TECHNIQUES FOR ESTIMATING MAGNITUDE AND FREQUENCY OF FLOODS IN MINNESOTA

U. S. GEOLOGICAL SURVEY

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Prepared in cooperation with the
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and
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TECHNIQUES FOR ESTIMATING MAGNITUDE AND FREQUENCY OF FLOODS IN MINNESOTA

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ABSTRACT

The magnitude and frequency of floods up to the 100-year recurrence interval can be determined for most streams in Minnesota by methods presented in this report. By multiple regression analysis, equations have been developed for estimating flood-frequency relations at ungaged sites on all natural flow streams which are not significantly affected by man-made regulation, diversion, or urbanization. Eight distinct hydrologic regions are delineated within the State with boundaries defined generally by river basin divides. In a few instances the regional divides were based on topographic or geologic considerations. Regression equations are provided for each region which relate the 2-, 5-, 10-, 25-, 50- and 100-year floods to significant basin parameters. In four regions, drainage area, slope, and storage are used as estimating variables; in two regions, drainage area and slope are used; and, in the remaining two regions, only the drainage area is used as the significant variable. Accuracy of resulting frequency estimates and limitations on the use of the equations are discussed.

For main-stem streams, which traverse regional divides and which may be affected by regulation, graphs are presented showing floods for selected recurrence intervals plotted against contributing drainage area. Flow-frequency estimates for intervening sites along the Minnesota River, Mississippi River, and the Red River of the North can be derived from these graphs.

Flood-frequency characteristics are tabulated for 201 gaging stations having 10 or more years of record. These frequency data may provide the best estimates of floods for the specified streams at sites in the vicinity of the gaging station.

INTRODUCTION

A reliable estimate of the magnitude and frequency of floods is essential to the efficient design of bridges, culverts, dams, and other hydraulic structures. In more recent years, the need for flow-frequency estimates has greatly expanded through implementation of the State Flood Plain Management program and the Federal Flood Insurance Act.

Purpose and Scope

The purpose of this report is to provide engineers and designers with improved techniques for estimating flow-frequency relations for most streams in Minnesota. Regression equations are presented for estimating the magnitude of floods having recurrence intervals ranging from 2 to 100 years at ungaged sites on streams which are not significantly affected by man-made regulation, diversion, or urbanization. The equations apply to natural flow streams of all sizes with the exception of the main stems of the Minnesota River, Mississippi River and Red River of the North. Input to the equations requires only the measurement of selected basin characteristics which can be obtained from topographic maps of the basin under consideration.

Individual graphs are presented for the main-stem streams noted above from which selected frequency floods can be determined at ungaged sites on the basis of contributing drainage area. The effects of regulation were included in these analyses where applicable and no further adjustment is required if the degree of regulation remains unchanged.

Flood-frequency data for 201 gaged sites on natural flow streams are tabulated for use in defining flood-frequency characteristics at upstream or downstream locations. These data may be transferred by drainage area ratio and can provide an alternative to computation of flood frequency by regression equation.

Recurrence interval is the average interval of time, in years, within which the given flood magnitude can be expected to be exceeded once. It is the inverse of probability; thus a flood having an exceedance probability of 5-percent would have a 20-year recurrence interval, and a flood having an exceedance probability of 1-percent would have a 100-year recurrence interval.

Flow-frequency estimating methods for Minnesota presented in this report supersede those in earlier publications of the U.S. Geological Survey and the Minnesota Department of Conservation.

Previous Reports

Previous reports by Prior (1949), Prior and Hess (1961), Wiitala (1965), and Patterson and Gamble (1968), also provided flood-frequency estimating techniques. Considerable flood data have become available since these analyses were prepared by the accumulation of additional years of record for established gaging stations, and by expansion of the gaging network through installation of crest-stage stations on small watersheds. The latter program made possible the definition of flood characteristics over a larger range in drainage area size. The additional data base and improved analytical methods warrant greater confidence in the estimates derived from the techniques provided in this report than the estimates based on previous studies.

Gaging Station Numbering System

Each gaging station has been assigned a unique number in downstream order in accordance with the permanent numbering system adopted by the U.S. Geological Survey. Stations are numbered in a downstream direction along the main stream, and stations on tributaries between main-stream stations are numbered in the order they enter the main stream. Stations on other ranks of tributaries are treated in the same manner. The complete 8-digit station number, such as 05134200, includes the major basin part number "05" and a 6-digit station number.

Cooperation

The frequency analyses in this report were based on data collected and published by the U.S. Geological Survey as part of cooperative programs with various State and Federal agencies. The report was prepared as part of cooperative programs with the Minnesota Department of Transportation, Division of Highways and the Minnesota Department of Natural Resources, Division of Waters. Opinions, findings, and conclusions expressed in this publication are those of the U.S. Geological Survey and not necessarily those of any cooperating agency.

Use of Metric Units

The analyses and data compilations in this report are based on English units of measurement. Equivalent metric units (SI) are given in the text. Space limitations precluded the use of a dual system of units in the tables and only English units are shown. Metric units can be obtained by use of the conversion factors in table 1.

Table 1.--Conversion factors

The following factors may be used to convert English units published herein to the International System of units (SI).

Multiply English units	By	To obtain SI units
Feet (ft)	.3048	meters (m)
Miles (mi)	1.609	kilometers (km)
Square miles (mi^2)	2.590	square kilometers (km^2)
Cubic feet per second (ft^3/s)	.02832	cubic meters per second (m^3/s)
Feet per mile (ft/mi)	.1894	meters per kilometer (m/km)

ESTIMATING FLOOD FREQUENCY

It is generally accepted that the most reliable estimates of flood characteristics are those based on a frequency analysis of recorded floods at the site under consideration. Usually such records are not available and estimates must be obtained by transfer of flow-frequency data from gaged sites to the site being investigated, or must be computed from generalized flood-frequency relations.

Transfer of Defined Flood Characteristics

The flood characteristics defined by frequency analyses of gaging-station records listed in table 2 may provide the basis for satisfactory estimates at ungaged locations near the station, particularly where long-term records are available. Location of gaging stations for which frequency relations are presented are shown in figure 1. Where the period of record is short, flow-frequency estimates based on regional relations would likely provide more reliable results. Transfer of defined flow-frequency data to upstream or downstream sites on the same stream should be accomplished by an adjustment factor derived from drainage area ratio. Frequency data can be transferred

Table 2.--Flood-frequency and basin characteristics for gaging stations in Minnesota

Map No.	Station number	Station name	Drainage area (mi^2)	Slope (ft/mi)	Storage %	Discharge, in ft^3/s, for indicated recurrence intervals						Years of record
						Q2	Q5	Q10	Q25	Q50	Q100	
1	04010500	Pigeon River at Middle Falls, near Grand Portage, MN	600	13.0	14	4,550	6,760	8,320	10,400	12,000	13,600	46
2	04011370	Little Devil Track River near Grand Marais, MN	7.49	51.4	10	140	279	400	587	752	940	14
3	04012500	Poplar River at Lutsen, MN	114	25.0	7.9	827	1,200	1,450	1,780	2,030	2,280	31
4	04013100	Lake Superior tributary near Taconite Harbor, MN	1.56	226	7.7	90	194	291	448	592	760	11
5	04013200	Caribou River near Little Marais, MN	22.7	52.6	7.0	622	1,030	1,350	1,780	2,140	2,520	14
6	04014500	Baptism River near Beaver Bay, MN	140	57.6	4.4	2,470	3,920	4,980	6,440	7,600	8,820	39
7	04015150	Crow Creek near Silver Creek, MN	1.07	108	19	44	80	110	154	191	232	15
8	04015200	Encampment River tributary at Silver Creek, MN	0.96	183	0	57	107	150	213	268	330	15
9	04015300	Little Stewart River near Two Harbors, MN	5.54	53.8	3.2	190	290	362	458	533	611	15
10	04015360	Lake Superior tributary No. 2 at French River, MN	1.41	144	0	135	278	406	608	790	999	11
11	04015370	Talmadge River at Duluth, MN	5.79	92.7	3.1	299	514	682	922	1,120	1,340	11
12	04015400	Miller Creek at Duluth, MN	4.92	28.0	7.5	209	337	427	546	637	730	15
13	04016500	St. Louis River near Aurora, MN	312	9.8	29	1,540	2,430	3,090	3,980	4,700	5,450	28
14	04017000	Embarrass River at Embarrass, MN	93.8	4.9	28	571	994	1,330	1,810	2,210	2,650	22
15	04019000	West Two River near Iron Junction, MN	68.4	10.8	2.1	557	739	857	1,000	1,110	1,220	14
16	04019500	East Swan River near Toivola, MN	112	11.2	42	1,140	1,480	1,700	1,960	2,150	2,340	15
17	04024100	Rock Creek near Blackhoof, MN	4.94	41.7	0	447	839	1,150	1,590	1,950	2,340	13
18	04024110	Rock Creek tributary near Blackhoof, MN	0.20	90.9	0	16	28	38	51	61	71	14
19	04024200	South Fork Nemadji River near Holyoke, MN	19.4	36.8	7.6	810	1,440	1,920	2,590	3,130	3,690	14
20	05030000	Otter Tail River near Detroit Lakes, MN	270	3.4	22	168	258	320	399	458	518	34
21	05040500	Pelican River near Fergus Falls, MN	482	3.1	24	283	436	545	693	809	930	30
22	05049000	Mustinka River above Wheaton, MN	834	0.7	8.5	799	2,200	3,540	5,700	7,700	10,000	36
23	05060800	Buffalo River near Callaway, MN	94.5	6.03	27	227	379	489	637	751	869	15
24	05061000	Buffalo River near Hawley, MN	322	8.1	5.2	646	1,110	1,450	1,920	2,290	2,670	26
25	05061200	Whiskey Creek at Barnesville, MN	25.3	18.6	8.7	144	267	365	503	615	734	14
26	05061400	Hay Creek above Downer, MN	5.81	16.0	2.2	57	172	305	565	840	1,200	14
27	05061500	South Branch Buffalo River at Sabin, MN	522	13.8	1.7	1,250	2,670	3,900	5,760	7,370	9,150	26
28	05062000	Buffalo River near Dilworth, MN	1,040	9.7	2.5	1,180	2,880	4,590	7,540	10,400	13,900	40
29	05062280	Mosquito Creek near Bagley, MN	3.98	11.4	3.0	31	59	80	112	137	165	14
30	05062470	Marsh Creek tributary near Mahnomen, MN	11.9	4.01	4.8	92	247	406	677	933	1,240	14

Table 2.--Flood-frequency and basin characteristics for gaging stations in Minnesota--Continued

Map No.	Station number	Station name	Drainage area (mi²)	Slope (ft/mi)	Storage %	Discharge, in ft³/s, for indicated recurrence intervals Q2	Q5	Q10	Q25	Q50	Q100	Years of record
31	05062500	Wild Rice River at Twin Valley, MN	888	7.2	7.0	1,170	2,370	3,370	4,860	6,110	7,480	49
32	05062700	Wild Rice River tributary near Twin Valley, MN	4.72	17.9	3.0	76	189	298	475	637	826	14
33	05062800	Coon Creek near Twin Valley, MN	50.8	15.2	1.5	630	1,300	1,770	2,430	3,000	3,550	13
34	05063200	Spring Creek tributary near Ogema, MN	4.99	20.2	21	59	83	98	117	131	145	12
35	05073600	South Branch Battle River at Northome, MN	2.80	9.72	14	49	88	118	160	194	229	15
36	05073750	Spring Creek near Blackduck, MN	7.96	13.1	15	84	167	240	350	447	555	15
37	05073800	Perry Creek tributary near Shooks, MN	1.14	10.5	51	33	56	73	95	113	131	15
38	05076000	Thief River near Thief River Falls, MN	959	1.0	31	1,340	2,450	3,300	4,600	5,550	6,700	59
39	05076600	Red Lake River tributary near Thief River Falls, MN	2.33	5.71	0	74	121	154	199	233	269	13
40	05077700	Ruffy Brook near Gonvick, MN	45.2	13.0	24	216	374	492	654	781	914	10
41	05078000	Clearwater River at Plummer, MN	512	4.4	12	1,390	2,340	3,030	3,970	4,690	5,450	32
42	05078100	Lost River at Gonvick, MN	53.6	12.2	18	136	250	338	463	563	670	13
43	05078180	Silver Creek near Clearbrook, MN	4.96	39.6	15	51	100	139	196	243	294	15
44	05078200	Silver Creek tributary at Clearbrook, MN	6.02	36.4	8.8	59	101	132	174	207	240	15
45	05078400	Clearwater River tributary near Plummer, MN	6.51	8.31	1.5	62	125	176	252	316	385	12
46	05078500	Clearwater River at Red Lake Falls, MN	1,370	4.6	7.3	2,830	5,080	6,810	9,210	11,100	13,200	44
47	05079000	Red Lake River at Crookston, MN	5,280	2.2	24	6,650	12,300	16,700	22,600	27,000	31,000	67
48	05087500	Middle River at Argyle, MN	265	7.5	7.5	843	1,770	2,570	3,770	4,800	5,940	21
49	05094000	South Branch Two Rivers at Lake Bronson, MN	444	3.2	8.3	1,140	2,420	3,530	5,210	6,650	8,240	33
50	05095500	Two Rivers below Hallock, MN	644	5.4	8.5	906	1,840	2,610	3,760	4,730	5,790	11
51	05104500	Roseau River below South Fork near Malung, MN	573	5.3	6.5	1,590	3,210	4,340	5,730	6,690	7,590	41
52	05106000	Sprague Creek near Sprague, Manitoba	169	6.9	20	595	1,220	1,680	2,280	2,770	3,250	42
53	05107000	Pine Creek near Pine Creek, MN	74.6	11.0	1.3	279	531	730	1,010	1,240	1,480	25
54	05107500	Roseau River at Ross, MN	1,220	3.7	12	1,540	2,720	3,620	4,850	5,840	6,870	42
55	05125500	Stony River near Isabella, MN	180	12.6	19	835	1,330	1,670	2,130	2,470	2,820	12
56	05126000	Dunka River near Babbitt, MN	53.0	18.8	32	348	498	595	715	803	889	11
57	05126500	Bear Island River near Ely, MN	68.5	2.6	26	199	326	417	539	632	728	10
58	05128500	Pike River near Embarrass, MN	115	12.1	23	802	1,310	1,670	2,140	2,510	2,880	12
59	05128700	Pike River tributary near Wahlsten, MN	1.93	18.1	36	40	70	92	122	146	171	14

Table 2.--Flood-frequency and basin characteristics for gaging stations in Minnesota--Continued

Map No.	Station number	Station name	Drainage area (mi²)	Slope (ft/mi)	Storage %	Discharge, in ft³/s, for indicated recurrence intervals						Years of record
						Q2	Q5	Q10	Q25	Q50	Q100	
60	05129000	Vermilion River below Vermilion Lake, near Tower, MN	483	2.8	23	1,100	1,570	1,880	2,260	2,540	2,820	48
61	05130300	Boriin Creek near Chisholm, MN	13.7	13.8	20	218	374	491	649	774	904	16
62	05130500	Sturgeon River near Chisholm, MN	187	9.6	11	1,090	1,630	2,020	2,520	2,920	3,330	28
63	05131000	Dark River near Chisholm, MN	50.6	16.2	10	343	550	704	917	1,090	1,270	24
64	05131500	Little Fork River at Littlefork, MN	1,730	2.2	17	9,210	13,900	17,200	21,200	24,300	27,400	50
65	05132000	Big Fork River at Big Falls, MN	1,460	1.9	19	5,180	8,960	11,800	15,600	18,700	21,800	45
66	05134200	Rapid River near Baudette, MN	543	2.7	78	2,930	4,820	6,100	7,700	8,800	10,000	14
67	05139500	Warroad River near Warroad, MN	162	6.3	59	603	1,230	1,770	2,560	3,230	3,960	25
68	05140000	Bulldog Run near Warroad, MN	11.1	8.0	9.0	161	334	482	702	890	1,100	10
69	05140500	East Branch Warroad River near Warroad, MN	45.8	6.2	47	386	753	1,050	1,480	1,840	2,230	13
70	05210200	Smith Creek near Hill City, MN	8.00	41.9	20	111	234	328	453	547	640	14
71	05216980	Swan River tributary at Warba, MN	3.95	15.9	24	34	50	60	74	83	93	14
72	05217000	Swan River near Warba, MN	254	5.1	15	718	949	1,090	1,260	1,380	1,490	16
73	05217700	Bluff Creek near Jacobson, MN	1.50	12.7	27	33	53	67	83	94	104	14
74	05244000	Crow Wing River at Nimrod, MN	1,010	3.8	11	1,260	1,910	2,350	2,910	3,330	3,740	45
75	05244100	Kitten Creek near Sebeka, MN	14.7	15.4	4.5	118	223	306	424	521	625	14
76	05244200	Cat River near Nimrod, MN	49.2	6.90	15	258	404	506	638	738	839	14
77	05267800	Big Mink Creek tributary near Lastrup, MN	1.53	24.9	10	13	32	49	76	101	129	14
78	05267900	Hillman Creek near Pierz, MN	46.7	9.53	20	766	1,760	2,550	3,640	4,470	5,310	11
79	05270300	Sauk River tributary at Spring Hill, MN	7.06	16.8	2.4	166	254	315	392	450	509	15
80	05270310	Sauk River tributary No. 2 near St. Martin, MN	0.24	78.4	2.5	19	34	47	64	78	93	14
81	05270500	Sauk River near St. Cloud, MN	925	2.3	4.3	1,400	2,920	4,230	6,200	8,000	10,000	44
82	05271800	Johnson Creek tributary at Luxemburg, MN	3.82	7.38	14	31	58	79	110	135	161	11
83	05272000	Johnson Creek tributary No. 2 near St. Augusta, MN	13.4	16.6	4.3	71	133	182	251	308	368	10
84	05272300	Johnson Creek near St. Augusta, MN	46.7	15.4	2.4	222	404	546	744	904	1,070	11
85	05273700	Otsego Creek near Otsego, MN	3.11	24.1	2.3	78	176	266	406	529	669	11
86	05274200	Stony Brook tributary near Foley, MN	2.26	10.7	8.8	40	84	121	177	224	276	15
87	05275000	Elk River near Big Lake, MN	615	4.7	1.3	1,630	3,300	4,650	6,600	8,200	10,000	46
88	05276000	North Fork Crow River near Regal, MN	215	5.1	7.9	825	1,260	1,550	1,930	2,210	2,490	11
89	05276100	North Fork Crow River tributary near Paynesville, MN	0.55	48.1	1.6	16	35	51	77	100	125	15

Table 2.--Flood-frequency and basin characteristics for gaging stations in Minnesota -- Continued

Map No.	Station number	Station name	Drainage area (mi^2)	Slope (ft/mi)	Storage %	Discharge, in ft^3/s, for indicated recurrence intervals						Years of record
						Q2	Q5	Q10	Q25	Q50	Q100	
90	05278000	Middle Fork Crow River near Spicer, MN	179	2.6	10	160	284	379	510	615	725	22
91	05278350	Fountain Creek near Montrose, MN	6.73	3.49	12	52	76	93	113	129	144	13
92	05278500	South Fork Crow River at Cosmos, MN	221	1.1	8.6	328	722	1,100	1,670	2,200	2,800	20
93	05278700	Otter Creek near Lester Prairie, MN	30.2	3.27	4.1	130	264	376	542	681	834	14
94	05278750	Otter Creek tributary near Lester Prairie, MN	1.54	14.5	2.6	32	49	60	75	86	97	13
95	05278850	Buffalo Creek tributary near Brownton, MN	9.45	2.90	14	31	60	82	115	141	170	14
96	05279000	South Fork Crow River near Mayer, MN	1,170	3.1	3.9	2,030	5,170	8,260	13,100	17,700	22,500	37
97	05280000	Crow River at Rockford, MN	2,520	3.3	4.6	3,010	6,920	10,500	16,300	21,800	28,000	49
98	05280300	School Lake Creek tributary near St. Michael, MN	2.04	10.6	6.4	44	109	171	273	365	472	11
99	05284100	Mille Lacs Lake tributary near Wealthwood, MN	0.58	33.9	6.9	12	32	50	81	109	142	12
100	05284600	Robinson Brook near Onamia, MN	4.79	9.48	24	94	199	289	426	543	672	15
101	05284620	Rum River tributary near Onamia, MN	2.37	13.1	20	68	143	208	305	388	480	15
102	05284920	Stanchfield Creek tributary near Day, MN	1.26	34.9	8.7	32	76	116	180	236	301	14
103	05286000	Rum River near St. Francis, MN	1,360	3.7	37	3,920	6,590	8,300	10,700	12,200	14,000	41
104	05289500	Minnehaha Creek at Minnetonka Mills, MN	130	0.14	30	57	149	243	402	551	728	11
105	05290000	Little Minnesota River near Peever, SD	447	3.2	1.1	817	2,050	3,250	5,230	7,050	9,170	30
106	05291000	Whetstone River near Big Stone City, SD	389	10.9	1.5	941	2,730	4,650	8,060	11,400	15,400	43
107	05293000	Yellow Bank River near Odessa, MN	398	17.7	1.3	1,240	3,020	4,710	7,450	9,940	12,800	31
108	05294000	Pomme de Terre River at Appleton, MN	905	2.5	5.4	730	1,710	2,620	4,100	5,300	6,700	40
109	05299100	Lazarus Creek tributary near Canby, MN	2.97	67.9	2.0	138	410	671	1,080	1,420	1,780	15
110	05300000	Lac qui Parle River near Lac qui Parle, MN	983	12.7	0.9	1,480	3,780	6,150	10,300	14,300	19,300	43
111	05301200	Minnesota River tributary near Montevideo, MN	0.40	10.3	5.0	7	27	53	103	157	228	15
112	05302970	Outlet Creek tributary near Starbuck, MN	0.47	51.2	0	7	20	33	55	77	102	13
113	05303450	Hassel Creek near Clontarf, MN	7.53	40.4	2.1	62	117	162	231	291	357	13
114	05304500	Chippewa River near Milan, MN	1,870	4.1	5.2	1,560	3,440	5,100	7,650	9,880	12,400	34
115	05305200	Spring Creek near Montevideo, MN	16.0	5.68	1.2	110	255	388	597	784	996	16
116	05311200	North Branch Yellow Medicine River near Ivanhoe, MN	14.8	11.8	2.7	96	324	594	1,110	1,650	2,330	15

Table 2.--Flood-frequency and basin characteristics for gaging stations in Minnesota--Continued

Map No.	Station number	Station name	Drainage area (mi²)	Slope (ft/mi)	Storage %	Discharge, in ft³/s, for indicated recurrence intervals: Q2	Q5	Q10	Q25	Q50	Q100	Years of record
117	05311250	North Branch Yellow Medicine River tributary near Wilno, MN	0.33	87.7	0	22	49	70	98	119	141	15
118	05311300	North Branch Yellow Medicine River tributary No. 2 near Porter, MN	3.70	30.9	0.5	91	148	189	243	284	327	15
119	05313500	Yellow Medicine River near Granite Falls, MN	653	12.4	0.5	1,160	3,650	6,460	11,700	16,900	23,400	39
120	05313800	Kandiyohi County ditch 16 near Blomkest, MN	0.83	7.75	0	32	64	88	118	141	163	14
121	05314900	Redwood River at Ruthton, MN	6.18	42.4	0.2	148	369	583	936	1,260	1,640	16
122	05315000	Redwood River at Marshall, MN	307	17.0	1.7	647	1,760	2,850	4,600	6,200	8,200	31
123	05315200	Prairie Ravine near Marshall, MN	5.63	11.4	0.4	31	81	131	214	292	383	16
124	05316500	Redwood River near Redwood Falls, MN	697	11.0	0.4	811	2,710	5,100	10,000	15,500	22,900	45
125	05316550	West Fork Beaver Creek near Olivia, MN	12.2	4.57	3.7	71	163	246	377	493	624	16
126	05316700	Spring Creek near Sleepy Eye, MN	31.3	2.88	4.2	185	399	586	871	1,120	1,390	16
127	05316800	Cottonwood River tributary near Balaton, MN	0.91	42.8	0	22	55	87	138	185	239	16
128	05316850	Meadow Creek tributary near Marshall, MN	0.54	57.0	0	17	55	100	185	273	384	12
129	05316900	Dry Creek near Jeffers, MN	3.13	61.4	0	131	321	503	798	1,070	1,380	14
130	05317000	Cottonwood River near New Ulm, MN	1,280	6.0	0.7	2,970	7,420	11,700	18,800	25,400	33,000	44
131	05317850	Foster Creek near Alden, MN	2.26	20.1	0	82	168	236	332	409	488	16
132	05318000	East Branch Blue Earth River near Bricelyn, MN	132	3.2	5.3	332	755	1,140	1,740	2,270	2,870	20
133	05318100	East Branch Blue Earth River tributary near Blue Earth, MN	9.20	10.5	0	147	271	369	506	617	735	15
134	05318300	Watonwan River near Delft, MN	13.0	15.7	1.9	121	361	624	1,100	1,570	2,140	15
135	05320000	Blue Earth River near Rapidan, MN	2,430	2.7	0.8	7,150	14,700	21,400	32,000	41,800	54,000	28
136	05320200	Le Sueur River tributary near Mankato, MN	0.07	158	0	20	38	53	73	90	107	16
137	05320300	Cobb River tributary near Mapleton, MN	7.25	4.02	3.6	161	285	380	510	614	722	16
138	05320400	Maple River tributary near Mapleton, MN	6.22	9.30	0.1	137	309	463	704	915	1,150	16
139	05320440	Judicial ditch 49 near Amboy, MN	18.0	8.82	0.9	204	395	558	807	1,020	1,270	14
140	05320500	Le Sueur River near Rapidan, MN	1,100	8.1	2.7	4,190	9,000	13,700	20,800	27,300	34,600	27
141	05330150	Sand Creek tributary near Montgomery, MN	0.36	68.7	5.6	21	30	36	43	48	53	14
142	05330200	Rice Lake tributary near Montgomery, MN	3.16	10.0	12	50	101	144	206	259	316	15
143	05330300	Sand Creek near New Prague, MN	62.4	5.97	11	255	541	788	1,160	1,480	1,840	15

Table 2.--Flood-frequency and basin characteristics for gaging stations in Minnesota -- Continued

Map No.	Station number	Station name	Drainage area (mi^2)	Slope (ft/mi)	Storage %	Discharge, in ft^3/s, for indicated recurrence intervals Q2	Q5	Q10	Q25	Q50	Q100	Years of record
144	05330550	Raven Stream tributary near New Prague, MN	22.1	10.0	10	179	324	443	616	763	925	15
145	05330600	Sand Creek tributary No. 2 near Jordan, MN	2.62	30.9	6.1	68	138	194	274	340	413	15
146	05336200	Glaisby Brook near Kettle River, MN	24.2	11.5	17	427	742	979	1,300	1,560	1,830	15
147	05336300	Moose River tributary at Moose Lake, MN	1.23	30.4	3.3	81	157	219	309	383	464	15
148	05336550	Wolf Creek tributary near Sandstone, MN	5.46	12.4	58	57	128	192	291	377	475	15
149	05336600	Kettle River tributary at Sandstone, MN	0.65	32.4	28	17	34	49	72	91	112	15
150	05338200	Mission Creek near Hinckley, MN	3.84	12.7	20	76	137	184	249	302	357	15
151	05338500	Snake River near Pine City, MN	958	5.3	43	4,960	8,280	10,900	14,300	17,000	20,000	24
152	05340000	Sunrise River near Stacy, MN	167	1.9	47	307	466	574	712	815	918	17
153	05345900	Vermillion River tributary near Hastings, MN	14.3	5.53	16	28	134	295	665	1,110	1,740	13
154	05352700	Turtle Creek tributary No. 2 near Pratt, MN	1.26	36.2	0.8	64	135	196	287	365	451	15
155	05352800	Turtle Creek tributary near Steele Center, MN	5.01	16.4	0.8	105	201	279	391	483	582	15
156	05355100	Little Cannon River tributary near Kenyon, MN	2.20	53.4	0	194	412	600	884	1,130	1,400	15
157	05355150	Pine Creek near Cannon Falls, MN	20.2	12.8	1.3	131	394	683	1,200	1,720	2,350	15
158	05355200	Cannon River at Welch, MN	1,320	4.2	2.4	5,880	11,000	15,300	21,700	27,200	34,000	43
159	05355230	Cannon River tributary near Welch, MN	0.05	140	0	23	42	57	77	94	111	15
160	05373000	South Fork Zumbro River near Rochester, MN	304	9.3	0.2	4,410	8,830	12,500	17,900	22,400	27,500	19
161	05373350	Zumbro River tributary near South Troy, MN	0.16	156	0	23	50	73	109	140	175	13
162	05373700	Spring Creek near Wanamingo, MN	9.93	20.7	0	417	843	1,200	1,730	2,170	2,660	15
163	05373900	Trout Brook tributary near Goodhue, MN	0.40	88.9	0	88	161	220	306	380	461	15
164	05374000	Zumbro River at Zumbro Falls, MN	1,130	7.7	0.1	10,400	17,400	22,500	29,400	34,700	40,200	49
165	05374500	Zumbro River at Theilman, MN	1,320	6.4	0.1	12,600	19,400	24,000	30,000	34,500	39,100	19
166	05375800	East Indian Creek tributary near Weaver, MN	0.22	604	0	12	27	40	61	79	99	13
167	05376500	South Fork Whitewater River near Altura, MN	76.8	22.3	0	1,750	3,520	4,990	7,160	8,980	11,000	31
168	05377500	Whitewater River at Beaver, MN	288	15.5	0	4,670	8,100	10,800	14,500	17,500	21,000	20

Table 2.--Flood-frequency and basin characteristics for gaging stations in Minnesota--Continued

Map No.	Station number	Station name	Drainage area (mi^2)	Slope (ft/mi)	Storage %	Discharge, in ft^3/s, for indicated recurrence intervals Q2	Q5	Q10	Q25	Q50	Q100	Years of record
169	05378300	Straight Valley Creek near Rollingstone, MN	5.16	113	0	258	578	866	1,310	1,710	2,150	16
170	05379000	Gilmore Creek at Winona, MN	8.95	109	0	370	1,040	1,750	2,990	4,180	5,620	25
171	05383600	North Branch Root River tributary near Stewartville, MN	0.73	47.3	0	59	176	297	499	686	900	17
172	05383700	Mill Creek tributary near Chatfield, MN	2.36	80.8	0.4	406	603	735	901	1,020	1,150	16
173	05383720	Mill Creek near Chatfield, MN	22.4	50.4	0	1,240	2,800	4,200	6,390	8,310	10,500	13
174	05383850	South Fork Bear Creek near Grand Meadow, MN	14.0	14.5	0	622	1,230	1,730	2,460	3,070	3,730	13
175	05384000	Root River near Lanesboro, MN	615	7.5	0	8,430	15,500	20,400	26,700	31,100	35,400	38
176	05384100	Duschee Creek near Lanesboro, MN	3.85	70.8	0.2	265	605	914	1,400	1,830	2,320	16
177	05384150	Root River tributary near Whalan, MN	0.08	243	0	23	52	79	121	159	202	16
178	05384200	Gribben Creek near Whalan, MN	7.80	101	0.1	738	1,760	2,730	4,270	5,670	7,270	16
179	05384300	Big Springs Creek near Arendahl, MN	0.14	100	0	17	41	65	104	142	188	16
180	05384400	Pine Creek near Arendahl, MN	28.1	18.3	0	776	1,820	2,790	4,340	5,730	7,310	16
181	05384500	Rush Creek near Rushford, MN	129	28.0	0	2,670	6,440	9,590	14,000	17,500	21,100	29
182	05385000	Root River near Houston, MN	1,270	6.5	0	10,200	18,700	25,500	34,900	42,600	51,500	49
183	05385500	South Fork Root River near Houston, MN	275	7.6	0	2,670	5,100	7,200	10,000	12,700	15,500	18
184	05386000	Root River below South Fork near Houston, MN	1,560	6.4	0	13,300	22,200	28,900	38,400	46,100	55,500	24
185	05457000	Cedar River near Austin, MN	425	4.0	0.7	3,860	7,090	9,620	13,200	16,100	19,100	31
186	05457080	Rose Creek tributary near Dexter, MN	1.17	37.9	0	79	146	199	273	333	396	13
187	05474750	Beaver Creek tributary No. 2 near Slayton, MN	3.53	43.7	0	61	116	162	232	293	360	15
188	05474760	Beaver Creek tributary above Slayton, MN	2.20	38.8	0.3	40	77	108	156	197	243	15
189	05475400	Warren Lake tributary near Windom, MN	1.39	17.4	0	54	109	158	233	301	378	14
190	05475800	Des Moines River tributary near Jackson, MN	1.52	20.6	0.7	26	71	118	197	273	363	15
191	05475900	Des Moines River tributary No. 2 near Lakefield, MN	5.18	12.1	0	67	136	193	279	351	430	15
192	05476000	Des Moines River at Jackson, MN	1,220	2.6	4.5	1,470	3,720	6,000	10,000	14,000	19,000	45
193	05476010	Nelson Creek at Jackson, MN	6.19	46.3	0	335	667	941	1,340	1,680	2,040	12
194	05476100	Story Brook near Petersburg, MN	25.8	23.2	0	663	1,360	1,950	2,830	3,580	4,400	13
195	05476900	Fourmile Creek near Dunnell, MN	14.0	17.2	0	310	743	1,150	1,800	2,390	3,070	15

Table 2.--Flood-frequency and basin characteristics for gaging stations in Minnesota--Continued

Map No.	Station number	Station name	Drainage area (mi^2)	Slope (ft/mi)	Storage %	Discharge, in ft^3/s, for indicated recurrence intervals						Years of record
						Q2	Q5	Q10	Q25	Q50	Q100	
196	06482950	Mound Creek near Hardwick, MN	2.47	25.3	0.3	33	106	190	349	511	714	16
197	06482960	Mound Creek tributary at Hardwick, MN	0.19	112	0	38	115	201	358	514	707	16
198	06483050	Rock River tributary near Luverne, MN	0.21	100	0	34	103	179	317	454	622	14
199	06483200	Kanaranzi Creek tributary near Lismore, MN	0.14	66.0	0	89	162	219	298	363	431	16
200	06603520	Judicial ditch 28 tributary near Spafford, MN	2.66	14.5	0.1	48	111	169	261	343	436	14
201	06603530	Little Sioux River near Spafford, MN	41.1	6.39	0.3	217	738	1,360	2,560	3,800	5,390	13

most reliably by the following relation which is applicable to most areas in Minnesota.

$$Q_u = Q_g \, (A_u/A_g)^{0.6}$$

where: Q_u is the flood-frequency estimate for the ungaged site

Q_g is the flood-frequency value for the gaged site (from table 2)

A_u is the drainage area for the ungaged site

A_g is the drainage area for the gaged site (from table 2)

Local conditions may warrant a slight increase or decrease of the 0.6 exponent, which must be based on engineering judgment. Use of the transfer relation should be limited to sites which differ in drainage area size by no more than 40 percent from the gaged site.

Regional Analyses for Ungaged Sites

Equations derived from multiple regression analyses can be used to obtain flood-frequency estimates for ungaged sites on natural flow streams. Peak discharges for the selected recurrence intervals can be computed from these mathematical equations tabulated in table 3, which relate flood magnitude to basin characteristics. A set of equations to estimate flood peaks for the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals (identified as Q_2, Q_5, Q_{10}, etc.) are provided for each of the hydrologic regions into which the State has been divided. The eight regions are outlined on figure 1. The regional boundaries cannot be defined precisely; therefore, where the estimating site falls close to a regional divide, consideration should be given to averaging the results obtained by computation of the flood magnitudes from the equations for the two adjoining regions. Particular care should be exercised when the site in question has a large value for a basin characteristic that is not used in the regression relation for both regions. If a flood-frequency estimate is to be made downstream from a regional divide which the stream crosses, the discharge at the site should be determined by weighting the regression estimates computed from both regional relations according to drainage area.

Due regard should be given to the limitations of these equations as discussed in a following section (Accuracy and Limitations).

Table 3.--Regional flood-frequency equations

Region A

$Q_{2} = 29.2\ A^{.62}$

$Q_{5} = 54.2\ A^{.62}$

$Q_{10} = 73.8\ A^{.62}$

$Q_{25} = 101\ A^{.62}$

$Q_{50} = 124\ A^{.62}$

$Q_{100} = 149\ A^{.62}$

Region B

$Q_{2} = 5.71\ A^{.660}\ S^{.407}\ St^{-.027}$

$Q_{5} = 16.1\ A^{.646}\ S^{.452}\ St^{-.231}$

$Q_{10} = 26.8\ A^{.642}\ S^{.473}\ St^{-.333}$

$Q_{25} = 46.5\ A^{.636}\ S^{.492}\ St^{-.443}$

$Q_{50} = 65.2\ A^{.634}\ S^{.505}\ St^{-.513}$

$Q_{100} = 88.4\ A^{.631}\ S^{.516}\ St^{-.575}$

Region C

$Q_{2} = 10.5\ A^{.764}\ S^{.375}$

$Q_{5} = 15.9\ A^{.736}\ S^{.421}$

$Q_{10} = 19.8\ A^{.722}\ S^{.447}$

$Q_{25} = 24.5\ A^{.708}\ S^{.476}$

$Q_{50} = 28.1\ A^{.699}\ S^{.495}$

$Q_{100} = 32.0\ A^{.690}\ S^{.512}$

Region D

$Q_{2} = 7.90\ A^{.654}\ S^{.356}$

$Q_{5} = 25.1\ A^{.666}\ S^{.288}\ St^{-.175}$

$Q_{10} = 44.8\ A^{.673}\ S^{.252}\ St^{-.265}$

$Q_{25} = 79.7\ A^{.682}\ S^{.217}\ St^{-.354}$

$Q_{50} = 115\ A^{.688}\ S^{.194}\ St^{-.411}$

$Q_{100} = 157\ A^{.695}\ S^{.175}\ St^{-.460}$

Region E

$Q_{2} = 1.91\ A^{.913}\ S^{.883}$

$Q_{5} = 5.76\ A^{.852}\ S^{.774}$

$Q_{10} = 9.83\ A^{.821}\ S^{.725}$

$Q_{25} = 17.0\ A^{.790}\ S^{.674}$

$Q_{50} = 23.9\ A^{.770}\ S^{.644}$

$Q_{100} = 32.4\ A^{.753}\ S^{.616}$

Region F

$Q_{2} = 83.8\ A^{.47}$

$Q_{5} = 208\ A^{.49}$

$Q_{10} = 322\ A^{.50}$

$Q_{25} = 487\ A^{.51}$

$Q_{50} = 580\ A^{.52}$

$Q_{100} = 762\ A^{.52}$

Region G

$Q_{2} = 15.8\ A^{.687}\ S^{.253}\ St^{-.115}$

$Q_{5} = 32.1\ A^{.723}\ S^{.294}\ St^{-.212}$

$Q_{10} = 45.6\ A^{.741}\ S^{.313}\ St^{-.258}$

$Q_{25} = 66.3\ A^{.761}\ S^{.329}\ St^{-.306}$

$Q_{50} = 83.5\ A^{.774}\ S^{.340}\ St^{-.337}$

$Q_{100} = 102\ A^{.786}\ S^{.349}\ St^{-.363}$

Region H

$Q_{2} = 23.2\ A^{.787}\ S^{.348}\ St^{-.753}$

$Q_{5} = 55.0\ A^{.753}\ S^{.324}\ St^{-.640}$

$Q_{10} = 86.4\ A^{.735}\ S^{.309}\ St^{-.584}$

$Q_{25} = 135\ A^{.716}\ S^{.295}\ St^{-.520}$

$Q_{50} = 183\ A^{.704}\ S^{.283}\ St^{-.481}$

$Q_{100} = 236\ A^{.694}\ S^{.274}\ St^{-.447}$

Variables used for the equations in table 3 have the following measurement units:

Q_T - Peak discharge for T-year recurrence interval, in cubic feet per second.

A - Drainage area, in square miles.

S - Average main channel slope, between 10 and 85 percent points, in feet per mile.

St - Area of lakes, ponds and swamps, expressed as percentage of drainage area and increased by 1 percent.

Values for the basin characteristics used in the regression analyses were determined by the methods outlined below. Required independent variables used for estimated flood characteristics at ungaged sites should be determined in a like manner.

1. Drainage area.- Trace contributing drainage-area outline on topographic maps along divides indicated by contour elevations, starting at point on stream where frequency characteristics are to be defined. U.S. Geological Survey topographic maps, 7½-minute or 15-minute quadrangles, should be used for basins smaller than 150 square miles. For larger basins, the 1:250,000 scale topographic maps may be used. Planimeter the outlined area to obtain drainage area (A) in square miles.

2. Main channel slope.- Determine the main channel of the stream on the drainage area map, from the point selected for the frequency estimate, to the extreme rim of the basin. Extension of the main channel to the basin divide, beyond the upstream end of the defined stream, should be made as indicated by contours. Upstream from each stream junction, choose the main channel as the fork which drains the larger area. Measure the total length by dividers set at appropriate intervals, such as 0.1 mile for 7½-minute quadrangles, 0.25 mile for 15-minute quadrangles, and 0.5 mile for the 1:250,000 scale maps. Locate points 10 and 85 percent of the main channel length upstream from the point of interest, and determine the elevation of these points by interpolation between contours. The average main channel slope (S) is computed as the difference in elevation, in feet, divided by the length, in miles, between the 10 and 85 percent points.

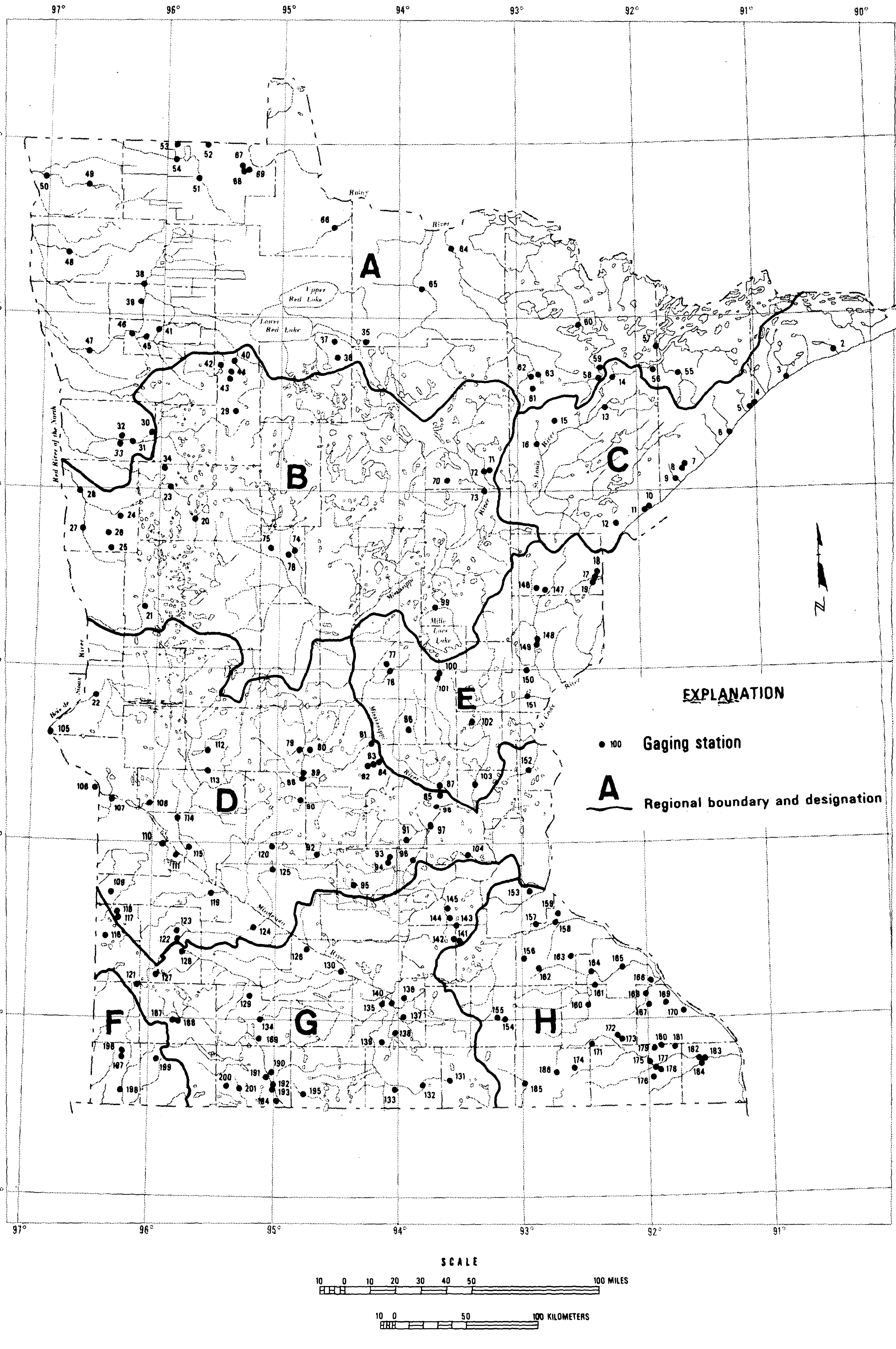

Figure 1.--Map of Minnesota showing location of gaging stations and hydrologic regions used in regression analysis.

3. Storage.- Measure the area of lakes, ponds and swamps in the drainage basin on topographic maps. Storage areas can be measured by planimeter or by using a transparent grid. The grid is placed over the water and swamp areas and the number of squares, and estimated fractional parts of squares, are summed up and multiplied by the area of each square, as calculated for the scale of the map being used. The total area of lakes, ponds and swamps is expressed as a percentage of the total contributing area. This percentage is then increased by 1 percent to obtain the storage parameter (St) used in the equations.

A transparent grid suitable to most map scales is enclosed in a packet at the back of this report.

Illustrative Examples

The following examples illustrate use of the relations to compute flow frequency estimates.

Example 1.- Estimate the 50-year flood on the Sauk River at Cold Spring, an ungaged site.

Solution:

1) Inspection of figure 1 and table 2 indicate the availability of gaging-station data for the Sauk River in close proximity to Cold Spring. The station is identified as Sauk River near St. Cloud, map no. 81 (Station No. 05270500).

2) Contributing drainage area at Cold Spring is planimetered on topographic maps as 832 mi^2.

3) Reduction in drainage area at Cold Spring is only 10 percent from the 925 mi^2 listed in table 2 for the St. Cloud gaging station. Therefore, a transfer of flood characteristics by drainage area ratio is appropriate.

4) From table 2, Q_g = 8,000 ft^3/s for 50-year flood.

5) By substitution into transfer equation:

$$Q_u = Q_g \, (A_u/A_g)^{0.6}$$

$$Q_{50} = 8{,}000 \, (832/925)^{0.6}$$

$$Q_{50} = 8{,}000 \times 0.938$$

$$Q_{50} = 7{,}500 \text{ ft}^3/\text{s} \; (212 \text{ m}^3/\text{s})$$

Example 2.- Estimate the 25-year peak discharge for an ungaged site on Spring Creek in Swift County, at the crossing of State Highway 9, 3½ miles west of Sunburg.

1) Inspection of figure 1 and table 2 indicate that no gaging-station data are available on this stream, therefore, flow-frequency estimates must be derived from regional equations.

2) Site is identified from figure 1 as being in Region D. Applicable equation for 25-year flood is located in table 3.

3) Drainage area is outlined on topographic map, De Graff SE 7½- minute quadrangle.

4) Drainage area (A) is planimetered as 1.28 mi^2, and main channel length is measured as 1.49 mi to the watershed divide.

5) The main channel slope is computed by dividing the difference in elevations at mile 0.15 (0.10 x 1.49) and mile 1.27 (0.85 x 1.49) by 1.12 (1.27 - 0.15), the distance between the two points.

   Elevation at mile 1.27 is 1235 ft

   Elevation at mile 0.15 is 1212 ft

   Main channel slope (S) = (1235 - 1212)/1.12 = 20.5 ft/mi

6) Total lake, pond and swamp area is determined from the map by the grid system described in the discussion on storage preceding example 1. Fifteen of the small grid squares are counted as storage area.

   $$15 \text{ squares} \times 0.00144 \text{ mi}^2 = 0.02 \text{ mi}^2$$

   $$\text{Storage} = \frac{0.02}{1.28} \times 100 = 1.6 \text{ percent}$$

   Storage index (St) = 1.6 + 1.0 = 2.6 percent

7) Region D equation for 25-year flood from table 3:

   $$Q_{25} = 79.7\ A^{.682} S^{.217} St^{-.354}$$

8) By substitution of the variables:

   $$Q_{25} = 79.7\ (1.28)^{.682}\ (20.5)^{.217}\ (2.6)^{-.354}$$

9) Solving the equation:

$$Q_{25} = 130 \text{ ft}^3/\text{s} \ (3.68 \text{ m}^3/\text{s})$$

Plotting points to define a frequency curve for the site can be obtained by solution of equations for other recurrence intervals.

Main-stem Streams

Estimating relations given previously do not apply to the main stem of the Minnesota River, Mississippi River and Red River of the North. The effects of regulation, interregional character of the streams and (or) the large drainage areas involved, require unique definition of the flood characteristics for these streams. Individual relations between flood magnitude and contributing drainage area were prepared based on interpolation between gage sites on the main stems. Flood-frequencies indicated for regulated reaches of the main-stem streams are based on the assumption that past records represent homogeneous regulation patterns and are applicable only if such regulation patterns remain unchanged in the future.

The 100-year flood estimates for the Minnesota River, Red River of the North, and Mississippi River (between Aitkin and St. Paul) have been coordinated under an interagency agreement. Agencies involved in this coordination process, with limitations imposed by their area of interest or jurisdiction, are as follows: St. Paul District-Corps of Engineers, Soil Conservation Service, U.S. Geological Survey, Minnesota Department of Natural Resources, and North Dakota Water Commission (Red River of the North Regional Flood Analysis, 1971).

Graphs showing flood estimates for selected recurrence intervals versus contributing drainage area for the Minnesota River, Mississippi River, and Red River of the North are presented in figures 2 - 4, respectively. When using the frequency graph for the Red River, it should be recognized that plotting positions of drainage areas from Halstad to Emerson have been corrected by subtracting 3,800 mi^2 (9842 km^2) for closed basins in the Sheyenne River basin in North Dakota.

Definition of flood characteristics for the main stem of the St. Croix River from St. Croix Falls to Prescott, Wisconsin is very complex owing to regulation of flows and the backwater effect from the Mississippi River, which affects elevation-frequency relations through a large part of this reach. Such analyses are outside the scope of this report. Frequency data for this section of the St. Croix River can be obtained from the report "St. Croix River Regional Flood Analysis" (Wiitala, 1973).

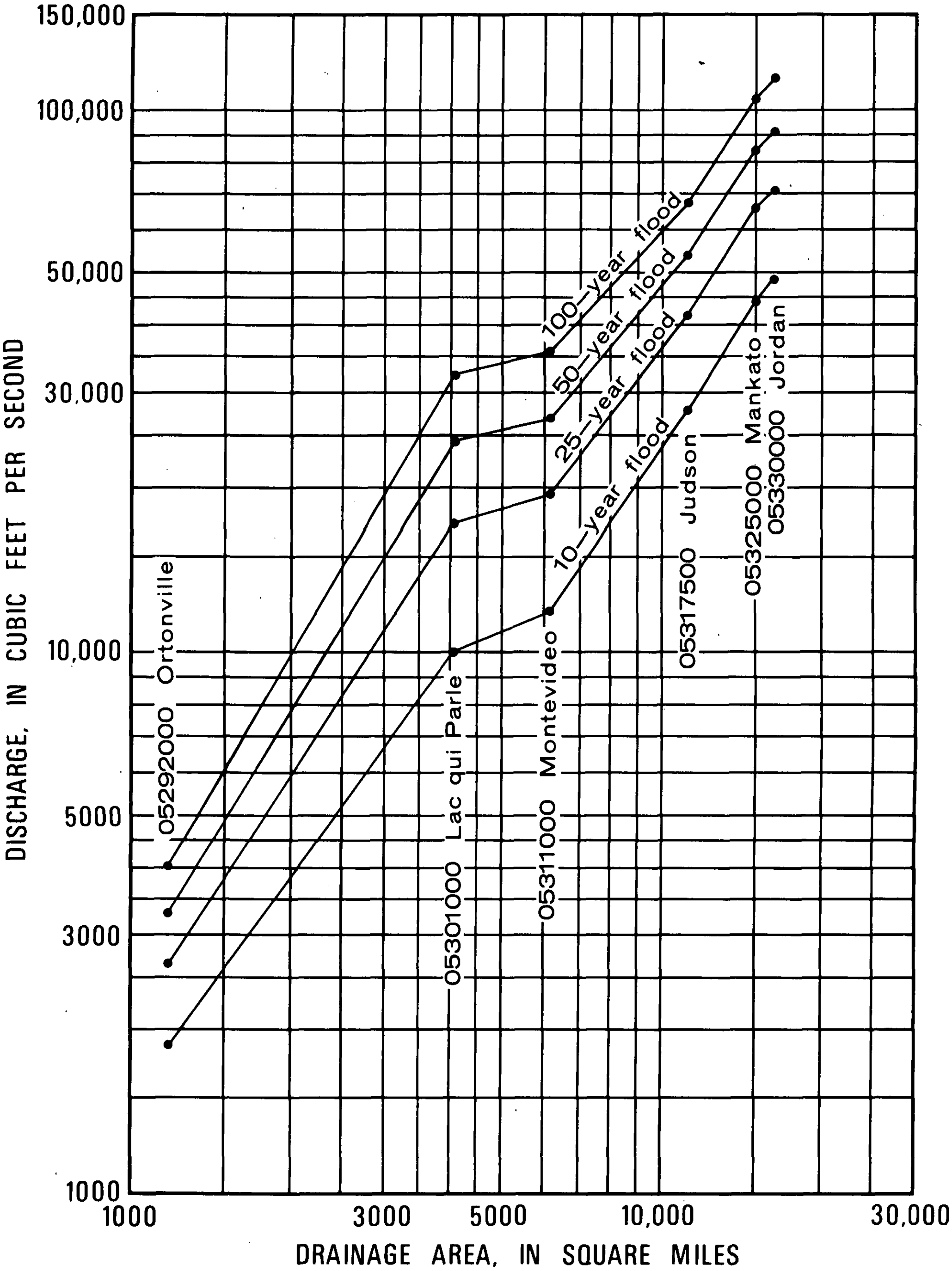

Figure 2.--Relation of flood magnitudes for selected recurrence intervals to drainage area, Minnesota River main stem.

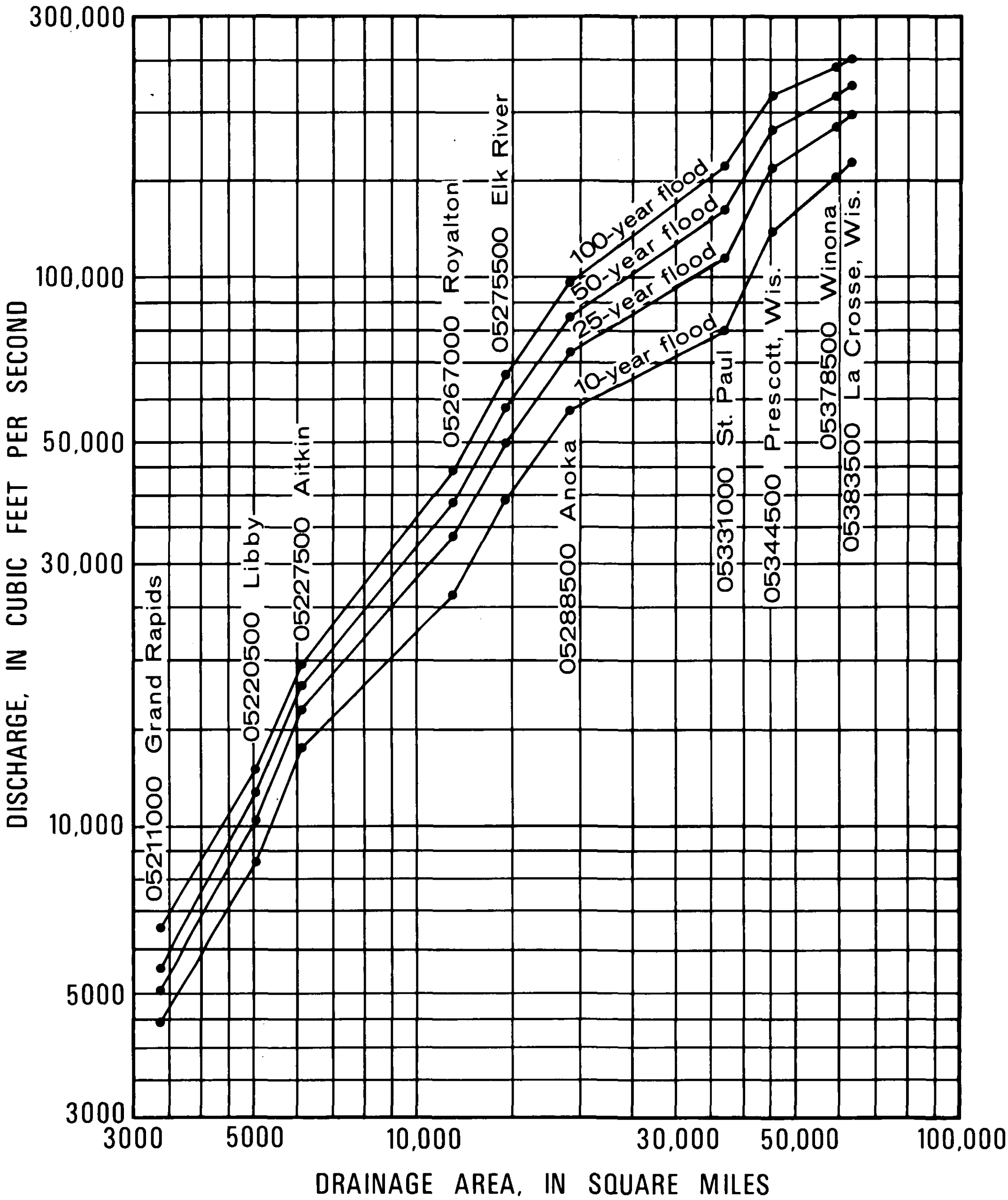

Figure 3.--Relation of flood magnitudes for selected recurrence intervals to drainage area, Mississippi River main stem.

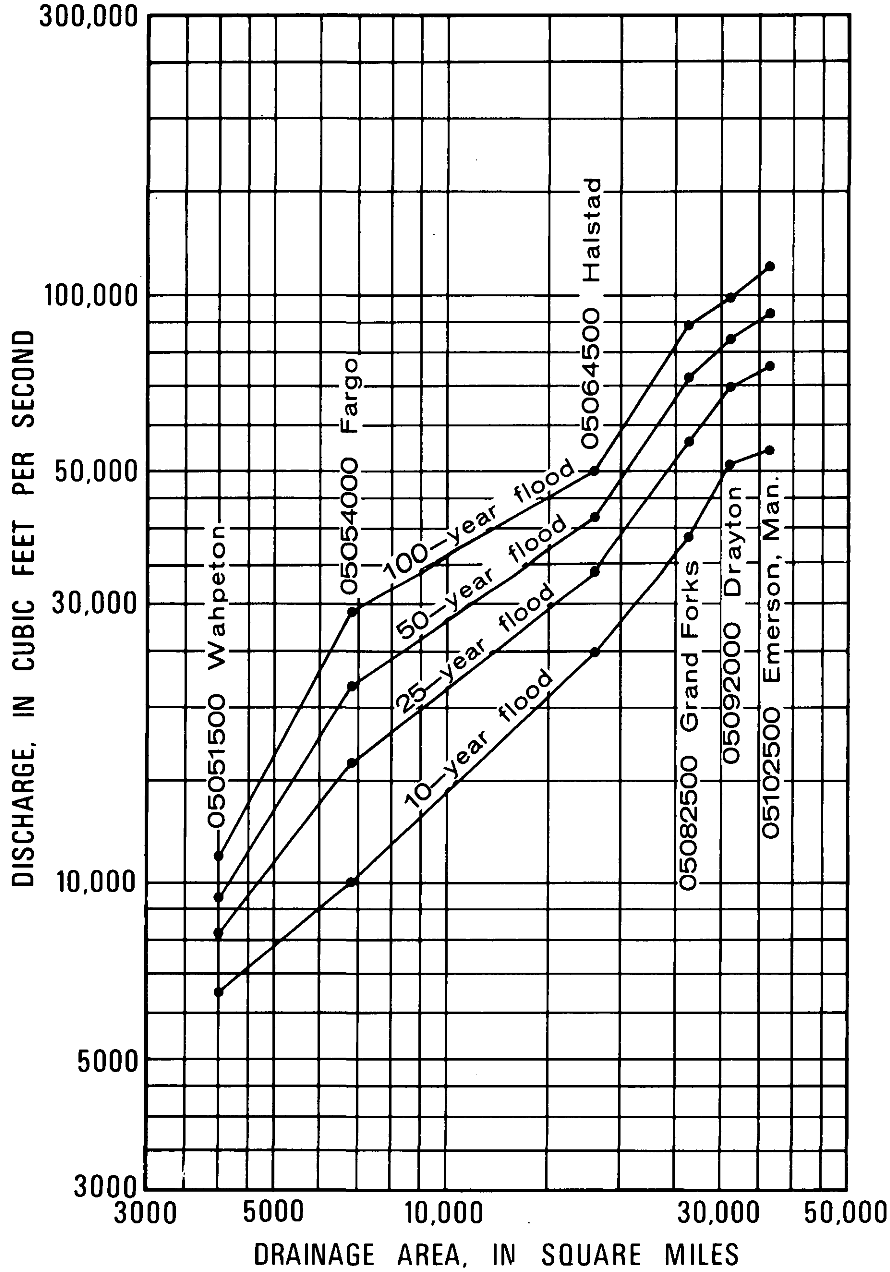

Figure 4.--Relation of flood magnitudes for selected recurrence intervals to drainage area, Red River of the North main stem.

Accuracy and Limitations

In general, estimates of future flood occurrences over a long time period become more reliable with greater length of record (Hardison, 1969). The standard error of estimate decreases with increasing years of available record, but at a decreasing rate. At or near gage sites (excluding main-stem streams), flood characteristics may be based on analysis of actual records collected at the site (from table 2), or may be computed from regional estimating relations. As noted previously, regional estimating relations will probably provide more reliable results than the use of on-site gaging-station data if the period of record is short. It is recommended that use of tabulated gaging-station data for estimating flood characteristics at on-site, or by transfer to nearby locations, be restricted to those frequency relations based on more than 20 years of record.

The reliability of a regression equation may be judged by the standard error of estimate, which is a measure of the distribution of the observed data about the regression equation. The standard error, given in percent, is the range of error to be expected two-thirds of the time. That is, the difference between the computed and the observed discharge for two-thirds of the frequency estimates will be within plus or minus one standard error of estimate. Because the variables used in these analyses were expressed in logarithmic form, standard errors are larger in the positive direction. A graphical interpretation of the standard error for the 10-year frequency relation in Region G is shown in figure 5. Table 4 lists the average standard errors of estimate for the defined relations in each region, except for Region F. Relations for that region were adapted from regression equations developed by Becker (1974) for the adjacent area in South Dakota.

Flood-frequency relations expressed in this report may be used to estimate magnitude and frequency of floods on most Minnesota streams. Applicability and reliability of these relationships is dependent on the basin characteristics at the site under consideration being within the range of characteristics used to define the frequency relations. The range in sampled basin parameters is large enough to allow use of the frequency relations at virtually all sites where streamflow is not significantly affected by regulation, diversion, or urbanization. Exceptions will occur in those instances where the site, for which estimates are required, falls immediately below a lake or ponding area where large storage capacity, in relation to total drainage area size, could seriously alter the outflow flood characteristics. In such cases, the frequency relations may be used as an aid in developing an inflow hydrograph for use in routing through the storage area.

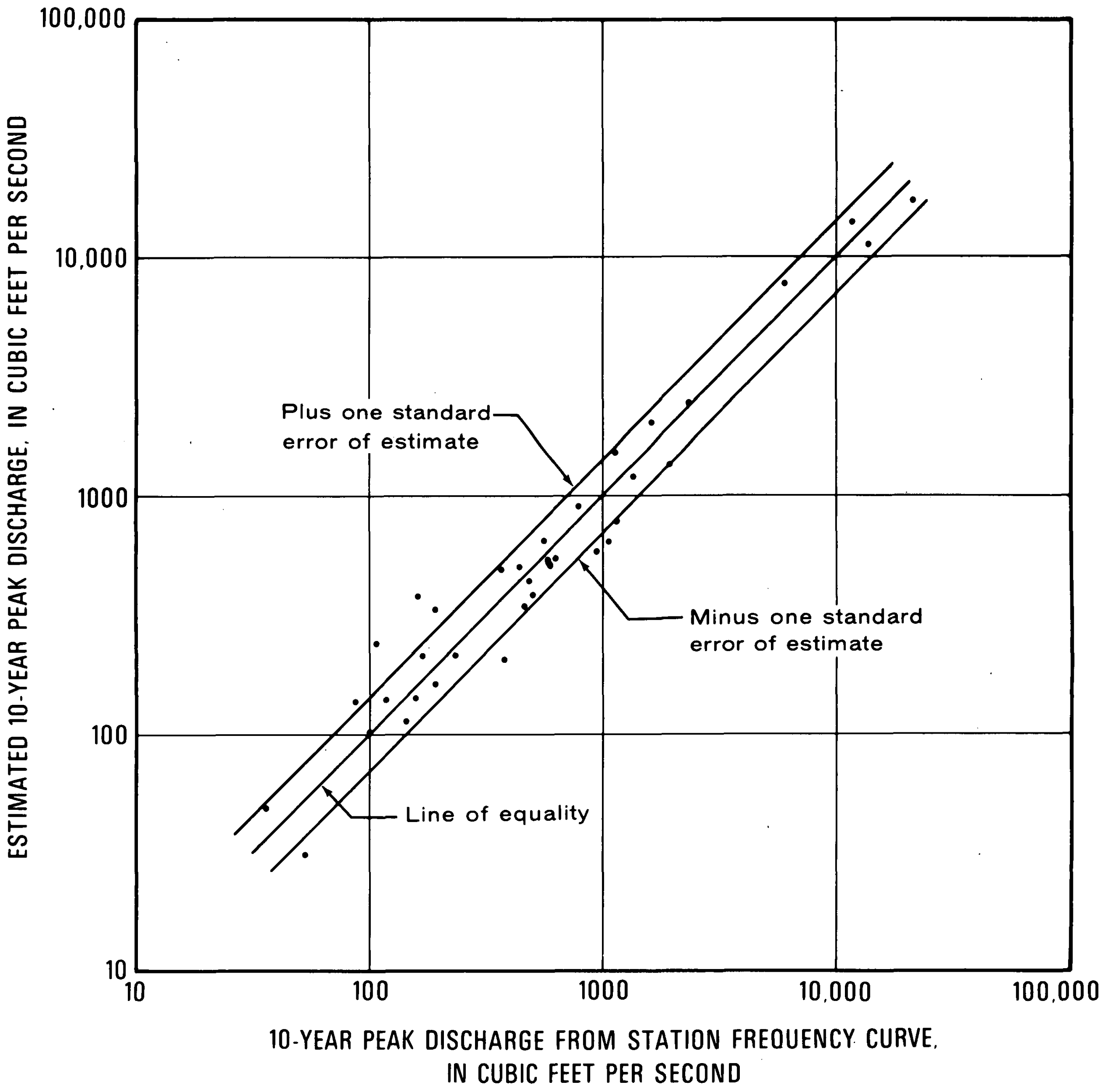

Figure 5.--Graphical interpretation of standard error of estimate for 10-year flood in Region G.

Table 4.--Standard error of estimates for defined relations

Recurrence interval (years)	Standard error of estimate (percent)
Region A	
2	45
5	38
10	39
25	42
50	45
100	49
Region B	
2	36
5	34
10	36
25	38
50	41
100	43
Region C	
2	34
5	34
10	35
25	37
50	39
100	41
Region D	
2	46
5	44
10	47
25	52
50	56
100	61
Region E	
2	56
5	54
10	54
25	55
50	55
100	55
Region G	
2	47
5	37
10	37
25	39
50	42
100	46
Region H	
2	37
5	28
10	28
25	32
50	35
100	39

ANALYTICAL TECHNIQUES

Data Used

Flood-frequency data used in the regression analysis were derived from records of 10 or more years length collected at 219 gaging stations located on natural flow streams. Stations operated by the Minnesota district consisted of 78 sites classified as continuous-record stations and 123 as partial-record stations. Records for 18 sites in adjoining states were also included. Annual peak data through the 1974 water year were considered for the Minnesota partial-record stations, through the 1972 water year for stations in adjoining states, and through the 1970 water year for Minnesota continuous-record stations. Frequency data for many of the continuous-record stations are the result of interagency coordination of 100-year flood estimates required for numerous studies conducted in Minnesota. Where such coordination occurred, frequency curves developed by individual participating agencies were adjusted to provide a uniform peak discharge at the 100-year recurrence interval.

Flow-frequency Analysis at Gaging Stations

A flood-frequency curve for each gaging station was prepared by fitting a log-Pearson Type III frequency distribution to observed annual peaks, using regionalized coefficients of skewness. The log-Pearson Type III method is documented in U.S. Water Resources Council Bulletin No. 15 (1967).

Analysis of frequency characteristics, in connection with interagency coordination activities, had indicated a developing pattern to the variation of computed skew coefficients. Log-Pearson computations based on records starting in the early 1930's generally had large negative skew values while computations based on longer term records produced skew coefficients more nearly approaching zero. Large negative coefficients of skewness were also prevalent at sites where streamflow was significantly affected by natural storage. Skew coefficients generated from records which commenced in the early 1930's, a sustained period of severe widespread drouth in Minnesota, apparently are affected to a varying degree by one or more low outliers. With extension of the record, low outliers are no longer evident.

Adoption of generalized coefficients of skewness applicable to a region was found to significantly improve the fit of the computed frequency curves as the effect of outliers (both high and low) is greatly diminished. Based on analysis of long-term records, adjusted plotting position of outstanding floods recorded at short-term record sites, and extension of some records by correlation, generalized skew coefficients ranging from zero to -0.2 were selected for the log-Pearson analysis of Minnesota gaging-station records.

A later publication by the Water Resources Council, Bulletin 17 (1976), recommends virtually the same procedures for log-Pearson Type III frequency analyses of gaging station records as were used in this report. Differences as they would apply to Minnesota streams are mostly in the regionalized skewness coefficient and in the treatment of historical peaks. Recommendations for generalized (regional) coefficients of skewness in Bulletin 17 range from -0.1 to -0.4 in Minnesota, which differ only slightly from the assigned skew coefficients used in this study. Historical peak adjustments would have only a minor effect on the regression analysis as historical peak data is available at only about 6-percent of the sites analyzed for this report.

Frequency analyses for each gaging station were developed by computer using standard U.S. Geological Survey programs. A computer printed plot of the frequency curve was obtained to visually compare the fit of the computed frequency curve to the observed annual peaks. Modification of the initial frequency curve, by graphical interpretation or use of a different coefficient of skewness, was made in a few instances as dictated by the available data. A sample frequency curve is shown in figure 6.

From the frequency analyses, peak discharges for recurrence intervals of 2, 5, 10, 25, 50 and 100 years, listed as Q_2, Q_5, Q_{10}, etc. in table 2, were selected for the regression analysis.

It should be noted that changing analytical methods, interagency coordination activities, and increasing length of record will undoubtedly result in variations from the frequency estimates listed in table 2.

Multiple-regression Model

Relations between peak discharge (dependent variable) and a set of basin characteristics (independent variables) were developed by multiple-regression techniques. Past experience has shown that peak discharges are linearly related to most basin characteristics if the log transformations of the variables

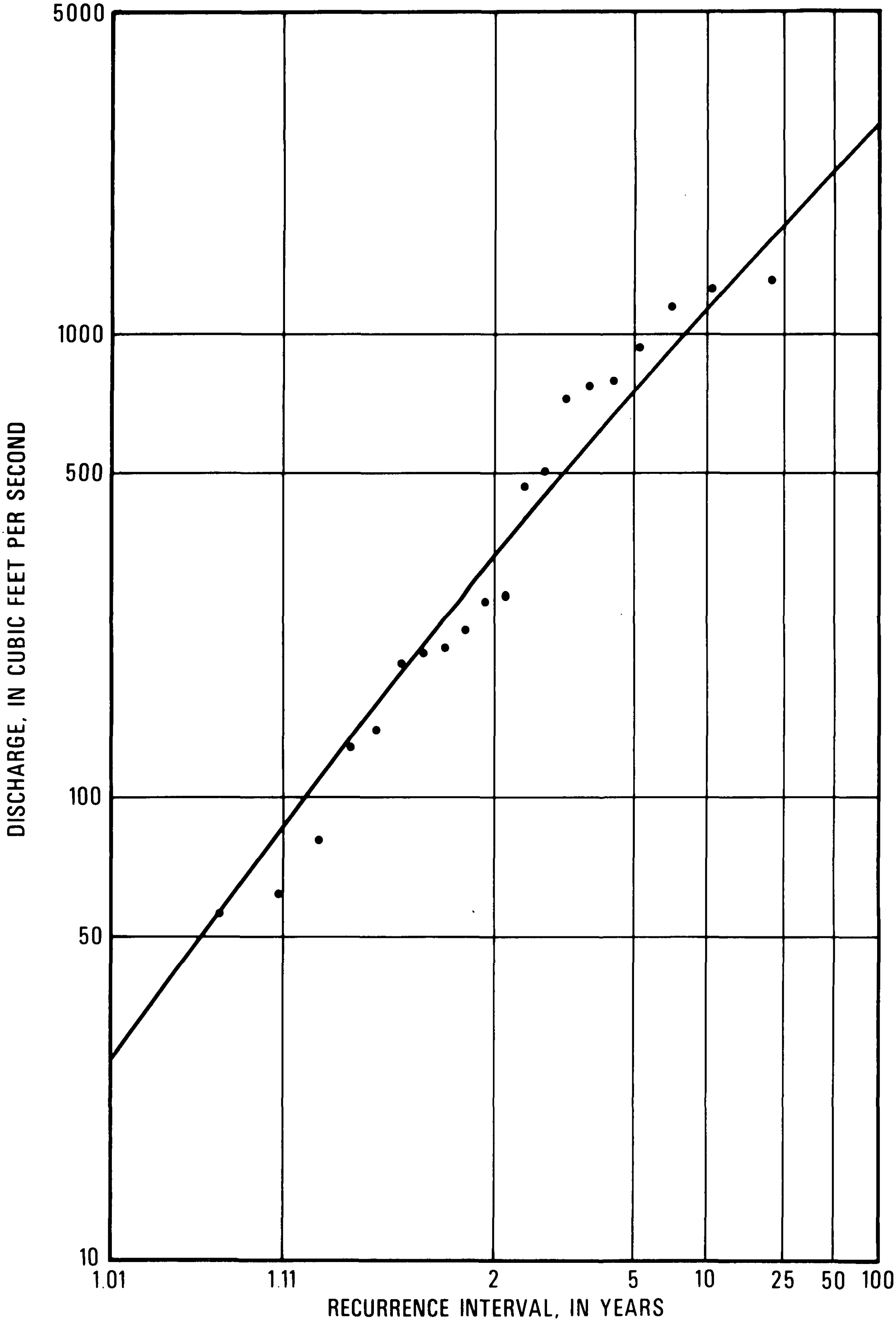

Figure 6.--Flood frequency curve for East Branch Blue Earth River near Bricelyn, Minnesota.

are used. The regression model then is of the form:

$$\text{Log } Q_T = \log a + x \log A + y \log B + z \log C$$

or it's equivalent:

$$Q_T = a\, A^x\, B^y\, C^z$$

where:

Q_T is the peak discharge for T-year recurrence interval

a is a constant

x, y, and z are regression coefficients

A, B, and C are basin characteristics

The step-forward method of multiple-regression analysis was used wherein the regression equation is generated by adding the independent variables in the order of greatest significance to the estimating relation. The variable added for each step is the one which makes the greatest reduction in the standard error of estimate. Only those independent variables statistically significant at greater than the 95 percent confidence level are included in the equations. The analysis defines the regression constant and coefficients, standard error of estimate, and other statistical data for each frequency relation.

In a few instances, independent variables were added or deleted from the equations in order to standardize, on a regional basis, the variables to be considered at the various recurrence intervals. Original equations, in such cases, resulted in frequency curves that were irregularly shaped. Continuity of the frequency curves was vastly improved by addition or deletion of such variables with little effect on the standard error of estimate.

Hydrologic regions shown on figure 1 were defined by plotting residual values on a map. The residual errors from the regression analysis are the differences between observed and computed flood magnitudes and can be expressed in terms of ratios. The plot of residual ratios illustrated the geographical bias inherent in statewide frequency relations. The 8 regions were delineated by removal of successive areas from the regression, based on groupings of the residual values. As each area was removed, new regression relations were computed utilizing the remaining input data, and the residuals again plotted to define the remaining areal bias.

Inter-regional comparisons of the regression equations were made by computing flood magnitudes, at selected recurrence intervals, using constant basin characteristics for each regional relation. These tests showed considerable variability in computed flood characteristics across the State for a fixed set of independent variables.

Regional boundaries outlined on figure 1 generally follow basin divides. The following exceptions based on topographic or geologic features are: 1) in the southwestern part of the State, where the regional boundary follows the break in slope along the Coteau des Prairie and crosses the upper end of the Redwood, Yellow Medicine and Lac qui Parle River basins; and 2) in the northwestern part, where the regional boundary follows an upper beach ridge of glacial Lake Agassiz and crosses the upper end of the Wild Rice, Marsh, Sand Hill, and Clearwater River basins.

Basin Characteristics Investigated

A precondition established for this report was that the number of basin characteristics used in the regression be limited in number, and be readily determined from available maps, to eliminate the necessity for on-site measurements. Independent variables investigated in addition to area, slope and storage, were forest cover and soil type. Forest cover index was used as the percentage of the drainage area covered by forests increased by 1 percent. The soil index was determined by averaging residuals from an initial regression according to different soil types. The soil index was tested separately on a multiple regression analysis of small basins where soil homogeneity was more probable. Neither basin characteristic improved the estimating relations.

SUMMARY

Basin characteristics and peak flows for 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals were tabulated for 201 gaging stations ranging in size from 0.05 to 5,280 mi^2. The data from these 201 stations were grouped according to eight distinct hydrologic regions and equations were developed for each region by relating peak flows to basin characteristics. The resulting equations provide a method for estimating flood-frequency relations for ungaged sites on all natural streams. In addition, graphs are presented for determining floods of selected recurrence intervals for large streams which may be significantly affected by regulation.

The equations developed by multiple regression for estimating peak flows at ungaged sites determined that drainage area, slope, and storage are significant basin parameters for estimating 2-, 5-, 10-, 25-, 50-, and 100-year floods. Drainage area, slope, and storage were significant in 4 of the 8 regions, drainage area and slope in 2, and only drainage area in the remaining 2 regions. Accuracy of estimates obtained by using the equations are discussed and the standard error of estimate is given for each equation. Standard errors ranged from 28 to 61 percent.

Analytical techniques are discussed for determining flow frequency at gaging stations and for making estimates at ungaged sites. The regional regression equations provide more reliable results than frequency relations defined for gaging stations if the period of record is short. For sites at or near gaging stations having 20 or more years of record, the tabulated station data are considered more accurate than estimates from the regression equations.

REFERENCES

Becker, L. D., 1974, A method for estimating magnitude and frequency of floods in South Dakota: U.S. Geol. Survey Water-Resources Inv. 35-74, 78 p.

Hardison, C. H., 1969, Accuracy of streamflow characteristics: in Geological Survey Research, U.S. Geol. Survey Prof. Paper 650-D, p. D210-214.

Patterson, J. L., and Gamble, C. R., 1968, Magnitude and frequency of floods in the United States, Part 5: U.S. Geol. Survey Water-Supply Paper 1678, 546 p.

Prior, C. H., 1949, Magnitude and frequency of floods in Minnesota: Minnesota Dept. of Conservation, Div. of Waters Bull. 1, 128 p.

Prior, C. H., and Hess, J. H., 1961, Floods in Minnesota, magnitude and frequency: Minnesota Dept. of Conservation, Div. of Waters Bull. 12, 142 p.

Thomas, D. M., and Benson, M. A., 1970, Generalization of streamflow characteristics from drainage-basin characteristics: U.S. Geol. Survey Water-Supply Paper 1975, 55 p.

U.S. Water Resources Council, 1967, A uniform technique for determining flood flow frequencies: Hydrology Committee Bull. 15, 15 p.

____ 1976, Guidelines for determining flood flow frequency: Hydrology Committee Bull. 17, 196 p.

Wiitala, S. W., 1965, Magnitude and frequency of floods in the United States, Part 4: U.S. Geol. Survey Water-Supply Paper 1677, 357 p.

____ 1971, Red River of the North regional flood analysis: North Dakota State Water Commission and Minnesota Dept. of Natural Resources, 19 p.

____ 1973, St. Croix River regional flood analysis (St. Croix Falls, Wis. to mouth): Minnesota Dept. of Natural Resources and Wisconsin Dept. of Natural Resources, 19 p.

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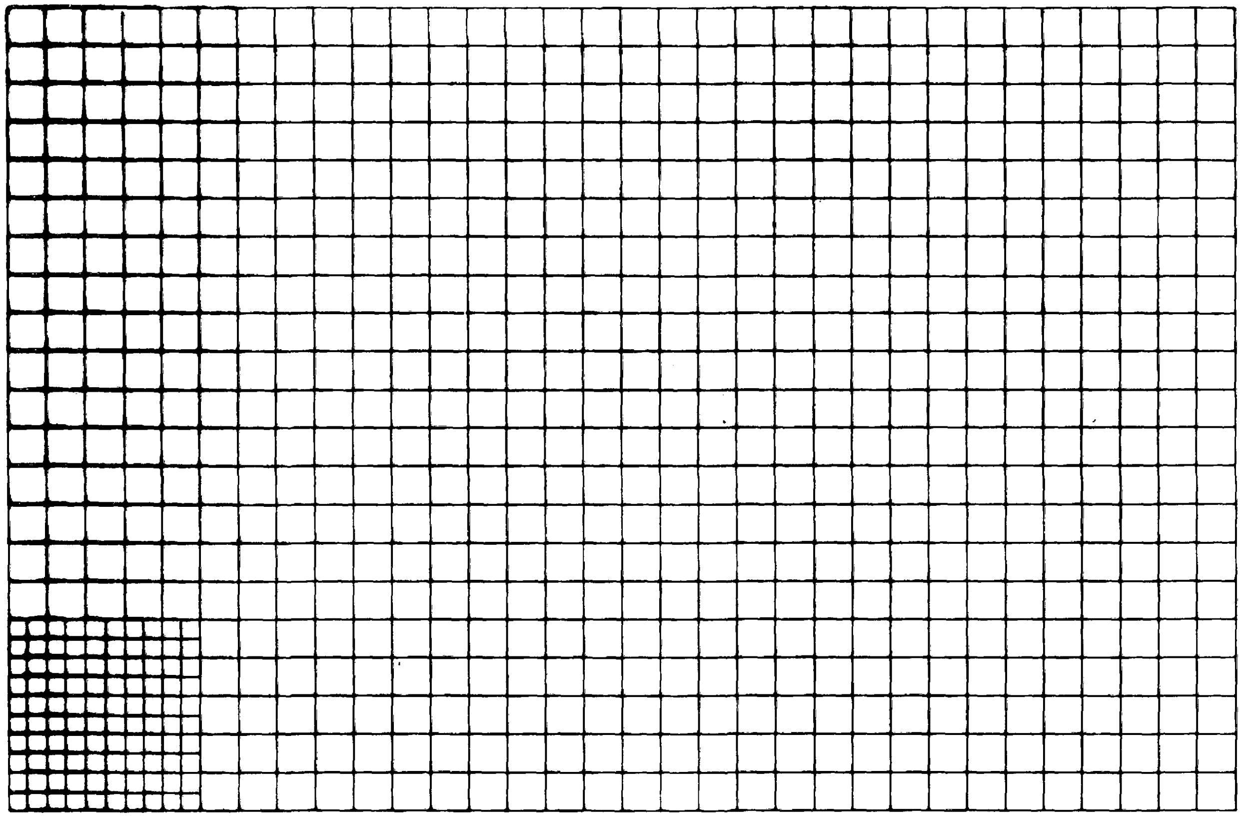
AREA GRID



7½-minute quadrangle (Scale 1:24,000)

Area of small squares = 0.00144 square mile

Area of large squares = 0.00578 square mile

15-minute quadrangle (Scale 1:62,500)

Area of small squares = 0.00976 square mile

Area of large squares = 0.0389 square mile