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Evaluation of Drainage-Area Ratio Method Used to Estimate Streamflow for the Red River of the North Basin, North Dakota and Minnesota

Scientific Investigations Report 2005–5017

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

Emerson, Vecchia, and Dahl—**Evaluation of Drainage-Area Ratio Method Used to Estimate Streamflow for the Red River of the North Basin, North Dakota and Minnesota**—Scientific Investigations Report 2005–5017

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Contents

Figures

Tables

Conversion Factors and Datum

Multiply	By	To obtain
	Length	
inch	25.4	millimeter
foot	0.3048	meter
mile	1.609	kilometer
	Area	
square mile	2.590	square kilometer
	Flow rate	
cubic foot per second	0.02832	cubic meter per second
	Hydraulic gradient	
foot per mile	0.1894	meter per kilometer

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Altitude, as used in this report, refers to distance above the vertical datum.

Evaluation of Drainage-Area Ratio Method Used to Estimate Streamflow for the Red River of the North Basin, North Dakota and Minnesota

By Douglas G. Emerson, Aldo V. Vecchia, and Ann L. Dahl

Abstract

The drainage-area ratio method commonly is used to estimate streamflow for sites where no streamflow data were collected. To evaluate the validity of the drainage-area ratio method and to determine if an improved method could be developed to estimate streamflow, a multiple-regression technique was used to determine if drainage area, main channel slope, and precipitation were significant variables for estimating streamflow in the Red River of the North Basin. A separate regression analysis was performed for streamflow for each of three seasons--winter, spring, and summer. Drainage area and summer precipitation were the most significant variables. However, the regression equations generally overestimated streamflows for North Dakota stations and underestimated streamflows for Minnesota stations. To correct the bias in the residuals for the two groups of stations, indicator variables were included to allow both the intercept and the coefficient for the logarithm of drainage area to depend on the group. Drainage area was the only significant variable in the revised regression equations. The exponents for the drainage-area ratio were 0.85 for the winter season, 0.91 for the spring season, and 1.02 for the summer season.

Introduction

Many water-management programs require streamflow data for sites where no data were collected or for streamflow-gaging stations for periods during which the gage was not operated. For example, the Bureau of Reclamation needs estimated monthly streamflow data for the Red River Water Supply Project because the periods of record for the continuous-record streamflow-gaging stations in the Red River of the North Basin vary (Burr and others, 2003; Harkness and others, 2003; Mitton and others, 2003). Methods used to estimate streamflow for sites where no streamflow data were collected include the drainage-area ratio method, regional statistics, regression, and precipitation-runoff modeling. For partial-record streamflow-gaging stations, record extension methods, such as maintenance of variance extension type 1 (MOVE.1), can be used to extend the streamflow record (Hirsch, 1982).

Hirsch (1979) evaluated the drainage-area ratio method, regional regression equations, linear regression equations, and log-log regression equations to reconstruct streamflow records and noted that "...log regressions appear superior to the linear. The regional statistics method is distinctly superior to the drainage area ratio method, but comparison between the regional statistics and the log regression method is ambiguous." Hirsch (1979) also noted that the drainage-area ratio method works relatively well if streams have similar flow characteristics. However, if streamflow is being estimated for an ungaged site, especially if no gaged data are available for the stream on which the site is located, then the flow characteristics probably are unknown and how well the drainage-area ratio method works also is unknown.

The drainage-area ratio method was used extensively in several studies (Wiche and others, 1989; Guenthner and others, 1990; Emerson and Dressler, 2002) to estimate monthly streamflow for North Dakota and Minnesota. The method is easy to use, requires little data, does not require any development, and, many times, is the only method available because regional statistics or precipitation-runoff models have not been developed. Therefore, to evaluate the validity of the drainage-area ratio method and to determine if an improved method could be developed to estimate streamflow, the U.S. Geological Survey, in cooperation with the Bureau of Reclamation, conducted a study to evaluate the drainage-area ratio method for the Red River of the North Basin in North Dakota and Minnesota. The evaluation of the drainage-area ratio method for the Red River of the North Basin is described in this report. A multiple regression technique was used to determine if drainage area, main channel slope, and precipitation were significant variables for estimating streamflow. Monthly streamflows for 27 streamflow-gaging stations (fig. 1) in the Red River of the North Basin were used in the study. The streamflow-gaging stations were selected on the basis of minimum streamflow regulation, and the period of record for each station was 1971 through 2000. Precipitation

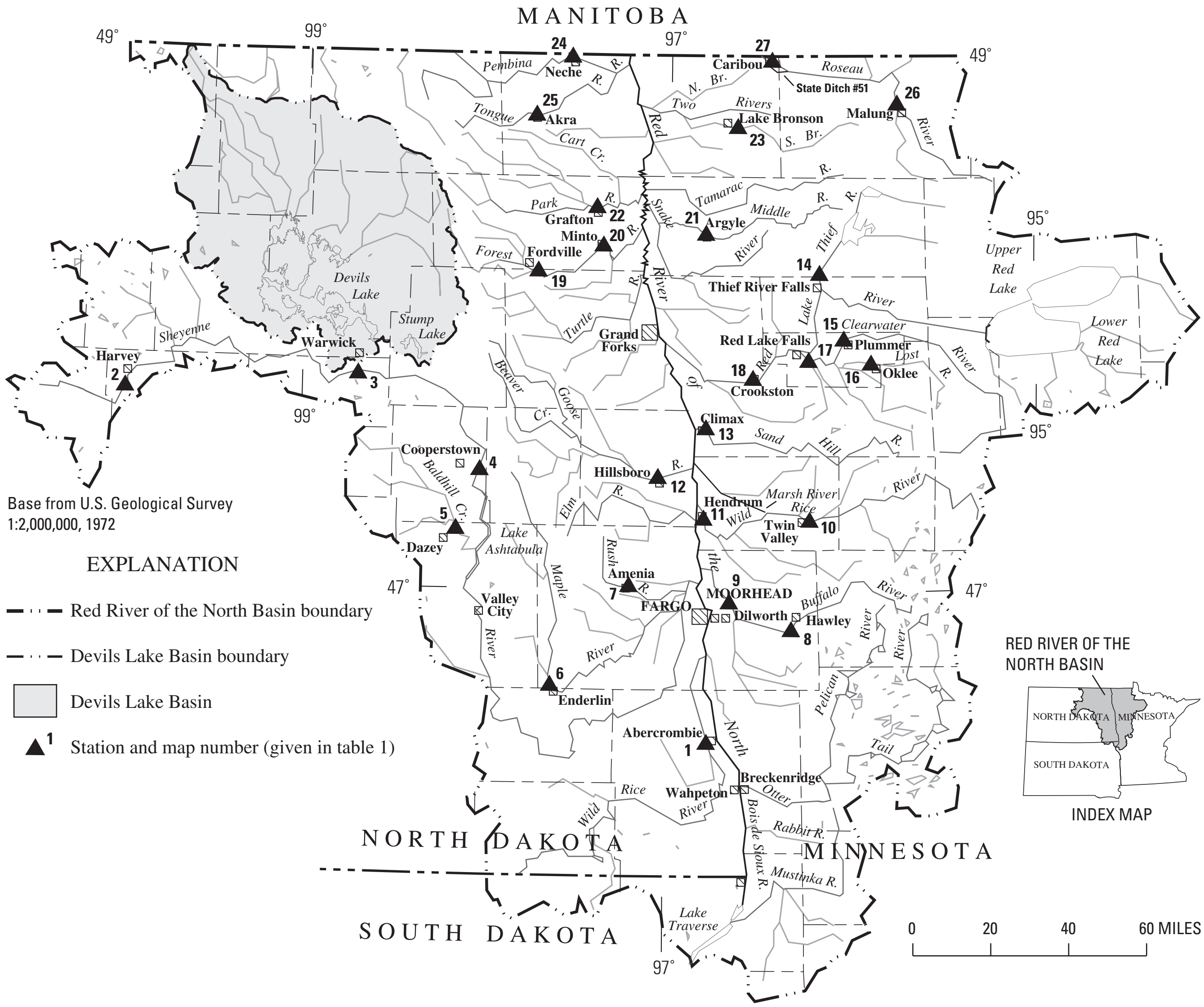

Figure 1. Locations of streamflow-gaging stations used in study.

data for 90 sites for which the periods of record also were 1971 through 2000 also were used in the study.

Description of Red River of the North Basin

The Red River of the North (fig. 1), which begins at the confluence of the Bois de Sioux and Otter Tail Rivers, flows northward and drains parts of North Dakota, South Dakota, and Minnesota before entering Canada. The Red River of the North Basin has relatively little topographic relief. Altitudes in the basin range from about 2,350 feet in the extreme western part of the basin to about 750 feet where the river enters Canada. The relatively little topographic relief was caused by glaciation and geologically recent erosion. Glacial Lake Agassiz formed a flat lake plain along the axis of the Red River of the North, and ice sheets advanced and recessed to leave upland moraines and glacial drift that extended east and west of the lake plain. The slope of the main stem of the Red River of the North is nearly flat; the river drops only about 200 feet in a 394-mile course from its beginning to the United States-Canada border. The slope of the main stem ranges from 1.3 feet per mile at Wahpeton, N. Dak., to 0.2 foot per mile at the border. The drainage area of the Red River of the North Basin at the border is about 36,400 square miles. The drainage area does not include the noncontributing Devils Lake Basin.

Drainage-Basin Characteristics

Topographic and meteorologic characteristics of a drainage basin affect streamflow from the basin. The characteristics that were used in this study to evaluate the drainage-area ratio method were drainage area, main channel slope, and precipitation. If available, the noncontributing drainage area was excluded and only the contributing drainage area was used. The main channel slope that was used was the slope, as defined by Benson (1962), that is between points that are 85 and 10 percent upstream from the site of interest. The drainage area and the main channel slope for the streamflow-gaging stations used in this study were obtained from the U.S. Geological Survey's basin characteristics file, Williams-Sether (1992), or Lorenz and others (1997). The precipitation data used in this study were obtained from the U.S. Department of Commerce, National Climatic Data Center (2002). Data for 1971 through 2000 were used to compute mean annual winter/spring precipitation and mean annual summer precipitation for each of 90 sites in or near the Red River of the North Basin. Winter/spring precipitation was defined as the average precipitation for January, February, March, April, May, November, and December. Those months were chosen to represent the months for which snowfall accumulation and precipitation would affect spring streamflow. Summer precipitation was defined as the average precipitation for June, July, August, September, and October. Those months were chosen to represent the months for which rainfall would affect summer streamflow. After the winter/spring and summer precipitation was computed for each site, a geographic information system (GIS) was used to develop isohyetal maps of the mean annual winter/spring precipitation (fig. 2) and the mean annual summer precipitation (fig. 3). The National Elevation Dataset (U.S. Geological Survey, 2003) was used to estimate the area of the basin upstream from each of the 27 streamflow-gaging stations, and the estimated area then was used with the isohyetal maps to calculate the area-weighted mean precipitation for each basin (table 1).

Evaluation of Drainage-Area Ratio Method

The drainage-area ratio method is based on the assumption that the streamflow for a site of interest can be estimated by multiplying the ratio of the drainage area for the site of interest and the drainage area for a nearby streamflow-gaging station by the streamflow for the nearby streamflow-gaging station. Thus, the drainage-area ratio method is given by

$$\tilde{Y}_{ij} = \left(\frac{A_y}{A_x}\right) X_{ij} \tag{1}$$

where

$\tilde{Y}_{ij}$ is the estimated streamflow, in cubic feet per second, for month i and year j for the site of interest;

A_y is the drainage area, in square miles, for the site of interest;

A_x is the drainage area, in square miles, for the streamflow-gaging station; and

X_{ij} is the streamflow, in cubic feet per second, for month i and year j for the streamflow-gaging station.

For the drainage-area ratio method (eq. 1), the assumption is made that the exponent of $\left(\frac{A_y}{A_x}\right)$ is 1. To test this assumption, the drainage areas for the 27 streamflow-gaging stations were used in equation 1 to estimate streamflow. To simplify the evaluation and to determine if the estimated streamflow was an unbiased estimate of the actual streamflow, the average streamflow for various seasons for the period of record (1971-2000) was used rather than the streamflow for individual months. Thus, estimated streamflow for a particular season and period of record is given by

$$\tilde{Y}_M = \left(\frac{A_y}{A_x}\right) X_M \tag{2}$$

where

$\tilde{Y}_M$ is $\mathrm{Ave}\{\tilde{Y}_{ij};\ i \in M,\ 1971 \le j \le 2000\}$, and

X_M is $\mathrm{Ave}\{X_{ij};\ i \in M,\ 1971 \le j \le 2000\}$.

Ave { } denotes the average of the values in the braces, and M is a collection of months defining the season of interest.

To test the validity of equation 2 and to determine if the use of main channel slope and precipitation would give a better estimate of streamflow, the following general equation was developed:

$$\hat{Y}_M = \left(\frac{A_y}{A_x}\right)^{\alpha} \left(\frac{P_y}{P_x}\right)^{\beta} \left(\frac{S_y}{S_x}\right)^{\gamma} X_M \tag{3}$$

where

$\hat{Y}_M$ is the estimated seasonal streamflow, in cubic feet per second;

P_y is precipitation, in inches, for the site of interest;

P_x is precipitation, in inches, for the streamflow-gaging station;

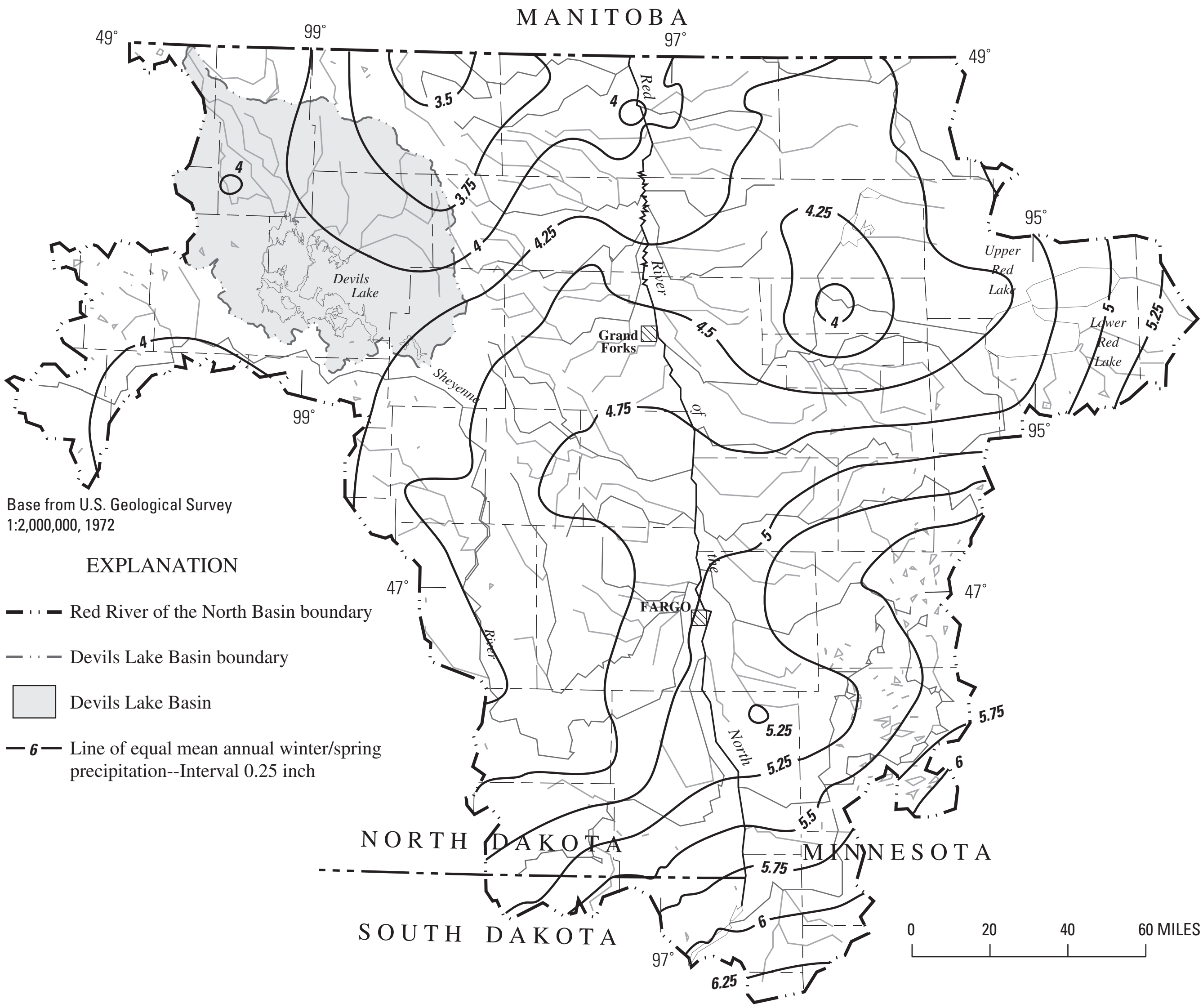

Figure 2. Mean annual winter/spring (January, February, March, April, May, November, and December) precipitation for 1971 through 2000.

S_y is the main channel slope, in feet per mile, for the site of interest;

S_x is the main channel slope, in feet per mile, for the streamflow-gaging station; and

α, β, and γ are coefficients to be estimated.

Equations 2 and 3 are equivalent if $\alpha = 1$, $\beta = 0$, and $\gamma = 0$.

To obtain unbiased estimates of actual seasonal streamflow, the actual seasonal streamflow for the site of interest was expressed as the estimated seasonal streamflow multiplied by an error term:

$$Y_M^{\ *} = \hat{Y}_M 10^{\varepsilon} \tag{4}$$

where

$Y_M^{\ *}$ is the actual seasonal streamflow for the site of interest; and

10^{ε} is a multiplicative error.

If equations 3 and 4 hold (not only for two locations but for a series of nested basins that have drainage areas that range over a continuous interval), then streamflow for both sites X and Y must be represented by the generic equation

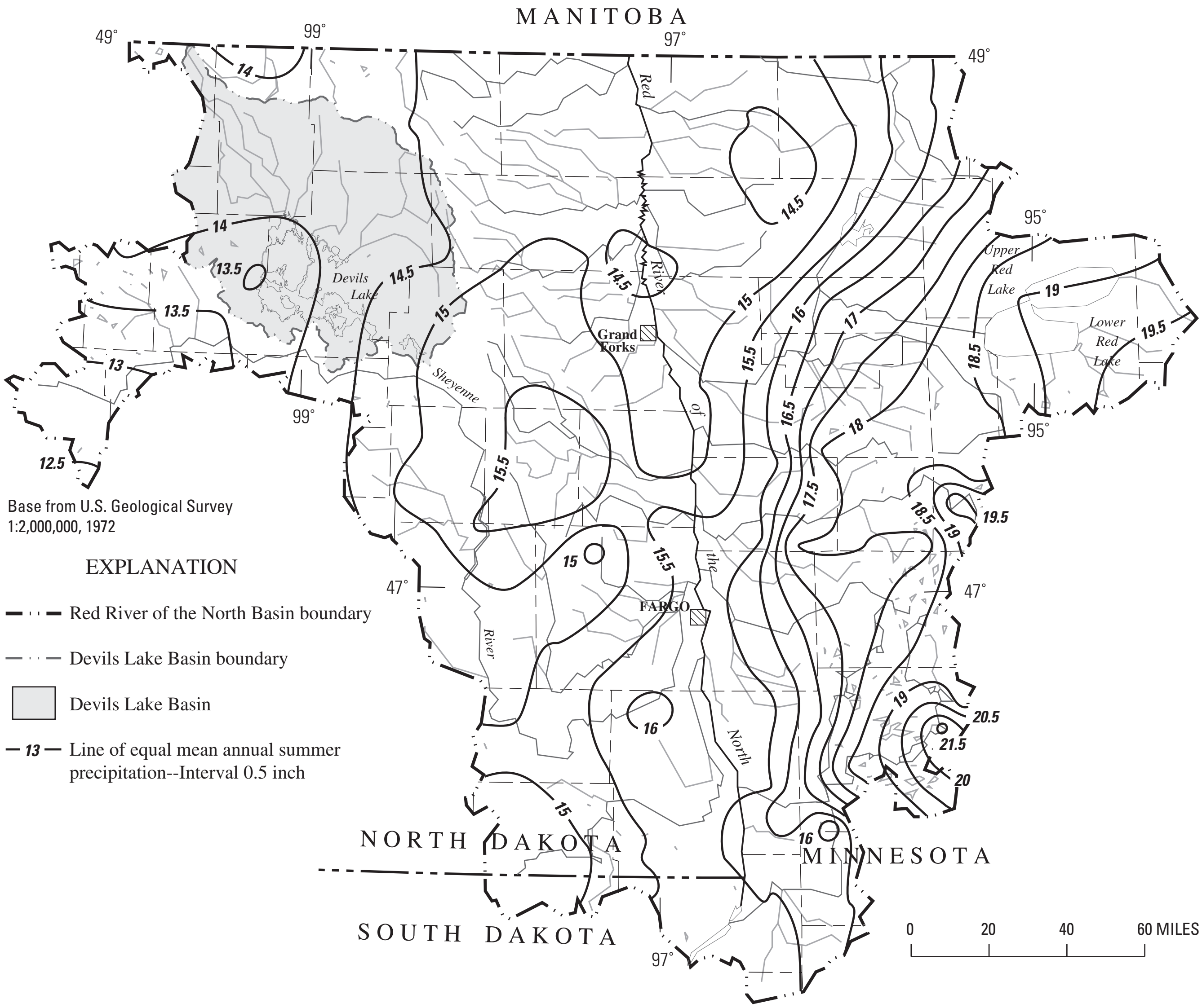

Figure 3. Mean annual summer (June, July, August, September, and October) precipitation for 1971 through 2000.

$$\log Q = C + \alpha \log A + \beta \log P + \gamma \log S + \eta \qquad (5)$$

where

- log denotes base-10 logarithm;
- Q is the streamflow, in cubic feet per second, for site X or Y;
- C is the intercept, a constant;
- A is the drainage area, in square miles, for site X or Y;
- P is precipitation, in inches, for site X or Y;
- S is the main channel slope, in feet per mile, for site X or Y; and
- η is an error that has an expected value of zero.

If equation 5 holds, then equations 3 and 4 (with ε in equation 4 equal to $\eta_y - \eta_x$) must hold as well. However, the reverse also is true--that is, if equations 3 and 4 hold, then equation 5 must hold as well (provided some fairly general conditions are satisfied). Equation 4 can be formulated in terms of a random cascade model (Ghupta and Waymire, 1990; Troutman and Vecchia, 1999), and the only solution that can satisfy the equation for a continuous range of drainage areas is equation 5. The intercept, C, in equation 5 is equal to the limit, as $n \to \infty$, of $\sum_{i=1}^{n} \varepsilon_i$, where the ε_i's are independent, identically distrib-

Table 1. Basin characteristics for 27 streamflow-gaging stations in the Red River of the North Basin, North Dakota and Minnesota.

Map number (figure 1)	Streamflow-gaging station number	Streamflow-gaging station name	Drainage area (square miles)	Main channel slope (feet per mile)	Area-weighted mean winter/spring precipitation (inches)	Area-weighted mean summer precipitation (inches)	Annual streamflow (cubic feet per second)	Winter streamflow (cubic feet per second)	Spring streamflow (cubic feet per second)	Summer streamflow (cubic feet per second)
1	05053000	Wild Rice River near Abercrombie, N. Dak.	1,490	2.1	5.12	15.29	129.43	11.81	366.61	80.83
2	05054500	Sheyenne River above Harvey, N. Dak.	154	3.0	4.04	12.72	14.72	3.24	40.97	8.08
3	05056000	Sheyenne River near Warwick, N. Dak.	760	1.6	4.08	13.46	79.82	12.88	231.24	42.38
4	05057000	Sheyenne River near Cooperstown, N. Dak.	1,270	.8	4.17	13.93	155.27	26.98	417.64	100.45
5	05057200	Baldhill Creek near Dazey, N. Dak.	351	3.0	4.41	14.88	30.48	3.81	92.56	14.54
6	05059700	Maple River near Enderlin, N. Dak.	796	3.0	4.63	15.07	65.69	6.00	192.29	37.18
7	05060500	Rush River at Amenia, N. Dak.	116	3.5	4.63	14.69	15.71	1.58	46.39	8.64
8	05061000	Buffalo River near Hawley, Minn.	325	6.2	5.44	17.71	92.78	37.50	174.80	83.65
9	05062000	Buffalo River near Dilworth, Minn.	975	2.6	5.26	16.85	188.01	52.40	417.12	158.37
10	05062500	Wild Rice River at Twin Valley, Minn.	934	4.2	5.33	18.33	245.55	90.16	498.92	217.31
11	05064000	Wild Rice River at Hendrum, Minn.	1,560	4.4	5.27	17.82	382.60	111.38	860.38	330.22
12	05066500	Goose River at Hillsboro, N. Dak.	1,093	4.1	4.68	15.56	128.21	15.09	377.00	69.51

Table 1. Basin characteristics for 27 streamflow-gaging stations in the Red River of the North Basin, North Dakota and Minnesota.—Continued

Map number (figure 1)	Streamflow-gaging station number	Streamflow-gaging station name	Drainage area (square miles)	Main channel slope (feet per mile)	Area-weighted mean winter/spring precipitation (inches)	Area-weighted mean summer precipitation (inches)	Annual streamflow (cubic feet per second)	Winter streamflow (cubic feet per second)	Spring streamflow (cubic feet per second)	Summer streamflow (cubic feet per second)
13	05069000	Sand Hill River at Climax, Minn.	420	4.8	4.81	16.90	95.82	26.64	233.12	71.70
14	05076000	Thief River near Thief River Falls, Minn.	985	1.9	4.41	16.50	226.78	40.33	480.41	221.84
15	05078000	Clearwater River at Plummer, Minn.	555	3.4	4.60	18.12	177.80	73.65	316.81	179.08
16	05078230	Lost River at Oklee, Minn.	254	4.9	4.58	18.06	73.71	19.30	166.27	63.05
17	05078500	Clearwater River at Red Lake Falls, Minn.	1,380	5.3	4.59	17.94	370.52	127.87	745.93	344.38
18	05079000	Red Lake River at Crookston, Minn.	5,270	2.2	4.62	17.89	1,446.46	805.46	2,397.75	1,385.85
19	05084000	Forest River near Fordville, N. Dak.	336	11.0	4.08	14.86	43.96	9.82	123.65	23.39
20	05085000	Forest River at Minto, N. Dak.	620	10.0	4.15	14.91	55.38	6.67	166.23	27.88
21	05087500	Middle River at Argyle, Minn.	255	4.3	4.27	14.74	48.57	4.94	126.29	36.40
22	05090000	Park River at Grafton, N. Dak.	695	6.5	3.91	14.77	68.02	4.48	221.91	26.75
23	05094000	South Branch Two Rivers at Lake Bronson, Minn.	422	4.0	4.36	14.61	100.80	8.56	270.73	79.63
24	05100000	Pembina River at Neche, N. Dak.	3,410	4.0	3.78	14.31	320.60	27.15	893.32	210.80
25	05101000	Tongue River at Akra, N. Dak.	160	21.7	3.68	14.63	20.64	5.42	62.66	11.04

Table 1. Basin characteristics for 27 streamflow-gaging stations in the Red River of the North Basin, North Dakota and Minnesota.—Continued

Map number (figure 1)	Streamflow-gaging station number	Streamflow-gaging station name	Drainage area (square miles)	Main channel slope (feet per mile)	Area-weighted mean winter/spring precipitation (inches)	Area-weighted mean summer precipitation (inches)	Annual streamflow (cubic feet per second)	Winter streamflow (cubic feet per second)	Spring streamflow (cubic feet per second)	Summer streamflow (cubic feet per second)
26	05104500	Roseau River below South Fork near Malung, Minn.	424	3.3	4.56	15.98	127.35	22.92	313.44	99.33
27	05112000	Roseau River below State Ditch 51 near Caribou, Minn.	1,420	1.3	4.52	15.73	332.23	64.93	678.37	322.30

uted, random variables that have the same distribution as ε in equation 4. This limit exists provided the distribution of ε satisfies certain constraints.

From equation 5, it follows that

$$E\left(\frac{Y_M}{X_M}\right)^* = \left(\frac{A_y}{A_x}\right)^{\alpha}\left(\frac{P_y}{P_x}\right)^{\beta}\left(\frac{S_y}{S_x}\right)^{\gamma}E(10^{\eta_y - \eta_x}) \tag{6}$$

where

E denotes the expected value.

Therefore, equation 3, multiplied by a bias-correction factor, $E(10^{\eta_y - \eta_x})$, is an unbiased estimate of Y_M^* (given X_M).

Assuming the 27 streamflow-gaging stations could be treated as a homogeneous group--that is, assuming equation 5 holds for all 27 stations--the equation was fitted to the streamflow data using ordinary least-squares regression. A separate regression analysis was performed for each of three seasons--winter (January, February, November, and December), spring (March, April, and May), and summer (June, July, August, September, and October). Drainage area, main channel slope, winter/spring precipitation, and summer precipitation were used as potential explanatory variables. The regression equation for spring streamflow was

$$\log\hat{Q} = -1.09 + 0.93\log A + 1.39\log P_{\text{winter/spring}} \tag{7}$$

where

$\hat{Q}$ is the estimated spring streamflow, in cubic feet per second, for the site of interest.

The coefficients given in equation 7 for both drainage area and winter/spring precipitation were highly significant (p-values of less than 0.01). The remaining variables were not significant when drainage area and winter/spring precipitation were included in the regression equation. The recorded spring streamflow values and the fitted spring streamflow values computed from the regression model are shown in figure 4. The coefficient of determination was 89 percent. However, the recorded streamflow values for the North Dakota stations tended to be less than the fitted streamflow values, and the recorded streamflow values for the Minnesota stations tended to be greater than the fitted streamflow values.

The results of the regression analyses for the winter and summer streamflows were similar to the results of the regression analysis for the spring streamflow. Drainage area was the most significant variable for both the winter and summer streamflows, but summer precipitation also was a significant variable. The regression equations generally overestimated streamflows for the North Dakota stations and underestimated streamflows for the Minnesota stations.

To correct the bias in the residuals for the two groups of stations (the North Dakota stations and the Minnesota stations), indicator variables were included in the regression equation to allow both the intercept and the coefficient for $\log A$ to depend on the group. The indicator variables for the intercept were given by

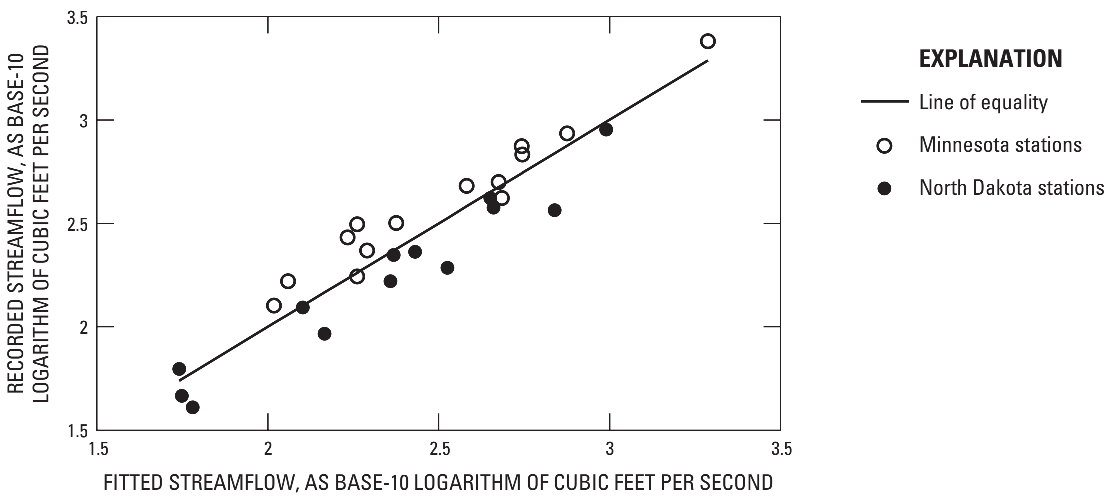

Figure 4. Recorded spring streamflow and fitted spring streamflow computed from the regression model with the logarithm of drainage area and the logarithm of winter/spring precipitation as explanatory variables.

$$C = C_1 + C_2 I(MN) \quad (8)$$

where

C_1 and C_2 are regression coefficients, and
$I(MN)$ is equal to zero for the North Dakota stations and 1 for the Minnesota stations.

The indicator variables for the coefficient for $\log A$ were given by

$$\alpha = \alpha_1 + \alpha_2 I(MN) \quad (9)$$

where

α_1 and α_2 are regression coefficients.

Results from the revised regression model indicate C_2 was positive and highly significant for all three seasons and α_2 was not significantly different from zero for all three seasons. Furthermore, main channel slope, winter/spring precipitation, and summer precipitation were not significant variables and drainage area was the only significant variable. The revised regression equations--that is, the equations that include the indicator variables--are given in table 2, and the fitted regression lines for the winter, spring, and summer streamflows are shown in figure 5.

Table 2. Regression equations used to estimate log-transformed seasonal streamflow for the Red River of the North Basin, North Dakota and Minnesota.

[R^2, coefficient of determination; log, base-10 logarithm; Q, average seasonal streamflow, in cubic feet per second, for 1971 through 2000; C, intercept; A, drainage area, in square miles; the number in parentheses (0.10) is the standard error of the coefficient]

Season	Regression equation	R^2 (percent)
Winter (January, February, November, and December)	$\log Q = C + 0.85 \log A$ (0.10) $C = -1.43$ for North Dakota stations[1] $C = -0.67$ for Minnesota stations[1]	90
Spring (March, April, and May)	$\log Q = C + 0.91 \log A$ (0.03) $C = -0.27$ for North Dakota stations $C = -0.01$ for Minnesota stations	98
Summer (June, July, August, September, and October)	$\log Q = C + 1.02 \log A$ (0.10) $C = -1.30$ for North Dakota stations $C = -0.83$ for Minnesota stations	97

[1]The South Branch Two Rivers at Lake Branson, Minnesota, streamflow-gaging station and the Middle River at Argyle, Minnesota, streamflow-gaging station were included in the North Dakota group of stations for the winter season.

The regression model with the two groups of stations separated provided a better fit than the regression model with the two groups of stations combined as indicated by comparing figure 4 and the middle graph in figure 5. Because potential evapotranspiration in the basin generally decreases from southwest to northeast (Stoner and others, 1993) and is highly correlated (negatively) with precipitation, differences in evapotranspiration were not expected to cause the distinct groupings for each state. Therefore, basin characteristics other than main channel slope and precipitation (characteristics such as land cover and soil) may be important factors in causing the distinct groupings.

The regression equations given in table 2 indicate the estimated coefficients for $\log A$ were less than 1 for the winter and spring seasons and essentially equal to 1 for the summer season. The use of conservation of mass considerations (Ghupta and Waymire, 1990) indicates the actual coefficient for drainage area must be less than or equal to 1. The p-values for testing the null hypothesis that the coefficient was equal to 1 versus the alternative that the coefficient was less than 1 were $p = 0.07$ for the winter season and $p = 0.003$ for the spring season. Therefore, a strong indication exists that the coefficients are less than 1, especially for the spring season. The coefficient for the summer season, although slightly greater than 1, was not significantly different from 1. A highly significant difference (a p-value of less than 0.01) occurred in the intercept for the North Dakota stations and the intercept for the Minnesota stations in

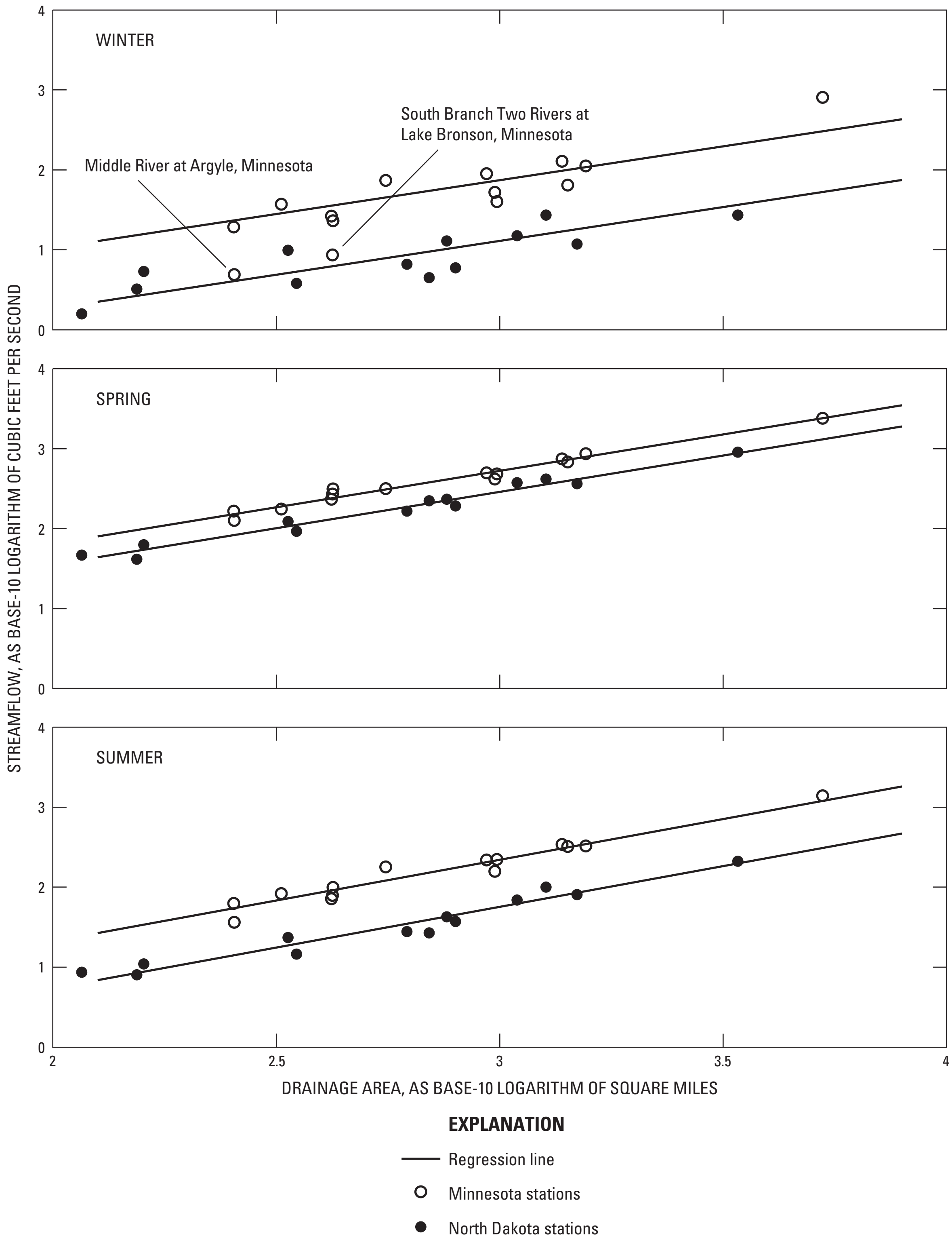

Figure 5. Regression lines for winter, spring, and summer streamflows computed from the revised regression model with drainage area as the explanatory variable.

all three seasons. Therefore, streamflow at a Minnesota station should not be used with equation 3 to estimate streamflow at a North Dakota station or vice versa. No significant differences occurred between the coefficient for $\log A$ for the North Dakota stations and the coefficient for $\log A$ for the Minnesota stations.

As shown in figure 5, the regression equations provided a good fit to streamflow data for the spring and summer seasons. For the winter season, however, the streamflow data for two Minnesota stations (South Branch Two Rivers at Lake Bronson, Minn., and Middle River at Argyle, Minn.--sites 21 and 23, respectively; fig. 1) were outliers when the stations were included in the Minnesota group of stations. Therefore, those two stations were included in the North Dakota group of stations for the winter season. If the stations had been included in the Minnesota group of stations, a significant difference would have occurred between the slopes of the regression lines for the two groups of stations, and the slope of the regression line for the Minnesota group of stations would have been greater than one. Winter streamflow for all stations was predominantly ground-water discharge, and the assumption could be made that ground-water discharge would increase less, in relation to an increased drainage area, than precipitation or snowmelt runoff.

The bias-correction factor, $E(10^{\eta_y - \eta_x})$, given in equation 6 was estimated using the nonparametric method described by Duan (1983). The bias-correction factor for each season was estimated by the average of $10^{e_i - e_j}$ for all pairs of residuals (e_i, e_j) from the revised regression model. Computing separate bias-correction factors for the two groups of stations resulted in negligible differences, so the residuals from the two groups of stations were combined. The regression equations (table 2) for the combined groups with the bias-correction factors included are given by

$$\text{Winter:} \quad Q_y = 1.24\left(\frac{A_y}{A_x}\right)^{0.85} Q_x, \qquad (10)$$

$$\text{Spring:} \quad Q_y = 1.02\left(\frac{A_y}{A_x}\right)^{0.91} Q_x, \qquad (11)$$

and

$$\text{Summer:} \quad Q_y = 1.06\left(\frac{A_y}{A_x}\right)^{1.02} Q_x. \qquad (12)$$

Although the regression equations do not fit the streamflow data particularly well for the winter season, the equations were deemed adequate because streamflow data for the winter season generally are rated poor because of ice conditions.

Summary

Many water-management programs require streamflow data for sites where no data were collected or for streamflow-gaging stations for periods during which the gage was not operated. Methods used to estimate streamflow for sites where no streamflow data were collected include the drainage-area ratio method. To evaluate the validity of the drainage-area ratio method and to determine if an improved method could be developed to estimate streamflow, a multiple regression technique was used to determine if drainage area, main channel slope, and precipitation were significant variables for estimating streamflow. Monthly streamflows for 27 streamflow-gaging stations in the Red River of the North Basin and precipitation data for 90 sites were used in the study. The period of record for each station and each site was 1971 through 2000. The precipitation data were used to compute mean annual winter/spring precipitation and mean annual summer precipitation for each of the 90 sites. Winter/spring precipitation was defined as the average precipitation for January, February, March, April, May, November, and December. Summer precipitation was defined as the average precipitation for June, July, August, September, and October.

The drainage-area ratio method is based on the assumption that the streamflow for a site of interest can be estimated by multiplying the ratio of the drainage area for the site of interest and the drainage area for a nearby streamflow-gaging station by the streamflow for the nearby streamflow-gaging station. To simplify the evaluation and to determine if the estimated streamflow was an unbiased estimate of the actual streamflow, the average streamflow for various seasons was used rather than streamflow for individual months. A separate ordinary least-squares regression analysis was performed for streamflow for each of three seasons--winter (January, February, November, and December), spring (March, April, and May), and summer (June, July, August, September, and October). Drainage area, main channel slope, winter/spring precipitation, and summer precipitation were used as potential explanatory variables. Drainage area and summer precipitation were the most significant variables. However, the regression equations generally overestimated streamflows for North Dakota stations and underestimated streamflows for Minnesota stations. To correct the bias in the residuals for the two groups of stations, indicator variables were included to allow both the intercept and the coefficient for the logarithm of drainage area to depend on the group. Drainage area was the only significant variable in the revised regression equations. The exponents for the drainage-area ratio were 0.85 for the winter season, 0.91 for the spring season, and 1.02 for the summer season.

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