.969	.030	.001
36	.979	.021	.001

Table 10.--Summary of missing-record probabilities for non-manometer-type gaging stations

ε_f: Fraction of time that primary recorders are functioning.

ε_r: Fraction of time that secondary source of information is available to reconstruct streamflow records.

ε_e: Fraction of time that primary recorders are not functioning and secondary source of information is unavailable.

Number of visits per year	ε_f	ε_r	ε_e
0	0.000	0.000	1.000
1	.731	.177	0.092
2	.851	.120	.029
4	.921	.070	.008
6	.947	.050	.004
8	.960	.038	.002
9	.964	.034	.002
10	.968	.031	.001
12	.973	.026	.001
15	.978	.021	.001
20	.984	.016	.000
24	.986	.013	.000
36	.991	.009	.000

Definition of Cross-Correlation Coefficient
Coefficient of Variation

Daily streamflow records for each station were used to compute the values of V and V of the uncertainty functions. Records for water years 1951 through 1981, were retrieved from WATSTORE (Hutchinson, 1975), a computerized data base, and used for the computation. For each of the stream gages, the value of $\bar{C}_v$ was computed and various options, based on combinations of other correlative stream gage records, were explored to determine the maximum ρ_c. In addition to other nearby stream gages some of the stations had other means by which streamflow data could be reconstructed when the primary recorder was malfunctioning. Some stations are equipped with telemetry systems that operate independently from the primary recorder and are routinely queried one or more times per day. At several sites, flow records based upon turbine ratings are available from nearby hydropower plants and can be used for streamflow reconstruction. Other sites are near control structures (non-hydropower) and records of discharge are available for them as well. At five sites, an auxiliary recorder is operated at the station to provide backup stage record. Analyses were performed to determine cross correlations between daily discharges at each of the stations and one or another of these types of auxillary records.

As explained in a previous section, the uncertainty V_e can be assumed to be equal to $\bar{C}_v$ the seasonally-averaged coefficient of variation. For New Hampshire and Vermont, this assumption was felt to be overly restrictive. It was reasoned that if the primary source for record reconstruction is not available, there would always be a secondary source for reconstruction. This value of ρ_c, the secondary cross-correlation coefficient, is designated as R_2. The value R_2 is chosen such that it is the second-highest cross-correlation value obtained in the ρ_c analysis. During periods of record reconstruction from a secondary source, the value of uncertainty, V_e, is assumed to be equal to the product $(1 - (R_2)^2)\ (\bar{C}_v)^2$.

For the case of available once-daily telemetric or observer readings, station Plymouth (076500), which had the highest $\overline{C}_v$ (116 percent) of any unregulated telemetered or observer site, yielded a ρ_c of 0.98 for once daily readings. Because a higher $\overline{C}_v$ indicates a relatively flashy stream, this value of ρ_c was assumed to be a worst case and was used for all other telemetered or observer stations that were read once daily. Some telemetered stations are queried more than once daily, on a variable basis. Because such a practice would be expected to yield a higher ρ_c than once-daily reading, a ρ_c of 0.99 was used for these stations. Other stations are queried on a once-daily basis only five times per week. It would be assumed that to reconstruct missing record on the remaining two days, another source for reconstruction would have to be used. For these cases, the value of ρ_c used was a time-weighted average value as calculated by:

$$\rho_c = \left[\frac{5(\rho_{cT})^2 + 2\ (\rho_{cO})^2}{7} \right]^{1/2} \qquad (18)$$

where

ρ_{cT} is the ρ_c for once-daily telemetric readings, and

ρ_{cO} is the ρ_c for the alternate source of record reconstruction.

In all cases, the alternate source of record reconstruction (ρ_c) selected for this calculation was the one with the next lowest ρ_c than for once-daily telemetric readings. Telemetric readings were not used for record reconstruction for those telemetered stations that are not queried routinely.

The Plymouth station was also used as a worst case situation for those stations with nearby control structure flow records (hydropower and non-hydropower). The selection of this station was predicated on the fact that the source of record for the control structure are reservoir inflow records from Plymouth, inherently more difficult to accurately compute than outflow records. The ρ_c developed for this source of record reconstruction was 0.99. This value was used for all stations with nearby control structure flow records.

At five stations, the only primary or secondary source for record reconstruction is control structure operation records. Unlike control structure flow records, they are comprised only of gate operation data. At these control structures, the gates or the structures themselves have never been rated to determine discharge. The operator log contains only the time and magnitude of the gate changes. The ability to accurately reconstruct missing streamflow record is based upon such information as the completeness of the operator log and the amount of unaccounted flow over the structure. Because of the inability to quantify such information, the value of ρ_c for use in such cases was estimated subjectively to be 0.90.

Record reconstruction based upon an auxiliary recorder at the gaging site would be expected to produce results nearly as accurate, if not as accurate, as the primary recorder. A ρ_c of 0.99 was assumed between the primary and auxiliary recorders at these sites.

The values of seasonally-averaged coefficient of variation ($\overline{C}_v$) and cross correlations for both the primary source for record reconstruction (ρ_c) and the secondary source for record reconstruction (R_2) are listed in table 11.

Table 11.--Statistics of record reconstruction

$\bar{C}_v$: Seasonally-averaged coefficient of variation, in percent.
ρ_c: Cross correlation coefficient for station and source for reconstructing records.
R_2: Secondary cross correlation coefficient.

Station no.	$\bar{C}_v$	ρ_c	R_2	Source(s) for reconstructing records
064300	103	0.89	---	064400 137500
	103	---	0.76	064400
064400	125	.85	---	064300 064500
	125	---	.84	054200 (station in Maine)
065000	77.0	.97	---	065500
	77.0	---	.90	066000
072100	71.1	.91	---	Telemetry, once daily, 5 times per week; 073000 089000
	71.1	---	.69	073000 089000
073000	128	.86	---	073600 089000
	128	---	.78	073600
073600	166	.79	---	073000 089000
	166	---	.66	089000
075800	161	.85	---	078000 137500 141800
	161	---	.81	078000 137500
076500	116	.99	---	Control structure flow records.
	116	---	.99	Telemetry, more than once daily.
077000	63.1	.90	---	Control structure operation records.
	63.1	---	.34	076500 078000
078000	122	.91	---	076500 141800
	122	---	.85	076500

Table 11.--Statistics of record reconstruction--Continued

Station no.	$\bar{C}_v$	ρ_c	R_2	Source(s) for reconstructing records
081000	61.4	0.96	---	Telemetry, once daily, 5 times per week; 080500
	61.4	---	0.89	080500
083000	95.2	.99	---	Supplemental recorder at site.
	95.2	---	.63	093800
085500	92.8	.77	---	085800 089000
	92.8	---	.64	085800
085800	139	.84	---	078000 093800
	139	---	.74	078000
087000	101	.81	---	078000 089000
	101	---	.74	089000
089000	107	.99	---	Telemetry, more than once daily.
	107	---	.85	078000 087000
090800	110	.99	---	Control structure flow records.
	110	---	.72	089000 093800
092000	79.3	.99	---	Control structure flow records.
	79.3	---	.95	100000 (station in Massachusetts)
093800	127	.79	---	085800 087000
	127	---	.56	087000
127880	104	.79	---	129300 296000
	104	---	.64	296000
128500	109	.99	---	Control structure flow records.
	109	---	.90	Control structure operation records.

Table 11.--Statistics of record reconstruction--Continued

Station no.	$\overline{C}_v$	ρ_c	R_2	Source(s) for reconstructing records
129200	71.5	0.92	---	Telemetry, once daily, 5 times per week; 129300 129500
	71.5	---	0.74	129300 129500
129500	73.6	.98	---	Telemetry, once daily.
	73.6	---	.88	130000 131500
130000	96.5	.98	---	Telemetry, once daily.
	96.5	---	.92	134500 137500 052500 (station in Maine)
131500	73.4	.98	---	Telemetry, once daily.
	73.4	---	.98	129500 130000 134500
134500	112	.85	---	130000 137500
	112	---	.74	137500
135500	89.6	.98	---	Telemetry, once daily.
	89.6	---	.94	134500 137500
137500	109	.87	---	064500 130000
	109	---	.81	130000
138500	74.9	.99	---	Control structure flow records.
	74.9	---	.98	Telemetry, once daily.
139000	92.1	.87	---	135500 137500
	92.1	---	.76	137500
139800	106	.82	---	142500 287000
	106	---	.79	287000
141500	102	.99	---	Control structure flow records.
	102	---	.85	141800 144000

Table 11.--Statistics of record reconstruction--Continued

Station no.	$\overline{C}_v$	ρ_c	R_2	Source(s) for reconstructing records
141800	139	0.80	---	075800 085800
	139	---	0.69	085800
142500	96.7	.96	---	139800 144000 287000
	96.7	---	.92	287000
144000	96.4	.98	---	Telemetry, once daily.
	96.4	---	.92	076500 287000
144500	77.6	.99	---	Control structure flow records.
	77.6	---	.99	Telemetry, more than once daily.
150500	94.2	.90	---	Control structure operation records.
	94.2	---	.70	141800 144000
151500	107	.99	---	Control structure flow records.
	107	---	.95	Telemetry, once daily, 5 times per week; 141800 144000
152500	107	.92	---	078000 085800
	107	---	.76	085800
153000	117	.99	---	Auxiliary recorder at site.
	117	---	.99	Control structure flow records.
154500	80.4	.99	---	Control structure flow records.
	80.4	---	.98	Telemetry, once daily.
155500	138	.99	---	Auxiliary recorder at site.
	138	---	.99	Control structure flow records.
156000	139	.99	---	Auxiliary recorder at site.
	139	---	.99	Control structure flow records.

Table 11.--Statistics of record reconstruction--Continued

Station no.	$\overline{C}_v$	ρ_c	R_2	Source(s) for reconstructing records
158000	120	0.99	---	Auxiliary recorder at site.
	120	---	0.99	Control structure flow records.
158600	124	.99	---	Control structure flow records.
	124	---	.87	093800 161000
161000	99.8	.91	---	158000 158600
	99.8	---	.86	158000
334000	90.8	.81	---	161000 282000
	90.8	---	.66	161000
280000	127	.81	---	144000 282000
	127	---	.77	144000
282000	92.7	.95	---	Telemetry, once daily, 5 times per week; 280000 287000
	92.7	---	.86	280000 287000
284000	133	.88	---	285500 286000
	133	---	.74	285500
285500	114	.91	---	284000 286000
	114	---	.74	284000
286000	89.3	.99	---	Control structure flow records.
	89.3	---	.98	Observer readings, once daily.
287000	111	.91	---	139800 144000
	111	---	.79	139800
289000	86.7	.90	---	Control structure operation records.
	86.7	---	.48	139800 287000

Table 11.--Statistics of record reconstruction--Continued

Station no.	$\overline{C}_v$	ρ_c	R_2	Source(s) for reconstructing records
290500	93.5	0.99	---	Control structure flow records.
	93.5	---	0.94	286000
292000	91.0	.99	---	Control structure flow records.
	91.0	---	.94	292500
292500	92.0	.97	---	292000 293500
	92.0	---	.86	293500
293500	110	.89	---	292000 296000
	110	---	.81	292000
296000	98.0	.84	---	129300 134500
	98.0	---	.75	129300
296500	66.2	.96	---	Control structure flow records; 04296000 01129300
	66.2	---	.65	129300 296000

Stations for which missing streamflow record can best be reconstructed are those with a low $\overline{C}_v$ and a high ρ_c and R_2. Values for $\overline{C}_v$ ranged from 61.4 to 166 percent. The lower values of $\overline{C}_v$ generally indicate a regulated stream. Missing record can be more easily reconstructed for stations with a low $\overline{C}_v$ because there is less variation in the streamflow record. High values of ρ_c and R_2 (near one) indicate a good linear relation between the streamflow record for a station and its source for reconstruction. Values for ρ_c ranged from 0.77 to 0.99 and for R_2 ranged from 0.34 to 0.99. The best sources for reconstruction are telemetry or daily observer readings (used for 16 stations), control structure flow records (18 stations), and auxilliary recorders (at 4 stations). Record reconstruction based on streamflow records from nearby stations varies greatly in accuracy as indicated by ρ_c and R_2.

Kalman-Filter Definition of Variance

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

Long-term ratings for the open-water periods at the New Hampshire and Vermont gaging stations were determined by applying a non-linear statistical fitting routine (SAS Institute Inc., 1979) to discharge measurements and correlative data. During periods of open water, the correlative data for a discharge rating function is the gage height. The rating function that was fit to this data was of the general form:

$$LQM = B_1 + B_3 * \ln (GHT-B_2) \qquad (19)$$

where

- LQM is the logarithmic (base e) value of the measured discharge,
- GHT is the recorded gage height corresponding to the measured discharge,
- B_1 is the logarithm (base 10) of discharge for an effective flow depth of 1 foot,
- B_2 is the gage height of zero flow,
- B_3 is the slope of the rating curve, and
- ln is the natural logarithm function.

The fitting routine computed the values for B1, B2, and B3 that best fit the given data sets. The best-fit rating function was then used to compute the rated discharge for the given gage heights. Residuals were computed as the rated discharge minus the measured discharge. The residuals divided by the rated discharge gives the percent error.

The long-term open-water rating functions for the Poultney (280000) gage are given by the formulas:

$$LQM = 3.75 + 2.16 * \ln(GHT-1.07) \quad \text{for } GHT < 3.69 \qquad (20)$$

$$LQM = 5.71 + 0.93 * \ln(GHT-2.56) \quad \text{for } GHT \geq 3.69 \qquad (21)$$

A tabular presentation of the residuals as computed using these formulas in given in table 12. The data for Poultney is presented as an example only. Most of the long-term ratings were computed using a data-set of 50 to 60 measurements.

Table 12.--Residual data for Poultney (open-water period)

Measurement number	Date	Measured discharge (ft^3/s)	Residual (ft^3/s)	Percent error
434	Oct. 1, 1969	101	3.65	3.8
435	Nov. 5, 1969	65.2	2.52	4.0
436	Dec. 17, 1969	236	-6.52	-2.7
442	Sep. 25, 1970	184	-1.64	-0.9
443	Nov. 4, 1970	66.6	-0.70	-1.0
449	Nov. 9, 1971	78.9	-0.74	-0.9
450	Dec. 15, 1971	522	21.8	4.3
452	May 3, 1972	607	1.50	0.2
453	Jun. 6, 1972	208	3.60	1.8
457	Dec. 5, 1972	485	-4.36	-0.9
458	Mar. 20, 1973	1,090	0.15	0.0
459	Apr. 23, 1973	198	4.14	2.1
464	Dec. 5, 1973	52.5	-2.52	-4.6
465	Apr. 4, 1974	1,100	-5.25	-0.5
492	Aug. 27, 1980	89.5	-0.81	-0.9
493	Apr. 9, 1981	365	-20.0	-5.2
494	Jul. 23, 1981	80.4	-3.16	-3.8
495	Aug. 27, 1981	58.5	1.35	2.4
499	Mar. 18, 1982	462	-5.54	-1.2
500	May 6, 1982	168	-1.77	-1.0
503	Jun. 17, 1982	94.5	0.00	0.0
505	Jul. 23, 1982	4.85	0.01	0.3
506	Sep. 9, 1982	4.55	-0.01	-0.1
507	Nov. 1, 1982	213	6.45	3.1
509	Jan. 12, 1983	258	6.00	2.4

The determination of the open-water rating function for the West Hopkinton (085500) station was complicated by a recurring period of backwater due to the growth of vegetation on the control, the degree of growth being quite variable. For this station, two different ratings were determined for the open-water period. One was for the period of no vegetation and the other was for the period when vegetation was present. The correlative data for both ratings were gage height.

For many stations, backwater from ice formation during the winter period further complicated the determination of long-term ratings. Forty stations in the New Hampshire and Vermont programs had significant periods (27 or more days) of backwater due to ice. Ideally, the computation of the error variance, V_f, for a station during the ice-backwater period should be based upon a time-series of residuals computed using a rating function determined specifically for the winter period. Unfortunately, many stations in New Hampshire and Vermont lacked a suitable number of winter measurements to compute a rating function and, subsequently, V_f, for the winter period. Fifteen stations in the two states had a suitable number of measurements (at least 2 per winter) and winter ratings were determined for them.

Winter ratings were determined by applying a linear regression routine (SAS Institute Inc., 1979) to solve for the dependent variable, measured discharge, as a function of selected independent variables. The independent variables included in the analysis for each winter discharge rating can be classified into three catagories. These are data from the site for which a rating was desired, climatological data, and data from other stream gages. Data from the site in question included measured stage and the discharge corresponding to the measured stage determined from the open-water rating (indicated discharge). Climatological data taken from National Weather Service sites closest to the stream gages in question included the minimum and mean temperature for the given day of the measurement, the maximum temperature on the prior day, and the mean temperature for the prior 7 and prior 30 days. Also included is the total precipitation on the prior day and the prior 7 days. Data from other stream gages included the indicated mean daily discharge, based on the open-water rating curve, for sites that are both proximate and (or) located in physiographically similar regions.

Results of the winter rating analyses often yielded ratings about which there was a large amount of variance, but some of the ratings had relatively good fits about the available discharge measurements. Examples of both types of ratings are given below for typical winter backwater periods in New Hampshire and Vermont.

The best-fit rating function for the winter (ice-backwater) period at White (144000) is given by the formula:

$$Q = -31.6 + 0.564(QI) + 2.31(DOG) + 0.0249(PLYMOUTH) \qquad (22)$$

where

Q — is the discharge at White in cubic feet per second,

QI — is the indicated discharge at White in cubic feet per second,

DOG — is the indicated discharge at station Dog (287000) in cubic feet per second, and

PLYMOUTH — is the indicated discharge at the Plymouth (076500) station in cubic feet per second.

The coefficient of determination (R^2) for this model is 0.95. A tabular presentation of the residuals of the measured discharges about the winter rating curve (measured discharge minus rated discharge for this station is given in table 13.

Table 13.--Residual data for White (ice-backwater period)

Measurement number	Date	Measured discharge (ft^3/s)	Residual (ft^3/s)	Percent error
490	Dec. 19, 1969	960	-60.9	-6.0
491	Jan. 23, 1969	470	-112	-19.2
492	Feb. 18, 1969	564	17.4	3.2
498	Feb. 18, 1970	1,250	66.0	5.6
499	Mar. 20, 1970	623	88.4	16.5
506	Jan. 22, 1971	247	-41.2	-14.3
516	Jan. 20, 1972	965	110	12.9
535	Jan. 18, 1974	772	41.3	5.6
553	Jan. 19, 1976	518	-18.8	-3.5
561	Jan. 25, 1977	446	18.1	4.2
562	Feb. 23, 1977	296	-62.0	-17.3
569	Dec. 18, 1977	1,070	5.84	0.5
579	Dec. 27, 1978	408	1.43	0.4
580	Jan. 26, 1979	898	-20.6	-2.2
586	Jan. 10, 1980	460	54.3	-13.4
587	Feb. 25, 1980	249	47.8	23.8
595	Feb. 16, 1982	788	-116	-12.8
603	Feb. 25, 1983	530	-20.3	-3.7

The best-fit rating function determined for Jail Branch (284009) is given by the formula:

$$Q = 915 - 361(GHT) + 1.81(QI) + 0.295(COVENTRY) \qquad (23)$$

where

Q	is the discharge at Jail Branch in cubic feet per second,
GHT	is the measured stage in feet,
QI	is the indicated discharge at Jail Branch in cubic feet per second, and
COVENTRY	is the indicated discharge at Coventry (296000) in cubic feet per second.

The coefficient of determination (R^2), for the Jail Branch model is 0.96. A tabular presentation of the residuals of the measured discharges about the winter rating curve for this station is given in table 14.

The time series of residuals (in logarithmic units) computed for the open-water and winter ratings are used to compute sample estimates of q and β, two of the three parameters required to compute V_f, by determining a best-fit autocovariance function to the time series of residuals. As discussed earlier, q and β can be expressed as the process variance, p, of the residuals from the rating curve and the 1-day autocorrelation coefficient, RHO, of these residuals. Measurement variance, the third parameter, is determined from an assumed constant percentage standard error. For the New Hampshire and Vermont programs, all open-water measurements were assumed to have a measurement error of 2 percent except those for Dudley (073600), where the measurement error was assumed to be 3 percent. All ice measurements were assumed to have a measurement error of 10 percent.

Table 14.--Residual data for Jail Branch (ice-backwater period)

Measurement number	Date	Measured discharge (ft^3/s)	Residual (ft^3/s)	Percent error
482	Jan. 4, 1973	59.1	14.0	19.2
483	Feb. 6, 1973	71.5	1.24	1.7
491	Jan. 9, 1974	25.8	14.9	36.5
492	Feb. 12, 1974	120.5	-0.56	-2.8
493	Mar. 27, 1974	54.6	-21.3	-64.0
499	Dec. 17, 1974	65.8	-43.8	-199.6
500	Apr. 1, 1975	30.7	2.87	8.5
505	Dec. 17, 1975	60.6	-30.4	-100.8
506	Feb. 25, 1976	45.4	23.6	34.2
511	Feb. 1, 1977	6.99	26.4	79.0
517	Jan. 5, 1978	26.5	-16.7	-171.1
518	Feb. 16, 1978	139.4	-12.3	-45.6
526	Jan. 23, 1979	61.8	33.7	35.3
527	Mar. 7, 1979	542	-17.4	-3.3
534	Dec. 4, 1979	23.9	22.8	48.8
535	Feb. 19, 1980	3.80	6.94	64.6
543	Dec. 9, 1980	76.0	37.2	32.8
544	Jan. 20, 1981	4.86	3.72	43.3
552	Jan. 4, 1982	30.6	-18.5	-153.3
553	Feb. 8, 1982	46.1	-27.0	-140.9

Autocovariance functions for sample stations in New Hampshire and Vermont are illustrated in figures 9 through 11. Table 15 presents a summary of the autocovariance analysis for the open-water and winter ratings expressed in terms of process variance and 1-day autocorrelation. The last column in the table is the length of period, in days, to which the computed parameters were applied. In table 15, a 9 was added to the last digit of the station number to indicate that the parameters pertain to the winter portion of the year as determined using a winter rating analysis. A 5 was added to the last digit of the station number to denote that the parameters are for the period of backwater due to vegetation as determined using a separate backwater rating analysis.

Twenty-five stations in New Hampshire and Vermont have a significant period of backwater from ice but they did not have a suitable long-term period of measurements to compute winter ratings. For these stations, it was assumed that the variance, V_f, for the winter period could be approximated by the expression $(1 - \rho c^2)\ \bar{C}_v^{\,2}$. The $\bar{C}_v$ which had been previously computed for the entire year was re-computed to reflect only that portion of the year to which it would be applied. This was accomplished by applying the following revised form of equation 15.

$$\bar{C}_{v(w)} = \left[\frac{1}{N} \sum_{i=1}^{N} \left(\frac{\sigma i}{\mu i}\right)^2\right]^{1/2} \qquad (24)$$

where

$\bar{C}_{v(w)}$ is the seasonally-averaged coefficient of variation for the winter (ice-backwater) period, and

N is the average length of the winter period for all stations in New Hampshire and Vermont, in days (N used in this analysis was 90 days).

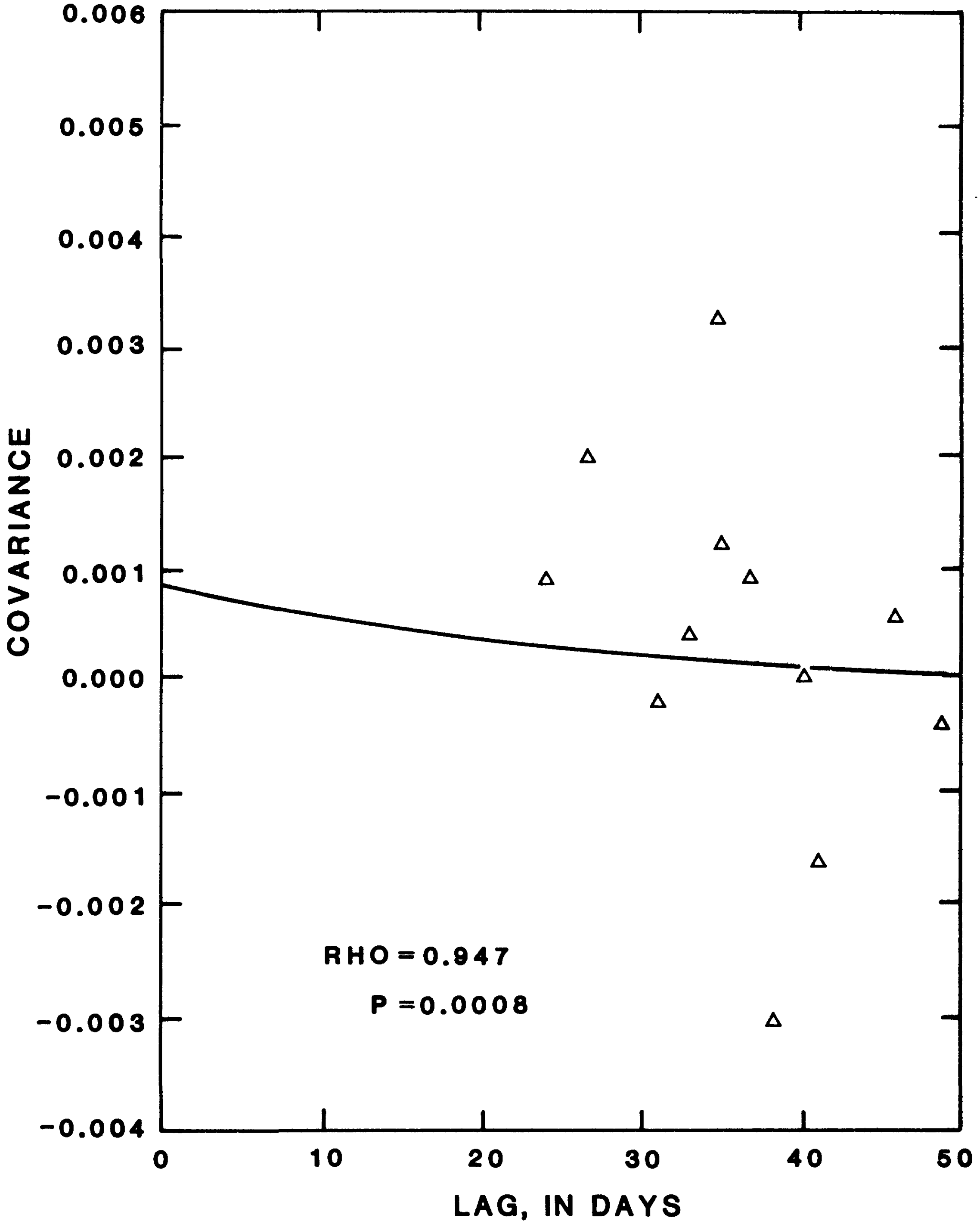

Figure 9.--Open-water period autocovariance function for Indian Stream (129200).

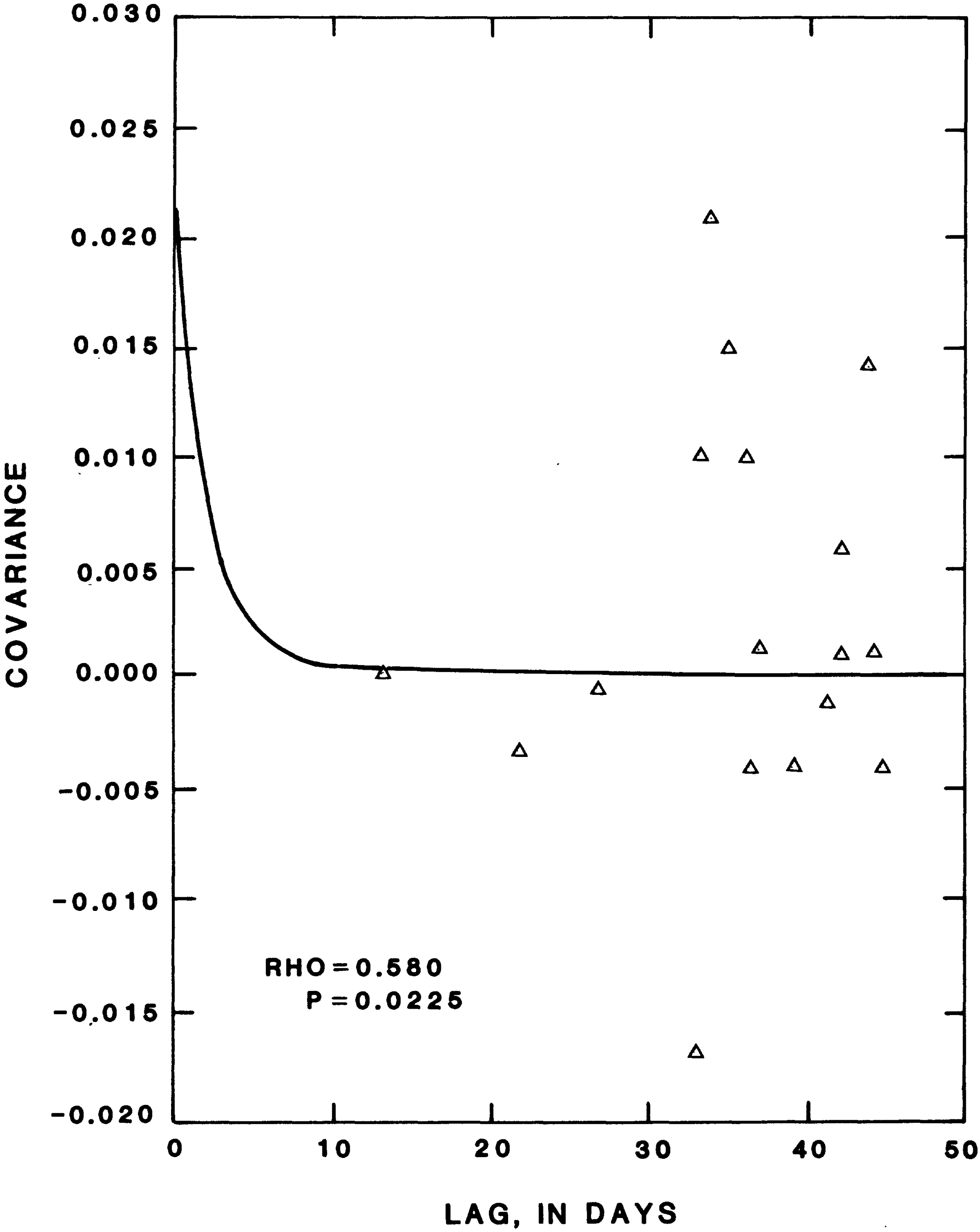

Figure 10.--Open-water period autocovariance function for Ayers (142500).

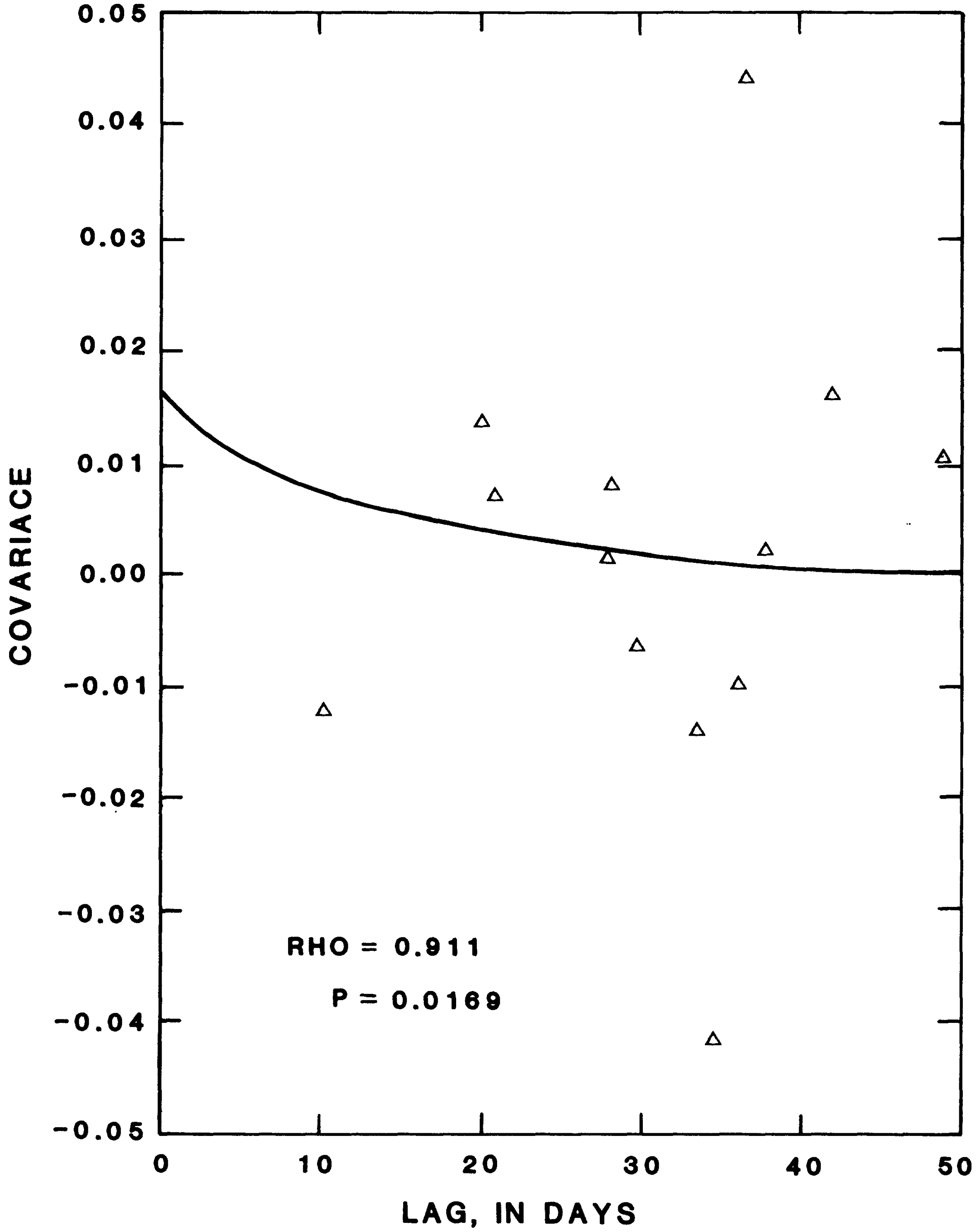

Figure 11.--Ice-backwater period autocovariance function for Passumpsic (135500).

Table 15.--Summary of the autocovariance analysis

Station no.	RHO (1-day autocorrelation coefficient)	Measurement variance (log base e)^2	Process variance (log base e)^2	Length of period (days)
064300	0.709	0.0004	0.0006	290
064309	.953	.0100	.0574	75
064400	.992	.0004	.0645	290
065000	.838	.0004	.0003	365
072100	.973	.0004	.0014	365
073000	.887	.0004	.0060	325
073600	.982	.0009	.0008	315
075800	.993	.0004	.5134	290
076500	.989	.0004	.1403	285
076509	.971	.0100	.0376	80
077000	.881	.0004	.0009	365
078000	.977	.0004	.0019	325
078009	.958	.0100	.0067	40
081000	.992	.0004	.0023	365
083000	.967	.0004	.0030	305
085500	.978	.0004	.0004	215
085505	.865	.0004	.0087	90
085509	.907	.0100	.0268	60
085800	.896	.0004	.0059	290
087000	.705	.0004	.0003	335
089000	.995	.0004	.2646	315
090800	.951	.0004	.0016	365
092000	.971	.0004	.0003	365
093800	.995	.0004	.1305	305
127880	.979	.0004	.0025	290
127889	.645	.0100	.0857	75
128500	.895	.0004	.0050	365
129200	.947	.0004	.0008	365
129500	.641	.0004	.0031	285
130000	.649	.0004	.0480	290
130009	.959	.0100	.1828	75
131500	.955	.0004	.0009	365
134500	.636	.0004	.0011	315
135500	.942	.0004	.0004	285
135509	.911	.0100	.0169	80

Table 15.--Summary of the autocovariance analysis--(Continued)

Station no.	RHO (1-day autocorrelation coefficient)	Measurement variance (log base e)^2	Process variance (log base e)^2	Length of period (days)
137500	0.945	0.0004	0.0008	290
137509	.936	.0100	.0398	75
138500	.663	.0004	.0009	315
139000	.696	.0004	.0016	305
139800	.987	.0004	.0506	285
139809	.964	.0100	.1105	80
141500	.981	.0004	.0322	305
141509	.629	.0100	.0685	60
141800	.997	.0004	.1317	290
142500	.580	.0004	.0225	290
144000	.859	.0004	.0001	290
144009	.578	.0100	.0033	75
144500	.698	.0004	.0035	290
150500	.992	.0004	.0078	365
151500	.654	.0004	.0014	305
152500	.981	.0004	.0018	290
153000	.992	.0004	.0063	365
154500	.648	.0004	.0006	365
155500	.987	.0004	.0029	290
156000	.993	.0004	.0017	315
158000	.967	.0004	.0014	365
158600	.990	.0004	.0020	365
161000	.971	.0004	.0009	365
334000	.989	.0004	.0017	365
280000	.833	.0004	.0002	365
282000	.929	.0004	.0013	365
284000	.985	.0004	.0005	315
284009	.994	.0100	.4791	50
285500	.674	.0004	.0008	290
286000	.702	.0004	.0009	285
286009	.668	.0100	.0364	80
287000	.984	.0004	.0010	325
287009	.896	.0100	.0308	40
289000	.983	.0004	.0010	365
290500	.926	.0004	.0010	290

Table 15.--Summary of the autocovariance analysis--(Continued)

Station no.	RHO (1-day autocorrelation coefficient)	Measurement variance (log base e)^2	Process variance (log base e)^2	Length of period (days)
292000	0.967	0.0004	0.0030	290
292500	.976	.0004	.0006	285
293500	.980	.0004	.0009	285
293509	.909	.0100	.0540	80
296000	.975	.0004	.0012	315
296500	.995	.0004	.0532	365

The results of this ice-backwater variance analysis are summarized in table 16. Once again, a 9 was added to the last digit of the station number to identify it as an ice-backwater station.

The ice-backwater analysis assumes that winter streamflow records for these stations are computed using the methods of record reconstruction and are not based on streamflow measurements. This implies that the standard error of the streamflow records will not vary in response to changes in measurement or visitation frequency. In order to "flatten" the shape of the uncertainty functions, a RHO of zero was assumed for these stations.

The autocovariance parameters summarized in tables 15 and 16, data from the definition of missing record probabilities summarized in tables 9 and 10, and the statistics of record reconstruction (table 11), are used jointly to define uncertainty functions for each gaging station. The uncertainty functions are the relation of total error variance to the annual number of discharge measurements. Three typical uncertainty functions are presented in figure 12. These functions are for the graphical fits of the autocovariance functions that are shown in figures 9, 10, and 11 and are based on the assumption that a measurement was made during each visit to the station.

The 1-day autocorrelation coefficient, RHO, determines the shape of the uncertainty functions that are computed for each station. A high RHO value indicates that there is a great deal of information transfer between successive discharge measurements and this results in more accurate discharge computation during the period between measurements. The shape of an uncertainty curve in this instance would not be as "flat" as that for a lower RHO value. There is a greater relative improvement in the standard error of the daily mean streamflow record as additional discharge measurements are made within a given time interval. A

Table 16.--Summary of the ice-backwater variance analysis

$\bar{C}_{v(w)}$=: Seasonally-averaged coefficient of variation for the ice-backwater period.

Station no.	$\bar{C}_{v(w)}$	Winter variance (log base e)^2	Length of period (days)
064409	1.418	0.4377	75
073009	1.131	.2817	40
073609	1.433	.5757	50
075809	1.622	.5507	75
083009	0.838	.0139	60
085809	1.406	.4481	75
087009	0.935	.2671	30
089009	0.968	.0185	50
093809	1.134	.3995	60
129509	0.515	.0089	80
134509	1.069	.2709	50
138509	0.776	.0089	50
139009	0.868	.1635	60
141809	1.187	.4088	75
142509	0.893	.0606	75
144509	0.737	.0107	75
151509	0.931	.0171	60
152509	0.992	.1398	75
155509	1.115	.0244	75
156009	1.124	.0248	50
285509	1.003	.1651	75
290509	0.829	.0136	75
292009	0.864	.0148	75
292509	0.901	.0484	80
296009	0.897	.2165	50

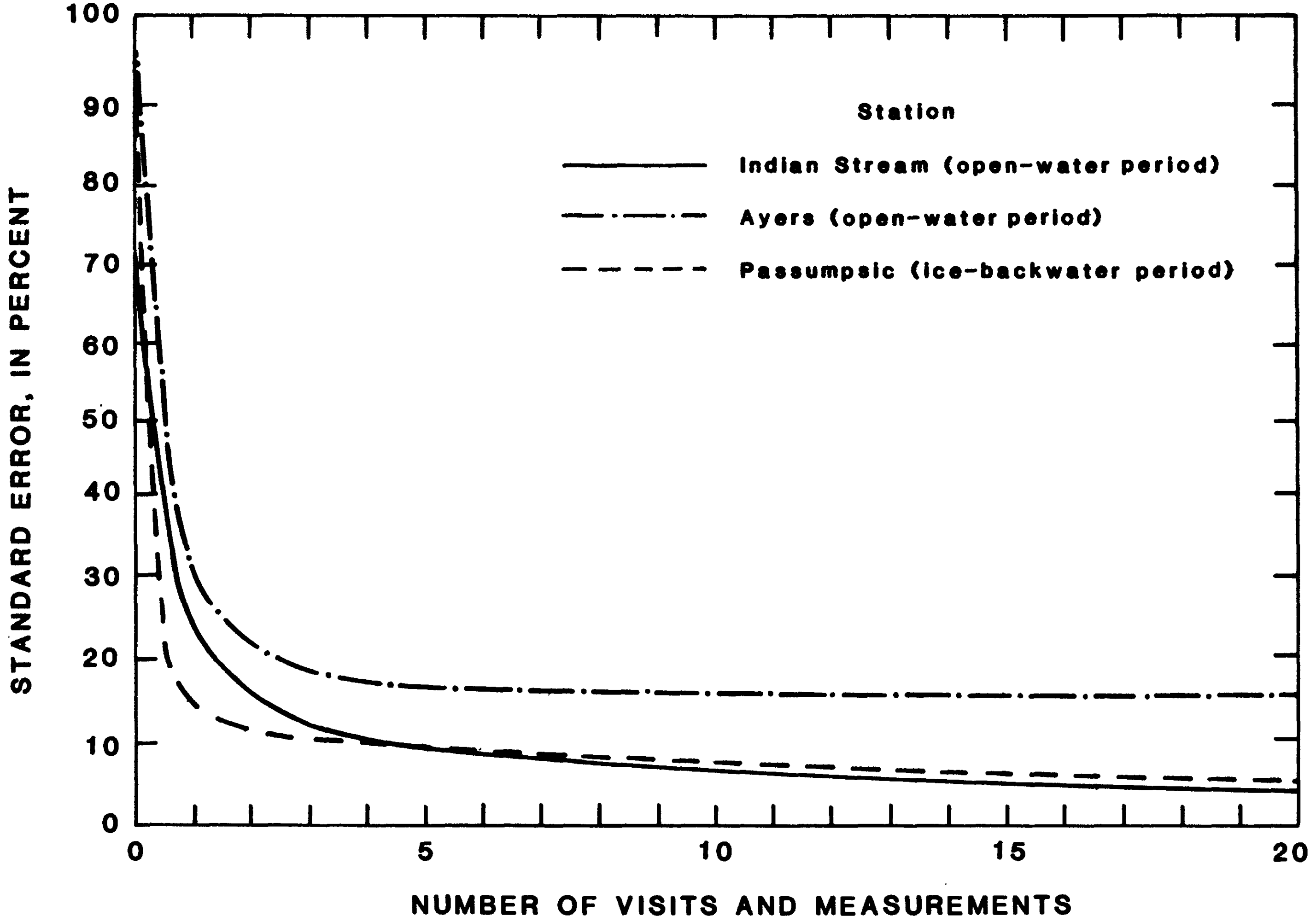

Figure 12.--Typical uncertainty functions for instantaneous discharge.

low RHO value indicates that there is less information transfer between successive measurements and there would be less relative improvement in the standard error of the streamflow record with shorter time intervals between measurements. In figure 12, the uncertainty curve for Ayers (RHO = 0.580) is much "flatter" than the curves for Passumpsic (RHO = 0.911) or Indian Stream (RHO = 0.947).

Costs and routes

Fixed costs were estimated for each station in the New Hampshire and Vermont programs. Fixed costs include such things as equipment rental, batteries, electricity, data processing and storage, computer charges, maintenance and miscellaneous supplies, and analysis and supervisory charges. Average values of fixed costs were applied to each station for all of the above categories except analysis and supervision. Analysis and supervision, which can vary greatly between stations, was determined separately for each station.

Visit costs are those associated with paying the hydrographer for the time actually spent at a station servicing the equipment and making a discharge measurement. These costs vary from station to station and are a function of the difficulty and time required to make the discharge measurement. Average visit times were calculated for each station based on an analysis of discharge measurement data available. This time was then multiplied by the average hourly salary of hydrographers in the New Hampshire and Vermont offices to determine total visit costs.

Route costs include vehicle costs 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.

Feasible routes which could be used to visit the stations in New Hampshire and Vermont were determined. In addition to continuous stream gages, a variety of other stations are visited and maintained as part of the surface-water program. No uncertainty functions are determined for these stations because they do not require continuous recording of streamflow data. They do, however, have costs associated with them which must be accounted for in the Traveling Hydrographer Program. These stations, termed "dummy" stations, which include partial record and lake and reservoir stage stations, are listed in table 17. Appropriate fixed and measurement costs were determined for the dummy stations.

The routes and stations visited on each are summarized in table 18. The 173 routes include combinations that describe the current operating practice, alternatives under consideration, routes that visit individual stations, and combinations of stations that grouped proximate gages where the level of uncertainty indicated a similar frequency of visits. A designation of "R" in the route number indicates a route that includes only regular stations, as opposed to dummy stations. A designation of "W" indicates that the route is used for the winter portion of the year while a "V" indicates a route used for periods of backwater from vegetation.

K-CERA Results

The "Traveling Hydrographer Program" utilizes the uncertainty functions along with the appropriate cost data and route definitions to compute the most cost-effective way of operating the stream-gaging program. Due to a great deal of overlap between the New Hampshire and Vermont programs, no attempt was made to analyze them separately.

Table 17.--Dummy stations used in the Traveling Hydrographer Program

Standard station number	Abbreviated station number	Station Name	Type of station
01075000	075000	Pemigewasset River at Woodstock, N.H.	Partial record
01076000	076000	Baker River near Rumney, N.H.	Partial record
01080000	080000	Lake Winnipesaukee at Weirs Beach, N.H.	Lake stage
01081500	081500	Merrimack River at Franklin Jct., N.H.	Partial record
01082000	082000	Contoocook River at Peterborough, N.H.	Partial record
01091500	091500	Piscataquog River near Goffstown, N.H.	Partial record
01094000	094000	Souhegan River at Merrimack, N.H.	Partial record
01129300	129300	Halls Stream near East Hereford, Quebec, Canada	International
01145000	145000	Mascoma River at West Cannan, N.H.	Partial record
04283500	283500	East Barre Detention Reservoir at East Barre, Vt.	Reservoir stage
04285000	285000	Wrightsville Detention Reservoir at Wrightsville, Vt.	Reservoir stage
04288500	288500	Waterbury Reservoir near Waterbury, Vt.	Reservoir stage
04294500	294500	Lake Champlain at Burlington, Vt.	Lake stage
04295500	295500	Lake Memphremagog at Newport, Vt.	Lake stage

Table 18.--Summary of the routes that may be used to visit stations in New Hampshire and Vermont

Route number	Stations serviced on the route				
1	141800	145000	150500		
1R	141800	150500			
1W	141809	145000	150500		
1WR	141809	150500			
2	075800	076000	078000		
2R	075800	078000			
2W	075809	076000	078009		
2WR	075809	078009			
3	075000	076500	077000		
3R	076500	077000			
3W	075000	076509	077000		
3WR	076509	077000			
4	064300	064400	065000	080000	081000
4R	064300	064400	065000	081000	
4W	064309	064409	065000	080000	081000
4WR	064309	064409	065000	081000	
5	072100	073000			
5W	072100	073009			
6	089000	073600			
6W	089009	073609			
7	094000	092000	091500		
7R	092000				
8	087000	090800	081500	085500	
8R	087000	090800	085500		

Table 18.--Summary of the routes that may be used to visit stations in New Hampshire and Vermont--Continued

Route number	Stations serviced on the route				
8V	087000	090800	081500	085505	
8VR	087009	090800	085505		
8W	087009	090800	081500	085509	
8WR	087009	090800	085509		
9	085800	152500	154500		
9W	085809	152509	154500		
10	158000	158600	161000		
11	083000	082000	093800		
11R	083000	093800			
11W	083009	082000	093809		
11WR	083009	093809			
12	296500	295500	296000	293500	292500
	290500	294500			
12R	296500	296000	293500	292500	290500
12W	296500	295500	296009	293509	292509
	290509	294500			
12WR	296500	296009	293509	292509	290509
13	292000	288500	289000		
13R	292000	289000			
13W	292009	288500	289000		
13WR	292009	289000			
14	285000	285500	286000		
14R	285500	286000			
14W	285000	285509	286009		
14WR	285509	286009			

Table 18.--Summary of the routes that may be used to visit stations in New Hampshire and Vermont--Continued

Route number	Stations serviced on the route				
15	134500	135500			
15W	134509	135509			
16	139000	138500			
16W	139009	138509			
17	284000	283500	139800	287000	
17R	284000	139800	287000		
17W	284009	283500	139809	287009	
17WR	284009	139809	287009		
18	142500	141500	144000		
18W	142509	141509	144009		
19	144500	151500			
19W	144509	151509			
20	282000	280000			
21	334000	155500	156000	153000	
21W	334000	155509	156009	153000	
22	137500	130000	129500	131500	127880
	128500	129200	129300		
22R	137500	130000	129500	131500	127880
	128500	129200			
22W	137509	130009	129509	131500	127889
	128500	129200	129300		
22WR	137509	130009	129509	131500	127889
	128500	129200			
23	072100	073000	073600	089000	
23W	072100	073009	073609	089009	
24	087000	085800			

Table 18.--Summary of the routes that may be used to visit stations in New Hampshire and Vermont--Continued

Route number	Stations serviced on the route				
24W	087009	085809			
25	085500	090800	091500		
25R	085500	090800			
25V	085505	090800	091500		
25VR	085505	090800			
25W	085509	090800	091500		
25WR	085509	090800			
26	083000	082000	093800		
26R	083000	093800			
26W	083009	082000	093809		
26WR	083009	093809			
27	094000	092000			
27R	092000				
28	158000	158600	061000		
29	141800	150500	145000	144500	151500
	144000	141500			
29R	141800	150500	144500	151500	144000
	141500				
29W	141809	150500	145000	144509	151509
	144009	141509			
29WR	141809	150500	144509	151509	144009
	141509				
30	078000	075800	076000	076500	077000
	075000	137500	131500	130000	129500
	129200	129300	128500	127880	
30R	078000	075800	076500	077000	137500
	131500	130000	129500	129200	128500
	127880				

Table 18.--Summary of the routes that may be used to visit stations in New Hampshire and Vermont--Continued

Route number	Stations serviced on the route				
30W	078009	075809	076000	076509	077000
	075000	137509	131500	130009	129509
	129200	129300	128500	127889	
30WR	078009	075809	076509	077000	137509
	131500	130009	129509	129200	128500
	127889				
31	064400	064300	065000	080000	081000
	081500				
31R	064400	064300	065000	081000	
31W	064409	064309	065000	080000	081000
	081500				
31WR	064409	064309	065000	081000	
32	152500	153000	154500	156000	155500
	334000				
32W	152509	153000	154500	156009	155509
	334000				
33	142500	282000	280000		
33W	142509	282000	280000		
34	284000	283500	139800		
34R	284000	139800			
34W	284009	283500	139809		
34WR	284009	139809			
35	139000	138500			
35W	139009	138509			
36	134500	135500			
36W	134509	135509			
37	287000	286000	285500	285000	288500
	289000				

Table 18.--Summary of the routes that may be used to visit stations in New Hampshire and Vermont--Continued

Route number	Stations serviced on the route				
37R	287000	286000	285500	289000	
37W	287009 289000	286009	285509	285000	288500
37WR	287009	286009	285509	289000	
38	296000	296500	295500	293500	292000
38R	296000	296500	293500	292000	
38W	296009	296500	295500	293509	292009
38WR	296009	296500	293509	292009	
39	292500	290500	294500		
39R	292500				
39W	292509	290509	294500		
39WR	292509	290509			
40	075800	076500			
40W	076509	075800			
41	064400				
42	089000	093800			
43	141500	141800			
44	139800				
44W	139809				
45	296500				
46	284009	287009			
47	293509				
48	135509				
49	130009	137509			

Table 18.--Summary of the routes that may be used to visit stations in New Hampshire and Vermont--Continued

Route number	Stations serviced on the route		
50	085509		
51	064309		
52	075800		
53	089000		
54	076500		
55	093800		
56	141500		
57	141800		
58	076509		
59	130009		
60	137509		
61	284009		
62	287009		
63	085505	085800	
64	073000		
65	153000		
66	128500		
67	085505		
68	085800		
69	078009		
70	064400	064309	
71	089000	093800	085509
72	139800	284009	287009
73	296500	293509	

Table 18.--Summary of the routes that may be used to visit stations in New Hampshire and Vermont--Continued

Route number	Stations serviced on the route		
74	085505	085800	078009
75	073000	073600	
75W	073009	073609	
76	073600		
77	085500		
78	087000		
79	127880		
80	134500		
81	334000		
82	280000		
83	296000		
84	073009	073609	
85	085509	087009	093809
86	064409		
87	075809		
88	141809		
89	134509		
90	296009		

The first step in the analysis was to simulate the current practice and determine the total uncertainty associated with the current budget of the stream-gaging programs. The number of visits being made to each stream gage and the specific routes that are presently (1984) being used to make these visits were fixed. In New Hampshire and Vermont, the current practice is to visit each station every six weeks. The current frequency of discharge measurements was also fixed for each stream gage. For gaging stations with seasonal ratings, the seasonal uncertainties were weighted by the percentage of time that each applies to obtain a weighted average for the station's uncertainty function.

The resulting average error of estimation for the current operation in New Hampshire and Vermont is plotted as a point in figure 13 and is 17.9 percent. The budget required for the current operation reflects only stream-gaging activities. Some aspects of the New Hampshire and Vermont stream-gaging programs are only indirectly related to stream-gaging activities. This required modification of the total budget of the combined programs before submittal to the cost-effective analysis. These portions of the budget included experimental testing of new streamflow recording equipment, supplying telemetric equipment to cooperators, and miscellaneous acitivities that involve only very infrequent visits to gage sites operated by another agency. Additionally, eight stations have been excluded from this analysis based upon preceeding sections of this report. When the total cost of these activities is considered, the resultant net budget of the combined stream-gaging program which is appropriate for cost-effective analysis is $297,000.

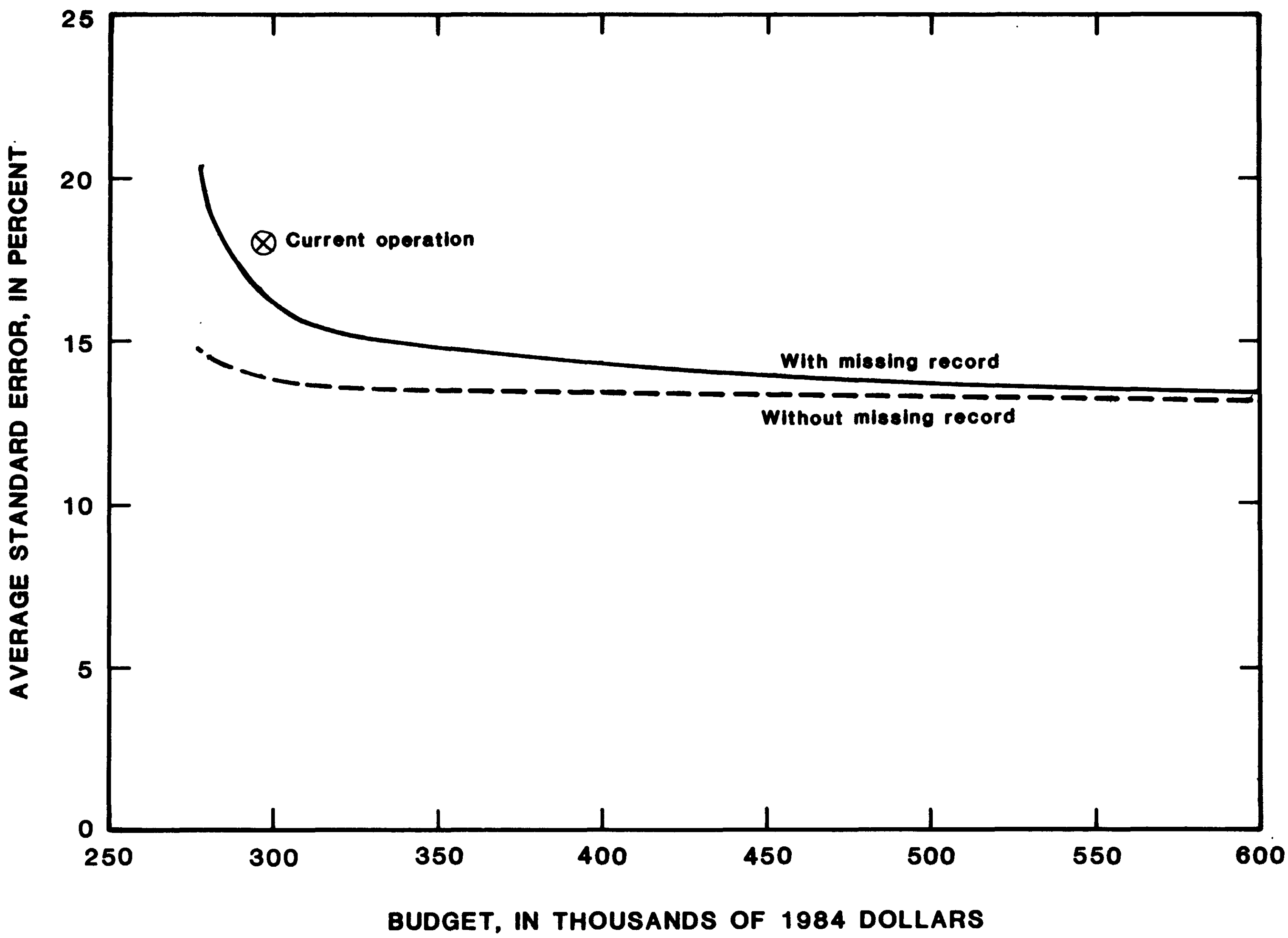

Figure 13.—Optimum average standard error for stream gages for various budgets.

The solid line in figure 13 represents the minimum average standard error that can be obtained for a given budget with the existing instrumentation and technology. The line was defined by several runs of the "Traveling Hydrographer Program" with different budget constraints. The dashed line in figure 13 indicates the impact that missing record has on the average standard error. Another constraint on the operation of the stream-gaging program was the minimum number of times per year that each station had to be visited. This constraint was determined by considering only the physical limitations of the method used to record the surface-water data. These limitations include the need to maintain batteries that drive equipment, capacities of spools on recorders, and the need to protect gages from freezing conditions during the winter months. For the gages in both New Hampshire and Vermont, a minimum requirement of five visits per year was determined and applied to all stations. At stations where the year was split into winter and summer seasons, the minimum was three visits for the summer period and two visits for the winter period. No other visit constraints, such as the need for water-quality sampling, were more restrictive than these.

Another consideration for the K-CERA analysis is that a streamflow measurement is not always made during a station visit. For a given station, the measurement frequency will affect the relation of the standard error to the number of visits and the cost associated with each visit. To account for this, a measurement probability factor from 0.0 (never measure) to 1.0 (always measure) was input to the Traveling Hydrographer Program for each station.

The results in figure 13 and table 19 summarize the K-CERA analysis. It should be emphasized that the results are based on various assumptions (stated previously) concerning both the time series of shifts to the stage-discharge releationship and the methods of record reconstruction. Where a choice of assumptions was available, the assumptions that would not underestimate the magnitude of the error variances was chosen.

Table 19 summarizes the standard error of instantaneous discharge that is obtained for each station and the average standard error per station for the actual current operation of the New Hampshire and Vermont stream-gaging programs. Included in the table are the minimum cost-effective standard errors that could be obtained for various budgetary levels. For those stations that had both open-water and ice-backwater uncertainty functions, the standard errors for an entire year can be calculated by weighting the variances (where variance equals the square of standard error) by the number of days per year that each uncertainty function is applicable. The number of days that each function is applicable to may be obtained from tables 15 and 16. For example, the year-round standard error at station 064300 for current operation is 16.1 percent $[(290/365 \times 14.3^2) + (75/365 \times 21.6^2)]^{0.5}$. For those stations that had an ice-backwater variance analysis (as opposed to a winter-rating autocovariance analysis), there is very little, if any, change in the winter period standard error regardless of the budget used. This is because the ice-backwater variance analysis did not make use of a winter rating and is, therefore, not dependent on the frequency of visitation to the station.

Table 19.--Selected results of K-CERA analysis

[Footnotes are at end of table]

Station identification	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread, in percent] (Number of visits per year)					
	Current operation 1/	Budget, in thousands of 1984 dollars				
		278	297	350	400	600
Average per station 2/	17.9	19.2	16.6	14.8	14.3	13.5
064300 Ellis-S 3/	14.3 [2.7] (7)	22.2 [3.2] (3)	15.5 [2.7] (6)	10.1 [2.4] (14)	8.5 [2.3] (20)	6.0 [2.0] (42)
064309 Ellis-W 4/	21.6 [18.8] (2)	21.6 [18.8] (2)	16.4 [14.3] (4)	11.4 [9.8] (9)	9.0 [7.8] (15)	6.7 [5.8] (28)
064400 Lucy-S	20.7 [9.8] (7)	26.8 [13.9] (4)	17.4 [8.0] (10)	11.6 [5.0] (23)	9.6 [4.1] (34)	6.7 [2.9] (71)
064409 Lucy-W	73.5 [73.4] (2)	73.5 [73.4] (2)	73.5 [73.4] (2)	73.5 [73.4] (2)	73.5 [73.4] (2)	73.5 [73.4] (2)
065000 Ossipee-W	3.9 [1.7] (9)	5.2 [1.8] (5)	4.1 [1.7] (8)	3.1 [1.6] (16)	2.7 [1.5] (22)	2.0 [1.3] (44)

Table 19.--Selected results of K-CERA analysis--Continued

Station identification	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread, in percent] (Number of visits per year)					
	Current operation	Budget, in thousands of 1984 dollars				
		278	297	350	400	600
072100 Salmon Falls	9.6 [2.8] (9)	13.2 [3.7] (5)	9.6 [2.9] (9)	6.3 [2.0] (20)	5.1 [1.7] (30)	3.6 [1.2] (61)
073000 Oyster-S	14.9 [7.4] (7)	17.2 [7.8] (5)	11.0 [6.4] (15)	7.1 [4.6] (40)	5.9 [3.8] (60)	4.2 [2.7] (121)
073009 Oyster-W	57.2 [57.2] (2)	57.2 [57.2] (2)	57.2 [57.2] (2)	57.2 [57.2] (2)	57.1 [57.1] (3)	57.1 [57.1] (7)
073600 Dudley-S	31.4 [1.8] (7)	27.8 [1.6] (9)	17.8 [1.0] (22)	11.7 [0.7] (51)	9.8 [0.6] (73)	7.0 [0.4] (144)
073609 Dudley-W	89.1 [88.9] (2)	89.1 [88.9] (2)	89.1 [88.9] (2)	88.6 [88.6] (4)	88.6 [88.5] (5)	88.4 [88.4] (10)
075800 Stevens-S	33.4 [25.5] (7)	33.4 [25.5] (7)	19.0 [13.3] (22)	12.3 [8.4] (53)	10.4 [7.1] (74)	7.5 [5.1] (144)
075809 Stevens-W	85.7 [85.7] (2)	85.7 [85.7] (2)	85.7 [85.7] (2)	85.7 [85.7] (2)	85.7 [85.7] (2)	85.7 [85.7] (3)

Table 19.--Selected results of K-CERA analysis--Continued

Station identification	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread, in percent] (Number of visits per year)					
	Current operation	Budget, in thousands of 1984 dollars				
		278	297	350	400	600
076500 Plymouth-S	15.2 [15.2] (7)	16.4 [16.4] (6)	10.1 [10.0] (16)	6.9 [6.8] (34)	5.7 [5.6] (50)	4.1 [4.0] (103)
076509 Plymouth-W	14.0 [14.0] (2)	14.0 [14.0] (2)	14.0 [14.0] (2)	9.1 [9.0] (6)	7.2 [7.1] (10)	5.5 [5.4] (18)
077000 Squam	6.3 [3.0] (9)	8.4 [3.2] (5)	8.4 [3.2] (5)	6.0 [3.0] (10)	4.6 [2.8] (19)	3.2 [2.3] (47)
078000 Smith-S	10.8 [3.1] (7)	12.7 [3.6] (5)	8.7 [2.6] (11)	6.0 [1.9] (23)	5.0 [1.6] (33)	3.5 [1.1] (70)
078009 Smith-W	8.3 [5.0] (2)	8.3 [4.9] (2)	8.3 [4.9] (2)	8.3 [4.9] (2)	6.9 [4.1] (3)	4.9 [2.9] (6)
081000 Tilton	3.9 [2.1] (9)	5.3 [2.8] (5)	4.2 [2.2] (8)	2.9 [1.6] (16)	2.5 [1.4] (22)	1.8 [1.0] (44)
083000 Nubanusit-S	5.0 [4.0] (7)	7.3 [5.2] (3)	5.3 [4.2] (6)	3.8 [3.2] (13)	3.3 [2.8] (17)	2.2 [1.9] (38)

Table 19.--Selected results of K-CERA analysis--Continued

Station identification	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread, in percent] (Number of visits per year)					
	Current operation	Budget, in thousands of 1984 dollars				
		278	297	350	400	600
083009 Nubanusit-W	11.9 [11.9] (2)	11.9 [11.9] (2)	11.9 [11.9] (2)	11.9 [11.9] (3)	11.9 [11.8] (4)	11.8 [11.8] (7)
085500 West Hopkinton-S	17.9 [1.4] (5)	23.0 [1.8] (3)	11.6 [0.9] (12)	7.9 [0.6] (26)	6.5 [0.5] (38)	4.7 [0.4] (73)
085505 West Hopkinton-V 5/	20.0 [9.6] (2)	20.0 [9.6] (2)	11.9 [7.1] (7)	8.2 [5.1] (16)	6.6 [4.2] (25)	4.9 [3.1] (46)
085509 West Hopkinton-W	19.9 [14.5] (2)	19.9 [14.5] (2)	17.2 [12.9] (3)	11.5 [8.9] (8)	9.2 [7.2] (13)	6.5 [5.1] (27)
085800 Bradford-S	23.0 [7.6] (7)	29.8 [8.8] (4)	15.2 [5.9] (17)	10.2 [4.3] (39)	8.5 [3.6] (57)	6.0 [2.6] (113)
085809 Bradford-W	75.3 [75.2] (2)	75.3 [75.2] (2)	75.3 [75.2] (2)	75.3 [75.2] (2)	75.2 [75.2] (3)	75.2 [75.2] (4)
087000 Blackwater-S	12.5 [1.8] (7)	16.4 [1.9] (4)	9.6 [1.7] (12)	6.2 [1.6] (30)	5.3 [1.5] (42)	3.8 [1.2] (85)

Table 19.--Selected results of K-CERA analysis--Continued

Station identification	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread, in percent] (Number of visits per year)					
	Current operation	Budget, in thousands of 1984 dollars				
		278	297	350	400	600
087009 Blackwater-W	55.4 [55.4] (2)	55.4 [55.4] (2)	55.4 [55.4] (2)	55.4 [55.4] (2)	55.4 [55.4] (2)	55.4 [55.4] (3)
089000 Soucook-S	14.9 [14.7] (7)	19.8 [19.4] (4)	10.1 [10.0] (15)	6.6 [6.5] (35)	5.5 [5.4] (52)	4.0 [3.9] (100)
089009 Soucook-W	13.8 [13.7] (2)	13.8 [13.7] (2)	13.8 [13.7] (2)	13.8 [13.7] (2)	13.8 [13.7] (2)	13.7 [13.7] (3)
090800 Everett Dam	8.9 [3.8] (9)	13.7 [4.4] (5)	6.9 [3.5] (13)	4.4 [2.8] (27)	3.6 [2.4] (38)	2.5 [1.8] (76)
092000 Goffs Falls	2.7 [1.6] (9)	3.6 [1.7] (5)	3.6 [1.7] (5)	3.3 [1.7] (6)	2.9 [1.6] (8)	2.1 [1.4] (17)
093800 Stony-S	26.0 [11.3] (7)	34.4 [16.2] (4)	16.6 [6.8] (17)	10.9 [4.4] (40)	9.0 [3.7] (58)	6.6 [2.8] (109)
093809 Stony-W	70.8 [70.7] (2)	70.8 [70.7] (2)	70.8 [70.7] (2)	70.5 [70.4] (3)	70.4 [70.4] (4)	70.2 [70.2] (7)

Table 19.--Selected results of K-CERA analysis--Continued

Station identification	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread, in percent] (Number of visits per year)					
	Current operation	Budget, in thousands of 1984 dollars				
		278	297	350	400	600
127880 Big Brook-S	19.0 [3.2] (7)	25.0 [4.3] (4)	19.0 [3.2] (7)	12.2 [2.0] (17)	10.0 [1.7] (25)	5.7 [1.0] (79)
127889 Big Brook-W	33.1 [30.6] (2)	33.1 [30.6] (2)	33.1 [30.6] (2)	31.3 [29.5] (3)	28.5 [27.5] (6)	21.0 [20.5] (22)
128500 First Ct. Lake	7.2 [6.6] (9)	7.9 [7.0] (6)	7.9 [7.0] (6)	6.6 [6.2] (14)	5.6 [5.4] (27)	3.3 [3.2] (101)
129200 Indian Stream	6.1 [2.6] (9)	7.4 [2.8] (6)	7.4 [2.8] (6)	5.0 [2.4] (14)	3.7 [2.0] (27)	2.0 [1.2] (101)
129500 North Stratford-S	6.2 [5.7] (7)	6.9 [5.9] (4)	6.9 [5.9] (4)	6.0 [5.6] (11)	5.7 [5.5] (21)	5.2 [5.1] (79)
129509 North Stratford-W	9.8 [9.6] (2)	9.8 [9.6] (2)	9.8 [9.6] (2)	9.7 [9.6] (3)	9.5 [9.5] (6)	9.5 [9.5] (22)
130000 Groveton-S	21.5 [21.5] (7)	21.8 [21.7] (4)	21.8 [21.7] (4)	21.1 [21.1] (11)	20.2 [20.2] (21)	15.4 [15.3] (79)

Table 19.--Selected results of K-CERA analysis--Continued

Station identification	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread, in percent] (Number of visits per year)					
	Current operation	Budget, in thousands of 1984 dollars				
		278	297	350	400	600
130009 Groveton-W	31.5 [31.4] (2)	31.5 [31.4] (2)	27.3 [27.2] (3)	18.8 [18.7] (7)	15.1 [15.0] (11)	10.6 [10.6] (23)
131500 Dalton	3.6 [2.5] (9)	4.2 [2.8] (6)	4.2 [2.8] (6)	3.1 [2.2] (14)	2.3 [1.7] (27)	1.3 [1.0] (101)
134500 Victory-S	12.3 [3.4] (7)	18.4 [3.7] (3)	11.5 [3.4] (8)	8.2 [3.2] (17)	6.9 [3.1] (25)	5.1 [2.7] (53)
134509 Victory-W	55.8 [55.8] (2)	55.8 [55.8] (2)	55.8 [55.8] (2)	55.8 [55.8] (2)	55.8 [55.8] (2)	55.8 [55.8] (4)
135500 St. Johnsbury-S	3.9 [1.7] (7)	5.9 [2.0] (3)	5.1 [1.9] (4)	3.4 [1.5] (9)	2.8 [1.3] (14)	2.0 [1.0] (27)
135509 St. Johnsbury-W	12.4 [12.3] (2)	12.4 [12.3] (2)	12.4 [12.3] (2)	12.4 [12.3] (2)	9.8 [9.7] (8)	6.8 [6.8] (22)
137500 Bethlehem Jct.-S	10.6 [2.5] (7)	13.8 [2.8] (4)	13.8 [2.8] (4)	8.5 [2.2] (11)	6.2 [1.8] (21)	3.2 [1.0] (79)

Table 19.--Selected results of K-CERA analysis--Continued

Station identification	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread, in percent] (Number of visits per year)					
	Current operation	Budget, in thousands of 1984 dollars				
		278	297	350	400	600
137509 Bethlehem Jct.-W	18.9 [16.9] (2)	18.9 [16.9] (2)	18.9 [16.9] (2)	15.1 [13.8] (4)	11.4 [10.4] (8)	7.2 [6.6] (22)
138500 Connecticut at Wells-S	3.6 [3.1] (7)	4.4 [3.3] (3)	3.9 [3.1] (5)	3.3 [3.0] (12)	3.1 [2.9] (18)	2.8 [2.6] (40)
138509 Connecticut at Wells-W	9.5 [9.5] (2)	9.5 [9.5] (2)	9.5 [9.5] (2)	9.5 [9.5] (2)	9.5 [9.5] (2)	9.5 [9.5] (2)
139000 Wells at Wells-S	9.7 [4.1] (7)	14.3 [4.4] (3)	11.3 [4.2] (5)	7.8 [3.9] (12)	6.7 [3.7] (18)	4.9 [3.3] (40)
139009 Wells at Wells-W	42.2 [42.2] (2)	42.2 [42.2] (2)	42.2 [42.2] (2)	42.2 [42.2] (2)	42.2 [42.2] (2)	42.2 [42.2] (2)
139800 East Orange-S	15.1 [10.3] (7)	15.1 [10.3] (7)	9.8 [6.5] (17)	6.6 [4.4] (37)	5.5 [3.6] (54)	4.1 [2.7] (100)
139809 East Orange-W	25.3 [23.7] (2)	25.3 [23.7] (2)	15.9 [14.7] (6)	11.1 [10.2] (13)	9.0 [8.2] (20)	7.3 [6.8] (31)

Table 19.--Selected results of K-CERA analysis--Continued

Station identification	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread, in percent] (Number of visits per year)					
	Current operation	Budget, in thousands of 1984 dollars				
		278	297	350	400	600
141500 Ompompanoosuc-S	10.2 [9.9] (7)	14.4 [13.6] (3)	8.7 [8.4] (10)	6.0 [5.8] (21)	5.0 [4.9] (30)	3.5 [3.4] (61)
141509 Ompompanoosuc-W	25.4 [25.3] (2)	25.4 [25.3] (2)	25.4 [25.3] (2)	25.4 [25.3] (2)	25.0 [24.9] (3)	15.2 [15.2] (30)
141800 Mink-S	25.6 [8.6] (7)	38.5 [15.1] (3)	17.6 [5.5] (15)	11.5 [3.6] (35)	9.6 [3.0] (51)	6.8 [2.3] (102)
141809 Mink-W	70.6 [70.5] (2)	70.6 [70.5] (2)	70.6 [70.5] (2)	70.6 [70.5] (2)	70.6 [70.5] (2)	70.6 [70.5] (2)
142500 Ayers-S	15.4 [15.1] (7)	15.6 [15.2] (6)	15.6 [15.2] (6)	14.1 [14.0] (24)	12.8 [12.7] (48)	9.9 [9.9] (118)
142509 Ayers-W	25.1 [25.1] (2)	25.1 [25.1] (2)	25.1 [25.1] (2)	25.1 [25.1] (2)	25.0 [25.0] (3)	25.0 [25.0] (30)
144000 White-S	4.0 [1.0] (7)	6.4 [1.1] (3)	6.4 [1.1] (3)	4.4 [1.0] (6)	3.1 [0.9] (12)	1.9 [0.7] (32)

Table 19.--Selected results of K-CERA analysis--Continued

Station identification	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread, in percent] (Number of visits per year)					
	Current operation	Budget, in thousands of 1984 dollars				
		278	297	350	400	600
144009 White-W	6.7 [5.8] (2)	6.7 [5.8] (2)	6.7 [5.8] (2)	6.7 [5.8] (2)	6.3 [5.7] (3)	4.1 [4.0] (30)
144500 West Lebanon-S	6.4 [6.1] (7)	7.0 [6.5] (3)	7.0 [6.5] (3)	6.6 [6.2] (5)	6.4 [6.1] (7)	5.7 [5.6] (20)
144509 West Lebanon-W	10.4 [10.4] (2)	10.4 [10.4] (2)	10.4 [10.4] (2)	10.4 [10.4] (2)	10.4 [10.4] (2)	10.4 [10.4] (2)
150500 Mascoma	8.7 [3.3] (9)	11.8 [4.5] (5)	8.2 [3.1] (10)	5.6 [2.1] (21)	4.6 [1.8] (31)	3.2 [1.3] (65)
151500 Ottauquechee-S	4.8 [3.8] (7)	6.4 [4.1] (3)	6.4 [4.1] (3)	5.3 [3.9] (5)	4.8 [3.8] (7)	3.9 [3.5] (20)
151509 Ottauquechee-W	13.2 [13.2] (2)	13.2 [13.2] (2)	13.2 [13.2] (2)	13.2 [13.2] (2)	13.2 [13.2] (2)	13.2 [13.2] (2)
152500 Sugar-S	8.7 [2.5] (7)	13.5 [3.6] (3)	9.4 [2.7] (6)	6.3 [1.9] (13)	5.3 [1.6] (18)	3.8 [1.2] (36)

Table 19.--Selected results of K-CERA analysis--Continued

Station identification	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread, in percent] (Number of visits per year)					
	Current operation	Budget, in thousands of 1984 dollars				
		278	297	350	400	600
152509 Sugar-W	38.9 [38.9] (2)	38.9 [38.9] (2)	38.9 [38.9] (2)	38.9 [38.9] (2)	38.9 [38.9] (2)	38.8 [38.8] (4)
153000 North Springfield	4.5 [3.4] (9)	5.8 [4.5] (5)	5.8 [4.5] (5)	4.5 [3.4] (9)	3.7 [2.8] (13)	2.6 [1.9] (28)
154500 North Walpole	3.2 [2.5] (9)	3.8 [2.6] (5)	3.3 [2.5] (8)	2.9 [2.5] (15)	2.8 [2.4] (20)	2.6 [2.4] (40)
155500 Jamaica-S	4.4 [2.6] (7)	6.5 [3.9] (3)	6.5 [2.9] (3)	4.4 [2.6] (7)	3.6 [2.1] (11)	2.4 [1.4] (25)
155509 Jamaica-W	15.9 [15.8] (2)	15.9 [15.8] (2)	15.9 [15.8] (2)	15.9 [15.8] (2)	15.9 [15.8] (2)	15.8 [15.8] (3)
156000 Newfane-S	6.0 [1.7] (7)	8.8 [2.9] (3)	8.8 [2.9] (3)	6.0 [1.7] (7)	4.9 [1.3] (11)	3.3 [0.9] (25)
156009 Newfane-W	16.1 [16.0] (2)	16.1 [16.0] (2)	16.1 [16.0] (2)	16.1 [16.0] (2)	16.1 [16.0] (2)	16.0 [16.0] (3)

Table 19.--Selected results of K-CERA analysis--Continued

Station identification	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread, in percent] (Number of visits per year)					
	Current operation	Budget, in thousands of 1984 dollars				
		278	297	350	400	600
158000 Surry Mountain	4.2 [2.9] (9)	5.3 [3.4] (5)	4.6 [3.1] (7)	3.3 [2.3] (16)	2.8 [2.0] (23)	2.1 [1.5] (43)
158600 Otter Brook	7.6 [2.3] (9)	11.6 [3.2] (5)	9.1 [2.6] (7)	5.1 [1.7] (16)	4.1 [1.4] (23)	2.8 [1.0] (43)
161000 Hindsdale	8.4 [2.2] (9)	11.1 [2.7] (5)	9.5 [2.4] (7)	6.3 [1.8] (16)	5.3 [1.5] (23)	3.9 [1.2] (43)
334000 Bennington	10.4 [1.9] (9)	13.9 [2.6] (5)	12.7 [2.4] (6)	8.0 [1.5] (15)	6.8 [1.3] (21)	4.9 [0.9] (41)
280000 Poultney	14.1 [1.4] (9)	18.8 [1.5] (5)	13.4 [1.4] (10)	8.9 [1.3] (23)	7.2 [1.1] (36)	4.7 [0.9] (86)
282000 Center Rutland	9.4 [3.3] (9)	12.7 [4.0] (5)	8.9 [3.2] (10)	5.9 [2.4] (23)	4.7 [2.0] (36)	3.1 [1.3] (86)
284000 Jail Branch-S	20.2 [1.3] (7)	20.2 [1.3] (7)	12.8 [0.8] (17)	8.6 [0.6] (37)	7.1 [0.5] (54)	5.2 [0.4] (100)

Table 19.--Selected results of K-CERA analysis--Continued

Station identification	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread, in percent] (Number of visits per year)					
	Current operation	Budget, in thousands of 1984 dollars				
		278	297	350	400	600
284009 Jail Branch-W	22.0 [17.5] (2)	22.0 [17.5] (2)	15.8 [12.4] (4)	11.3 [8.8] (8)	9.6 [7.5] (12)	7.8 [6.2] (19)
285500 North Branch Winooski-S	10.0 [2.9] (7)	15.2 [3.1] (3)	10.7 [2.9] (6)	6.8 [2.7] (16)	6.0 [2.6] (21)	4.3 [2.3] (47)
285509 North Branch Winooski-W	42.6 [42.6] (2)	42.6 [42.6] (2)	42.6 [42.6] (2)	42.6 [42.6] (2)	42.5 [42.5] (4)	42.4 [42.4] (30)
286000 Winooski-S	3.8 [3.0] (7)	4.7 [3.2] (3)	3.9 [3.0] (6)	3.2 [2.8] (16)	3.0 [2.7] (21)	2.5 [2.3] (47)
286009 Winooski-W	18.5 [18.4] (2)	18.5 [18.4] (2)	18.5 [18.4] (2)	18.5 [18.4] (2)	17.9 [17.9] (4)	11.8 [11.8] (30)
287000 Dog-S	9.7 [1.8] (7)	12.9 [2.3] (4)	7.7 [1.5] (11)	5.0 [1.0] (26)	4.3 [0.9] (34)	3.0 [0.6] (71)
287009 Dog-W	14.8 [13.8] (2)	14.8 [13.8] (2)	14.8 [13.8] (2)	10.0 [9.4] (6)	8.3 [7.9] (9)	5.8 [5.5] (20)

Table 19.--Selected results of K-CERA analysis--Continued

Station identification	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread, in percent] (Number of visits per year)					
	Current operation	Budget, in thousands of 1984 dollars				
		278	297	350	400	600
289000 Little River	7.8 [1.7] (9)	9.8 [2.1] (6)	7.8 [1.7] (9)	5.1 [1.2] (20)	5.0 [1.2] (21)	5.0 [1.2] (21)
290500 Essex Jct.-S	4.1 [3.2] (7)	5.6 [3.4] (3)	5.0 [3.3] (4)	3.9 [3.1] (9)	3.6 [3.1] (12)	3.2 [2.9] (22)
290509 Essex Jct.-W	11.8 [11.8] (2)	11.8 [11.8] (2)	11.8 [11.8] (2)	11.8 [11.8] (2)	11.8 [11.8] (2)	11.8 [11.8] (2)
292000 Johnson-S	4.5 [3.8] (7)	4.3 [3.6] (8)	4.3 [3.6] (8)	3.9 [3.3] (10)	3.4 [3.0] (13)	2.8 [2.4] (20)
292009 Johnson-W	12.3 [12.2] (2)	12.3 [12.2] (2)	12.3 [12.2] (2)	12.3 [12.2] (2)	12.3 [12.2] (2)	12.3 [12.2] (2)
292500 East Georgia-S	4.9 [1.8] (7)	7.8 [2.4] (3)	6.7 [2.2] (4)	4.3 [1.6] (9)	3.7 [1.5] (12)	2.8 [1.1] (22)
292509 East Georgia-W	22.4 [22.3] (2)	22.4 [22.3] (2)	22.4 [22.3] (2)	22.4 [22.3] (2)	22.4 [22.3] (2)	22.4 [22.3] (2)

Table 19.--Selected results of K-CERA analysis--Continued

Station identification	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread, in percent] (Number of visits per year)					
	Current operation	Budget, in thousands of 1984 dollars				
		278	297	350	400	600
293500 East Berkshire-S	10.0 [1.8] (7)	13.2 [2.2] (4)	11.8 [2.0] (5)	7.6 [1.4] (12)	6.2 [1.1] (18)	4.4 [0.8] (36)
293509 East Berkshire-W	22.2 [21.0] (2)	22.2 [21.0] (2)	22.2 [21.0] (2)	15.2 [14.5] (7)	13.2 [12.6] (10)	9.3 [8.8] (22)
296000 Coventry-S	11.0 [2.3] (7)	14.5 [2.9] (4)	11.0 [2.3] (7)	7.6 [1.7] (15)	6.3 [1.4] (22)	4.4 [1.0] (44)
296009 Coventry-W	49.3 [49.3] (2)	49.3 [49.3] (2)	49.3 [49.3] (2)	49.3 [49.3] (2)	49.3 [49.3] (2)	49.3 [49.3] (2)
296500 Clyde	7.4 [6.5] (9)	10.0 [8.9] (5)	10.0 [8.9] (5)	6.3 [5.6] (12)	5.1 [4.5] (18)	3.7 [3.3] (36)

Footnotes for Table 19

1/ Curent operation and associated errors for 1984 budget of 297,000 dollars.
2/ Square root of seasonally-averaged station variance.
3/ Summer season.
4/ Winter season.
5/ Vegetation season.

A minimum budget of $278,000 is required to operate the current stream-gaging program. At this budget, the average standard error per gage would be 20.4 percent. A budget less than this would not permit the minimum service and maintenance requirements for the gages and recorders to be met. Stations would have to be eliminated if the budget fell below this level. The minimum standard error for any of the gages would be 3.6 percent at 092000 (Goffs Falls). The maximum standard error for a gage (not considering stations which had an ice-backwater variance analysis) would be 39.2 percent for the summer period at Stevens (075800).

The current operational policy results in an average standard error of 17.9 percent. This policy requires a budget of $297,000 to operate the 60 regular stream gages. The range of standard errors is from 2.7 percent at Goffs Falls (092000) to 85.7 percent for the winter period (ice-backwater variance analysis) at Stevens (075800). The standard error for the summer period at Stevens (075800) is 33.4 percent. Figure 13 indicates that it would be possible to obtain the same average standard error with a reduced budget of about $285,000 by redistributing stream-gaging resources optimally among all the gages.

When the cost-effective analysis is applied to the current budget, the minimum average standard error per gage would be 16.6 percent, a decrease of 1.3 percent as compared to current practice. The standard error at Goffs Falls would increase to 3.6 percent but the standard error for the summer period at Stevens would be reduced by 14.4 percent to 19.0 percent.

The highest budget for which the cost-effective analysis was applied was $600,000. At this level, the average standard error per gage would be 13.5 percent. The maximum standard error for a single gage (not considering stations with an ice-backwater variance analysis) would be 15.4 percent for the summer period at Groveton (130000). Figure 13, however, indicates that only relatively small incremental improvements in the average standard error would be obtained for budget increases above approximately $350,000.

The K-Cera analysis was also performed under the assumption that there was no missing record of correlative data at any of the stream gages. On figure 13, the curve labelled "Without missing record" indicates the average standard errors of estimation of streamflow that could be obtained if perfectly reliable systems were available to measure and record the correlative data. For the minimal operational budget of $278,000, the effects of less than perfect equipment are greatest; average standard errors increase from 14.8 to 20.4 percent.

At the other budgetary extreme of $600,000, under which stations are visited more frequently, average standard errors increase from 13.1 percent for ideal equipment to 13.5 percent for the current systems of sensing and recording of hydrologic data. Thus, improved equipment can have a very positive impact on streamflow record uncertainties of the stream-gaging programs in New Hampshire and Vermont, especially at lower budgetary levels.

Conclusions pertaining to the K-CERA analysis

The Traveling Hydrographer Program is a tool which may be used to better manage the field activities of the stream-gaging programs of New Hampshire and Vermont. Cost-effective management implies that rather than giving equal attention to all gages, more effort (and money) is expended for those gages that will best respond. This relation is revealed by the way the standard errors and EGS (equivalent Gaussian spread) for each gage are altered by increases in the budget. EGS is strongly influenced by the stability of the stage-discharge relation. A lower percentage indicates a better and more stable relation.

Goffs Falls (092000) has had its current discharge rating in effect since 1954 and it requires only occasional measurements to verify that the rating is still valid. Under current program operation, this station has a standard error of 2.7 percent and an EGS of 1.6 percent for 9 visits per year. Table 19 indicates that at a reduced effort of 5 visits per year, the standard error would rise only to 3.6 percent. If the current budget were to be doubled, 17 visits per year could be made but the standard error would be lowered by only 0.6 percent. Conversely, Stevens (075800) is a station that experiences frequent rating changes. Under current practice, the summer season of Stevens has a standard error of 33.4 percent and an EGS of 25.5 percent for 7 open-water visits per year. If the current budget were doubled, the standard error would drop to 7.5 percent with 144 visits per year. While it is unrealistic for a station to be visited so frequently, it is apparent that Stevens should be given a much higher priority for field activities than Goffs Falls. There is a greater return in accuracy for each dollar spent on Stevens than on Goffs Falls.

SUMMARY

Currently, there are 73 continuous stream gages which are operated in New Hampshire and Vermont. An analysis of the placement of the stream gages in the two states revealed areas with relatively poor coverage in terms of collecting regionally-transferable hydrologic information. These regions include the Southern Highlands, White Mountains, Green Mountain Highlands, the Taconic Highlands, and the Champlain Lowlands.

Eight separate sources of funding contribute to the stream-gaging programs and up to nine separate uses were identified for data from a single gage. Based on this information, eight stations were identified as being candidates for suspension. As funding becomes available, it should be used to establish new gages (especially regional hydrology gages) in areas where more streamflow information would be useful. Four stream gages in New Hampshire were excluded from subsequent portions of the cost-effective analysis because their funding and operation originates from the Maine office.

Flow-routing and statistical models were investigated as possible alternatives to operating stream gages. Four stations were identified as having good applicability to either or both of these methods of streamflow synthesis. None of these methods, however, can simulate the needed hydrologic data at these sites within an acceptable degree of accuracy.

The current budget that is allocated to the operation of the stream-gaging program in New Hampshire and Vermont is $297,000 per year. It was demonstrated that the current average standard error of the instantaneous discharge of 17.9 percent could be maintained if the budget were reduced to about $285,000. At the current budgetary level of $297,000, cost-effective analysis reveals that a change in policy concerning field activities could improve the average standard error by 1.3 percent. The minimum budget that could sustain the current number of gages is $278,000.

It would be more cost-effective to allocate the stream gaging effort to favor those stations that the K-CERA analysis indicates would best respond to the increased attention. The resources to do this would come from a relative decrease in effort expended on stations which are less sensitive to visitation frequency. The amount of funding for stations with accuracies that are not acceptable for the data uses should be renegotiated with the data users.

A significant component of the error in streamflow records at lower budgetary levels is caused by loss of correlative data at the stream gages because of malfunctioning of sensing and recording equipment. Upgrading equipment and developing strategies to minimize lost record appear to be important actions required to improve the reliability and accuracy of the streamflow data generated in New Hampshire and Vermont.

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

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