HYDROMETEOROLOGICAL REPORT NO. 48

Probable Maximum Precipitation and Snowmelt Criteria For Red River of the North Above Pembina, and Souris River Above Minot, North Dakota

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS

Washington, D.C.
May 1973

HYDROMETEOROLOGICAL REPORTS

*No 1 Maximum possible precipitation over the Ompompanoosuc Basin above Union Village, Vt 1943
*No 2 Maximum possible precipitation over the Ohio River Basin above Pittsburgh, Pa 1942
*No 3 Maximum possible precipitation over the Sacramento Basin of California 1943
*No 4 Maximum possible precipitation over the Panama Canal Basin 1943
*No 5 Thunderstorm rainfall 1947
*No 6 A preliminary report on the probable occurrence of excessive precipitation over Fort Supply Basin, Okla 1938.
*No 7 Worst probable meteorological condition on Mill Creek, Butler and Hamilton Counties, Ohio 1937 (Unpublished) Supplement, 1938
*No 8 A hydrometeorological analysis of possible maximum precipitation over St Francis River Basin above Wappapello, Mo 1938
*No 9. A report on the possible occurrence of maximum precipitation over White River Basin above Mud Mountain Dam site, Wash 1939
*No 10 Maximum possible rainfall over the Arkansas River Basin above Caddoa, Colo 1939 Supplement, 1939
*No 11 A preliminary report on the maximum possible precipitation over the Dorena, Cottage Grove, and Fern Ridge Basins in the Willamette Basin, Oreg, 1939.
*No 12 Maximum possible precipitation over the Red River Basin above Denison, Tex 1939.
*No 13 A report on the maximum possible precipitation over Cherry Creek Basin in Colorado, 1940
*No 14 The frequency of flood-producing rainfall over the Pajaro River Basin in California 1940
*No 15. A report on depth-frequency relations of thunderstorm rainfall on the Sevier Basin, Utah. 1941
*No 16. A preliminary report on the maximum possible precipitation over the Potomac and Rappahannock River Basins 1943
*No 17 Maximum possible precipitation over the Pecos Basin of New Mexico 1944 (Unpublished.)
*No 18. Tentative estimates of maximum possible flood-producing meteorological conditions in the Columbia River Basin 1945
*No 19. Preliminary report on depth-duration-frequency characteristics of precipitation over the Muskingum Basin for 1- to 9-week periods 1945
*No 20 An estimate of maximum possible flood-producing meteorological conditions in the Missouri River Basin above Garrison Dam site 1945.
*No 21 A hydrometeorological study of the Los Angeles area 1939.
*No 21A Preliminary report on maximum possible precipitation, Los Angeles area, California 1944
*No 21B Revised report on maximum possible precipitation, Los Angeles area, California 1945
*No 22 An estimate of maximum possible flood-producing meteorological conditions in the Missouri River Basin between Garrison and Fort Randall 1946
*No 23 Generalized estimates of maximum possible precipitation over the United States east of the 105th meridian, for areas of 10,200, and 500 square miles 1947
*No 24 Maximum possible precipitation over the San Joaquin Basin, Calif 1947
*No 25 Representative 12-hour dewpoints in major United States storms east of the Continental Divide 1947.
*No 25A Representative 12-hour dewpoints in major United States storms east of the Continental Divide 2d edition. 1949
*No. 26 Analysis of winds over Lake Okeechobee during tropical storm of August 26–27, 1949 1951
*No 27. Estimate of maximum possible precipitation, Rio Grande Basin, Fort Quitman to Zapata. 1951
*No 28 Generalized estimate of maximum possible precipitation over New England and New York 1952.
*No 29 Seasonal variation of the standard project storm for areas of 200 and 1,000 square miles east of 105th meridian 1953
*No. 30 Meteorology of floods at St Louis 1953 (Unpublished)
*No 31 Analysis and synthesis of hurricane wind patterns over Lake Okeechobee, Florida 1954
*No 32 Characteristics of United States hurricanes pertinent to levee design for Lake Okeechobee, Florida 1954
No. 33 Seasonal variation of the probable maximum precipitation east of the 105th meridian for areas from 10 to 1,000 square miles and durations of 6, 12, 24, and 48 hours 1956
No 34 Meteorology of flood-producing storms in the Mississippi River Basin. 1956.
No. 35 Meteorology of hypothetical flood sequences in the Mississippi River Basin 1959.
*No 36 Interim report—probable maximum precipitation in California 1961. Also available is a supplement, dated October 1969.
No 37 Meteorology of hydrologically critical storms in California. 1962
No 38 Meteorology of flood-producing storms in the Ohio River Basin 1961
No. 39. Probable maximum precipitation in the Hawaiian Islands 1963
No 40 Probable maximum precipitation, Susquehanna River drainage above Harrisburg, Pa 1965
No 41 Probable maximum and TVA precipitation over the Tennessee River Basin above Chattanooga 1965
No 42 Meteorological conditions for the probable maximum flood on the Yukon River above Rampart, Alaska 1966
No 43 Probable maximum precipitation, Northwest States 1966
No 44 Probable maximum precipitation over South Platte River, Colorado, and Minnesota River, Minnesota 1969
No 45 Probable maximum and TVA precipitation for Tennessee River Basins up to 3,000 square miles in area and durations to 72 hours 1969
No 46 Probable maximum precipitation, Mekong River Basin 1970
No. 47 Meteorological criteria for extreme floods for four basins in the Tennessee and Cumberland River Watersheds 1973

---

* Out of print

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

U.S. DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS

HYDROMETEOROLOGICAL REPORT NO. 48

Probable Maximum Precipitation and Snowmelt Criteria For Red River of the North Above Pembina, and Souris River Above Minot, North Dakota

Prepared by
John T. Riedel
Hydrometeorological Branch
Office of Hydrology
National Weather Service

WASHINGTON, D.C.
May 1973

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402.
Price $0.95 domestic postpaid or $0.70 G.P.O. Bookstore.

UDC 551.577.37:551.579.2:556.124.3(282.4)(784)

551.5	Meteorology
.577	Precipitation
.37	Maximum precipitation
.579	Hydrometeorology
.2	Water supply from snow melt
556	Hydrology
.124	Snowpack
.3	Melting-of-snow rate
(282.4)	River basins
(784)	N. Dakota

CONTENTS

CONTENTS--Continued

TABLES

FIGURES

FIGURES--Continued

PROBABLE MAXIMUM PRECIPITATION AND SNOWMELT CRITERIA FOR RED RIVER OF THE NORTH ABOVE PEMBINA, AND SOURIS RIVER ABOVE MINOT, NORTH DAKOTA

Chapter I

INTRODUCTION

Purpose

The purpose of this study is to provide estimates of probable maximum precipitation (PMP) and other meteorological criteria needed for determining the combined snowmelt and rain flood for 11 subbasins of the Red River of the North above Pembina, N. Dak. and two subbasins of the Souris River above Minot, N. Dak.

Figures 1-1 and 1-2 show outlines of the drainages. The largest of the 11 Red River of the North, figure 1-1, subbasins is the total area above Pembina, N. Dak., a drainage of 40,200 sq mi. A large portion of the Souris River Basin above Minot, N. Dak., figure 1-2, is in Canada. Total drainage above Minot is 11,300 sq mi.

Authorization

Authorization for the study is given in a memorandum to the Hydrometeorological Branch from the Office of the Chief, Corps of Engineers, dated August 3, 1970. Attachments to the memorandum included a list of the 13 subbasins for which PMP estimates were required. These are listed in table 1-1. Index numbers for projects correspond with project locations shown in figures 1-1 and 1-2.

Scope

Estimates of PMP were requested for the period March 15 to April 15 in addition to the all-season PMP, or the greatest PMP for any time of year. Critical sequences of winds, temperatures, and dew points are needed prior to, during, and after the spring PMP storm in order to evaluate the snowmelt contribution to the maximum flood. Estimates of the maximum snowpack available for melt in March and April were also required.

Total drainage and direct contributing areas (table 1-1) were supplied by the Corps of Engineers for each of the 13 subbasins. These imply there are areas that do not contribute to most flood hydrographs. For rains of PMP magnitude, however, it appears likely that at least some runoff from these areas will contribute to the resulting flood. Other factors being equal, PMP depth decreases with increasing area size. Thus, it is possible that a greater rain depth concentrated over a smaller area (considering the contributing portion of the basin only) may result in higher peak flow. It is therefore suggested that at least two trial floods be evaluated; one for the total subbasin area, the other for the contributing area only.

For this study, generalized estimates of PMP have been prepared. From the charts and graphs presented, estimates of PMP may be determined for any selected subbasin in the two river drainages. There are several reasons for this approach. First, estimates are available for possible future project sites. Secondly, the complication of various parts of the drainages possibly being noncontributing results in numerous hydrologic trails that can best be handled by generalized charts. Lastly, a generalized approach insures consistency in PMP estimates from one subbasin to another.

Organization and Summary of Report

Tables and figures are at the end of the chapter to which they apply. A list of the chapters and brief summary of their contents follow.

Chapter 2. Meteorology of major storms. Meteorological summaries are given of the major weather features of the storms most important to setting the level of PMP.

Chapter 3. All-season probable maximum precipitation. Derivation is given of probable maximum precipitation (PMP) estimates for subbasins from 10 to 40,000 sq mi in area, for durations from 6 to 72 hr , centered on the Souris and Red River of the North drainages. Transposition, moisture maximization, and envelopment of major areal storm rainfall depths succinctly summarizes the method used for PMP.

Chapter 4. Seasonal and geographic variation. The chapter first covers the March 15 and April 15 PMP estimates. Transposition, maximization, and envelopment of the relatively few storms in this season is not sufficient for setting the PMP. Other rainfall indices such as station maximum 1-day rainfall, maximum weekly and monthly areal rainfalls, and maximum moisture gave guidance on seasonal variation. Geographic variation in PMP estimates within each of the two drainages is also based on these indices. Previous and current generalized studies provided additional control.

Chapter 5. Time and areal distribution. A method is given for sequencing 6-hr PMP rain increments during the 3-day PMP storm. The procedure conforms, in general, to sequences in storms of record and essentially maintains the prescribed PMP for all durations. A generalized procedure is presented for obtaining areal distribution, through an elliptically-shaped hypothetical isohyetal pattern. Nomograms are provided for determining values of the isohyets for any selected drainage. The isohyets give rainfall depths that are consistent with depth-area rainfall relations of storms in the region.

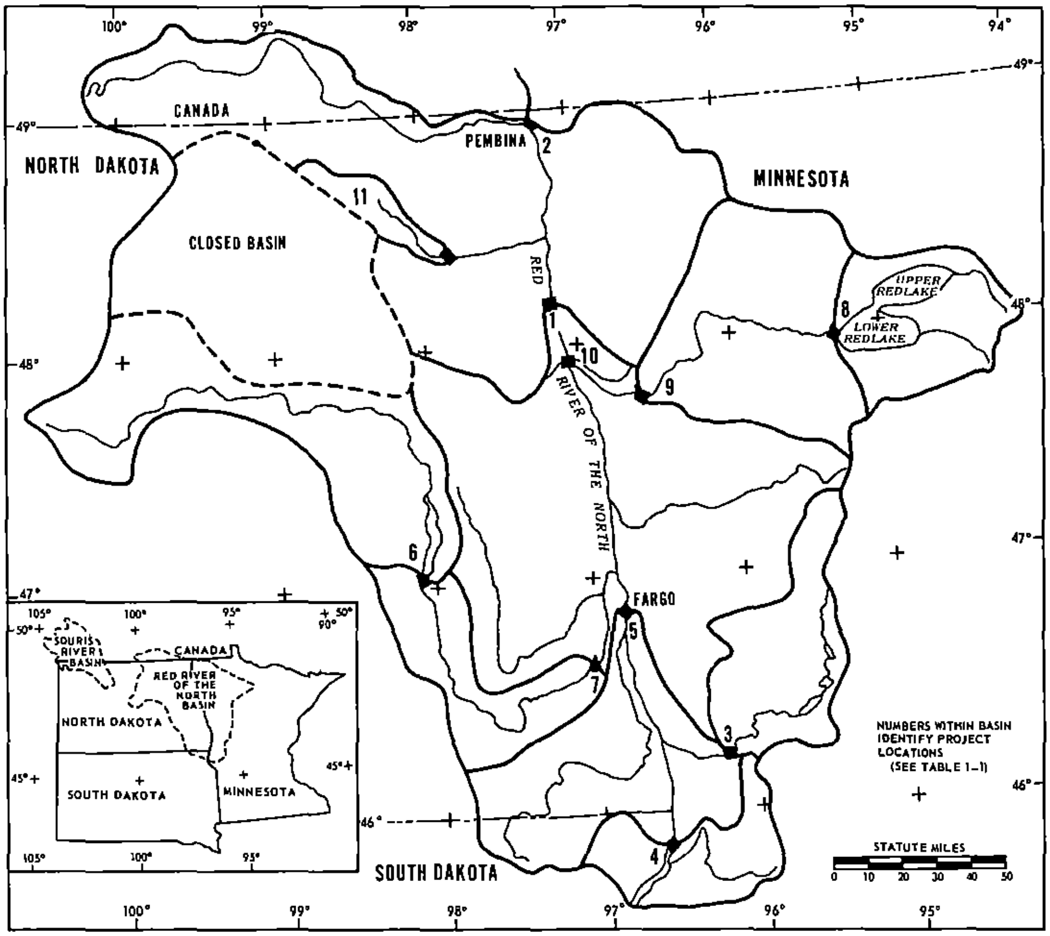
Chapter 6. Snowmelt criteria. Critical snowmelting temperatures, dew points, and windspeeds are given for 10 days prior to the PMP, during it, and for 3 days after. During the storm, the criteria are given by 6-hr averages. These should be arranged in sequence in accordance with the adopted sequence of 6-hr rains. Prior to and after the PMP, daily averages of the criteria are given with a recommendation for obtaining half-day values of temperatures and dew points if required. Temperatures prior to the storm are based on observed temperatures when snow existed on the ground in order that they be consistent with the proposed spring maximum snowpack. During the PMP, temperatures are derived from maximum persisting dew points of record in the region. Trends in temperature after major storms are the primary guidance for post-PMP temperatures. Windspeeds are derived from a statistical analysis of observed springtime winds at Fargo and Bismarck, N. Dak. and from observed winds associated with major storms.

Chapter 7. Snowpack available for spring melt. Observed areal water-equivalent of snowpacks in the North Central States for six major snow cover situations were analyzed to obtain maximum depth-area curves for each. These were then transposed to each of the two basins with an adjustment based on the ratio of 100-yr return period station water equivalent in the basin to that at the observed locations. A variation of snowpack between March 15 and April 15 is included.

Chapter 8. Procedure for use of criteria and example. Here a stepwise procedure is given for obtaining PMP and the snowmelt criteria for any subbasin. This is followed by an example for a selected subbasin.

Table 1-1.--Subbasins of the Souris River and Red River of the North

	Index number	Drainage area (sq mi)	
		Total	Direct contributing
Red River of the North at Oslo, Minn.	1	31,200	17,300
Red River of the North at Pembina, N. Dak.	2	40,200	23,400
Ottertail River at Orwell Dam, Minn.	3	1,830	245
Bois de Sioux River at White Rock Dam, S. Dak.	4	1,160	1,160
Red River of the North at Fargo, N. Dak.	5	6,800	3,470
Sheyenne River at Baldhill Dam, N. Dak.	6	7,470	1,910
Sheyenne River near Kindred, N. Dak.	7	8,800	3,020
Red Lake River at outlet Red Lake, Minn.	8	1,950	1,950
Red Lake River at Crookston, Minn.	9	5,280	2,550
Red River of the North at Grand Forks, N. Dak.	10	30,100	16,200
Park River at Homme Dam, N. Dak.	11	226	226
Souris River near Foxholm, N. Dak.	12	10,200	3,500
Souris River at Minot, N. Dak.	13	11,300	4,200



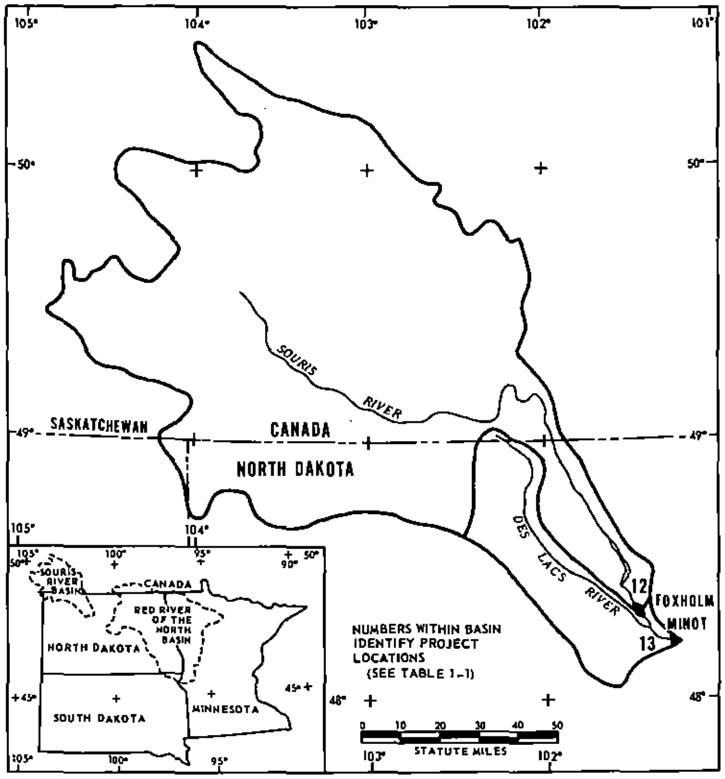


Figure 1-1.--Red River of the North drainage above Pembina, N. Dak.

Figure 1-2.--Souris River drainage above Minot, N. Dak.

Chapter 2

METEOROLOGY OF MAJOR STORMS

Narrative meteorological discussions are given here for transposed storms that provide the greatest adjusted rainfall depths (see chapter 3) over the Red River of the North and Souris River drainages.

Most of the storms come from the catalogue of maximum areal storm rainfall depths (Corps of Engineers 1945-). A survey was made of Canadian storm rainfall (Atmospheric Environment Service 1961) for those transposable to the basins. A comparison of these with transposed U.S. storm rainfall showed the latter depths were greater for all area sizes and durations of concern. A search of climatological records was made for other large-area storms that might be helpful in setting the level of PMP. Some storms were found and maximum depth-area-duration (DAD) values of rainfall computed. In developing all-season PMP, two of these (identified with a number preceded by HMB in the following headings), gave greater adjusted depths for certain area sizes and durations than any in the catalogue of United States storm rainfall (Corps of Engineers 1945-).

Each storm in the following summary is identified by the date of the rainfall, location of the rainfall center and the Corps of Engineers Assignment Number or Hydrometeorological Branch number. The combined adjustment for moisture and transposition to the Red River of the North is given near the end of each summary narrative. Figures 2-1a and 2-1b show the center of heaviest rainfall by an "x" and an outer isohyet for each storm. These are numbered and added to the end of the storm identification.

July 18-21, 1897 - Lambert, Minn. (UMV 1-2), Figure 2-1a, No. 1

Weather maps for this early storm and discussion in the Monthly Weather Review indicate the heaviest bursts of rain occurred on July 20 while a quasi-stationary low centered in southeastern South Dakota was intensifying. The greatest measured rainfall was at Lambert, Minn. where 8 in. fell in a little over 2 days. The low then moved across central Minnesota during the night of July 20 before turning toward the northeast on July 21. Rainfall was well centered over the Red River of the North Basin. This storm is important for extreme rainfall over large areas (50,000 sq mi) for short durations. The storm adjustment is 148 percent (48-percent increase).

June 9-10, 1905 - Bonaparte (nr), Iowa (UMV 2-5), Figure 2-1a No. 2

An unusually large high pressure center over the Great Lakes on June 8 slowly shifted to the southeast, reaching Cape Hatteras by June 10. The return flow from the south around this high was an important feature for bringing in warm, moist air from the Gulf of Mexico.

A low had developed over Wyoming on the 8th. This moved east to the northeast corner of Nebraska by 6 a.m. of the 9th and to southeast Iowa by 6 a.m. of the 10th. A strong pressure gradient between the high and low was responsible for northerly transport of warm, moist air. A wave on a warm front on the northern bound of the warm air reached Nebraska by a.m. of the 9th. Relatively slow movement of the anticyclone and low associated with the wave concentrated the rain to give a little over 12 in. of rain near Bonaparte, Iowa, between evening of the 9th and morning of the 10th. Convergence associated with the low was the primary factor causing the heavy rain. The storm adjustment is 128 percent.

July 18-23, 1909 - Beaulieu, Minn. (UMV 1-11a), Figure 2-1a, No. 3

A low formed over South Dakota on July 19 in an eastward-moving low pressure trough. This low moved slowly to the north-northeast. The heavy burst of precipitation (12 in. in 60 hr) centered at Beaulieu, Minn., late on July 19 occurred ahead of a warm front associated with this low, while farther east at Ironwood, Mich., heavy rain occurred on July 21-22 in the warm sector of the low. The rainfall associated with the western center was the greatest, and only the western half of the total isohyetal map is used for this study. A strong inflow of moisture was augmented by the circulation of a tropical storm along the Gulf coast. A cold-front passage between July 21-22 ended the precipitation. Storm adjustment is 134 percent.

June 1-6, 1917 - Atlantic, Iowa (MR 2-16), Figure 2-1b, No. 4

Thunderstorms, associated with two occluded frontal systems that moved northeastward across Iowa during June 1-6, produced the important rainfall for this period.

On the morning of June 1, a trailing cold front extended from a low near the Great Lakes southwestward to Texas. Warm gulf air circulated around a bulge of high pressure over the Southeastern States. During the day cyclogenesis occurred on the front in a low in Texas. The resulting wave rapidly moved northeastward and occluded over Iowa. This system produced the severe thunderstorms between evening of the 1st and 6 a.m. of the 2nd. Rain ceased with the passage of the occluded system to the northeast.

Following a high-pressure center moving northeast out of the area on the 3rd, a circulation of warm gulf air was reestablished. The approach of a new cold front from the north (3rd and 4th) to Iowa over which warm gulf air was lifted caused thunderstorms primarily during the evening of the 4th. The front progressed slowly southward allowing additional thunderstorms on the evening of the 5th over the same area. The rain ceased as a stronger push of cold air spread over the area on the 6th. Storm adjustment is 171 percent.

September 17-19, 1926 - Boyden (nr), Iowa (MR 4-24), Figure 2-1b, No. 5

A well-defined cold front in a NE-SW-oriented trough of low pressure with high pressure centers to the northwest and southeast advanced into southeastern South Dakota by the morning of September 17. Continued southeastward movement set off heavy showers and thunderstorms in the warm, moist air flowing northeastward over northwest Iowa on the afternoon and evening of September 17. Maximum observed rainfall was 24 in. in 18 hr . Clearing took place as cool,dry air moved in the following passage of the cold front. Storm adjustment is 122 percent.

June 3-4, 1940 - Grant Township, Nebr. (MR 4-5), Figure 2-1a, No. 6

The Bermuda High extended well over the central East Coast States for several days prior to June 3. Southerly flow on the western side of this high brought warm, moist and convectively unstable air from the gulf as far north as Nebraska and Iowa. A trough of low pressure oriented almost north-south near the eastern border of Colorado on the 3rd moved eastward to central Nebraska by the morning of the 4th. The cold front approaching from the northwest set off heavy showers and thunderstorms in the warm air on the afternoon and night of June 3. The greatest measured rainfall was 13 in. in 6 hr . Almost 9 in. occurred over 1000 sq mi in 12 hr . Weather maps indicate northward movement of a small wave along the front was instrumental in positioning the heavy rainfall. The storm adjustment is 148 percent.

August 12-16, 1946 - Collinsville, Ill. (MR 7-2b), Figure 2-1b, No. 7

A mass of cold air covered most of the Eastern and Central United States, except Florida and most of Texas, on the morning of August 12. One of a number of waves in Wyoming and Colorado on the boundary of this cold air mass moved eastward, causing heavy precipitation between the evenings of the 12th and 14th over eastern Kansas and much of Missouri. Unstable, warm, moist air from the Gulf of Mexico in the warm sector of the wave overrunning the cold air to the northeast caused the general rains. This warm-frontal rain advanced into southern Illinois on the night of August 14, ending with the passage of the warm front. Heaviest showers of the storm period then broke out in the warm sector of the wave on the night of August 15-16. Maximum station rainfall was close to 19 in. in 3 days. Drier air came in aloft and the showers decreased in intensity and ended following passage of a cold front on August 18. Storm adjustment is 116 percent.

July 9-12, 1951 - Council Grove (nr), Kans. (MR 10-2), Figure 2-1b, No. 8

The meteorology of this storm, important for long durations over large areas, both where it occurred and when transposed, is discussed in detail in Weather Bureau Technical Paper No. 17 (U.S. Weather Bureau 1952b), and is summarized here. Beginning with the 9th and through the 12th, high pressure persisted in the North Central States, extending south to near the Kansas-Oklahoma border. A weak low at the same time persisted in New

Mexico. This situation set up a strong east-west pressure gradient through Texas and Oklahoma resulting in strong northward flow of warm, moist air into the heavy rain area. A particularly strong surge of cold air on the 10th forced upward motion of the moist air and heavy rainfall in Kansas. The strong inflow of moisture, the energy associated with the high temperature contrast, the instability of the warm air, and the fact that the frontal boundary between the cold and warm air remained nearly stationary for several days are apparent factors contributing to the heavy rain. Storm adjustment is 122 percent.

Transposition limits determined for Technical Paper No. 17 extend to the southeast corner of the basin. These limits have been extended in the present study to include the entire Red River of the North. This extension was based on consideration of the meteorology of some additional storms investigated as part of an ongoing study of generalized PMP estimates for large basins. These storms were not considered in developing the limits set in Technical Paper No. 17.

June 7-8, 1953 - Ritter, Iowa (HMB 6-53), Figure 2-1a, No. 9

A cold air mass preceded by a cold front moved southward over the North and Central Plains States a few days before the heavy rainfall. A low-pressure center formed on the front in Colorado on the morning of June 7. This low deepened and moved quickly northeastward to east-central Minnesota by the morning of June 8, then continued east-northeastward into Canada. Very heavy rains occurred in thunderstorms ahead of the warm front and in the warm sector as the low moved across northwest Iowa the latter half of June 7. The 700-mb charts prior to and during the storm showed strong southerly moist flow from the Gulf of Mexico around a westerly extension of the Bermuda High. A cold front moving southeastward following passage of the low center ended the rain. Storm adjustment is 155 percent.

September 11-13, 1961 - Shelbina, Mo. (HMB 9-61), Figure 2-1a, No. 10

Moisture associated with Hurricane Carla was responsible for the large area of heavy rainfall on September 11-13 centered in northeast Missouri. The 4-in. isohyet extended from Oklahoma to Lake Michigan. Carla crossed the gulf coast approximately 70 mi northeast of Corpus Christi in the later hours of the 11th with a northwesterly heading. Shortly thereafter the storm took a northerly course,reaching the southern border of Oklahoma by 1 a.m. of the 13th. By 1 p.m. the tropical storm merged with a cold front, then moved northeast to Lake Michigan by 1 a.m. of the 14th as a low on the front. Heaviest rains occurred well ahead of the storm center from the evening of the 12th to noon of the 13th while the tropical storm was changing to a northeasterly track. The deep northerly flow of moisture (surface dew points were within a few degrees of the maximum 12-hr persisting dew points for September near the gulf coast) moving upward over the cold front and convergence of the moist air about the low center produced the heavy rainfall. Storm adjustment is 105 percent.

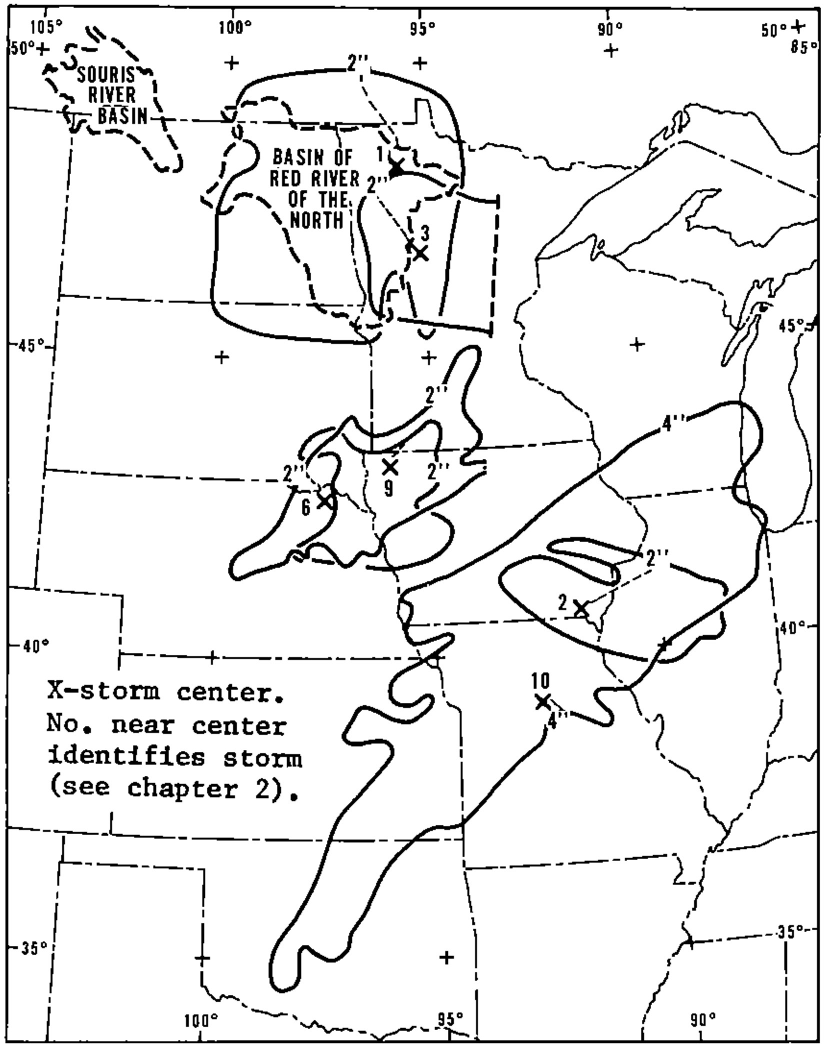


Figure 2-1a.--Outer isohyets of storms important to PMP for the Red River of the North and the Souris River drainage basins.

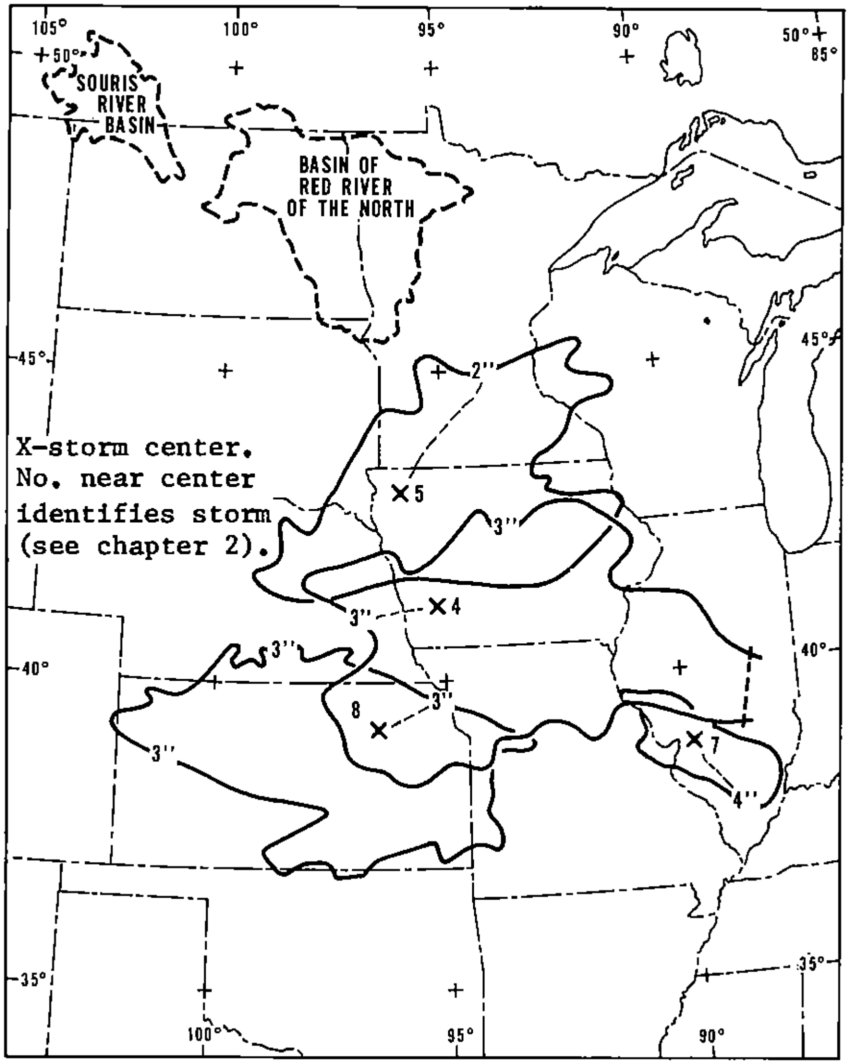


Figure 2-1b.--Outer isohyets of storms important to PMP for the Red River of the North and the Souris River drainage basins.

Chapter 3

ALL-SEASON PROBABLE MAXIMUM PRECIPITATION

Method of Estimating PMP

The method in most general use for estimating probable maximum precipitation (PMP) in the United States where topography has little or only a minor influence may be termed the moisture-maximization transposition procedure. This has been used in the present study for estimates of all-season and springtime PMP. The method can be summarized by the following three steps:

1. Moisture maximize the greatest areal storm rainfall depths that have occurred in the meteorologically homogeneous region surrounding the drainage area under study by adjusting them to the highest atmospheric moisture observed in the region. In practice, surface dew points are used to obtain the moisture adjustment factor because of lack of upper-air soundings in early storms, and because there is a much more dense network of surface dew-point observations than of upper-air observations. The storm 12-hr persisting dew point representative of the moisture inflow is reduced pseudoadiabatically to 1000 mb and the precipitable water computed in a saturated air column with that 1000-mb dew point value. A moist adiabatic lapse rate is assumed. The maximum precipitable water is obtained in a similar way, based on the maximum persisting 12-hr 1000-mb dew point (Environmental Data Service 1968) within 15 days of the date of the storm. The ratio of the maximum to the storm precipitable water is the moisture adjustment factor by which maximum observed storm depth-area-duration rainfall values are multiplied.

2. Transpose maximized storm rainfall depths to the basin. Transposition requires identifying the type of storm and isolating the factors important to heavy rain. A survey of weather charts will help to delineate the region within which a particular storm type has occurred. The climatology of storm tracks frequently is additional guidance. In transposing a storm, a relocation adjustment is applied. This is the ratio of the maximum persisting 12-hr 1000-mb dew point in the transposed location to that where the storm occurred.

3. Envelop transposed and maximized storms. Smooth envelopes of the adjusted storm rainfalls are made with duration for selected area sizes. Thus, maximized depths for two durations, for example, 24- and 72-hr, from two different storms when enveloped with a smooth curve, may determine the depths for intermediate durations. Similar smooth envelopes are then made across area for each duration.

The basic concepts in this method can be summarized as follows: All factors conducive to heavy rain, except moisture, may be termed storm "mechanism." If there are sufficient transposed major storms, it is assumed maximum or near-maximum values of storm mechanism have been experienced such that with moisture maximization an estimate of the rainfall potential is obtained.

Some discussion of the moisture maximization procedure is covered in Hydrometeorological Report No. 33 (U.S. Weather Bureau 1956). Technical Memorandum WBTM HYDRO-5 (Myers 1967) discusses the several steps of this method for obtaining PMP.

Storms Processed and PMP Estimates

"Storm Rainfall in the United States" (U.S. Army Corps of Engineers 1945-) and its counterpart in Canada (Atmospheric Environment Service 1961) were the basic sources of storm data. Because these contain relatively few large-area storms, a survey was made of the precipitation amounts in "Climatological Data for the United States by Sections" (U.S. Weather Bureau 1970) for additional storms that would appear to provide critical rainfall depths. Some critical rainfall periods were found and preliminary storm rainfall values computed for each. Two of these storms were important in setting the level of PMP. Table 3-1 lists the major storms considered. The last two columns of the table give the combined adjustment for moisture maximization and transposition to the centers of the Red River of the North and Souris River Basins, respectively.

Adjusted storm depths for each basin were plotted on semi-logarithmic paper and smooth enveloping depth-area curves drawn for each duration, figure 3-1. Further smoothing was obtained for selected standard size areas by means of depth-duration plots (not shown).

The storms that are controlling or near-controlling (that is, those giving the greatest depths for particular area sizes and durations) for either of the two basins are marked with an asterisk in table 3-1. Figure 2-1a and b show the centers of these storms and outer isohyets. Table 3-2 lists the controlling storms for standard areas and durations.

Figure 3-1 gives enveloping PMP for the center of the Red River of the North by the solid curves. A separate set of curves (not shown) were prepared for the Souris River Basin. Comparison of the enveloping DAD curves for the centers of the Red River of the North and Souris River Basins shows relatively small differences. A 10-percent reduction of the Red River of the North envelopes reproduces the independently determined Souris River DAD envelopes without significantly overenveloping or undercutting adjusted data. Therefore, a basic PMP estimate for a Souris River subbasin may be obtained by taking 90 percent of PMP for the Red River of the North. Geographic variation within basins is obtained from figures 4-2 and 4-3.

Dashed curves of figure 3-1 are depth-area curves used in distributing PMP within basins. Their development and use are discussed in chapter 5.

Comparison With Other PMP Estimates

A PMP study for an adjoining drainage, the Minnesota River (U.S. Weather Bureau 1969), provides a test for consistency with the present estimates. Between 1,000 and 10,000 sq mi, Red River of the North estimates are 2 to 8 percent lower. At the 20,000-sq-mi area, the Red River of the North estimates are 10 percent greater for 6 hr and down to 2 percent greater at 72 hr. The additional storm rainfall data from the storm search in the present study and some variation in degree of envelopment account for these increases.

A study (U.S. Weather Bureau 1952c) for portions of the Red River was made in 1952. Basic enveloping PMP values in that study were determined for areas up to 5,000 sq mi. PMP estimates for 6 hr in that report are the same as in this study for 1,000- to 5,000-sq-mi areas. For longer durations, this study is higher; by 10 percent for 24 hr and up to 28 percent for 72 hr. Most of these differences are due to unavailability of the July 1951 Council Grove, Kans., storm (MR 10-2) rainfall depths for the earlier estimate.

Generalized PMP for areas up to 1,000 sq mi and durations to 48 hr (U.S. Weather Bureau 1956) are in good agreement with the present study. For large areas, a current study giving tentative generalized estimates of all-season PMP in the Central and Eastern States shows approximately the same values as given here.

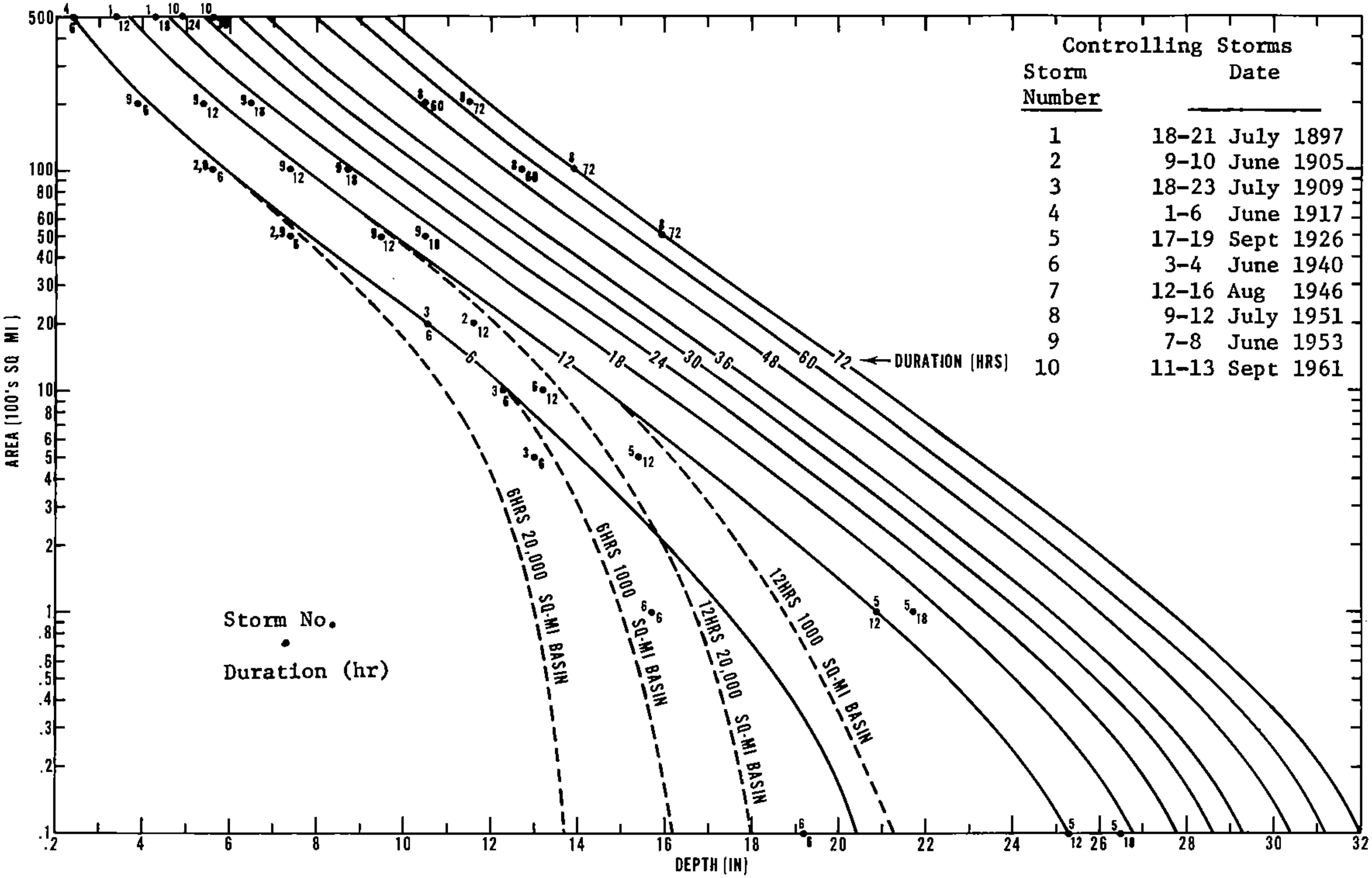
Table 3-1.--Major storms considered for Red River of North and Souris River Basins all-season PMP

Assignment number	Storm date	Storm center	Storm adjustment (percent)	
			Red River of North	Souris River
*UMV 1-2	July 18-21, 1897	Lambert, Minn.	148	141
MR 1-5	July 14-17, 1900	Primghar, Iowa	128	122
UMV 1-6	Sept. 7-11, 1900	Elk Point, S. Dak.	122	116
MR 1-10	Aug. 24-28, 1903	Woodburn, Iowa	116	100
GL 2-12	June 3-7, 1905	Medford, Wis.	122	110
*UMV 2-5	June 9-10, 1905	Bonaparte (nr), Iowa	128	116
UMV 2-18	Sept. 12-19, 1905	Boonville, Mo.	141	116
MR 5-13	June 6-8, 1906	Warrick, Mont.	189	189
*UMV 1-11a	July 18-23, 1909	Beaulieu, Minn.	134	128
MR 4-14a	June 25-28, 1914	Hazelton, N. Dak.	134	128
*MR 2-16	June 1-6, 1917	Atlantic, Iowa	171	156
MR 4-21	June 17-20, 1921	Springbrook, Mont.	128	128
*MR 4-24	Sept. 17-19, 1926	Boyden (nr), Iowa	122	110
MR 5-2	June 6-8, 1934	Akron, Iowa	171	163
*MR 4-5	June 3-4, 1940	Grant Township, Nebr.	148	127
UMV 1-22	Aug. 28-31, 1941	Hayward, Wis.	134	122
MR 6-15	June 10-13, 1944	Stanton (nr), Nebr.	128	116
SASK 7-46	July 9-10, 1946	Rhodes Ranch, Mont.	171	163
MR 7-2a	Aug. 12-15, 1946	Cole Camp, Mo.	116	105
*MR 7-2b	Aug. 12-16, 1946	Collinsville, Ill.	116	105
*MR 10-2	July 9-12, 1951	Council Grove (nr), Kans.	122	110
*HMB 6-53[1]	June 7-8, 1953	Ritter, Iowa	155	141
*HMB 9-61[1]	Sept. 11-13, 1961	Shelbina, Mo. (CARLA)	105	90

*Controlling or near-controlling all-season PMP.
[1] Preliminary DAD data by Hydrometeorological Branch.

Table 3-2.--Observed rainfall (in.) for controlling or near-controlling storms, all-season PMP Red River of the North

Duration (hr)	Area (sq mi)				
	1,000	5,000	10,000	20,000	50,000
6	9.2 (UMV 1-11a)	5.8 (UMV 2-5)	4.4 (UMV 2-5)	2.5 (HMB 6-53)	1.4 (MR 2-16)
12	8.9 (MR 4-5)	6.1 (HMB 6-53)	4.8 (HMB 6-53)	3.5 (HMB 6-53)	2.3 (UMV 1-2)
18	-	6.8 (HMB 6-53)	5.6 (HMB 6-53)	4.2 (HMB 6-53)	2.9 (UMV 1-2)
24	-	-	6.1 (HMB 6-53)	-	4.7 (HMB 9-61)
36	14.7 (MR 7-2b)	10.4 (MR 7-2b)	-	-	5.3 (HMB 9-61)
60	15.9 (MR 7-2b)	11.7 (MR 10-2)	10.4 (MR 10-2)	8.6 (MR 10-2)	-
72	15.5 (MR 10-2)	13.0 (MR 10-2)	11.4 (MR 10-2)	9.4 (MR 10-2)	-



Controlling Storms

Storm Number	Date
1	18-21 July 1897
2	9-10 June 1905
3	18-23 July 1909
4	1-6 June 1917
5	17-19 Sept 1926
6	3-4 June 1940
7	12-16 Aug 1946
8	9-12 July 1951
9	7-8 June 1953
10	11-13 Sept 1961

Figure 3-1.--Enveloping depth-area-duration values of PMP for the center of the Red River of the North above Pembina, N. Dak.

Chapter 4

SEASONAL AND GEOGRAPHIC VARIATION

Seasonal Variation

For determining the maximum flood from combined snowmelt and a rainstorm, it is necessary for this region to define PMP for the primary snowmelt months, March and April. There are an insufficient number of severe storms in these months so that a direct approach (moisture maximization, transposition, and envelopment), as was used for all-season PMP, will not give reliable PMP estimates. Other precipitation indices used as guidance in determining the recommended seasonal variation are described in the following paragraphs. Figure 4-1 summarizes the indices.

Month of Highest PMP

Station maximum 1-day precipitation of record, useful in determining seasonal variation at least for small areas, indicates the all-season PMP can occur as early as June in the region of these drainages. Station maximum precipitation for the U.S. was obtained from Weather Bureau Technical Paper No. 16 (U.S. Weather Bureau 1952a). It covers the period of record through 1949. Maximum station precipitation for Canada comes from (Department of Transport 1958). Table 4-1 shows which months contributed the greatest 1-day rains at 206 stations with long records in states or provinces near the drainages. Only one station with a long record had its annual maximum outside the April-October season. This is Crosby, N. Dak. (4.02 in., Nov. 7, 1915). June contributed the greatest number, 70, with 48 for July and 46 for August.

Four of the 10 storms most critical for the all-season PMP (table 3-1), occurred in the first part of June. These are the storms of June 9-10, 1905 (UMV 2-5); June 1-6, 1917 (MR 2-16); June 3-4, 1940 (MR 4-5); and June 7-8, 1953 (HMB 6-53). Of the remaining six storms, three occurred in July, two in September, and one in August.

It is concluded the all-season PMP can occur as early as June 1.

Station Precipitation as Guidance to Seasonal Variation

The highest 1-day precipitation values for February through June at stations with 30 or more years of record in Minnesota (north of 46° latitude) and North Dakota were extracted from published summaries (U.S. Weather Bureau 1952a). The ratio of the highest 1-day value for each month to that for June was computed for each station. The resulting station average ratios, or average percents of June, for each state are shown by the crosses in figure 4-1. Highest average percents of June are: February 37, March 47, April 63, and May 84.

Other Indices

Variation of maximum moisture is an index to be considered in the variation of PMP. The seasonal variation of moisture over the drainages, as determined from maximum persisting 12-hr dew points (Environmental Data Service 1968) and expressed in percent of moisture in June, ranges from 23 percent in February to 73 percent in May.

Another clue to seasonal variation of precipitation is temperature contrast, which represents potential energy subject to transformation into kinetic energy. As a qualitative index to temperature contrast, the maximum 1000- to 700-mb thickness gradient within 300 mi of Fargo obtained from normal maps (U.S. Weather Bureau 1952d) is plotted in percent of mid-June on figure 4-1. Expressed in percent of June values, the highest percentage (167) comes in February, with a smooth decrease in the monthly percentages to June. Combination of moisture and temperature contrasts, by multiplication of corresponding monthly values, results in a seasonal variation not too different from that of maximum station precipitation. It progresses from 35 percent of June in February to 83 percent of June in May.

The recommended seasonal variation and supporting data are shown in figure 4-1. The adopted variation is somewhat above the average percents of June for 1-day maximum precipitation. Percents of all-season PMP taken from the figure for March and April are shown in table 4-2.

Geographic Variation

There is variation in PMP within each basin, largely because of the distance from moisture source. Other factors remaining constant, rainfall decreases as the distance from the Gulf of Mexico increases. For this study, the variation was developed from HMR No. 33 (U.S. Weather Bureau 1956) and a tentative variation from an ongoing large-area PMP study for the eastern two-thirds of the United States. A compromise between the two studies was adopted. Geographic variation from the two mentioned sources gives somewhat different values from the adopted 90 percent of the Red River of the North for the Souris River Basin. However, it is considered acceptable within the limitations of the data. Geographic variation for March, April, and June is given in figures 4-2a to c for the Red River of the North Basin and figures 4-3a to c for the Souris River Basin.

On each map, 100 percent is drawn through the center of the basin, the location for which the PMP was determined and to which the seasonal variation applies.

Table 4-1.--Month in which greatest 1-day station precipitation of record occurred

(U.S. stations with 30 or more yr of record; Canadian stations with 10 or more yr)

State or province	Number of stations	Number of stations with greatest 1-day precipitation in indicated month						
		Apr.	May	June	July	Aug.	Sept.	Oct.
Minnesota (north of 46° lat.)	41	0	2	6	12	15	5	1
Montana (east of 109th meridian)	27	1	4	12	5	2	3	0
North Dakota	77	2	8	30	16	14	5	1
Saskatchewan	26	0	3	10	7	5	1	0
Manitoba	35	0	3	12	8	10	1	1
	206	3	20	70	48	46	15	3

Table 4-2.--Recommended seasonal variation of PMP

(Percent of all-season values, fig. 3-1)

Date	Percent
Mar. 1	45
Mar. 15	53
Apr. 1	62
Apr. 15	72

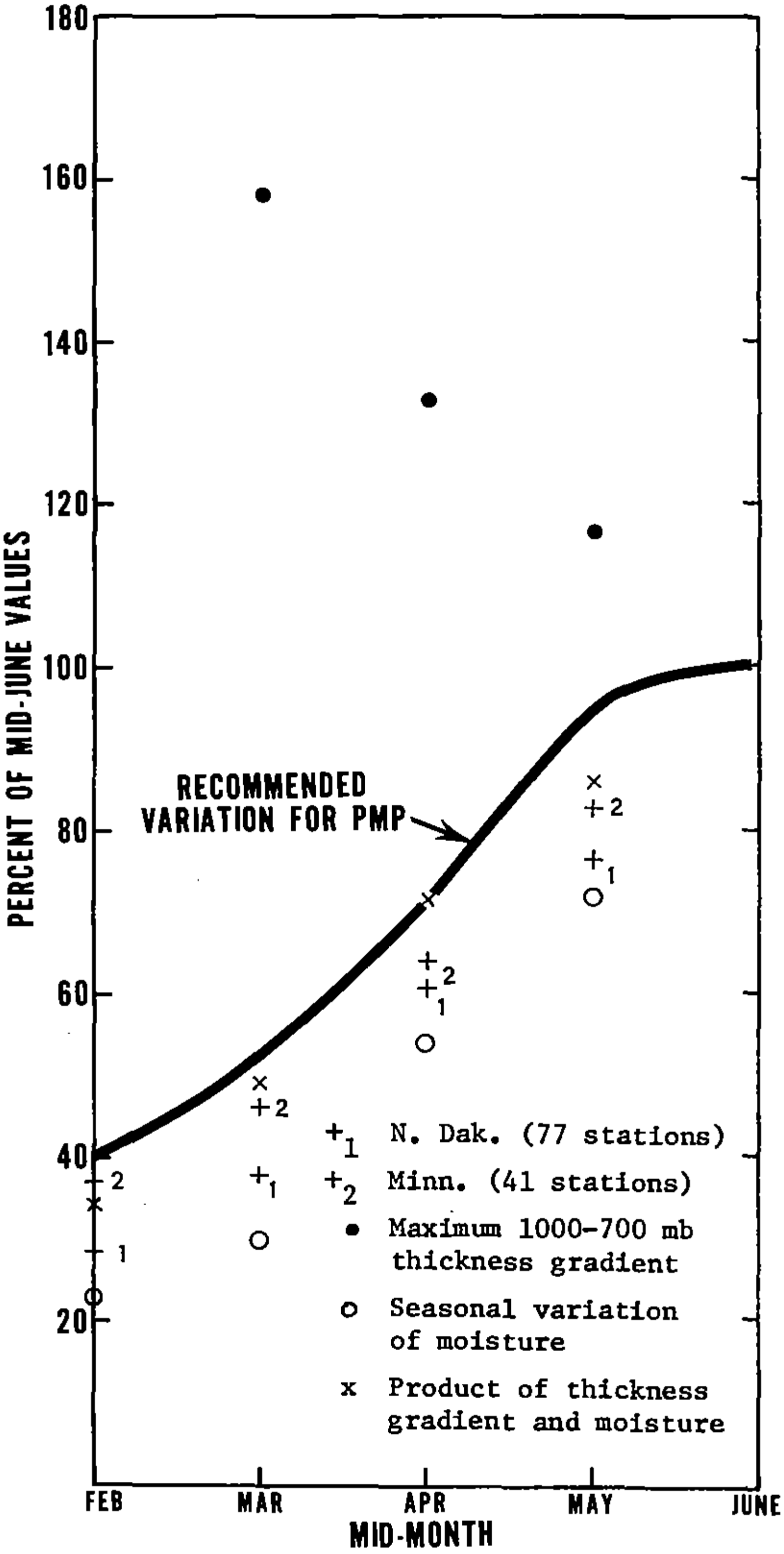


Figure 4-1.--Adopted seasonal variation of PMP and supporting data.

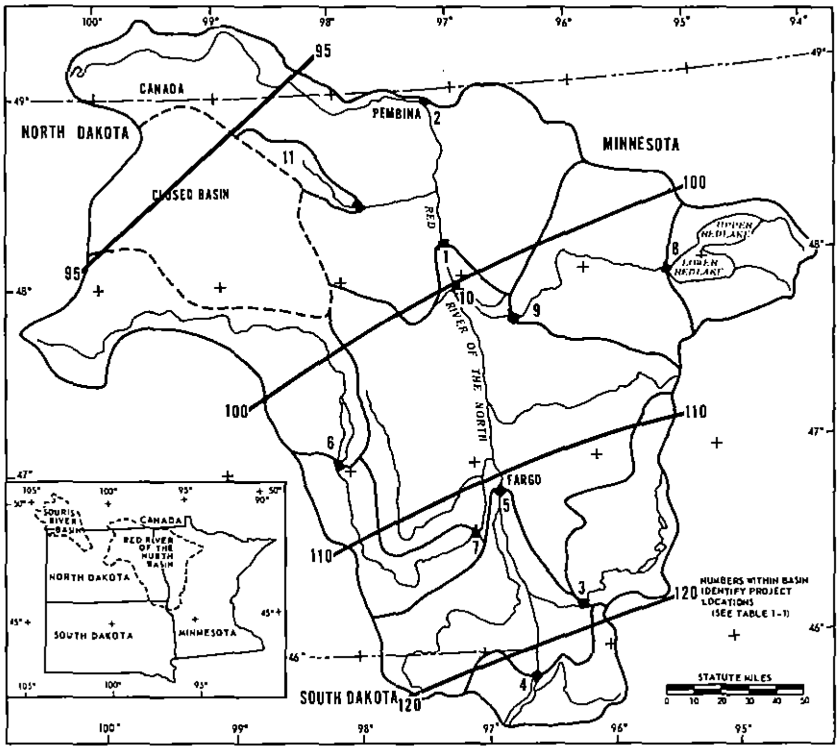


Figure 4-2a.--Geographic variation of PMP. Red River of the North. March.

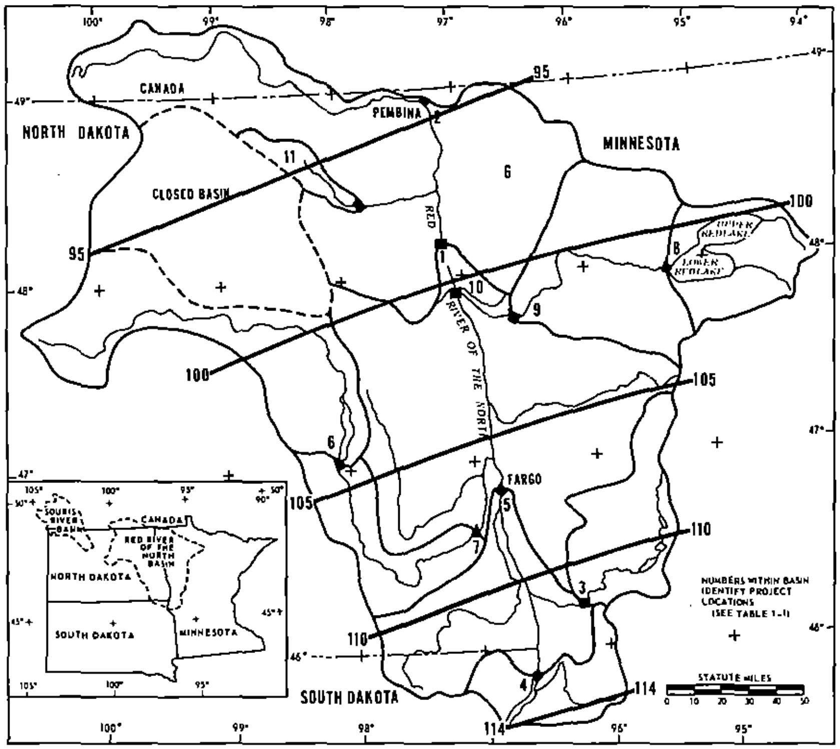


Figure 4-2b.--Geographic variation of PMP. Red River of the North. April.

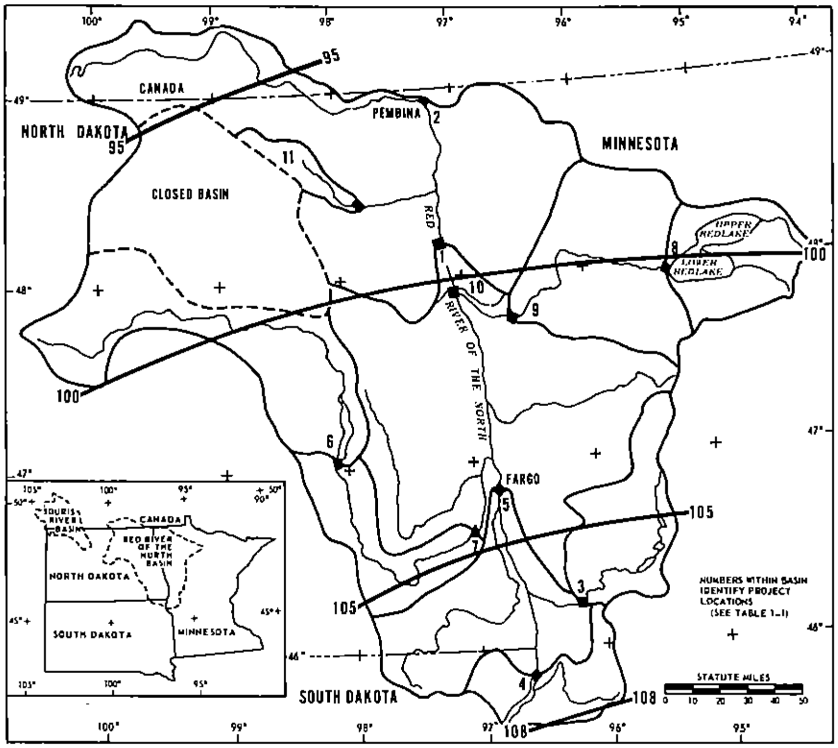


Figure 4-2c.--Geographic variation of PMP. Red River of the North. All season.

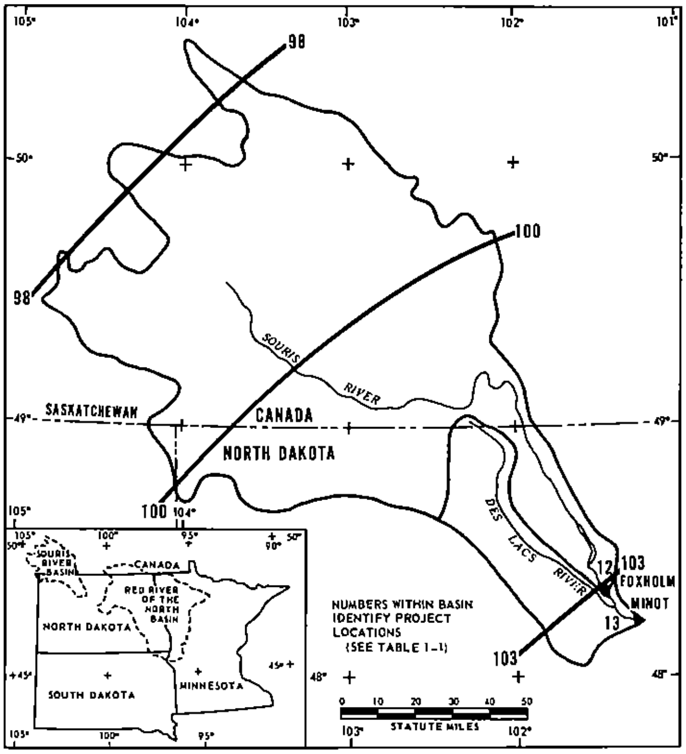


Figure 4-3a.--Geographic variation of PMP. Souris River. March.

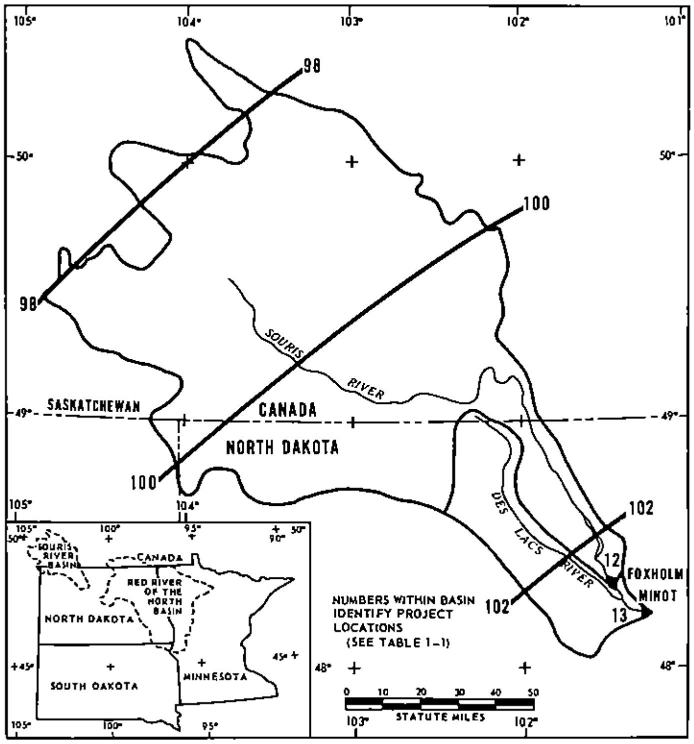


Figure 4-3b.--Geographic variation of PMP. Souris River. April.

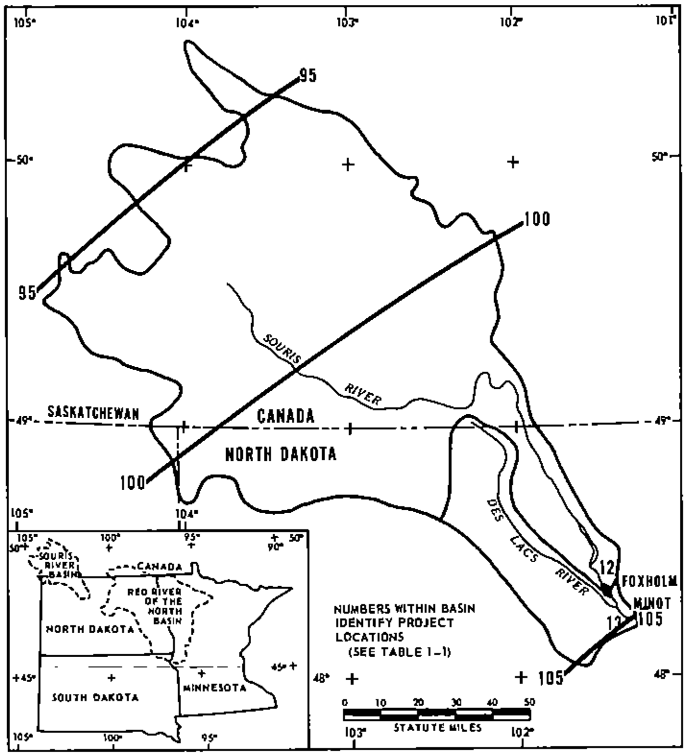


Figure 4-3c.--Geographic variation of PMP. Souris River. All season.

Chapter 5

TIME AND AREAL DISTRIBUTION

In determining a flood hydrograph, the magnitude of the flood is often dependent on the manner in which a given precipitation volume (average depth over the area) is distributed. Also, the degree of concentration of precipitation with time during a storm and the sequence of incremental precipitation values for short time periods are important considerations. In this chapter a procedure is suggested for the time and areal distribution that is patterned after major storms, essentially maintains PMP magnitude for all durations, is relatively simple, and will result in consistency among the subbasins.

Time Distribution

It is assumed that a single storm can produce PMP for all durations over a subbasin. Therefore, basic all-season PMP for all durations for a subbasin may be read from figure 3-2, at the area of the subbasin. These values are then adjusted for location and season. Six-hour PMP increments from the greatest (1st) to lowest (12th) are obtained by successive subtraction after drawing a smooth durational curve of rainfall through the accumulated adjusted values.

Having determined the 6-hr rain increments, the question remains of how these should be sequenced relative to each other in the PMP storm. Inspection of many storm mass rainfall curves shows a wide variety of possible sequences. One fairly consistent pattern is for bursts to last from 6 to 18 hr with lulls between them. Such sequences, followed closely, will not yield the required PMP values for each duration from 6 to 72 hr . A compromise between the storm mass curve indications and the desirability for maintaining PMP for all durations is to apply the following guidelines:

1. Group the four highest 6-hr increments of the 72-hr PMP in a 24-hr period, the middle four increments in a 24-hr period, and the lowest four increments in a 24-hr period.

2. Within each of these 24-hr periods, arrange the four increments in accordance with the sequential requirement for maintaining PMP. That is, the second highest next to the highest, the third highest adjacent to these, and the fourth highest at either end.

3. Arrange the three 24-hr periods with the second highest 24-hr period next to the highest and the third at either end. Any possible sequence of three 24-hr periods is acceptable with the exception of placing the lowest 24-hr period in the middle.

Areal Distribution

It is assumed uniform areal distribution may be used for all 6-hr PMP increments over drainages of less than 1,000 sq mi. For larger areas, we recommend distribution of the two greatest 6-hr PMP increments by a hypothetical isohyetal pattern. The remaining PMP increments may be distributed uniformly, that is, one average depth for the drainage.

Shape of Isohyetal Pattern

One consideration in areal distribution is the shape of the isohyetal pattern. Unless a subbasin outline is quite elongated or irregular it is reasonable to assume the isohyets could essentially conform to the outline. For this study, we suggest the elliptical isohyetal pattern shown in figure 5-1. This pattern has a major-to-minor axis ratio of 2 to 1. Table 5-1 gives the areas of the isohyets in the pattern.

Computations were made to check the reduction in rainfall that would result from differences in the shape of the pattern and subbasin shapes. For an extreme case, the contributing drainage area (1,910 sq mi) of the Sheyenne River above Baldhill Dam, N. Dak., the reduction is 25 percent for the greatest 6-hr period and 10 percent for the second greatest. Similar reductions were computed for the Sheyenne River above Kindred, N. Dak. (drainage area 3,020 sq mi). Generally, reductions between 5 and 10 percent resulted for the remaining subbasins.

Orientation of Isohyetal Pattern

In a study for the Tennessee Valley Authority, Schwarz (1970) found a relation between the magnitude of 3-day rains and the orientation of the isohyets. Direction of flow of moisture from its source region relative to upper-air steering currents in major storms tended to produce greater rainfall volumes in certain isohyetal orientations. A similar study was carried out for the region of the present study. A number of storms from Storm Rainfall (U.S. Army Corps of Engineers 1945-) with isohyets extending into North Dakota, South Dakota, Minnesota, Wisconsin, Nebraska, Iowa, and northern Illinois were considered as well as Canadian storms (U.S. Army Corps of Engineers 1945-) in the southern half of eastern Saskatchewan, Manitoba, and western Ontario. This gave an average of 95 storms for 72-hr duration for which the orientations of the isohyets and rainfall depths for numerous area sizes, from 5,000 to 20,000 sq mi, were correlated. One extreme depth for a storm with an isohyetal pattern extending into Iowa and southern Minnesota but centered in Oklahoma, has far greater depths than the more northerly storms for large areas with nearly a north-south (20°) isohyetal orientation. Because the storm was centered farther south than the others, it was not given full weight. Envelopment and compositing of greatest rain depths plotted against orientation of major axes of isohyets showed maximum values for orientations between 20° and 100° from the north. Figure 5-2 is an example of the data for 72-hr duration for 20,000 sq mi with the adopted variation. This variation in rain depths with isohyetal orientations is also shown in table 5-2. Orientations other than those listed, if needed, may be obtained by interpolation.

Isohyetal Values

For smaller areas within the total area of a subbasin, we recommend an areal rain distribution that falls between using uniform distribution and assuming PMP for all area sizes within the subbasin. Depth-area relations giving such areal distributions are shown by dashed lines at key areas and durations on figure 3-2. These were derived from rainfall depth-area relations of major storms in the region of the basins. For identification purposes they are termed "within basin" depth-area curves. For example, the "within basin" depth-area curve shown for 6-hr duration for basin sizes of 10,000 sq mi or more is a composite of depth-area relations in major storms of the region that had controlling or near controlling 6-hr depths for 10,000 sq mi. It was found that this curve is representative of storm depth-area relations for area sizes up to 50,000 sq mi. The 6-hr curve for 1,000-sq-mi basins is the average depth-area relation of controlling storms for that duration and area size. Depth-area curves (not shown) were also determined in a similar way for 5,000-sq-mi basins.

A full family of "within basin" depth-area curves were derived for area sizes from 1,000 to 10,000 sq mi for the greatest and second greatest 6-hr PMP increments by interpolating between the sets for 1,000, 5,000 and 10,000 sq mi or greater. Then nomograms were computed relating percent of PMP for basin sizes to areas of isohyets. These nomograms are shown in figures 5-3 and 5-4 for the greatest and second greatest 6-hr PMP increments. They will give consistent isohyetal labels for drainages up to 40,000 sq mi in area.

For the remaining ten 6-hr PMP increments, uniform areal distribution may be used.

Chapter 8 outlines a procedure for using the nomograms of figures 5-3 and 5-4, as well as the geographic and seasonal adjustments.

Table 5-1.--Areas of pattern storm isohyets (fig. 5-1)

Isohyet	Area (sq mi)
P	10
A	35
B	270
C	800
D	3200
E	8700
F	19700
G	42300
H	76600

Table 5-2.--Variation in PMP with orientation of isohyetal pattern

Orientation of major axis from north	Percent of basic PMP from fig. 3-1
10°	95
20° to 100°	100
120°	95
140° to 180°	87

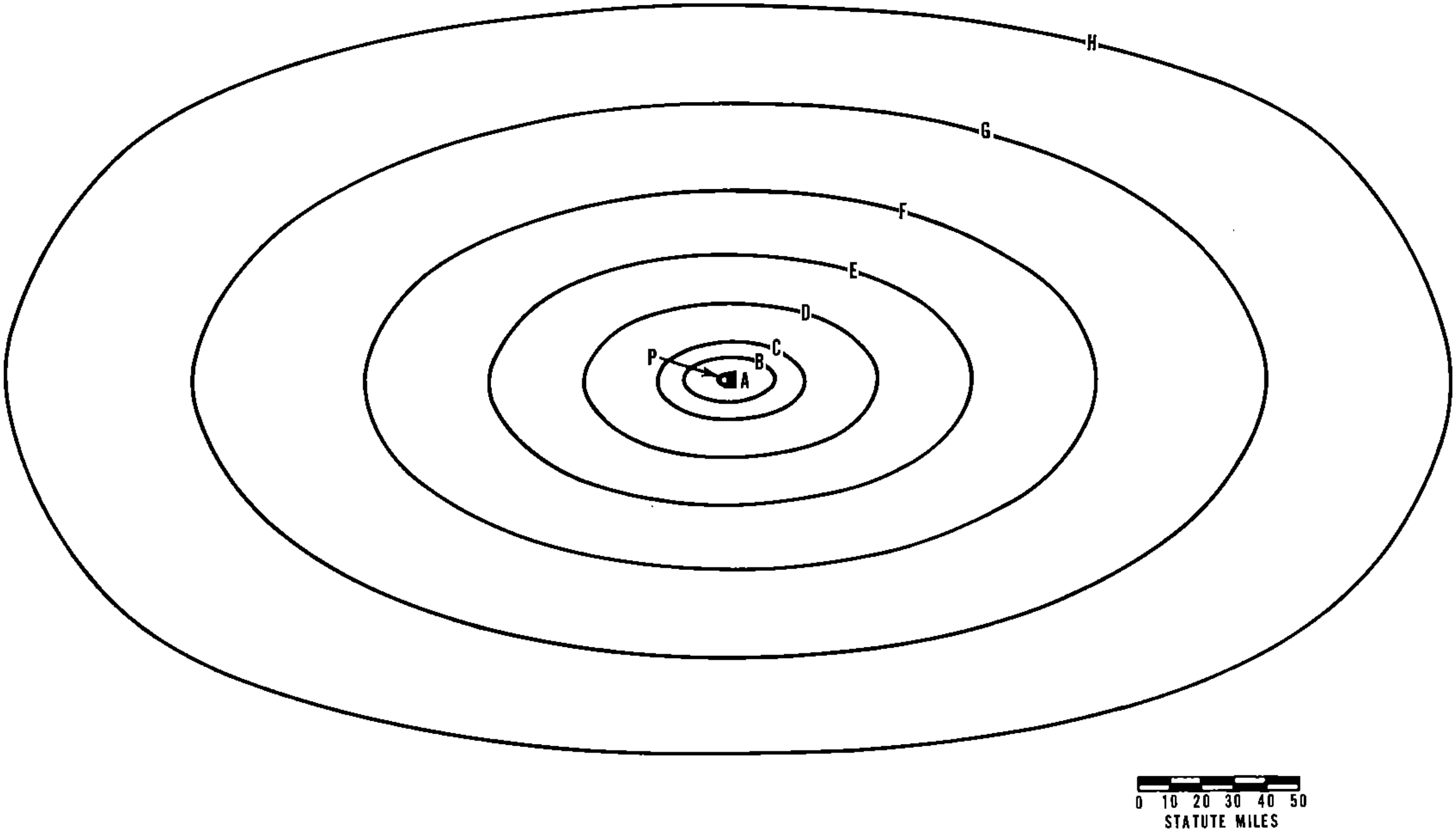


Figure 5-1.--Isohyetal pattern for distribution of the two greatest 6-hr PMP increments.

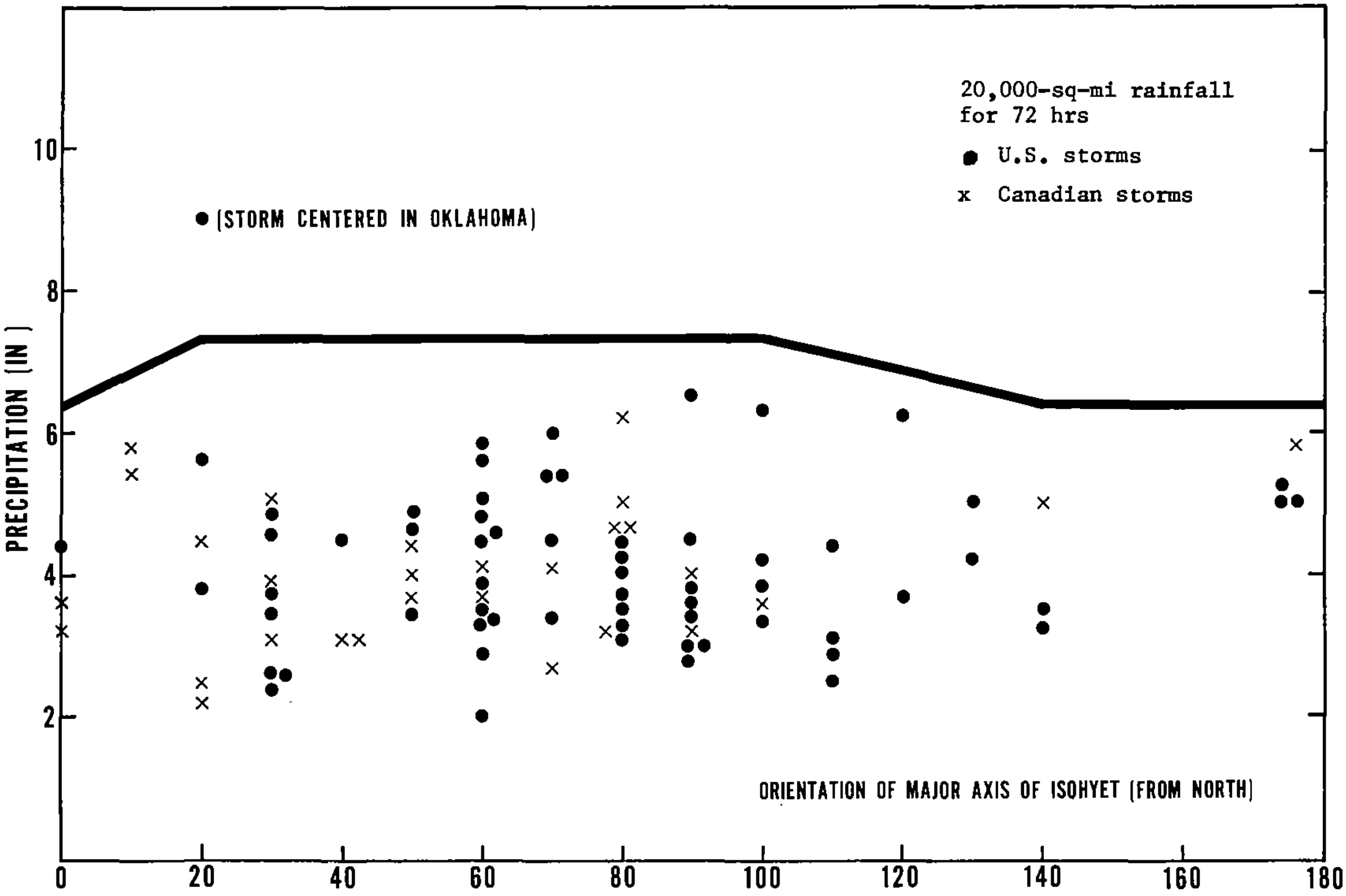


Figure 5-2.--Example of variation in rainfall with isohyetal orientation.

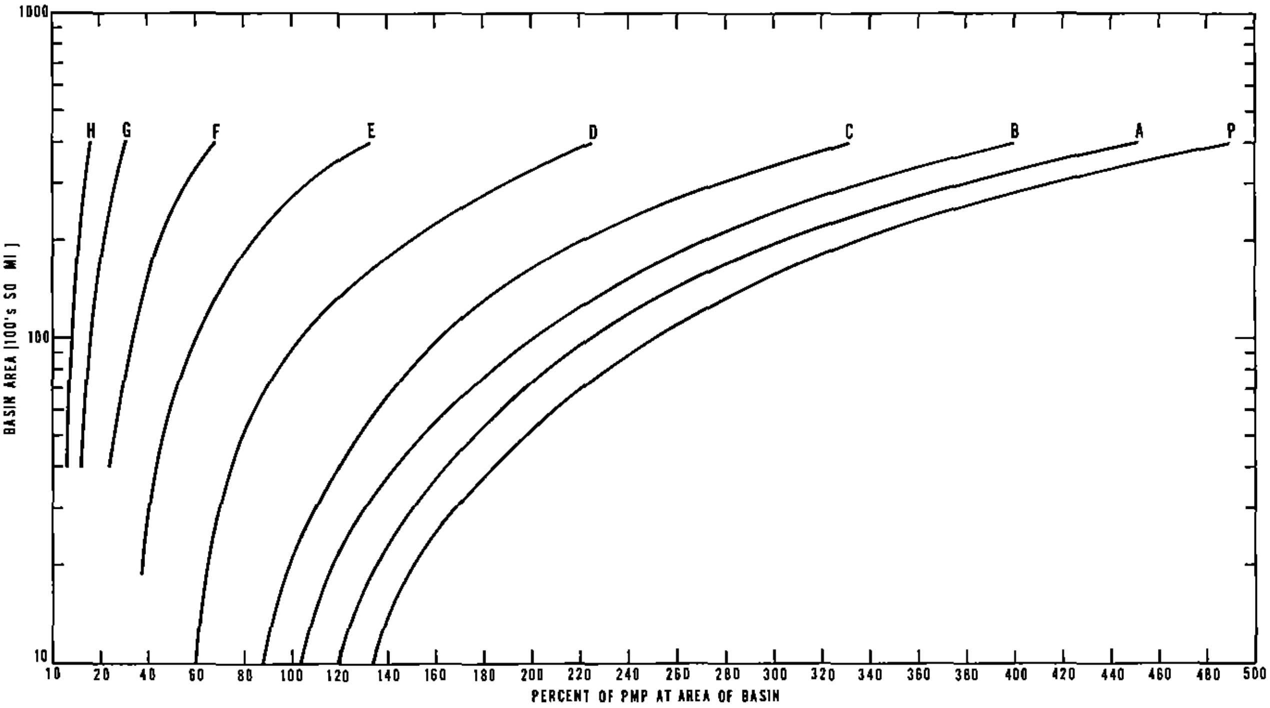


Figure 5-3.--Nomogram for determining isohyet values for greatest 6-hr PMP increment.

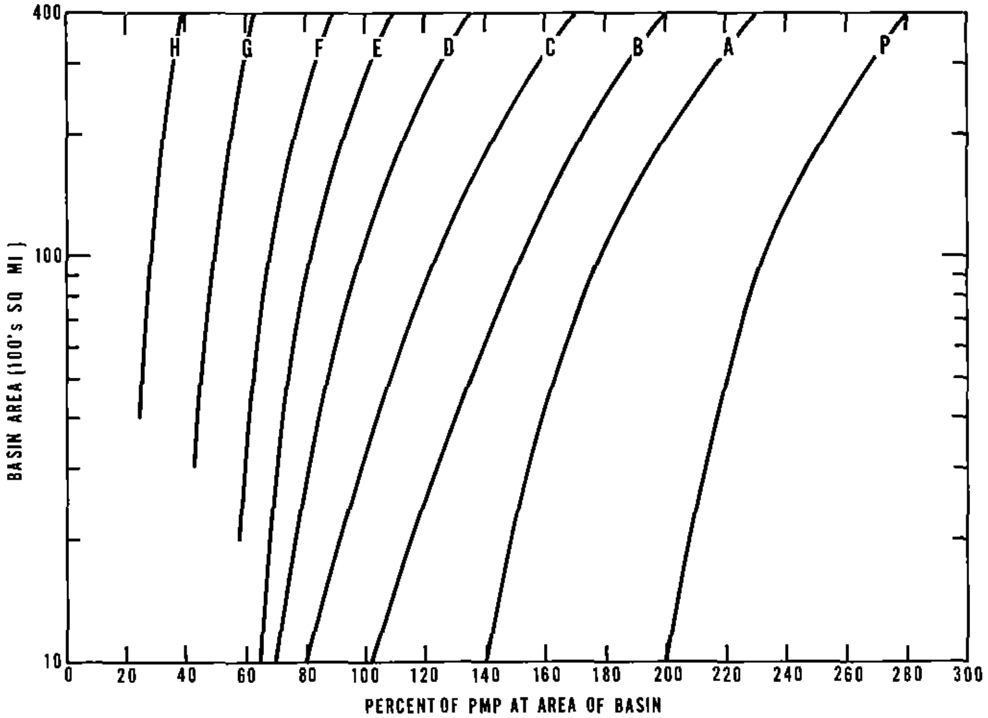


Figure 5-4.--Nomogram for determining isohyet values for 2nd greatest 6-hr PMP increment.

Chapter 6

SNOWMELT CRITERIA

Introduction

This chapter presents critical sequences of temperatures, dew points, and winds that can accompany the spring PMP storm. Criteria are given for the storm period (part A); for 10 days prior to the storm (part B); and for 3 days after the storm (part C). Other considerations required for computing snowmelt such as amount and type of forest cover and radiation are not a part of this study. Critical snowpack for spring melt is covered in chapter 7.

A. Temperatures and Windspeeds During the PMP Storm

Dew Points

Dew-point temperatures for occurrence with the spring PMP storm are based on maximum persisting 12-hr 1000-mb dew points (Environmental Data Service 1968) over each basin. From Weather Bureau Technical Paper No. 5 (U.S. Weather Bureau 1948), the durational variation in persisting dew points was computed for 4 stations near the two basins for March and April. Differences in values between stations and between the two months were not significant; therefore, one variation was adopted. This average is shown in percent of the precipitable water (associated with the persisting dew point for each duration) for 12 hr , in table 6-1.

Maximum 12-hr dew points vary sufficiently over the basins so that they should be specified for the location of a particular subbasin being studied. Figures 6-1 and 6-2 are maps of the maximum persisting 12-hr dew points for March 15 and April 15. Figure 6-3 shows the relation between precipitable water and associated dew points. Steps that will give 6-hourly dew points for a basin are as follows:

1. Determine the maximum persisting 12-hr 1000-mb dew point for the basin from figure 6-1 (March 15) and figure 6-2 (April 15).

2. Interpolate for an intermediate date if required.

3. Obtain precipitable water (W_p) corresponding to this interpolated dew point from figure 6-3.

4. Multiply W_p of step 3 by percents listed in table 6-1.

5. Enter figure 6-3 with precipitable water values of step 4 to obtain 6-hr dew points for each 6-hr period.

Elevation Adjustment

Basic dew point criteria (maps of figures 6-1 and 6-2), are for 1000 mb, or near sea level. For use over a basin in a storm, the dew points determined in the last paragraph need to be adjusted to the elevation of the basin. This adjustment during the PMP storm is approximately 3°F decrease per 1,000 ft above sea level based on the assumption of a saturated pseudo-adiabatic lapse rate.

Air Temperatures

With the assumption of a saturated pseudo-adiabatic sounding during the PMP storm, air temperatures equal the dew-point temperatures.

Windspeeds

Two types of anemometer level wind observations at Fargo and Bismarck, N. Dak. were analyzed for determining critical windspeeds during the PMP storm.

The first type are daily average windspeeds with the direction not specified. Such winds were available for 21 yrs at Fargo and 26 yrs at Bismarck. The highest daily average wind for each March and each April was extracted for each station, plotted on normal probability graph paper and the windspeed with a probability of 0.02 determined from a straight line fitted by eye. At Fargo the 0.02 probability windspeeds were 39 and 40 mph for March and April, respectively, while at Bismarck they were 37 and 31 mph. An average of 37 is considered appropriate for both months for the highest 1-day average wind.

The other type of data are "fastest-mile" winds for each day with direction specified. These were available for 29 yr at Fargo and 35 at Bismarck. "Fastest mile" is the speed computed for passage of a mile of wind. The series of fastest mile winds were extracted for each March and April at each station and the 0.02 probability values determined in the same manner as with the daily average winds. This was done for two categories of data; first, regardless of direction and then only those winds from southeast through southwest. The two groups of data allow an evaluation of the relative magnitude of southerly winds compared to any direction. The former are consistent with moist air inflow during storm periods. The 0.02 probability fastest-mile winds (mph) were as follows:

	March		April	
	SE-SW	Any direction	SE-SW	Any direction
Bismarck	41	59	56	64
Fargo	49	58	53	67
Avg	45	58.5	54.5	65.5

The average ratio of restricted direction windspeeds (SE-SW) to any direction is 0.80. This ratio is considered a reasonable factor for converting daily average windspeeds, any direction, to a southerly wind. We thus obtain a 1-day average southerly windspeed of 30 mph (0.80 x 37) with a probability of 0.02.

Comparisons of Frequency Distributions

The method used for obtaining windspeeds having a probability of 0.02, using normal probability paper and fitting the data to a straight line, assumes the winds are normally distributed. Some tests were made with other frequency distributions to evaluate the normality assumption. The other distributions were:

1. Fisher-Tippet Type I (Gumbel). This is a double exponential distribution fitted to the data by Gumbel (1958) through the method of moments.

2. Fisher-Tippet Type I (Lieblein): Lieblein (1954) fits the data to this distribution by a method that applies a weighting function to ranked data in chronological groups.

3. Fisher-Tippet Type II (Lieblein). This is also a double exponential distribution where the moments are limited. Thom (1966) states that with transformation of the variate x to log x., the Type II distribution may be fit by the Type I distribution. The Lieblein method of fitting the data was used here.

4. Log normal. In this distribution the Naperian logarithm of the variate is used (Chow 1964). The log normal distribution may be obtained by fitting a straight line to data plotted on semi-logarithmic probability paper.

5. Pearson III. This is a skewed distribution with limited range in the left direction (Chow 1964).

These five distributions were fitted to six sets of the wind data -- two of the daily average wind sets and four of the fastest mile sets.

Plots of the data compared with the six frequency curves showed that the normal distribution fit the data best at the upper or high wind end in five of the six sets. Pearson III appeared somewhat better in the other set.

The windspeeds with 0.02 probability from the log normal distribution was within 1 mph of that from the eye-fitted normal distribution method -- averaging 2/3 mph less. The Fisher-Tippett Type I (Gumbel) 0.02 probability winds averaged a little less than 4 mph higher than the normal 0.02 probability values. The Fisher-Tippett II (Lieblein) procedure gave the highest values averaging about 8 mph greater than the normal distribution method. It also departed the most from the data above the 0.25 probability level.

The Pearson Type III distribution averaged 1 mph less than the normal distribution at the 0.02 probability level. Figure 6-4 is an example of one of the six sets of data tested; the fastest-mile winds at Fargo, N. Dak., for March for restricted directions between SE and SW.

It was concluded from these comparisons that the assumed normal distribution used for obtaining a rare wind event is satisfactory.

Durational Variation

Strong wind situations in March and April at Fargo and Bismarck were selected for guidance in determining a durational variation in windspeeds. Five cases were selected from each station on the basis of high southerly winds from the tabulations of fastest-mile winds from the restricted direction.

The winds observed every 6 hr for a 6-day period bracketing the time of the "fastest-mile" wind were tabulated. The highest of any three adjacent wind observations was considered a 12-hr average and the highest average of four adjacent winds, an 18-hr average. The same procedure was carried out to the highest of 13 adjacent observations (of the 24 tabulated) to give 72-hr (3-day) average winds. These average winds for the 10 selected cases were plotted on a graph (windspeed against duration). There was considerable variation among the 10 cases. For example, the ratio of 72- to 24-hr duration winds (average 0.78) varied between 0.94 and 0.67. Variation in the durational relations could not be attributed to the month or place of occurrence, therefore, the average durational relation of the 10 cases was adopted. Table 6-2 shows this relation in part a.

Winds for snowmelt computations are used more easily if in the form of averages by 6-hr periods during the PMP storm. Therefore, the durational variation was converted to 6-hr incremental variation and 6-hr wind averages computed based on a maximum 24-hr average of 30 mph. (The .02 probability southerly wind.) The 6-hr wind averages are shown in table 6-2b.

An example of how these incremental 6-hr average winds were determined follows: With a 30-mph average 24-hr windspeed, the greatest 6-hr average to nearest whole miles is 37 mph (30 x 100 ÷ 82). The second greatest 6-hr average in percent of the greatest is 84% [2(.92) - 1.00]; and the 3rd greatest is 74% [3 (.86) - 1.84]. Similar computations were continued on the 12th greatest, or least, 6-hr wind average.

B. Temperatures and Windspeeds Prior to the PMP Storm

Temperatures

In deriving critical temperatures for spring snowmelt, a restriction is that these temperatures should be compatible with the postulated snowpack antecedent to the PMP storm. Two types of data meeting the criteria were considered. One is published daily records of temperatures with concurrent snow on ground (U.S. Weather Bureau 1970). The other set of data is derived from generalized snow cover maps and temperatures in the "Weekly Weather and Crop Bulletin" (Environmental Data Service 1970).

Envelopment of the highest temperatures from these sources, for snow-on-ground conditions, expressed in terms of departure from normal, is the basis for sequences of critical temperatures for 10 days prior to the spring PMP storm.

Analysis of Data

Consider first station daily temperature values restricted to snow-on-ground conditions. We selected Fargo (21-yr record) and Minot (33-yr record), N. Dak., as representative of the Red River of the North, and the Souris River, respectively.

Highest average temperatures with snow on ground were determined within each half month period beginning March 1 and ending April 30 for 1-, 2-, 3-, 5- and 10-day durations. In surveying a particular half month the condition was set that all days except one in each duration could be in the previous half month.

The requirement for snow on ground was relaxed to the extent of allowing one day of bare ground in each duration. The maximum one-day temperature thus could have occurred with bare ground but with snow on the ground on the previous and following days. This relaxation is reasonable since experience shows that snow cover often still exists in surrounding areas after it has disappeared at an observation site in or near a city.

The highest average temperatures meeting the above restrictions were plotted on a seasonal chart at the middle of the observed period. Of the cases contributing the highest temperatures for any duration, Fargo and Minot often had snow cover on the same dates, indicating that these cases consisted of large areas with snow on the ground.

The other set of data, weekly maps in the "Weekly Weather and Crop Bulletin" (Environmental Data Service 1970) provide temperature departures from normal and maps of the extent of snow on ground as of the last day of each week. These maps are available through March of each year. Large departures from normal temperature were considered if they occurred in Wisconsin, Minnesota, North Dakota, or eastern Montana. The largest departures were checked against daily station temperatures and whatever information was available concerning snow on the ground since the weekly maps sometimes smoothed out details. Some of the most extreme cases did not meet the requirement of continuous snow cover through the week.

Figure 6-5 shows the highest temperatures found from both sets of data and the adopted enveloping curves. The higher departures from normal in March compared to April are notable.

Snow cover into the middle of April is a severe restriction since in most years the ground is snow-free by this date. Shapes of the adopted envelopes to April 15, shown in figure 6-5 with dashed curves, are therefore partially based on highest temperatures without snow cover. High temperatures plotted after April 1 in figure 6-5 are based on snow-free conditions.

Smoothed departures from normal temperatures for durations of 1 to 10 days are shown in figure 6-6 for March 15, March 31, and April 15. These come directly from figure 6-5. Incremental daily average temperature departures from highest (day 1) to lowest (day 10), derived from figure 6-6, are given in table 6-3, rounded to the nearest whole degree for three dates for the beginning of the PMP storm. Temperature departures for an intermediate date may be interpolated.

After the daily temperature departures are obtained for a selected date, they may be added to the normal temperature for the basin under concern for that date. Figure 6-7 gives normal temperatures for the center of the Red and Souris River drainages. These were determined from monthly normal temperature maps (Environmental Data Service 1968; Canada, Department of Transport 1967; and U.S. Weather Bureau 1963).

A refinement is to use the normal daily temperatures for a particular drainage. These can be obtained for March and April from figures 6-8 and 6-9. Linear interpolation between values over a specific subbasin yields normal daily temperatures for an intermediate date.

Sequences of Daily Temperatures

The preceding sets critical daily temperatures for 10 days prior to the springtime PMP storm. It remains to specify a sequence of the values. Temperatures accompanying March and April storms of record in the north Central States were considered as guidance to sequences of temperatures prior to the rainfall. These storms are listed in table 6-4 and the outer isohyets are shown in figures 6-10a and b. Two of the storms come from "Storm Rainfall," (U.S. Army Corps of Engineers 1945-, Atmospheric Environment Service 1961). The remaining are the most intense known for these months in this region from a search of precipitation records.

Temperatures for four stations in or near the rain patterns were averaged for each of the 10 days prior to each storm. Ranking these average daily temperatures by magnitude then allowed comparison among storms. There is a wide variation in possible temperature sequences, with the following general features.

1. The lowest daily average temperature was on the 9th or 10th day prior to the storm in eight of the nine cases.

2. The highest daily average temperature was on the 1st or 2nd day prior in six of the cases.

3. A slight tendency in three storms was for warming until the 7th to 5th day prior, 2 days of cooler temperatures, and then a continuing warming trend to the storm period.

In view of these features, for the PMP storms we recommend a continuing warming trend from the 10th day prior to the beginning of the storm.

Windspeeds

The weather situations that control the highest points on the envelope of critical snowmelt temperatures (Fargo or Minot), figure 6-5, were examined for highest winds. The maximum winds found ranged from a 1-day value of 38 mph to a maximum 10-day average of 16.5 mph. Winds were not restricted with regard to direction. April 1964, March 1966, and April 1955 had the highest winds.

Winds prior to the March and April storms of record, table 6-4, were another set of data considered. Of the nine storms, daily winds were available from within the rain area, or nearby, for six. The highest average winds for each duration were determined. These ranged from 24 mph for a 1-day duration to 13 mph for 7 days or longer. The April 1924 and April 1947 storms contributed to highest values.

Figure 6-11 shows the two sets of high winds and an average curve adopted for use with snowmelting temperatures. The highest winds for all durations are from the critical temperatures with snow cover situations. The lower set are associated with March and April storms. A compromise of the two sets of data is considered a reasonable maximization for winds prior to the PMP storm. Table 6-5 lists daily windspeeds computed from the adopted curve of figure 6-11. They are listed from lowest to highest daily values, and should be used in this sequence, that is, the lowest wind 10 days prior to the PMP storm and the highest on the day preceding the PMP storm.

The windspeeds of table 6-5 are for both basins. The basic wind observations were from stations varying in elevation from 600 ft to a little over 2,000 ft. Consistent variations with elevation could not be found within the data studied. It is recommended that these winds be used for the range of elevations in the basins. They are representative of windspeeds at an average anemometer level of 30 ft.

Dew Points

Average daily dew point temperatures prior to the PMP storm are based on differences between air temperatures (T) and dew points (T_d) in the selected storms (table 6-4) over the northern Central States and during the extreme high temperature periods with snow cover (fig. 6-5). Differences ($T-T_d$) in both sets of data were scattered. Prior to the storms, they averaged 10°F, ranging from 2° to 23°F, with some tendency for greater differences in the earlier days prior to the storm. Differences ($T-T_d$) associated with snow-cover periods also averaged 10°F. For temperatures lower than 32°F, the range was from 2 to 16, with a wide range, from 1° to 26°F, for higher temperatures.

We recommend dew point temperatures that are 9°F lower than the air temperature on the 10th day prior to the storm, with linear interpolation to 3°F lower on the first day prior to the storm. Such a sequence of dew points reflects a gradual change toward near saturation at the beginning of the storm. Figure 6-12 shows recommended temperature minus dew point differences.

For this study the maximum persisting 12-hr dew point charts (figs. 6-1 and 6-2) are recommended as an upper limit to daily average dew points. The recommended temperature dew point spread may result in values that exceed this limit. In that case, use a dew point that is 1°F lower than the 12-hr persisting value for the 1st day prior to the storm.

C. Temperatures and Windspeeds After the PMP Storm

Temperatures

The highest daily temperature during each record March and April storm, table 6-4, was compared with daily temperatures for the 3 days after. In each storm daily averages were based on four stations with published records in or nearest to the storm isohyets. The mean of the differences (highest daily temperature during storm minus daily temperatures for three days after), rounded to whole degrees, were 7°F for the first day after the storm, 9° for the second day, and 10° for the third day. These differences are recommended for determining the daily temperatures after the spring PMP storm.

Dew Points

For recommendations on dew points for several days after the PMP storm, observations for each of the spring storms (table 6-4) were considered. Six storms had nearby dew point observations for which differences were computed between daily average temperatures and dew points for each of the three days after each storm. These differences averaged 9°F for the six storms with a range of 3° to 14° for the 1st day after the storm, 2° to 12° for the 2nd day, and 2° to 13° for the 3rd day. For the PMP situation, we suggest a spread of 6°F between daily average temperatures and dew points for each of the three days.

Recommended differences between temperatures and dew points for the spring PMP storm are shown in figure 6-12.

Windspeeds

Daily average winds during the spring storms were compared with daily average winds for each of the three days after the storms. Windspeed comparisons were as follows.

Daily Average Windspeed (mph)

	During storms	Day after storms		
		1	2	3
Average	13	16	9	9
range	9-18	11-26	7-11	4-19

For the first day after, the windspeeds average somewhat higher than during the storm, with considerably lower values for the next two days. There is some tendency for rising winds on the third day compared to the 2nd. This occurred in four out of six of the storms with available wind data near the rainfall. In view of the maximum winds (table 6-2) for occurrence during the PMP storm, we recommend average daily winds of 28 mph for the 1st day, 10 mph for the 2nd, and 12 mph for the 3rd. These winds are given in table 6-6.

Table 6-1.--Variation of precipitable water during 3-day spring PMP storm

6-hr period											
1	2	3	4	5	6	7	8	9	10	11	12
Precipitable water in percent of 12-hr value											
107	100	94	90	86	82	79	76	74	72	70	68

Table 6-2.--Durational variation of windspeeds (derived from the five highest fastest mile southerly winds at Bismark and Fargo)

Duration (hr)											
6	12	18	24	30	36	42	48	54	60	66	72
a. Windspeed in percent of greatest 6-hr value											
100	92	86	82	78	74	72	69	67	65	63	61
6-hr period											
1	2	3	4	5	6	7	8	9	10	11	12
b. 6-hr average windspeeds (mph)											
37	31	27	25	23	21	21	19	18	17	16	14

Table 6-3.--Adopted maximum daily average temperature departures from normal

Day 10: day of lowest temperature
Day 1 : day of highest temperature

Date for storm beginning	10	9	8	7	6	5	4	3	2	1
	Temperature Departures (°F)									
March 15	10	10	11	11	12	14	16	17	21	31
March 31	6	7	7	7	7	8	10	13	19	28
April 15	3	3	3	3	4	5	7	8	14	22

Table 6-4.--March and April storms in North Central States used for critical temperatures and winds prior to spring PMP

Storm Identification No.	Date	No.	Location
MR 5-10	Apr 22-24, 1900	1	Central Mont.
Man 4-24	Apr 14-17, 1924	2	So. Manitoba, NE N. Dak., NW Minn.
	Apr 22-24, 1932	3	No. Central S. Dak., So. Central N. Dak.
	Apr 4-5, 1947	4	NE Mo., SE Iowa, No. Ill., NE Ind., SW Mich.
	Apr 25-27, 1954	5	Central Minn., No. Wis.
	Mar 29-30, 1933	6	NW Minn.
	Apr 22-25, 1950	7	SE Iowa, No. Ill., SW Mich.
	Mar 24-25, 1954	8	NE Mo., No. Ill.
	Mar 2-5, 1966	9	No. Central S. Dak., E N. Dak., NW Minn.

Table 6-5.--Daily average windspeeds for 10 days prior to March and April storms

Day prior									
10	9	8	7	6	5	4	3	2	1
Windspeed (mph)									
10	10	12	13	13	14	15	15	18	31

Table 6-6.--Windspeeds after the PMP storm

Day after storm		
1	2	3
Windspeed (mph)		
28	10	12

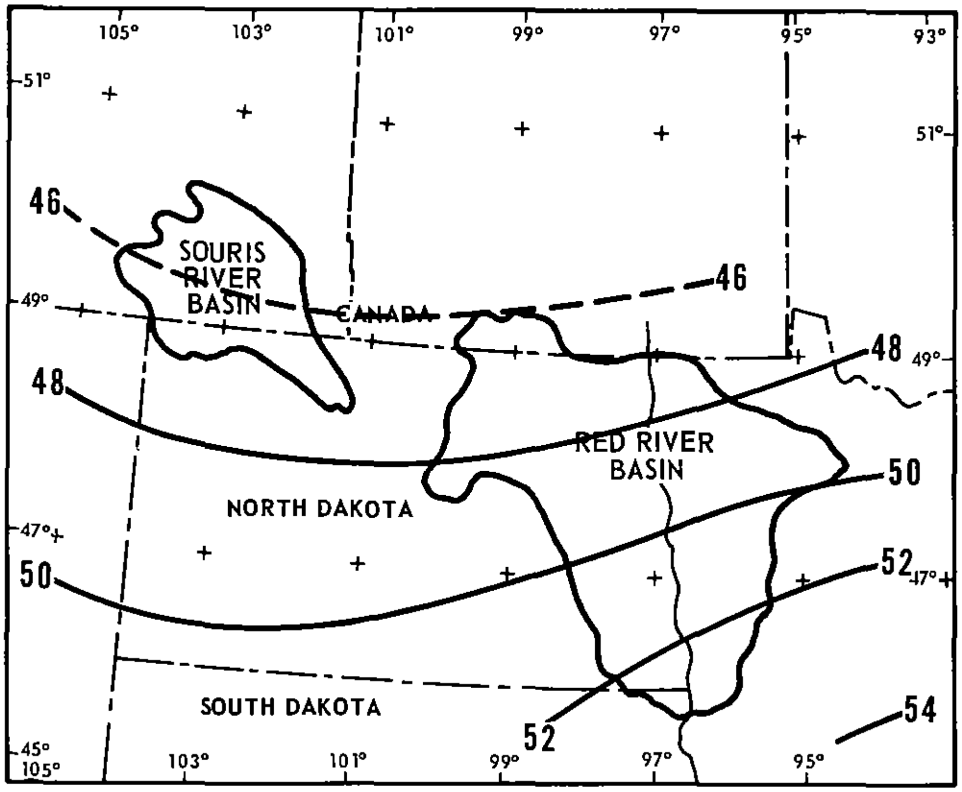


Figure 6-1.--Maximum persisting 12-hr 1000-mb dew points (°F). March 15.

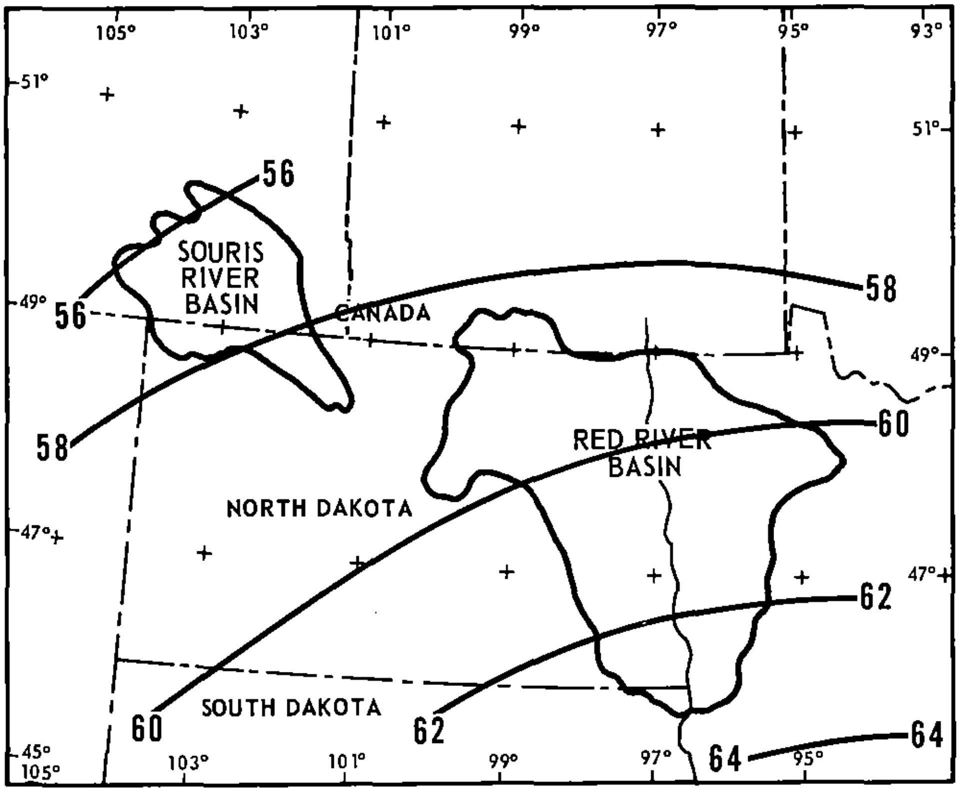


Figure 6-2.--Maximum persisting 12-hr 1000-mb dew points (°F). April 15.

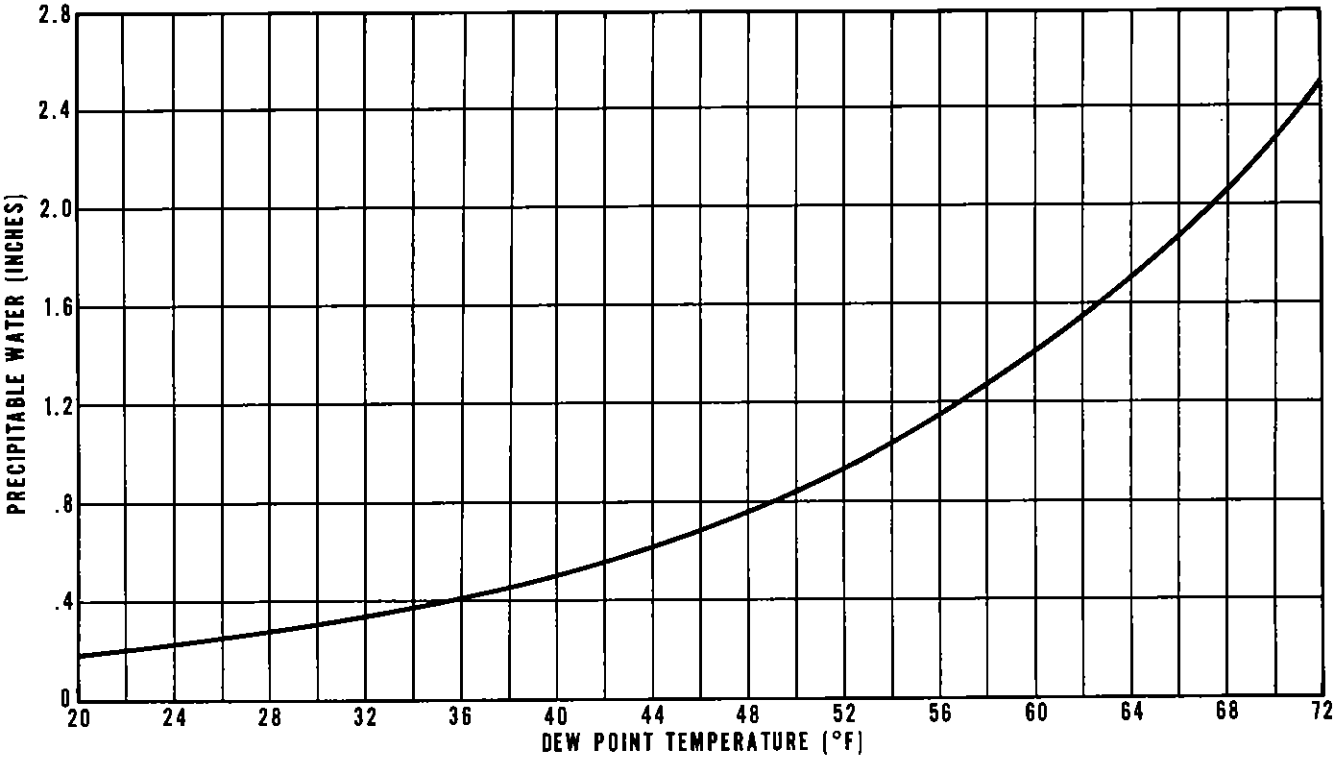


Figure 6-3.--Total precipitable water to top of column (300 mb) for given 1000-mb dew point.

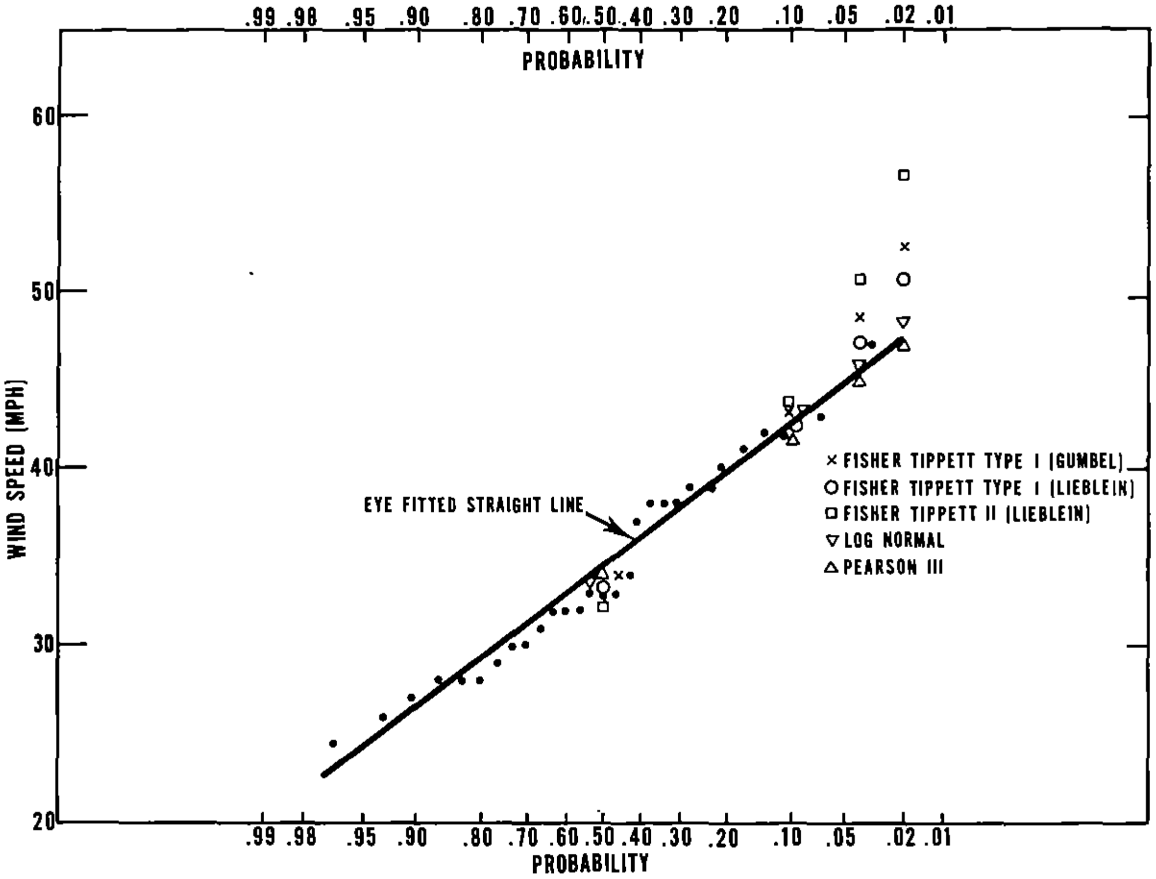


Figure 6-4.--Comparisons of several extreme value distributions.

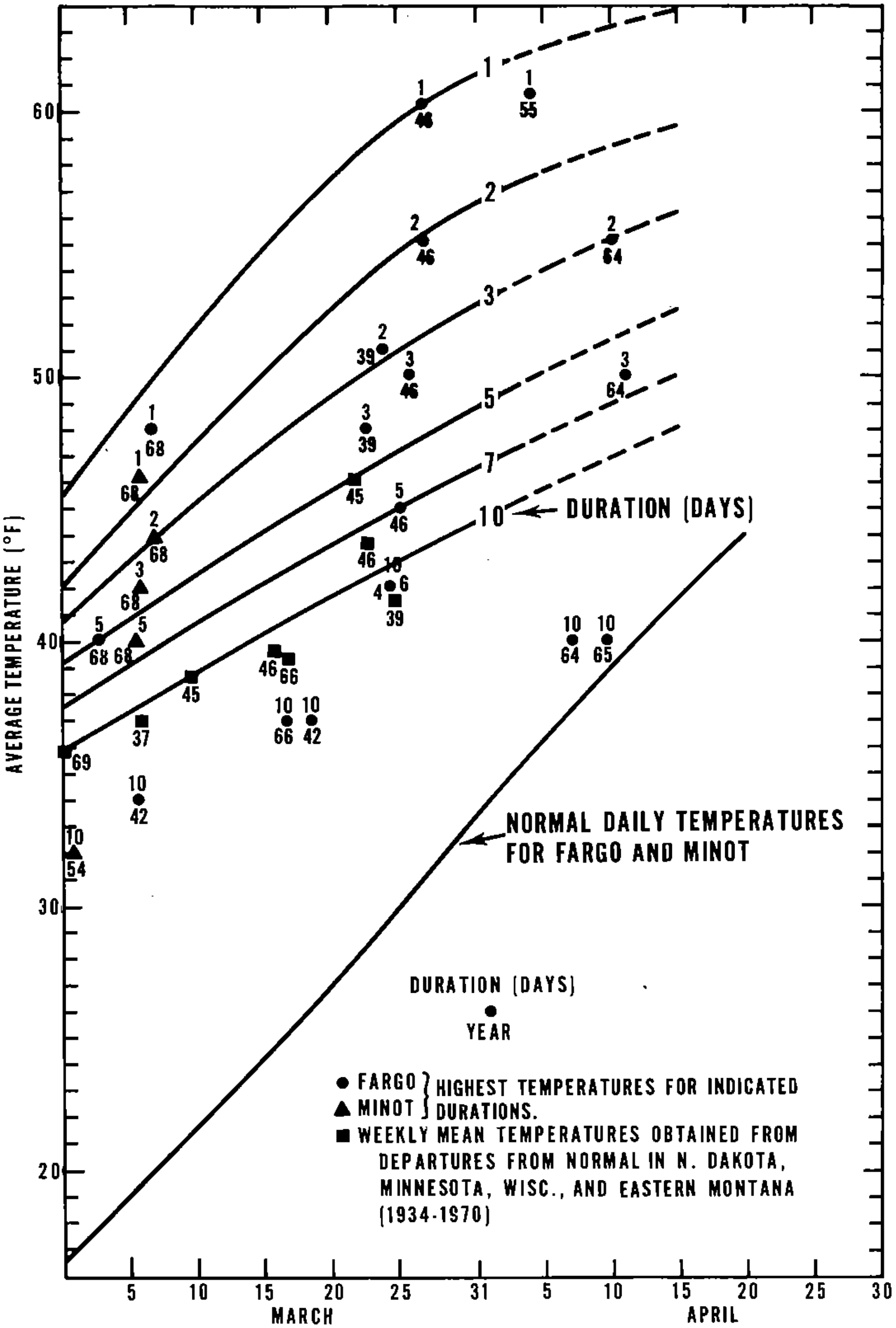


Figure 6-5.--Adopted critical temperatures for snow-on-ground conditions.

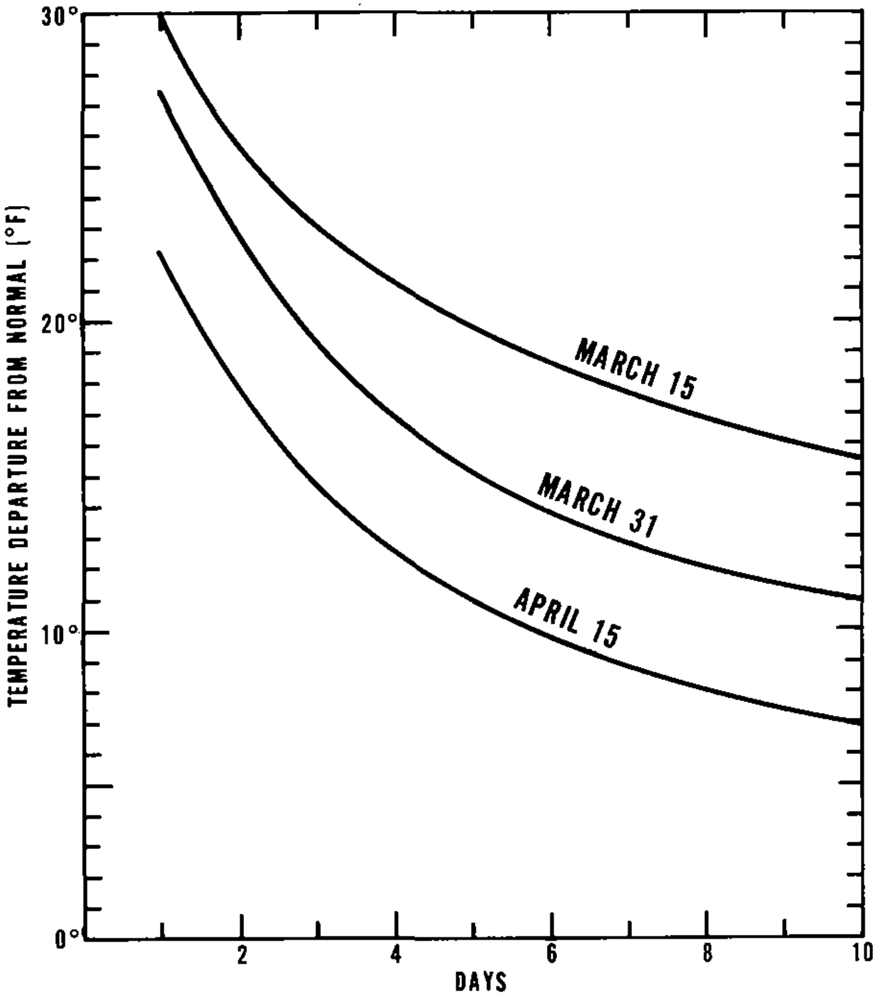


Figure 6-6.--Departure from normal temperatures for 1 to 10 days duration.

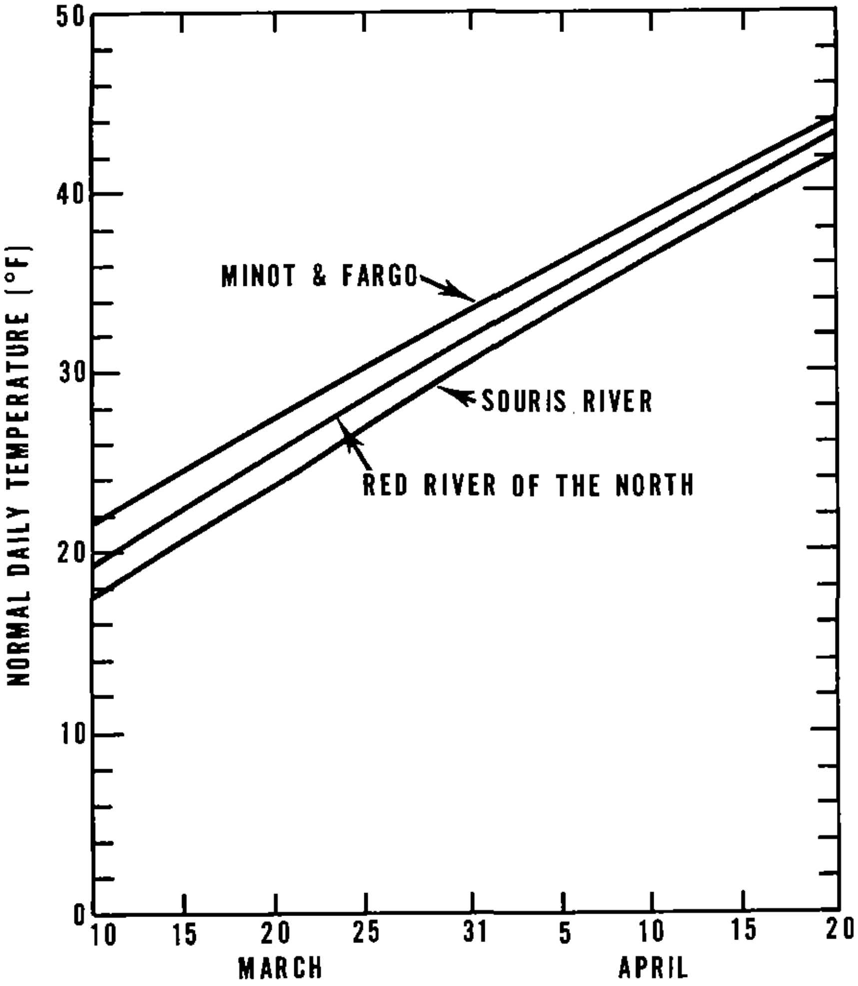


Figure 6-7.--Normal daily temperatures (basin averages).

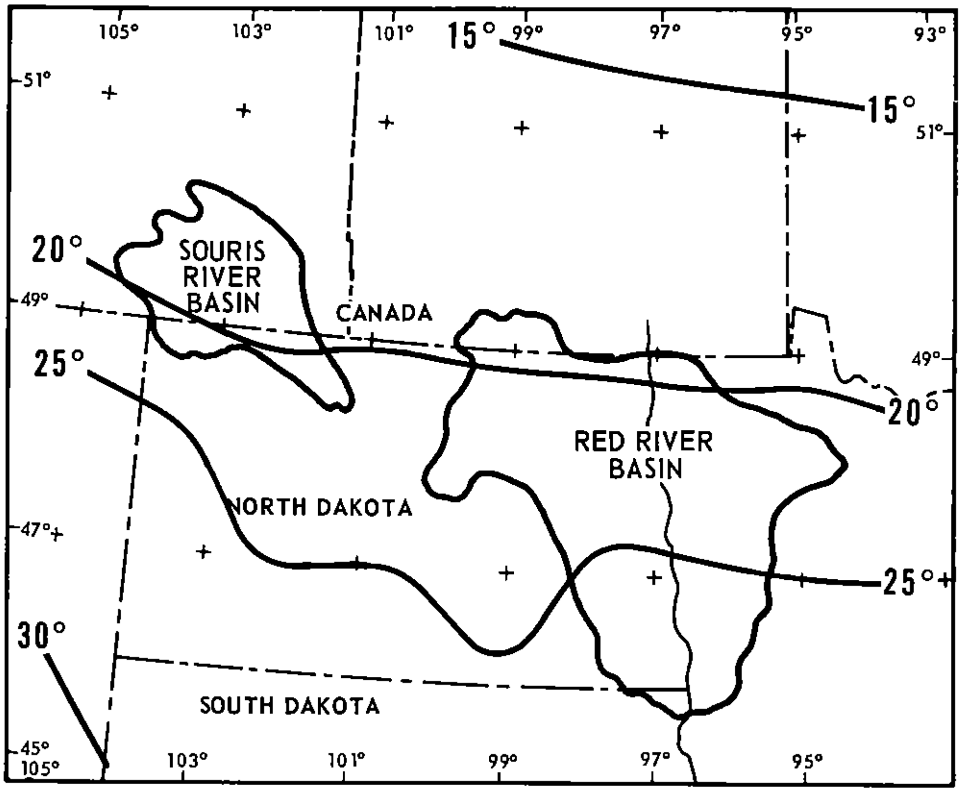


Figure 6-8.--Normal daily temperatures (°F). March.

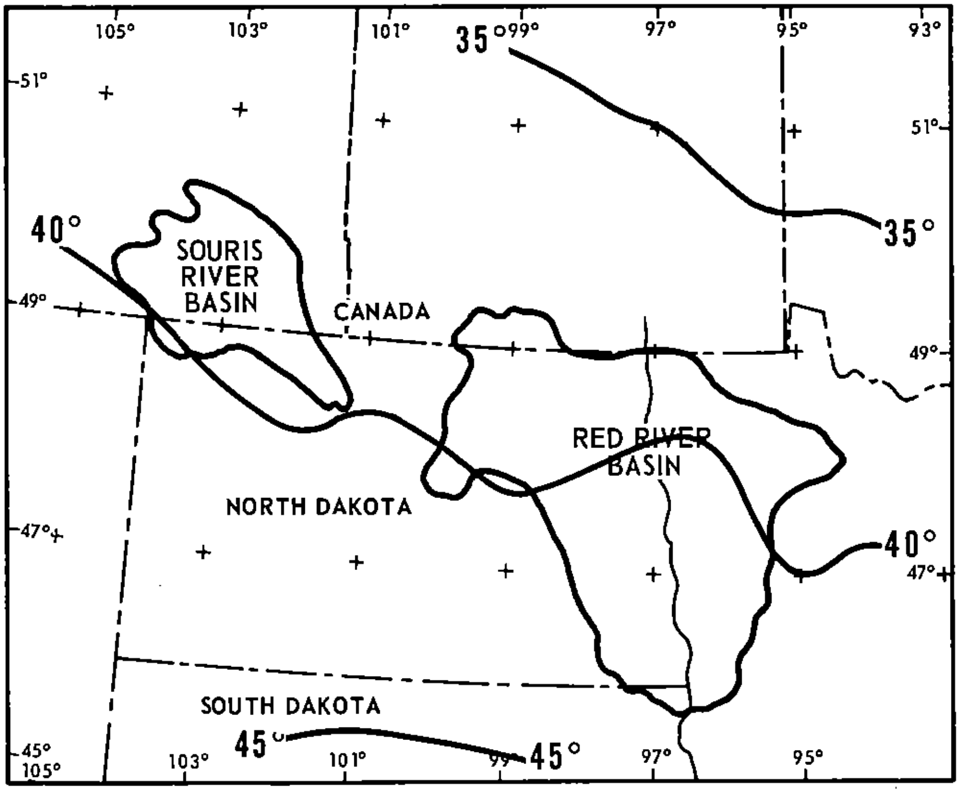


Figure 6-9.--Normal daily temperatures (°F). April.

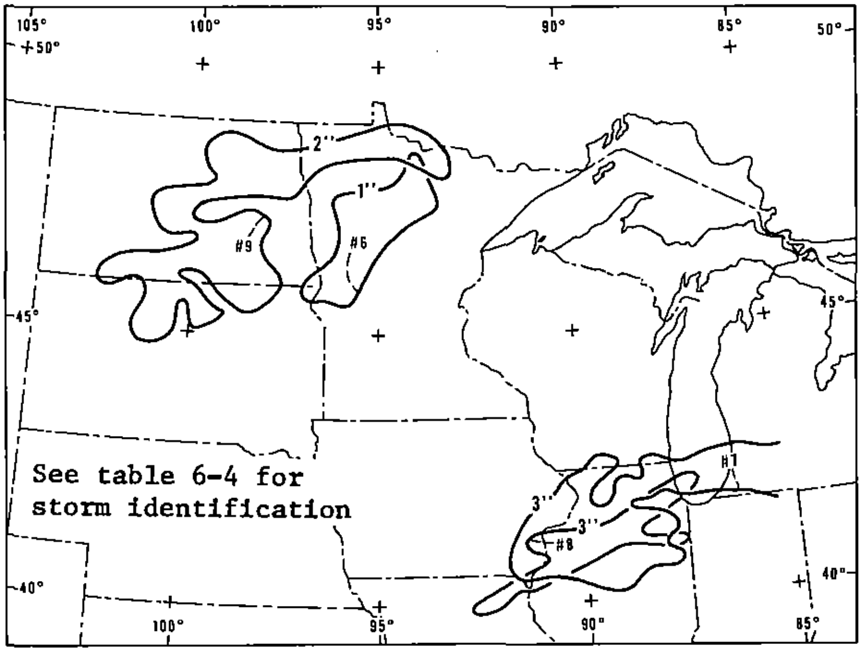


Figure 6-10a.--Outer isohyets of major March and April storms.

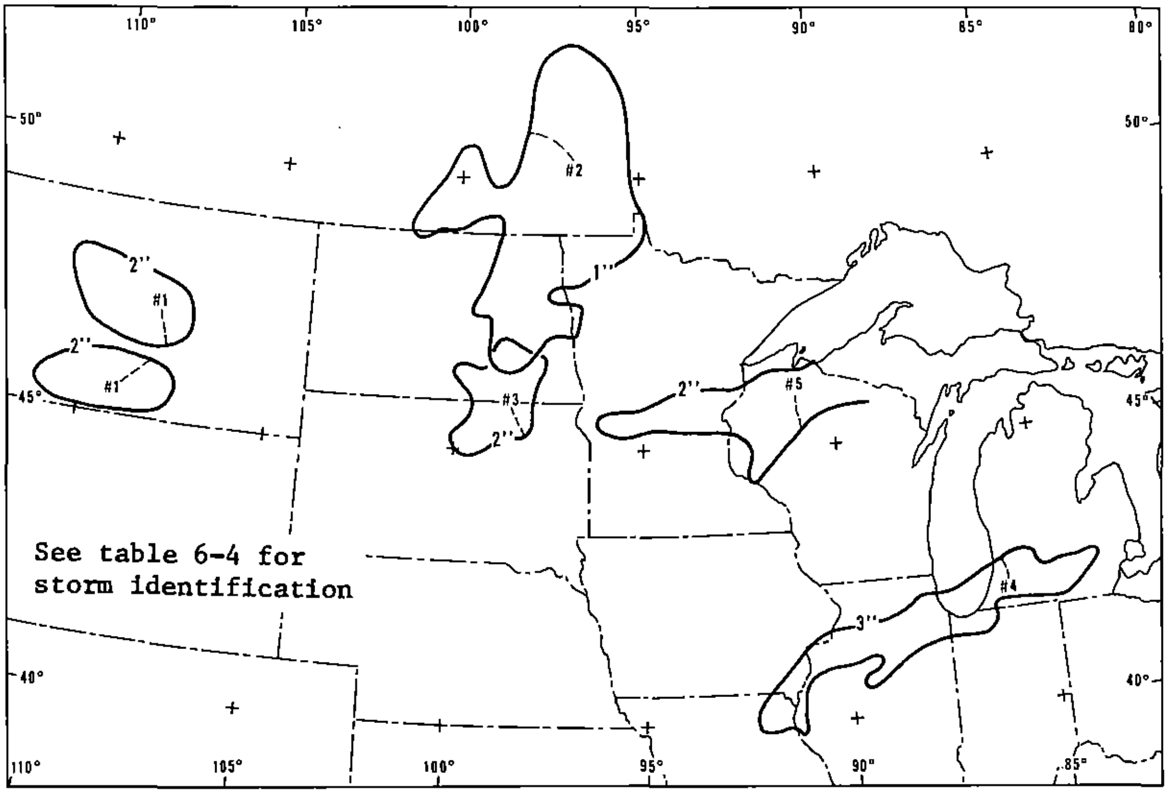


Figure 6-10b.--Outer isohyets of major March and April storms.

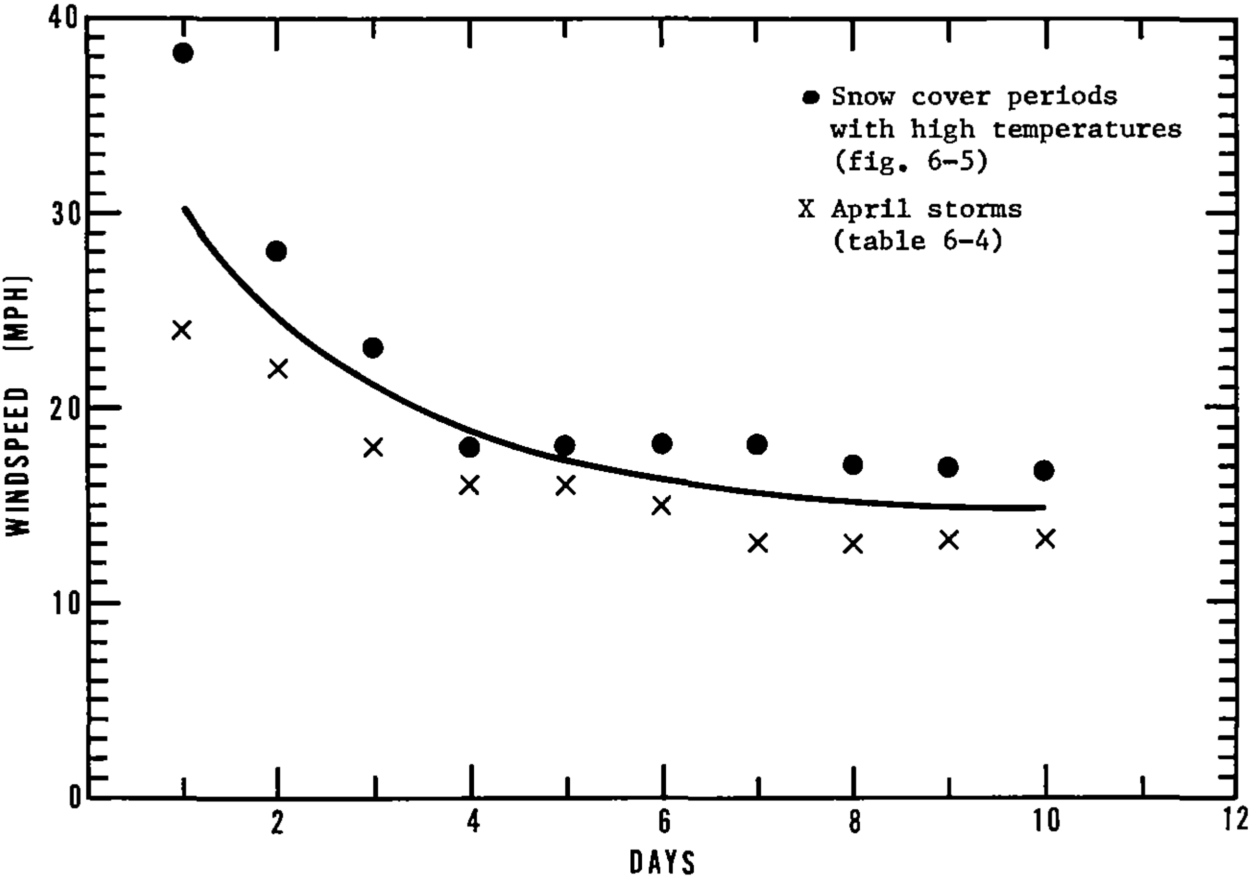


Figure 6-11.--Durational variation of windspeed.

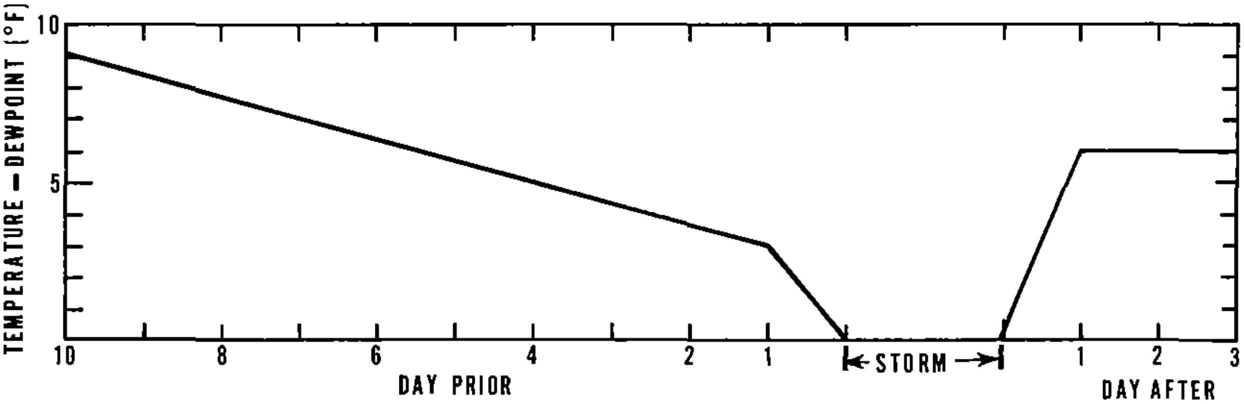


Figure 6-12.--Recommended temperature - dew point differences for PMP storm.

Chapter 7

SNOWPACK AVAILABLE FOR SPRING MELT

Introduction

A first approximation of snowpack available for spring melt may be obtained from Weather Bureau Technical Paper No. 50 (U.S. Weather Bureau 1964). Based on records prior to 1964, the paper gives maps of station maximum water equivalent of snow on the ground during March 1-15 and March 16-31 for 50-, 20-, 10-, 4-, 2- and 1-percent probability levels. For example, the average station value at the 1-percent probability level for the Red River drainage during March 16-31, is 7.6 in. The purpose of this study is to develop estimates of a reasonably severe areal snowpack without specifying the frequency, based on observed severe cases.

Data

Basic data used in Technical Paper No. 50 (U.S. Weather Bureau 1964) were used to determine the dates that provided the greatest observed station snowpacks of record up to 1964. Many of the greatest observed cases came during the March 16-31, 1962, and March 16-31, 1951, periods. In addition, three cases of large snowpacks were selected from recent years not covered in Technical Paper No. 50. Table 7-1 lists the six cases and other information. Data for 1952 came from Weather Bureau Technical Paper No. 23 (U.S. Weather Bureau 1954); for 1965 from ESSA Technical Report No. WB-4 (Paulhus 1967) and for 1969 from NOAA Technical Report NWS 13 (Paulhus 1971).

For the two cases selected from Technical Paper No. 50, the highest snowpacks, in terms of water equivalent, for each observation station during the 15-day period were plotted on maps. These then were analyzed and isopleths of water equivalent drawn. For these two cases the highest water equivalent within a 15-day period was selected for each station; thus the analyzed map is probably a slight maximization of actual water equivalent for any single day. Maps of water equivalent for the other four dates were already available from the cited publications.

Figures 7-1a and 7-1b give the outer isopleths of snowpack (water equivalent) for each date or period. Maximum areal depths of water equivalent were then computed and curves of maximum depth of water equivalent versus area determined for each case. Figure 7-2 shows these resulting curves.

Most of the outlines of high snow-on-ground situations are south of the two drainages, and direct transposition of these unadjusted snowpacks to the two basins would not be warranted. Hence, we adjusted the maximum areal values on the basis of station 1-percent probability water equivalent maps (U.S. Weather Bureau 1964). The ratio of the average 1-percent probability value over the basin to the average 1-percent probability value where the snowpack was observed is the adjustment applied. Table 7-1 gives these adjustments for transposition to the basins.

Figure 7-3 shows the resulting depth-area curves of maximum water equivalent for each of the six cases after adjustment to the Red River Basin. Figure 7-4 shows the adjusted values for the Souris River drainage. The greatest depths for both basins for any size area came from the March 14, 1969, values of snow on the ground.

Maximum Snowpack From Synthetic Season Approach

An alternate method of estimating maximum spring snowpack, termed the synthetic season approach, is to combine the highest precipitation of record for set time increments of the precipitation accumulation season. For example, the highest November precipitation of record added to the highest December precipitation, etc., on to the highest March precipitation would give a synthetic season of high precipitation. This procedure has been used in Hydrometeorological Report No. 42 (U.S. Weather Bureau 1966) for the Yukon River Basin of Alaska and in numerous studies for basins in Canada (Bruce 1962). The duration of the time increments of precipitation used in this procedure necessarily has a large effect on the seasonal accumulated precipitation. As the time increment becomes shorter, the accumulated precipitation becomes larger. Because of this variation, the synthetic-season approach is normally used in conjunction with other methods. The synthetic season approach was applied in this study using monthly precipitation (1931-60) averaged over state divisions. The subdivisions used are heavily outlined in figure 7-5. The Northwest Division of North Dakota was chosen as representative of the Souris drainage; the other three divisions (Northeast and East Central North Dakota and Northwest Minnesota) as representative of the Red River drainage. For the various division sizes, the highest adjusted water-equivalent values from figures 7-3 and 7-4 are compared with the synthetic season approach in the last two columns in table 7-2. Transpositions of actual snowpacks give greater depths than the synthetic season approach for each state division. We recommend the greatest adjusted water-equivalent depths of figures 7-3 and 7-4 for the March 15 PMP storm for the two drainages of this study.

Seasonal Variation

The recommended water equivalents are considered appropriate for March 15. As the season progresses it would be difficult to maintain these depths. Data from the March 1969 snowpacks (extrapolated) indicate a decrease of approximately 40 percent by April 15. A similar extrapolation of the station 1-percent probability values (U.S. Weather Bureau 1964) indicates a reduction of 56 percent. We recommend April 15 values that are 50 percent of the March 15 depths. Depths of intermediate dates may be interpolated.

Table 7-1.--Dates or periods of high-water equivalent in North Central States and transposition adjustments (see figs. 7-1a and 7-1b for location of snowpacks)

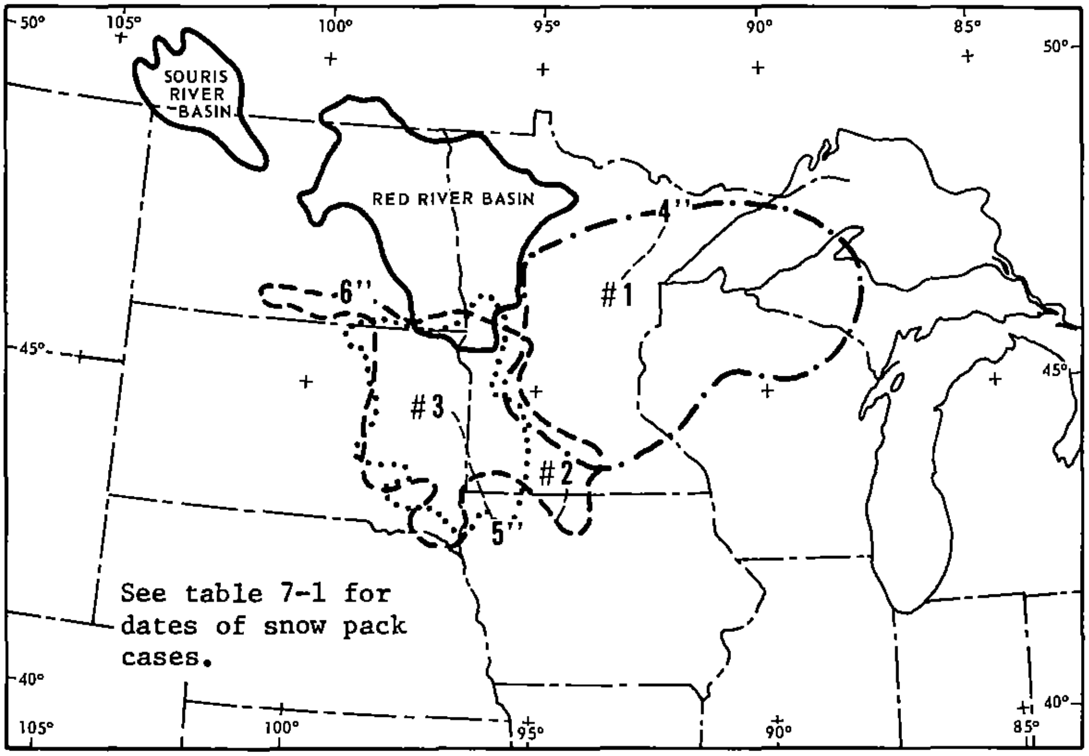
	Date	Adjustment for Red River Drainage	Adjustment for Souris Drainage
1	Mar. 30, 1965	0.58	0.32
2	Mar. 14, 1969	1.27	0.70
3	Mar. 28, 1969	1.31	0.72
4	Mar. 20, 1952	1.38	0.76
5	Mar. 16-31, 1951*	0.76	0.42
6	Mar. 16-31, 1962*	0.81	0.45

*Water equivalents based on highest station values for any day of period.

Table 7-2.--Comparison of highest November through March precipitation (1931-60) for selected State divisions with adopted maximum snowpacks by transposition

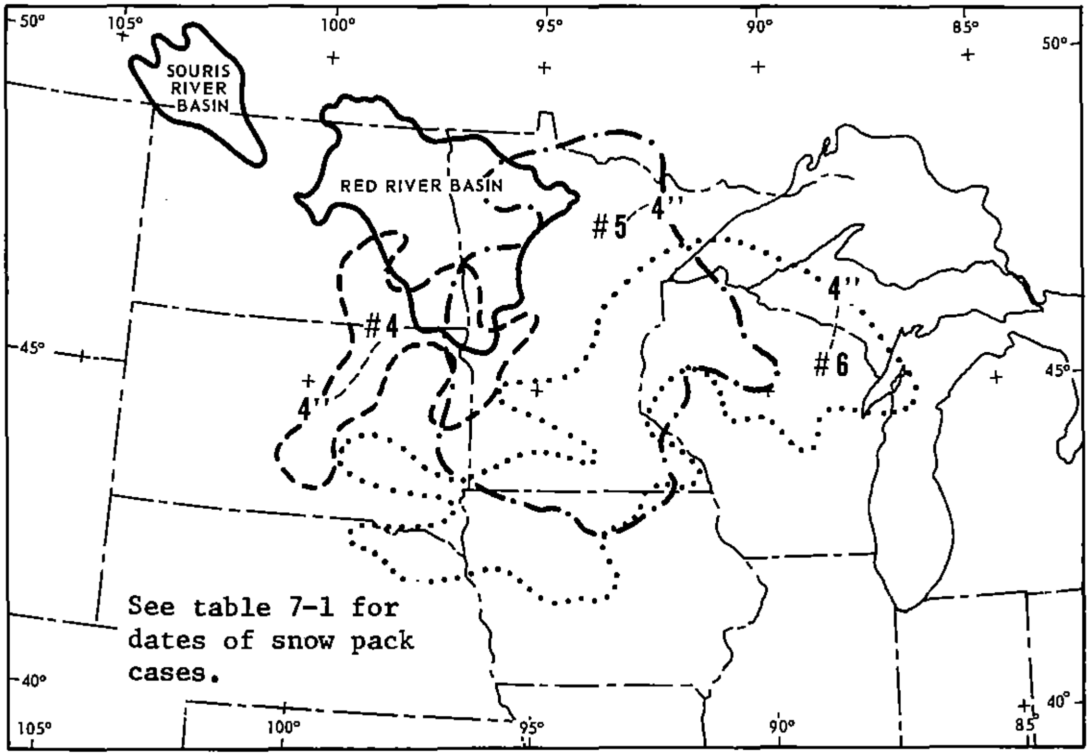
State and division	Normal precip. (in.)	Highest Actual seasonal precip. (in.) and season		Synthetic season of highest monthly precip. for each month (Nov-March) (in.)	Adjusted Snowpacks from figs. 7-3 or 7-4 for same size of area as state divisions (in.)*
North Dakota					
Northwest Division	2.3	4.1	(1948-49)	6.1	6.6
Northeast Division	3.0	5.4	(1944-45)	9.3	12.0
East Central Division	2.9	5.0	(1947-48)	9.3	12.4
Minnesota					
Northwest Division	3.5	5.3	(1949-50)	9.0	11.4

*See figure 7-5 for division location and area.



See table 7-1 for dates of snow pack cases.

Figure 7-1a.--Outer isopleths of snowpack water equivalent (in.) for selected cases.



See table 7-1 for dates of snow pack cases.

Figure 7-1b.--Outer isopleths of snowpack water equivalent (in.) for selected cases.

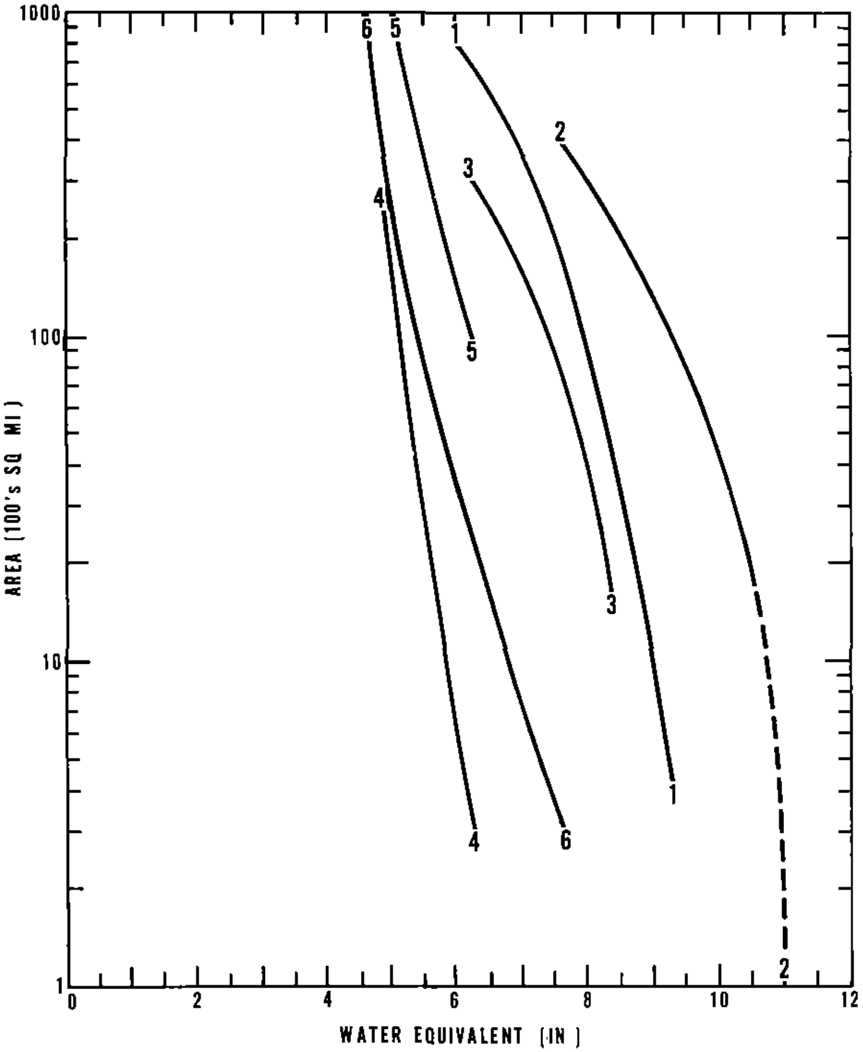


Figure 7-2.--Observed maximum water equivalents. (See table 7-1 for dates of the 6 snowpack cases).

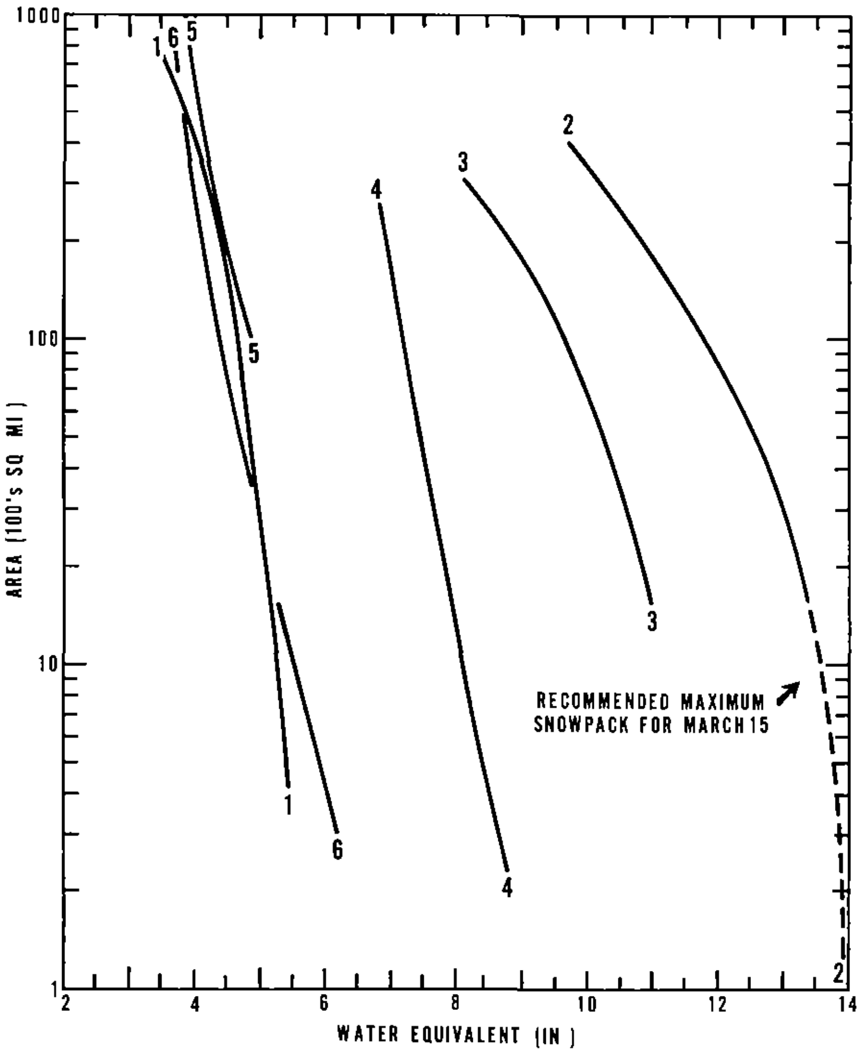


Figure 7-3.--Snowpack water equivalents transposed to Red River of the North Basin.

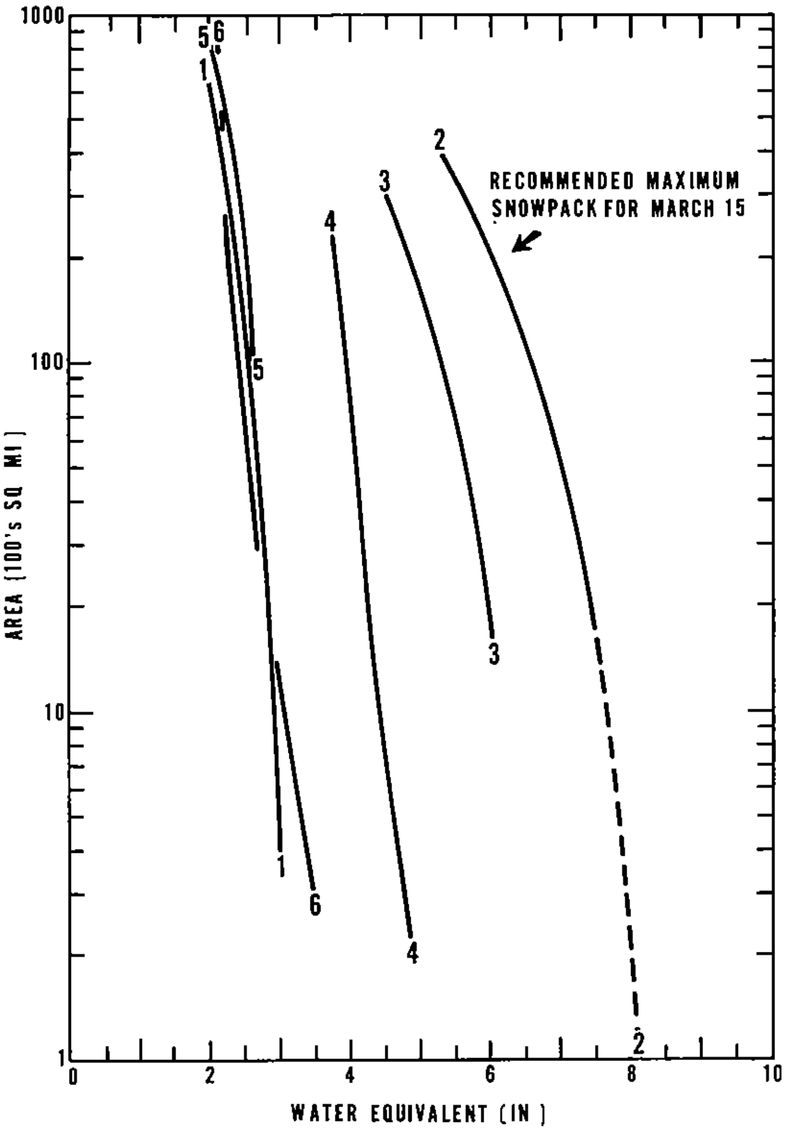
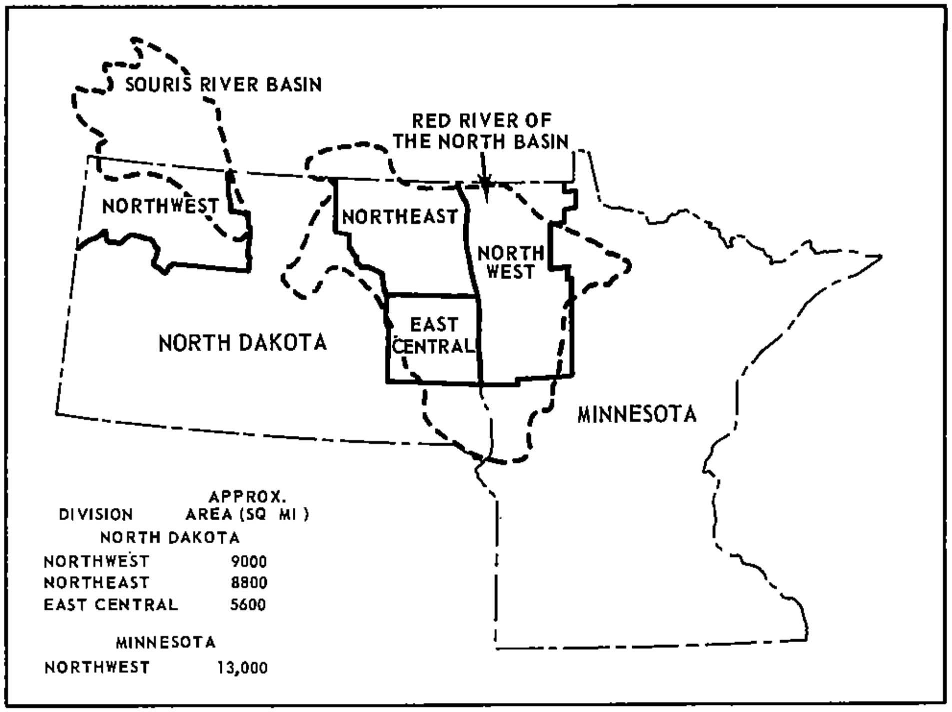


Figure 7-4.--Snowpack water equivalents transposed to Souris River Basin.



DIVISION	APPROX. AREA (SQ MI)
NORTH DAKOTA	
NORTHWEST	9000
NORTHEAST	8800
EAST CENTRAL	5600
MINNESOTA	
NORTHWEST	13,000

Figure 7-5.--State divisions used for synthetic season approach to maximum snowpack.

Chapter 8

PROCEDURE FOR USING CRITERIA WITH EXAMPLE

Introduction

Use of the various figures and charts to obtain PMP estimates and the recommended snowmelt criteria are summarized in this chapter. This is followed by an example for a selected subbasin.

A. All-season PMP

1. Basic PMP values

    a. Enter figure 3-1 with area of subbasin. Read PMP for the given durations on abscissa.

    (For Souris River subbasins, reduce PMP values by 10 percent)

2. Geographic adjustment

    a. Outline subbasin on figure 4-2c. Estimate average percent geographic adjustment.

    (Use figure 4-3c for Souris River subbasins)

    b. Multiply durational values of 1a by this adjustment.

3. 6-hr incremental PMP

    a. Plot values of 2b on a time scale. From a smooth curve connecting the values, interpolate for 42-, 54-, and 66-hr PMP.

    b. Successively subtract durational PMP to obtain 6-hr incremental PMP.

4. Sequence of 6-hr PMP increments

    a. Arrange 6-hr PMP increments in accordance with guidelines in chapter 5, page 24.

5. Areal distribution

    (Assume uniform areal distribution of all 6-hr PMP increments for subbasins less than 1,000 sq mi in area. For subbasins larger than 1,000 sq mi use the isohyetal pattern, figure 5-1, for the two greatest 6-hr PMP increments. Use uniform areal distribution for remaining PMP increments.)

   a. Enter figure 5-3 with area of subbasin. Read isohyetal values on abscissa for greatest 6-hr PMP increment in percent of subbasin 6-hr PMP. Use figure 5-4 in a similar manner to obtain isohyet values for the 2nd greatest 6-hr PMP increment.

   b. Multiply percents from figure 5-3 by greatest 6-hr PMP increment, step 3b, to obtain isohyetal values in inches. Multiply percents from figure 5-4 by second greatest 6-hr PMP increment, step 3b, to obtain isohyetal values for second greatest 6-hr PMP increment.

6. Adjustment of PMP for orientation of isohyetal pattern

   a. Lay isohyetal pattern, figure 5-1, over subbasin so as to obtain greatest volume of rain within subbasin. (Note step e for other possible more critical orientations.)

   b. From table 5-2 determine percent adjustment for this orientation.

   c. Multiply isohyetal values of step 5b by the percent adjustment to obtain final isohyetal values for the two greatest 6-hr PMP increments.

   d. Multiply remaining 6-hr PMP increments, step 3b, by the same percent adjustment.

   e. Test fitting the isohyetal pattern over the subbasin within the no adjustment limits of table 5-2 and for a more critical hydrologic centering to compare resulting floods. Use most critical isohyetal placement.

B. Seasonal variation of PMP

1. Determine geographic adjustment for March 15 and April 15 for subbasin from figures 4-2a and 4-2b, respectively. Interpolate for desired date of PMP.

   (For Souris River drainage use figures 4-3a and 4-3b)

2. Use table 4-2 to obtain seasonal adjustment for center of Red River of the North and Souris River drainages. Interpolate for desired date.

3. Multiply geographical adjustment (B1) by seasonal adjustment (B2). This product, divided by the all-season geographical adjustment (A2a) gives a factor for multiplying all-season isohyet values (A6c) to obtain isohyet values for the date selected.

4. Multiply remaining 6-hr PMP increments (A3b) by the same factor as in 3 above.

C. Snowmelt Criteria

   1. Winds

      a. Daily average winds for <u>10 days prior to storm</u> are given in table 6-5.

      b. Six-hour average winds <u>during PMP storm</u> are given in table 6-2b. Arrange these into same sequential order as rainfall (see A4a).

      c. Daily average winds for <u>3 days after storm</u> given in table 6-6.

   2. Temperatures

      a. Prior to storm

         (1) Determine normal daily temperatures (March 15 and April 15) over subbasin from figures 6-8 and 6-9. Interpolate for required date prior to selected day for beginning of storm.

         (2) Daily departures from normal temperatures for the 10 days prior to storm given in table 6-3 for three dates. Interpolate for required date.

         (3) Daily temperatures for 10 days prior to storm obtained by adding normal subbasin temperature, item 2a (1), to each temperature departure, item 2a (2).

      b. During storm (Temperature = dew point)

         (1) Determine average 12-hr persisting dew point (March 15 and April 15) over subbasin from figures 6-1 and 6-2. Interpolate for required date.

         (2) Determine precipitable water (W_p) for this dew point from figure 6-3.

         (3) Multiply W_p by percents of table 6-1 to obtain W_p corresponding to 6-hr incremental dew points.

         (4) Enter figure 6-3 with W_p values to obtain 6-hr dew points.

(5) Adjust these values to elevation of the basin by decreasing at the rate of 3°F per 1,000 ft above sea level.

(6) Arrange elevation adjusted 6-hr values in the same sequential order as rainfall (item A4a).

c. After storm

(1) Average daily temperatures are 7°F lower on the 1st day, 9°F on the 2nd, and 10°F on the 3rd day after the storm than on the last day of the storm.

3. Dew Points

a. Prior to storm

(1) Subtract indicated degrees given in figure 6-12, from each daily average temperature of C2a (3).

b. During storm

(1) Same as temperatures, see C2b (6)

c. After storm

(1) Daily dew points are 6°F lower than temperatures, see item C2c (1).

Note: If half-day temperatures and dew point are required, add and subtract 6°F from daily averages.

D. Maximum Snowpack Water Equivalent

1. Read value of recommended maximum snowpack water equivalent from figure 7-3 for the area of the subbasin. (Use fig. 7-4 for Souris River Basin). This is for March 15.

2. For April 15 use 50 percent of March 15 value. Interpolate for required date.

Example

The drainage of the Red Lake River above Crookston, Minn., a 5280-sq-mi subbasin, is used here as an example of how developed criteria may be applied. For snowmelt computations, the average elevation of this basin is assumed to be 1,500 ft. In actual problems concerned with larger basins, the criteria may be determined for elevation bands, if desired.

The identification letters and numbers in the example correspond to the steps in the outlined procedure.

A. All-season PMP

	Duration (hr)											
	6	12	18	24	30	36	42	48	54	60	66	72
	PMP (in.)											
1. Basic PMP values (fig. 3-1)	7.7	9.6	10.8	11.6	12.4	13.1	-	14.3	-	15.1	-	15.8
2. Geographic adjustment												
a. From figure 4-2c=100 percent												
b. Geographically adjusted PMP values of A1 times 100 percent	7.7	9.6	10.8	11.6	12.4	13.1	-	14.3	-	15.1	-	15.8
3. 6-hr incremental PMP												
a. Geographically adjusted PMP with interpolations	7.7	9.6	10.8	11.6	12.4	13.1	13.7	14.3	14.7	15.1	15.5	15.8
	6-hr period (1=highest, 12= lowest)											
	1	2	3	4	5	6	7	8	9	10	11	12
b. 6-hr incremental PMP (in.)	7.7	1.9	1.2	0.8	0.8	0.7	0.6	0.6	0.4	0.4	0.4	0.3
4. Sequence of 6-hr PMP increments												
	Time (hr) from beginning of storm											
	6	12	18	24	30	36	42	48	54	60	66	72
	Sequence of 6-hr increments											
a. A sequence selected from chapter 5, p. 24	8	6	5	7	4	2	1	3	9	10	11	12
6-hr PMP increments (in.)	0.6	0.7	0.8	0.6	0.8	1.9	7.7	1.2	0.4	0.4	0.4	0.3

5. Areal distribution

(Assume uniform areal distribution for all 6-hr increments except the two greatest.)

	Isohyet						
	P	A	B	C	D	E	F
a. Isohyet values in percent of greatest 6-hr PMP increment from figure 5-3 for 5,280 sq mi	200	179	157	130	80	47	26
Isohyet values in percent of 2nd greatest 6-hr PMP increment from figure 5-4	221	164	137	110	88	75	63
b. Isohyet values (in.) for greatest 6-hr PMP increment (percents of a times 7.7)	15.4	13.8	12.1	10.0	6.2	3.6	2.0
Isohyet values (in.) for 2nd greatest 6-hr PMP increment (percents of a times 1.9)	4.2	3.1	2.6	2.1	1.7	1.4	1.2

6. Adjustment for orientation of isohyetal pattern

a & b. Orientation of isohyetal pattern figure 5-1 for best fit to subbasin outline, 80°-260°, indicates no reduction in PMP (table 5-2).

c & d. Final isohyet values for all-season PMP are given in 5b. Other 6-hr PMP increments are given in A4a.

e. For this example, it is assumed the best fit orientation is the most critical.

B. Seasonal variation of PMP

(PMP criteria in this example are determined for April 15.)

1. Geographical adjustment over subbasin for April 15 (fig. 4-2b)=101 percent

2. Seasonal adjustment for April 15 from table 4-2=72 percent

3. Geographical adjustment times seasonal adjustment (101x72)=73 percent; 73 percent divided by all-season geographic adjustment (the latter is 100 percent from A2a)=73 percent

April 15 isohyet values (in.) (values of A5b times 73 percent)

	Isohyet						
	P	A	B	C	D	E	F
Greatest 6-hr PMP increment	11.2	10.1	8.8	7.3	4.5	2.6	1.5
2nd greatest 6-hr PMP increment	3.1	2.3	1.9	1.5	1.2	1.0	0.9

4. All-season incremental PMP times 0.73, arranged in same sequence as for all-season PMP (see A4a)

6-hr period											
8	6	5	7	4	2	1	3	9	10	11	12
April 15 6-hr incremental PMP (in.)											
0.4	0.5	0.6	0.4	0.6	1.4	5.6	0.9	0.3	0.3	0.3	0.2

C. Snowmelt criteria

1. Winds

	Day prior to storm									
	10	9	8	7	6	5	4	3	2	1
	Windspeed (mph)									
a. Daily average winds <u>prior to storm</u> (from table 6-5)	10	10	12	13	13	14	15	15	18	31

	Sequence of 6-hr increments											
	8	6	5	7	4	2	1	3	9	10	11	12
	Windspeed (mph)											
b. 6-hr winds <u>during storm</u> (table 6-2b), arranged in same sequence as rainfall (see A4a)	19	21	23	21	25	31	37	27	18	17	16	14

	Day after storm		
	1	2	3
	Windspeed (mph)		
c. Daily average winds after storm (from table 6-6)	28	10	12

2. Temperatures

a. Prior to storm

(1) Normal daily temperature over subbasin for April (fig. 6-9) = 39° F

	Day prior to storm									
	10	9	8	7	6	5	4	3	2	1
	Temperature (°F)									
(2) Daily dep. from normal temp. (°F) for April 15 (table 6-3)	3	3	3	3	4	5	7	8	14	22
	Temperature (°F)									
(3) Temp. dep. added to 39° F	42	42	42	42	43	44	46	47	53	61

b. During storm (temperatures = dew points)

(1) 12-hr persisting dew point, figure 6-2, for subbasin = 60° F

(2) Precipitable water (W_p) for this dew point from figure 6-3 is 1.41 in.

	6-hr period											
	1	2	3	4	5	6	7	8	9	10	11	12
	W_p (in.)											
(3) W_p times percents of table 6-1	1.51	1.41	1.33	1.27	1.21	1.15	1.11	1.07	1.04	1.01	.99	.96
	°F											
(4) Dew points corresponding to W_p, figure 6-3	61.8	60.5	59.2	58.3	57.4	56.5	55.7	55.0	54.4	53.8	53.3	52.7
	°F											
(5) Dew points reduced to 1,500 ft elev. (3° F /1,000 ft)	57.3	56.0	54.7	53.8	52.9	52.0	51.2	50.5	49.9	49.3	48.8	48.2

	6-hr periods in same sequence as rainfall											
	8	6	5	7	4	2	1	3	9	10	11	12
(6) 6-hr dew points and temperatures (to whole degrees), ° F.	50	52	53	51	54	56	57	55	50	49	49	48

c. After storm

(1) Temperatures are 7°, 9°, and 10° F lower than on last day of storm for the 1st, 2nd, and 3rd days after the storm, respectively. (Last day of storm t = 49° F

Day after storm	1	2	3
Average daily temperature, ° F	42	40	39

3. Dew points

a. Prior to storm

	Day prior to storm									
	10	9	8	7	6	5	4	3	2	1
(1) Temperature minus dew point from figure 6-12, °F	9	8	8	7	6	6	5	4	4	3
Differences subtracted from daily temperatures of C2a(3), °F	33	34	34	35	37	38	41	43	49	58

b. During storm. Dew points = temperatures, see C2b(6)

c. After storm

(1) Daily dew points are 6° F lower than temperatures (see C2c(1)), giving 36°, 34°, and 33° F for the 1st, 2nd, and 3rd days, respectively, after the storm.

D. Maximum snowpack water equivalent

1. Maximum depth of March 15 water equivalent from figure 7-3 for 5,280 sq mi is 12.5 in.

2. Use 50 percent of March 15 for April 15 values, giving 6.3 in.

ACKNOWLEDGMENTS

The author is grateful for the help of numerous members of the Hydrometeorological Branch staff in the course of this study. Francis Schwarz made helpful suggestions in developing the snowmelt criteria and in editing the report. Calvin Cochrane, William Swayne and Roger Watkins carried out details of the PMP estimates and isohyetal values. Marshall Hansen carried out the tests of the frequency distributions. Miriam McCarty, Marion Choate, Wallace Brewer and Ray Evans made detailed computations, data extractions, many charts and maps. Typing was done by Christina Ebner, Edna Grooms and Cora Ludwig. Finally, many suggestions were made by John Miller, Chief of Water Management Information Division, Office of Hydrology, National Weather Service.

REFERENCES

Atmospheric Environment Service, "Storm Rainfall in Canada," Downsview, Ontario, Canada, 1961.

Bruce, J. P., "Snowmelt Contributions to Maximum Floods," Proceedings Eastern Snow Conference, pp. 85-103, 1962.

Canada, Department of Transport, Meteorological Branch, "Maximum Precipitation Reported on any Observation Day, 1931-1958," Summary of data through 1958.

Canada, Department of Transport, Meteorological Branch, "Atlas of Climatic Maps," 1967.

Chow, V. T., Handbook of Applied Hydrology, McGraw-Hill, New York, 1964.

Corps of Engineers, U. S. Army, "Storm Rainfall in the United States," Washington, D. C., 1945-.

Environmental Data Service, "Climatic Atlas of the United States," ESSA, U.S. Department of Commerce, 1968.

Environmental Data Service, "Maximum Persisting 12-hour 1000-mb Dew Points (°F) Monthly and of Record," Climatic Atlas of the United States, ESSA, U. S. Department of Commerce, 1968.

Environmental Data Service, "Weekly Weather and Crop Bulletins," ESSA, U.S. Department of Commerce and U.S. Department of Agriculture, Statistical Reporting Service, Washington, D.C., 1970 (weekly publication).

Gumbel, E. J., "Statistics of Extremes," Columbia University Press, New York, 1958.

Lieblein, J., "A New Method of Analyzing Extreme Value Data," NACA Technical Note 3053, 1954.

Myers, V. A., "Meteorological Estimation of Extreme Precipitation for Spillway Design Floods," Weather Bureau Technical Memorandum, WBTM-HYDRO-5, ESSA, U. S. Department of Commerce, 1967.

Paulhus, J.L.H., and Nelson, E.R., "The March-May 1965 Floods in the Upper Mississippi, Missouri, and Red River of the North Basins," ESSA Technical Report WB-4, 1967.

Paulhus, J.L.H., "The March-April 1969 Snowmelt Floods in the Red River of the North, Upper Mississippi and Missouri Basins," NOAA Technical Report NWS 13, 1971

REFERENCES (Cont'd)

Schwarz, F. K., "Probable Maximum and TVA Precipitation Estimates for the Drainage above Kentucky Dam and Below the Major Tributary Reservoirs," unpublished manuscript to the Tennessee Valley Authority, August 1970.

Thom, H.C.S., "Some Methods of Climatological Analysis," World Meteorological Organization, Technical Note 81, 1966.

U.S. Weather Bureau, "Highest Persisting Dew Points in the Western United States," Technical Paper No. 5, 1948.

U.S. Weather Bureau Technical Paper No. 16, "Maximum 24-Hour Precipitation in the United States," January 1952a.

U.S. Weather Bureau, "Kansas-Missouri Floods of June-July 1951," Technical Paper No. 17, July 1952b.

U.S. Weather Bureau, "Preliminary Estimate of Probable Maximum Precipitation over the Red Lake River Basin above Crookston, Minn. and the Huot Reservoir Site," Memorandum to Office of the Chief, Corps of Engineers, October 1952c.

U.S. Weather Bureau, "Normal Weather Charts for the Northern Hemisphere," Technical Paper No. 21, 1952d.

U.S. Weather Bureau, "Floods of April 1952--Upper Mississippi, Missouri, Red River of the North," Technical Paper No. 23, 1954.

U.S. Weather Bureau, "Seasonal Variation of the Probable Maximum Precipitation East of the 105th Meridian for Areas from 10 to 1000 Square Miles and Durations of 6, 12, 24 and 48 Hours," Hydrometeorological Report No. 33, 1956.

U.S. Weather Bureau, "Decennial Census of the United States Climate, Monthly Averages for State Climatic Divisions, 1931-1960," Washington, D.C., 1963.

U.S. Weather Bureau, "Frequency of Maximum Water Equivalent of March Snow Cover in North Central United States," Technical Paper No. 50, 1964.

U.S. Weather Bureau, "Meteorological Conditions for the Probable Maximum Flood on the Yukon River above Rampart, Alaska," Hydrometeorological Report No. 42, ESSA, U. S. Department of Commerce, 1966.

U.S. Weather Bureau, "Probable Maximum Precipitation over South Platte River, Colorado, and Minnesota River, Minnesota," Hydrometeorological Report No. 44, ESSA, U. S. Department of Commerce, Washington, D. C., 1969.

U.S. Weather Bureau, "Climatological Data for the United States by Sections," Washington, D.C., 1970 (monthly publication).

☆ U.S. GOVERNMENT PRINTING OFFICE : 1973—511-327/294

NTIS

Mail to: National Technical Information Service
DEPARTMENT OF COMMERCE
P.O. Box 1553, Springfield, Virginia 22151

Please send me ____________ copies of INDEXED BIBLIOGRAPHY OF THERMAL EFFECTS LITERATURE—2 at $10 each. $12.50 foreign. ORNL-NSIC 97. ☐ Check here for microfiche.

Please send me ____________ copies of INDEXED BIBLIOGRAPHY ON ENVIRONMENTAL MONITORING FOR RADIOACTIVITY at $10.00 each. $12.50 foreign. ORNL-NSIC 101. Check here for microfiche.

Please send me ____________ copies of INDEXED BIBLIOGRAPHY ON NUCLEAR FACILITY SITING at $10.00 each. $12.50 foreign. ORNL-NSIC 105. ☐ Check here for microfiche.

Please send me ____________ copies of COMPILATION OF NUCLEAR STANDARDS, 8th EDITION, 1971—Part I: United States Activities and Part II: National (excluding U. S.) and International Activities at $22.00 each set. $24.50 foreign. ORNL-NSIC Part I 98 and Part II 102. ☐ Check here for microfiche.

Please send me ____________ copies of SUMMARY OF RECENT LEGISLATIVE AND REGULATORY ACTIVITIES AFFECTING THE ENVIRONMENTAL QUALITY OF NUCLEAR FACILITIES at $10.00 each. $12.50 foreign. ORNL-NSIC 93. ☐ Check here for microfiche.

Method of Payment

☐ Charge to my NTIS deposit account no. ____________________.
☐ Bill me (not applicable to foreign orders). Add 50¢ each title.
☐ Here is my check for $____________________.

Name ____

Address ____

City, State, Zip ____

Nuclear Materials Problems?

Here are five answers.

1. "Indexed Bibliography of Thermal Effects Literature"—a compilation and annotated bibliography of information previously published in technical literature on the subject of thermal discharges from power plants and their interaction with aquatic ecology. Included are an author index, keyword index, abstracts and the KWIC title index. Engineering aspects of thermal effluent control are covered as well.
2. "Indexed Bibliography on Environmental Monitoring for Radioactivity"—850 abstracts on environmental monitoring with background material to put monitoring problems in perspective. Lists pertinent references for a general environmental monitoring program emphasizing the normal operation of a nuclear facility.
3. "Indexed Bibliography on Nuclear Facility Siting" 900 abstracts of documents pertaining to various phases of siting with emphasis on the reports and questions that arise during the licensing of a nuclear plant. Keyword, author and KWIC indexes are provided.
4. "Compilation of Nuclear Standards 8th Edition, 1971: Part I—United States Activities; Part II—National (excluding U. S.) and International Activities"—all U. S., national, and international nuclear standards with relevant regulations established by government agencies. Both volumes divided by organization and permuted title.
5. "Summary of Recent Legislative and Regulatory Activities Affecting the Environmental Quality of Nuclear Facilities" a summary of recent legislative and regulatory activities, proposed and adopted Federal and State legislation which might affect the development of utilization of nuclear energy. Also included are executive orders and water quality standards for all states.

Add these five references from the Nuclear Safety Information Center to your research library.
Order now, by completing the coupon below.

IF YOU'RE RUSTY ON THE SUBJECT OF CORROSION, READ THESE!

Here are four Metals & Ceramics Information Center reports on corrosion and its treatment:

"The Corrosion of Metals in Marine Environments" is a current resource of information on the advanced metals and their use in hostile marine environment. It helps you to choose materials and equipment right for your job.

"Hot Corrosion in Gas Turbines" deals primarily with the sulfidation problem and explains major testing methods and research.

"Oxidation of Iron, Nickel and Cobalt-base Alloys" guides the engineer or metallurgist to current data on oxidation of the pure metals and their alloys, as well as of more complex engineering alloys.

"Shot Peening for Improved Fatigue Properties and Stress Corrosion" contains a summary of current peening procedures, methods of control and improvement that can be achieved with these techniques.

Any one or all four of these studies can be invaluable to you in your research or in practical day-to-day operations. Put them on your shelf by filling out and returning the coupon below.

NTIS **Mail to:** National Technical Information Service
Department of Commerce P.O. Box 1553
Springfield, Virginia 22151

GENTLEMEN:

☐ Please send me ____________ copies of the MCIC report THE CORROSION OF METALS IN MARINE ENVIRONMENTS. hard cover copies $12.50 each ($15.00 foreign) or ____________ soft cover copies at $7.50 each ($10.00 foreign) AD-712 585-H or AD-712 585-S.

☐ Send me ________ copies of the MCIC Report HOT CORROSION IN GAS TURBINES at $10.75 each ($13.25 foreign) AD-745 474.

☐ Send me ________ copies of the MCIC report OXIDATION OF IRON, NICKEL AND COBALT-BASE ALLOYS at $10.75 each ($13.25 foreign) AD-745 473.

☐ Send me ________ copies of the MCIC report SHOT PEENING FOR IMPROVED FATIGUE PROPERTIES AND STRESS CORROSION at $7.50 each ($10.00 foreign) AD-735 409.

Please check method of payment.

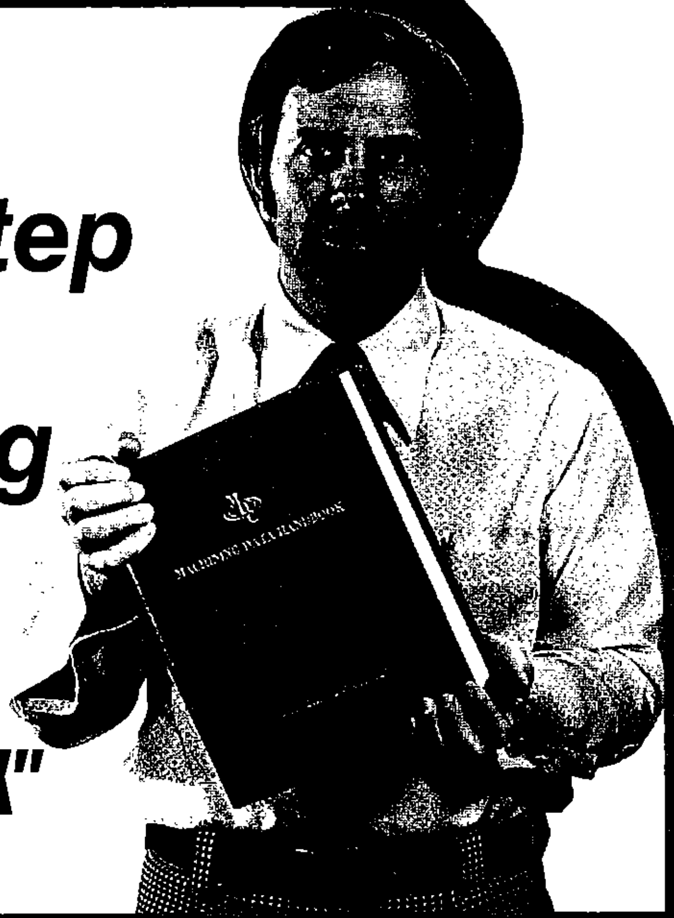
☐ Charge to my NTIS account no. ____________________
☐ Bill me *(not applicable to foreign orders)*. Add 50¢ for each title.
☐ Here is my check for ____________________

Name ____

Title, Organization ____

Address ____

City, State, Zip ____


MACHINING DATA HANDBOOK