Magnitude and Frequency of Peak Discharges for Mississippi River Basin Flood of 1993

W. O. THOMAS, JR., AND D. A. EASH

The magnitude and frequency of the 1993 peak discharges in the upper Mississippi River Basin are characterized by applying Bulletin 17B and L-moment methods to annual peak discharges at 115 unregulated watersheds in the basin. The analysis indicated that the 1993 flood was primarily a 50-year or less event on unregulated watersheds less than about 50,000 km^2 (20,000 mi^2). Of the 115 stations analyzed, the Bulletin 17B and L-moment methods were used to identify 89 and 84 stations, respectively, having recurrence intervals of 50 years or less, and 31 and 26 stations, respectively, having recurrence intervals greater than 50 years for the 1993 peak discharges. The 1993 flood in the upper Mississippi River Basin was significant in terms of (*a*) peak discharges with recurrence intervals greater than 50 years at approximately 25 percent of the stations analyzed, (*b*) peak discharges of record at 33 of the 115 stations analyzed, (*c*) extreme magnitude, duration, and areal extent of precipitation, (*d*) flood volumes with recurrence intervals greater than 100 years at many stations, and (*e*) extreme flood damage and loss of lives. Furthermore, peak discharges on several larger, regulated watersheds also exceeded the 100-year recurrence interval. However, for about 75 percent of the 115 unregulated stations in the analysis, the frequency of the 1993 peak discharges was less than a 50-year event.

From April through August 1993, severe flooding occurred in the upper Mississippi River Basin above Thebes, Illinois (Figure 1). Twenty million acres of agricultural and urban lands were inundated, damaged highways and submerged roads disrupted overland transportation throughout the flooded region, and the Mississippi and Missouri rivers were closed to navigation during the flood. Total damage estimates are approximately $16 billion, and 47 lives were lost because of the flooding (*1*).

Information on the frequency of major flood events, such as the 1993 flood in the midwestern United States, is needed for floodplain management and the design and repair of flood-control reservoirs and levees. The purposes of this paper are to (*a*) characterize the frequency of the peak discharges that occurred throughout the area (Figure 1) and (*b*) compare flood-frequency estimates from the Bulletin 17B and L-moment methods. For comparative purposes, the frequency of peak discharges are referenced to a specific recurrence interval or probability of exceedance. The recurrence interval is the average number of years between occurrences of annual peak discharges that exceed a specified discharge. For example, a discharge that has a 100-year recurrence interval is so large that a greater annual peak discharge is expected, on average, only once in any 100-year period. In any given year, the annual peak discharge has 1 chance in 100, or a 0.01 probability, of exceeding the 100-year flood discharge.

The procedures described in Bulletin 17B (*2*) and the method of L moments as described in a work by Hosking and Wallis (*3*) are compared and used to characterize the frequency of flooding. The Bulletin 17B method is used for single-station frequency analysis and includes the use of regional skew. The L-moment method is a regional method that includes statistical tests for determining homogeneous regions and the appropriate frequency distributions for use within the homogeneous regions. Descriptions of the data base and the Bulletin 17B and L-moment methods follow.

DATA BASE

The data base for the study initially included annual peak discharges for the 154 streamflow stations documented elsewhere (*4*). Of the 154 stations, 37 have significant regulation due to major flood-control structures. Regulated streams were not included in this study because of the difficulty in accounting for the effect of regulation. Of the remaining 117 stations, 2 stations were excluded because they had record lengths less than 10 years, resulting in 115 unregulated stations used for the frequency analysis. This sample includes most, but not all, of the unregulated stations that experienced major floods during April to August 1993. The 1993 peak discharge and the previous maximum peak discharges for the 115 stations are given in Table 1.

The annual peak discharges in the U.S. Geological Survey Peak Flow File (*5*), including the 1993 peak discharges, were used for analysis. For the 115 stations used in the analysis, the drainage areas ranged from 47.4 to 95,312 km^2 (18.3 to 36,800 mi^2), and record lengths ranged from 11 to 125 years. Most of the stations had record lengths between 25 and 60 years. All mainstem Missouri River stations, most stations in the Kansas River Basin, a few stations in the Des Monies River Basin, and all mainstem Mississippi River stations, except for the Mississippi River at St. Paul, Minnesota, were excluded from the analysis because of the effect of regulation. The Mississippi River station at St. Paul, Minnesota, has the largest drainage area and the longest record of any station used in the analysis.

BULLETIN 17B METHOD

Bulletin 17B procedures are used by all federal agencies in the United States for single-station flood-frequency analysis (*2*). The procedures include (*a*) fitting a Pearson Type III frequency distribution to the logarithms of the annual peak discharges using the sample moments (mean, standard deviation, and skew) to estimate the parameters of the distribution, (*b*) identifying and adjusting for

---

W. O. Thomas, Jr., U.S. Geological Survey, 415 National Center, Reston, Va. 22092. D. A. Eash, U.S. Geological Survey, P. O. Box 1230, Iowa City, Iowa 52244.

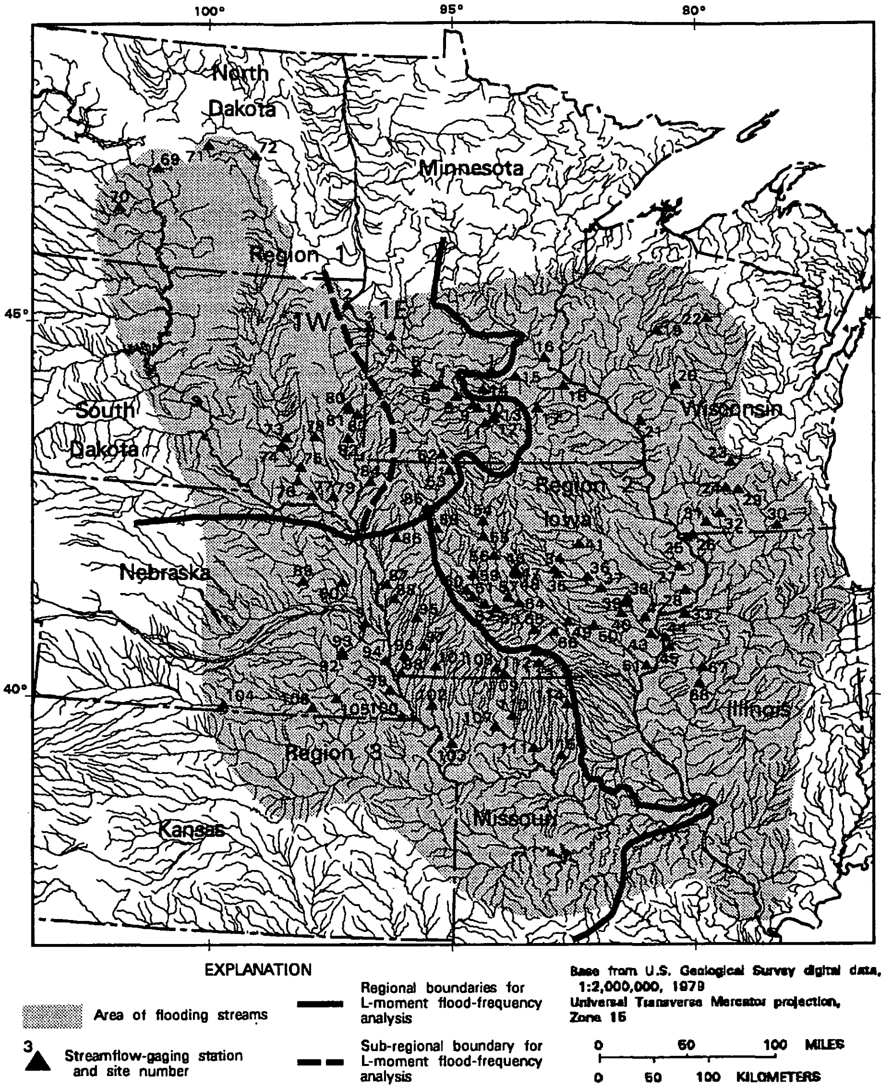

FIGURE 1 Study area and flood-frequency regions.

low outliers and zero flows, (*c*) adjusting for high outliers and historic flood data, and (*d*) weighting sample or station skew with a regional value of skew. The basis and justification for the use of the Pearson Type III distribution, the logarithmic transformation, and regional skew are described in a work by Beard (*6*). A summary of Beard's study is given in Appendix 14 of Bulletin 17B (*2*).

METHOD OF L MOMENTS

The frequency of peak discharges is determined by fitting selected frequency distributions to the untransformed annual peak discharges using L moments to estimate the distribution parameters. In the L-moment method, a regional frequency curve is obtained by averaging the slopes of the station flood-frequency curves in a given homogeneous region. L moments are analogous to ordinary moments in that their purpose is to summarize theoretical probability distributions and observed samples. Because L moments are computed as linear combinations of the ranked observations (instead of squaring and cubing the observations), they are subject to less variability in small samples than ordinary moments. A work by Hosking (*7*) describes the theory of L moments and their relation to ordinary moments, provides computational equations for L moments, and defines the relation between L moments and the parameters of several commonly used frequency distributions. Procedures for computing and applying L moments are also described elsewhere (*8,9,3*).

The sample L moments or sample L-moment ratios needed to describe the frequency distributions and apply various statistical tests are as follows:

- l_1 = first L moment, measure of location (mean),
- l_2 = second L moment, measure of scale (dispersion),
- l_2/l_1 = L coefficient of variation (L-CV),
- l_3 = third L moment,
- l_4 = fourth L moment,
- $t_3 = l_3/l_2$, measure of skewness (L skewness), and
- $t_4 = l_4/l_2$, measure of kurtosis (L kurtosis).

The above sample L moments and L-moment ratios are analogous to their counterparts defined for ordinary moments. Three

TABLE 1 **Summary of Peak Discharges at Selected Streamflow-Gaging Stations in Upper Mississippi River Basin**

				Flood data			
				Flood of April-August 1993		Previous maximum discharge	
Site no.	Station name and number	Flood region	Drainage area (mi^2)^a	Peak discharge (ft^3/sec)^b	Date	Maximum discharge (ft^3/sec)^b	Date
1	Buffalo Creek near Glencoe, MN 05278930	1E	374	3,380	06/19	4,300	09/1991
2	Little Minnesota River near Peever, SD 05290000	1E	447	8,900	07/25	4,730	04/1952
3	Minnesota River at Ortonville, MN 05292000	1E	1,160	2,950	07/28	3,060	04/1952
4	Pomme De Torre River at Appleton, MN 05294000	1E	905	2,370	07/10	5,520	07/1969
5	Yellow Medicine River near Granite Falls, MN 05313500	1E	653	8,380	06/21	25,200	06/1919
6	Redwood River near Redwood Falls, MN 05316500	1E	629	12,600	06/18	19,700	06/1957
7	Beaver Creek at Beaver Falls, MN 05316570	1E	194	2,750	06/17	1,070	04/1985
8	Spring Creek near Sleepy Eye, MN 05316700	1E	31.3	960	06/17	930	04/1965
9	Cottonwood River near New Ulm, MN 05317000	1E	1,280	24,300	06/19	28,700	04/1969
10	Little Cottonwood River near Courtland, MN 05317200	1E	230	3,520	06/20	1,340	03/1985
11	Wantonwan River near Garden City, MN 05319500	1E	812	13,900	06/20	19,000	04/1965
12	Le Sueur River near Rapidan, MN 05320500	1E	1,100	11,500	06/21	24,700	04/1965
13	Minnesota River at Mankato, MN 05325000	1E	14,900	75,600	06/21	110,000	04/1881
14	Middle Branch Rush River near Gaylord, MN 05326100	2S	68.5	1,380	06/17	920	06/1983
15	Minnesota River near Jordan, MN 05330000	2L	16,200	92,200	06/24	117,000	06/1965
16	Mississippi River at St. Paul, MN 05331000	2L	36,800	104,000	06/26	171,000	04/1965
17	Straight River near Faribault, MN 05353800	2S	442	5,730	06/17	6,030	07/1990
18	Cannon River at Welch, MN 05355200	2L	1,320	17,200	06/17	36,100	04/1965
19	Jump River at Sheldon, WI 05362000	2L	576	16,400	06/21	46,000	08/1941

(continued on next page)

statistical tests based on these L moments that are used to identify homogeneous regions and the appropriate frequency distributions to use within these regions are briefly described (*3*).

Discordancy Test

The discordancy test is used to identify those stations that are grossly discordant with the group as a whole. Discordancy is measured in terms of the L moments of the sample data. The discordancy measure is defined as

$$D_i = {}^1\!/_3\, (\boldsymbol{u}_i - \boldsymbol{u})^T S^{-1} (\boldsymbol{u}_i - \boldsymbol{u}) \qquad (1)$$

where

$\boldsymbol{u}_i$ = vector of L-CV, L skewness, L kurtosis for site i,
$\boldsymbol{u}$ = mean of vector $\boldsymbol{u}_i$,
S = covariance matrix of $\boldsymbol{u}_i$, and
T = transform of the vector $(\boldsymbol{u}_i - \boldsymbol{u})$.

A given station is considered to be discordant if $D_i > 3$. The work by Hosking and Wallis (*3*) provides the motivation and the theory for the test. This test allows the analyst to identify those stations whose L moments are not consistent with other stations in a given group or region and that should be considered to be in some other region.

Heterogeneity Test

The heterogeneity test is used to estimate the degree of heterogeneity in a group of stations and to assess whether they might reasonably be within a given homogeneous region. Specifically, the heterogeneity measure compares the between-station variations in the sample L-CV values for the group of stations with what would be expected for a homogeneous region. The heterogeneity measure is defined as

$$H = \frac{(V - m_v)}{s_v} \qquad (2)$$

TABLE 1 (*continued*)

				Flood data			
				Flood of April-August 1993		Previous maximum discharge	
Site no.	Station name and number	Flood region	Drainage area (mi^2)^a	Peak discharge (ft^3/sec)^b	Date	Maximum discharge (ft^3/sec)^b	Date
20	Black River at Neillsville, WI 05381000	2L	749	30,400	06/20	48,800	09/1938
21	Black River near Galesville, WI 05382000	2L	2,080	64,000	06/21	65,500	04/1967
22	Spirit River at Spirit Falls, WI 05393500	2S	81.6	2,730	06/20	4,180	09/1942
23	Baraboo River near Baraboo, WI 05405000	2L	609	6,340	07/18	7,900	03/1917
24	Black Earth Creek at Black Earth, WI 05406500	2S	45.6	1,320	07/06	1,750	07/1954
25	Sinsinawa River near Menominee, IL 05414820	2S	39.6	10,900	07/05	11,600	06/1969
26	Galena River at Buncombe, WI 05415000	2S	125	16,000	07/06	29,700	06/1969
27	Maquoketa River near Maquoketa, IA 05418500	2L	1,553	35,300	07/06	48,000	06/1944
28	Wapsipinicon River near DeWitt, IA 05422000	2L	2,330	22,300	07/08	31,100	06/1990
29	Pheasant Br. at Middleton, WI 05427948	2S	18.3	746	07/06	516	03/1975
30	Turtle Creek at Carvers Rock Road near Clinton, WI 05431486	2S	199	5,580	06/30	16,500	04/1973
31	Pecatonica River at Darlington, WI 05432500	2S	273	12,400	07/06	22,000	07/1950
32	East Br Pecatonica River near Blanchardville, WI 05433000	2S	221	5,650	07/06	11,700	02/1948
33	Mill Creek at Milan, IL 05448000	2S	62.4	7,680	06/25	9,300	04/1973
34	Iowa River at Marshalltown, IA 05451500	2L	1,564	20,400	08/17	42,000	06/1918
35	Timber Creek near Marshalltown, IA 05451700	2S	118	8,870	07/09	12,000	08/1977
36	Salt Creek near Elberon, IA 05452000	2S	201	36,600	07/09	35,000	06/1947
37	Iowa River at Marengo, IA 05453100	2L	2,794	38,000	07/19	37,500	07/1993
38	Clear Creek near Coralville, IA 05454300	2S	98.1	6,760	07/06	10,200	06/1990
39	Old Mans Creek near Iowa City, IA 05455100	2S	201	13,000	07/06	13,500	06/1982
40	English River at Kalona, IA 05455500	2L	573	36,100	07/06	20,000	09/1965
41	Black Hawk Creek at Hudson, IA 05463500	2S	303	9,670	07/09	19,300	07/1969
42	Cedar River near Conesville, IA 05465000	2L	7,785	66,500	07/07	74,000	04/1993
43	Iowa River at Wapello, IA 05465500	2L	12,499	111,000	07/07	94,000	06/1947
44	Pope Creek near Keithsburg, IL 05467000	2S	174	6,860	07/24	8,900	04/1973
45	Henderson Creek near Oquakwka, IL 05469000	2S	432	30,800	07/25	34,600	07/1982
46	South Skunk River near Ames, IA 05470000	2S	315	11,200	08/16	11,100	07/1993

(continued on next page)

where V is the standard deviation of L-CV (weighted by record length) for stations in a given group, and m_v, s_v are the mean and standard deviation of V based on a large number (500) of V values determined from simulation.

A given group of stations is considered to be homogeneous if $H < 2$. The mean and standard deviation of $V\,(m_v, s_v)$ are determined by simulating L moments for a homogeneous region with sites having record lengths and average L moments the same as those of the observed data. To avoid committing later to a particular two- or three-parameter frequency distribution (in the goodness-of-fit test), a four-parameter kappa distribution is used for the simulations (*3*).

Goodness-of-Fit Test

The purpose of this test is to determine whether given frequency distributions fit the data acceptably close. Four three-parameter frequency distributions are evaluated: Generalized Logistic (GLO), Generalized Extreme Value (GEV), Lognormal (LN), and Pearson Type III (PIII). The goodness-of-fit measure is defined as:

$$Z^{\mathrm{DIST}} = \frac{(t_4^{\mathrm{DIST}} - \bar{t}_4 + B_4)}{s_4} \tag{3}$$

TABLE 1 *(continued)*

Site no.	Station name and number	Flood region	Drainage area (mi^2)[a]	Flood data			
				Flood of April-August 1993		Previous maximum discharge	
				Peak discharge (ft^3/sec)[b]	Date	Maximum discharge (ft^3/sec)[b]	Date
47	Squaw Creek at Ames, IA 05470500	2S	204	24,300	07/09	12,500	06/1990
48	South Skunk River below Squaw Creek near Ames, IA 05471000	2S	556	26,500	07/09	14,700	06/1975
49	South Skunk River near Oskaloosa, IA 05471500	2L	1,635	20,700	07/15	37,000	05/1944
50	North Skunk River near Sigourney, IA 05472500	2L	730	17,500	07/06	27,500	03/1960
51	Skunk River at Augusta, IA 05474000	2L	4,303	46,600	07/10	66,800	04/1973
52	Des Moines River at Jackson, MN 05476000	1E	1,220	8,250	07/07	15,700	04/1969
53	Des Moines River at Esterville, IA 05476500	1E	1,372	9,330	06/30	16,000	04/1969
54	Des Moines River at Humboldt, IA 05476750	2L	2,256	19,000	07/13	18,000	04/1969
55	Des Moines River at Fort Dodge, IA 05480500	2L	4,190	31,200	04/01	35,600	04/1965
56	Des Moines River near Stratford, IA 05481300	2L	5,452	42,300	04/02	57,400	06/1954
57	Beaver Creek near Grimes, IA 05481950	2S	358	14,300	07/10	7,980	06/1986
58	North Raccoon River near Newell, IA 05482135	2S	233	2,420	07/11	2,850	06/1984
59	North Raccoon River near Jefferson, IA 05482500	2L	1,619	16,900	07/10	29,100	06/1947
60	Middle Raccoon River near Bayard, IA 05483450	2S	375	27,500	07/09	14,600	07/1973
61	Middle Raccoon River at Panora, IA 05483600	2S	440	22,400	07/09	15,300	06/1986
62	South Raccoon River at Redfield, IA 05484000	2L	994	44,000	07/10	35,000	07/1958
63	Raccoon River at Van Meter, IA 05484500	2L	3,441	70,100	07/10	41,200	06/1947
64	Fourmile Creek at Des Moines, IA 05485640	2S	92.7	4,200	07/09	5,340	06/1974
65	White Breast Creek near Dallas, IA 05487980	2S	342	25,500	07/06	37,300	07/1982
66	Cedar Creek near Bussey, IA 05489000	2S	374	36,100	07/05	96,000	07/1982
67	Spoon River at London Mills, IL 05569500	2L	1,072	22,600	07/25	41,000	06/1974
68	Spoon River at Seville, IL 05570000	2L	1,636	34,700	07/26	37,300	08/1924
69	Painted Woods Creek near Wilton, ND 06341800	1W	427	1,580	07/23	4,050	04/1979
70	Big Muddy Creek near Almont, ND 06347500	1W	456	8,390	07/23	20,200	04/1950
71	James River near Manfred, ND 06467600	1W	253	2,700	07/23	2,000	04/1979
72	James River near Grace City, ND 06468170	1W	1,060	3,520	07/28	3,100	04/1969
73	Rock Creek near Fulton, SD 06477150	1W	240	1,880	07/06	2,040	04/1969

(continued on next page)

where

t_4^{DIST} = L kurtosis from fitting the candidate distributions (DIST can be GLO, GEV, LN, or PIII) to the regional L moments,
$\bar{t}_4$ = mean L kurtosis for a given group of stations based on simulation,
B_4 = bias of L kurtosis based on simulation, and
s_4 = standard deviation of L kurtosis based on simulation.

A given distribution is considered to have a good fit if $|Z^{DIST}| \leq 1.64$ (90 percent level of significance). The bias and standard deviation of L kurtosis (B_4, s_4) are defined from the simulations described earlier. The selected frequency distribution is fitted to the untransformed annual peak discharges rather than the logarithms as in the Bulletin 17B method.

ANALYSIS RESULTS

The magnitude and frequency of the 1993 peak discharges in the upper Mississippi River Basin varies across the flooded area according to the magnitude and duration of the precipitation events that caused the flooding. Information is provided (*10*) about the magnitude and variability of the precipitation that occurred during the period January through July 1993. In the current study the recur-

TABLE 1 *(continued)*

				Flood data			
				Flood of April-August 1993		Previous maximum discharge	
Site no.	Station name and number	Flood region	Drainage area (mi^2)^a	Peak discharge (ft^3/sec)^b	Date	Maximum discharge (ft^3/sec)^b	Date
74	Enemy Creek near Mitchell, SD 06478052	1W	163	4,050	07/06	4,280	06/1984
75	Wolf Creek near Clayton, SD 06478390	1W	396	5,390	07/05	6,520	06/1984
76	James River near Scotland, SD 06478500	1W	20,653	17,600	07/06	29,400	06/1984
77	James River near Yankton, SD 06478513	1W	20,942	15,800	07/08	26,400	06/1984
78	Little Vermillion River near Salem, SD 06478540	1W	78.6	3,300	07/04	900	06/1984
79	Vermillion River near Wakonda, SD 06479000	1W	2,170	14,000	07/07	17,000	06/1984
80	Medary Creek near Brookings, SD 06479980	1W	200	3,710	07/04	2,590	06/1984
81	Big Sioux River near Brookings, SD 06480000	1W	3,898	13,300	07/04	33,900	04/1969
82	Spring Creek near Flandreau, SD 06480400	1W	63.2	4,480	07/03	2,030	06/1984
83	Big Sioux River near Dell Rapids, SD 06481000	1W	4,483	16,400	07/04	41,300	04/1969
84	Rock River near Rock Valley, IA 06483500	1W	1,592	29,300	07/12	40,400	04/1969
85	Little Sioux River at Linn Grove, IA 06605850	1E	1,548	16,100	07/02	13,100	06/1984
86	Little Sioux River at Correctionville, IA 06606600	3L	2,500	22,600	07/18	29,800	04/1965
87	Soldier River at Pisgah, IA 06608500	3L	407	23,400	07/10	22,500	06/1950
88	Boyer River at Logan, IA 06609500	3L	871	26,200	07/09	30,800	06/1990
89	Union Creek at Madison, NE 06799230	3S	174	13,700	07/09	15,100	06/1990
90	Elkhorn River at West Point, NE 06799350	3L	5,100	28,800	07/09	33,000	06/1969
91	Elkhorn River at Waterloo, NE 06800500	3L	6,900	33,500	07/11	100,000	06/1944
92	Salt Creek at Lincoln, NE 06803500	3L	684	28,400	07/24	28,200	06/1951
93	Little Salt Creek near Lincoln, NE 06803510	3S	43.6	8,480	07/24	8,000	07/1985
94	Weeping Water Creek at Union, NE 06806500	3S	241	65,100	07/23	60,300	05/1950
95	West Nishnabotna River at Hancock, IA 06807410	3L	609	30,100	07/10	26,400	09/1972
96	West Nishnabotna River at Randolph, IA 06808500	3L	1,326	22,100	07/23	40,800	05/1987
97	East Nishnabotna River near Red Oak, IA 06809500	3L	894	21,600	08/31	38,000	09/1972
98	Nishnabotna River above Hamburg, IA 06810000	3L	2,806	37,700	07/25	55,500	06/1947
99	Little Nemaha River at Auburn, NE 06811500	3L	793	105,000	07/24	164,000	05/1950
100	Big Nemaha River at Falls City, NE 06815000	3L	1,340	59,000	07/06	71,600	10/1973

(continued on next page)

rence intervals of the 1993 peak discharges were determined at 115 unregulated stations by applying Bulletin 17B and L-moment methods to annual peak discharges at these stations. The frequency of flooding is characterized by determining distribution of recurrence intervals of the 1993 peak discharges for selected stations.

Information on the magnitude and frequency of major floods, occurring before, during, or after systematic data collection, was used in the Bulletin 17B analysis. For example, information that the 1993 peak discharge was the highest peak discharge in a time period greater than the systematic record is used in computing the Bulletin 17B frequency curve. The historic floods and large floods in the systematic record are given a different weight than the systematic peaks to account for the fact that they are representative of a longer time period.

The Bulletin 17B historic weighting procedure is shown schematically in Figure 2. In the hypothetical example in Figure 2, it is assumed that there are only two peak discharges ($Z = 2$) that exceed a given discharge threshold (X_H) in historic period H. One of these peak discharges is a historic peak occurring before systematic data collection, and the other is a high outlier that occurred during systematic data collection. There are $N + L$ other systematic peak discharges of which L are below the low outlier threshold (X_L).

TABLE 1 (*continued*)

Site no.	Station name and number	Flood region	Drainage area (mi^2)[a]	Flood data: Flood of April-August 1993: Peak discharge (ft^3/sec)[b]	Date	Previous maximum discharge: Maximum discharge (ft^3/sec)[b]	Date
101	Nodaway River at Clarinda, IA 06817000	3L	762	28,000	07/22	31,100	06/1947
102	Nodaway River near Graham, MO 06817700	3L	1,380	78,300	07/23	26,600	09/1989
103	Platte River near Agency, MO 06820500	3L	1,760	60,800	07/25	53,000	07/1965
104	Thompson Creek at Riverton, NE 06851500	3S	279	7,000	07/17	12,200	07/1950
105	Big Blue River at Beatrice, NE 06881500	3L	3,900	28,800	07/26	55,100	06/1984
106	Little Blue River at Fairbury, NE 06884000	3L	2,350	24,100	07/27	54,000	07/1992
107	Grand River near Gallatin, MO 06897500	3L	2,250	89,800	07/08	69,100	06/1947
108	Elk Creek near Decatur City, IA 06897950	3S	52.5	32,800	07/05	18,400	06/1993 07/1990
109	Thompson River at Davis City, IA 06898000	3L	701	30,300	07/05	57,000	09/1992
110	Thompson River at Trenton, MO 06899500	3L	1,670	54,000	07/06	95,000	06/1947
111	Grand River near Sumner, MO 06902000	3L	6,880	166,000	07/26	180,000	06/1947
112	Chariton River near Chariton, IA 06903400	3S	182	14,900	07/05	37,700	09/1992
113	South Fork Chariton River near Promise City, IA 06903700	3S	168	16,900	07/05	70,600	09/1992
114	Chariton River at Novinger, MO 06904500	3L	1,370	21,500	07/24	22,900	06/1947
115	Chariton River near Prarie Hill, MO 06905500	3L	1,870	31,500	07/01	31,900	04/1973

[a] 1 mi^2 = 2.59 km^2

[b] 1 ft^3/sec = 0.0283 m^3/sec

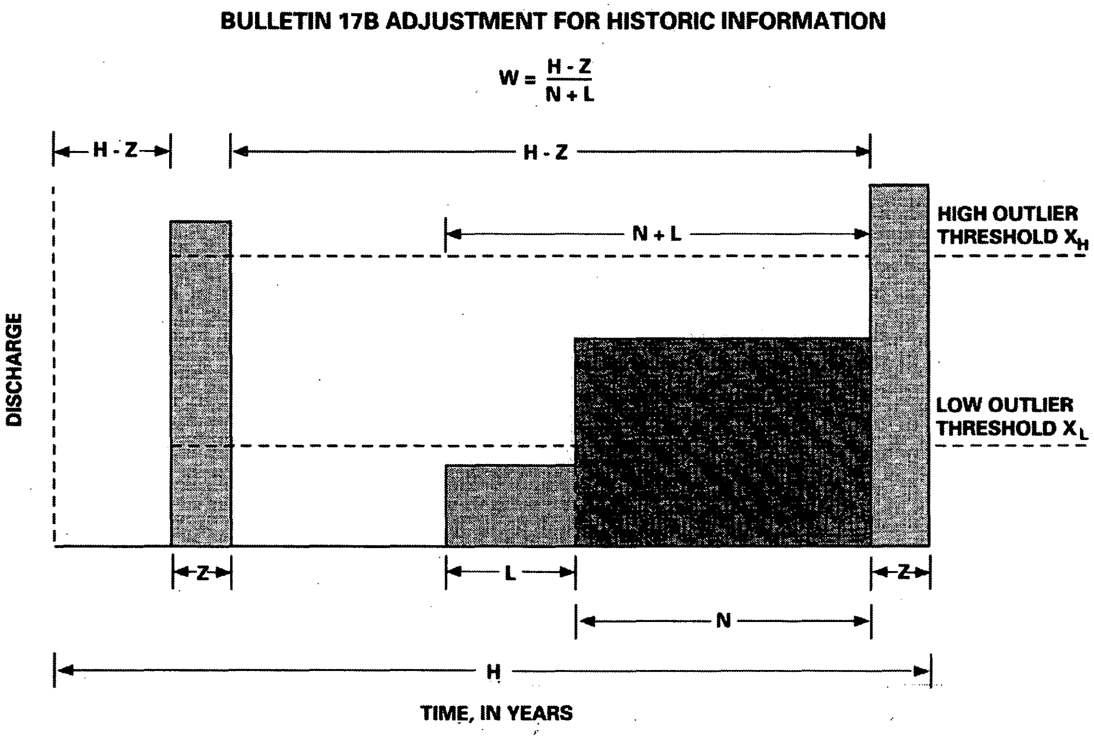

FIGURE 2 Bulletin 17B historic weighting procedure.

TABLE 2 Number of Stations and Drainage-Area Ranges for Each Flood Region

Region	Number of stations	Drainage-area range (km^2)
Region 1W	16	164 to 54,240
1E	16	81.1 to 38,591
Region 2L	25	1,484 to 95,312
2S	28	47.4 to 1,440
Region 3L	21[a]	1,054 to 17,871
3S	7	113 to 723

[a] Two stations excluded from regional analysis.

The systematic peaks are replicated by giving them a weight of $W = (H - Z)/(N + L)$, and the two highest peaks are given a weight of 1 in computing the sample moments. The assumptions are that the $N + L$ systematic peak discharges are representative of all peaks below X_H in the period $H - Z$ (where $Z = 2$) and that all peaks above X_H are known in the historic period H. The effective record length becomes H through the use of historic flood information.

Of the 115 stations used in the analysis, 45 stations had historic flood information with 23 stations with high outliers in the systematic record and 22 stations with historic peaks occurring before systematic data collection. The L-moment method does not include procedures for including historic information. For this study, historic peak discharges were excluded from the L-moment analysis, and high outliers were included and given the same weight as the other systematic peak discharges.

The L-moment method was initially used to define three flood regions with similar flood characteristics (Figure 1). These flood regions were then further subdivided to achieve more homogeneous flood characteristics. The study area is limited to those stream reaches in the shaded area in Figure 1. Region 1 includes the upper Missouri River upstream from the Little Sioux River, the Des Moines River upstream of Esterville, Iowa, and the Minnesota River upstream from Mankato, Minnesota. This region was further divided into a western and eastern portion where the upper Missouri River basin formed Region 1 west (1W), and the other portion of the region formed Region 1 east (1E). Region 2 includes the Mississippi River Basin upstream from the Missouri River excluding the reaches of the Des Moines and Minnesota rivers in Region 1. Region 3 includes those streams in the lower Missouri River Basin downstream from the Little Sioux River. Most of the stations in the Kansas River Basin are excluded from Region 3 because of the effect of regulation. Regions 2 and 3 were further subdivided also on the basis of drainage area, with Regions 2S and 3S consisting of the smaller watersheds and Regions 2L and 3L consisting of the larger watersheds. The number of stations in each flood region and the range of drainage areas are given in Table 2.

The three flood regions in Figure 1 were defined on the basis of the statistical tests of Equations 1 and 2. Two stations were identified as discordant or nonhomogeneous with other stations in Region 3L and were not included in the determination of the regional frequency curve. Frequency estimates at these stations were determined using the annual peak discharges at each station. Based on Equation 3, the generalized extreme value (GEV) distribution was determined to be the only distribution acceptable in each region. In some regions, more than one frequency distribution was determined to be acceptable. However, for consistency, the frequency estimates from the GEV distribution are used for the L-moment method.

The L-moment method produces a single, dimensionless frequency curve for each homogeneous flood region that is based on ratios of discharge instead of on actual values of discharge. Thus, each value of discharge for a given recurrence interval is expressed as a ratio to the mean of the annual peak discharges at each station. Because the mean of the annual peak discharges is simply the first L moment, l_1, flood discharge Q_T, for a given recurrence interval T, is estimated for each station by multiplying the appropriate regional frequency curve ratio by l_1.

The regional frequency-curve ratios (q_T) are provided in Table 3 to clarify and illustrate the method. For Region 1, separate regional frequency curves were computed for the western and eastern portion of the region. For Regions 2 and 3, separate frequency curves were computed for the large and small watersheds.

As described, Q_T for an individual station is made by multiplying the first L moment (l_1) by the ratios (q_T) in Table 2, explicitly $Q_T = l_1 * q_T$. In Region 1, the regional ratios for Region 1W, the area of lesser precipitation, are higher than the ratios for Region 1E and the other regions. The higher ratios in Region 1W are consistent with the greater variability of peak discharges that occur in regions of lesser precipitation. In Regions 2 and 3, the regional ratios for the smaller watersheds are higher than those for the larger watersheds, which is also consistent with the greater variability of peak discharges for smaller watersheds.

TABLE 3 Regional Frequency-Curve Ratios from L-Moment Method

	Recurrence interval, in years				
Region	2	10	50	100	500
Region 1W	0.57	2.15	5.12	7.18	15.19
1E	0.70	2.04	4.15	5.45	9.49
Region 2L	0.86	1.77	2.75	3.22	4.45
2S	0.79	1.87	3.36	4.21	6.83
Region 3L	0.87	1.82	2.78	3.22	4.32
3S	0.65	2.05	4.48	6.07	11.92

TABLE 4 Number of Stations for Which 1993 Peak Discharges were within Each Recurrence-Interval Range for Each Method

	Recurrence-interval range				
Method	<10	10-50	>50-100	>100-500	>500
Bulletin 17B	8	76	15	13	3
L-moment	9	80	12	13	1
Parrett and others	5	63	20	27	*

*Parrett and others *(4)* did not identify a >500 category.

Frequency curves that were computed with the Bulletin 17B and L-moment methods were used to estimate the frequency of the 1993 peak discharges at the 115 unregulated stations. The frequency of the 1993 flood may be characterized by determining the number of stations for which the 1993 peak discharges were within the following recurrence-interval ranges: < 10 years, 10–50 years, >50–100 years, >100–500 years, and >500 years. Results of this analysis for the Bulletin 17B and L-moment methods, including similar results from Parrett et al. (*4*), are summarized in Table 4. The recurrence-interval data (*4*) are revised results based on the most current data for the 1993 flood discharges.

The data in Table 4 are also illustrated in Figure 3. The frequency estimates given in Parrett et al. (*4*) were based on the most current published United States Geological Survey flood-frequency report for states in the area of flooding and, therefore, did not consider 1993 peak discharges. Use of the L-moment method results in more stations with recurrence intervals in the lower recurrence-interval ranges and less stations in the higher recurrence-interval ranges than does the Bulletin 17B method. As shown in Figure 3, the L-moment method results in more stations where the recurrence intervals of the 1993 peak discharges were 10 to 50 years than the Bulletin 17B method. Conversely, Figure 3 shows that the Bulletin 17B method results in more stations where the recurrence interval of the 1993 flood was >50 to 100 years than the L-moment method. Both methods result in generally lower estimates of the recurrence intervals of the 1993 flood than found in the work by Parrett et al. (*4*), presumably because the 1993 flood discharges were not included in the analysis.

The results in Figure 3 and Table 3 indicate that for about 75 percent of the unregulated watersheds in the analysis, the 1993 peak discharges were equal to or less than a 50-year event. Use of the Bulletin 17B and L-moment methods to determine the recurrence intervals of the 1993 flood for the 115 stations resulted in 84 and 89 stations, respectively, having recurrence intervals of 50 years or less and 31 and 26 stations, respectively, having recurrence intervals greater than 50 years. Because of the long duration and magnitude of the precipitation, the recurrence intervals of flood volume (average daily discharge for *n* consecutive days) were generally greater than the recurrence intervals of the peak discharges. The recurrence intervals of *n*-day flood volumes for many stations in the flooded area exceeded 100 years.

The recurrence intervals for the 1993 peak discharges from the Bulletin 17B and L-moment methods are shown in Figure 4 for 111 stations. The four stations for which the recurrence interval was greater than 500 years, from either method, are not plotted. The tendency for estimating higher recurrence intervals for the 1993 flood from the Bulletin 17B method can be noted in Figure 4, in which more stations plot below the equality line than above it.

As shown in Figures 3 and 4, the Bulletin 17B and L-moment methods assign somewhat different recurrence intervals to the 1993 peak discharges. Part of this difference is probably attributable to

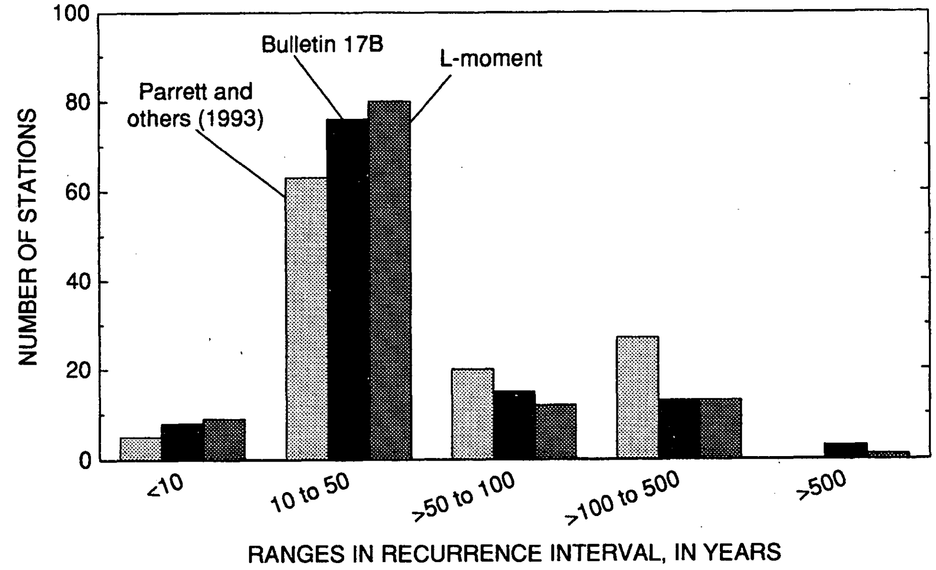

FIGURE 3 Number of stations in various recurrence-interval ranges for 1993 peak discharges.

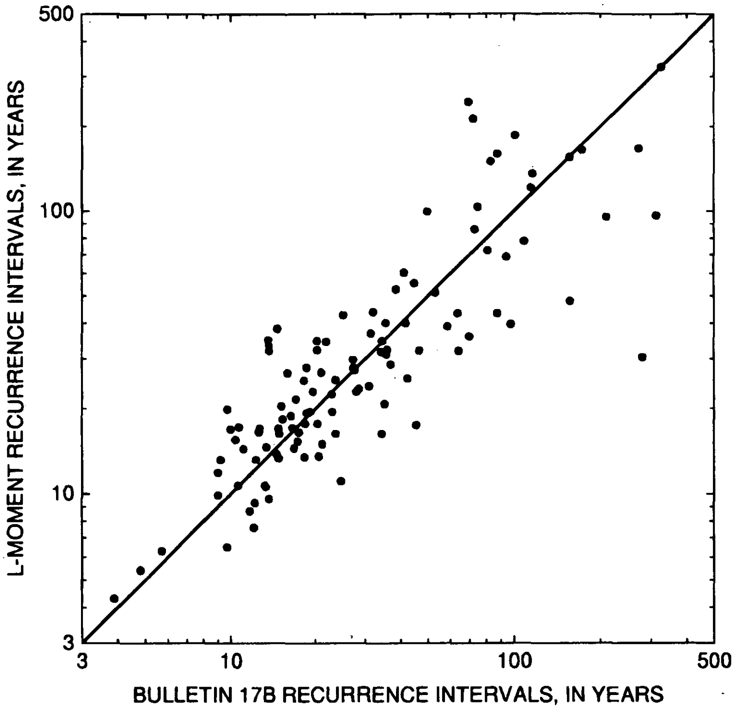

FIGURE 4 Comparison of Bulletin 17B and L-moment estimates of recurrence intervals for 1993 peak discharges.

the different treatment of high outliers and historic peaks in the two methods. Furthermore, the Bulletin 17B method is a single-station method in which the PIII distribution was fit to the logarithms of the annual peak discharges. On the other hand, the L-moment method is a regional method (slope of frequency curve averaged over several stations) in which the GEV distribution was fit to the untransformed annual peak discharges. Even given these differences, the characterization of the frequency of the 1993 flood is quite similar for the two methods.

CONCLUDING REMARKS

The 1993 flood in the upper Mississippi River Basin was significant in terms of (*a*) peak discharges with recurrence intervals greater than 50 years at approximately 25 percent of the stations analyzed, (*b*) peak discharges of record at 33 of the 115 stations analyzed, (*c*) extreme magnitude, duration, and areal extent of precipitation, (*d*) flood volumes with recurrence intervals greater than 100 years at many stations, and (*e*) extreme flood damage and loss of lives. Furthermore, the work by Parrett et al. (*4*) indicates that the frequency of the 1993 peak discharges was greater than a 100-year event on the larger regulated stations on the Missouri River downstream from Rulo, Nebraska, and a reach of the Mississippi River from Keokuk, Iowa, to St. Louis, Missouri. However, for about 75 percent of the unregulated streams, less than about 50,000 km^2 (20,000 mi^2) in the analysis, the recurrence intervals of the 1993 peak discharges were equal to or less than 50 years.

REFERENCES

1. Natural Disaster Survey of the Great Flood of 1993. National Oceanic and Atmospheric Administration, National Weather Service, Silver Spring, Md., 1994.
2. Guidelines for Determining Flood Flow Frequency. Interagency Advisory Committee on Water Data, *Bulletin 17B,* Hydrology Subcommittee, Office of Water Data Coordination, U.S. Geological Survey, Reston, Va., 1982.
3. Hosking, J. R. M., and J. R. Wallis. Some Statistics Useful in Regional Frequency Analysis. *Water Resources Research,* Vol. 29, No. 2, 1993, pp. 217–281.
4. Parrett, C., N. B. Melcher, and R. W. James, Jr. Flood Discharge in the Upper Mississippi River Basin, 1993. U.S. Geological Survey Circular 1120-A, 1993.
5. Lepkin, W. D., M. M. DeLapp, W. H., Kirby, and T. A. Wilson. WATSTORE User's Guide, Vol. 4, Chap. I, Instructions for Peak Flow File. U.S. Geological Survey Open-File Report 79-1336-I, 1979.
6. Beard, L. R. Flood Flow Frequency Techniques. Technical Report CRWR-119. Center for Research in Water Resources, The University of Texas at Austin, 1974.
7. Hosking, J. R. M. L-moments: Analysis and Estimation of Distributions Using Linear Combinations of Order Statistics. *Journal of Royal Statistical Society B,* Vol. 52, No. 1, 1990, pp. 105–124.
8. Wallis, J. R. *Regional Frequency Studies using L-Moments.* Research Report RC-14597. IBM Research Division, T. J. Watson Research Center, Yorktown Heights, N.Y., 1989.
9. Hosking, J. R. M. *Fortran Routines for Use with the Method of L-Moments,* Version 2. Research Report RC-17097. IBM Research Division, T.J. Watson Research Center, Yorktown Heights, N.Y., 1991.
10. Wahl, K. L., K. C. Vining, and G. J. Wiche. *Precipitation in the Upper Mississippi River Basin, January 1 through July 31, 1993.* U.S. Geological Survey Circular 1120-B, 1993.