SIXTEEN YEAR STUDY OF MINNESOTA FLASH FLOODS

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Minnesota Department of Natural Resources
Division of Waters
State Climatology Office
and
University of Minnesota
Soil Science Department

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ADDENDUM

1. INTRODUCTION

This study provides climatological data and facts on 16 years of flash floods in Minnesota that occurred from 1970 through 1985. The information is based on 57 flash floods and includes data on their areal extent, maximum rainfall amounts, orientation, time of occurrence, probability of occurrence, and precipitation network history.

The definition of a flash flood as used here is the occurrence of 6-inches or more rainfall within a 24-hour period. The size of a flash flood is the measured area in square miles over which a 4-inch or more rainfall occurs. The rationale for using these two criteria is that a rainfall of six inches in a 24-hour period is near the 100-year return period in Minnesota and, second, a 4-inch and greater rainfall approximates the level at which newspaper reports indicate increased erosion or other economic damages are associated.

2. HISTORY

Documentation of flash floods across Minnesota prior to 1970 was made only for the most damaging floods. In the first 8 years of this study, 1970-1977, only the larger and more damaging storms could be documented, since the smaller flash floods passed between the rain gage network and could not be identified. During the last 8 years, 1978-1985, all flash floods as defined above are believed to be documented as a result of a marked increase in gage distribution and density. The documentation consists of collecting as many rainfall reports as possible from the raingage network. From these preliminary network reports a general outline of the flash flood is made from plotted data. The next step is to obtain reports from residents living near the 'core' of the flash flood (use of telephone is the most efficient method). Identification of the 'core' of the flash flood is most important. Unless a dense and well distributed rainfall network is available, few flash flood analyses can be made, since most can not be adequately identified. Case in point: the May 27-28, 1970, flash flood in Goodhue and Wabasha Counties in which extreme rainfall amounts failed to be observed by a formal rain gage network, but were found by a 'bucket survey' (see Minnesota Climatological Data for May, 1970, published by the National Climatic Data Center, Asheville, North Carolina). A 'bucket survey' is accomplished by direct contact with individuals, generally farmers, who measured the rainfall amounts using a gage or an estimate from pails or buckets left out of doors and which can serve as proxy gages. Analysis by bucket survey was the practice in Minnesota prior to 1971 and was generally made only when lives were lost or great economic damage occurred. Bucket surveys of the past were made mostly by National Weather Service personnel traveling from location to location, a costly and time consuming effort.

Minnesota has a history of establishing raingage networks in the metro Twin Cities area as well as statewide. To date there are 10 different precipitation networks operating in parts of the State. In addition to the statewide National Weather Service Cooperative Network two additional statewide networks have been established: the Future Farmers of America (FFA) in 1971 and the Soil and Water Conservation District (SWCD) in 1977 and 1978. The FFA network was established within school districts and is operated by high school students. Because the FFA network was spatially dense, it has done a good job in identifying flash floods occurring within the school districts and has proved to be a very rapid and efficient mechanism for acquiring rainfall data for flash floods. The FFA rain gage network has largely given way to the Soil and Water Conservation Districts (SWCD) precipitation network, which was established for climatological data as well as operational use as, for example, flash floods. The network was initiated in 1977 and 1978 with an observer located, with some exceptions, every 12 miles across the state. The observations are taken on a 'year-round' basis. A reason for documenting all flash floods only in the last 8 years was that prior to this time there was a lack of data across the state. However, with the establishment of a statewide Soil and Water Conservation District precipitation network with rain gages every 12 miles beginning in 1977, adequate data to identify nearly all flash floods as defined above became available. An exception exists in part of north central and northeastern Minnesota where there is a lack of rain gages because of the sparse population. Presently, the SWCD network with 8 complete years of data together with data from 9 other networks provides the state of Minnesota with a most complete long term, well distributed, high density and large data set. It is unique for a state as a whole and something no other mid-west state can boast. The location of the reporting stations in the current Minnesota networks is shown in Figure 1.

a. GAGE DENSITY

Gage distribution from the SWCD network is nearly ideal. However, the distribution (as noted in Figure 1) shows areas which could be improved. The SWCD network began in 1977-78, and since then some counties have added observers, yet there are a few counties that have lost observers over time. Networks within the seven-county Twin Cities area give a gage density of one gage per 15 square miles, which is approximately 6 times that in the outstate area. However, there remains a need for observers in the business and industrial areas of the two cities. The State Forestry District and Deep Portage networks have provided additional coverage in the northern and central parts of the state.

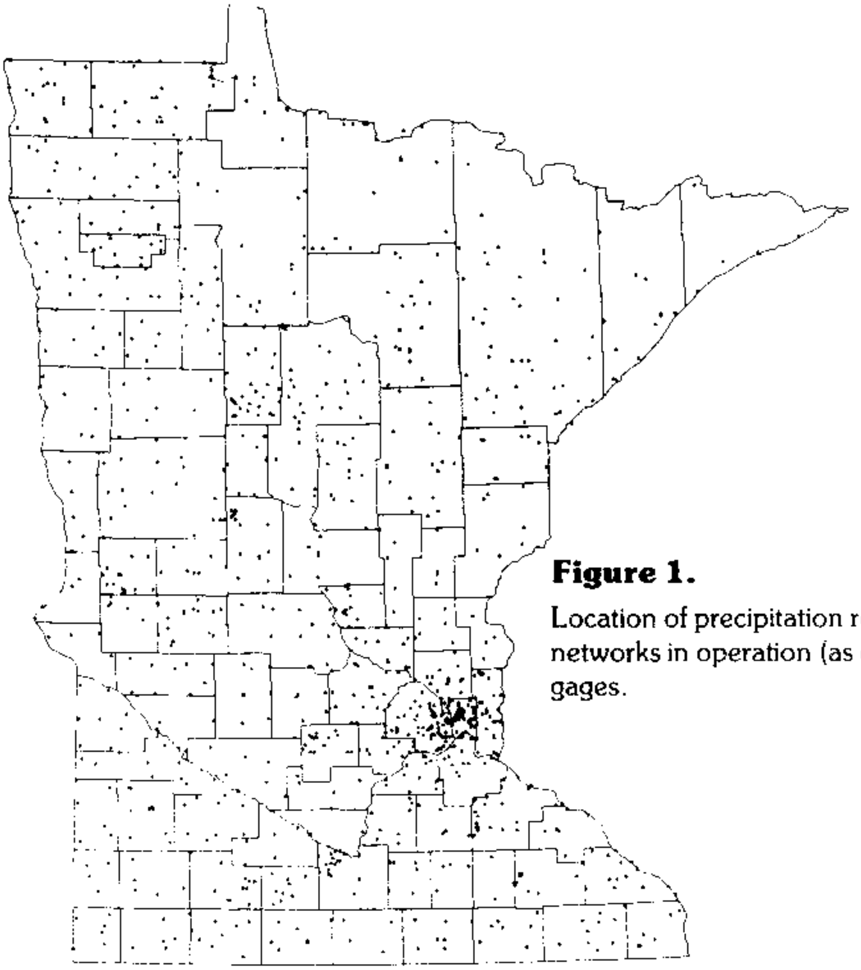


Figure 1.

Location of precipitation reporting statings in Minnesota. The ten networks in operation (as of July 1985), have a total of 1062 gages.

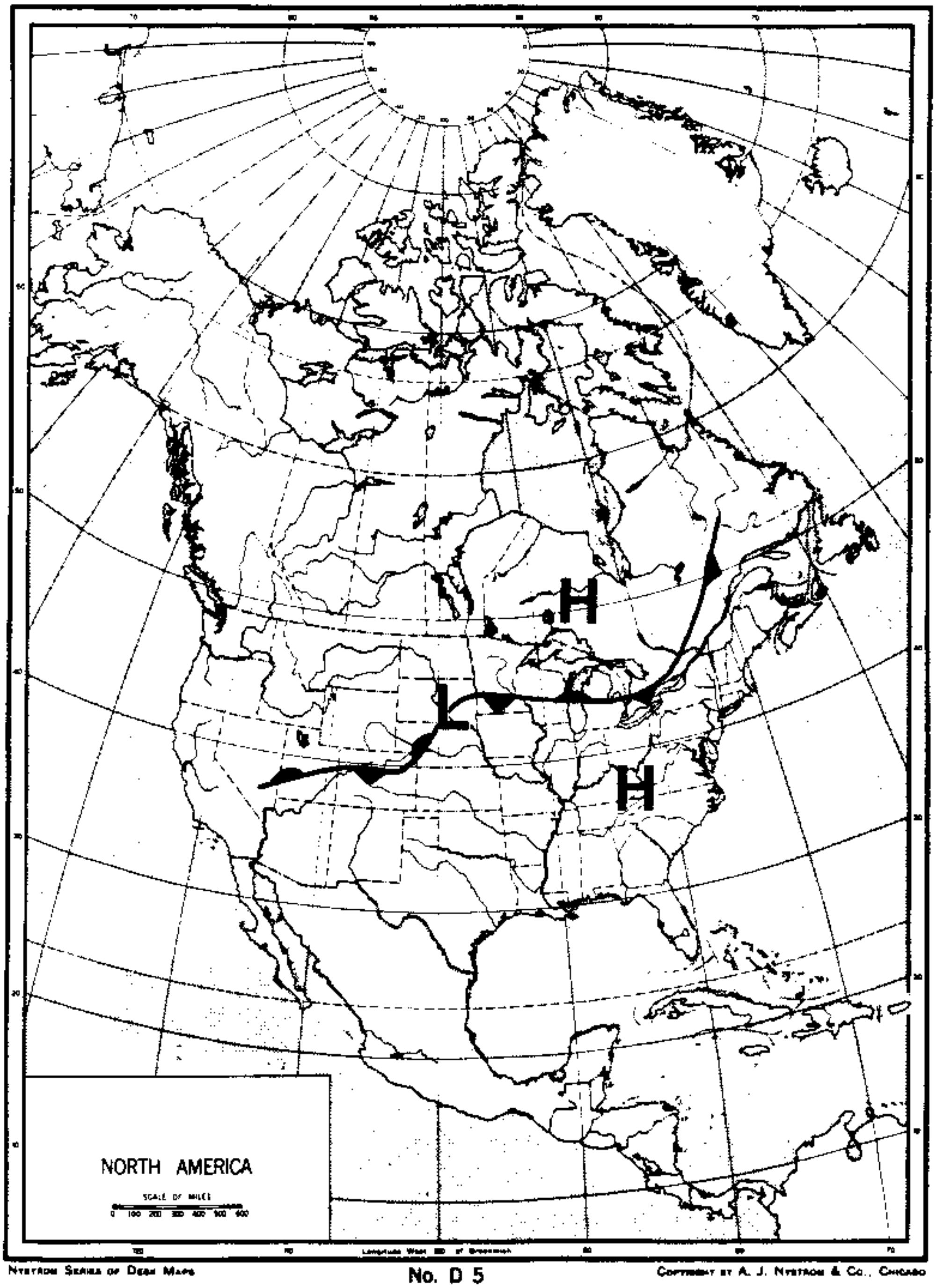


Figure 2. Basic surface synoptic weather pattern associated with Minnesota flash floods.

3. WEATHER PATTERNS ASSOCIATED WITH FLASH FLOODS

Weather patterns associated with flash floods show a number of similarities. When looking at the weather patterns at the surface and the upper atmosphere, specific combinations of patterns of the two exist for many Minnesota flash floods.

The basic surface pattern places a low pressure center or a wave in the Dakota's, with a cold front extending to the southwest of the low and a stationary front extending east or southeast across Minnesota where it separates two high pressure systems as illustrated in Figure 2. The two highs may cover the area from the Carolina's north to Hudson Bay. The location of the southern high pressure system is such that very moist Gulf of Mexico air is drawn northward into the stationary front across Minnesota. The low pressure system will generally remain in the Dakota's or move slowly eastward.

The basic upper air pattern shows a 500 millibar (18,000 foot level) upper air trough located in the Rockies or farther west with a high pressure ridge or center that can be located anywhere from Kansas to the Carolina's (Figure 3). It was noted that on the days of flash floods a weak ridging generally occurred over Minnesota. This upper air pattern shows flow from the southwest extending from the Rockies to the Dakota's with a somewhat weaker southwest upper air flow over Minnesota. The basic ingredients for flash floods in Minnesota therefore are: a southwesterly flow aloft with a good southerly surface gulf flow (providing the moisture) and a slow moving to nearly stagnant system (resulting in large concentrated precipitation amounts).

The weather pattern described above means energy from the slowing down of the moderate southwest flow as it moves over Minnesota can be transformed into convective activity or thunderstorms. With thunderstorms over the stationary front which is receiving very moist gulf air, flash floods can be expected to occur as long as this surface and upper air combination exists.

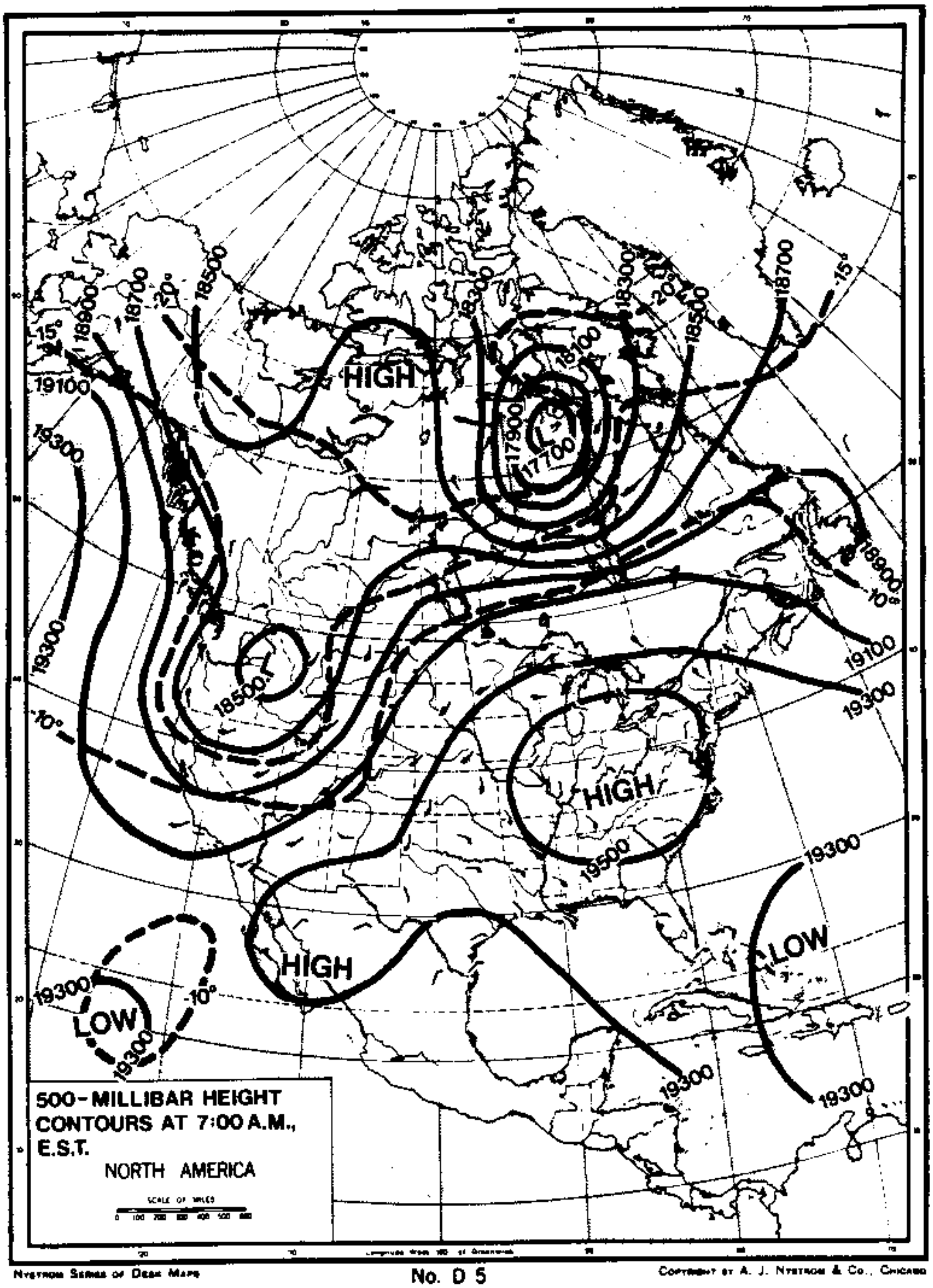


Figure 3. Basic upper air pattern associated with Minnesota flash floods.

4. TEMPORAL DISTRIBUTION

A. ANNUAL DISTRIBUTION OF FLASH FLOODS

All flash floods are believed to have been recognized and recorded in the last eight years, 1978 through 1985, which is the period the high-density SWCD precipitation network has been in operation. Analysis of the last 16 years showed that there is no significant difference in the number of flash floods in the northern, the central, and the southern parts of the state.

If the last eight years are used to estimate annual averages we could expect for the state as a whole (Table 1): five flash floods annually or four flash flood-days annually.

Table 1. Annual Distribution of Flash Floods

YEAR	NUMBER RECORDED	FLASH FLOOD DAYS
1970	1	
1971	1	
1972	5	
1973	0	
1974	2	
1975	4	
1976	0	
1977	4	
Total 1970-77	17	
1978	13	8
1979	5	4
1980	4	4
1981	5	4
1982	1	1
1983	7	7
1984	0	0
1985	5	4
Total 1978-85	40	32 days
Average	5	4 days

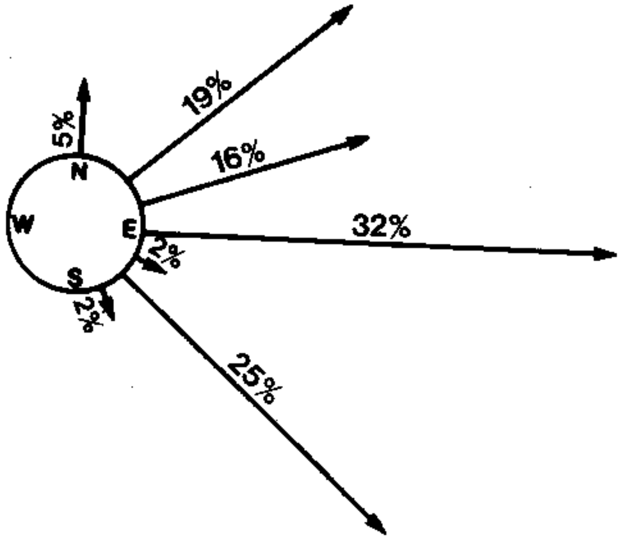
b. MONTHLY DISTRIBUTION OF FLASH FLOODS, 1970 – 1985

The monthly distribution of flash floods shows June with the greatest number with 17 or 30% of the annual total (Table 2). July is a close second with 16 or 28% of the total. The earliest flash flood occurred on May 6-7, 1983, in Lyon County and the latest on September 30, 1977, in Worthington, Nobles County. The most flash floods to occur in a 24-hour period was on June 30-July 1, 1978, when five separate flash flood cells evolved out of a huge complex storm extending from the Twin Cities southeast to the Iowa border. The median date of the flash flood season is July 11. This is not far from the warmest day of the year which, on the average, is July 23.

Table 2. Monthly distribution of Flash Floods 1970-1985

Month	Number of Flash Floods	Percent of Flash Floods
April	0	0%
May	5	9%
June	17	30%
July	16	28%
August	10	17%
September	9	16%
October	0	0%
Total	57	100%

Figure 4. Orientation of Flash Floods.



c. TIME OF DAY FLASH FLOODS COMMENCE 1970-1985

Analysis of 51 flash floods shows that 37% of them began between 6 PM and 8PM and over 50% began in the evening between 6PM to 11PM (Table 3). From midnight through 7AM some 27% of the flash floods begin. As a rule during the midnight to 7AM period the rains are generally of higher intensity but a shorter time frame. We are unable to offer a reason at this time, but more rapid cooling of the upper surface of thunderstorms during night hours (causing greater instability) and lesser winds may be a plausible explanation. The beginning times of the flash floods were acquired from both telephone contact with the observers, usually the day after the storm, and from the "Remarks Section" of the monthly report form each observer sends to the State Climatoloty Office.

For a typical mass curve of a flash flood (weighing rain gage chart), see Appendix for the June 30-July 1, 1978, storm. The curve on the chart shows the amount and time of occurrence.

Table 3. Time of day Flash Floods Begin
1970-85

HOUR OF THE DAY	NUMBER OF FLASH FLOODS
Midnight	2
01 AM	2
02	2
03	3
04	0
05	2
06	0
07	3
08	0
09	0
10	3
11	1
Noon	0
01 PM	1
02	2
03	2
04	2
05	0
06	13
07	6
08	4
09	1
10	0
11	2
TOTAL	51

5. AREAL DISTRIBUTION

a. ORIENTATION OF FLASH FLOODS

The orientation of flash floods, which is based on the surface rainfall isohyet maps, shows that the west to east rain storms number approximately one-third of the total (Table 4). The orientation of the flash floods, in general, shows where the stationary front is located. The bracketed section of Table 4 represents the orientation of two-thirds of the flash floods apparently take, while the single orientation, northwest through southeast represents, 25 percent. Analysis shows no significant orientation preference statewide, except that storms moving from the NW showed a slight increase in the southern part of the state. (See Figure 4).

Table 4. Flash Flood Orientation

Direction		Number	Percent
S to N		3	5%
SSW to NNE		0	0%
(SW to NE		11	19%)
(WSW to ENE		9	16%)
(W to E		18	32%)
WNW to ESE		1	2%
NW to SE		14	25%
NNW to SSE		1	2%
	TOTAL	57	

b. SHAPES — "CIGAR" AND "OBLONG"

The shapes or outline designs of flash floods were grouped into two general shapes: "cigar" shape, when the length to width ratio was more than four to one, and an "oblong" shape, when the length to width ratio was less than four to one. About two-thirds of all flash floods were "cigar" shaped and one-third were "oblong". The median dimensions were a 14-mile width and a 75-mile length for the "cigar" shape, and a 11-mile width and a 27-mile length for the "oblong" shape. Further investigation showed that the "oblong" shapes were on the average considerable smaller of the two, and they showed a poorer definition in a map analysis because of generally fewer rainfall observations as a whole. This may mean that some of the "oblong" shapes would show a "cigar" shape if more observations were available.

The areal distribution or rainfall pattern of flash floods result from slow moving moisture-laden thunderstorm cells. If a thunderstorm cell remained stationary a circular pattern would probably occur. Oblong shapes usually arise from very slow moving cells, while cigar shaped floods can occur from either slow moving cells of longer duration or several cells moving along the same path. An average cigar shaped flood is about 75 miles long and most of the rain falls in 3 to 9 hours. With a mean rainfall of 6 hours in duration and a cell length of 75 miles, a cell movement of about 12 mph is indicated.

c. AREA COVERED BY FLASH FLOOD EVENTS

The "area" referred to is that part of the flash flood covered by 4 inches or more of rain. The range in the area of the flash floods within this study is 25 square miles to 6800 square miles. The median size is approximately 600 square miles. The Rochester flash flood on July 5-6, 1978, is considered a typical flash flood. (see Appendix).

The four largest flash floods by area are listed in Table 5, and they occurred in the same period as the warmest summer temperatures that extend from June 21 to August 21 at Minneapolis-St. Paul Airport, with temperatures 70 degrees Fahrenheit and greater. Fifty-six percent of the flash floods occur at this time.

Table 5. The four largest "area" flash floods, 1970-85.

	Date	Area in Square Miles	Location
1	July 21-22, 1972	6800	Alexandria east into Wisconsin
2	June 28-29, 1975	6000	Southwest of Fargo to northeast of Fargo into Clay County, MN
3	July 1-2, 1975	4500	Kittson county southeast thru lower Beltrami county
4	August 22-23, 1978	4100	Lake Itasca to Duluth

6. MAXIMUM PRECIPITATION AMOUNT FOR FLASH FLOODS

The maximum rainfall amount known and recorded for each of the flash floods show a range from 6 inches to 14 inches (6-inches and greater for a 24-hour period is the definition of a flash flood). The median or the expected rainfall maximum amount for any "flash flood" is 7.2 inches. The larger rainfall amount flash floods occurred between June 21 and July 29 (Table 6). This is near the warmest day of the summer season. (July 23). The largest rainfall amount in a flash flood occurred on July 21-22, 1972.

Table 6. The four largest rainfall amounts of 57 flash floods.

	Date	Area	Location of Greatest Amount
1st	July 21-22, 1972	14.00 inches	10 miles southwest of Little Falls
2nd	July 28-29, 1975	13.00 inches	Northeast of Fargo near Ulen
3rd	June 21, 1983	12.00 inches	10 miles north of Litchfield
4th	July 11, 1981	10.04 inches	10 miles southwest of Rochester.

7. PROBABILITY OF OCCURENCE

a. FOUR-INCH RETURN PERIODS

Return periods for 4-inch or greater rainfalls associated with flash flood events have been computed from the data observed from 1978 through 1985. For the eight-year period all flash floods are considered to have been recorded. The calculation of a "4-inch rainfall area" return period based on data from this study is done here for illustrative purposes.

CALCULATION OF 4-INCH RAINFALL AREAS:

(1. Total area of Minnesota = 84,068 square miles

(2. Total 4-inch flash flood area in the last 8 years = 29,467 square miles.

(3. Return Period $\frac{\text{Total Area}}{\text{(Area/Year)}}$ = 84,068/ (29,469/8) = 22.8 years

The U.S. Weather Bureau Technical Publication # 40 (Hershfield, D, 1961, "Rainfall Frequency Atlas of the United States", U.S. Department of Agriculture; "TP 40") shows the 10-year return period for a 24-hour rainfall across Minnesota from north to south to vary from 3.5 to 4.5 inches while the 25-year return period varies from 4 to 5 inches from north to south.

It is apparent that the 4-inch flash flood area return period of 22.8 years obtained in this study is comparable to the results in TP 40.

b. SIX – INCH RETURN PERIODS

The return period for 6-inch per 24 hours rainfall has also been computed. The "6-inch rainfall areas" shown on the maps in this study were not measured for size because of a lack of 6-inch and greater observations necessary for the analysis. However, an estimate was made from a ratio of the 4-inch area to the 6-inch area from several flash floods. The ratio of the "6-inch rainfall area" compared to the larger "4-inch rainfall areas" is approximately 35%, while for smaller "4-inch rainfall areas" the ratio is 15%. Then using a mean of 25% as the ratio of the "6-inch rainfall' to that of the known "4-inch rainfall area" a similar calculation for 6-inch and greater rainfall return periods was made for the last eight year period.

CALCULATION OF 6-INCH RAINFALL AREAS:

1.) Return Period $\frac{\text{Area}}{\text{(Area x \%)/year)}}$ = 84,068/(29,469 x 25%/8) = 91.3 years

TP 40 shows the 100-year return period for 24-hour rainfall events across Minnesota from north to south to vary from 5 to 6.2 inches. The 91.3-year return period for a "6-inch rainfall area" obtained in this study is in reasonable agreement to TP 40. The similarity between the TP 40 point probabilities and the '6-inch area" probabilities shows that area frequency amounts can be substituted for point frequency amounts. As a result, the record period necessary to determine frequencies does not have to be as lengthy as normally required for point measurements.