In cooperation with the
NEW HAMPSHIRE DEPARTMENT OF ENVIRONMENTAL SERVICES

A Stream-Gaging Network Analysis for the 7-Day, 10-Year Annual Low Flow in New Hampshire Streams

Water-Resources Investigations Report 03-4023

U.S. Department of the Interior
U.S. Geological Survey

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U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3)

Temperature in degrees Fahrenheit (^oF) may be converted to degrees Celsius (^oC) as follows:

$$^oC=(^oF-32)/1.8.$$

VERTICAL DATUM

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum *derived* from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

ABBREVIATIONS

Organizations

NHDES	New Hampshire Department of Environmental Services
USGS	U.S. Geological Survey

Basin Characteristics

ABT	Average mean annual basin temperature, in Fahrenheit
DA	Drainage area, in square miles
SGP	Average summer gage precipitation, in inches

Miscellaneous

7Q10	7-day, 10-year low-flow frequency
GIS	Geographic information system
GLS	Generalized-least-squares regression analysis
GLSNET	Generalized-least-squares network computer software
OLS	Ordinary-least-squares regression analysis
WLS	Weighted-least-squares regression analysis

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ABSTRACT

The 7-day, 10-year (7Q10) low-flow-frequency statistic is a widely used measure of surface-water availability in New Hampshire. Regression equations and basin-characteristic digital data sets were developed to help water-resource managers determine surface-water resources during periods of low flow in New Hampshire streams. These regression equations and data sets were developed to estimate streamflow statistics for the annual and seasonal low-flow-frequency, and period-of-record and seasonal period-of-record flow durations. Generalized-least-squares (GLS) regression methods were used to develop the annual 7Q10 low-flow-frequency regression equation from 60 continuous-record stream-gaging stations in New Hampshire and in neighboring States. In the regression equation, the dependent variables were the annual 7Q10 flows at the 60 stream-gaging stations. The independent (or predictor) variables were objectively selected characteristics of the drainage basins that contribute flow to those stations. In contrast to ordinary-least-squares (OLS) regression analysis, GLS-developed estimating equations account for differences in length of record and spatial correlations among the flow-frequency statistics at the various stations.

A total of 93 measurable drainage-basin characteristics were candidate independent variables. On the basis of several statistical parameters that were used to evaluate which combination of basin characteristics contribute the most to the predictive power of the equations, three drainage-basin characteristics were determined to be statistically significant predictors of the annual 7Q10: (1) total drainage area, (2) mean summer stream-gaging station precipitation from 1961 to 90, and (3) average mean annual basinwide temperature from 1961 to 1990.

To evaluate the effectiveness of the stream-gaging network in providing regional streamflow data for the annual 7Q10, the computer program GLSNET (generalized-least-squares NETwork) was used to analyze the network by application of GLS regression between streamflow and the climatic and basin characteristics of the drainage basin upstream from each stream-gaging station. Improvement to the predictive ability of the regression equations developed for the network analyses is measured by the reduction in the average sampling-error variance, and can be achieved by collecting additional streamflow data at existing stations. The predictive ability of the regression equations is enhanced even further with the addition of new stations to the network. Continued data collection at unregulated stream-gaging stations with less than 14 years of record resulted in the greatest cost-weighted reduction to the average sampling-error variance of the annual 7Q10 regional regression equation. The addition of new stations in basins with underrepresented values for the independent variables of the total drainage area, average mean annual basinwide temperature, or mean summer stream-gaging station precipitation in the annual 7Q10 regression equation yielded a much greater cost-weighted reduction to the average sampling-error variance than when more data were collected at existing unregulated stations. To maximize the regional information obtained from the stream-gaging network for the annual 7Q10, ranking of the streamflow data can be used to determine whether an active station should be continued or if a new or discontinued station should be activated for streamflow data collection. Thus, this network analysis can help determine the costs and benefits of continuing the operation of a particular station or activating a new station at another location to predict the 7Q10 at ungaged stream reaches. The decision to discontinue an existing station or activate a new station, however, must also consider its contribution to other water-resource analyses such as flood management, water quality, or trends in land use or climatic change.

INTRODUCTION

The network of stream-gaging stations operated by the U.S. Geological Survey (USGS) and other agencies throughout the United States provides essential data for water-resource management. Using data collected from the stream-gaging network in New Hampshire and the surrounding States, Flynn (2002) developed regression equations and a geographic information system (GIS) to estimate low-flow statistics (seasonal and annual low-flow frequencies, and seasonal period-of-record and period-of-record low-flow durations) at ungaged and unregulated stream reaches in the New Hampshire. That study was done by the USGS, in cooperation with the New Hampshire Department of Environmental Services (NHDES), to provide streamflow statistics for the State of New Hampshire for use in the management of sustainable water resources for the benefit of water users and the environment.

Operation of a stream-gaging network is costly, and a network analysis is an objective method of determining the most cost-effective network for providing estimates of a particular streamflow statistic in a region. Network analysis results can help determine the tradeoff between the future costs of operating the network and the overall reduction in the prediction error of the regression equations (Thomas, 1994) that are used to determine the flow statistic of interest. The effectiveness of a particular stream-gaging station is determined by how much the data collected reduces the prediction error. In general, a cost-effective network covers the region of interest, has an adequate period-of-record, and includes the range of critical drainage-basin and streamflow characteristics in the region (Straub, 1998).

This USGS network analysis was conducted, in cooperation with the NHDES, to determine the most cost-effective strategy for collecting streamflow data for estimating the value of the low-flow statistic called the “7Q10” by use of the annual 7Q10 regression equation developed by Flynn (2002). The annual 7Q10 low flow is defined as the annual minimum average 7-consecutive-day streamflow that has an annual non-exceedence probability of 0.10, or that is expected not to be exceeded in 1 of 10 years. Low-flow statistics such as the 7Q10 are widely used for managing water quality through the regulation of wastewater discharges to receiving waters and for the estimation of surface-water availability for domestic, agricultural, industrial, and recreational uses and for aquatic-habitat maintenance. The annual 7Q10 low-flow regression equation (Flynn, 2002) was developed using daily-mean flows for all of the complete climatic years of record at each stream-gaging station through 1999 to determine low-flow statistics. The season for the *n*-day low flow typically is the climatic year that begins on April 1 and ends on March 31 of the following year. The station network was evaluated for the current (through climatic year 1999) condition (or zero-year planning horizon) of the network, as well as for estimated conditions of various network strategies if streamflow data were collected for an additional 5 and 20 years (5- and 20-year planning horizons).

Purpose and Scope

The purpose of this report is to describe the results of an analysis of the New Hampshire stream-gaging network to assess the contribution of individual stream-gaging stations to the total streamflow information provided by the network for the annual 7Q10, and to explore the cost-effectiveness of various network scenarios. In addition, this report describes how the network analysis was developed and evaluated.

A network analysis of the stream-gaging stations provides a quantitative measure of the contribution of each active, discontinued, and potential station in providing information on the annual 7Q10. Only unregulated streamflow data were used to develop regression equations for estimating the annual 7Q10. In order to determine the contribution of the data for each station site to regional streamflow information, the network analysis used regression equations in combination with information on location, period-of-record and cost of operation. The contribution to the effectiveness of the analyses for each station was based on the cost-weighted reduction of the mean square error (average sampling-error variance) associated with the regional regression equation developed for the annual 7Q10 low-flow statistic. Each station was analyzed and ranked according to this cost-weighted reduction of the mean square error.

Previous Studies

Previous studies in which the network-analysis method was used to evaluate the effectiveness of a stream-gaging network to provide regional information include those for Kansas (Medina, 1987), Kentucky (Ruhl, 1993), and Ohio (Straub, 1998). In those studies, data from existing stations were used in combination with hypothetical stations to evaluate current and potentially new networks for various planning horizons.

Acknowledgments

The author thanks Gary Tasker of the U.S. Geological Survey for sharing his extensive experience with generalized-least-squares (GLS) regression methods and the computer program generalized-least-squares NETwork (GLSNET). In addition, Dr. S.L. Dingman of the University of New Hampshire, reviewed this study and contributed many valuable comments.

METHOD FOR NETWORK ANALYSIS OF ANNUAL 7-DAY, 10-YEAR LOW FLOW

A stream-gaging-network analysis is used to maximize the regional station information for a given period of time and budget or to determine the effect of a change in a station's operating budget on the information provided by the network. The regional regression approach used in the GLSNET (Tasker and Stedinger, 1989) computer program evaluates the likelihood of improving the regression relation between basin characteristics and a streamflow statistic by the addition of streamflow data. In this study, the annual 7Q10 was selected because many State and local agencies use this statistic to regulate wastewater discharges to surface waters. In contrast to ordinary-least-squares (OLS) and weighted-least-squares (WLS) regression, GLS regression accounts for cross-correlation between concurrent stream-gaging station record and for varying lengths of record among stations.

Description of Method

The network analysis for this study involved the use of GLSNET. This program uses GLS regression methods to estimate the prediction error at each station for selected streamflow characteristics. There are two parts to the prediction mean square error: the model error and the sampling error. The prediction mean square error, or variance of prediction, for an ungaged site is calculated as the square root of the sum of the model error and the sampling error. The GLS-regression method evaluates the benefit of additional data collection by considering the model error and sampling error separately. The model error can be improved by developing a better model, and the sampling error can be improved by collecting additional streamflow data (Straub, 1998). The objective of the stream-gaging-network analysis is to obtain the largest reduction in sampling error, which is equivalent to the most improvement in the regional streamflow information (Thomas, 1994). For a given planning horizon and regression model, the network-analysis method can be used to improve the regional information by minimizing the average sampling-error variance of the gaging-station network subject to budgetary constraints (Straub, 1998).

The developed regression equation for the annual 7Q10 for 5- and 20-years in the future (planning horizon) was used in a network analysis to improve the regional streamflow data by minimizing the average sampling-error variance of the stream-gaging network without consideration of any future budgetary constraints. The model error is assumed to be constant in the network analysis. The average sampling-error variance is a measure of the error in the average regression prediction in a region that results from estimating with sample estimates of the regression coefficients (Ruhl, 1993). The average sampling-error variance is a function of the record length of the stations, location of the stations in relation to one another, and the values of the basin and climatic and streamflow characteristics used in the regression equation. In addition to those properties that affect the average sampling-error variance, the cost of the operation and maintenance of a station can be applied to each station to determine if the cost-weighted contribution of the station will reduce the average sampling-error variance. Because of these properties, the average sampling-error variance was used to evaluate whether to add additional station sites in a network analysis or to rely solely on the current network (Ruhl, 1993). The network-analysis results help determine whether to spend available resources collecting additional data at active sites, add new sites, or do both. The addition of new stations (or the reactivation of discontinued stations) to the network will enhance the predictive ability of the regression model by increasing the number of observation points, whereas the continued operation of the active stations will improve the predictive ability of a regional regression model by reducing the sampling errors in the flow statistics at the stations. The additional streamflow data will increase the reliability of the estimated regression coefficients by reducing the average sampling-error variance of the regression equations. The length of time over which additional data are to be collected is referred to as the “planning horizon.” The number of years selected for the planning horizon results in an associated reduction in the average sampling-error variance. Typically, the largest relative decreases in average sampling-error variance are achieved for the stations with the fewest years of record.

Tasker and Stedinger (1989) describe the mathematical formulation of the network analysis methods used in this study. In addition to evaluating the probability of improving the regression relation, GLSNET is used to determine the relative contribution of each station in providing streamflow information if additional streamflow data were collected for a specified time period. A step-backward algorithm is used to determine which stations provide the smallest cost-weighted reduction in the average sampling variance. Each station is then incrementally removed from the network (in the order of increasing contribution to error-variance reduction) until no stations remain. The last station that is removed from the network analysis contributes the largest cost-weighted reduction in the average sampling-error variance. The order that the stream-gaging stations are removed from the network can be used to rank each station by its relative contribution to the regression information for each flow characteristic and each planning horizon (Straub, 1998).

A database containing a representative set of drainage basins for the low-flow analysis was developed on the basis of the following criteria: (1) a station (whether active or discontinued) was required to have a minimum of 10 years of continuous-record data, as shorter records may not provide a sufficient sampling of the variation that may exist in the population; (2) natural streamflow was not significantly affected by regulation, diversion, or augmentation and (3) in Vermont, only those stations in the Connecticut River Basin were included in this study, and in Maine and Massachusetts, only those stations within 25 mi of the New Hampshire border were included. The data from all 60 of the unregulated stations used in the development of the annual 7Q10 regression equation (Flynn, 2002) were included in the network analysis for the annual 7Q10. All of the streamflow data included in this study were unregulated for the period used in the analysis. Stream-gaging station records through climatic year 1999 were used to compute the annual 7Q10 for each of the stream-gaging stations and lengths of record ranged from 10 to 95 years. The names and descriptions of the 60 stream-gaging stations are shown in table 1. The locations of the stations, streams, associated drainage basins, and towns are shown on figures 1 and 2.

The values of 93 physical and climatic (seasonal and annual) basin-characteristic explanatory variables (independent variables in the regression equations) were determined for each of the 60 unregulated stations (Appendix 1). Most of the basin characteristics were determined within a GIS (Environmental Systems Research Institute, Inc., 1994) using available and created data layers. Three of the 93 basin and climatic characteristics were determined to be the most statistically significant in explaining the variability of the dependent (response) variable of annual 7Q10. The annual 7Q10 equation as determined in Flynn (2002) is:

$$7Q10 = 1.28 \times 10^{5.33} \times (DA)^{1.39} \times (ABT)^{-7.67} \times (SGP)^{4.17} \qquad (1)$$

where

1.28	bias correction factor;
$10^{5.33}$	constant;
DA	total drainage area, in square miles;
ABT	average mean annual basinwide temperature, in degrees Fahrenheit; and
SGP	average summer precipitation at the stream-gaging station, in inches.

Table 1. Descriptions of stream-gaging stations used to develop the regression analysis for New Hampshire streams

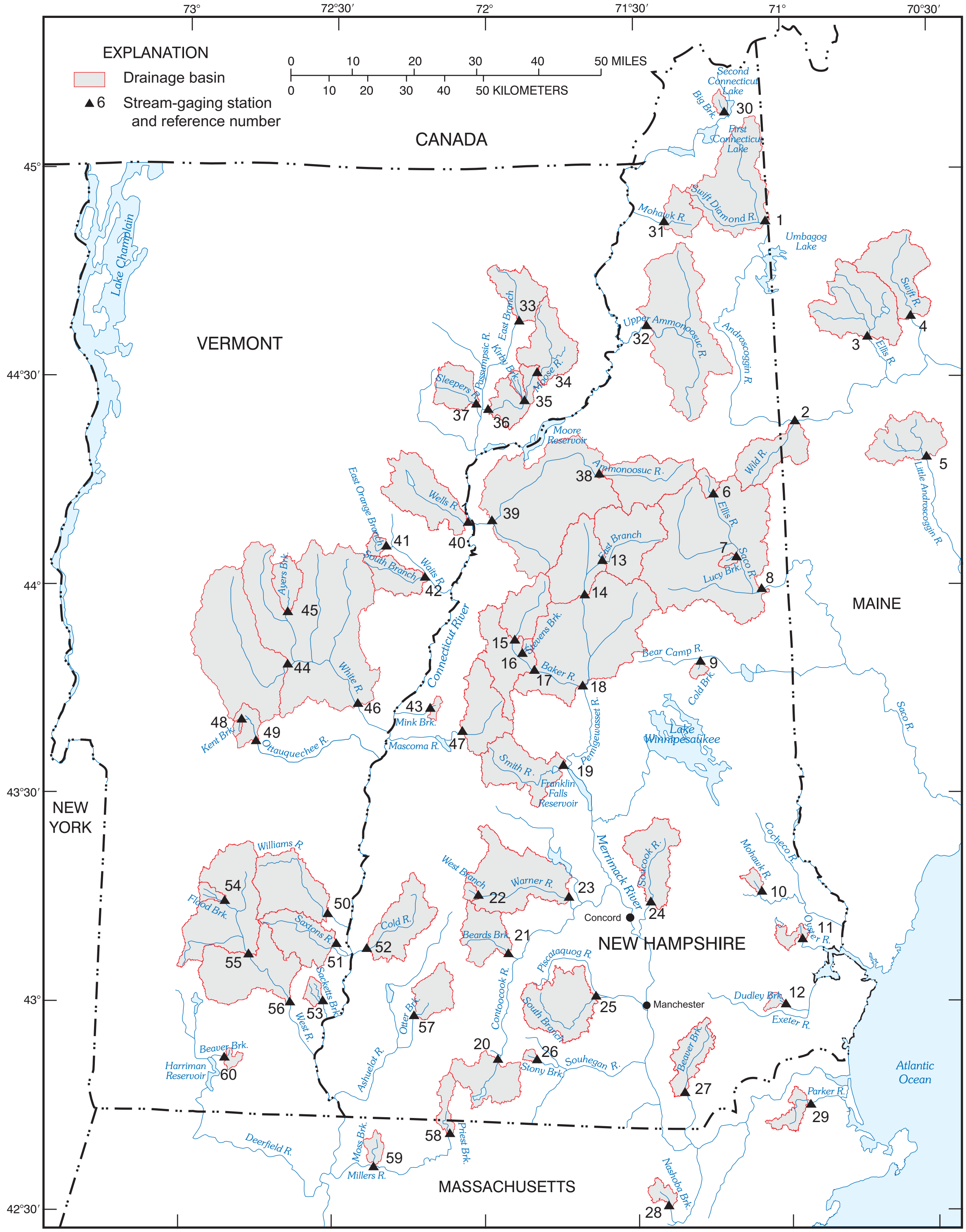
[No., number; fig., figure; mi^2, square miles; present in period of record refers to data through water year 1999]

Stream-gaging station reference No. (fig. 1)	Stream-gaging station No.	Latitude (decimal degrees)	Longitude (decimal degrees)	River name	Location (fig. 2)	Period of record, year	Drainage area (mi^2)
1	1052500	44.8778	71.0569	Diamond River	Wentworth Location, N.H.	1941-present	153
2	1054200	44.3908	70.9797	Wild River	Gilead, Maine	1964-present	69.9
3	1054300	44.5936	70.7336	Ellis River	South Andover, Maine	1963-82	130
4	1055000	44.6422	70.5881	Swift River	near Roxbury, Maine	1929-present	96.8
5	1057000	44.3033	70.5394	Lower Androscoggin River	near South Paris, Maine	1913-24, 1931-99	74.1
6	1064300	44.2200	71.2500	Ellis River	near Jackson, N.H.	1963-present	10.5
7	1064400	44.0694	71.1750	Lucy Brook	near North Conway, N.H.	1964-92	4.68
8	1064500	43.9908	71.0914	Saco River	near Conway, N.H.	1903-12, 1929-present	385
9	1064800	43.8158	71.2975	Cold Brook	South Tamworth, N.H.	1964-73	5.41
10	1072850	43.2631	71.0972	Mohawk River	Center Strafford, N.H.	1964-77,	7.47
11	1073000	43.1486	70.9656	Oyster River	Durham, N.H.	1934-present	12.2
12	1073600	42.9936	71.0233	Dudley Brook	Exeter, N.H.	1962-85	5.85
13	1074500	44.0600	71.6200	East Branch Pemigewasset	near Lincoln, N.H.	1928-53	106
14	1075000	43.9761	71.6800	Pemigewasset River	Woodstock, N.H.	1940-77	195
15	1075500	43.8681	71.9097	Baker River	Wentworth, N.H.	1940-52	57.8
16	1075800	43.8367	71.8853	Stevens Brook	Wentworth, N.H.	1963-98	3.29
17	1076000	43.7961	71.8450	Baker River	Rumney, N.H.	1929-75	143
18	1076500	43.7592	71.6861	Pemigewasset River	Plymouth, N.H.	1903-present	623
19	1078000	43.5675	71.7483	Smith River	near Bristol, N.H.	1918-present	86.0
20	1082000	42.8625	71.9597	Contoocook River	Peterborough, N.H.	1945-77	67.0
21	1084500	43.1142	71.9267	Beards Brook	Hillsboro, N.H.	1945-70	55.3
22	1085800	43.2592	72.0264	West Branch Warner River	near Bradford, N.H.	1962-present	5.91
23	1086000	43.2517	71.7317	Warner River	Davisville, N.H.	1940-78	146
24	1089000	43.2394	71.4622	Soucook River	near Concord, N.H.	1952-87, 1988-present	77.8
25	1091000	43.0136	71.6419	South Branch Piscataquog River	near Goffstown, N.H.	1940-78	103
26	1093800	42.8600	71.8333	Stony Brook Tributary	near Temple, N.H.	1964-present	3.62
27	10965852	42.7831	71.3539	Beaver Brook	North Pelham, N.H.	1986-present	47.8
28	1097300	42.5108	71.4069	Nashoba Brook	near Acton, Mass.	1963-present	12.8
29	1101000	42.7528	70.9461	Parker River	Byfield, Mass.	1945-present	21.2
30	1127880	45.1350	71.2064	Big Brook	Pittsburg, N.H.	1965-83	6.50
31	1129440	44.8744	71.4106	Mohawk River	near Colebrook, N.H.	1986-present	35.3
32	1130000	44.6250	71.4694	Upper Ammonoosuc River	near Groveton, N.H.	1940-80, 1982-present	230

Table 1. Descriptions of stream-gaging stations used to develop the regression analysis for New Hampshire streams--Continued

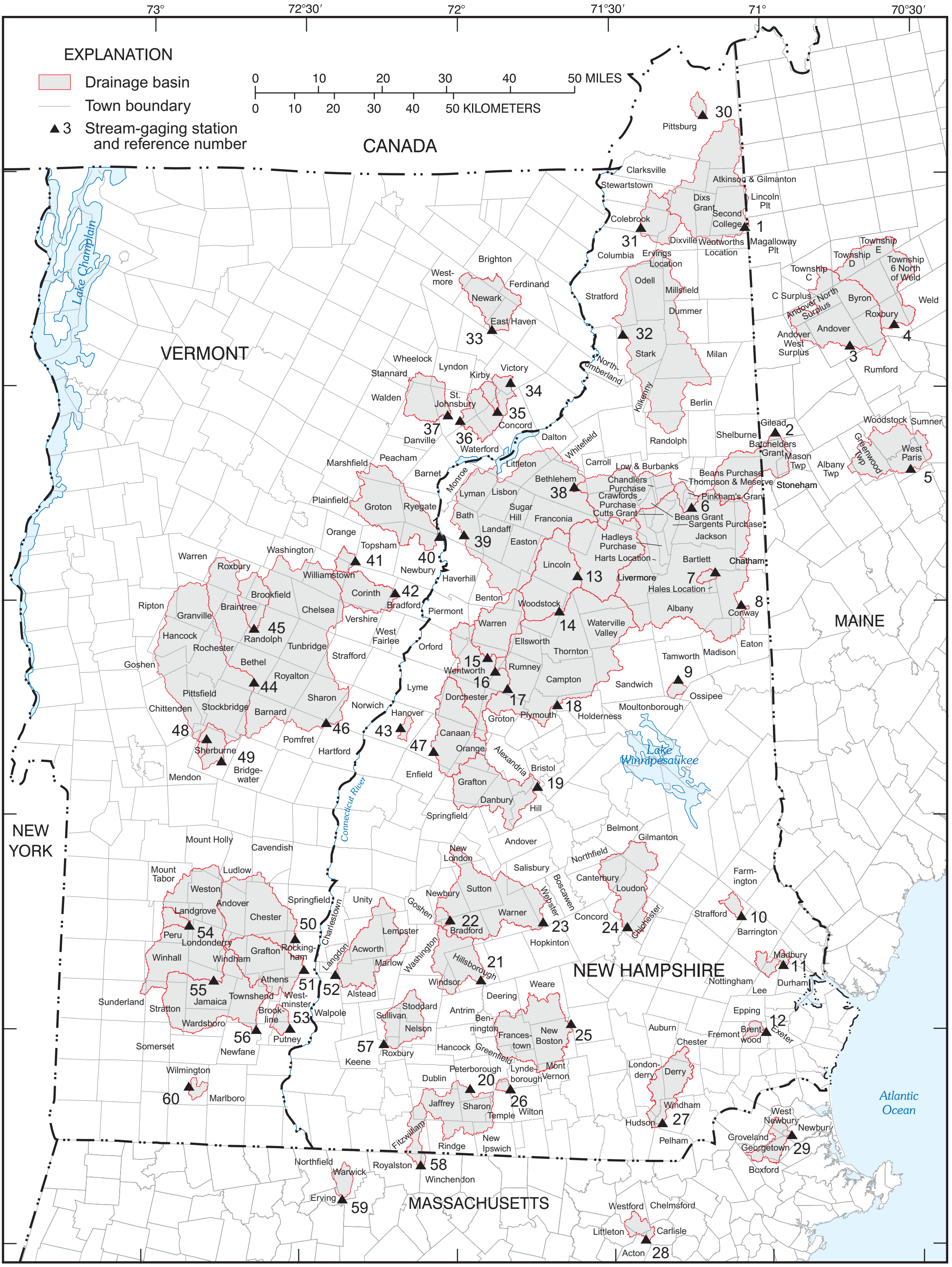
[No., number; fig., figure; mi^2, square miles; present in period of record refers to data through water year 1999]

Stream-gaging station reference No. (fig. 1)	Stream-gaging station No.	Latitude (decimal degrees)	Longitude (decimal degrees)	River name	Location (fig. 2)	Period of record, year	Drainage area (mi^2)
33	1133000	44.6339	71.8981	East Branch Passumpsic	East Haven, Vt.	1939-45, 1948-79	51.3
34	1134500	44.5117	71.8369	Moose River	Victory, Vt.	1947-present	75.2
35	1134800	44.4419	71.8792	Kirby Brook	Concord, Vt.	1963-74	8.13
36	1135000	44.4228	72.0006	Moose River	St. Johnsbury, Vt.	1928-83	129
37	1135300	44.4344	72.0394	Sleepers River (W-5)	St. Johnsbury, Vt.	1989-present	42.5
38	1137500	44.2689	71.6311	Ammonoosuc River	Bethlehem Junction, N.H.	1939-present	88.2
39	1138000	44.1539	71.9861	Ammonoosuc River	Bath, N.H.	1935-80	396
40	1139000	44.1508	72.0653	Wells River	Wells River, Vt.	1940-present	98.7
41	1139800	44.0928	72.3361	East Orange Branch	East Orange, Vt.	1958-present	8.79
42	1140000	44.0181	72.2083	South Branch Waits River	near Bradford, Vt.	1940-51	43.8
43	1141800	43.7022	72.1875	Mink Brook	Etna, N.H.	1962-98	4.75
44	1142000	43.8125	72.6569	White River	Bethel, Vt.	1931-55	239
45	1142500	43.9344	72.6583	Ayers Brook	Randolph, Vt.	1939-75, 76-present	30.5
46	1144000	43.7142	72.4186	White River	West Hartford, Vt.	1915-present	689
47	1145000	43.6500	72.0806	Mascoma River	West Canaan, N.H.	1939-78	80.4
48	1150800	43.6733	72.8092	Kent Brook	Sherburne, Vt.	1964-74	3.26
49	1150900	43.6222	72.7594	Ottauquechee River	West Bridgewater, Vt.	1984-present	23.3
50	1153500	43.2086	72.5181	Williams River	Brockways Mills, Vt.	1940-84	102
51	1154000	43.1372	72.4881	Saxtons River	Saxtons River, Vt.	1940-82	72.1
52	1155000	43.1317	72.3897	Cold River	Drewsville, N.H.	1940-78	83.3
53	1155200	42.9992	72.5331	Sacketts Brook	Putney, Vt.	1963-74	10.1
54	1155300	43.2364	72.8564	Flood Brook	Londonderry, Vt.	1963-74	9.28
55	1155500	43.1089	72.7758	West River	Jamaica, Vt.	1946-60	177
56	1156000	42.9958	72.6389	West River	Newfane, Vt.	1919-23, 1928-60	306
57	1158500	42.9653	72.2333	Otter Brook	Keene, N.H.	1924-58	41.9
58	1162500	42.6825	72.1156	Priest Brook	Winchendon, Mass.	1963-present	19.0
59	1165500	42.6028	72.3600	Moss Brook	Wendell Depot, Mass.	1909-10, 1916-82	12.2
60	1167800	42.8606	72.8511	Beaver Brook	Wilmington, Vt.	1963-77	6.36



Base from U.S. Geological Survey
Digital line graphs, 1:24,000 or
1:25,000 scale, 1983

Figure 1. Location of streams, drainage basins, and stream-gaging stations in the study area that were used to develop the equations for estimating the annual 7-day, 10-year annual low flow for New Hampshire streams. (Descriptions of the stations are in table 1.)



Base from U.S. Geological Survey
Digital line graphs, 1:24,000 or
1:25,000 scale, 1983

Figure 2. Location of towns, drainage basins, and stream-gaging stations in the study area. (For detailed information on stream-gaging stations, refer to table 1.)

Application of the Method to the New Hampshire Stream-gaging Network

In the regression analysis, all unregulated stations with streamflow records greater than 10 years were included in the analyses. In the network analysis, all unregulated stations with less than 10 years of record were included as new stations. Only three unregulated stations with records less than 10 years were within the geographic boundaries of the low-flow regression analyses (Flynn, 2002). All of the basin and climatic characteristics were determined on the basis of actual characteristics within a GIS. The measured basin characteristics for the stations used in the regression and network analysis are provided in table 2.

Three planning horizons for the collection of streamflow data were considered in this study. The 0-year planning horizon represents the current (1999) conditions and includes no additional data collection. The 5-year planning horizon represents the short term, and the 20-year planning horizon represents the long-term period of additional data collection. GLSNET network analysis requires that a cost be assigned to all stations in the network. The assigned cost varies depending on which planning horizon is being considered. An operation and maintenance cost was assigned to each station used in the analysis based on whether it was active or discontinued. Most of the stations in New Hampshire and Vermont have nearly equal standard operation and maintenance costs; therefore, the active stations were assigned an identical cost in GLSNET. A cost equal to one unit was assigned to each currently active unregulated station. Discontinued stations that could provide unregulated streamflow record if they were reactivated were assigned a cost equal to the active stations plus the cost to reactivate the gage. This cost was distributed over the planning horizon. New stations with less than 10 years of record were included in the network analysis for the 5- and 20-year planning horizon but were not considered for the 0-year planning horizon as additional data collection would not influence the results of the analysis. Similar to the discontinued stations, new stations were assigned a cost equal to the active stations plus the cost to activate the gage, which was distributed over the planning horizon.

Regulated stations, or those subject to diversion, were excluded from the network analysis because only active, unregulated stations can contribute additional regional information. Stream-gaging stations were ranked in reverse order from the order in which the GLSNET model removed them from the network. This ranking indicates the order of importance of the stations in providing regional streamflow information for the annual 7-day, 10-year low-flow statistic. For example, for a particular planning horizon, the station that was assigned the rank of one was the station that provided the largest cost-weighted reduction in average sampling-error variance for the annual 7Q10.

NETWORK ANALYSIS SCENARIOS

Three network analysis scenarios were looked at for improving the sampling-error variance of the annual 7Q10 regression equation. In scenario 1, drainage basins with underrepresented geographic locations or underrepresented values of drainage area used for developing the regression equations were added to the network analysis. In scenario 2, drainage basins with underrepresented values of the regression equation independent variables of *ABT* and *SGP* were added to the network analysis. In scenario 3, two groups of prospective stream-gaging stations were added to the network analysis. One group was located in northern New Hampshire and the other group was located in southern New Hampshire.

Scenario 1

For scenario 1 of the network analysis, four different situations were assessed for the 5- and 20-year planning horizons. The first situation excluded the addition of any new stations to the 60 currently active stations for the 5- and 20-year planning horizons (fig. 3). The second situation added three unregulated stations for the 5- and 20-year planning horizons (fig. 3). These three stations are currently (1999) active and unregulated but have less than 10 years of data. The USGS stream-gaging station numbers are 1064801, 1079602, and 1079900 (reference numbers 61, 63, and 64, respectively in table 3) with drainage areas of 67.6, 6.38, and 6.99 mi^2, respectively. The third situation included the three previously mentioned stations plus two other USGS stations, numbered 1073500 and 1081000 (reference numbers 62, and 65, respectively in table 3), which are currently (1999) regulated with drainage areas of 183 and 471 mi^2, respectively (fig. 4) for a total of 5 new stations.

Table 2. Basin characteristics for stream-gaging stations used in the regression and network analysis for the annual 7-day, 10-year low flow

[No., number; fig., figure; mi^2, square mile; in., inch; ° F, degrees Fahrenheit]

Stream-gaging station reference No. (fig. 1)	Stream-gaging station No.	Basin characteristics: Drainage area (mi^2)	Average summer precipitation (in.)	Average mean annual basin temperature (° F)
		Basin characteristic abbreviations		
		DA	SGP	ABT
1	1052500	153	17.9	37.0
2	1054200	69.9	19.9	40.7
3	1054300	130	17.7	40.0
4	1055000	96.8	18.1	38.9
5	1057000	74.1	18.3	42.6
6	1064300	10.5	22.4	36.8
7	1064400	4.68	20.3	41.7
8	1064500	385	19.1	40.5
9	1064800	5.41	21.2	41.6
10	1072850	7.47	17.9	45.4
11	1073000	12.2	16.9	46.8
12	1073600	5.86	17.4	46.9
13	1074500	106	22.0	39.3
14	1075000	195	19.6	40.3
15	1075500	57.8	17.7	42.2
16	1075800	3.29	17.8	42.9
17	1076000	143	18.2	42.5
18	1076500	623	17.4	41.7
19	1078000	86.0	18.4	43.1
20	1082000	67	18.1	44.4
21	1084500	55.3	17.5	45.1
22	1085800	5.91	18.3	44.6
23	1086000	146	17.0	44.4
24	1089000	77.8	16.5	44.5
25	1091000	103	17.0	44.8
26	1093800	3.62	18.9	44.6
27	10965852	47.8	17.4	46.8
28	1097300	12.8	17.6	48.3
29	1101000	21.2	17.6	48.7
30	1127880	6.50	23.1	36.1

Table 2. Basin characteristics for stream-gaging stations used in the regression and network analysis for the annual 7-day, 10-year low flow--Continued

[No., number; fig., figure; mi^2, square mile; in., inch; ° F, degrees Fahrenheit]

Stream-gaging station reference No. (fig. 1)	Stream-gaging station No.	Basin characteristics: Drainage area (mi^2)	Average summer precipitation (in.)	Average mean annual basin temperature (° F)
		Basin characteristic abbreviations: DA	SGP	ABT
31	1129440	35.3	21.1	37.8
32	1130000	230	19.1	40.0
33	1133000	51.3	20.9	39.2
34	1134500	75.2	20.2	40.1
35	1134800	8.13	18.8	41.3
36	1135000	129	18.2	40.8
37	1135300	42.5	18.3	40.0
38	1137500	88.2	19.8	39.3
39	1138000	396	17.4	41.4
40	1139000	98.7	17.4	41.0
41	1139800	8.79	19.7	40.6
42	1140000	43.8	18.3	41.3
43	1141800	4.75	18.4	43.3
44	1142000	239	17.2	41.9
45	1142500	30.5	17.0	41.9
46	1144000	689	16.7	42.0
47	1145000	80.4	17.6	42.9
48	1150800	3.26	22.8	41.5
49	1150900	23.3	21.0	41.3
50	1153500	102	17.5	43.0
51	1154000	72.1	17.9	42.6
52	1155000	83.3	16.8	44.5
53	1155200	10.1	17.4	43.9
54	1155300	9.28	20.2	42.1
55	1155500	177	19.1	41.7
56	1156000	306	17.9	41.7
57	1158500	41.9	17.6	43.9
58	1162500	19.0	17.7	44.1
59	1165500	12.2	18.2	44.8
60	1167800	6.36	21.8	42.6

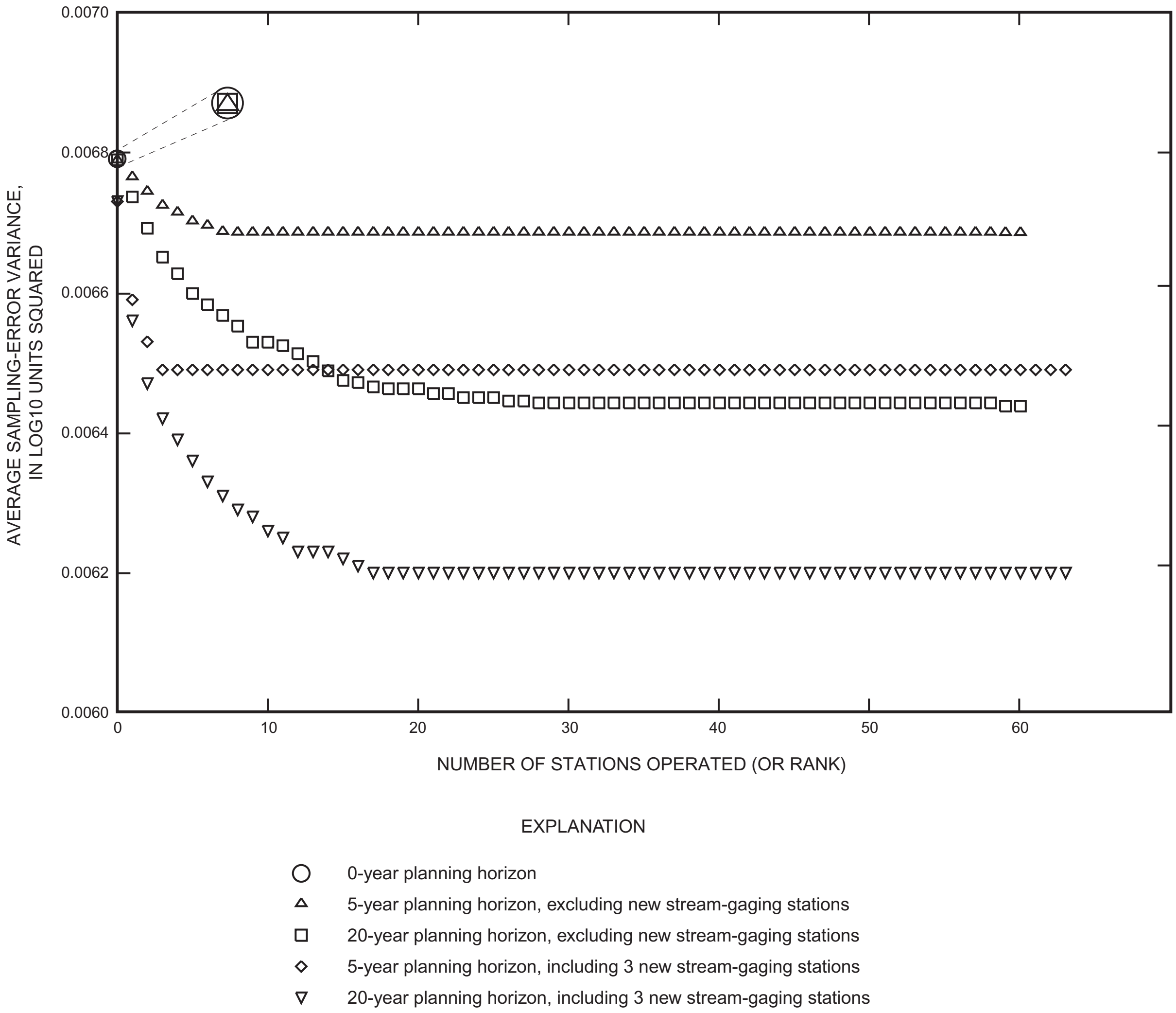


Figure 3. The average sampling-error variance for the annual 7-day, 10-year annual low flow as a function of the number and rank of stations operated for scenario 1 in the analysis of the stream-gaging network in New Hampshire.

These two stations are in an area that is not well represented in the network data and were included in the network analysis as if they were unregulated. These two stations represent proposed sites on unregulated streams with basin characteristics similar to those of stations 1081000 and 1073500. The fourth situation (fig. 4) added the three previously mentioned stations (USGS gage stations, numbered 1064801, 1079602, and 1079900) and two hypothetical stations. The two hypothetical stations were added in the same underrepresented area as stations 1081000 and 1073500 for a total of 5 new stations. A drainage area of 525 mi^2 was assigned to each of these stations because this value is near the upper limit of the drainage areas used in the study and is not well represented in the streamflow data. The addition of two large basins with underrepresented drainage areas in the network analysis may not be as important in reducing the average sample-error variance for the 7Q10 as including station data from small drainage basins in underrepresented areas in the data. In a network analysis for Kentucky, peak-, mean-, and low-flow data were considered (Ruhl, 1993), and the reduction of the average sampling-error variance was most pronounced for the stream-gaging stations in drainage areas less than 100 mi^2. In the Ohio study, which also considered peak-, mean- and low-flow data (Straub, 1998), the reduction of the average sampling-error variance was most pronounced for drainage areas less than 200 mi^2. The effect of streamflow data provided by the new stations decreased as the size of the drainage area increased. Both situations three and four had similar results but only the results of situation 3 were reported in table 4.

Table 3. Selected basin characteristics of actual and hypothetical stream-gaging stations for network scenarios 1-3 used in the analysis of the stream-gaging network

[No., number; fig., figure; mi^2, square miles; ° ′ ″, degrees, seconds, minutes; *ABT*, Average mean annual basin temperature, in degrees Fahrenheit (° F); *SGP*, Average summer gage precipitation, in inches (in.); <, less than; --, no data]

Stream-gaging station reference No. (fig. 1)	Stream-gaging station No.	Location	Notes	Drainage area (mi^2)	Latitude (decimal degrees)	Longitude (decimal degrees)	*ABT*	*SGP*
61	1064801	Bear Camp River, South Tamworth, N.H.	<10 years record	67.6	43° 83′ 00″	71° 28′ 83″	42.4	18.4
62	1073500	Lamprey River, Newmarket, N.H.	Regulation	183	43° 10′ 25″	70° 95′ 31″	46.9	17.1
63	1079602	Poorfarm Brook, Gilford, N.H.	<10 years record	6.38	43° 57′ 28″	71° 35′ 55″	44.4	17.2
64	1079900	Shannon Brook, Moultonborough, N.H.	<10 years record	6.99	43° 73′ 03″	71° 35′ 78″	43.2	19.3
65	1081000	Winnipesaukee River, Tilton, N.H.	Regulation	471	43° 44′ 19″	71° 58′ 89″	44.1	17.5
66	--	Mad River, Thornton, N.H.	New gage	49.0	43° 87′ 94″	71° 60′ 03″	40.7	20.7
67	--	Big River, Barnstead, N.H.	New gage	18.8	43° 33′ 14″	71° 22′ 67″	45.0	19.1
68	--	North Branch Contoocook River, Antrim, N.H.	New gage	46.8	43° 07′ 50″	72° 04′ 00″	44.7	19.1
69	--	Hubbard Brook, Thornton, N.H.	New gage	13.2	43° 92′ 08″	71° 68′ 31″	42.2	19.0
70	--	Dead Diamond River, Second College Grant, N.H.	New gage	71.9	44° 93′ 81″	71° 08′ 97″	36.6	20.2
71	--	Clear Stream, Errol, N.H.	New gage	42.9	44° 79′ 97″	71° 19′ 33″	38.5	19.1
72	--	Stony Brook, Gorham, N.H.	New gage	40.7	44° 36′ 42″	71° 17′ 56″	39.1	21.3
73	--	Saco River, Bartlett, N.H.	New gage	132	44° 10′ 39″	71° 17′ 28″	40.4	20.3
74	--	Swift River, Conway, N.H.	New gage	85.9	43° 98′ 47″	71° 12′ 53″	40.5	19.3
75	--	Exeter River, Exeter, N.H.	New gage	87.5	42° 97′ 25″	70° 94′ 19″	47.1	17.4

Scenario 2

For scenario 2 of the network analysis, stations 1064801, 1079602, and 1079900 (reference numbers 61, 63, and 64, respectively in table 3), currently (1999) active and unregulated with less than 10 years of streamflow data, were analyzed with 11 basins (reference numbers 62, 66, 67, 68, 69, 70, 71, 72, 73, 74, and 75 in table 3) for a total of 14 new stations. These 11 basins have values that are underrepresented with respect to the independent variables of *ABT* or *SGP* used in the development of the annual 7Q10 regression equation (fig. 5). Scenario 2 was assessed for both the 5- and 20-year planning horizons.

Scenario 3

For scenario 3 of the network analysis, two situations were assessed for both the 5- and 20-year planning horizons. In the first situation, unregulated stations 1064801, 1079602, and 1079900 (reference numbers 61, 63, and 64, respectively in table 3), that are currently active and have less than 10 years of streamflow data, were analyzed with seven other basins (reference numbers 66, 69, 70, 71, 72, 73, and 74 in table 3) in northern New Hampshire with underrepresented values of the independent variables of *ABT* and *SGP* (fig. 6) for a total of 10 new stations. In the second situation, stations 1064801, 1079602, and 1079900 (reference numbers 61, 63, and 64, respectively in table 3) were analyzed with four other basins (reference numbers 62, 67, 68, and 75 in table 3) in southern New Hampshire that have underrepresented values of the independent variables of *ABT* and *SGP* (fig. 6), for a total of 7 new stations. Scenario 3 was assessed for the 5- and 20-year planning horizons. The dividing line between southern and northern New Hampshire was set at Lake Winnipesaukee. All of the basins selected represent proposed stations on unregulated streams with basin characteristics similar to those of the stations used in the regression and network analyses.

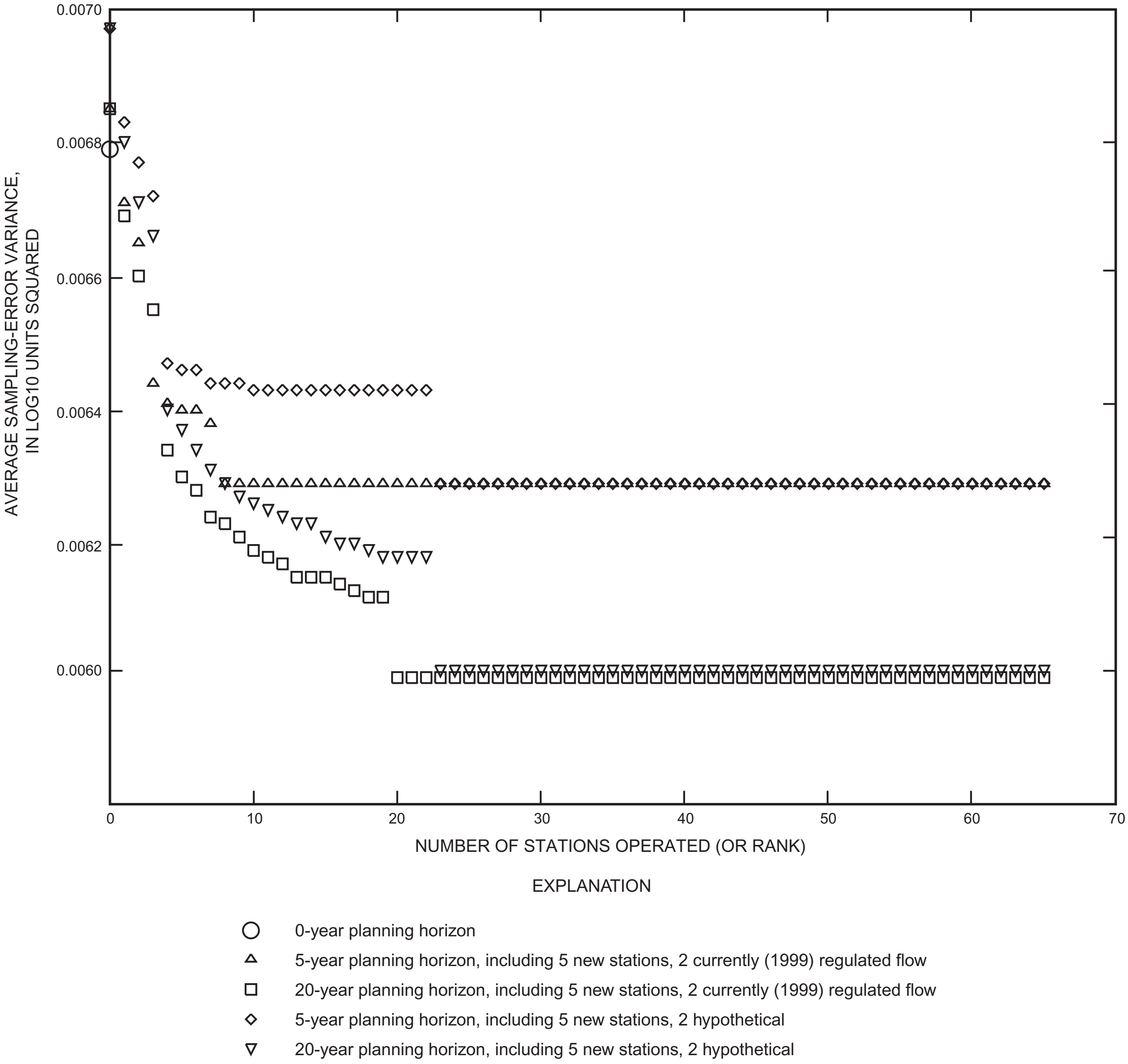


Figure 4. The average sampling-error variance for the 7-day, 10-year annual low flow as a function of the number and rank of stations operated for scenario 1 in the analysis of the stream-gaging network in New Hampshire.

RESULTS OF THE STREAM-GAGING NETWORK ANALYSIS

The average sampling-error variance of the annual 7Q10 regression equation for the current (1999) network was determined using GLSNET. The average sampling-error variance for various network strategies also was determined if additional streamflow data were collected at stations in the network. The average sampling-error variance computed for the current (1999) annual 7Q10 flow characteristic (0-year planning horizon) and the estimated average sampling-error variances for the 5- and 20-year planning horizons, including and excluding new stations, are shown in table 4. The average sampling-error variances are the result of the network analyses in which all available stations (active and discontinued) with unregulated streamflow contribute to the regional information. Continued operation of the network will result in a decrease in the average sampling-error variances and a greater decrease is expected if the network is expanded through the addition of new stations. The decrease in the average sampling error as a function of the number of stream-gaging stations

Table 4. Average sampling-error variance for selected network scenarios used in the analysis of the stream-gaging network in New Hampshire

[*ABT*, Average mean annual basin temperature (degrees Fahrenheit); *SGP*, Average summer gage precipitation (inches); 7Q10, 7-day, 10-year low flow]

	Annual 7-day, 10-year low-flow network analysis						
Scenario 1	**0-Year**	**5-Year**			**20-Year**		
		Excluding	**Including**		**Excluding**	**Including**	
		New stations	**3 new stations[1]**	**5 new stations[2]**	**New stations**	**3 new stations[1]**	**5 new stations[2]**
Number of stream-gaging stations	60	60	63	65	60	63	65
Average sampling-error variance (log 10 squared)	0.00679	0.00669	0.00649	0.00629	0.00644	0.00619	0.00600
Percentage reduction from 0-year planning horizon	0	1.47	4.42	7.36	5.15	8.84	11.63

Scenario 2	**0-Year**	**5-Year**		**20-Year**	
		Excluding	**Including**	**Excluding**	**Including**
		New stations	**14 new stations[3]**	**New stations**	**14 new stations[3]**
Number of stream-gaging stations	60	60	74	60	74
Average sampling-error variance (log 10 squared)	0.00679	0.00669	0.00582	0.00644	0.00543
Percentage reduction from 0-year planning horizon	0	1.47	14.29	5.15	20.03

Scenario 3	**0-Year**	**5-Year**			**20-Year**		
		Excluding	**Including**		**Excluding**	**Including**	
		New stations	**10 new stations (north)[4]**	**7 new stations (south)[5]**	**New stations**	**10 new stations (north)[4]**	**7 new stations (south)[5]**
Number of stream-gaging stations	60	60	70	67	60	70	67
Average sampling-error variance (log 10 squared)	0.00679	0.00669	0.00606	0.00621	0.00644	0.00569	0.00586
Percentage reduction from 0-year planning horizon	0	1.47	10.75	8.54	5.15	16.20	13.70

[1] Indicates active stream-gaging stations on unregulated streams, which have less than 10 years of record (Stream-gaging station numbers 1064801, 1079602, 1079900).

[2] Indicates active stream-gaging stations on unregulated streams, which have less than 10 years of record (Stream-gaging station numbers 1064801, 1079602, 1079900) and two stations on unregulated streams with basin characteristics similar to station numbers 1073500 and 1081000.

[3] Indicates active stream-gaging stations on unregulated streams, which have less than 10 years of record (Stream-gaging station numbers 1064801, 1079602, 1079900); as well as 11 basins, which have values that are underrepresented with respect to the independent variables of *ABT* and *SGP* used in the development of the annual 7Q10 regression equation.

[4] Indicates active stream-gaging stations on unregulated streams, which have less than 10 years of record (Stream-gaging station numbers 1064801, 1079602, 1079900); as well as 7 basins, which have values that are underrepresented with respect to the independent variables of *ABT* and *SGP* used in the development of the annual 7Q10 regression equation. These basins are north of Lake Winnipesaukee.

[5] Indicates active stream-gaging stations on unregulated streams, which have less than 10 years of record (Stream-gaging station numbers 1064801, 1079602, 1079900); as well as 4 basins, which have values that are underrepresented with respect to the independent variables of *ABT* and *SGP* used in the development of the annual 7Q10 regression equation. These basins are south of Lake Winnipesaukee.

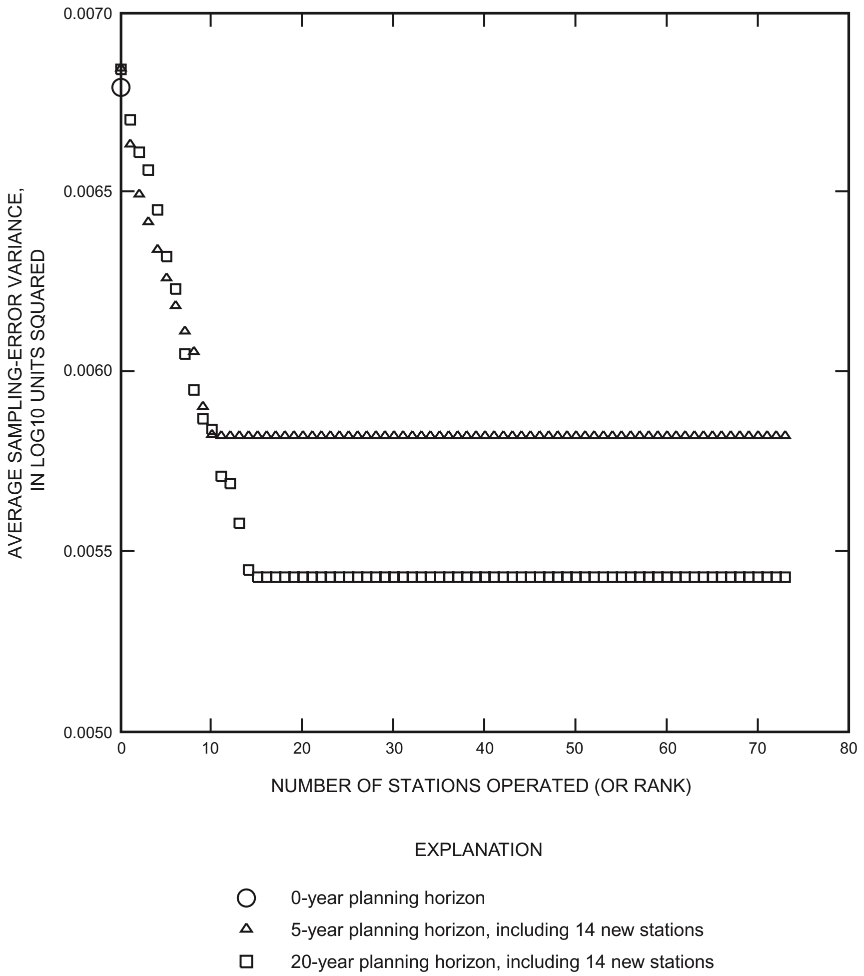


Figure 5. The average sampling-error variance for the 7-day, 10-year annual low flow as a function of the number and rank of stations operated for scenario 2 in the analysis of the stream-gaging network in New Hampshire.

being operated is presented in figures 3, 4, 5 and 6, and in table 4. Average sampling-error variance is expressed in base 10 logarithmic units squared. In figures 3-6, the circle symbol represents the current conditions (1999 or zero-year planning horizon), which is the average sampling-error variance if no stations were continued nor added, and is the average sampling-error variance associated with the GLS regression equation.

The curves associated with each scenario, including or excluding new stations, have different starting locations for zero sites operated because the average sampling-error variances are computed over different stream-gage networks. The points on the graphs represent sampling errors such that the station that is most effective in reducing the sampling error is at the left and each station toward the right is progressively less effective. The slope of the graph represents the marginal decrease in average sampling-error variance associated with the operation of a particular station (including new stations) used in the network analysis. The graphs show that a reduction in sampling error is greater for a 20-year planning horizon than for a 5-year planning horizon. This reduction in error is related to increased record length. The steep part of each curve represents those stations that are the most effective in reducing the sampling-mean-square error. The flat part of the curve indicates those stations whose future operation would contribute little to the reduction of the sampling error for the annual 7Q10 low-flow statistic. These stations could be considered for discontinuance based solely on the contribution of each to the regional annual 7Q10 low-flow statistic. Their operating costs could then be applied toward new stations that would contribute more toward the reduction of the sampling error (Thomas, 1994).

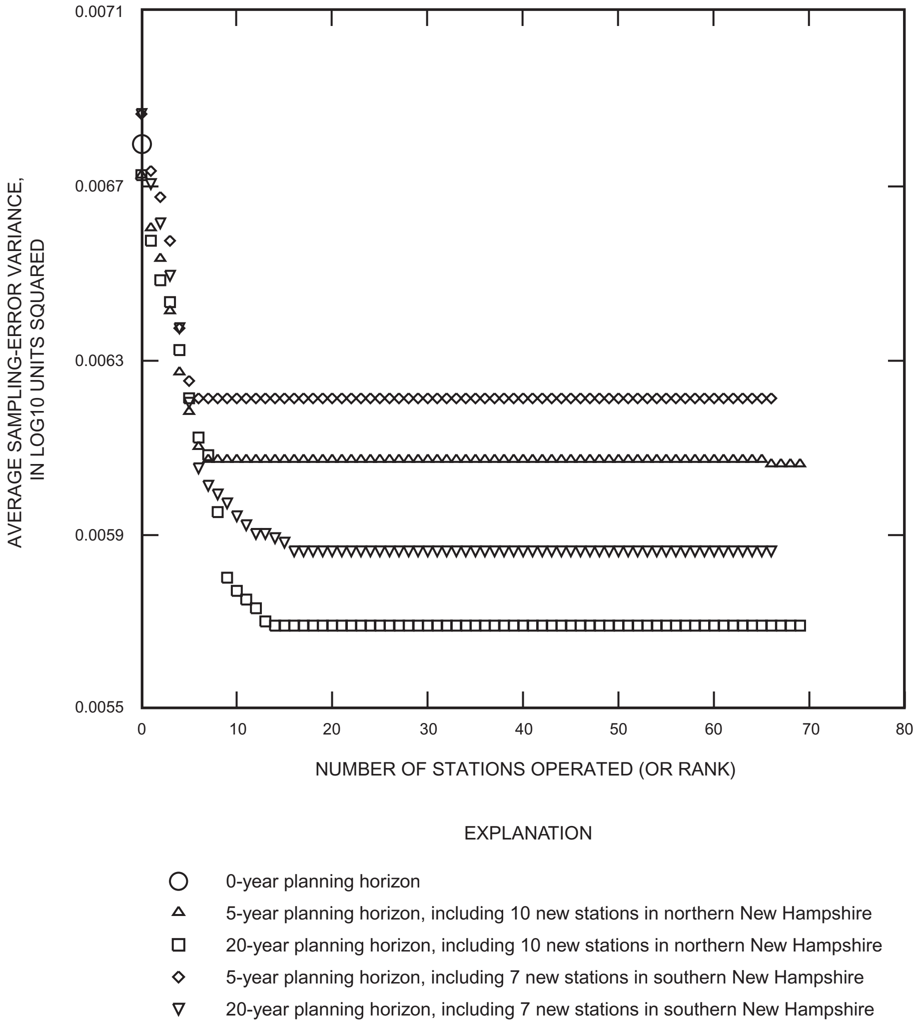


Figure 6. The average sampling-error variance for the 7-day, 10-year annual low flow as a function of the number and rank of stations operated for scenario 3 in the analysis of the stream-gaging network in New Hampshire.

Although, in figures 3, 4, 5, and 6, it appears that the first 5 to 15 stations account for the largest percentage reduction in average sampling-error variance, the composition of the first 5 to 15 stations changes as a function of planning horizon and network strategy. Each station contributes to the overall information that is provided by the stream-gaging network; however, the amount of information provided depends on the variability of streamflow, the combination of physical and climatic characteristics, and the length of record at the end of each planning horizon (Medina, 1987). Because of this relation, each station has a unique affect on the average sampling-error variance.

Other factors must also be taken into consideration when locating new stations. Although the network analysis may indicate that a new site has particular basin characteristics that are helpful in reducing the average sampling-error variance, a new stream-gaging site with these exact, particular basin characteristics may be difficult to locate. In addition to the value of a station in providing a range of streamflow information, other factors that must be considered in locating a station are hydraulic conditions, accessibility to the stream, and human activities in the basin that may affect the stream characteristics (Ruhl, 1993).

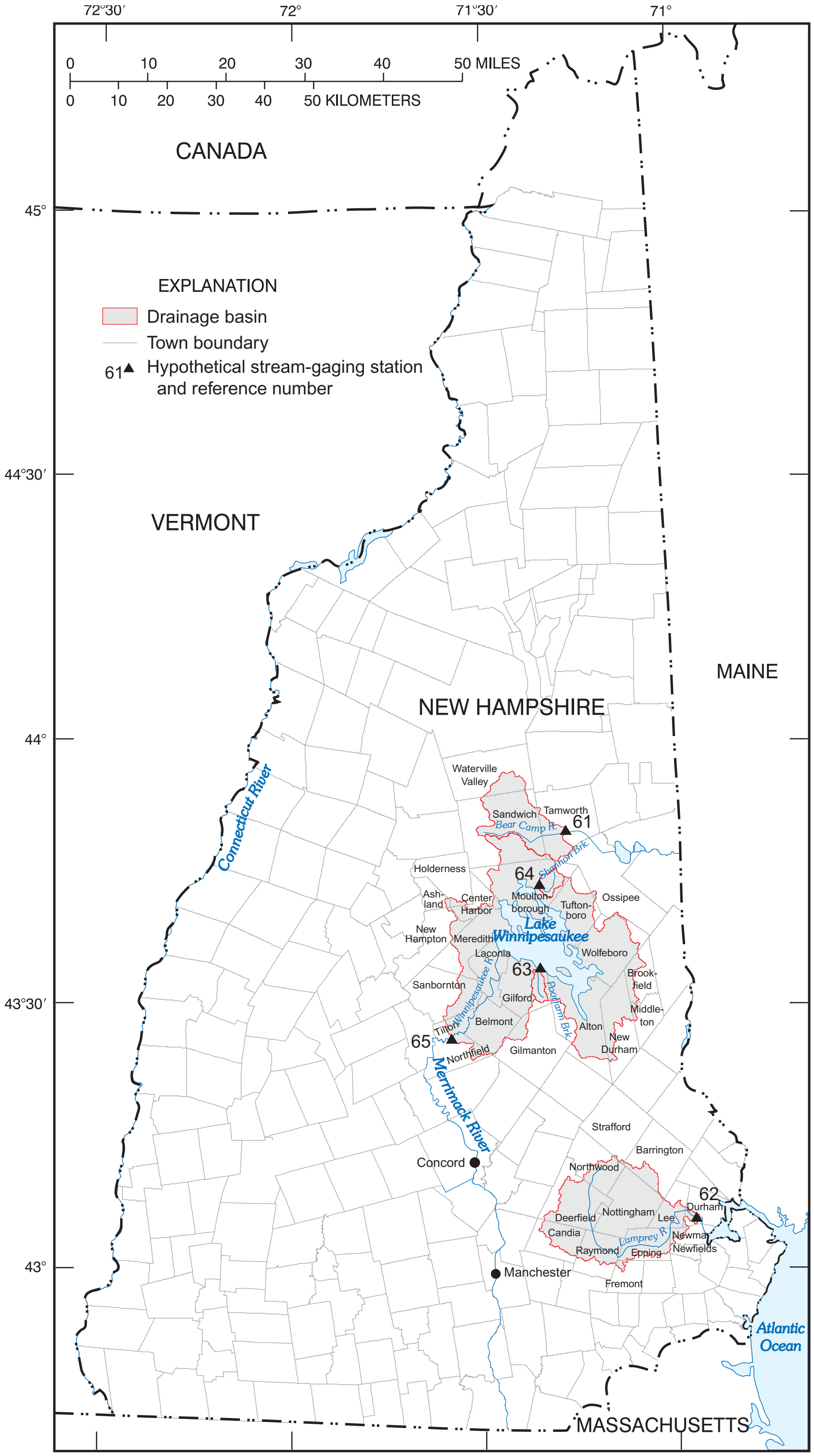
Selected basin characteristics of the actual and hypothetical stream-gaging stations used in the network analysis for network scenarios 1-3 in New Hampshire can be found in table 4. The locations of the additional stations included in the network analysis in scenario 1 can be found on figure 7. The locations of the additional stations included in the network analysis in scenario 2 and 3 can be found on figure 8.

If no new stations are added to the network for the three scenarios, the average sampling-error variance from current (1999) conditions is reduced by 1.47 percent and 5.15 percent for the 5- and 20-year planning horizons, respectively (table 4). In scenario 1, a reduction in the average sampling-error variance of 7.36 percent will result after 5 years with the addition of five new stations as compared to the 0-year planning horizon. After 20 years, the average sampling-error variance is reduced by 11.63 percent with the addition of five new stations as compared to the 0-year planning horizon. A greater reduction in the average sampling-error variance occurs for the 20-year planning horizon with the addition of five new stations as compared to the 20-year planning horizon with no new stations. In scenario 2, the average sampling-error variance is reduced by 14.29 percent after 5 years with the addition of 14 new stations as compared to the 0-year planning horizon. After 20 years, a reduction of 20.03 percent will occur with the additional 14 stations. In scenario 3, the average sampling-error variance is reduced by 10.75 percent after 5 years with the addition of 10 new stations in northern New Hampshire, whereas a reduction of 8.54 percent will result after 5 years with the addition of seven new stations in southern New Hampshire. The average sampling-error variance is reduced by 16.20 percent after 20 years with the addition of 10 new stations in northern New Hampshire, and by 13.70 percent after 20 years with the addition of seven new stations in southern New Hampshire.

These results indicate that the addition of the 14 stations in scenario 2 produced the largest reduction in the average sampling-error variance. The addition of the three active stream-gaging stations on unregulated streams with less than 10 years of record combined with 11 basins, with underrepresented values with respect to the independent variables of *ABT* and *SGP*, yielded a reduction in the average sampling-error variance after 5 years and a greater reduction in the average sampling-error variance after 20 years as compared to the reduction in the average sampling error when only three active stations on unregulated streams with less than 10 years of record are added to the network (scenario 1). The results of scenario 3 indicate that the addition of the three active stream-gaging stations on unregulated streams with less than 10 years of streamflow record combined with seven other stations in northern New Hampshire that have underrepresented values for the independent variables of *ABT* and *SGP* reduced the variance more than by adding the same three active stations on unregulated streams with four other stations in southern New Hampshire, which also have underrepresented values for the independent variables of *ABT* and *SGP*.

For these network analyses, using GLS regression equations developed for the annual 7Q10 low flow, minimizing the average sampling-error variance is equivalent to maximizing the available streamflow data. Network-analyses results of the stream-gaging station ranking in order of importance in providing regional streamflow data for the annual 7Q10 low flow is listed in table 5 for the addition of five new stations (scenario 1) and in table 6 for the addition of 14 new stations (scenarios 2 and 3). The stations are ranked by the contributions they make in reducing the average sampling-error variance from the current (1999) conditions associated with the regional regression equations. In this study, as in Ruhl (1993), it was found that new stations provide the greatest reduction in the average sampling-error variance for current conditions although continuation of many active stations will also improve regional streamflow data.

The network analysis was based on reducing the sampling error by collecting long-term records at existing stations and(or) installing new stream-gaging stations to reduce the spatial-sampling error. If the model error is large in relation to the sampling error, then little improvement can be expected in the standard error of prediction by collecting additional streamflow data (Thomas, 1994). By reducing the model error, if it is large in comparison to the sampling error, the value from the collection of additional streamflow data can be properly evaluated (Thomas, 1994). The model error in this study was 0.0852 (log 10 units squared) for the annual 7Q10 and the sampling error was 0.0068 (log 10 units squared). The model error is assumed to be constant for the network analysis, but it could be improved by developing a better regression model.



Base from U.S. Geological Survey
Digital line graphs, 1:24,000 or
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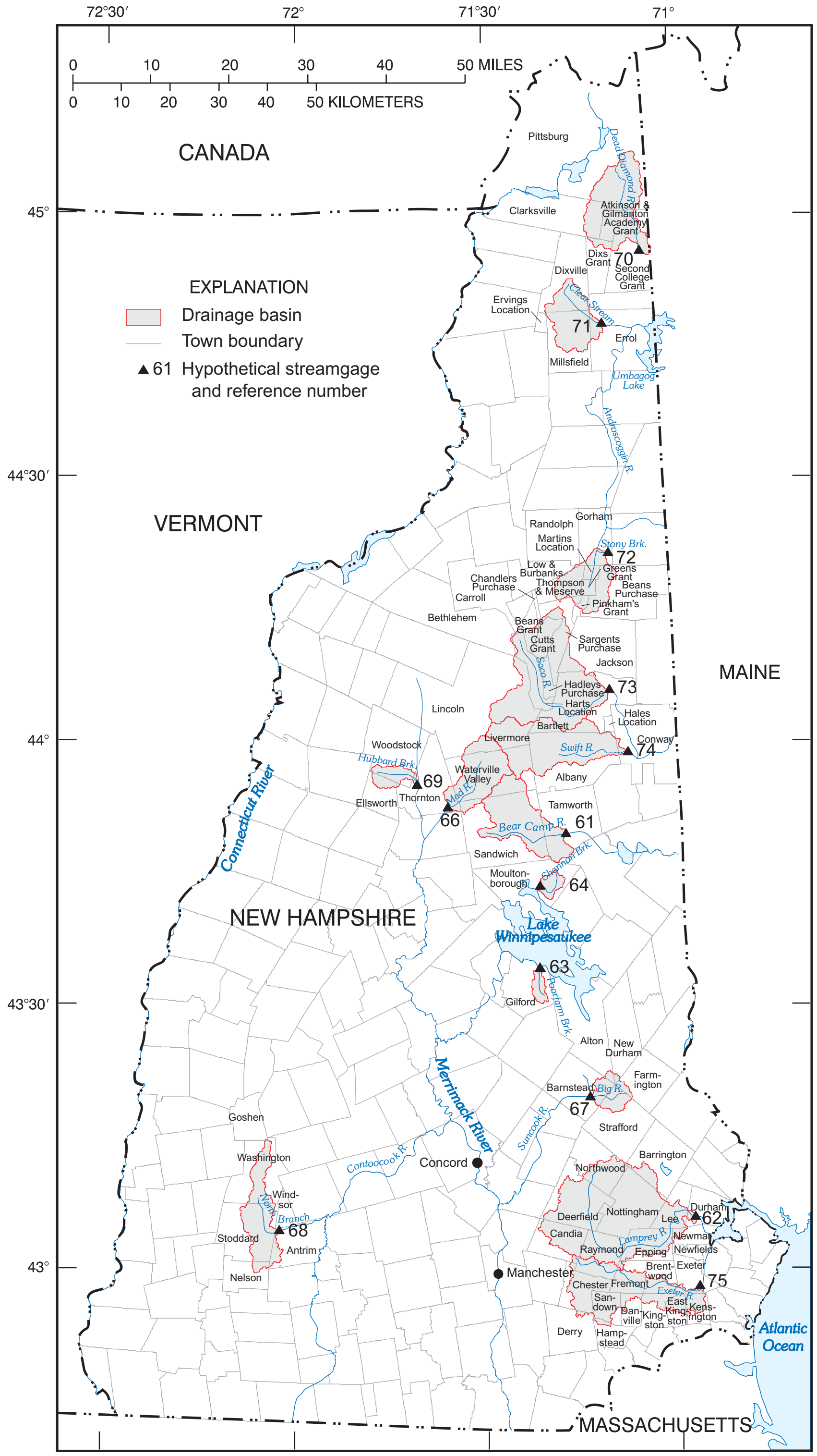
Figure 7. Location of streams, drainage basins, and stream-gaging stations for network analysis used in scenario 1.



Base from U.S. Geological Survey
Digital line graphs, 1:24,000 or
1:25,000 scale, 1983

Figure 8. Location of streams, drainage basins, and stream-gaging stations, and towns for network analysis used in scenarios 2 and 3.

Table 5. Station ranking in order of importance in providing regional streamflow information for the annual 7-day, 10-year low-flow statistic (with an additional 5 stream-gaging stations) for the 0-, 5-, and 20-year planning horizons for scenario 1

[No., number; fig., figure; Scenario 1 described in table 4; --, no data]

Stream-gaging station reference No. (figs. 1 and 7)	Stream-gaging station No.	River name	Location	Station ranking for the annual 7-day, 10-year low-flow statistic		
				0-year planning horizon	5-year planning horizon	20-year planning horizon
1	1052500	Diamond River	Wentworth Location, N.H.	43	55	56
2	1054200	Wild River	Gilead, Maine	30	37	40
3	1054300	Ellis River	South Andover, Maine	34	31	27
4	1055000	Swift River	near Roxbury, Maine	46	56	58
5	1057000	Lower Androscoggin River	near South Paris, Maine	60	62	61
6	1064300	Ellis River	near Jackson, N.H.	15	25	28
7	1064400	Lucy Brook	near North Conway, N.H.	20	23	21
8	1064500	Saco River	near Conway, N.H.	57	60	60
9	1064800	Cold Brook	South Tamworth, N.H.	2	5	5
61	[1]1064801	Bear Camp River	South Tamworth, N.H.	--	4	3
10	1072850	Mohawk River	Center Strafford, N.H.	3	6	6
11	1073000	Oyster River	Durham, N.H.	27	33	41
62	[2]1073500	Lamprey River	Newmarket, N.H.	--	3	4
12	1073600	Dudley Brook	Exeter, N.H.	14	17	19
13	1074500	East Branch Pemigewasset	near Lincoln, N.H.	55	51	45
14	1075000	Pemigewasset River	Woodstock, N.H.	48	50	46
15	1075500	Baker River	Wentworth, N.H.	22	20	16
16	1075800	Stevens Brook	Wentworth, N.H.	21	24	22
17	1076000	Baker River	Rumney, N.H.	50	53	51
18	1076500	Pemigewasset River	Plymouth, N.H.	59	63	63
19	1078000	Smith River	near Bristol, N.H.	53	59	59
63	[1]1079602	Poorfarm Brook	Gilford, N.H.	--	1	1
64	[1]1079900	Shannon Brook	Moultonborough, N.H.	--	2	2
65	[2]1081000	Winnipesaukee River	Tilton, N.H.	--	8	20
20	1082000	Contoocook River	Peterborough, N.H.	33	35	31
21	1084500	Beards Brook	Hillsboro, N.H.	28	29	26
22	1085800	West Branch Warner River	near Bradford, N.H.	11	22	24
23	1086000	Warner River	Davisville, N.H.	42	44	43
24	1089000	Soucook River	near Concord, N.H.	29	34	35
25	1091000	South Branch Piscataquog River	near Goffstown, N.H.	39	40	38
26	1093800	Stony Brook Tributary	near Temple, N.H.	8	21	23
27	10965852	Beaver Brook	North Pelham, N.H.	5	12	18
28	1097300	Nashoba Brook	near Acton, Mass.	17	27	29
29	1101000	Parker River	Byfield, Mass.	26	32	37
30	1127880	Big Brook	Pittsburg, N.H.	10	14	13

Table 5. Station ranking in order of importance in providing regional streamflow information for the annual 7-day, 10-year low-flow statistic (with an additional 5 stream-gaging stations) for the 0-, 5-, and 20-year planning horizons for scenario 1--Continued

[No., number; fig., figure; Scenario 1 described in table 4; --, no data]

Stream-gaging station reference No. (figs. 1 and 7)	Stream-gaging station No.	River name	Location	Station ranking for the annual 7-day, 10-year low-flow statistic		
				0-year planning horizon	5-year planning horizon	20-year planning horizon
31	1129440	Mohawk River	near Colebrook, N.H.	6	15	15
32	1130000	Upper Ammonoosuc River	near Groveton, N.H.	47	57	57
33	1133000	East Branch Passumpsic	East Haven, Vt.	41	39	36
34	1134500	Moose River	Victory, Vt	37	47	53
35	1134800	Kirby Brook	Concord, Vt.	16	18	17
36	1135000	Moose River	St. Johnsbury, Vt.	56	58	55
37	1135300	Sleepers River (W-5)	St. Johnsbury, Vt.	4	11	12
38	1137500	Ammonoosuc River	Bethlehem Junction, N.H.	36	46	52
39	1138000	Ammonoosuc River	Bath, N.H.	51	54	50
40	1139000	Wells River	Wells River, Vt.	35	43	49
41	1139800	East Orange Branch	East Orange, Vt.	18	28	30
42	1140000	South Branch Waits River	near Bradford, Vt.	25	19	11
43	1141800	Mink Brook	Etna, N.H.	23	26	25
44	1142000	White River	Bethel, Vt.	31	36	33
45	1142500	Ayers Brook	Randolph, Vt.	32	41	48
46	1144000	White River	West Hartford, Vt.	58	61	62
47	1145000	Mascoma River	West Canaan, N.H.	40	42	39
48	1150800	Kent Brook	Sherburne, Vt.	1	7	7
49	1150900	Ottauquechee River	West Bridgewater, Vt.	13	16	14
50	1153500	Williams River	Brockways Mills, Vt.	49	49	47
51	1154000	Saxtons River	Saxtons River, Vt.	45	45	44
52	1155000	Cold River	Drewsville, N.H.	38	38	34
53	1155200	Sacketts Brook	Putney, Vt.	12	10	9
54	1155300	Flood Brook	Londonderry, Vt.	7	9	8
55	1155500	West River	Jamaica, Vt.	19	64	64
56	1156000	West River	Newfane, Vt.	44	65	65
57	1158500	Otter Brook	Keene, N.H.	54	48	42
58	1162500	Priest Brook	Winchendon, Mass.	24	30	32
59	1165500	Moss Brook	Wendell Depot, Mass.	52	52	54
60	1167800	Beaver Brook	Wilmington, Vt.	9	13	10

[1] Indicates an active stream-gaging station on an unregulated stream that has less than 10 years of record.

[2] Indicates a proposed stream-gaging station on an unregulated stream, which has basin characteristics similar to those of the stream-gaging station number given.

Table 6. Station ranking in order of importance in providing regional streamflow information for the annual 7-day, 10-year low-flow statistic (with an additional 14 stream-gaging stations) for the 0-, 5-, and 20-year planning horizons for scenarios 2 and 3

[No., number; fig., figure; Scenario 2 described in table 3; --, no data]

Stream-gaging station reference No. (fig. 1)	Stream-gaging station No.	River name	Location	Station ranking for annual 7-day, 10-year low-flow statistic		
				0-year planning horizon	5-year planning horizon	20-year planning horizon
1	1052500	Diamond River	Wentworth Location, N.H.	43	67	67
2	1054200	Wild River	Gilead, Maine	30	45	46
3	1054300	Ellis River	South Andover, Maine	34	40	38
4	1055000	Swift River	near Roxbury, Maine	46	69	69
5	1057000	Lower Androscoggin River	near South Pari s, Maine	60	72	72
6	1064300	Ellis River	near Jackson, N.H.	15	36	37
7	1064400	Lucy Brook	near North Conway, N.H.	20	30	31
8	1064500	Saco River	near Conway, N.H.	57	71	71
9	1064800	Cold Brook	South Tamworth, N.H.	2	15	15
61	[1]1064801	Bear Camp River	South Tamworth, N.H.	--	11	12
10	1072850	Mohawk River	Center Strafford, N.H.	3	17	16
11	1073000	Oyster River	Durham, N.H.	27	49	54
62	[2]1073500	Lamprey River	Newmarket, N.H.	--	1	7
12	1073600	Dudley Brook	Exeter, N.H.	14	27	28
13	1074500	East Branch Pemigewasset	near Lincoln, N.H.	55	50	45
14	1075000	Pemigewasset River	Woodstock, N.H.	48	55	56
15	1075500	Baker River	Wentworth, N.H.	22	29	29
16	1075800	Stevens Brook	Wentworth, N.H.	21	33	32
17	1076000	Baker River	Rumney, N.H.	50	60	59
18	1076500	Pemigewasset River	Plymouth, N.H.	59	74	74
19	1078000	Smith River	near Bristol, N.H.	53	70	70
63	[1]1079602	Poor Farm Brook	Gilford, N.H.	--	13	1
64	[1]1079900	Shannon Brook	Moultonborough, N.H.	--	8	2
20	1082000	Contoocook River	Peterborough, N.H.	33	41	41
21	1084500	Beards Brook	Hillsboro, N.H.	28	37	36
22	1085800	West Branch Warner River	near Bradford, N.H.	11	35	35
23	1086000	Warner River	Davisville, N.H.	42	53	53
24	1089000	Soucook River	near Concord, N.H.	29	52	51
25	1091000	South Branch Piscataquog River	near Goffstown, N.H.	39	48	48
26	1093800	Stony Brook Tributary	near Temple, N.H.	8	32	33
27	10965852	Beaver Brook	North Pelham, N.H.	5	25	23
28	1097300	Nashoba Brook	near Acton, Mass.	17	38	39
29	1101000	Parker River	Byfield, Mass.	26	47	49
30	1127880	Big Brook	Pittsburg, N.H.	10	20	22
31	1129440	Mohawk River	near Colebrook, N.H.	6	22	21
32	1130000	Upper Ammonoosuc River	near Groveton, N.H.	47	68	68
33	1133000	East Branch Passumpsic	East Haven, Vt.	41	44	44
34	1134500	Moose River	Victory, Vt.	37	61	63
35	1134800	Kirby Brook	Concord, Vt.	16	23	27

Table 6. Station ranking in order of importance in providing regional streamflow information for the annual 7-day, 10-year low-flow statistic (with an additional 14 stream-gaging stations) for the 0-, 5-, and 20-year planning horizons for scenarios 2 and 3--Continued

[No., number; fig., figure; Scenario 2 described in table 3; --, no data]

Stream-gaging station reference No. (fig. 1)	Stream-gaging station No.	River name	Location	Station ranking for annual 7-day, 10-year low-flow statistic		
				0-year planning horizon	5-year planning horizon	20-year planning horizon
36	1135000	Moose River	St. Johnsbury, Vt.	56	66	66
37	1135300	Sleepers River (W-5)	St. Johnsbury, Vt.	4	24	25
38	1137500	Ammonoosuc River	Bethlehem Junction, N.H.	36	63	65
39	1138000	Ammonoosuc River	Bath, N.H.	51	65	62
40	1139000	Wells River	Wells River, Vt.	35	64	64
41	1139800	East Orange Branch	East Orange, Vt.	18	39	40
42	1140000	South Branch Waits River	near Bradford, Vt.	25	28	26
43	1141800	Mink Brook	Etna, N.H.	23	34	34
44	1142000	White River	Bethel, Vt.	31	43	43
45	1142500	Ayers Brook	Randolph, Vt.	32	62	61
46	1144000	White River	West Hartford, Vt.	58	73	73
47	1145000	Mascoma River	West Canaan, N.H.	40	51	50
48	1150800	Kent Brook	Sherburne, Vt.	1	16	17
49	1150900	Ottauquechee River	West Bridgewater, Vt.	13	26	24
50	1153500	Williams River	Brockways Mills, Vt.	49	58	58
51	1154000	Saxtons River	Saxtons River, Vt.	45	54	55
52	1155000	Cold River	Drewsville, N.H.	38	46	47
53	1155200	Sacketts Brook	Putney, Vt.	12	21	19
54	1155300	Flood Brook	Londonderry, Vt.	7	18	18
55	1155500	West River	Jamaica, Vt.	19	31	30
56	1156000	West River	Newfane, Vt.	44	57	57
57	1158500	Otter Brook	Keene, N.H.	54	56	52
58	1162500	Priest Brook	Winchendon, Mass.	24	42	42
59	1165500	Moss Brook	Wendell Depot, Mass.	52	59	60
60	1167800	Beaver Brook	Wilmington, Vt.	9	19	20
66	[2]990003	Mad River	Thornton, N.H.	--	5	6
67	[2]990004	Big River	Barnstead, N.H.	--	3	4
68	[2]990005	North Branch Contoocook River	Antrim, N.H.	--	4	5
69	[2]990006	Hubbard Brook	Thornton, N.H.	--	14	3
70	[2]990007	Dead Diamond River	Second College Grant, N.H.	--	9	14
71	[2]990008	Clear Stream	Errol, N.H.	--	10	13
72	[2]990009	Stony Brook	Gorham, N.H.	--	7	8
73	[2]9900010	Saco River	Bartlett, N.H.	--	6	9
74	[2]9900011	Swift River	Conway, N.H.	--	12	10
75	[2]9900012	Exeter River	Exeter, N.H.	--	2	11

[1] Indicates an active station on an unregulated stream that has less than 10 years of record.

[2] Indicates a proposed station on an unregulated stream, which has basin characteristics similar to those of the station location given. These areas have values, which are underrepresented with respect to the independent v‘ariables of average mean annual basin temperature (degrees Fahrenheit) and average summer station precipitation (inches) used in the development of the annual 7-day, 10-year regression equation.

Results of the network analysis can be used to review the stream-gaging network in New Hampshire. The rank of each station, based entirely on its contribution to the regional streamflow information for the annual 7Q10 low-flow statistic, can be used to assist in determining whether to continue the operation of existing stations, add new stations, or reestablish discontinued stations. Station rank, however, should not be the only consideration concerning stream-gaging station operations. Prior to making any modifications to the stream-gaging station network, a number of other factors need to be addressed. The network analysis was done to maximize the available streamflow information for the 7Q10 low-flow statistic; however, data from a station are used for a variety of purposes in addition to providing information with which to derive equations for estimating low-flow characteristics. Other potential uses of station data include providing flood forecasting, operational information for water-resource facilities and information on impending drought conditions, assessing trends in flow and chemical-loading characteristics, and evaluating surface and ground-water interactions (Straub, 1998). High- and mean-flow streamflow characteristics can be evaluated in a network analysis in a similar manner to that of low flow to determine more accurately whether or not a station should be added or removed from the stream-gaging station network. As many stations have more than one category of use, it is not appropriate to rely solely on a network analysis for decisions regarding the removal or addition of stations even though the evaluation using a GLSNET model results in prioritizing gages that provide regional streamflow information. Wahl and Crippen (1984) detailed a number of practical factors that might be considered before altering a stream-gaging station network. These factors include site characteristics, existing and potential beneficial uses of the water, magnitude of water-resource problems, data uses for planning and water-resource management, and economic considerations.

SUMMARY AND CONCLUSIONS

Streamflow data sets, hydrologic statistical relations, and a geographic information system (GIS) of coverages for the state of New Hampshire were developed by the U.S. Geological Survey (USGS), in cooperation with the New Hampshire Department of Environmental Services (NHDES). These streamflow data sets will aid in the management of water resources in a sustainable manner for the benefit of water users and the environment.

The effectiveness of the stream-gaging network in New Hampshire in providing regional low-flow streamflow information was analyzed by the use of the generalized-least-squares-NETwork (GLSNET) method. GLSNET is a method for network analysis that can be used to either optimize the regional information obtained from a stream-gaging network for a given set of budgetary and time constraints or to provide information that is necessary to make management decisions related to changes in funding. Stream-gaging stations with unregulated record were used to develop regional regression equations for the annual 7Q10 (7-day, 10-year) low flow by means of generalized-least-squares (GLS) regression. The annual 7Q10 is the annual minimum average 7-consecutive-day streamflow that has an annual non-exceedence probability of 0.10, or that is expected not to be exceeded in 1 of 10 years. GLS regression allows for the adjustment of the cross correlation (dependent variable highly correlated with flow characteristics at other stream-gaging stations) in the concurrent record and for differing record lengths between stations. The accuracy of the regional regression equations for predicting streamflow characteristics can be increased by collecting more data at the stations used in the development of the regression equation for the 7Q10 and by adding new stations to the existing stream-gaging network. In general, adding new stations provides greater accuracy in the regional streamflow information. Optimization of the regional information is obtained by minimizing the average sampling-error variance.

The GLSNET network-analysis method is dependent on the GLS regression equations, the location of each station, the number of years of unregulated streamflow record, and the cost associated with each station in order to determine a cost-weighted reduction to the sampling-error variance of each regression equation. Data from stations with 10 or more years of unregulated streamflow record were used to develop regression equations for the 7Q10 low flow. The stream-gaging network in New Hampshire was analyzed using these equations for the current (1999) conditions and for additional hypothetical periods of data collection of 5 and 20 years. The stream-gaging network also was analyzed for network strategies that included and excluded new stations. The relative contribution of each station to the reduction of the average sampling-error variance of the regression equations was used to rank the stations.

The results of the network analysis can be used to review the stream-gaging network in New Hampshire. A rank was determined for each stream-gaging station; however, this rank is based solely on the contribution of each gage to the regional annual 7Q10 low-flow statistic. To determine whether or not to continue operating existing stations, other factors need to be evaluated as stations rarely are operated for the sole purpose of collecting streamflow data for regional information. Streamflow data are used for many purposes such as the operation of water-resource facilities, correlation with partial-record stations, trend analysis, flood forecasting, and short-term projects. The value of a stream-gaging station increases when there are multiple uses of the data, and a greater weight for continuation of the station may be required than that indicated by a network analysis alone.

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APPENDIX 1

APPENDIX 1. BASIN CHARACTERISTICS TESTED FOR SIGNIFICANCE IN THE REGRESSION ANALYSIS

- **Total drainage area**, in square miles, is the area measured in a horizontal plane that is enclosed by a drainage divide.
- **Basin length**, in miles, is the length of the basin measured along a line areally centered through the drainage divide data layer from the basin outlet to where the main channel extended meets the basin divide.
- **Basin perimeter**, in miles, is the length as measured along the entire drainage-basin boundary.
- **Average basin slope**, in percent, is the average slope of the drainage basin measured using a Digital Elevation Model (DEM) in the computer software ARC-INFO.
- **Basin relief**, in feet, is the measured difference between the elevation of the highest grid cell and the elevation of the grid cell at the basin outlet. A lattice data layer, created using ARC-INFO, is used to determine the minimum and maximum land-surface elevation.
- **Basin azimuth**, in degrees, is the direction of a line projected from where the main channel meets the basin divide downslope to the basin outlet (clockwise from north = 0 degrees).
- **Basin azimuth**, in radians.
- **Basin azimuth region**: Four quadrants where 0-90 degrees = 1, 90-180 degrees = 2, 180-270 degrees = 3, and 270-360 degrees = 4.
- **Effective basin width**, in miles, is the ratio of the total drainage area to the basin length.
- **Shape factor**, dimensionless, is the ratio of basin length to the effective basin width.
- **Compactness ratio**, dimensionless, is the ratio of the perimeter of the basin to the circumference of a circle of equal area.
- **Relative relief**, in foot per mile, is the ratio of the basin relief to the basin perimeter.
- **Main channel length**, in miles, is measured along the main channel from the basin outlet to where the main channel meets the basin divide using centerlined hydrography.
- **Main channel slope**, in foot per mile, is the slope of the main channel based on the difference in streambed elevation at points 10 and 85 percent of the distance along the main channel from the basin outlet to the basin divide.
- **Main channel sinuosity ratio**, dimensionless, is the ratio of the main channel length to the basin length.
- **Stream density**, in miles per square mile, is the ratio of the main channel length to the drainage area.
- **Main channel slope proportion**, dimensionless, is the ratio of the main channel length to the square root of the main channel slope.
- **Ruggedness number**, in feet per mile, is the product of the stream density multiplied by the Basin Relief.
- **Slope ratio**, dimensionless, is the ratio of the main channel slope to the basin slope.
- **Minimum basin elevation**, in feet, is the minimum elevation in the drainage basin based on the intersection of the basin polygon coverages and the DEMs.
- **Maximum basin elevation**, in feet, is the maximum elevation in the drainage basin based on the intersection of the basin polygon coverages and the DEMs.
- **Mean basin elevation**, in feet, is mean basin elevation in the drainage basin based on the intersection of the basin polygon coverages and the DEMs.
- **Median basin elevation**, in feet, is the median basin elevation in the drainage basin based on the intersection of the basin polygon coverages and the DEMs.
- **Ground-water head**, in feet, is a surrogate for the effective head in the sand and gravel deposits determined by subtracting the minimum basin elevation from the mean basin elevation.

- **Basin elevation group**, either a 1 or a 2, is based on the median value of the mean basin elevations for all 60 basins used to develop the regression equations, which is 1,498 feet above mean sea level. A “1” indicates that the mean basin elevation is above this value and a “2” indicates that the mean basin elevation is below this value.
- **Standardized centroid latitude and longitude** is the latitude and longitude of the basin centroid, which was standardized by replacing the centroid latitude (and similarly centroid longitude) of each basin with (Latitude – mean (Latitude) divided by the Standard Deviation (Latitude). The standardized latitude and longitude are symmetrically distributed with a mean of zero and a standard deviation of one.
- **Centroid latitude and longitude**, in decimal degrees, is the latitude and longitude at the centroid of the drainage basin.
- **Significant sand and gravel deposits**, in square miles plus 0.01, is the total area of sand and gravel deposits in the basin plus 0.01.
- **Percent sand and gravel in basin**, in percent plus 0.01, is the percentage of the total drainage basin area, which has sand and gravel deposits, to the total drainage basin area plus 0.01.
- **Ratio of sand and gravel in basin in contact with stream network to total drainage basin area**, in percent plus 0.01, is the percent of drainage basin underlain by sand and gravel, which is in contact with the stream network (based on the intersection of stream centerline data and polygon coverages of sand and gravel deposits) as a percentage of the total drainage-basin area.
- **Minimum elevation of sand and gravel deposits**, in feet, is the minimum elevation of the sand and gravel deposits based upon DEMs and sand and gravel data.
- **Maximum elevation of sand and gravel deposits**, in feet, is the maximum elevation of the sand and gravel deposits based upon DEMs and sand and gravel data.
- **Mean elevation of sand and gravel deposits**, in feet, is the mean elevation of the sand and gravel deposits based upon DEMs and sand and gravel data.
- **Maximum sand and gravel deposit elevation above minimum basin elevation**, in feet plus 0.01, is the difference in elevation between the maximum and minimum sand and gravel deposit elevations as determined from DEMs and sand and gravel data (plus 0.01).
- **Mean sand and gravel deposit elevation above minimum basin elevation**, in feet plus 0.01, is the difference in elevation between the mean sand and gravel deposit elevation and the minimum basin elevation based upon DEMs and sand and gravel data (plus 0.01).
- **Mean sand and gravel deposit elevation above minimum basin elevation divided by drainage area**, in feet plus 0.01, is the difference in elevation between the mean sand and gravel deposit elevation and the minimum basin elevation divided by drainage area and based upon DEMs and sand and gravel data (plus 0.01).
- **Relief of sand and gravel deposits**, in feet plus 0.01, is the difference between the maximum sand and gravel elevation and minimum sand and gravel elevation based upon DEMs and sand and gravel data (plus 0.01).
- **Mean annual and seasonal precipitation**, in inches, at a stream-gaging station, is from PRISM average monthly and annual precipitation data from 1961 to 1990. It is based on 2-kilometer grid data. Five parameters were determined based on these data:
    - annual gage
    - winter gage (January 1 – March 15)
    - spring gage (March 16 – May 31)
    - summer gage (June 1 – October 31)
    - fall gage (November 1 – December 31)
- **Mean annual and seasonal precipitation**, in inches, at the centroid of the basin, is from PRISM average monthly and annual precipitation data from 1961 to 1990. It is based on 2-kilometer grid data. Five parameters were determined based on these data:
    - annual centroid
    - winter centroid (January 1 – March 15)
    - spring centroid (March 16 – May 31)

  - summer centroid (June 1 – October 31)
  - fall centroid (November 1 – December 31)
- **Mean annual and seasonal precipitation**, in inches, as a basin average for the drainage basin, is from PRISM average monthly and annual precipitation data from 1961 to 1990. It is based on 2-kilometer grid data. Five parameters were determined based on these data:
  - annual basin
  - winter basin (January 1 – March 15)
  - spring basin (March 16 – May 31)
  - summer basin (June 1 – October 31)
  - fall basin (November 1 – December 31)
- **Average mean, minimum, and maximum annual and seasonal basin temperature**, in degrees Fahrenheit, is based on monthly data acquired from PRISM for 1961-90. It is based on 2-kilometer grid data. The temperature values for the entire month of March were used for each of the seasonal “winter and spring” periods.
  - annual basin mean, minimum, maximum
  - winter basin mean, minimum, maximum (January 1 – March 31)
  - spring basin mean, minimum, maximum (March 1 – May 31)
  - summer basin mean, minimum, maximum (June 1 – October 31)
  - fall basin mean, minimum, maximum (November 1 – December 31)
- **Soil drainage**, in percent, is the percentage of drainage basin that is well drained as determined from STATSGO (State Soil Geographic) (Schwarz and Alexander, 1995; and U.S. Department of Agriculture, 1991) data.
- **Mean permeability**, in inches per hour, is the mean permeability in each basin as determined from STATSGO (Schwarz and Alexander, 1995, and U.S. Department of Agriculture, 1991) data.
- **32fday**, in days, is the seasonally and annually determined basinwide average number of days in which the temperature was a minimum of 32 degrees or less. The seasonal value for the month of March was determined by dividing the March value in half (assumes uniform distribution).
  - annual basinwide
  - winter basinwide (January 1 – March 15)
  - spring basinwide (March 16 – May 31)
  - summer basinwide (June 1 – October 31)
  - fall basinwide (November 1 – December 31)
- **Curve_25thquartile**, dimensionless, is the curvature of the basin based on a DEM for all of New Hampshire and Vermont and part of Maine and Massachusetts. The area encompasses all of the 60 basins used in this study. The curvature command was used in a grid of the DEM. A slope and a curvature grid were generated. The lowest 25 percent of slope and curvature grid cells were given a value of one while everything else was given a value of zero. These two grids were then cross-multiplied and a grid was produced that identifies those cells representing the lowest 25 percent of both slope and curvature. The curvature grid calculates the curvature of a surface at each cell center and the slope grid show the rate of maximum change in *Z* value from each cell. Slope is the first derivative of surface; curvature is the second derivative of surface. A negative value indicates that the surface (relative to a best fit plane) is concave at that cell. The basin characteristic is the lowest 25-percent quartile of curvature and slope relative to a best fit plane and indicates the smallest change in *Z* value from each cell (slope grid) and most curved cell surfaces (curvature grid). This grid was intersected with the basin grids to obtain percent flat and curved in each basin.
- **Curve cell_relief**, dimensionless, is the relief (maximum – minimum) of curvature of the basin grid surface at each cell center for each basin.
- **Profile curve** (mean, minimum, maximum), dimensionless, is the average curvature of the grid surface at each cell center in the direction of slope for each basin.
- **Total stream length**, in miles, is the total length of all streams in the basin.
- **Area of water bodies**, in square miles plus 0.01, is the total area of water bodies in the basin.

- **Percent water bodies**, in percent plus 0.01, is the percent of each drainage basin that contains a body of water.
- **Area of sand and gravel in contact with the stream network**, in square feet plus 0.01, is the total area of sand and gravel in each drainage basin in contact with the stream network.
- **Ratio of sand and gravel deposits to streams which are in contact with the sand and gravel deposits in the basin**, in miles plus 0.01, is the ratio of the square miles of sand and gravel deposits to the miles stream length in contact with the sand and gravel deposits plus 0.01.
- **Ratio of sand and gravel deposits to the total stream length in the basin**, in miles plus 0.01, is the ratio of the square miles of sand and gravel deposits to the miles of total stream length plus 0.01. The stream centerline data was intersected with the polygon coverages of sand and gravel deposits.
- **Annual snowfall**, in inches, is the mean annual basin average snowfall for each of the basins based on monthly data acquired from 2-kilometer PRISM grid data from 1961 to 1990.
- **Forest coverage**, in percent, is National Land Cover Dataset (NLCD) data used to determine the percent of the basin that is forested.
- **Deciduous forest**, in percent, is the percent of the basin that is deciduous. Defined in NLCD metadata as areas dominated by trees where 75 percent or more of the tree species shed foliage simultaneously in response to seasonal change.
- **Coniferous forest**, in percent, is the percent of the basin that is coniferous. Defined in NLCD metadata as areas dominated by trees where 75 percent or more of the tree species maintain their leaves all year. Canopy is never without green foliage.
- **Mixed Coniferous / Deciduous forest**, in percent, is the percent of the basin that is mixed coniferous and deciduous. Defined in NLCD metadata as areas dominated by trees where neither deciduous nor evergreen species represent more than 75 percent of the cover present.

Hypsometric curve area, dimensionless, is the area under the curve for a hypsometric curve of the basin elevation. Elevation data was grouped in equal-area classifications to create a hypsometric curve and the area under the curve was determined by summing the products of elevation and basin area above a given maximum elevation for each of the particular equal area groupings.