USGS
science for a changing world

In cooperation with the Minnesota Pollution Control Agency

Methods Used to Compute Low-Flow Frequency Characteristics for Continuous-Record Streamflow Stations in Minnesota, 2006

Open-File Report 2007–1033

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

Methods Used to Compute Low-Flow Frequency Characteristics for Continuous-Record Streamflow Stations in Minnesota, 2006

By Thomas A. Winterstein, Allan D. Arntson, and Gregory B. Mitton

In cooperation with the Minnesota Pollution Control Agency

Open-File Report 2007–1033

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

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers Director

U.S. Geological Survey, Reston, Virginia: 2007

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS--the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Suggested citation:
Winterstein, T.A., Arntson, A.D., and Mitton, G.B., 2007, Methods used to compute low-flow frequency characteristics for continuous-record streamflow stations in Minnesota, 2006: U.S. Geological Survey Open-File Report 2007–1033, 762 p.

Contents

Figures

Tables

Conversion Factors

Multiply	By	To obtain
Area		
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
Flow rate		
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

This page is intentionally blank.

Methods Used to Compute Low-Flow Frequency Characteristics for Continuous-Record Streamflow Stations in Minnesota, 2006

By Thomas A. Winterstein, Allan D. Arntson, and Gregory B. Mitton

Abstract

The 1-, 7-, and 30-day low-flow series were determined for 120 continuous-record streamflow stations in Minnesota having at least 20 years of continuous record. The 2-, 5-, 10-, 50-, and 100-year statistics were determined for each series by fitting a log Pearson type III distribution to the data. The methods used to determine the low-flow statistics and to construct the plots of the low-flow frequency curves are described. The low-flow series and the low-flow statistics are presented in tables and graphs.

Introduction

Each year, increased demand is placed on Minnesota's surface-water resources. Information about low-flow characteristics of rivers and streams is needed for water-supply planning for municipalities, industries, irrigation, and waste disposal.

Low-flow characteristics can be defined for continuous-record streamflow stations by use of low-flow probability curves derived from annual minimum flows. Low-flow statistics also can be defined for partial-record and miscellaneous low-flow stations by use of a correlation method between a low-flow station and a continuous-record streamflow station as described by Riggs (1972).

Riggs' method establishes a relation between a low-flow station and an index station, typically a continuous-record streamflow station that has similar basin characteristics and is near the low-flow station. The relation is based on the correlation of low-flow streamflow measurements at the low-flow station and concurrent daily flows at the index station. Low-flow characteristics can be estimated for the low-flow station by use of low-flow frequency characteristics for the index station in combination with the established relation.

Approximately 950 low-flow stations, which include about 830 partial-record stations and miscellaneous sites and 120 continuous-record streamflow stations, are in the U.S. Geological Survey (USGS) low-flow database for Minnesota, along with an additional several thousand streamflow measurements that were made during low-flow conditions. Additional low-flow stations and streamflow measurements are added to the database during periods of low flow.

Three previous reports have described the low-flow characteristics of Minnesota streams. Lindskov (1977) compiled low-flow frequency characteristics for 161 continuous-record streamflow stations in Minnesota having 8 or more years of record through the 1975 water year (October 1, 1974–September 30, 1975). Warne (1978) used Riggs' method and Lindskov's low-flow frequency determinations to estimate the 7-day 2-year and the 7-day 10-year low-flow discharges at about 300 low-flow stations in Minnesota. Arntson and Lorenz (1987) determined the 1-, 7-, and 30-day low-flow series for 175 continuous-record streamflow stations in and adjacent to Minnesota that had 10 or more years of continuous record through the 1983 water year (October 1, 1982–September 30, 1983). They computed the estimated discharges for the 2-, 5-, 10-, 20-, 50-, and 100-year recurrence intervals for each series for the climatic year (April 1–March 31) and a seasonal period (May–September).

Because it has been 23 years since the last report was compiled, the low-flow statistics compiled in Arntson and Lorenz (1987) may no longer be useful in estimating low-flow statistics at partial-record stations. As a result, the USGS, in cooperation with the Minnesota Pollution Control Agency, has determined the 1- , 7-, and 30-day low-flow series at 120 continuous-record streamflow stations in Minnesota with at least 20 years of record through climatic year 2005 (April 1, 2004–March 31, 2005). For each series, the estimated discharges for the 2-, 5-, 10-, 20-, 50-, and 100-year recurrence intervals were computed. The statistics and results of computations are presented in three Portable Document Format (PDF) files for each station. Two of the files contain graphs of the data and estimated statistics plotted in logarithmic space; in one graph the data and estimated statistics are plotted along a normal-probability axis (appendix 1), and on the other graph they are plotted along a Pearson type III probability axis (appendix 2). The third file (appendix 3) contains output from the computer program SWSTAT (Lumb and others, 1994) used to determine the statistics.

The purpose of this report is to list the stations used in this study, describe the methods used to determine the low-flow statistics, describe the methods used to graph the statistics, and show the graphs and output files.

Methods Used to Compute Low-Flow Statistics

The streamflow data for the 120 continuous-record streamflow stations used in this analysis (fig. 1, table 1) were retrieved from the National Water Inventory System (NWIS) (Mathey, 1998). The streamflow data for the period of record of each station through March 31, 2005, was used in this analysis. There are at least 20 years of record for each station.

Low flow is defined as the lowest average flow for some consecutive-day period. The 1-, 7-, and 30-day low-flow series were computed from the record of each station for each climatic year (April 1 through March 31). SWSTAT was used to determine the 1-, 7-, or 30-day low-flow series for each climatic year. The same program was used to determine the 2-, 5-, 10-, 20-, 50-, and 100-year recurrence intervals for each low-flow series by fitting a log Pearson type III frequency distribution to the low-flow series (Lumb and others, 1994, p. 25). Sample output from this program is shown in figure 2.

The columns "Non-exceedance Probability," "Recurrence Interval," and "Estimated Streamflow" (columns 1, 2, and 3 in fig. 2) were computed by SWSTAT. If the data series contained zero values, the skew and estimated discharge values at each non-exceedance probability were determined in SWSTAT from the nonzero values in the data set. The non-exceedance probabilities were then adjusted for each estimated discharge ("Estimated Streamflow" in fig. 2) according to this formula:

$$P_{an} = 1 - \left(\frac{N(1 - P_n)}{N + N_z}\right) \qquad (1)$$

where

P_{an} is the adjusted non-exceedance probability,
P_n is the non-exceedance probability,
N is the number of nonzero values in the data set,

and

N_z is the number of zero values in the data set.

The sample size of the data set is $N + N_z$. This equation is derived from the conditional probability adjustment given by the Interagency Advisory Committee on Water Data, (1982, p. 5-2, appendix 5)[1]. The adjusted non-exceedance probabilities are listed in the column headed "Adjusted Non-exceedance Probability," column 4 in figure 2. The estimated discharge also was adjusted in SWSTAT for each non-exceedance probability. The adjusted discharges are listed in the column headed "Adjusted Estimated Streamflow," column 5 in figure 2.

The low-flow series and the computed frequency curves were plotted on graphs (figs. 3–6). The position of the data points were computed by the Cunnane formula (Helsel and Hirsch, 2002, p. 23; Rao and Hamed, 2000, p. 6–8):

$$p = \frac{i - 0.4}{n + 0.2} \qquad (2)$$

where

p is the plotting position,
i is the rank of the low-flow statistic (from smallest to largest),

and

n is the sample size of the data set.

The plotting position is the initial estimate of the probability of non-exceedance (Rao and Hamed, 2000, p. 6). The Cunnane plotting positions determined for each value in the series were used to plot the 1-, 7-, and 30-day low-flow series. The non-exceedance probabilities and estimated streamflow computed by SWSTAT were used to plot the frequency curves.

If the data series contained zero values the estimates of non-exceedance (plotting positions) were adjusted by use of equation 1. The adjusted estimates of non-exceedance (adjusted plotting positions) were used to plot the 1-, 7-, and 30-day low-flow series. The non-exceedance probability and the adjusted estimated streamflow (columns 1 and 5 in fig. 2) computed by SWSTAT were used to plot the frequency curves. The adjusted non-exceedance probability and estimated streamflow (columns 4 and 3 in fig. 2) also could be used to plot the frequency curves.

[1]The adjusted probability of exceedance, $P_{ae} = \left(\frac{N}{N + N_z}\right)P_e$, where P_e is the probability of exceedance. The adjusted probability for non-exceedance, $P_{an} = 1 - P_{ae} = 1 - \left(\frac{N}{N + N_z}\right)P_e = 1 - \left(\frac{N(1 - P_n)}{N + N_z}\right)$.

Figure 1. Continuous-record streamflow stations used in low-flow analysis in Minnesota, 2006.

```
              Log-Pearson Type III Statistics

Notice -- Use of Log-Pearson Type III or Pearson-Type III
          distributions are for preliminary computations.
          User is responsible for assessment and
          interpretation.

                 05278000 - streamflow gaging station
           1-day low flow – low-flow statistic
                 April  1 - start of season
                 March 31 - end of season
              1950 - 1989 - time period
                       34 - nonzero values
                        4 - zero values
                        2 - years with missing values (not used)

          0.100      1.800     25.000      2.200      2.600
          3.400      1.400      1.900     35.000      0.500
          1.100      0.300      1.300      0.500      1.000
          2.200      1.900      1.800      1.900     27.000
         43.000      5.600      4.600      0.270      1.100
         19.000      2.200     13.000     24.000     36.000
         45.000     51.000     53.000     73.000


The following 7 statistics are based on non-zero values:

Mean (logs)                                          0.608
Variance (logs)                                      0.599
Standard Deviation (logs)                            0.774
Skewness (logs)                                      0.052
Standard Error of Skewness (logs)                    0.403
Serial Correlation Coefficient (logs)                0.508
Coefficient of Variation (logs)                      1.274
      (1)          (2)         (3)          (4)         (5)
    Non-                              Adjusted Non- Adjusted
 exceedance    Recurrence  Estimated   exceedance   Estimated
Probability     Interval   Streamflow  Probability  Streamflow
-----------  -----------  ---------  -----------  ---------
     0.0100       100.00      0.069       0.1142      0.000
     0.0200        50.00      0.110       0.1232      0.000
     0.0500        20.00      0.222       0.1500      0.000
     0.1000        10.00      0.417       0.1947      0.000
     0.2000         5.00      0.900       0.2842      0.436
     0.5000         2.00      3.991       0.5526      3.062
     0.8000         1.25     18.081       0.8211     15.805
     0.9000         1.11     40.180       0.9105     36.578
     0.9600         1.04     94.780       0.9642     86.502
     0.9800         1.02    165.607       0.9821    152.659
     0.9900         1.01    274.260       0.9911    258.456


Note -- Adjusted parameter values include zero values
        and correspond with non-exceedance probabilities
        in column 1 and recurrence interval in column 2.
        Parameter values in column 3 are based on
        nonzero values.
```

Basic information about the gaging station and the data used by program SWSTAT.

Low-flow values used by program SWSTAT to compute frequency statistics.

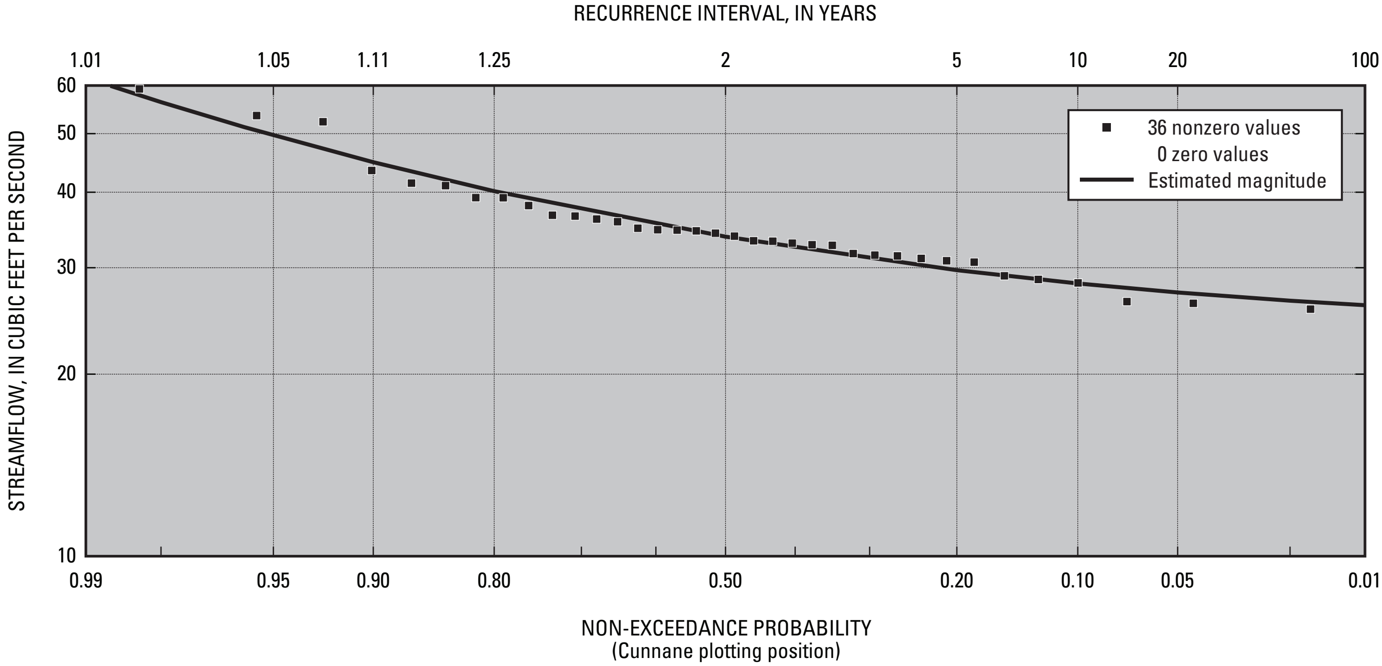
Note: These statistics are based on nonzero values.

Plotting column 5 with column 1 or plotting column 3 with column 4 will plot the correct frequency curve.

Values in columns 4 and 5 are not computed unless there are zero values.

Figure 2. Example of output from the computer program SWSTAT.

***A*, 30-day low-flow frequency curve for continous-record streamflow station 05384500, Rock Creek near Rushford, Minn. Skew is 1.040; period of record 1943-79.**



***B*, 30-day low-flow frequency curve for continous-record streamflow station 05211000, Mississippi River at Grand Rapids, Minn. Skew is -0.823; period of record 1944-2004.**

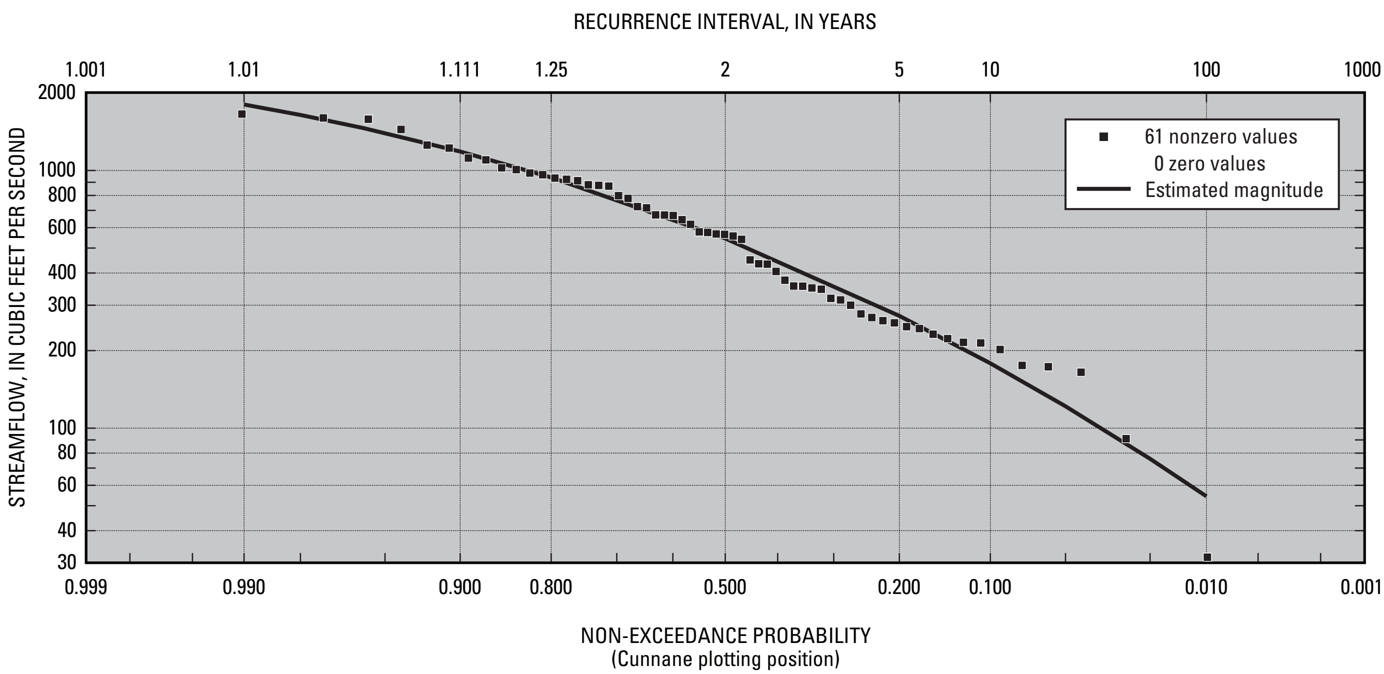


Figure 3. Low-flow frequency curves plotted along a normal probability axis showing effects of skews on the shape of the curve.

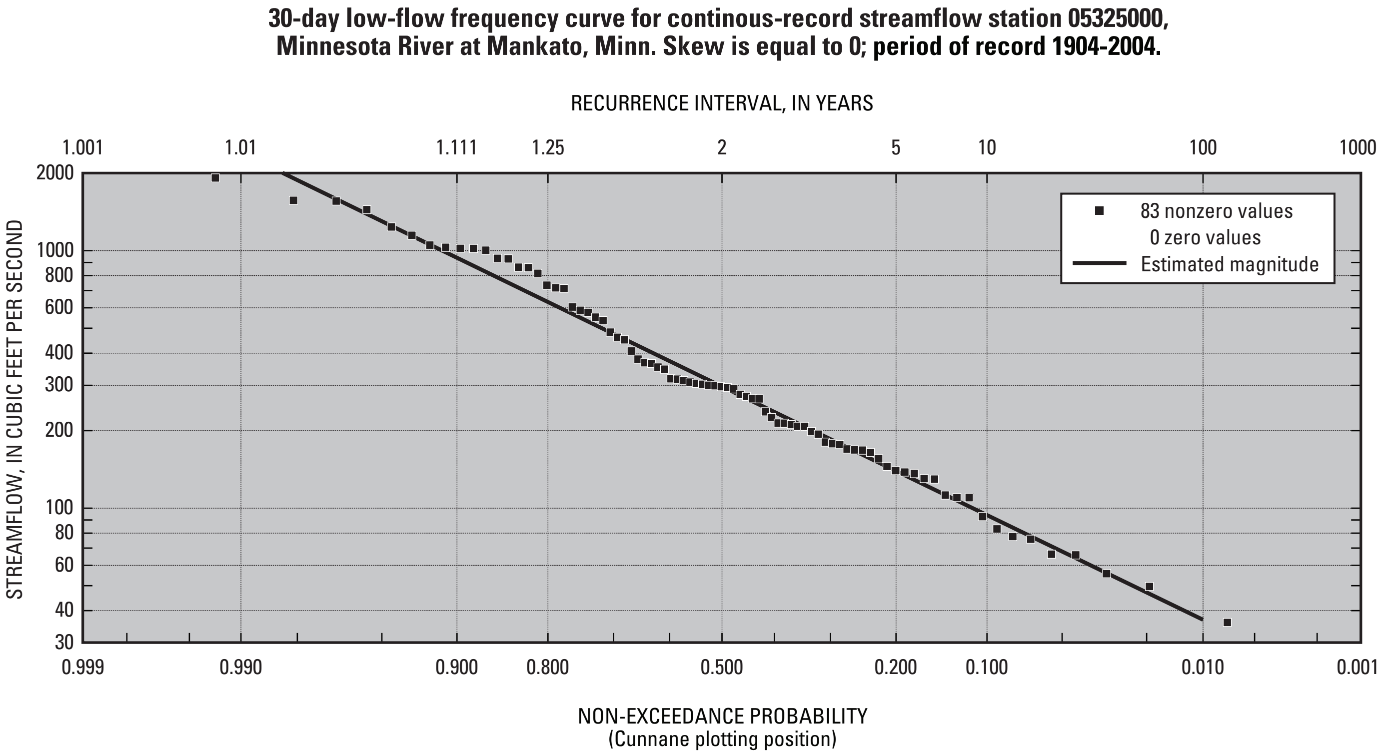


Figure 4. Low-flow frequency curve with skew equal to zero plotted along a normal probability axis.

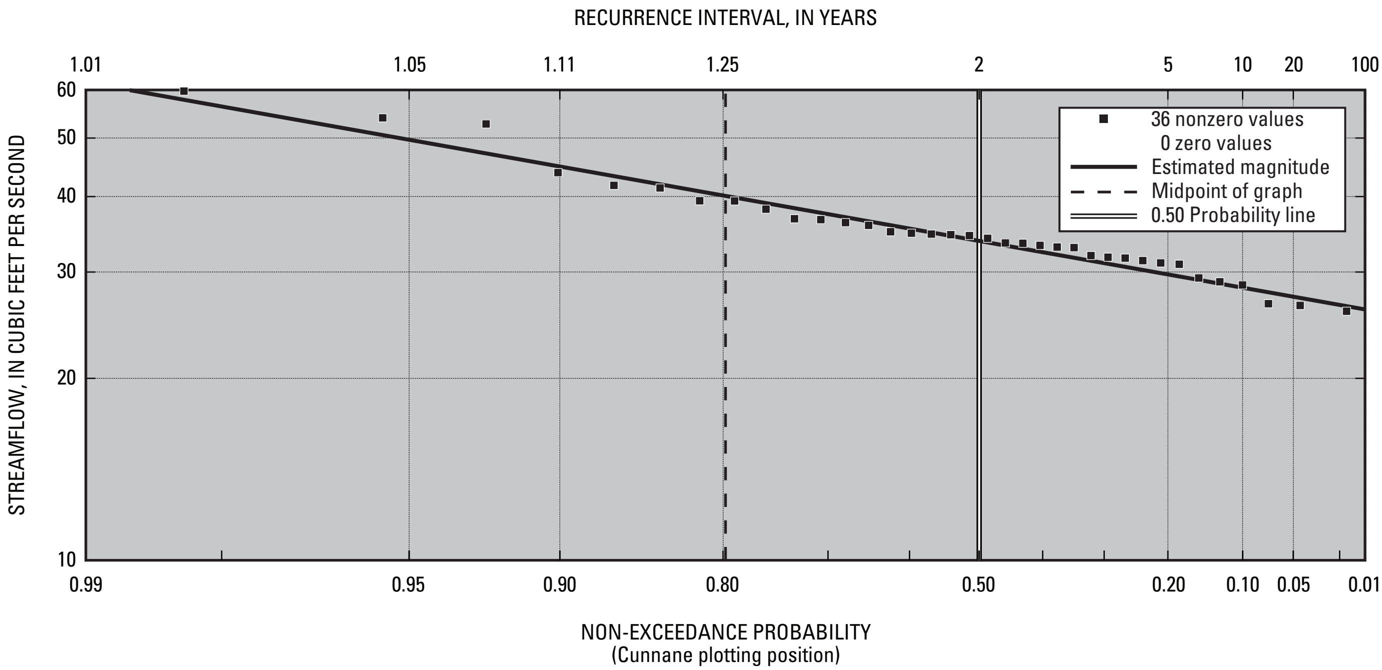
S-Plus statistical software (Insightful Corporation, 2005) was used to plot the statistical data and frequency curves in logarithmic space against the normal probability axis and the Pearson type III probability axis. In log normal probability plots, the frequency curve often is not a straight line (fig. 3). The curvature of the frequency curve increases with the absolute value of the skew. If the skew is 0, the curve is a straight line (fig 4.). In log Pearson type III probability plots the frequency curve is a straight line (fig. 5); however, the 0.5 probability line moves from the center of the graph. It moves to the left of center if the skew is negative and to the right of center if the skew is positive. The distance the 0.5 probability line moves increases with the absolute value of the skew.

If zero values were in the low-flow series, the adjusted non-exceedance probabilities (column 4 in fig. 2) were used to plot the data and frequency curve in lognormal probability plots (fig. 6A). This changed the shape of the frequency curve. In the log Pearson type III probability plots, the unadjusted non-exceedance probability (column 1 in fig. 2) was used to plot the data and frequency curve. This kept the frequency curve a straight line (fig. 6B), thus preserving the plot's most useful attribute and allowing the user to judge how well the frequency curve fits the data. Two probabilities were used to label the probability axis: the unadjusted non-exceedance probability and the adjusted non-exceedance probability, columns 1 and 4 in fig. 2.

Low-flow statistics derived from these frequency curves are listed with the plotted graphs. These statistics are described in terms of recurrence interval. Recurrence interval, in years, is the reciprocal of non-exceedance probability when the frequency curve is based on only one observation per year. Thus the 20-year recurrence interval corresponds to a non-exceedance probability of 0.05. The estimated discharges for each statistic were rounded to one decimal place or three significant figures.

Low-flow characteristics can and will vary for a station depending upon the number of years of record and the period gaged. When comparing low-flow characteristics between two or more stations, data users should remember that no provisions were made to use concurrent periods of record for stations along the same stream.

***A*, 30-day low-flow frequency curve for continous-record streamflow station 05384500, Rock Creek near Rushford, Minn. Skew is 1.040; period of record 1943-79.**



***B*, 30-day low-flow frequency curve for continous-record streamflow station 05211000, Mississippi River at Grand Rapids, Minn. Skew is -0.823; period of record 1944-2004.**

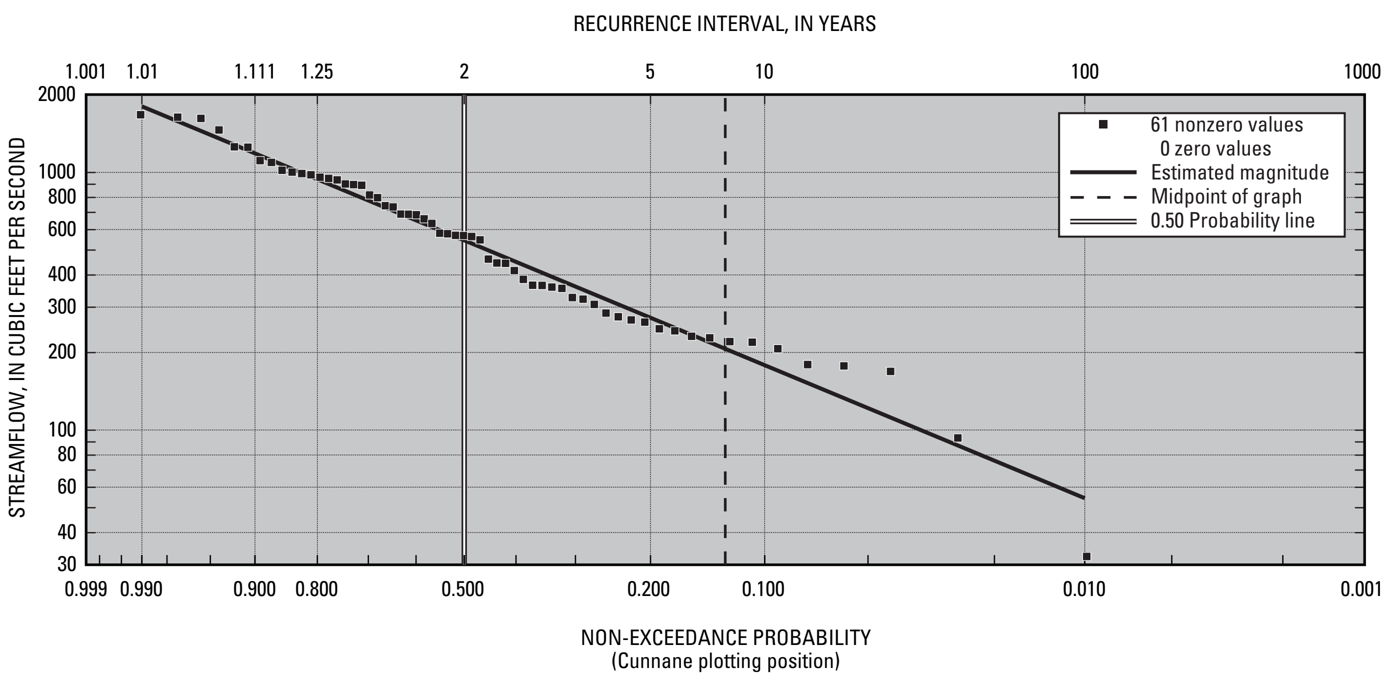


Figure 5. Low-flow frequency curves plotted along a Pearson type III probability axis showing effects of skew on the position of the 0.50 probability line.

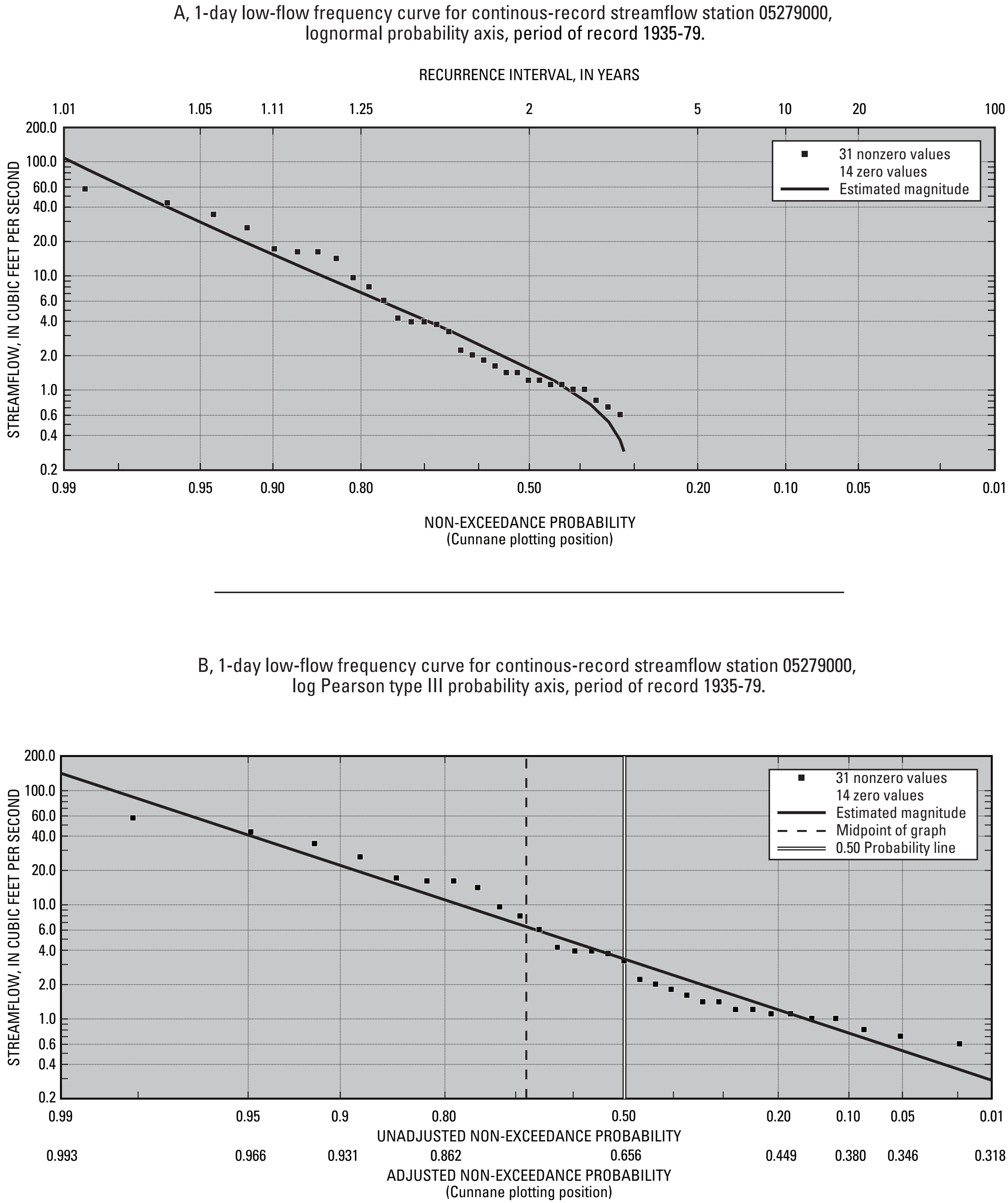


Figure 6. One-day low-flow frequency curves for continuous-record streamflow station 05279000, South Fork Crow River near Mayer, Minnesota, showing the effects of zero values on the shape of the frequency curve.

References Cited

Arntson, A.D., and Lorenz, D.L., 1987, Low-flow frequency characteristics for continuous-record streamflow stations in Minnesota: U.S. Geological Survey Water-Resources Investigations Report 86-4353, 354 p.

Helsel, D.R., and Hirsch, R.M., 2002, Statistical methods in water resources: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chap. A3: accessed January 5, 2007, at *http://pubs.er.usgs.gov/pubs/twri/twri04A3*

Insightful Corporation, 2005, S-Plus 7 for Windows user's guide: Seattle, 654 p.

Interagency Advisory Committee on Water Data, 1982, Flood flow frequency: U.S. Geological Survey, Interagency Advisory Committee on Water Data, Bulletin 17B of the Hydrology Subcommittee, [186] p.

Lindskov, K.L., 1977, Low-flow characteristics of Minnesota streams: U.S. Geological Survey Water-Resources Investigations Report 77–48, 197 p.

Lumb, A.M., Thomas, W.O. Jr., and Flynn, K.M., 1994, User's manual for SWSTAT—a computer program for interactive computation of surface-water statistics: U.S. Geological Survey, 48 p.

Mathey, S.B., ed., 1998, National Water Information System (NWIS): U.S. Geological Survey Fact Sheet FS–027–98, 2 p.

Rao, A.R., and Hamed, K.H., 2000, Flood frequency analysis: Boca Raton, Fla., CRC Press, 350 p.

Riggs, H.C., 1972, Low-flow investigations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chap. B1, 18 p.

Warne, S.A., 1978, Low-flow frequency of Minnesota streams: U.S. Geological Survey Water-Resources Investigations Report 78–132, 1 sheet.

This page is intentionally blank.

Table 1. Continuous-record streamflow stations used in the analysis.

Station number	Station name	Latitude	Longitude	Hydrologic unit	Drainage area (square miles)
04010500	Pigeon River at Middle Falls near Grand Portage, Minn.	48° 00’ 44”	-89° 36’ 58”	04010101	609
04012500	Poplar River at Lutsen, Minn.	47° 38’ 23”	-90° 42’ 31”	04010101	112
04014500	Baptism River near Beaver Bay, Minn.	47° 20’ 15”	-91° 12’ 02”	04010101	140
04015330	Knife River near Two Harbors, Minn.	46° 56’ 49”	-91° 47’ 32”	04010102	84
04015500	Second Creek near Aurora, Minn.	47° 31’ 25”	-92° 11’ 35”	04010201	29
04016000	Partridge River near Aurora, Minn.	47° 31’ 02”	-92° 11’ 24”	04010201	161
04016500	St. Louis River near Aurora, Minn.	47° 29’ 30”	-92° 14’ 20”	04010201	293
04017000	Embarrass River at Embarrass, Minn.	47° 39’ 24”	-92° 11’ 51”	04010201	88
04018750	St. Louis River at Forbes, Minn.	47° 21’ 48”	-92° 35’ 56”	04010201	713
04018900	East Two River near Iron Junction, Minn.	47° 24’ 04”	-92° 39’ 52”	04010201	40
04019000	West Two River near Iron Junction, Minn.	47° 24’ 05”	-92° 42’ 10”	04010201	65
04024000	St. Louis River at Scanlon, Minn.	46° 42’ 12”	-92° 25’ 07”	04010201	3,430
04024098	Deer Creek near Holyoke, Minn.	46° 31’ 30”	-92° 23’ 20”	04010301	8
05030000	Otter Tail River near Detroit Lakes, Minn.	46° 50’ 12”	-95° 41’ 57”	09020103	270
05040500	Pelican River near Fergus Falls, Minn.	46° 01’ 10”	-96° 07’ 10”	09020103	482
05046000	Otter Tail River below Orwell Dam near Fergus Falls, Minn.	46° 12’ 35”	-96° 11’ 05”	09020103	1,740
05049000	Mustinka River above Wheaton, Minn.	45° 49’ 15”	-96° 29’ 25”	09020102	810
05050000	Bois de Sioux River near White Rock, S. Dak.	45° 51’ 45”	-96° 34’ 25”	09020101	1,160
05051500	Red River of The North at Wahpeton, N. Dak.	46° 15’ 55”	-96° 35’ 40”	09020104	4,010
05054000	Red River of the North at Fargo, N. Dak.	46° 51’ 40”	-96° 47’ 00”	09020104	6,800
05061000	Buffalo River near Hawley, Minn.	46° 51’ 00”	-96° 19’ 45”	09020106	325
05061500	South Branch Buffalo River at Sabin, Minn.	46° 46’ 20”	-96° 37’ 40”	09020106	454
05062000	Buffalo River near Dilworth, Minn.	46° 57’ 40”	-96° 39’ 40”	09020106	975
05062500	Wild Rice River at Twin Valley, Minn.	47° 16’ 00”	-96° 14’ 40”	09020108	934
05064000	Wild Rice River at Hendrum, Minn.	47° 16’ 05”	-96° 47’ 50”	09020108	1,560
05064500	Red River of the North at Halstad, Minn.	47° 21’ 10”	-96° 50’ 50”	09020107	21,800

Table 1. Continuous-record streamflow stations used in the analysis.—Continued

Station number	Station name	Latitude	Longitude	Hydrologic unit	Drainage area (square miles)
05067500	Marsh River near Shelly, Minn.	47° 24’ 45”	-96° 45’ 50”	09020107	220
05069000	Sand Hill River at Climax, Minn.	47° 36’ 43”	-96° 48’ 52”	09020301	420
05074500	Red Lake River near Red Lake, Minn.	47° 57’ 27”	-95° 16’ 35”	09020302	1,950
05075000	Red Lake River at High Landing near Goodridge, Minn.	48° 02’ 34”	-95° 48’ 28”	09020303	2,300
05076000	Thief River near Thief River Falls, Minn.	48° 11’ 08”	-96° 10’ 11”	09020304	985
05078000	Clearwater River at Plummer, Minn.	47° 55’ 24”	-96° 02’ 46”	09020305	555
05078230	Lost River at Oklee, Minn.	47° 50’ 35”	-95° 51’ 30”	09020305	254
05078500	Clearwater River at Red Lake Falls, Minn.	47° 53’ 15”	-96° 16’ 25”	09020305	1,380
05079000	Red Lake River at Crookston, Minn.	47° 46’ 32”	-96° 36’ 33”	09020303	5,270
05082500	Red River of the North at Grand Forks, N. Dak.	47° 55’ 38”	-97° 01’ 34”	09020301	30,100
05087500	Middle River at Argyle, Minn.	48° 20’ 28”	-96° 49’ 04”	09020309	255
05092000	Red River of the North at Drayton, N. Dak.	48° 34’ 20”	-97° 08’ 50”	09020311	34,800
05094000	South Branch Two Rivers at Lake Bronson, Minn.	48° 43’ 57”	-96° 40’ 02”	09020312	422
05096000	North Branch Two Rivers near Lancaster, Minn.	48° 53’ 21”	-96° 40’ 01”	09020312	32
05102500	Red River of the North at Emerson, Manitoba, Canada	49° 00’ 30”	-97° 12’ 40”	09020311	40,200
05104500	Roseau River below South Fork near Malung, Minn.	48° 47’ 30”	-95° 44’ 40”	09020314	430
05106000	Sprague Creek near Sprague, Manitoba, Canada	48° 59’ 33”	-95° 39’ 43”	09020314	176
05107000	Pine Creek near Pine Creek, Minn.	48° 59’ 35”	-95° 55’ 04”	09020314	75
05107500	Roseau River at Ross, Minn.	48° 54’ 37”	-95° 55’ 18”	09020314	1,090
05112000	Roseau River below State Ditch 51 near Caribou, Minn.	48° 58’ 54”	-96° 27’ 46”	09020314	1,420
05124480	Kawishiwi River near Ely, Minn.	47° 55’ 22”	-91° 32’ 06”	09030001	254
05127000	Kawishiwi River near Winton, Minn.	47° 56’ 05”	-91° 45’ 50”	09030001	1,230
05127500	Basswood River near Winton, Minn.	48° 04’ 55”	-91° 39’ 10”	09030001	1,740
05129000	Vermilion River below Vermilion Lake near Tower, Minn.	47° 57’ 41”	-92° 28’ 33”	09030002	483
05129115	Vermilion River near Crane Lake, Minn.	48° 15’ 53”	-92° 33’ 57”	09030002	905
05130500	Sturgeon River near Chisholm, Minn.	47° 40’ 25”	-92° 54’ 00”	09030005	180

Table 1. Continuous-record streamflow stations used in the analysis.—Continued

Station number	Station name	Latitude	Longitude	Hydrologic unit	Drainage area (square miles)
05131000	Dark River near Chisholm, Minn.	47° 41’ 27”	-92° 49’ 15”	09030005	51
05131500	Little Fork River at Littlefork, Minn.	48° 23’ 45”	-93° 32’ 57”	09030005	1,680
05132000	Big Fork River at Big Falls, Minn.	48° 11’ 45”	-93° 48’ 25”	09030006	1,480
05133500	Rainy River at Manitou Rapids, Minn.	48° 38’ 04”	-93° 54’ 47”	09030004	19,400
05134200	Rapid River near Baudette, Minn.	48° 32’ 10”	-94° 33’ 45”	09030007	543
05139500	Warroad River near Warroad, Minn.	48° 52’ 00”	-95° 21’ 20”	09030009	162
05211000	Mississippi River at Grand Rapids, Minn.	47° 13’ 56”	-93° 31’ 48”	07010103	3,370
05212700	Prairie River near Taconite, Minn.	47° 23’ 20”	-93° 22’ 50”	07010103	371
05216860	Swan River near Calumet, Minn.	47° 17’ 20”	-93° 13’ 54”	07010103	114
05227500	Mississippi River at Aitkin, Minn.	46° 32’ 26”	-93° 42’ 26”	07010104	6,140
05242300	Mississippi River at Brainerd, Minn.	46° 22’ 40”	-94° 10’ 59”	07010104	7,320
05243725	Straight River near Park Rapids, Minn.	46° 52’ 30”	-95° 03’ 56”	07010106	53
05244000	Crow Wing River at Nimrod, Minn.	46° 38’ 25”	-94° 52’ 44”	07010106	1,030
05245100	Long Prairie River at Long Prairie, Minn.	45° 58’ 30”	-94° 51’ 56”	07010108	434
05247500	Crow Wing River near Pillager, Minn.	46° 18’ 18”	-94° 22’ 38”	07010106	3,760
05267000	Mississippi River near Royalton, Minn.	45° 51’ 40”	-94° 21’ 30”	07010104	11,600
05270500	Sauk River near St. Cloud, Minn.	45° 33’ 35”	-94° 14’ 00”	07010202	1,030
05270700	Mississippi River at St. Cloud, Minn.	45° 32’ 50”	-94° 08’ 44”	07010203	13,320
05275000	Elk River near Big Lake, Minn.	45° 20’ 02”	-93° 40’ 00”	07010203	559
05278000	Middle Fork Crow River near Spicer, Minn.	45° 15’ 45”	-94° 48’ 10”	07010204	179
05279000	South Fork Crow River near Mayer, Minn.	44° 54’ 20”	-93° 53’ 05”	07010205	1,170
05280000	Crow River at Rockford, Minn.	45° 05’ 12”	-93° 44’ 02”	07010204	2,640
05286000	Rum River near St. Francis, Minn.	45° 19’ 40”	-93° 22’ 20”	07010207	1,360
05287890	Elm Creek near Champlin, Minn.	45° 09’ 48”	-93° 26’ 11”	07010206	86
05288500	Mississippi River near Anoka, Minn.	45° 07’ 36”	-93° 17’ 48”	07010206	19,100
05290000	Little Minnesota River near Peever, S. Dak.	45° 36’ 05”	-96° 52’ 18”	07020001	438
05291000	Whetstone River near Big Stone City, S. Dak.	45° 17’ 30”	-96° 29’ 14”	07020001	398
05292000	Minnesota River at Ortonville, Minn.	45° 17’ 44”	-96° 26’ 38”	07020001	1,160

Table 1. Continuous-record streamflow stations used in the analysis.—Continued

Station number	Station name	Latitude	Longitude	Hydrologic unit	Drainage area (square miles)
05293000	Yellow Bank River near Odessa, Minn.	45° 13’ 37”	-96° 21’ 12”	07020001	459
05294000	Pomme de Terre River at Appleton, Minn.	45° 12’ 10”	-96° 01’ 20”	07020002	905
05300000	Lac Qui Parle River near Lac Qui Parle, Minn.	44° 59’ 42”	-95° 55’ 09”	07020003	960
05301000	Minnesota River near Lac Qui Parle, Minn.	45° 01’ 17”	-95° 52’ 05”	07020004	4,050
05304500	Chippewa River near Milan, Minn.	45° 06’ 30”	-95° 47’ 55”	07020005	1,880
05311000	Minnesota River at Montevideo, Minn.	44° 56’ 00”	-95° 44’ 00”	07020004	6,180
05311400	South Branch Yellow Medicine River at Minneota, Minn.	44° 33’ 50”	-95° 59’ 50”	07020004	115
05313500	Yellow Medicine River near Granite Falls, Minn.	44° 43’ 18”	-95° 31’ 07”	07020004	664
05315000	Redwood River near Marshall, Minn.	44° 25’ 49”	-95° 50’ 43”	07020006	259
05316500	Redwood River near Redwood Falls, Minn.	44° 31’ 25”	-95° 10’ 20”	07020006	629
05317000	Cottonwood River near New Ulm, Minn.	44° 17’ 29”	-94° 26’ 24”	07020008	1,300
05317200	Little Cottonwood River near Courtland, Minn.	44° 14’ 47”	-94° 20’ 19”	07020007	170
05319500	Watonwan River near Garden City, Minn.	44° 02’ 47”	-94° 11’ 43”	07020010	851
05320000	Blue Earth River near Rapidan, Minn.	44° 05’ 44”	-94° 06’ 33”	07020009	2,430
05320500	Le Sueur River near Rapidan, Minn.	44° 06’ 40”	-94° 02’ 28”	07020011	1,110
05325000	Minnesota River at Mankato, Minn.	44° 10’ 10”	-94° 00’ 15”	07020007	14,900
05327000	High Island Creek near Henderson, Minn.	44° 34’ 19”	-93° 55’ 18”	07020012	237
05330000	Minnesota River near Jordan, Minn.	44° 41’ 35”	-93° 38’ 30”	07020012	16,200
05331000	Mississippi River at St. Paul, Minn.	44° 56’ 02”	-93° 06’ 21”	07010206	36,800
05336700	Kettle River below Sandstone, Minn.	46° 06’ 20”	-92° 51’ 50”	07030003	868
05337400	Knife River near Mora, Minn.	45° 55’ 12”	-93° 18’ 26”	07030004	102
05338500	Snake River near Pine City, Minn.	45° 50’ 30”	-92° 56’ 00”	07030004	958
05340050	Sunrise River near Lindstrom, Minn.	45° 27’ 00”	-92° 53’ 10”	07030005	231
05344500	Mississippi River at Prescott, Wis.	44° 44’ 45”	-92° 48’ 00”	07040001	44,800
05345000	Vermillion River near Empire, Minn.	44° 40’ 00”	-93° 03’ 17”	07040001	129

Table 1. Continuous-record streamflow stations used in the analysis.—Continued

Station number	Station name	Latitude	Longitude	Hydrologic unit	Drainage area (square miles)
05353800	Straight River near Faribault, Minn.	44° 15’ 29”	-93° 13’ 51”	07040002	442
05355200	Cannon River at Welch, Minn.	44° 33’ 50”	-92° 43’ 55”	07040002	1,340
05372995	South Fork Zumbro River at Rochester, Minn.	44° 03’ 42”	-92° 27’ 58”	07040004	303
05373000	South Fork Zumbro River near Rochester, Minn.	44° 04’ 00”	-92° 27’ 55”	07040004	304
05374000	Zumbro River at Zumbro Falls, Minn.	44° 17’ 12”	-92° 25’ 56”	07040004	1,150
05376000	North Fork Whitewater River near Elba, Minn.	44° 05’ 30”	-92° 03’ 57”	07040003	101
05376500	South Fork Whitewater River near Altura, Minn.	44° 04’ 10”	-91° 58’ 49”	07040003	77
05378500	Mississippi River at Winona, Minn.	44° 03’ 20”	-91° 38’ 15”	07040003	59,200
05379000	Gilmore Creek at Winona, Minn.	44° 02’ 40”	-91° 41’ 25”	07040003	9
05384000	Root River near Lanesboro, Minn.	43° 44’ 58”	-91° 58’ 43”	07040008	615
05384500	Rush Creek near Rushford, Minn.	43° 50’ 00”	-91° 46’ 40”	07040008	132
05385000	Root River near Houston, Minn.	43° 46’ 07”	-91° 34’ 11”	07040008	1,250
05385500	South Fork Root River near Houston, Minn.	43° 44’ 19”	-91° 33’ 50”	07040008	275
05457000	Cedar River near Austin, Minn.	43° 38’ 11”	-92° 58’ 26”	07080201	399
05476000	Des Moines River at Jackson, Minn.	43° 37’ 10”	-94° 59’ 10”	07100001	1,250

This page is intentionally blank.

Appendixes