ANALYSIS OF THE PEAK-FLOW GAGING NETWORK IN NORTH DAKOTA

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Analysis of the Peak-flow Gaging Network in North Dakota

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ABSTRACT

A network analysis technique using generalized least-squares regression was used to evaluate the current (1993) peak-flow gaging network that provides regional peak-flow information for North Dakota. The analysis was conducted to evaluate the current (1993) network and to determine if reactivating discontinued gaging stations and adding new gaging stations on small drainage areas would improve regional peak-flow information.

Peak flows having recurrence intervals of 15, 50, and 100 years and planning horizons of zero and 10 years for three hydrologic regions in North Dakota were used in the network analysis. Results of the network analysis indicate that the average sampling mean-square error could be reduced by about 10 percent for the 15-, 50-, and 100-year recurrence intervals by reactivating a minimum of two to five discontinued gaging stations in each hydrologic region. The reactivated discontinued gaging stations added to the current (1993) network should be located on streams having small drainage areas and steep main-channel slopes. For the 15-year recurrence interval and a 10-year planning horizon, adding a new gaging station at two new locations in each region instead of reactivating two discontinued gaging stations in each region would reduce the average sampling mean-square error by an average of about 13 percent in each region. The new gaging stations added to the current (1993) network should be located on streams having small drainage areas and mild or steep main-channel slopes in order to obtain improved regional peak-flow information.

INTRODUCTION

Streamflow information are gathered at selected sites on streams across North Dakota on a continuous basis. Not all streams in the State are gaged, however. Peak-flow estimates for many of these ungaged streams are needed to provide essential flood information to planners and designers for various water-related projects. Peak-flow information collected at gaged streams are transferable to ungaged streams in a region through an empirical functional relation (usually a regression model) developed between streamflow characteristics and selected basin characteristics. This procedure is commonly referred to as "regionalization". Many of the streamflow-gaging stations in North Dakota were established primarily to provide information on current streamflow conditions at particular locations. However, information from some of these particular gaged locations may have limited transfer value, and are not suitable for regional analyses. Placement of streamflow-gaging stations to be used expressly for regionalization should provide spatial coverage of a region and should provide improved information for a range of basin and streamflow characteristics. Considered together, the group of stations and their characteristics make up a hypothetical data-collection "network" suitable for providing regional information.

Any long-term data collection network should be evaluated periodically because of changes in objectives, technology, or external constraints. The last major evaluation of the streamflow-gaging network in North Dakota was performed by Crosby (1970). The uses, funding, and availability of streamflow data in North Dakota through 1984 were documented by Ryan (1985). The cost effectiveness of the streamflow-gaging network in eastern North Dakota was addressed by Ryan (1989). A network analysis that addresses the effect on the regional information that might be obtained from improved regional regression equations has not been attempted recently.

Regression equations for estimating peak flow for selected recurrence intervals for rural ungaged drainage areas throughout North Dakota were reported by Crosby (1975) and were updated by Williams-Sether (1992) using generalized least-squares (GLS) regression. The GLS technique not only provides an improved method for developing estimating equations based on data from an existing streamflow gaging network, but also may be used in evaluating the effectiveness of hypothetical changes to the gaging network in improving regional flood information. The current (1993) streamflow-gaging network in North Dakota consists of 107 continuous- and partial-record streamflow-gaging stations. Most of the gaging stations are located in drainage areas larger than 100 square miles (fig. 1). Williams-Sether (1992) reviewed the flood frequency data base and concluded that not enough current peak-flow records exist for small drainage areas. According to Williams-Sether (1992, p. 18), "Future peak-flow frequency studies for North Dakota streams could be improved if additional gaging stations were established or previously discontinued gaging stations were reestablished on natural-flow streams, especially for sites on streams with drainage areas of less than 200 mi^2." Thus, a need exists to evaluate the current streamflow network emphasizing watersheds having small drainage areas.

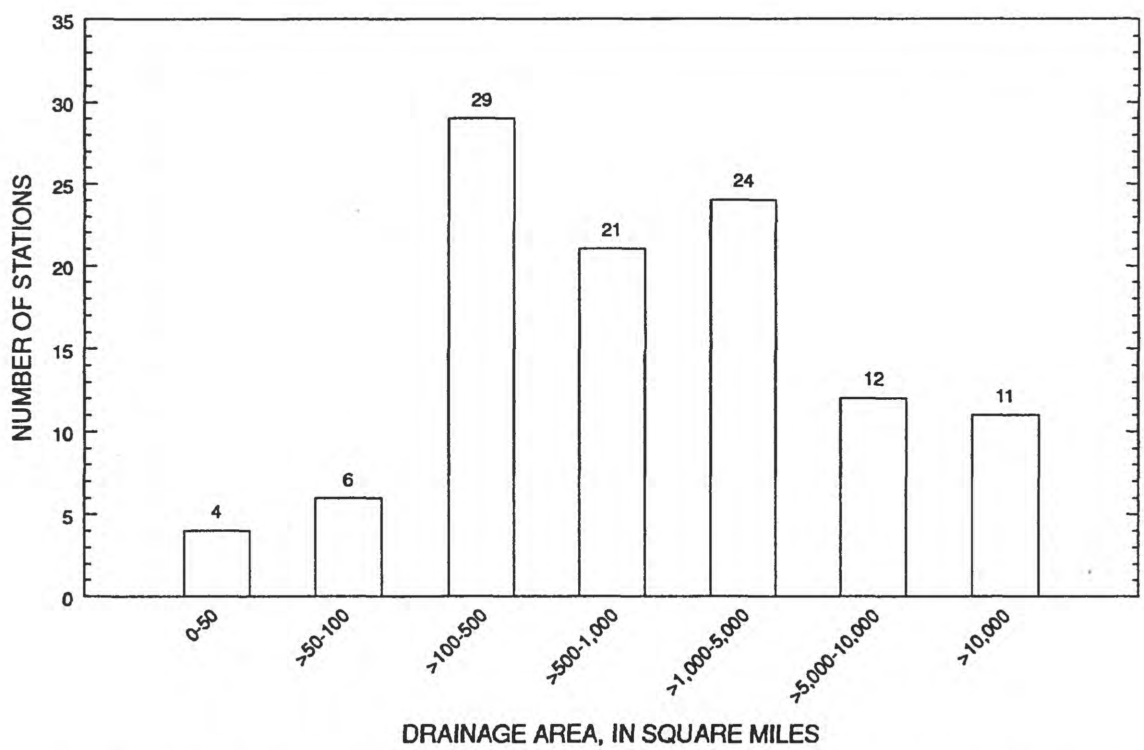

Figure 1. Distribution of current (1993) streamflow-gaging stations, by drainage area, in North Dakota.

The purpose of this study was to evaluate the North Dakota streamflow-gaging network to determine what changes to the streamflow network would provide improved regional peak-flow information for small drainage areas. Improved information is obtained by relating peak-flow estimates to selected basin characteristics. Specific objectives were to (1) determine the effectiveness of the 1993 streamflow-gaging network in providing regional peak-flow information and (2) evaluate the potential improvements in the effectiveness of the 1993 network that would result from reactivating discontinued gaging stations and adding new gaging stations to the network. New gaging stations, unless otherwise noted, includes both continuous- and partial-record gaging stations. The study was limited to analysis of gaging stations in North Dakota and selected gaging stations in adjacent states. The streamflow-gaging network that was evaluated consisted of streamflow-gaging stations that were active in 1993 and gaging stations used by Williams-Sether (1992) updated through 1993. This report, which was prepared in cooperation with the North Dakota Department of Transportation, describes results of the study.

NETWORK ANALYSIS TECHNIQUE

The network analysis technique used in this study is based on the GLS regression (Tasker, 1986; Tasker, 1987). The GLS regression (Stedinger and Tasker, 1985) allows adjustments to be made for the cross correlation in concurrent record and for various lengths of record among gaging stations. A valuable feature of the GLS regression procedure for network analysis is that it provides a reliable estimate of the regression sampling error. The sampling error is the error in predicting the value of a particular flow statistic (in this case peak flow) due to estimating the true regression parameters. The sampling error is affected by the length of peak-flow record at a gaging station, the variability of the peak-flow values, the cross correlation with data from other gaging stations, and the combination of physical and climatic characteristics associated with the gaging station drainage area. The sampling error can be used to help evaluate the effect of either discontinuing existing gaging stations or adding new gaging stations to the network.

The network analysis can be used to address the question of whether to spend limited resources on collecting additional data at existing gaging stations, adding new gaging stations, or doing both. This determination is made by maximizing the regional regression model's predictive capability which is expressed as the inverse of the average variance of prediction of the model. The average variance of prediction is the variances of prediction averaged for a representative set of streamflow sites in a region. The variance of prediction at a site is made up of two independent parts: (1) the model error, which can be improved only by choosing a better model and (2) the sampling error, which can be improved by collecting additional data at existing or new gaging stations. It is assumed that the model will not change; therefore, the model error remains constant. The objective then is to minimize the sampling error. The average sampling mean-square error is a measure of the error in the average regression prediction in a region due to estimating with sample estimates of the regression coefficients. The average sampling mean-square error is a function of not only how long the gaging stations have been operated, but also where the gaging stations are in relation to each other and what values of basin and climatic characteristics are used in the regression. These properties make the average sampling mean-square error a good criterion by which to evaluate the trade off between extended records and additional gaging stations in a network analysis (Ruhl, 1993). Further explanations and examples of using the GLS regression procedure for network analyses may be found in reports by Medina (1987), Omang (1992), and Ruhl (1993).

PEAK-FLOW GAGING NETWORK ANALYSIS

Approach

The network analyzed in this report consists of three sub-networks (fig. 2) corresponding to the three hydrologic regions specified by Williams-Sether (1992). In the network analysis, unregulated annual peak flow was the streamflow characteristic used for each gaging station for the period of record through water year 1993. All periods of record are in terms of water year. Water year in U.S. Geological Survey reports dealing with surface-water supply is the 12-month period October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 1993, is called the "1993 water year."

The basin characteristics used in the network analysis were those identified as significant in the GLS regression analyses by Williams-Sether (1992). The characteristics were contributing drainage area and main-channel slope. Because the flow of streams having large drainage areas generally is regulated and, therefore, is not applicable to the analysis, only gaging stations having drainage areas of 1,000 square miles or less were used in the network analysis.

Streamflow-gaging stations with 10 years or more of record were considered appropriate for use in the analysis. Exceptions were made for recently installed gaging stations in the current (1993) network that had 4 years or more of record. Three gaging stations in the current (1993) network had 3 years or less of record and were treated as new gaging stations in the network analysis. The gaging stations used in the analysis are listed in supplement 1 at the end of the report, and the locations are shown in figure 2.

The peak-flow regional regression equations for 15-, 50-, and 100-year recurrence intervals as defined by Williams-Sether (1992) were updated to include data through 1993. Two hundred and one gaging stations were used to update the regression analyses, and the results were used for the network analysis (supplement 1). Only 175 gaging stations were used in the network analysis. The gaging stations that were not used in the analyses did not have the necessary basin characteristics or they were discontinued gaging stations located outside of North Dakota. Planning horizons of zero and 10 years were chosen for the network analysis. A zero-year planning horizon refers to conditions of the current (1993) network zero years into the future and assumes that no additional data would be collected at existing gaging stations and no reactivated or new gaging stations would be added to the network. A 10-year planning horizon refers to conditions of the current (1993) network 10 years into the future and implies 10 years of additional data would be collected at existing gaging stations. A 10-year planning horizon may or may not include reactivated or new gaging stations added to the network during the 10-year period. The network analysis for each of the 15-, 50-, and 100-year recurrence interval peak flows consisted of (1) the existing gaging stations and (2) the existing gaging stations plus discontinued gaging stations and recently installed (3 years or less of record) gaging stations.

Results

Results of the network analysis for hydrologic regions A, B, and C using the 15-, 50-, and 100-year recurrence interval peak flow are presented in figures 3, 4, and 5 and tables 1, 2, and 3. The discontinued gaging stations and the recently installed gaging stations (one in region A and two in region B) are ranked in providing regional peak-flow information in tables 1, 2, and 3. The gaging stations are ranked according to a 10-year planning horizon and 15-, 50-, and 100-year recurrence intervals.

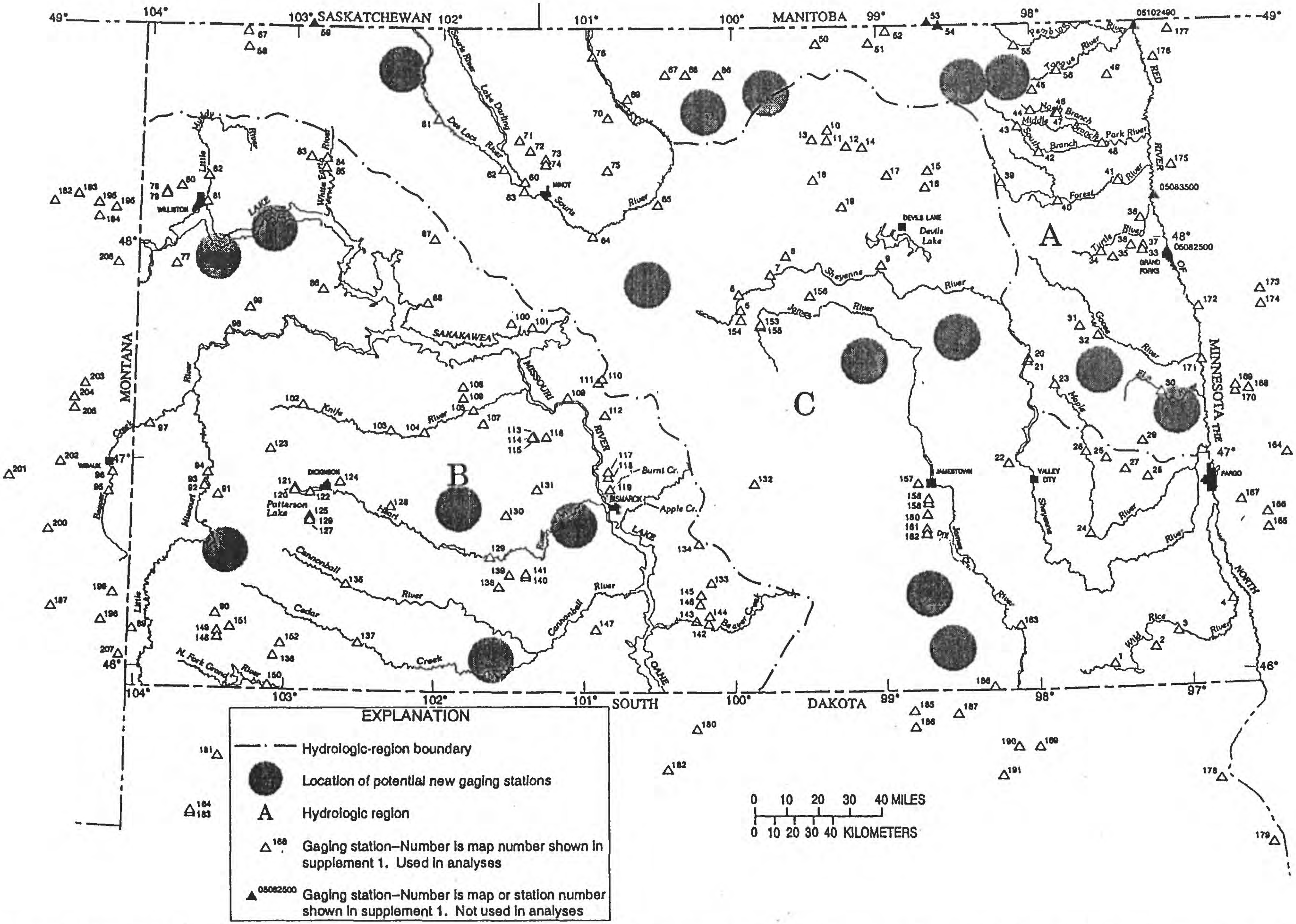

Figure 2. Location of gaging stations and hydrologic-region boundaries used in the generalized least-squares regression analysis update and the network analysis in North Dakota.

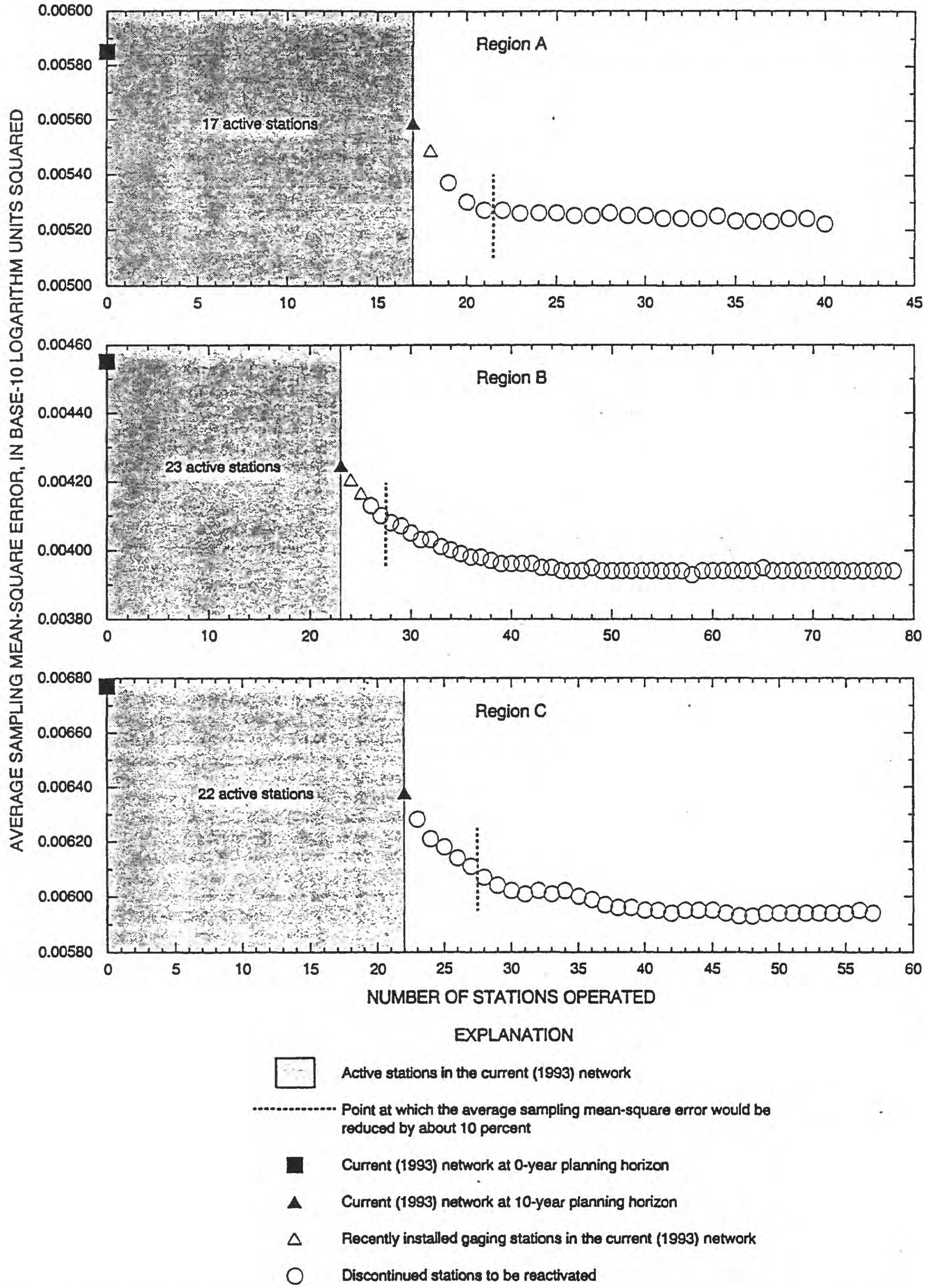

Figure 3. Results of network strategy in hydrologic regions A, B, and C to provide regional information on 15-year peak flow in North Dakota.

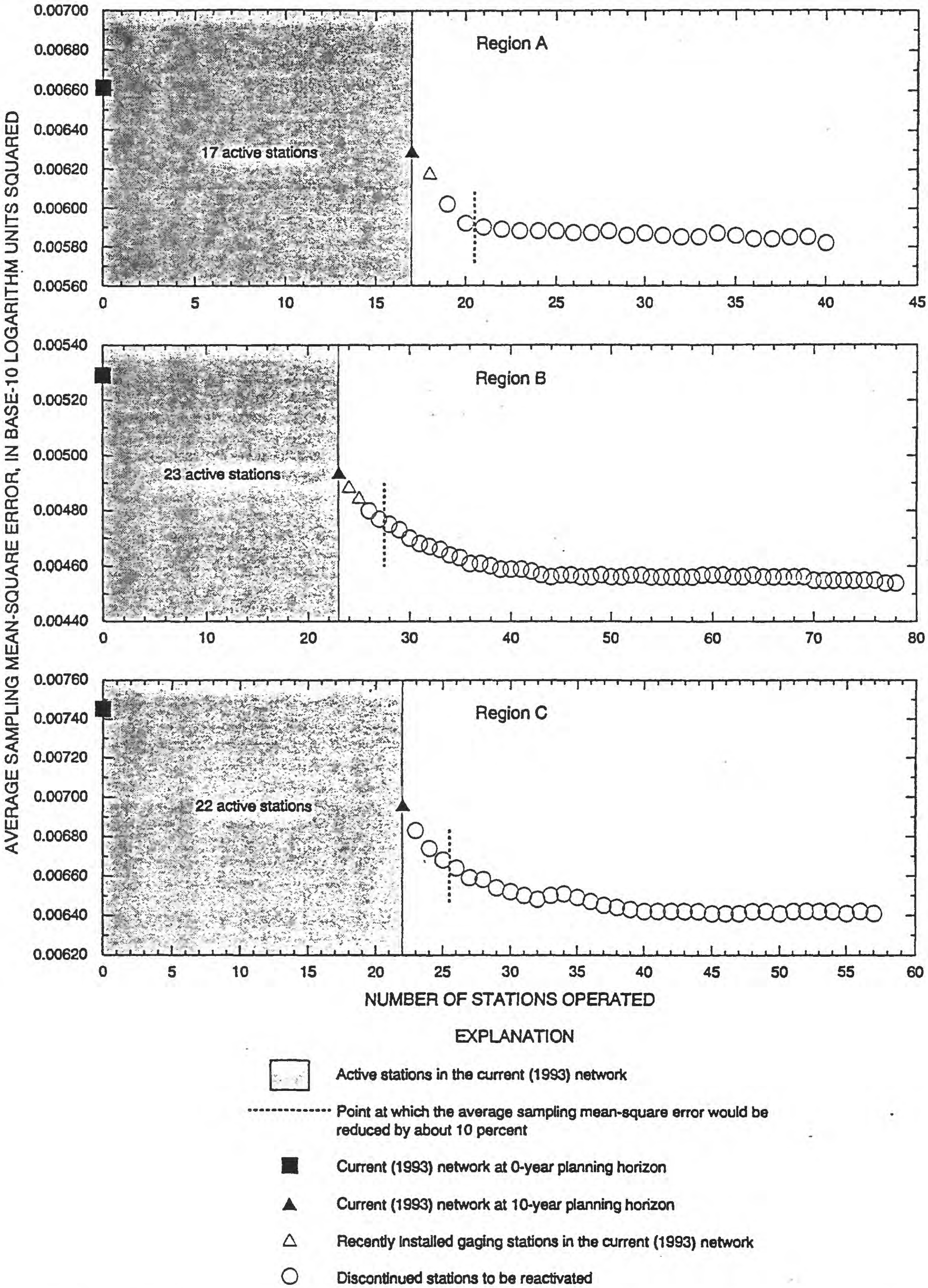

Figure 4. Results of network strategy in hydrologic regions A, B, and C to provide regional information on 50-year peak flow in North Dakota.

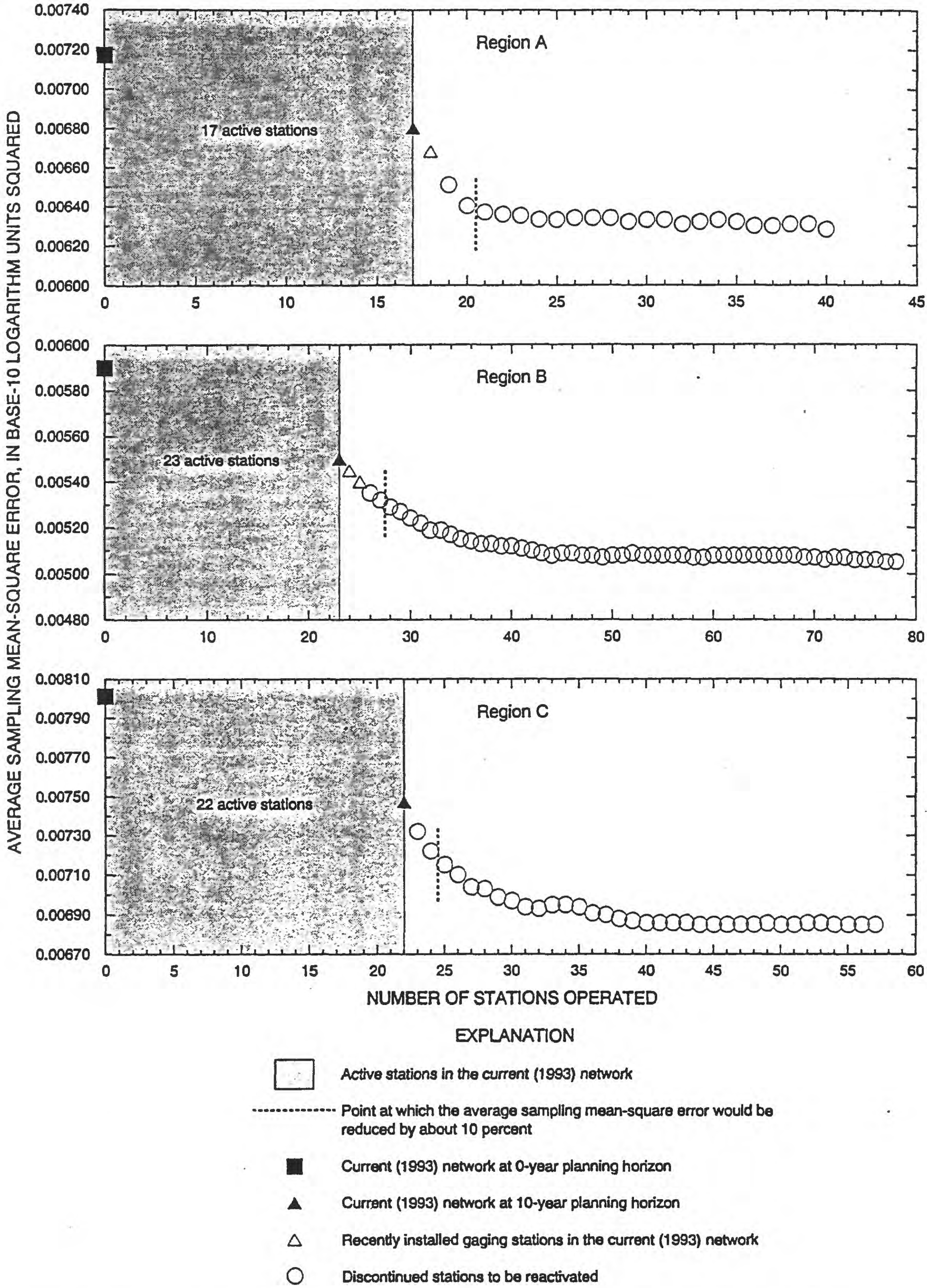

Figure 5. Results of network strategy in hydrologic regions A, B, and C to provide regional information on 100-year peak flow in North Dakota.

Table 1. Gaging station ranking in providing regional peak-flow information for hydrologic region A and the percent reduction in the average sampling mean-square error

Station number	Ranking for 15-year recurrence interval	Cumulative error reduction (percent)	Ranking for 50-year recurrence interval	Cumulative error reduction (percent)	Ranking for 100-year recurrence interval	Cumulative error reduction (percent)	Composite ranking
05056900	6	10.1	6	11.0	6	11.4	6
05056950	2	8.2	2	8.9	2	9.2	2
05062200	15	10.4	14	11.3	14	11.7	14
05065500	21	10.4	20	11.6	20	12.1	20
05082600	18	10.6	19	11.6	19	12.1	19
[1]05082625	1	6.3	1	6.6	1	7.0	1
05082680	9	10.2	9	11.2	7	11.7	9
05082700	20	10.6	21	11.5	21	12.0	21
05082900	14	10.4	15	11.5	15	12.0	15
05083600	19	10.6	18	11.3	18	11.8	18
05088000	7	10.1	7	11.0	9	11.6	7
05089100	16	10.4	16	11.5	16	11.8	16
05089200	10	10.2	10	11.2	11	11.6	10
05089500	11	10.1	11	11.0	10	11.6	11
05089700	13	10.2	13	11.2	13	11.7	13
05089800	23	10.8	23	12.0	23	12.4	23
05092200	22	10.4	22	11.5	22	12.0	22
05099400	17	10.2	17	11.2	17	11.7	17
05098800	12	10.2	12	11.3	12	11.8	12
05122500	8	10.1	8	11.0	8	11.7	8
05123300	4	9.9	4	10.7	4	11.2	4
05123350	3	9.4	3	10.4	3	10.7	3
05123500	5	9.9	5	10.9	5	11.3	5

[1]Recently installed gaging station in the current (1993) network.

Series of symbols plotted on figures 3, 4, and 5 will be referred to as curves. The steep part of each curve represents the gaging stations that would be most effective in reducing the average sampling mean-square error. The flat part of each curve represents the gaging stations that would be least effective in reducing the average sampling mean-square error for the respective recurrence interval and would probably not be considered for inclusion into the network.

Results of the 15-year peak-flow recurrence interval analyses for hydrologic regions A, B, and C are shown in figure 3. The average sampling mean-square error for the current (1993) network from the zero-year to the 10-year planning horizon is reduced by 4.6 percent (from 0.00585 to 0.00558) in region A, by 6.8 percent (from 0.00455 to 0.00424) in region B, and by 5.9 percent (from 0.00677 to 0.00637) in region C. Adding additional gaging stations to the network (23 in region A, 55 in region B, and 35 in region C) would reduce the average sampling mean-square error by 10.8 percent (from 0.00585 to 0.00522) in region A, by 13.4 percent (from 0.00455 to 0.00394) in region B, and by 12.3 percent (from 0.00677 to 0.00594) in region C. The additional gaging stations used in the analysis consisted of recently installed gaging stations in the current (1993) network and reactivated gaging stations that had been previously discontinued. The average sampling mean-square error would be reduced by about 10 percent (tables 1-3) by retaining recently installed gaging stations in the current (1993) network and by reactivating a minimum of three discontinued gaging stations in region A, a minimum of two discontinued gaging stations in region B, and a minimum of five discontinued gaging stations in region C.

Table 2. Gaging station ranking in providing regional peak-flow information for hydrologic region B and the percent reduction in the average sampling mean-square error

Station number	Ranking for 15-year recurrence interval	Cumulative error reduction (percent)	Ranking for 50-year recurrence interval	Cumulative error reduction (percent)	Ranking for 100-year recurrence interval	Cumulative error reduction (percent)	Composite ranking
06329597	26	13.4	25	13.8	25	13.9	25
06329700	16	13.0	16	13.2	17	13.2	16
06329800	52	13.4	52	14.0	52	14.2	52
06329900	27	13.4	28	13.8	28	13.9	28
06330100	33	13.4	32	13.8	32	13.9	32
06331900	44	13.4	46	13.8	46	14.1	46
06332000	48	13.4	47	14.0	48	14.2	47
06332150	4	9.9	4	9.8	4	9.8	4
06332520	22	13.4	19	13.4	19	13.6	19
[1]06332770	1	7.7	1	7.8	1	7.8	1
06335000	36	13.4	34	13.8	34	13.9	34
06335700	8	11.4	8	11.5	8	11.5	8
06336100	5	10.3	3	9.3	3	9.3	3
06336200	28	13.4	39	13.8	39	13.9	39
06336300	3	9.2	7	11.2	7	11.2	7
06336400	32	13.4	31	13.8	31	13.9	31
06336980	7	11.0	6	10.6	6	10.7	6
06337100	29	13.4	27	13.8	26	14.1	27
06337600	12	12.3	12	12.5	12	12.7	12
06337900	6	10.5	5	10.2	5	10.3	5
06339300	49	13.4	48	14.0	47	14.1	48
06339560	25	13.2	26	13.6	27	13.9	26
06340528	18	13.0	22	13.6	22	13.7	22
06340905	13	12.5	15	13.0	16	13.2	15
06341400	39	13.4	35	13.8	35	14.1	35
06342050	55	13.4	55	14.2	55	14.4	55
06342100	53	13.4	53	14.0	53	14.2	53
06342150	17	13.0	17	13.2	15	13.0	17
06342250	15	12.7	13	12.8	13	12.9	13
06342300	24	13.4	23	13.6	23	13.7	23
06342350	20	13.2	20	13.6	20	13.7	20
06343200	10	11.9	11	12.3	11	12.4	11
06344200	14	12.5	14	12.8	14	13.0	14
06345000	38	13.4	37	13.6	36	14.1	37
06345100	50	13.4	50	14.0	50	14.1	50
06345200	35	13.6	38	13.6	38	13.9	38
06345300	34	13.4	33	13.8	33	13.9	33
06345700	46	13.4	45	13.8	44	13.9	45
06347000	42	13.2	41	13.6	42	13.9	41
06348500	47	13.4	49	14.0	49	14.1	49
06349200	19	13.0	18	13.2	18	13.4	18
[1]06354815	2	8.6	2	8.5	2	8.6	2
06355310	9	11.4	9	11.7	10	12.0	9
06353600	11	12.1	10	11.9	9	12.0	10
06353700	21	13.2	21	13.8	21	13.9	21
06353800	45	13.4	44	13.8	45	13.9	44
06353900	43	13.4	42	13.8	41	13.9	42
06354500	37	13.4	36	13.6	37	13.9	36
06354700	30	13.4	30	13.6	30	13.9	30
06354750	23	13.4	24	13.8	24	13.9	24
06354800	41	13.4	43	13.8	43	13.9	43
06354900	54	13.4	54	14.2	54	14.4	54
06354950	40	13.4	40	13.8	40	13.9	40
06355000	31	13.4	29	13.6	29	13.7	29
06355200	51	13.4	51	14.0	51	14.2	51

[1]Recently installed gaging station in the current (1993) network.

Table 3. Gaging station ranking in providing regional peak-flow information for hydrologic region C and the percent reduction in the average sampling mean-square error

Station number	Ranking for 15-year recurrence interval	Cumulative error reduction (percent)	Ranking for 50-year recurrence interval	Cumulative error reduction (percent)	Ranking for 100-year recurrence interval	Cumulative error reduction (percent)	Composite ranking
05051800	4	9.3	3	10.3	3	10.7	3
05051900	24	12.3	28	14.0	28	14.5	28
05052500	30	12.3	26	13.8	26	14.5	26
05055000	10	11.1	11	12.8	11	13.2	11
05055100	34	12.1	34	13.8	34	14.5	34
05055200	22	12.1	21	13.8	20	14.4	21
05055520	8	11.1	8	12.5	8	13.0	8
05056020	27	12.3	29	13.8	29	14.5	29
05056040	19	12.1	19	13.8	19	14.4	19
05056080	31	12.3	31	13.8	31	14.4	31
05056300	23	12.1	25	14.0	25	14.5	25
05059800	33	12.3	32	13.8	32	14.5	32
05059850	14	11.5	13	12.9	13	13.4	13
05059900	28	12.3	30	13.8	30	14.4	30
05059950	18	12.1	18	13.8	18	14.4	18
05113450	9	11.2	9	12.8	10	13.5	9
05113520	2	8.3	2	9.5	2	9.9	2
05116100	1	7.2	1	8.3	1	8.6	1
05116200	5	9.7	4	10.9	4	11.4	4
05116550	12	11.1	12	12.6	12	13.2	12
05117200	3	8.7	6	11.7	6	12.2	6
05123520	15	11.8	14	13.2	14	13.7	14
05123540	32	12.3	33	14.0	33	14.5	33
05123560	7	10.8	7	12.2	7	12.7	7
05123580	35	12.3	35	14.0	35	14.5	35
05123600	26	12.4	24	14.0	22	14.5	24
06349100	13	11.4	15	13.4	15	13.8	15
06467650	20	12.3	20	13.8	21	14.4	20
06467800	21	12.1	22	13.8	24	14.5	22
06467900	11	11.2	10	13.0	9	13.4	10
06469500	29	12.3	27	13.8	27	14.4	27
06469600	16	12.0	16	13.6	16	14.1	16
06470200	6	10.3	5	11.5	5	12.1	5
06470300	25	12.4	23	14.0	23	14.5	23
06470400	17	12.0	17	13.7	17	14.2	17

Results of the 50-year peak-flow recurrence interval analyses for hydrologic regions A, B, and C are shown in figure 4. The average sampling mean-square error for the current (1993) network from the zero-year to the 10-year planning horizon is reduced by 5.0 percent (from 0.00661 to 0.00628) in region A, by 6.8 percent (from 0.00529 to 0.00493) in region B, and by 6.7 percent (from 0.00745 to 0.00695) in region C. Adding additional gaging stations to the network (23 in region A, 55 in region B, and 35 in region C) would reduce the average sampling mean-square error by 12.0 percent (from 0.00661 to 0.00582) in region A, by 14.2 percent (from 0.00529 to 0.00454) in region B, and by 14.0 percent (from 0.00745 to 0.00641) in region C. The additional gaging stations used in the analysis consisted of recently installed gaging stations in the current (1993) network and reactivated gaging stations that had been previously discontinued. The average sampling mean-square error would be reduced by about 10 percent (tables 1-3) by retaining recently installed gaging stations in the current (1993) network and by reactivating a minimum of two discontinued stations in regions A and B and a minimum of three discontinued gaging stations in region C.

Results of the 100-year peak-flow recurrence interval analyses for hydrologic regions A, B, and C are shown in figure 5. The average sampling mean-square error for the current (1993) network from the zero-year to the 10-year planning horizon is reduced by 5.3 percent (from 0.00717 to 0.00679) in region A, by 6.9 percent (from 0.00590 to 0.00549) in region B, and by 6.9 percent (from 0.00801 to 0.00746) in region C. Adding additional gaging stations to the network (23 in region A, 55 in region B, and 35 in region C) would reduce the average sampling mean-square error by 12.4 percent (from 0.00717 to 0.00628) in region A, by 14.4 percent (from 0.00590 to 0.00505) in region B, and by 14.5 percent (from 0.00801 to 0.00685) in region C. The additional gaging stations used in the analysis consisted of recently installed gaging stations in the current (1993) network and reactivated discontinued gaging stations. The average sampling mean-square error would be reduced by about 10 percent (tables 1-3) by retaining recently installed gaging stations in the current (1993) network and by reactivating two discontinued gaging stations in region A and a minimum of two discontinued gaging stations in regions B and C.

The results of the network analysis indicate that in order to obtain improved regional peak-flow information and reduce the average sampling mean-square error, emphasis should be on reactivating discontinued gaging stations at stream locations having small drainage areas and steep main-channel slopes. The average contributing drainage area and average main-channel slope of the current (1993) network with no additional gaging stations added to the network are 332 square miles and 7.8 feet per mile in region A, 264 square miles and 12.9 feet per mile in region B, and 263 square miles and 6.6 feet per mile in region C. The average contributing drainage area and average main-channel slope of the reactivated discontinued gaging stations in each region that provide about 10 percent reduction in the average sampling mean-square error of the current (1993) network for the 15-, 50-, and 100-year recurrence intervals are 1.2 square miles and 164 feet per mile in region A, 0.31 square miles and 120 feet per mile in region B, and 1.24 square miles and 103 feet per mile in region C.

NETWORK SENSITIVITY ANALYSIS

A network sensitivity analysis was performed to evaluate drainage area, main-channel slope, and location of gaging stations in reducing the average sampling mean-square error of the current (1993) network. Also determined in the analysis was whether a greater reduction in the average sampling mean-square error would occur by reactivating discontinued gaging stations or by adding new gaging stations to the network. Several analyses were made for each hydrologic region (A, B, and C) using peak flow for the 15-year recurrence interval and a 10-year planning horizon. Combinations of three drainage areas (0.5, 5.0, and 25.0 square miles) and three values of main-channel slopes (3.0, 30.0, and 300 feet per mile) were tested at various locations (fig. 2) in each region for a total of nine different site conditions at each new gaging-station location. Small drainage areas were chosen because of the general lack of small drainage areas in the current (1993) network, because the results of the network analysis for the 15-, 50-, and 100-year peak-flow recurrence intervals indicated their importance, and because most large drainage areas (>1,000) have regulation of some kind. Mild (3.0 feet per mile) and moderate (30.0 feet per mile) main-channel slopes were chosen because of the good possibility of finding such a slope at a given location. Steep (300 feet per mile) main-channel slopes, although uncommon, were chosen because the results of the network analysis for the 15-, 50-, and 100-year peak-flow recurrence intervals indicated their importance.

The results of the sensitivity analyses indicated that location was a factor in new gaging-station site selection. Selecting a location that is distant from existing gaging stations would provide greater reduction in error than selecting a location in an area with existing gaging stations. Small drainage areas and mild and steep main-channel slopes were indicated to be the preferable site conditions to be considered for potential new gaging-station sites (table 4). Depending on site conditions, adding a new gaging station at the best two of the six locations (fig. 1) in each region instead of reactivating two discontinued gaging stations in each region would reduce the average sampling mean-square error from about 9 percent in region A (table 1), about 10 percent in region B (table 2), and about 8 percent in region C (table 3) to an average of about 13 percent in each region. By adding a new gaging station at all six locations in each region, the average reduction in the average sampling mean-square error for all of the regions combined is about 19 percent. For a drainage area of 0.5 square mile and a main-channel slope of 3.0 feet per mile, adding two new locations for gaging stations in region A, one in region B, and two in region C instead of reactivating two discontinued gaging stations in each region would reduce the average sampling mean-square error by about 15 percent (fig. 6). If new locations with small drainage areas and mild or steep main-channel slopes are considered in future gaging-station site selections, a greater reduction in the average sampling mean-square error would occur than by reactivating discontinued gaging stations.

Table 4. Reduction in average sampling mean-square error with the addition of new gaging stations in hydrologic regions A, B, and C (for example, by adding a new gaging station that has a drainage area of 0.5 square mile and a main-channel slope of 3 feet per mile at the best two locations in region A, the error would be reduced by 15.2 percent)

Drainage area (square miles)	Main-channel slope (feet per mile)	Reduction in average sampling mean-square error[1] (percent)		
		Region A	Region B	Region C
		Best two locations		
0.5	3	15.2	17.4	15.1
.5	30	13.7	12.8	12.0
.5	300	16.4	13.8	14.6
5	3	11.8	14.5	11.4
5	30	10.8	10.8	9.6
5	300	15.0	14.7	14.3
25	3	9.9	12.3	9.3
25	30	9.7	10.6	9.3
25	300	14.7	15.6	14.8
		All six locations		
0.5	3	21.4	22.2	21.4
.5	30	20.7	17.8	18.6
.5	300	23.9	19.8	21.4
5	3	17.4	19.3	17.3
5	30	16.6	14.3	14.8
5	300	22.0	20.2	20.5
25	3	[2]16.2	16.7	[2]15.2
25	30	14.5	13.8	13.7
25	300	21.2	20.7	20.5

[1] Applies to current (1993) network at 10-year planning horizon and 15-year peak flow. One percent reduction in error is the error percentage of the current (1993) network that would be reduced if indicated number of new gaging stations were added.

[2] One discontinued gaging station included prior to inclusion of final six new gaging stations.

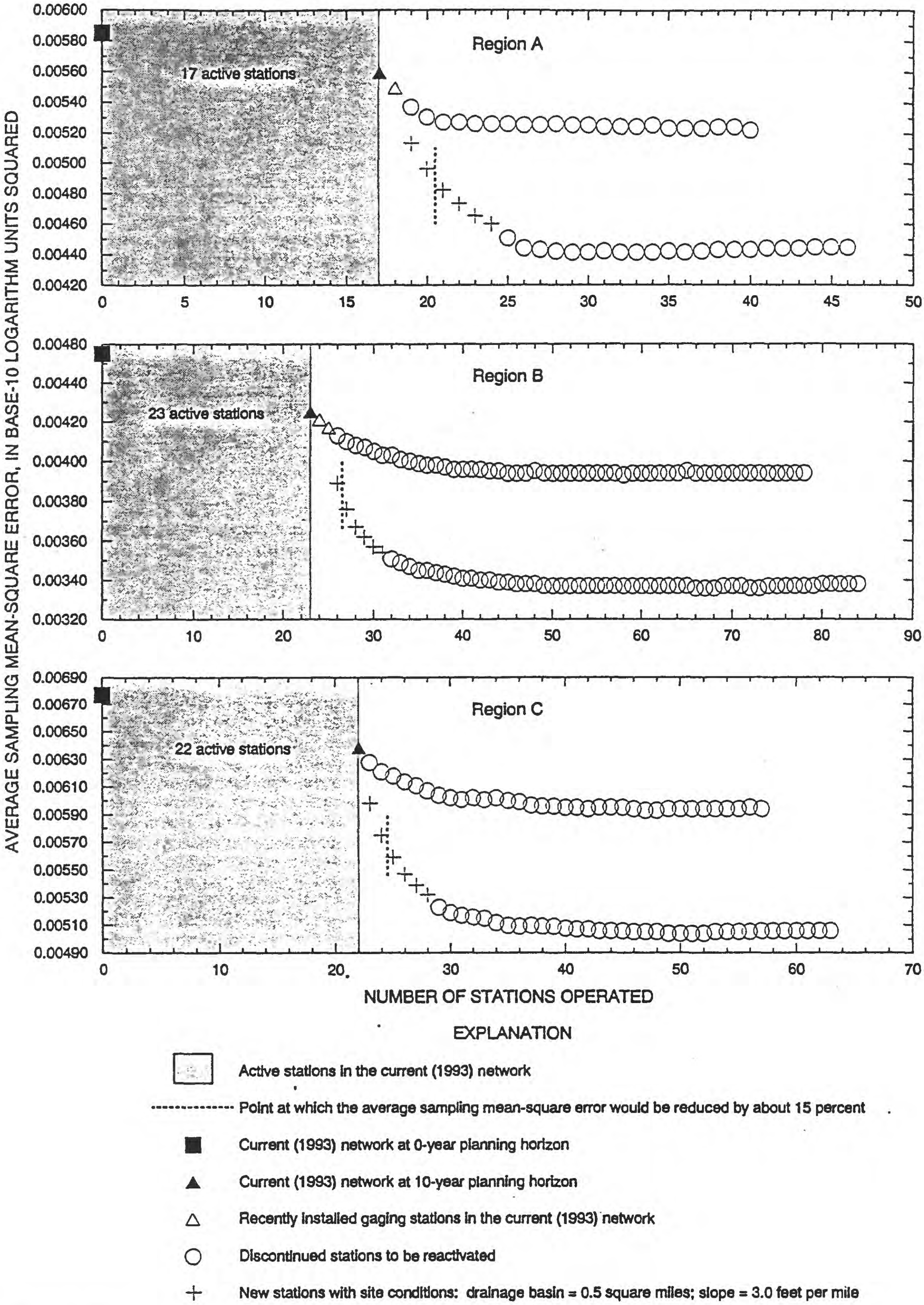

Figure 6. Example of the network sensitivity analysis in hydrologic regions A, B, and C to provide regional information on 15-year peak flow in North Dakota.

SUMMARY

A network analysis technique using generalized least-squares regression was used to evaluate the current (1993) peak-flow gaging network in North Dakota. The analysis was conducted to determine the effectiveness of the 1993 network in providing regional peak-flow information and to evaluate the potential improvements in the effectiveness of the 1993 network by reactivating discontinued gaging stations and adding new gaging stations on small drainage areas to provide improved regional peak-flow information. A network analysis that addresses the effect on the regional information that might be obtained from improved regression equations has not been attempted since the 1970's.

The network analysis was performed for three hydrologic regions using peak flows having recurrence intervals of 15, 50, and 100 years. Zero-year and 10-year planning horizons were considered. Results of the network analysis determined which discontinued gaging stations, if reactivated, would contribute most to reducing the average sampling mean-square error for the indicated recurrence intervals and planning horizons. If the current (1993) network with no additional gaging stations is continued for 10 additional years, the reduction in the average sampling mean-square error would range from 4.6 to 6.9 percent among the three hydrologic regions. The average sampling mean-square error of the current (1993) network would be reduced by about 10 percent for the 15-, 50-, and 100-year recurrence intervals by reactivating a minimum of two to three discontinued gaging stations in region A, two discontinued gaging stations in region B, and two to five discontinued gaging stations in region C. Results of the network analysis indicate that to obtain improved regional peak-flow information, emphasis should be on reactivating discontinued gaging stations in the current (1993) network that are located on streams having small drainage areas and steep main-channel slopes.

A network sensitivity analysis was performed to evaluate drainage area, main-channel slope, and location of gaging stations in reducing the average sampling mean-square error of the current (1993) network. For the 15-year recurrence interval and a 10-year planning horizon, adding a new gaging station at two new locations in each region instead of reactivating two discontinued gaging stations in each region would reduce the average sampling mean-square error by an average of about 13 percent in each region. Results of the sensitivity analysis indicate that adding new gaging stations with small drainage areas and mild or steep main-channel slopes would provide improved peak-flow information.

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Supplement 1. Selected information for the gaging stations used in the study

[D, discontinued; A, active; --, no data]

Map number	Station number	Station name	Status	Period of record used	Drainage area (square miles) Total	Drainage area (square miles) Contributing	Main-channel slope (feet per mile)
		Hydrologic region A					
20	05056900	Sheyenne River tributary near Cooperstown, N. Dak.	D	1959-73	15.2	15.2	29.0
21	05056950	Sheyenne River tributary no. 2 near Cooperstown, N. Dak.	D	1959-73	.08	.08	300.0
23	05059600	Maple River near Hope, N. Dak.	A	1965-93	20.2	17.4	11.0
29	05060500	Rush River at Amenia, N. Dak.	A	1947-93	116	116	3.5
30	05062200	Elm River near Kelso, N. Dak.	D	1956-73, 1981-86	194	194	5.5
31	05064900	Beaver Creek near Finley, N. Dak.	A	1965-93	148	98.0	7.2
32	05065500	Goose River near Portland, N. Dak.	D	1940-76, 1982-88	517	407	7.0
33	05082600	English Coulee tributary near Grand Forks, N. Dak.	D	1955-73, 1984	4.7	4.7	3.4
[1]34	05082625	Turtle River at Turtle River State Park near Arvilla, N. Dak.	A	1993	311	311	11.3
35	05082680	Saltwater Coulee tributary near Emerado, N. Dak.	D	1955-67, 1969-73	22.0	22.0	17.0
36	05082700	Saltwater Coulee near Emerado, N. Dak.	D	1950, 1955-73	110	110	12.0
37	05082900	Freshwater Coulee near Emerado, N. Dak.	D	1955-73	31.0	31.0	6.4
38	05083000	Turtle River at Manvel, N. Dak.	A	1946-70, 1972-73, 1980-90, 1993	613	556	7.8
39	05083600	Middle Branch Forest River near Whitman, N. Dak.	D	1961-90	47.7	38.6	4.5
40	05084000	Forest River near Fordville, N. Dak.	A	1940-93	456	336	11.0
41	05085000	Forest River at Minto, N. Dak.	A	1882, 1897, 1907, 1916, 1944-93	740	620	10.0
42	05088000	South Branch Park River near Park River, N. Dak.	D	1940-50	214	214	8.3
43	05089100	Middle Branch Park River near Union, N. Dak.	D	1966-86	15.3	15.3	21.0
44	05089200	North Branch Park River at Gardar, N. Dak.	D	1955-74	51.8	51.8	19.0
45	05089500	Cart Creek at mountain, N. Dak.	D	1954-84	16.9	16.9	58.0
46	05089700	Cart Creek at Crystal, N. Dak.	D	1955-74	74.0	74.0	12.0
47	05089800	Cart Creek tributary near Crystal, N. Dak.	D	1955-73	3.80	3.80	6.4
48	05090000	Park River at Grafton, N. Dak.	A	1897, 1916, 1932-93	695	695	6.5
49	05092200	Pembina County drain 20 near Glasston, N. Dak.	D	1972-86	80.0	80.0	5.3
50	05098700	Hidden Island Coulee near Hansboro, N. Dak.	A	1962-93	26.2	23.4	8.6

Supplement 1. Selected information for the gaging stations used in the study—Continued

[D, discontinued; A, active; --, no data]

Map number	Station number	Station name	Status	Period of record used	Drainage area (square miles)		Main-channel slope (feet per mile)
					Total	Contributing	
		Hydrologic region A—Continued					
51	05098800	Cypress Creek near Sarles, N. Dak.	D	1962-88	57.2	51.2	1.0
52	05098820	Cypress Creek above International Boundary near Sarles, N. Dak.	A	1989-93	83.0	83.0	4.3
[2]53	05099100	Snowflake Creek near Snowflake, Manitoba	A	1961-93	377	94.4	--
[2]54	05099150	Mowbray Creek near Mowbray, Manitoba	A	1962-93	101	65.7	--
55	05099400	Little Pembina River near Walhalla, N. Dak.	D	1956-82	182	172	11.6
[3]56	05101000	Tongue River at Akra, N. Dak.	A	1939-46, 1948-93	160	160	21.7
66	05122500	Willow Creek at Dunseith, N. Dak.	D	1954-73	142	91.0	36.4
67	05123300	Oak Creek tributary near Bottineau. N. Dak.	D	1955, 1959-73	3.10	3.10	58.3
68	05123350	Oak Creek tributary no. 5 near Bottineau, N. Dak.	D	1959-73	.56	.56	135.0
69	05123500	Stone Creek near Kramer, N. Dak.	D	1986-93	168	168	8.0
76	05123900	Boundary Creek near Landa, N. Dak.	A	1958-81, 1985-93	230	170	5.9
164	05060800	Buffalo River near Callaway, Minn.	A	1960-93	94.5	94.5	6.0
168	05062500	Wild Rice River at Twin Valley, Minn.	A	1909-17, 1931-93	888	888	7.2
[4]169	05062700	Wild Rice River tributary near Twin Valley, Minn.	D	1961-85	4.72	4.72	17.9
[4]170	05062800	Coon Creek near Twin Valley, Minn.	D	1962-84	50.8	50.8	15.2
171	05067500	Marsh River near Shelly, Minn.	A	1944-93	151	151	3.2
172	05069000	Sand Hill River at Climax, Minn.	A	1943-93	426	426	7.2
173	05076000	Thief River near Thief River Falls, Minn.	A	1909-17, 1919-26, 1929-93	959	959	1.0
[4]174	05076600	Red Lake River tributary near Thief River Falls, Minn.	D	1962-81	2.33	2.33	5.7
175	05087500	Middle River at Argyle, Minn.	A	1945, 1950-93	265	265	7.5
[4]176	05095500	Two Rivers below Hallock, Minn.	D	1945-55	644	644	5.4
[4]177	05096000	North Branch Two Rivers near Lancaster, Minn.	D	1930-38, 1941-55	32.0	32.0	4.8

Supplement 1. Selected information for the gaging stations used in the study—Continued

[D, discontinued; A, active; --, no data]

Map number	Station number	Station name	Status	Period of record used	Drainage area (square miles) Total	Drainage area (square miles) Contributing	Main-channel slope (feet per mile)
		Hydrologic region B					
77	06329597	Charbonneau Creek near Charbonneau, N. Dak.	D	1967-81	149	149	9.0
78	06329700	Painted Woods Creek tributary near Williston, N. Dak.	D	1955-73	.37	.37	80.0
79	06329800	Painted Woods Creek near Williston, N. Dak.	D	1955-73	17.0	17.0	35.0
80	06329900	Painted Woods Creek tributary no. 2 near Williston, N. Dak.	D	1955-73	8.30	8.30	30.0
81	06330100	Sand Creek near Williston, N. Dak.	D	1955-73	38.0	38.0	20.0
82	06331000	Little Muddy Creek below Cow Creek near Williston, N. Dak.	A	1955-93	875	775	8.3
83	06331900	White Earth River tributary near Tioga, N. Dak.	D	1960-73	9.60	9.60	29.0
84	06332000	White Earth River at White Earth, N. Dak.	D	1955-81	780	490	7.4
85	06332150	White Earth River tributary near White Earth, N. Dak.	D	1960-73	.32	.32	35.0
86	06332515	Bear Den Creek near Mandaree, N. Dak.	A	1967-93	74.0	74.0	16.5
87	06332520	Shell Creek near Parshall, N. Dak.	D	1966-81	465	145	2.6
[1]88	06332770	Deepwater Creek at mouth near Raub, N. Dak.	A	1992-93	220	220	10.7
89	06335000	Little Beaver Creek near Marmarth, N. Dak.	D	1939-79	587	587	11.4
90	06335700	Deep Creek near Bowman, N. Dak.	D	1955-73	.29	.20	190
91	06336100	Sheep Creek tributary near Medora, N. Dak.	D	1955-65, 1968-73	.29	.29	129
92	06336200	Sheep Creek tributary no. 2 near Medora, N. Dak.	D	1958-73	.42	.42	91.0
93	06336300	Little Missouri River tributary near Medora, N. Dak.	D	1955-73	.32	.32	195
94	06336400	Jules Creek near Medora, N. Dak.	D	1955-73	3.80	3.80	36.5
[4]95	06336450	Spring Creek near Wibaux, Mont.	D	1956-60, 1962-73	4.00	4.00	74.0
[4]96	06336500	Beaver Creek at Wibaux, Mont.	D	1938-44, 1946, 1948-67, 1969, 1979-83	351	351	5.0
97	06336600	Beaver Creek near Trotters, N. Dak.	A	1978-93	616	616	5.7
98	06336980	Little Missouri River tributary near Watford City, N. Dak.	D	1960-73	2.10	2.10	59.0
99	06337100	Spring Creek near Watford City, N. Dak.	D	1960-73	22.7	22.7	18.0
100	06337600	East Branch Douglas Creek tributary near Garrison, N. Dak.	D	1957, 1959-73	1.39	1.39	53.0
101	06337900	Snake Creek tributary near Garrison, N. Dak.	D	1959-73	1.22	1.22	17.0

Supplement 1. Selected information for the gaging stations used in the study—Continued

[D, discontinued; A, active; --, no data]

Map number	Station number	Station name	Status	Period of record used	Drainage area (square miles) Total	Drainage area (square miles) Contributing	Main-channel slope (feet per mile)
		Hydrologic region B—Continued					
102	06339100	Knife River at Manning, N. Dak.	A	1968-93	205	205	7.2
103	06339300	Knife River at Marshall, N. Dak.	D	1971-81	722	722	4.5
104	06339490	Elm Creek near Golden Valley, N. Dak.	A	1968-93	82.0	82.0	7.3
105	06339560	Brush Creek near Beulah, N. Dak.	D	1975-90	23.9	23.9	16.5
106	06340000	Spring Creek at Zap, N. Dak.	A	1924, 1946-93	549	549	3.3
107	06340200	West Branch Otter Creek near Beulah, N. Dak.	A	1965-93	26.5	26.5	16.4
108	06340528	West Branch Antelope Creek no. 4 near Zap, N. Dak.	D	1977-86	8.46	8.46	32.2
109	06340905	Coal Lake Coulee near Hensler, N. Dak.	D	1978-88	70.5	17.2	32.9
110	06341400	Turtle Creek near Turtle Lake, N. Dak.	D	1957-76	310	115	2.1
111	06341410	Turtle Creek above Washburn, N. Dak.	A	1987-93	350	155	3.0
112	06341800	Painted Woods Creek near Wilton, N. Dak.	A	1958-81, 1983-93	427	117	3.5
113	06342050	Square Butte Creek at Center, N. Dak.	D	1956-73	56.8	56.8	15.6
114	06342100	Square Butte Creek tributary no. 2 near Center, N. Dak.	D	1955-72	13.0	13.0	28.0
115	06342150	Square Butte Creek tributary near Center, N. Dak.	D	1955-73	.19	.19	158.0
116	06342250	Square Butte Creek tributary no. 3 near Center, N. Dak.	D	1956-73	1.68	1.68	59.8
117	06342300	Burnt Creek tributary near Baldwin, N. Dak.	D	1956-73	2.98	2.98	43.8
118	06342350	Burnt Creek tributary no. 2 near Baldwin, N. Dak.	D	1956-73	2.12	2.12	67.9
119	06342450	Burnt Creek near Bismarck, N. Dak.	A	1968-93	108	108	10.5
120	06343000	Heart River near South Heart, N. Dak.	A	1947-72, 1978-93	315	315	3.1
121	06343200	Heart River tributary near South Heart, N. Dak.	D	1955-73	.13	.13	148
122	06344200	Heart River tributary near Dickinson, N. Dak.	D	1955-73	1.72	1.72	32.6
123	06344600	Green River near New Hradec, N. Dak.	A	1964-93	152	152	6.8
124	06345000	Green River near Gladstone, N. Dak.	D	1946-76	356	356	3.0
125	06345100	Antelope Creek near Dickinson, N. Dak.	D	1955-73	69.2	69.2	15.0
126	06345200	Antelope Creek tributary near New England, N. Dak.	D	1955-73	13.0	13.0	25.0

Supplement 1. Selected information for the gaging stations used in the study—Continued

[D, discontinued; A, active; --, no data]

Map number	Station number	Station name	Status	Period of record used	Drainage area (square miles) Total	Drainage area (square miles) Contributing	Main-channel slope (feet per mile)
		Hydrologic region B—Continued					
127	06345300	Antelope Creek tributary no. 2 near New England, N. Dak.	D	1955-73	22.4	22.4	23.0
128	06345700	Government Creek near Richardton, N. Dak.	D	1950, 1955-73	33.4	33.4	12.0
129	06347000	Antelope Creek near Carson, N. Dak.	D	1943, 1949-76	221	221	5.2
130	06347500	Big Muddy Creek near Almont, N. Dak.	A	1946-73, 1991-93	456	456	7.3
131	06348500	Sweetbriar Creek near Judson, N. Dak.	D	1950, 1952-63	157	157	8.7
133	06349200	West Branch Long Lake Creek near Hazelton, N. Dak.	D	1955-58, 1960-73	16.5	16.5	14.6
134	06349215	Long Lake Creek above Long Lake near Moffitt, N. Dak.	A	1989-93	280	280	4.8
135	06350000	Cannonball River at Regent, N. Dak.	A	1950-93	580	580	4.5
136	06351680	White Butte Fork Cedar Creek near Scranton, N. Dak.	A	1965-93	42.9	42.9	9.6
137	06352000	Cedar Creek near Haynes, N. Dak.	A	1950-93	553	553	4.2
138	06353600	Louise Creek tributary near Brisbane, N. Dak.	D	1955-73	.29	.29	64.6
139	06353700	Louise Creek tributary near Lark, N. Dak.	D	1956-73	.79	.76	62.2
140	06353800	Louise Creek tributary no. 2 near Lark, N. Dak.	D	1956-73	7.70	7.70	36.8
141	06353900	Louise Creek above Flasher, N. Dak.	D	1955-73	110	110	16.2
142	06354500	Beaver Creek at Linton, N. Dak.	D	1950-89	717	617	3.0
143	06354580	Beaver Creek below Linton, N. Dak.	A	1990-93	765	665	3.0
144	06354700	Spring Creek near Linton, N. Dak.	D	1955-73	22.9	22.9	20.2
145	06354750	Sand Creek tributary near Hazelton, N. Dak.	D	1960-73	3.00	3.00	24.0
146	06354800	Sand Creek near Temvik, N. Dak.	D	1955-73	23.3	23.3	22.4
[1]147	06354815	Porcupine Creek near Fort Yates, N. Dak.	A	1992-93	220	220	7.6
148	06354900	Spring Creek near Bowman, N. Dak.	D	1955-73	51.2	51.2	20.0
149	06354950	Spring Creek tributary near Bowman, N. Dak.	D	1955-73	11.4	11.4	20.0
150	06355000	North Fork Grand River at Haley, N. Dak.	D	1909, 1912-15, 1917, 1946-66	509	509	4.9
151	06355200	Buffalo Creek tributary near Buffalo Springs, N. Dak.	D	1955-73	3.39	3.39	15.0
152	06355310	Buffalo Creek tributary near Gascoyne, N. Dak.	D	1975-87	15.7	15.4	30.8

Supplement 1. Selected information for the gaging stations used in the study—Continued

[D, discontinued; A, active; --, no data]

Map number	Station number	Station name	Status	Period of record used	Drainage area (square miles) Total	Drainage area (square miles) Contributing	Main-channel slope (feet per mile)
		Hydrologic region B—Continued					
180	06354860	Spring Creek near Herreid, S. Dak.	A	1963-86, 1989-93	440	220	4.7
181	06356000	South Fork Grand River at Buffalo, S. Dak.	A	1956-93	148	148	17.8
[4]182	06358520	Deadman Creek tributary near Mobridge, S. Dak.	D	1956-80	.30	.30	158
[4]183	06358600	South Fork Moreau River tributary near Redig, S. Dak.	D	1956, 1958-80	2.33	2.33	12.6
[4]184	06358620	Sand Creek tributary near Redig, S. Dak.	D	1956, 1958-72	.06	.06	100
[4]192	06181200	Missouri River tributary no. 2 near Brockton, Mont.	D	1962-76	1.60	1.60	86.9
[4]193	06185100	Big Muddy Creek tributary near Culbertson, Mont.	D	1963-77	7.38	7.38	34.5
[4]194	06185200	Missouri River tributary no. 3 near Culbertson, Mont.	D	1963-77	1.23	1.23	82.8
[4]195	06185300	Missouri River tributary no. 4 near Culbertson, Mont.	D	1963-77	11.6	11.6	41.7
196	06185400	Missouri River tributary no. 5 near Culbertson, Mont.	A	1963-93	3.67	3.67	119
[4]197	06326650	O'Fallon Creek tributary near Ismay, Mont.	D	1962-76	.16	.16	198
[4]198	06326700	Deep Creek near Baker, Mont.	D	1962-76, 1978	3.79	3.79	52.9
[4]199	06326800	Pennel Creek near Baker, Mont.	D	1962-91	.86	.86	87.4
200	06326940	Spring Creek tributary near Fallon, Mont.	A	1972-93	3.10	3.10	27.6
[4]201	06326950	Yellowstone River tributary no. 5 near Marsh, Mont.	D	1962-72, 1974-88	.87	.87	109
[4]202	06327700	Griffith Creek near Glendive, Mont.	D	1955-60, 1962-63, 1965-67	15.5	15.5	69.8
[4]203	06328800	Indian Creek at Intake, Mont.	D	1958-73	.46	.46	69.7
[4]204	06328900	War Dance Creek near Intake, Mont.	D	1958-73, 1980	3.69	3.69	62.5
[4]205	06329200	Burns Creek near Savage, Mont.	D	1958-67, 1975-84, 1986	233	233	27.2
206	06329570	First Hay Creek near Sidney, Mont.	A	1963-93	30.0	29.1	11.3
[4]207	06334720	Soda Creek tributary near Webster, Mont.	D	1962-91	2.22	2.22	29.0

Supplement 1. Selected information for the gaging stations used in the study—Continued

[D, discontinued; A, active; --, no data]

Map number	Station number	Station name	Status	Period of record used	Drainage area (square miles)		Main-channel slope (feet per mile)
					Total	Contrib-uting	
		Hydrologic region C					
1	05051600	Wild Rice River near Rutland, N. Dak.	A	1960-76, 1978-80, 1982-93	546	250	2.1
2	05051800	Grass Lake tributary near Lidgerwood, N. Dak.	D	1958-73	.61	.61	10.0
3	05051900	Wild Rice River tributary near Mantador, N. Dak.	D	1958-73	65.0	4.20	24.0
4	05052500	Antelope Creek near Dwight, N. Dak.	D	1944-47, 1949-73, 1975	293	278	3.4
5	05054500	Sheyenne River above Harvey, N. Dak.	A	1956-93	424	154	3.0
6	05055000	Sheyenne River near Harvey, N. Dak.	D	1943, 1946-56	534	173	2.7
7	05055100	North Fork Sheyenne River near Wellsburg, N. Dak.	D	1958-67	693	203	4.0
8	05055200	Big Coulee near Maddock, N. Dak.	D	1957-67, 1969-73	140	97.0	3.3
9	05055520	Big Coulee near Fort Totten, N. Dak.	D	1966-75	23.2	7.70	19.0
10	05056020	Mauvais Coulee tributary near Bisbee, N. Dak.	D	1955-73	8.90	8.90	9.0
11	05056040	Mauvais Coulee tributary no. 2 near Cando, N. Dak.	D	1955-73	17.1	17.1	7.1
12	05056060	Mauvais Coulee tributary no. 3 near Cando, N. Dak.	A	1955-73, 1989-93	129	60.2	11.0
13	05056080	Mauvais Coulee tributary no. 4 near Bisbee, N. Dak.	D	1955-73	59.6	53.0	10.0
14	05056100	Mauvais Coulee near Cando, N. Dak.	A	1957-93	387	377	5.1
15	05056200	Edmore COulee near Edmore, N. Dak.	A	1956-93	382	282	3.5
16	05056215	Edmore Coulee tributary near Webster, N. Dak.	A	1988-93	148	104	1.3
17	05056239	Starkweather Coulee near Webster, N. Dak.	A	1980-93	310	210	3.0
18	05056300	Little Coulee at Leeds, N. Dak.	D	1956-67, 1969-73	280	140	4.2
19	05056390	Little Coulee near Brinsmade, N. Dak.	A	1976-93	350	190	4.3
22	05057200	Baldhill Creek near Dazey, N. Dak.	A	1956-93	691	351	3.0
24	05059700	Maple River near Enderlin, N. Dak.	A	1956-93	843	796	3.0
25	05059800	Swan Creek near Absaraka, N. Dak.	D	1955-73	28.9	28.9	12.0
26	05059850	Swan Creek tributary near Ayr, N. Dak.	D	1955, 1957-73	4.00	4.00	12.9
27	05059900	Swan Creek near Casselton, N. Dak.	D	1955-62, 1964-73	14.0	14.0	10.5
28	05059950	Swan Creek tributary near Casselton, N. Dak.	D	1955-73	56.6	14.1	7.7

Supplement 1. Selected information for the gaging stations used in the study—Continued

[D, discontinued; A, active; --, no data]

Map number	Station number	Station name	Status	Period of record used	Drainage area (square miles) Total	Drainage area (square miles) Contributing	Main-channel slope (feet per mile)
		Hydrologic region C—Continued					
57	05113450	Long Creek tributary no. 2 near Crosby, N. Dak.	D	1960-73	6.70	5.60	15.0
58	05113520	Long Creek tributary near Crosby, N. Dak.	D	1960-70, 1972-73	.40	.40	18.0
[2]59	05113800	Short Creek below international boundary near Roche Percee, Saskatchewan	A	1960-77, 1979-93	466	125	--
60	05116100	Souris River tributary near Burlington, N. Dak.	D	1959-73	.13	.13	270
61	05116200	Des Lacs River tributary near Donnybrook, N. Dak.	D	1956-73	3.82	3.82	113
62	05116550	Fuller Coulee at Foxholm, N. Dak.	D	1955-73	5.90	5.90	49.0
63	05117200	Souris River tributary no. 2 near Burlington, N. Dak.	D	1960-73	2.04	2.04	60.0
64	05119410	Bonnes Coulee at Velva, N. Dak.	A	1987-93	53.0	53.0	21.0
65	05120500	Wintering River near Karlsruhe, N. Dak.	A	1937-93	705	285	3.7
70	05123510	Deep River near Upham, N. Dak.	A	1951, 1958-80, 1985-93	975	369	2.4
71	05123520	Egg Creek near Glenburn, N. Dak.	D	1955-73	20.9	7.00	4.4
72	05123540	Egg Creek near Ruthville, N. Dak.	D	1955-73	108	26.0	5.2
73	05123560	Egg Creek tributary near Deering, N. Dak.	D	1955-73	4.20	2.80	6.0
74	05123580	Egg Creek near Deering, N. Dak.	D	1956-73	136	43.6	4.2
75	05123600	Egg Creek near Granville, N. Dak.	D	1957-81	289	143	3.6
132	06349100	Dead Buffalo Lake tributary near Steele, N. Dak.	D	1960-73	5.90	5.90	17.0
153	06467600	James River near Manfred, N. Dak.	A	1955-93	253	56.0	6.4
154	06467650	James River tributary near Manfred, N. Dak.	D	1955-61, 1963-73	90.2	39.4	4.4
155	06467800	James River tributary no. 3 near Manfred, N. Dak.	D	1955-73	23.5	20.6	5.8
156	06467900	Big Slough at Hamberg, N. Dak.	D	1958-68, 1970-75	60.0	42.0	3.1
157	06469400	Pipestem Creek near Pingree, N. Dak.	A	1974-93	700	260	2.5
158	06469500	Pipestem Creek near Buchanan, N. Dak.	D	1950-74	758	298	2.3
159	06469600	Minneapolis Flats Creek tributary near Eldridge, N. Dak.	D	1955-68, 1970-73	9.91	9.91	30.9
160	06470200	Beaver Creek tributary near Eldridge, N. Dak.	D	1955-73	.19	.19	48.6
161	06470300	Beaver Creek near Sydney, N. Dak.	D	1955-73	224	62.0	14.1

Supplement 1. Selected information for the gaging stations used in the study—Continued

[D, discontinued; A, active; --, no data]

Map number	Station number	Station name	Status	Period of record used	Drainage area (square miles) Total	Drainage area (square miles) Contributing	Main-channel slope (feet per mile)
		Hydrologic region C—Continued					
162	06470400	Buffalo Creek tributary near Sydney, N. Dak.	D	1955-73	23.7	11.3	20.9
163	06470800	Bear Creek near Oakes, N. Dak.	A	1977-93	369	114	2.9
165	05061200	Whiskey Creek at Barnesville, Minn.	A	1961-93	62.5	25.3	18.6
166	05061400	Hay Creek above Downer, Minn.	A	1961-93	5.81	5.81	16.0
167	05061500	South Branch Buffalo River at Sabin, Minn.	A	1945-93	522	522	13.8
178	05290000	Little Minnesota River near Peever, S. Dak.	A	1940-81, 1990-93	447	447	3.2
179	05291000	Whetstone River near Big Stone City, S. Dak.	A	1910-12, 1931-93	389	389	10.9
[4]185	06471050	Elm River tributary near Leola, S. Dak.	D	1956-80	18.0	18.0	32.3
186	06471200	Maple River at North Dakota-South Dakota State Line	A	1957-93	750	480	4.8
[4]187	06471350	Maple River at Frederick, S. Dak.	D	1956-69	822	552	4.1
[4]188	06471400	Willow Creek tributary near Leola, S. Dak.	D	1956-80	6.69	6.69	10.0
[4]189	06472200	Mud Creek tributary near Groton, S. Dak.	D	1960-69, 1974-80	65.5	56.7	20.5
[4]190	06472250	Mud Creek tributary no. 2 near Groton, S. Dak.	D	1960-80	84.6	75.8	19.4
[4]191	06472500	Mud Creek near Stratford, S. Dak.	D	1956-73, 1977	730	460	5.4
		Current crest-stage gages (not used in analyses)					
--	05082500	Red River of the North at Grand Forks, N. Dak.	A	1882-1983, 1987-93	30,100	--	--
--	05083500	Red River of the North at Oslo, Minn.	A	1936-37, 1941-43, 1945-60, 1985-93	31,200	--	--
--	05102490	Red River of the North at Pembina, N. Dak.	A	1985-93	40,200	--	--

[1]Stations not used in the generalized least-squares regression analysis, but used in the network analysis.

[2]Stations not used in the analyses.

[3]Only unregulated period, 1939-46 and 1948-54, was used in the generalized least-squares regression analysis.

[4]Stations not used in the network analysis, but used to update the generalized least-squares regression analysis.