ESTIMATION OF FLOOD FLOWS ON THE BIG SIOUX RIVER BETWEEN AKRON, IOWA, AND NORTH SIOUX CITY, SOUTH DAKOTA

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ABSTRACT

This report presents estimated flood flows for specified frequencies at selected locations on the Big Sioux River between the Akron, Iowa, streamflow-gaging station and North Sioux City, South Dakota. The selected locations include: at the Akron gaging station, downstream from the Richland-Westfield Creek Basins, downstream from the Brule Creek Basin, downstream from the Upper West Boundary Big Ditch and Rock Creek Basins, downstream from Broken Kettle Basin, and downstream from North Sioux City. The flood flows for the 10-, 50-, 100-, and 500-year recurrence intervals will be used to support a Federal Emergency Management Agency Flood Insurance Study.

Four methods were used to estimate the flood flows. The first method involved the use of drainage-area ratios raised to specified exponents to transfer the flood-frequency relation from the Akron gage to the selected downstream locations. The second method was a flood-frequency analysis based on a summation of the Akron gaging-station peak flows and concurrent tributary daily flows from within the various study reaches. The third method was an independence/dependence analysis of the Akron gaging-station flows and the tributary flows from the various study reaches. The fourth method was a flood-frequency analysis assuming complete dependence of the Akron peak flows and the tributary peak flows from the various study reaches.

Based on the various analyses that were done, the drainage-area-ratio method best estimated the flood flows for the Akron to North Sioux City reach of the Big Sioux River. The best estimates of 10-, 50-, 100-, and 500-year flood flows at the location downstream from North Sioux City are 35,300, 70,400, 89,100, and 142,000 cubic feet per second, respectively.

INTRODUCTION

The National Flood Insurance Program (NFIP) was established by the National Flood Insurance Act of 1968 and further defined by the Flood Disaster Protection Act of 1973. The 1968 Act provided flood insurance within communities that were willing to adopt flood-plain management programs to mitigate future flood losses. In order to develop these programs, the identification of flood-plain areas within the United States and the establishment of flood-risk zones within these areas was required.

Flood Insurance Studies (FIS's), restudies, and Limited Map Maintenance Program FIS projects for flood-prone communities are necessary to meet the requirements of the National Flood Insurance and Flood Disaster Protection Acts. FIS's provide communities with sufficient technical information to enable them to adopt and amend flood-plain management measures required for participation in the NFIP. They also assist in developing flood-risk information necessary to establish and maintain accurate actuarial flood-insurance premiums.

North Sioux City, Union County, and the U.S. Geological Survey (USGS) entered into a cooperative agreement for 1995-96 to estimate flood flows on the Big Sioux River between Akron, Iowa, and the southern corporate limits of North Sioux City, South Dakota. The results of this hydrology study will be used by the U.S. Army Corps of Engineers to accomplish hydraulic analyses necessary to support a Federal Emergency Management Agency (FEMA) Flood Insurance Study for a portion of Union County and for North Sioux City.

Purpose

The purpose of this report is to present estimated flood flows for the 10-, 50-, 100-, and 500-year recurrence intervals at selected locations on the Big Sioux River between the Akron streamflow-gaging station and North Sioux City. Various methods were used to define a range of flood flows that could be expected for the various recurrence intervals. The estimated flood flows are presented to support a FEMA Flood Insurance Study for a portion of Union County and for North Sioux City.

Description of the Study Area

The study area is located in the Big Sioux River Basin in extreme southeastern South Dakota and extreme northwestern Iowa. The reach of the Big Sioux River between the Akron gaging station and North Sioux City (fig. 1) was studied in detail. Counties in the main study-area reach include Lincoln and Union Counties in South Dakota and Plymouth and Woodbury Counties in Iowa. The primary tributaries of the Big Sioux River in the study reach include Brule Creek (drainage area of 214.3 mi^2 (square miles)), Big Ditch (drainage area of 47.5 mi^2), and Union Creek (drainage area of 36.3 mi^2) in South Dakota and Broken Kettle Creek (drainage area of 98.8 mi^2) and Westfield Creek (drainage area of 30.2 mi^2) in Iowa. McCook Lake, Horseshoe Lake, and Lake Nixon are the largest lakes in the area.

The study area in South Dakota is located primarily in the Coteau des Prairies and the Missouri River trench. Pleistocene glacial deposits or nonglacial loess (windblown sand and silt) and stream deposits overlay the area. The glacial deposits are either till or outwash. The bedrock units underlying these deposits are primarily the Dakota Formation or the Carlile Shale (Niehus, 1994).

Drainage Basins

Drainage in southern Lincoln and Union Counties in South Dakota and Plymouth and Woodbury Counties in Iowa is well developed and is primarily by the Big Sioux River and its tributaries. The Big Sioux River in the study reach flows from north to south and forms the boundary between South Dakota and Iowa.

A summary of individual drainage basins between the Akron gaging station and North Sioux City are shown in table 1. Locations where the 10-, 50-, 100-, and 500-year recurrence interval flows were estimated are shown in table 2 and on figure 2. The locations were chosen at major drainage-basin divides, subdividing the Big Sioux River drainage between the Akron gaging station and North Sioux City into drainage areas ranging from 34.8 to 218.4 mi^2.

Streamflow

Two streamflow-gaging stations, the Big Sioux River at Akron (station 06485500) and Brule Creek near Elk Point (station 06485696), currently are operated by the USGS within the study area. During water years 1929-94, the average annual streamflow for the Akron gaging station was 1,126 ft^3/s (cubic feet per second), with a flow of 68 ft^3/s being exceeded 90 percent of the time. The highest instantaneous peak flow at this gaging station was 80,800 ft^3/s on April 9, 1969. The contributing drainage area for the Akron gaging station is 6,937 mi^2. During water years 1983-94, the average annual streamflow for the Elk Point gaging station was 66.5 ft^3/s, with a flow of 3.6 ft^3/s being exceeded 90 percent of the time. The highest instantaneous peak flow at this gaging station was 6,290 ft^3/s on June 28, 1983. The contributing drainage area for the Elk Point gaging station is 204 mi^2.

Another gaging station in the study area, West Union Creek near Alcester (06485550), was operated from 1969-79. However, it was not used for analysis because of its small drainage area (3.48 mi^2).

Other Big Sioux River gaging stations (fig. 1) used in this study included the Big Sioux River near Brookings (station 06480000), the Big Sioux River near Dell Rapids (station 06481000), the Big Sioux River at Sioux Falls (station 06482000), the Big Sioux River at North Cliff Avenue at Sioux Falls (station 06482020), and the Big Sioux River near Brandon (station 06482100). The contributing drainage areas of these five Big Sioux River stations range from 2,419 to 3,729 mi^2. Streamflow data from the Big

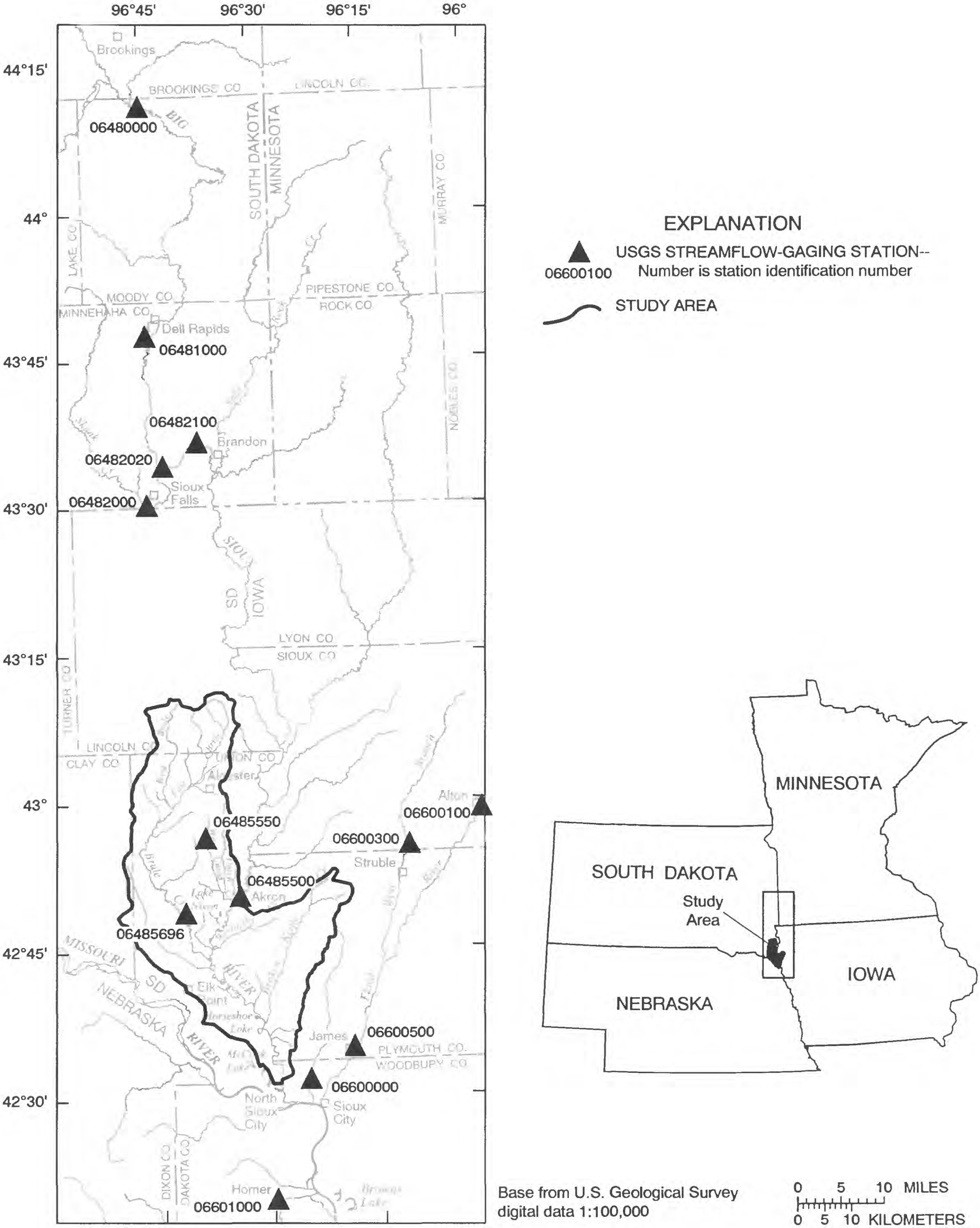
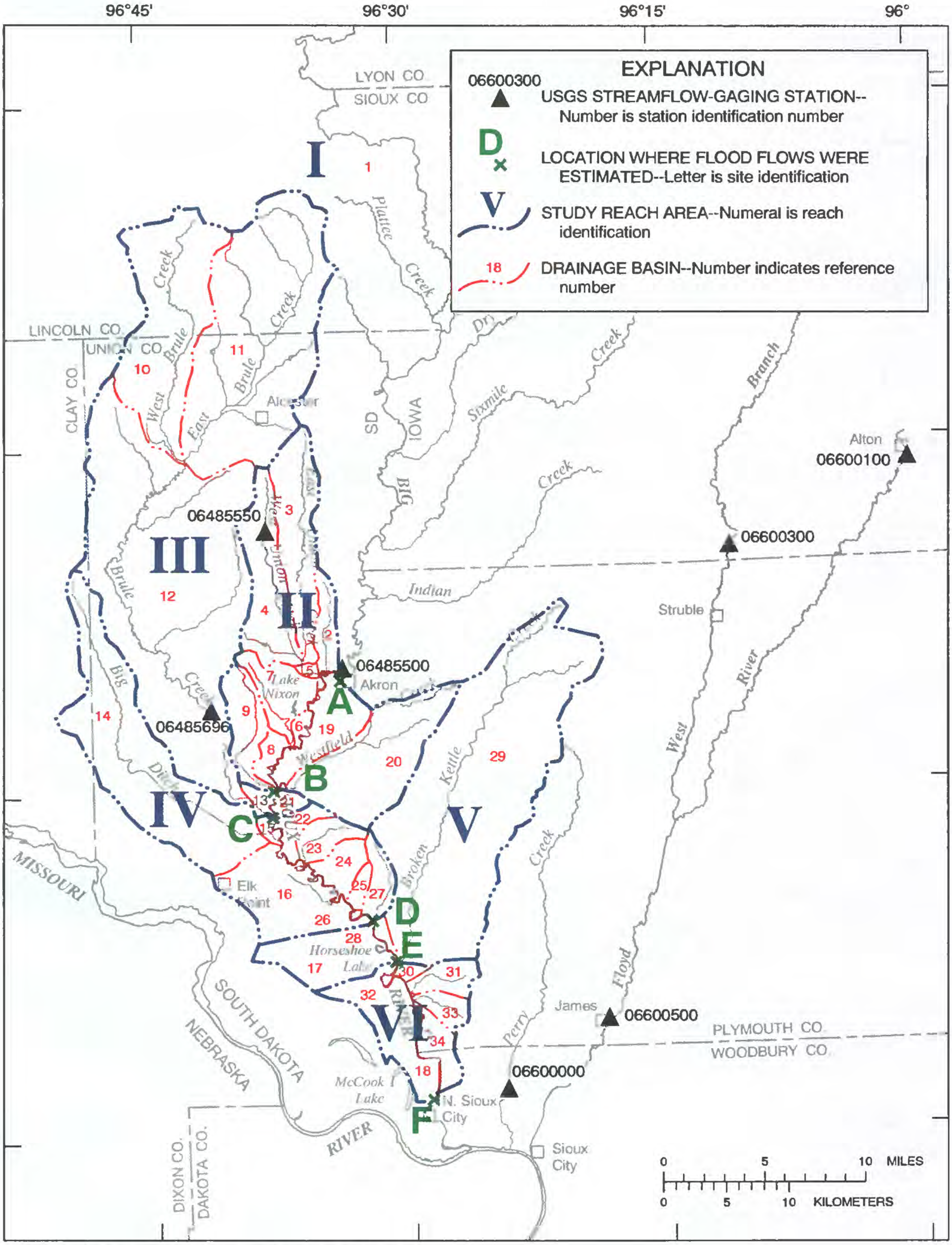


Figure 1. Selected streamflow-gaging stations in and near the study area.

Table 1. Summary of drainage basins in the study area

[mi^2, square miles]

Reference number (fig. 2)	Drainage basin name	Contributing drainage area (mi^2)	State	Reach numeral (fig. 2)
1	Above Akron Gaging Station	6,937	SD-IA-MINN	I
2	Union Creek-Akron Gaging Station	4.50	SD	II
3	East Union Creek	18.5	SD	II
4	West Union Creek	17.0	SD	II
5	Union Creek	0.76	SD	II
6	Union Creek-Sayles Creek	1.81	SD	II
7	Sayles Creek	8.67	SD	II
8	Sayles Creek-Richland Creek	2.75	SD	II
9	Richland Creek	8.63	SD	II
10	West Brule Creek	38.7	SD	III
11	East Brule Creek	69.6	SD	III
12	Brule Creek	106.0	SD	III
13	Richland Creek-Brule Creek	1.74	SD	III
14	Big Ditch Creek	47.5	SD	IV
15	Brule Creek-Big Ditch Creek	0.66	SD	IV
16	Upper West Boundary Big Ditch-Big Sioux River	17.2	SD	IV
17	Middle West Boundary Big Ditch-Big Sioux River	10.18	SD	V
18	Lower West Boundary Big Ditch-Big Sioux River	17.26	SD	VI
19	Westfield Creek-Akron Gaging Station	11.12	IA	II
20	Westfield Creek	30.2	IA	II
21	Plymouth County #1-Westfield Creek	2.39	IA	III
22	Plymouth County #1-Westfield Creek	3.26	IA	IV
23	Plymouth County #1	4.38	IA	IV
24	Joy Creek-Plymouth County #1	4.92	IA	IV
25	Joy Creek	1.35	IA	IV
26	Rock Creek-Joy Creek	0.38	IA	IV
27	Rock Creek	4.30	IA	IV
28	Broken Kettle Creek-Rock Creek	1.54	IA	V
29	Broken Kettle Creek	98.8	IA	V
30	Hancock North Creek-Broken Kettle Creek	1.42	IA	VI
31	Hancock North Creek	5.59	IA	VI
32	Hancock South Creek-Hancock North Creek	0.06	IA	VI
33	Hancock South Creek	4.16	IA	VI
34	North Sioux City-Hancock South Creek	6.40	IA	VI



Base from U.S. Geological Survey digital data 1:100,000

Figure 2. Drainage basins in the study area.

Table 2. Summary of drainage basins at selected locations between the Akron, Iowa, gaging station and North Sioux City, South Dakota

[mi^2, square miles]

Location where flood flows were estimated (fig. 2)	Reach (numeral: description)	Contributing drainage area in reach (mi^2)	Total contributing drainage area (mi^2)
A	I: Upstream from Akron streamflow-gaging station.	6,937	6,937
B	II: Akron gaging station to downstream from Richland Creek-Westfield Creek.	104.0	7,041
C	III: Downstream from Richland Creek-Westfield Creek to downstream from Richland Creek-Brule Creek/Plymouth County #1-Westfield Creek.	218.4	7,259
D	IV: Downstream from Richland Creek-Brule Creek/Plymouth County #1-Westfield Creek to downstream from Upper West Boundary Big Ditch-Big Sioux River/Rock Creek.	84.0	7,343
E	V: Downstream from Upper West Boundary Big Ditch-Big Sioux River/Rock Creek to downstream from Middle West Boundary Big Ditch-Big Sioux River/Broken Kettle Creek.	110.5	7,454
F	VI: Downstream from Middle West Boundary Big Ditch-Big Sioux River/Broken Kettle Creek to downstream from Lower West Boundary Big Ditch-Big Sioux River/North Sioux City-Hancock South Creek.	34.8	7,489

Sioux River at Sioux Falls, the Big Sioux River at North Cliff Avenue, at Sioux Falls, and the Big Sioux River near Brandon stations were combined to yield a single flood-frequency analysis for the Big Sioux River in the vicinity of Sioux Falls.

Several nearby streamflow-gaging stations in Iowa and Nebraska (fig. 1), located in basins that are near or adjacent to the study area, were used in the analyses. Data from these gaging stations were used to aid in assessing the representativeness of the period of record for the Brule Creek gaging station. The gaging stations that were used include the Floyd River at Alton, Iowa (station 06600100); the Floyd River at Struble, Iowa (station 06600300); the Floyd River at James, Iowa (station 06600500); Perry Creek at Sioux City, Iowa (station 06600000); and Omaha Creek at Homer, Nebraska (station 06601000). The drainage areas of these stations range from 65.1 to 882 mi^2.

A summary of data pertaining to the USGS streamflow-gaging stations in or near the study area is shown in table 3. Also, this table includes flood-frequency results for the gaging stations using the log-Pearson Type III procedure recommended by the U.S. Interagency Advisory Committee on Water Data (Bulletin 17B, 1982) for the 10-, 50-, 100-, and 500-year recurrence intervals.

ESTIMATED FLOOD FLOWS AT SELECTED SITES USING VARIOUS METHODS

Various methods were used to estimate flood flows for the 10-, 50-, 100-, and 500-year recurrence intervals at selected locations between the Akron gaging station and North Sioux City. All of the methods used the Akron annual peak-flow data, to varying degrees. The Akron station is the most important gaging station used in this study, mainly because of its long period of record (1929-94) and because its upstream drainage area constitutes 93 percent of the total drainage area of the Big Sioux River Basin upstream from North Sioux City. The flood-flow estimation methods, in various ways, adjust the Akron flow data or perform a hydrologic analysis of the contributing drainage area below the Akron station to account for the 7 percent of the total Big Sioux River drainage area between Akron and North Sioux City.

The methods used to estimate flood flows included:

1. Use of drainage-area ratios raised to specified exponents to transfer the Bulletin 17B flood-frequency results for Akron to selected downstream locations (between Akron and North Sioux City);

Table 3. Summary of flood-frequency results for selected gaging stations within and near the study area

[Based on procedure of U.S. Interagency Advisory Committee on Water Data (1982). u.s., upstream on the Big Sioux River; mi^2, square miles; ft^3/s, cubic feet per second; --, no analysis done]

General location	Station number (fig. 1)	Station name	Period of analysis (water years)	Contributing drainage area (mi^2)	Peak flow, in ft^3/s, for recurrence interval, in years and annual exceedance probability, in percent			
					Years: 10 Percent: 10	50 2	100 1	500 0.2
u.s. of study area	06480000	Big Sioux River near Brookings, SD	1954-94	2,419	10,600	23,000	29,800	48,700
u.s. of study area	06481000	Big Sioux River near Dell Rapids, SD	1949-94	3,004	13,100	28,100	36,300	59,400
u.s. of study area	06482000	Big Sioux River at Sioux Falls, SD	1944-60	3,780	--	--	--	--
u.s. of study area	06482020	Big Sioux River at North Cliff Ave., at Sioux Falls, SD	[1]1944-94	3,729	12,800	28,300	37,700	67,600
u.s. of study area	06482100	Big Sioux River near Brandon, SD	1960-72	3,840	--	--	--	--
in study area	06485500	Big Sioux River at Akron, IA	1929-94	6,937	34,000	66,700	83,500	129,000
in study area	06485550	West Union Creek near Alcester, SD	1969-79	3.48	--	--	--	--
in study area	06485696	Brule Creek near Elk Point, SD	1983-94	204	3,870	7,290	9,100	14,300
near the study area	06600000	Perry Creek at 38th Street, Sioux City, IA	1939-69, [2]1981-94	65.1	6,090	9,230	10,500	13,200
near the study area	06600100	Floyd River at Alton, IA	[3]1953, 1956-94	268	8,690	20,600	27,600	49,100
near the study area	06600300	West Branch Floyd River near Struble, IA	[4]1956-94	180	7,180	13,000	15,700	22,200
near the study area	06600500	Floyd River at James, IA	[5]1935-94	886	12,700	25,100	31,800	51,100
near the study area	06601000	Omaha Creek at Homer, NE	1940, [6]1946-94	174	9,480	18,600	23,700	38,800

[1]Period of analysis, 1944-60 from station 06482000 and 1960-72 from station 06482100.
[2]60 years of historic record used in analysis.
[3]119 years of historic record used in analysis.
[4]41 years of historic record used in analysis.
[5]119 years of historic record used in analysis.
[6]73 years of historic record used in analysis.

2. A flood-frequency analysis performed on a summation of the Akron gaging-station peak flows and concurrent daily flows from tributaries within the various reaches downstream from Akron;
3. An independence (flows are unrelated) versus dependence (flows are related) analysis of the Akron flows and tributary flows within the various study reaches; and
4. A flood-frequency analysis assuming complete dependence of the Akron peak flows and tributary peak flows within the various study reaches.

Locations where the flood flows were estimated are described in table 2 and shown in figure 2, and include:

A: at the Akron gaging station;
B: downstream from the Richland-Westfield Creek Basins;
C: downstream from the Brule Creek Basin;
D: downstream from the Upper West Boundary Big Ditch and Rock Creek Basins;
E: downstream from Broken Kettle Basin; and
F: downstream from North Sioux City.

Drainage-Area-Ratio Methods

The results of a Bulletin 17B frequency analysis (U.S. Interagency Advisory Committee on Water Data, 1982) for the gaging station on the Big Sioux River at Akron (site A) were used to estimate the 10-, 50-, 100-, and 500-year flood flows by applying drainage-area ratios at selected downstream locations. This gaging station represents most of the total drainage area of the Big Sioux River Basin upstream from North Sioux City. The following methods assume that flows within the remaining basin behave similarly to flows within the basin upstream from the Akron gaging station. The drainage-area ratios (drainage areas at selected locations downstream from the Akron gage divided by the drainage area at the Akron gage) were raised to specified exponents and multiplied by the appropriate flood flow for the Akron gaging station. The following equation was used:

$$Q = Q_A \times \left(\frac{DA}{DA_A}\right)^N \qquad (1)$$

where

Q = estimated flow at 10-, 50-, 100-, or 500-year recurrence intervals at a selected location downstream from the Akron gaging station;

Q_A = estimated flow at the Akron gaging station for 10-, 50-, 100-, or 500-year recurrence intervals;

DA = contributing drainage area at a selected location downstream from the Akron gaging station;

DA_A = contributing drainage area at the Akron gaging station; and

N = specified exponent.

The exponent, N, was first set at the value of 0.5, a widely used value for the exponent if no site-specific drainage-area-ratio analysis has been done. The 10-, 50-, 100-, and 500-year flood flows estimated at the location downstream from North Sioux City (site F) using exponents equal to 0.5 are 35,300, 69,300, 86,800, and 134,000 ft^3/s, respectively.

More site-specific results can be obtained if a drainage-area-ratio analysis has been done using data collected close to the site of interest. Accordingly, exponents for the Big Sioux Basin determined from work associated with an ongoing regional frequency study for South Dakota were used (S.K. Sando, U.S. Geological Survey, written commun., 1996). These exponents were determined by flood-frequency regression analysis, using drainage areas from 37 sites with greater than 10 years of record. Exponents determined from Sando's regional frequency study for the Big Sioux Basin are 0.539, 0.531, 0.530, and 0.528 for the 10-, 50-, 100-, and 500-year flood flows, respectively. Using these exponents, the estimated 10-, 50-, 100-, and 500-year flood flows estimated at the location downstream from North Sioux City are 35,500, 69,500, 87,000, and 135,000 ft^3/s, respectively. These flood flows are nearly equal to the values estimated using the previous drainage-area-ratio method, in which the exponent was set to 0.5 for all flood frequencies.

Another method is to determine the exponent by analyzing data between nearby Big Sioux River gaging stations. Equation 1 is solved for N instead of Q. The following equation was used in this analysis:

$$N = \left(\log\left(\frac{Q_{ds}}{Q_{us}}\right)\right) \div \left(\log\left(\frac{DA_{ds}}{DA_{us}}\right)\right) \qquad (2)$$

where

N = specified exponent;

Q_{ds} = estimated flow at the Big Sioux River downstream gaging station for recurrence intervals of 10, 50, 100, or 500 years;

Q_{us} = estimated flow at the Big Sioux River upstream gaging station for recurrence intervals of 10, 50, 100, or 500 years;

DA_{ds} = contributing drainage area at the Big Sioux River downstream gaging station; and

DA_{us} = contributing drainage area at the Big Sioux River upstream gaging station.

The N values were determined by plotting $\left(\log\left(\frac{Q_{ds}}{Q_{us}}\right)\right)$ versus $\left(\log\left(\frac{DA_{ds}}{DA_{us}}\right)\right)$ using concurrent data from the Big Sioux River gaging stations near Brookings, near Dell Rapids, and at Sioux Falls (see fig. 1). A combination of data from the Sioux Falls, Brandon, and North Cliff Avenue at Sioux Falls gaging stations was used to represent the "at Sioux Falls" peak-flow data. No comparisons were done upstream from the Akron gaging-station data because of the large increase in drainage area (over 3,000 mi^2) from the nearest upstream Big Sioux River gaging station to the Akron gaging station and because the log data did not fit with the other Big Sioux River gaging-station comparisons. The slope of a line connecting the log values for a certain flood-frequency was used to determine the values of N, which were 0.500, 0.710, 0.850, and 1.200 for the 10-, 50-, 100-, and 500-year flood flows, respectively. The estimated flood flows at the location downstream from North Sioux City for the 10-, 50-, 100-, and 500-year recurrence intervals are 35,300, 70,400, 89,100, and 142,000 ft^3/s, respectively. These estimated flood flows are nearly equal to the previous values for the 10- and 50-year frequencies using alternative values of N. The 100- and 500-year flood frequencies are a small percentage larger (less than 6 percent) using this analysis.

A summary of the 10-, 50-, 100-, and 500-year flood flows at selected locations estimated by raising the drainage-area ratios to specified exponents is shown in table 4. The summary includes results from the three methods outlined above.

Flood-Frequency Analysis of the Big Sioux River at Akron Gaging-Station Peak Flows and Concurrent Daily Flows from Tributaries within the Various Reaches

A flood-frequency analysis was done on synthesized peak-flow data, which consisted of a summation of the Akron gaging-station peak flows and concurrent daily flows from tributaries within the various study reaches. The method was done to synthesize an approximate routing of the flow from Akron to North Sioux City.

The period of analysis of 1983-94 was selected to coincide with the period of record for the Brule Creek near Elk Point gaging station. The Akron gaging station, by contrast, has a period of record of 1929-94. An adjustment to the 1983-94 analysis was necessary to account for these differing periods of record. A two-station comparison was done to adjust the logarithmic mean and standard deviation of the synthesized data for the short-term record (1983-94), on the basis of a regression analysis with the long-term record (1929-94) for the Akron gaging station (Matalas and Jacobs, 1964; U.S. Interagency Advisory Committee on Water Data, 1982). The estimated flood flows using this method then reflect the same long-term record (1929-94) as the Akron gaging station, thereby producing more accurate results.

Table 4. Summary of flood-frequency results at selected locations using the drainage-area method with specified exponents
[mi^2, square miles; ft^3/s, cubic feet per second; N, specified exponent]

Method	Location where flood flows were estimated (fig. 2 and table 2)	Contributing drainage area (mi^2)		Peak flow, in ft^3/s, for recurrence interval, in years, and annual exceedance probability, in percent			
			Years: / Percent:	10 / 10	50 / 2	100 / 1	500 / 0.2
Standard *N*			*N:*	0.500	0.500	0.500	0.500
	A	6,937		34,000	66,700	83,500	129,000
	B	7,041		34,300	67,200	84,100	130,300
	C	7,259		34,800	68,200	85,500	132,000
	D	7,343		35,000	68,600	85,900	133,000
	E	7,454		35,300	69,100	86,600	134,000
	F	7,489		35,300	69,300	86,800	134,000
N from regional flood frequency analysis for Big Sioux River Basin			*N:*	0.539	0.531	0.530	0.528
	A	6,937		34,000	66,700	83,500	129,000
	B	7,041		34,300	67,200	84,200	130,000
	C	7,259		34,900	68,300	85,600	132,000
	D	7,343		35,100	68,800	86,100	133,000
	E	7,454		35,400	69,300	86,800	134,000
	F	7,489		35,500	69,500	87,000	135,000
N from upstream Big Sioux River gaging station analysis			*N:*	0.500	0.710	0.850	1.200
	A	6,937		34,000	66,700	83,500	129,000
	B	7,041		34,300	67,400	84,600	132,000
	C	7,259		34,800	68,900	86,800	137,000
	D	7,343		35,000	69,400	87,700	138,000
	E	7,454		35,300	70,200	88,800	141,000
	F	7,489		35,300	70,400	89,100	142,000

Only the flood flows at North Sioux City were estimated using this method because of the lack of gaged daily-flow data for tributaries other than Brule Creek within the various study reaches. The daily flows for other tributaries within the various reaches were estimated by using a drainage-area-ratio equation (Hirsch, 1979), using the 1983-94 record of the Brule Creek near Elk Point gaging station as the base.

The following equations were used to synthesize the peak-flow data:

$$Q_P = Q_A + Q_E + Q_O \quad (3)$$

$$Q_O = Q_E \times \left(\frac{DA_O}{DA_E}\right) \quad (4)$$

where

Q_P = synthesized peak flow downstream from North Sioux City;

Q_A = peak flow at the Akron gaging station;

Q_E = Elk Point gaging station daily flow concurrent with Akron gaging station peak flow;

Q_O = ungaged tributary daily flow concurrent with Akron gaging station peak flow;

DA_O = contributing drainage area of ungaged tributary basins between Akron gage and North Sioux City; and

D_{AE} = contributing drainage area at Elk Point gaging station (204 mi^2).

Using this method, the estimated 10-, 50-, 100-, and 500-year flood flows at the location downstream from North Sioux City are 35,700, 70,700, 89,000, and 139,000 ft^3/s, respectively.

A flood-frequency analysis also was done on synthesized peak-flow data for the 1983-94 period, consisting of a summation of the gaged and estimated tributary peak flows within the various reaches and concurrent Akron gaging-station daily flows. This method should show how close the tributary peak flows occur to the Akron gaging-station peak flows. The largest peak flows on the Big Sioux River will occur when the peak flows at Akron occur at the same time as the peak flows on the tributaries. However, the 10-, 50-, 100-, and 500-year flood flows estimated using this method for the location downstream from North Sioux City were substantially less than the Akron Bulletin 17B gaging-station results and were not considered valid.

Independence/Dependence Analysis of the Big Sioux River at Akron Gaging-Station and Tributary Flows within the Various Reaches

An independence/dependence analysis was done on the Akron gaging-station flows and the tributary flows within the various study reaches. Complete independence at the confluence of two streams means that the peak-flow events on the two streams are entirely unrelated in cause and do not have any peak-flow relation. The peak flows do not occur at the same time on the two streams. If the flow events have probabilities of occurrence of p1 and p2, the probability that the flow events will occur at the same time is p1 times p2 (Linsley and Franzini, 1979). In contrast, complete dependence at the confluence of two streams means that the peak-flow events on the two streams are related in cause and have a close peak-flow relation. Flow events of two streams having equal probability are assumed to occur simultaneously for completely dependent streams. The flow at their confluence is the sum of the flows having the same recurrence intervals (Linsley and Franzini, 1979).

The Brule Creek near Elk Point gaging-station flows were used to represent the tributary flows within the various reaches. Flows from this gaging station were considered representative of the other tributary flows because of the fairly representative drainage-basin size (204 mi^2) and the close proximity to the other tributary drainage basins. Flows were compared to determine if independent or dependent relations existed.

Peak- and daily-flow relations of the Akron gaging station and tributaries within the various reaches were first investigated. A Spearman rank correlation analysis was done to show how strong a relation exists between the Akron and the Elk Point gaging-station peak and daily flows. This rank correlation analysis is used for nonparametric data and measures the monotonic association between the two samples (whether one sample increases or decreases with the other sample, even when the relation between the samples is not linear). The Spearman rank correlation results were both significant at the 5-percent confidence level, with a stronger relation between daily flows than between peak flows. The correlation coefficients were 0.85 using the 1983-94 daily-flow sample sets and 0.78 using the 1983-94 annual peak-flow sample sets.

Statistical comparisons of the Akron and the Elk Point gaging-station flows also were done to test for independence or dependence of data sets composed of peaks exclusively from rainfall events. Annual peaks from snowmelt events at both gaging stations were not considered due to the small data set in the 1983-94 period. The Spearman rank correlation results were significant (coefficient of 0.89), indicating a strong relation between 1983-94 rainfall peak flows. If only rainfall peak flows are considered, the two gaging stations show more of a dependent relation than if both snowmelt and rainfall peak flows are considered.

Although the rank correlation analysis indicates a strong monotonic relation between the Akron and Elk Point gaging-station peak and daily flows, the analysis does not necessarily indicate that the two sites behave dependently with respect to individual flood peaks. The strong positive correlation in flows probably shows that the hydrologic characteristics of the two drainage basins are dominated by similar areal moisture conditions from year to year and does not necessarily indicate dependence of the individual peak flows.

The peak and daily flows also were analyzed by plotting peak and daily flows at the Akron and Elk Point gaging stations for the concurrent period of record (1983-94) to compare the flow behavior at the two sites. Figure 3 (A, C, and D) shows the peak and daily flows for these two sites for selected periods during 1983-94 when the annual peak flows occurred at both locations during the spring. In June of 1983, the peak flow at the Akron gaging station occurred 6 days before the peak flow at the Elk Point gaging station (fig. 3 (A)). At the time of the Elk Point peak flow, the concurrent daily flow at the Akron gaging station was substantially lower than the peak that occurred on June 21. The estimated time it takes the peak flow at the Akron gaging station to arrive at the confluence with Brule Creek on the Big Sioux River is less than one day, based on an estimated time-of-travel velocity of 5 ft/s (feet per second). Thus, in 1983, the peak flows of the Big Sioux River and Brule Creek were not dependent. In 1987 and 1993 (fig. 3 (C and D)), the peak flows at the Elk Point gaging station occur 3 and 43 days, respectively, before the Akron gaging-station peak flows occur, again indicating that the peak flows are not dependent. Figure 3 (B) also shows the daily flows for these two sites for a portion of 1986, when the annual peak flows occurred during different seasons. The annual peak at the Akron gaging station occurred on September 25, whereas the annual peak at the Elk Point gaging station occurred on March 18. Again, peaks flows for 1986 at the two sites were not dependent.

The Brule Creek near Elk Point gaging-station peak and daily flows were compared to peak and daily flows at stations with similar-sized drainage basins in Iowa and Nebraska to determine if the Elk Point flows were representative of flows from smaller drainage basins in the study area. This was important because the joint frequency analysis relied heavily on the Elk Point gaging-station flows to represent all of the tributary flows within the various study reaches. The contributing drainage area from tributaries within the various reaches ranged from 34.8 to 218.4 mi^2 (table 2), as compared to 65.1 to 886 mi^2 for the nearby gaging stations (table 3). These gaging stations, listed in increasing drainage-area size, include Perry Creek at 38th Street, Sioux City, Iowa; Omaha Creek at Homer, Nebraska; West Branch Floyd River near Struble, Iowa; Floyd River at Alton, Iowa; and Floyd River at James, Iowa. A Spearman rank correlation analysis was used to determine how strong a relation exists between peak and daily flows at the Elk Point gaging station and at these nearby gaging stations during the 1983-94 period. The Spearman rank correlation results were all significant at the 5-percent confidence level, except for peak flows from the Perry Creek at Sioux City station. A much stronger relation existed between daily than between peak flows. The coefficients ranged from 0.75 to 0.89 using the 1983-94 daily-flow data sets and ranged from 0.60 to 0.81 using the 1983-94 annual peak-flow data sets (excluding the Perry Creek at Sioux City result for peak flows that was not significant). Plots of daily flows at the Elk Point and nearby gaging stations in Iowa and Nebraska for selected periods during 1983-94 (figs. 4 and 5) show that the daily flows at the Elk Point station behave similarly to daily flows at nearby gaging stations. Based on these analyses, the Elk Point gaging station appears to be representative of the tributary flows within the various study reaches.

A joint frequency analysis was done on the Akron gaging-station flows and the tributary flows within the various study reaches, where peak flows for Akron and the tributaries were assumed to have an independent relation. The Brule Creek near Elk Point gaging-station peak flows again were used to represent all tributary flows. Again, complete independence (unrelated in cause) at the confluence of two streams assumes that the probability that they will occur at the same time is the product of their independent probabilities (Linsley and Franzini, 1979). Thus, the probability of their joint occurrence is less than the probability of either event occurring independently. Application of this procedure to flood frequencies at

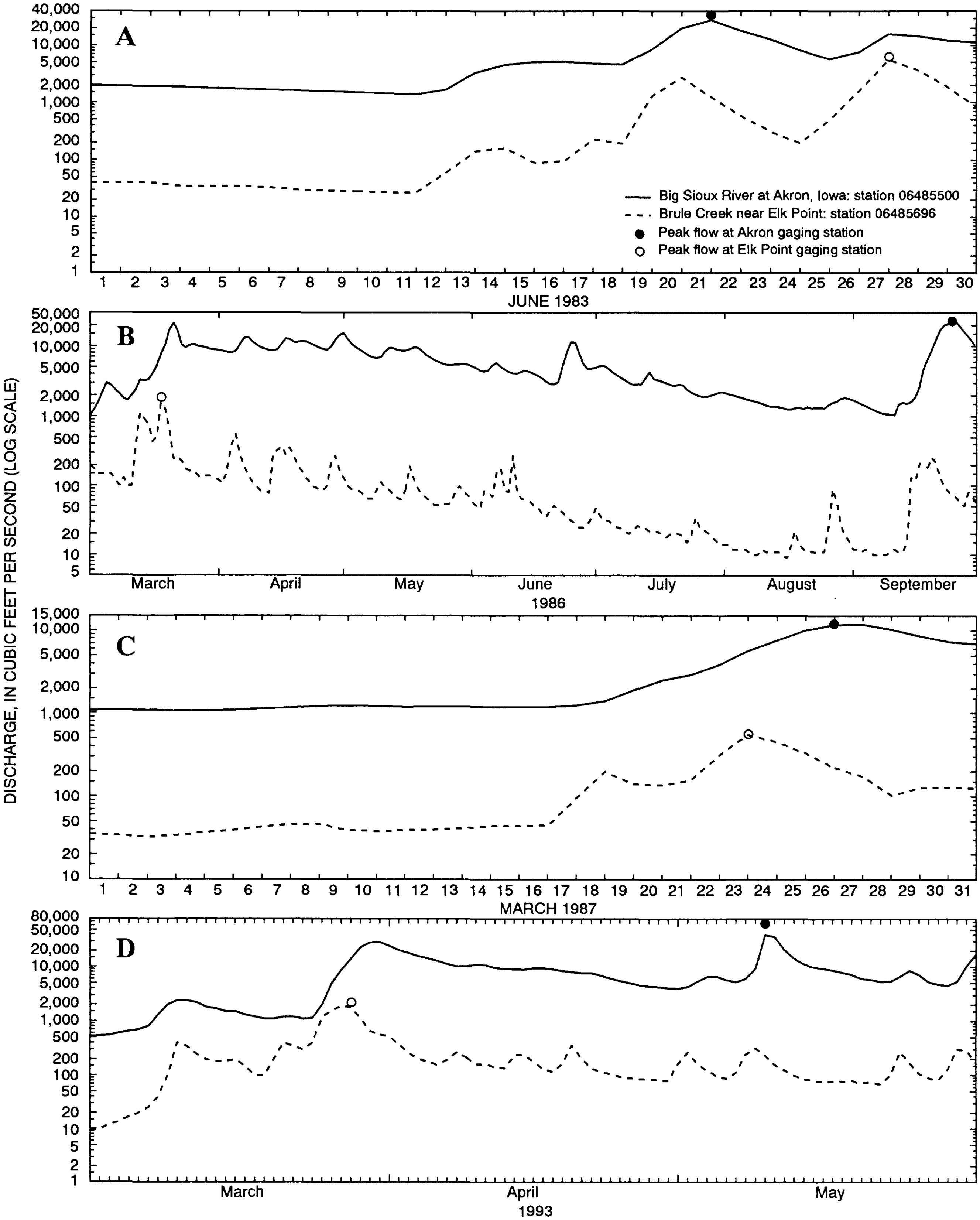


Figure 3. Peak and daily flows for selected periods for the Big Sioux River at Akron, Iowa, and Brule Creek near Elk Point, South Dakota, gaging stations.

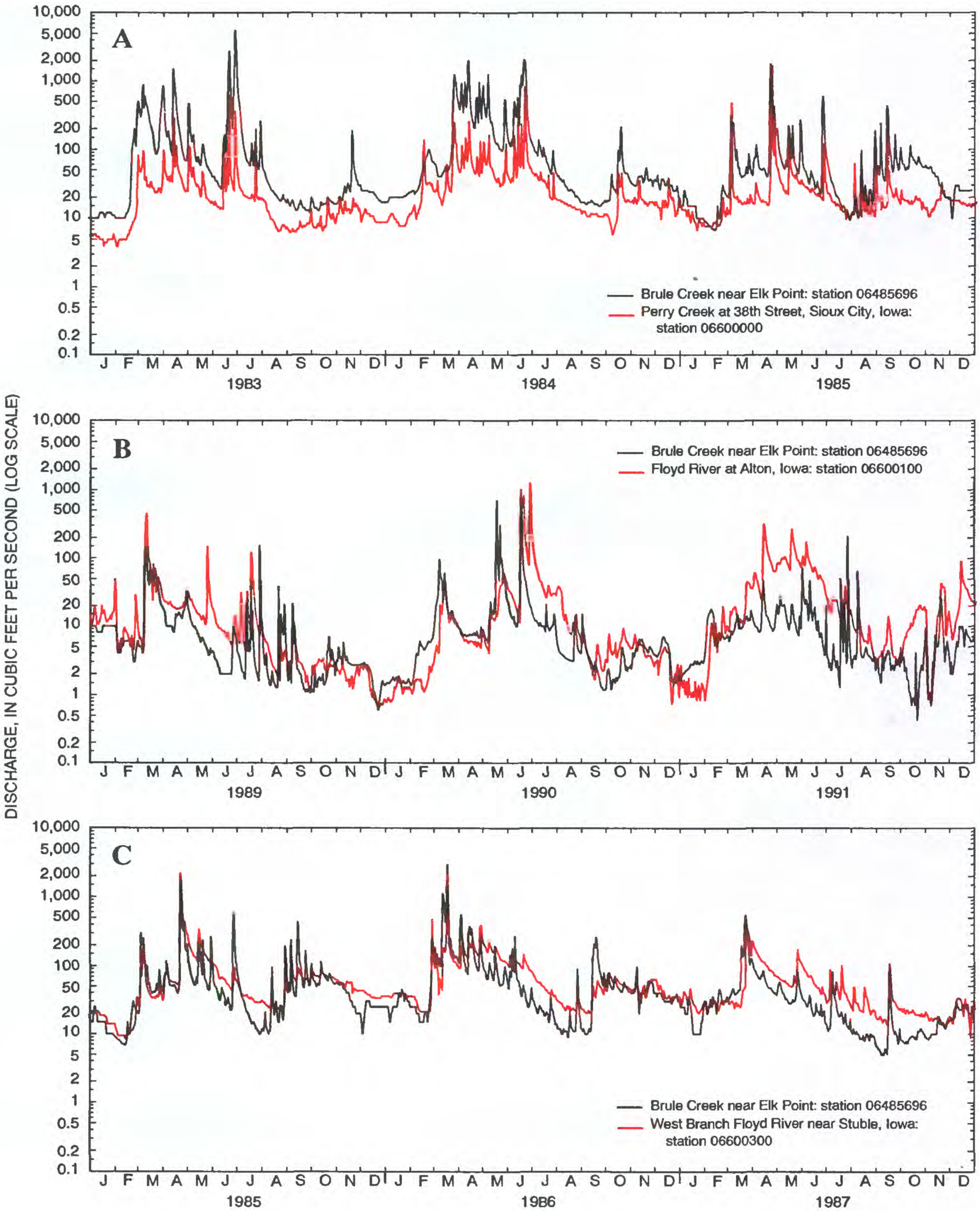


Figure 4. Daily flows for selected periods for the Brule Creek near Elk Point, South Dakota, and nearby Iowa gaging stations.

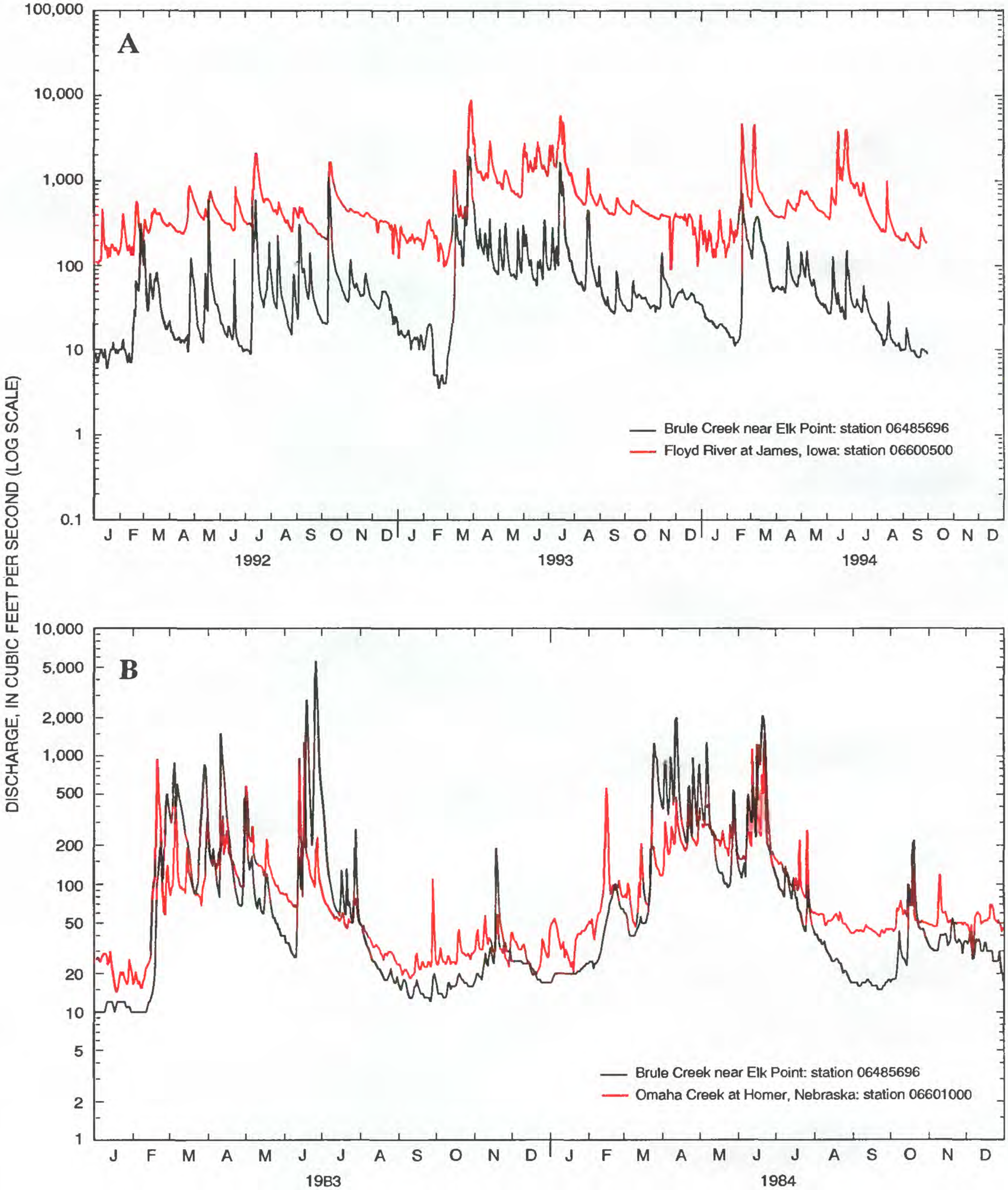


Figure 5. Daily flows for selected periods for the Brule Creek near Elk Point, South Dakota, and nearby Iowa and Nebraska gaging stations.

the Elk Point and Akron stations did not result in reasonable estimated flood flows. This procedure is not applicable to the conditions in the study area because of the large differences in drainage areas and in peak flows between the Big Sioux River main stem and tributaries.

Complete Dependence of the Big Sioux River at the Akron Gaging-Station and Tributary Peak Flows within the Various Reaches

The largest flows for the respective recurrence intervals should occur when the Akron peak flows and the tributary peak flows have an entirely dependent flow relation. If complete dependence is assumed, flow events of equal probability are assumed to occur simultaneously on the two streams. The flow at their confluence is the sum of the flows having the same recurrence intervals (Linsley and Franzini, 1979). Flood flows were estimated assuming complete dependence to compute the upper limit for Big Sioux River flood flows between the Akron gaging station and North Sioux City.

Peak-flow frequencies for the short-term record (1983-94) for the Brule Creek near Elk Point station were adjusted to make them consistent with the longer term record (1929-94) of the Akron gaging station. Again, the two-station comparison was used to adjust the logarithmic mean and standard deviation of the flow data of the short-term record of the Elk Point gaging station on the basis of a regression analysis with the long-term record of the Akron gaging station. The estimated flood flows using this method then reflect the same long-term record as the Akron gaging station, thereby producing more accurate results.

The flood flows were estimated by summing the flood-frequency results for the Akron gaging station (U.S. Interagency Advisory Committee on Water Data, 1982) and for the tributary reaches. The flood flows for the various recurrence intervals were determined for the tributary flows within the various reaches by using the previously discussed drainage-area-ratio equation (4), with exponents of 0.539, 0.531, 0.530, and 0.528 determined from the previously mentioned regional frequency study for the 10-, 50-, 100-, and 500-year flood flows, respectively. The Elk Point flows used in this equation were the two-station adjusted flows. The 10-, 50-, 100-, and 500-year flood flows at the location downstream from North Sioux City using this method are 39,400, 76,400, 95,600, and 148,000 ft^3/s, respectively. A summary of the 10-, 50-, 100-, and 500-year flood flows at selected locations, assuming complete dependence using the drainage-area method with the two-station adjustment for the Elk Point gaging-station estimated flows, is shown in table 5.

A second method was used to estimate peak-flow frequencies for the ungaged tributary basins without relying on the Brule Creek near Elk Point gaging-station data. The flood flows for the 10-, 50-, 100-, and 500-year recurrence intervals were estimated for the tributary reaches by using the regional regression equations being developed in South Dakota and already developed in Iowa. In South Dakota, the equations were developed for the Big Sioux River and Red River of the North subregion (S.K. Sando, U.S. Geological Survey, written commun., 1996) and are as follows:

$$Q_{10} = 0.061 \times (DA^{0.498}) \times (I^{8.56}) \quad (5)$$

$$Q_{50} = 0.249 \times (DA^{0.505}) \times (I^{7.84}) \quad (6)$$

$$Q_{100} = 0.379 \times (DA^{0.509}) \times (I^{7.64}) \quad (7)$$

$$Q_{500} = 0.837 \times (DA^{0.519}) \times (I^{7.26}) \quad (8)$$

where

Q = estimated flow, in cubic feet per second, at recurrence intervals of 10, 50, 100, or 500 years;

DA = contributing drainage area, in square miles; and

I = 24-hour maximum precipitation (2.75 or 2.80), in inches, for the 2-year recurrence interval.

The equations for Iowa (recurrence intervals 2, 5, 10, 25, 50, and 100 years) are for Iowa's hydrologic region 2 (Lara, 1987). The 500-year recurrence interval flood flows for Iowa drainage basins were estimated by plotting the 2- through 100-year flood-frequency curves for each location and extending the curves to the 500-year flood flows.

The contributing drainage areas used in the equations are the accumulative downstream tributary drainage areas. The flood flows were estimated assuming complete dependence by using the South Dakota and Iowa regional regression equations, but applying them in two different ways:

Table 5. Summary of flood-frequency results at selected locations using the drainage-area method, assuming complete dependence of the Big Sioux River and downstream tributaries

[mi^2, square miles; ft^3/s, cubic feet per second]

Location where flood flows were determined (fig. 2 and table 2)	Contributing drainage area (mi^2)	Peak flow, in ft^3/s, for recurrence interval, in years, and annual exceedance probability, in percent			
		Years: 10 Percent: 10	50 2	100 1	500 0.2
A	6,937	34,000	66,700	83,500	129,000
B	7,041	36,200	70,700	88,500	137,000
C	7,259	38,000	74,000	92,600	143,000
D	7,343	38,600	75,000	93,800	145,000
E	7,454	39,200	76,100	95,100	147,000
F	7,489	39,400	76,400	95,600	148,000

1. The South Dakota and Iowa equations were used for South Dakota and Iowa drainage basins, respectively.
2. The South Dakota equations were used for both the South Dakota and Iowa drainage basins.

The flood flows estimated at the location downstream from North Sioux City using these two methods are 51,800, 98,500, 123,000, and 190,000 ft^3/s (method 1) and 44,300, 87,400, 110,000, and 171,000 ft^3/s (method 2) for the 10-, 50-, 100-, and 500-year recurrence intervals, respectively. A summary of the 10-, 50-, 100-, and 500-year flood flows at selected locations assuming complete dependence using the regional regression equations is shown in table 6.

Summary of Estimated Flood Flows

Flood-flow frequency curves for the Big Sioux River downstream from North Sioux City (summarizing the results using the methods outlined in the previous sections) are shown in figure 6. The largest flood flows were estimated by assuming complete

Table 6. Summary of flood-frequency results at selected locations using the regional-regression equation method, assuming complete dependence of the Big Sioux River and downstream tributaries

[ft^3/s, cubic feet per second]

Method	Location where flood flows were determined (fig. 2 and table 2)	Peak flow, in ft^3/s, for recurrence interval, in years, and annual exceedance probability, in percent			
		Years: 10 Percent: 10	50 2	100 1	500 0.2
South Dakota and Iowa regional regression equations used to compute flows for main study-area drainage reaches.	A	34,000	66,700	83,500	129,000
	B	41,700	80,500	100,000	155,000
	C	44,400	86,100	108,000	166,000
	D	47,100	91,000	114,000	158,000
	E	51,000	97,300	121,000	187,000
	F	51,800	98,500	123,000	190,000
South Dakota regional regression equations used to compute flows for main study-area drainage reaches.	A	34,000	66,700	83,500	129,000
	B	38,500	75,700	94,800	147,000
	C	41,300	81,400	102,000	159,000
	D	42,900	84,500	106,000	165,000
	E	44,000	86,800	109,000	170,000
	F	44,300	87,400	110,000	171,000

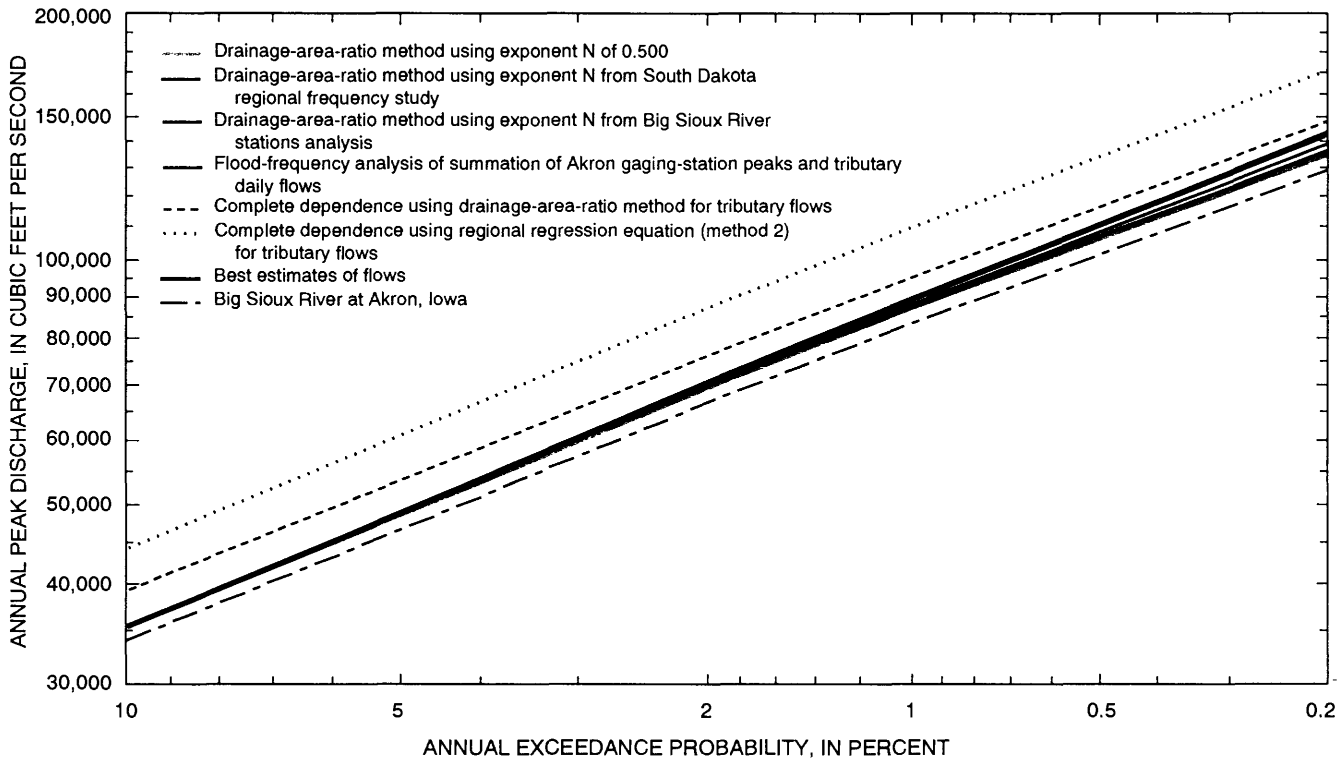


Figure 6. Flood-flow frequency curves for the Big Sioux River downstream from North Sioux City, South Dakota, using various methods, and for the Big Sioux River at Akron, Iowa.

dependence using the regional regression equations to estimate tributary flows within the various reaches. The smallest flood flows were estimated using the drainage-area-ratio method.

BEST ESTIMATE OF FLOOD FLOWS AT SELECTED SITES

Based on the independence/dependence analysis of the Big Sioux River at Akron and Brule Creek near Elk Point gaging-station flows, flows of the Big Sioux River and its downstream tributaries in the study reach are not completely dependent. The results obtained assuming complete dependence may represent an upper limit for flood-frequency estimates that could reasonably be expected to occur on the Big Sioux River downstream from the Akron gaging station.

Because significant correlation was found between the flows at the Akron and Elk Point gaging stations, the flows of the Big Sioux River and its tributaries in the study reach also are not completely independent. However, the estimated flood flows assuming complete independence were considered invalid, and it was concluded that the joint frequency was not applicable due to the large drainage-area differences between main-stem and tributary stations.

The combined flood flows of the Big Sioux River and its tributaries within the study reach almost always are likely to fall between the two extremes of complete dependence and complete independence; methods that account for this should provide the best flood-frequency estimates for the Big Sioux River downstream from North Sioux City.

The drainage-area-ratio methods using the Akron gaging station as a reference inherently account for dependence/independence effects because they are based on long-term gaging data that represent 93 percent of the basin upstream from North Sioux City, and they assume that the downstream 7 percent of the basin behaves similarly to the gaged part of the basin. Performing a flood-frequency analysis on the summation of Akron gaging-station peak flows and concurrent tributary daily flows should also produce flood flows that account for dependence/independence effects because this analysis extrapolates from actual gaging records to produce a reasonable estimate of peak flows downstream from North Sioux City during the period 1983-94. Using the two-station comparison to extend these data should then provide reasonable long-term flood-frequency estimates. The drainage-area-ratio methods and the Akron peak flows/tributary daily flows analyses produced very similar results.

The drainage-area-ratio methods were selected as the methods for best estimating flood flows for the 10-, 50-, 100-, and 500-year recurrence intervals for the Flood Insurance Study of this area. The results obtained at the location downstream from North Sioux City using these methods ranged from 35,300 to 35,500 ft^3/s for the 10-year flow-recurrence interval, from 69,300 to 70,400 ft^3/s for the 50-year flow-recurrence interval, from 86,800 to 89,100 ft^3/s for the 100-year flow-recurrence interval, and from 134,000 to 142,000 ft^3/s for the 500-year flow-recurrence interval. The percent difference in estimated flood flows for all locations between the Akron gaging station and North Sioux City using the three different drainage-area procedures ranged from less than 1 percent for the 10-year recurrence intervals to 6 percent for the 500-year recurrence intervals. In fact, the percent difference for the majority of flows at the various recurrence intervals was less than 3 percent. The maximum flood-frequency estimates from the drainage-area-ratio methods were selected as the best flood-frequency estimates for the Big Sioux River at North Sioux City because: (1) the drainage-area-ratio methods rely heavily on gaging records representing 93 percent of the basin above North Sioux City and inherently account for dependence/independence effects; (2) the drainage-area-ratio methods produced reasonable and very similar results; and (3) selecting the maximum of the drainage-area-ratio results provides a conservative estimate so as to avoid underestimating flood frequencies, an important consideration in flood studies. The 10-, 50-, 100-, and 500-year flood flows estimated at the location downstream from North Sioux City are 35,300, 70,400, 89,100, and 142,000 ft^3/s, respectively. The best flood-frequency estimates for the selected locations are shown in table 7.

Table 7. Summary of the best flood-frequency estimates at selected locations

[mi^2, square miles; ft^3/s, cubic feet per second]

Location where flood flows were estimated (fig. 2 and table 2)	Contributing drainage area (mi^2)	Peak flow, in ft^3/s, for recurrence interval, in years, and annual exceedance probability, in percent				
		Years: Percent:	10 10	50 2	100 1	500 0.2
A	6,937		34,000	66,700	83,500	129,000
B	7,041		34,300	67,400	84,600	132,000
C	7,259		34,800	68,900	86,800	137,000
D	7,343		35,000	69,400	87,700	138,000
E	7,454		35,300	70,200	88,800	141,000
F	7,489		35,300	70,400	89,100	142,000

SUMMARY

This report presents the estimated flood flows using various methods for the 10-, 50-, 100-, and 500-year recurrence intervals at selected locations on the Big Sioux River between the Akron, Iowa, streamflow-gaging station and North Sioux City, South Dakota. The selected locations where the Big Sioux River flood flows were estimated include: at the Akron gaging station, downstream from the Richland-Westfield Creek Basins, downstream from the Brule Creek Basin, downstream from the Upper West Boundary Big Ditch and Rock Creek Basins, downstream from Broken Kettle Basin, and downstream from North Sioux City. The estimated flood flows will be used to support a FEMA Flood Insurance Study. Records from two gaging stations within the study area, the Big Sioux River at Akron and Brule Creek near Elk Point (with periods of records of 1929-94 and 1983-94, respectively) were used extensively for this study.

The methods used to estimate the flood flows included: use of drainage-area ratios raised to specified exponents to transfer the Akron flood-frequency results to the selected downstream locations; a flood-frequency analysis on a summation of the Akron gaging-station peak flows and concurrent tributary daily flows from the various study reaches; an independence/dependence analysis of the Akron gaging-station flows and the tributary flows from the various study reaches; and a flood-frequency analysis assuming complete dependence of the Akron peak flows and the tributary peak flows from the various study reaches.

Three drainage-area-ratio methods were used to estimate flood flows. The specified exponent in the drainage-area-ratio equation was first set at the value of 0.5, the value widely used if no site specific drainage-area-ratio analysis has been done. To obtain more site-specific results, the exponent was set at values (0.539, 0.531, 0.530, and 0.528 for the 10-, 50-, 100-, and 500-year flood flows, respectively) determined from work associated with an ongoing regional frequency study for South Dakota. Finally, the exponents were determined from an analysis of flow data from upstream Big Sioux River gaging stations located near Brookings, near Dell Rapids, and at Sioux Falls. Values equal to 0.500, 0.710, 0.850, and 1.200 were determined for the 10-, 50-, 100-, and 500-year flood flows, respectively.

A flood-frequency analysis was done on synthesized peak flow data for the period 1983-94, consisting of a summation of the Akron gaging-station peak flows and concurrent daily tributary flows from the various reaches that were estimated by using Brule Creek near Elk Point flows adjusted by a drainage-area-ratio equation. A two-station comparison was done to adjust the logarithmic mean and standard deviation of the synthesized data for the short-term record (1983-94), on the basis of a regression analysis with the long-term record (1929-94) at Akron.

An independence/dependence analysis was done to compare Akron flows and the tributary flows within the various study reaches. Peak and daily flow relations were first investigated, and relatively strong relations were found. However, analysis of daily- and peak-flow plots at the Akron and Elk Point gaging stations for the concurrent period of record of 1983-94 shows that the two gaging stations do not have a completely dependent peak-flow behavior. The Elk Point peak flows were compared to peak and daily flows at stations with similar sized drainage basins in Iowa and Nebraska to determine if the Elk Point flows were representative of flows from smaller drainage basins in the study area. Analysis of daily flow plots show that daily flows for the Elk Point and nearby gaging stations behave similarly. A joint frequency analysis also was done on the Akron gaging-station flows and the tributary flows within the various reaches where the two stations were assumed to have a completely independent relation during peak flows. An attempt was made to apply joint frequency to flood frequencies from the Elk Point and Akron stations assuming complete independence. However, because of the large differences in drainage areas and peak flows between these stations, no reasonable flood flows could be estimated.

If complete dependence is assumed, flow events of two streams of equal probability are assumed to occur simultaneously. The flood flows were first estimated by summing the flood-frequency results (Bulletin 17B) for the Akron gaging station and estimated flood flows for the tributary reaches based on the drainage-area method using the Elk Point station as the reference. The flood flows also were estimated for the tributary reaches by using the regional regression equations being developed in South Dakota and already developed in Iowa, but applying them in two different ways.

The flow behavior of the Big Sioux River and its tributaries in the study reach are most likely between the two extremes of complete dependence or complete independence. Based on the various analyses that were done, the drainage-area-ratio methods were concluded the best to estimate the flood flows for the 10-, 50-, 100-, and 500-year recurrence intervals for the FEMA Flood Insurance Study of this area. The best estimates of 10-, 50-, 100-, and 500-year flood flows at the location downstream from North Sioux City are 35,300, 70,400, 89,100, and 142,000 ft^3/s, respectively.

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