HYDROMETEOROLOGICAL REPORT NO. 40

PROBABLE MAXIMUM PRECIPITATION SUSQUEHANNA RIVER DRAINAGE ABOVE HARRISBURG, PA.

U.S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
Washington
May 1965

HYDROMETEOROLOGICAL REPORTS

(Nos. 6–22 Numbered Retroactively)

*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 (Unpublished.)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 (Unpublished.)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 on probable maximum precipitation in California. 1961.
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.

---

*Out of print.

U.S. Department of Commerce
Weather Bureau

U.S. Department of the Army
Corps of Engineers

HYDROMETEOROLOGICAL REPORT NO. 40

PROBABLE MAXIMUM PRECIPITATION SUSQUEHANNA RIVER DRAINAGE ABOVE HARRISBURG, PA.

Prepared by
H. V. GOODYEAR and J. T. RIEDEL
Hydrometeorological Branch
Office of Hydrology
U.S. Weather Bureau

Washington, D.C.
May 1965

TABLE OF CONTENTS

TABLES

FIGURES

I. INTRODUCTION

Authorization

This report was prepared in compliance with a request from the Office of the Chief, U. S. Corps of Engineers.

Purpose

The purpose of this report is to provide probable maximum precipitation (PMP) estimates for any sub-basin of the Susquehanna River drainage above Harrisburg, Pa. Such estimates are necessary in the planning, design, and operation of dams, spillways, and other water control devices.

The report is part of a comprehensive Susquehanna River Basin study which is being undertaken by the state and federal agencies. The objective of the comprehensive study is to develop an overall plan for the most beneficial utilization of the water supply in the basin and for the control of floods.

Scope

Probable maximum precipitation is defined by 6-hr. duration intervals up to 3 days. Recommendations are given for the sequence of 6-hr. increments in the probable maximum storm.

Seasonal variation of PMP is not within the scope of this study. However for areas up to 5000 square miles the designated PMP would come in summer. For increasingly larger areas the cool seasons tend to become more dominant.

The areal distribution of rain in the PMP storm is defined by isohyetal patterns. Separate patterns are provided for each of eight assigned sub-basins; a generalized isohyetal pattern, adjusted by supplementary nomograms, can be applied to any other sub-basin. The geographical variation of the PMP within the drainage area is determined.

Topography has a modest influence on how rainfall is distributed over the basin. A suggested method is included for redistributing the total volume of rain within the basin for elevation differences.

II. ORGANIZATION AND DEVELOPMENT OF DERIVED CRITERIA

Enveloping depth-duration-area (DDA) curves of PMP were derived by moisture maximization of major storms of record and transposition to the center of the Susquehanna drainage area above Harrisburg. Orographic effects on the controlling storms were considered and are discussed in section III. The resulting enveloping curves for 6-, 12-, 24-, 48-, and 72-hr. duration are shown in figure 2. The storms which control these curves and their combined moisture and transposition adjustments are given in table 2. Geographical variation of PMP within the Susquehanna drainage above Harrisburg was determined. This is given in figure 1 in percent of the PMP at the center of the basin. The derivation of these basic PMP values is presented in section III.

Section IV considers meteorological aspects of major storms on or transposed to the basin. Adjustment of PMP for topography, derived in section V, was used to redistribute the volume of PMP within any specified sub-basin.

Time and areal distributions of PMP within a specified basin are covered in section VI. A generalized storm isohyetal pattern (figure 12) is given with instructions for redistributing PMP with elevation in a sub-basin. Section VII provides a summary and an example of the procedure for obtaining PMP storm values for a sub-basin.

In addition, the Corps of Engineers specified eight sub-basins (shown in figure 1) for which PMP values were to be individually tailored. The average depths of PMP by 6-hr. time steps to 72 hours for each of these basins are given in table 1 with individual isohyetal patterns shown in figures 13a-h. These (or the generalized pattern, figure 12) may be used for areal distribution.

An outline of the PMP procedure is presented in simplified schematic form on the following page. This enables the reader to picture how the various factors and developed relationships are used in determining probable maximum storm precipitation for a basin.

III. DERIVATION OF PMP FOR SUSQUEHANNA BASIN

Enveloping curves of PMP for 6-, 12-, 24-, 48-, and 72-hr. duration were obtained by transposing storms of record into the basin and adjusting them for maximum moisture at the transposed location. PMP values for intermediate durations may be obtained from smooth depth-duration curves. A survey of Storm Rainfall (1) provided the major storms considered transposable. These, along with their assignment numbers, are listed in table 2. From this group of storms, those giving highest values for standard size areas and selected durations, the controlling storms, are shown in table 3.

Storm adjustment

Moisture maximization is based on 1000-mb 12-hr. persisting dew points as an index to moisture through depth. In brief, observed storm precipitation is multiplied by the ratio of maximum precipitable water to precipitable water in a storm. The transposition adjustment is similar. Storm precipitation is multiplied by the ratio of maximum precipitable water for a transposed position to maximum precipitable water in place of occurrence. In each position the precipitable water pertains to a reference distance and direction from the storm center. Details of these adjustments may be found in HMR No. 33 (2). The combined moisture and transposition adjustments for the controlling storms in this study are listed in table 3.

Elevation considerations

In developing the PMP for the Susquehanna Basin above Harrisburg, no adjustment was made to transposed storm depths for difference in elevation. The differences between the average elevation of the Susquehanna Basin and the elevations of the terrain covered by the storm isohyets that were transposed are comparatively small. For example, while the Big Meadows, Va. storm center is at 3500 ft., the average elevation of the terrain covered by the 500-sq. mi. maximum rain in that storm averages about 1000 ft. There are no continuous upwind barriers to the Susquehanna Basin over 1000 ft. in elevation, while within the basin some isolated peaks are close to 2500 ft.

It is recognized that sometimes relatively small ridges or coastal effects play an important role in releasing storm rainfall. This is not thought to affect the basin volume of rain of storms transposed to the Susquehanna for several reasons. Two controlling storms, those at Altapass, N. C. and Big Meadows, Va. were already augmented by the mountains on which they centered. Other controlling storms were centered at lower elevations nearer to the coast. In these coastal stimulation of precipitation is qualitatively similar to stimulation by hilly terrain. Since the Wellsboro, Pa. storm occurred on the basin, no adjustment for elevation was required.

Consistency with other estimates

Enveloping DDA curves of PMP, given in figure 2, are consistent with the generalized PMP estimates given in HMR No. 33 (2). In that report PMP values are given for durations from 6 to 48 hours and areas from 10 to 1000 square miles. Percentages of 200-sq. mi., 24-hr. PMP by geographical zones are given in that report to obtain PMP values for other durations and for basins up to 1000 square miles in area. Four of these zones approximately divide the Susquehanna drainage equally. The PMP of this report, up to 1000 square miles, falls within the range of the PMP of these four regions, with the exception of that for 1000 square miles at 12 and 24 hours. Some slight departures (mostly negative) were permitted to allow for smooth depth-area curves for the larger areas.

Smoothness in the depth-duration relation given by the DDA curves was maintained by plotting PMP vs. duration for standard size areas and drawing a smooth envelope. This step led to slight over-envelopment for some durations.

The general level of PMP in this report is consistent with that of recent estimates for the Potomac and Delaware River drainage basins.

Geographical variation of PMP

The enveloping PMP curves (figure 2) are for the center of the Susquehanna drainage above Harrisburg, Pa. It might be suspected that there is a variation in PMP within this drainage area of over 24,000 square miles due to such large-scale effects as proximity to the coast, distance from southerly latitudes or moisture availability which should be considered in the PMP for sub-basins in the Susquehanna. Such variations over the eastern and central states have been incorporated in generalized estimates of PMP given in HMR No. 33 (2) by smooth patterns over the U. S. east of the 105th meridian. Figure 1 of this report shows the index lines of geographical variation of PMP in the Susquehanna Basin. The values of these lines were derived by using figure 1 of HMR No. 33 (2) and relabelling them in percentages of the value at the center of the Susquehanna drainage above Harrisburg. PMP values (figure 2) at the center of the total drainage are multiplied by the percent at the geographical center of each sub-basin to obtain the geographically adjusted PMP.

The geographical variation (figure 1), applies to all basin sizes. Within each zone of the generalized PMP charts of HMR No. 33 (2) it was found adequate to show no geographic variation in PMP with size of basin up to 1000 square miles or with storm duration up to 48 hours. In other words, the depth-duration-area relationship within a zone does not vary. In a region smaller than these zones, the Susquehanna Basin, it has been assumed that a constant depth-duration-area relation can be used.

IV. METEOROLOGY OF MAJOR STORMS

Introduction

This section outlines the general features of the storms considered in developing the PMP and discusses in more detail a few of the more important storms.

The major storms that either directly affected the Susquehanna above Harrisburg, or that affected areas from which transposition into the basin was made are of two types: the middle-latitude type of cyclone and storms of tropical origin.

General characteristics of extra-tropical storms on Susquehanna drainage basin

Major storms, exclusive of hurricanes, in or near the Susquehanna drainage have the following general characteristics:

(a) some mechanism, usually associated with a stronger than normal, almost stationary Bermuda High off the Atlantic Coast, which provides a copious supply of warm, moist air over the region, and

(b) a quasi-stationary surface trough just east of the Appalachians with low pressure disturbances of varying intensity moving up from the south. These low pressure systems help provide the convergence mechanism necessary for abundant rain.

Three outstanding flood-producing storms have been selected for detailed discussion.

Storm of May 30-June 1, 1889 (SA 1-1). One of the greatest floods on the Susquehanna resulted from the storm of May 30-June 1, 1889. This storm, which produced a historic flood at Johnstown, Pa., deposited heavy rains along a broad area mostly east of the Appalachians from Pennsylvania southward through North Carolina. The heaviest amounts, 8 to 9.8 inches in 24 hours fell in the Susquehanna Basin, with slightly lesser amounts in the Potomac and Rappahannock Basins. Four inches or less fell in North Carolina. When rain depths in this storm are adjusted for maximum moisture, they exceed all transposed storms for a substantial number of durations and areas (see table 3).

Since the meteorological features involved in this storm are typical of the more intense non-tropical storms in this area, the weather maps leading to and during this storm have been analyzed and are shown in figures 3a through 3d.

The main characteristics of the synoptic picture are: (1) the anomalously slow eastward progression of the systems (Lows, Highs and fronts) from the 30th on; (2) the persistent south and southeasterly flow of relatively warm and moist air onto the eastern seaboard; and (3), the succession of waves moving up along the slow-moving cold front as it approached the eastern seaboard.

These features, plus the persistence of high pressure over and just offshore from the New England States, are typical of stronger than normal south-north components of the windflow aloft. Although upper-air observations are lacking, it is more than likely that there was predominantly southwesterly flow aloft over the area of interest with the attendant developing Low over the Southern States. This last feature is evidenced by the trough preceding the cold front in the extreme south.

Of particular interest is that the cyclonic curvature of the warm, moist air flowing in from the Atlantic was periodically forced into a greater cyclonic flow by the waves moving up the cold front. This appears to be the case, for example, on May 31, a.m., figure 3c. The small Low over the Carolinas moving generally northward helped to trigger the heavy bursts of rain on that evening and early the following morning. The shaded regions in figure 3d are those in the area covered by the 4-inch isohyet.

The notable thing about such a situation is the nearly north-south orientation of the frontal system with waves together with its below-normal eastward movement.

To summarize, the heavy rains of May 30, 1889, through the morning of June 1st, were the result of: (1) converging of inflow of warm moist air from the Atlantic just ahead of a slow-moving cold front with parent Low just north of area; (2) further strengthening of the convergence process by waves moving up the cold front; and (3) lifting of the warm air up the cold frontal surface.

<u>Storm of March 6-21, 1936 (SA 1-27)</u>. This storm gave record flows for many localities in Pennsylvania. High antecedent rainfall which saturated the soil and snowmelt were both factors in this flood. Maximum depths of rain over standard size areas were considerably less than those resulting from the 1889 storm.

The synoptic situation (charts not shown) for this storm shows features similar to that of 1889; a center of blocking high pressure in the nearby North Atlantic and a quasi-stationary trough near the Atlantic Coast. The major rains on the 16th and 17th were associated with an occluded wave over the Northeastern States which had its origin in an open wave over the lower Mississippi Valley.

This wave had moved to the southern Appalachians by the 17th. In the meantime a high pressure center off Nova Scotia intensified. This blocking action resulted in a strong pressure gradient which brought in large volumes of low-level moist air from the Atlantic.

Heaviest rain, 7.9 inches, was measured at Romney, W. Va. Greater-than-5-inch amounts were measured in many localities in central and northeastern Pennsylvania.

The principal difference between this storm and that of 1889 appears to be that in the 1936 storm the frontal system east of the Appalachians moved more slowly, thus providing more opportunities for waves and a longer period of inflow of warm, moist air.

In summary, the heavy rains of March 6-21, 1936, were the result of a combination of events very similar to those of the storm of 1889. The principal difference appears to be one of timing. Whereas the 1889 storm deposited most of its rain within less than 3 days, the principal rains in the 1936 storm were spread out over a period of almost 6 days.

Storm of July 6-10, 1935 (NA 1-27). The July 6-10, 1935 storm brought record flows to many points in the northern portion of the Susquehanna drainage. Over 14 inches of rain were measured in about 48 hours at Hector, N. Y. An east-west oriented front extending from Minnesota to Newfoundland developed a wave which was occluding rapidly over the Great Lakes by the morning of the 7th. Concurrently a pressure trough extending to Florida was becoming well developed. In this trough a Low moved north-northeastward joining with one from the Great Lakes over New Jersey on the 9th. Winds were strong from the south and southeast offshore, transporting a rich supply of warm, moist air inland.

Major rainfall associated with tropical storms along the East Coast States

Hurricanes are a major rain threat to the Susquehanna Basin insofar as the probable maximum precipitation is concerned. Although no really severe hurricane rains have been observed in the basin in the last 75 years the risk is evident from storms near the basin.

To help evaluate this threat, the locations of intense rain associated with tropical storms along the eastern seaboard were examined. Figure 4 shows maximum point rainfall and the envelope of areas covered by 10 and 20 inches of rainfall associated with tropical storms. Envelopes of 5 inches in Pennsylvania have also been included. These areas were determined from "Rainfall Associated with Hurricanes" (3), which discusses the rainfall and shows isohyets in all storms of tropical origin which affected the coastal United States from 1900 through 1955, inclusive, and from "Storm Rainfall in the U. S." (1), which covers in addition the period back to 1867. The "Monthly Weather Review" series (4) and Weather Bureau Technical Paper No. 36 (5) were also referred to for corroboration of tracks of tropical storms.

Studying figure 4 one notes that the areas of heavy rainfall are rather randomly scattered. There are large areas where more than 10 inches of rain have never been recorded from tropical storm activity. Yet these areas are surrounded by others that have experienced not only 10 inches but point values as high as 24 inches in western North Carolina, 19 inches in northern Virginia, 14 inches in extreme northwestern Ohio, and 20 inches in southwestern Massachusetts.

There appears to be no sound meteorological reason why central Georgia, within the period surveyed, has not experienced heavy rain from a tropical storm. Similarly, in view of the fact that heavy occurrences have taken place to the northeast, east, south and west, there appears to be no meteorological or topographic control which would negate heavy rain from tropical storms in central Pennsylvania.

Tropical storm rain in vicinity of basin. Since 1894, 20 storms of tropical origin have caused precipitation (1 inch or more) in the Susquehanna Basin north of Harrisburg. This is an average roughly of one every three years. Storm paths and positions of centers at 7 a.m. EST are shown in figures 5 and 6. A list of the storm dates (and assignment numbers when available) as well as location of main precipitation center are shown in table 4.

Although most of the storms were of hurricane intensity at some time during their lifespan, all except four were either dissipating, or developed extra-tropical characteristics before the important portion of the precipitation in the basin had set in. Most of these storms moved from the south or southwest quadrants north of 35°N latitude, after typical recurvature from their initial westward or northward motion. The only notable and comparatively rare exceptions are storms shown by tracks numbered 2, 18, and 19, which turned again toward the northwest after recurvature.

Figure 7 together with table 5 show three more tropical storms that caused heavy precipitation in the vicinity of the basin but not in the basin itself. These three storms, plus three more in figures 5 and 6 (Assignment No. underlined in table 4) make up six of the seven control storms that went into the development of the PMP for the Susquehanna.

The storm of Ewan, N. J., September 1, 1940 is a mixed type. The heavy burst of rain appeared to be closely associated with a cold front that moved into New Jersey at the time a tropical storm was moving north-northeastward offshore. However, the involvement of a cold front is not unusual, as, for example, in the New England hurricane of 1938 which gave Buck, Conn. a total rain of nearly 16 inches. The tropical storm is undoubtedly the prime factor in bringing 24 inches of rain at Ewan.

Although most often a hurricane deposits its major burst of rainfall to the right of its track, some give very large amounts to the left. Some of these latter cases are: September 8-21, 1933 (14 inches at York, Pa. and 12.3 inches at Provincetown, Mass.); September 18-30, 1894 (9.3 inches at Corners, Pa.); October 5-10, 1903 (15 inches at Patterson, N. J.); and September 12-15, 1944 (12 inches at New Brunswick, N. J.).

Other tropical storms of the last century help support the belief that tropical storms pose a real threat to the Susquehanna Basin. The storms of September 16-18, 1876, September 9-13, 1878, and August 17-21, 1888 caused heavy rains to the west of the Susquehanna, beyond the main ridges in western Pennsylvania. That of September 1878 gave the greatest discharge of record on the Kanawha River, which drains an area farther inland than the Susquehanna.

In addition to the storms discussed above, there have been at least 35 more storms of tropical origin since about 1880 that have passed within 200 miles of the edge of the basin (mostly to the east) without producing any significant precipitation within the basin.

It must be assumed, therefore, that storms of tropical origin constitute a real threat to the basin and their consideration is necessary in the development of the PMP. Accordingly, suitable major hurricane rainfall was transposed to the basin as described in section III.

V. TOPOGRAPHICAL VARIATION OF PRECIPITATION WITHIN BASIN

The discussion in section III pointed out that in transposing major storms it was not necessary to adjust for difference in elevation of the storm site and the elevation of the Susquehanna Basin. However, one might ask whether there is any measurable precipitation redistribution due to the topography within the basin.

Relations between precipitation and elevation

To determine if there is a redistribution of rainfall with topography, comparisons were made between elevation and rainfall. This terrain feature in a general sense, is an index to degree of slope which increases with elevation. Another reason for this choice is that elevation is readily available and does not require detailed analysis of terrain beyond the scope of this study.

Several different approaches were made in attempting to find a relation between precipitation and elevation. No significant correlations resulted from the following tests:

(a) Maximum 24-hr. station precipitation in an 11-yr. period was catalogued for some 50 stations in the drainage area, for the months of June through October from Weather Bureau Technical Paper No. 15 (6). These maximum values were then plotted against station elevation both by individual month and then by highest value in the June-October season. No consistent relation with elevation was apparent.

(b) Using the data from (a) above, the 11-yr. 24-hr. maxima were grouped for cases where these maxima occurred on the same date at several stations. Thus these stations experienced their 24-hr. maximum precipitation in the same storm. As many as 18 stations recorded this maximum in the same storm. Again, plotting rain amounts vs. elevation separately by storms, gave inconclusive results.

(c) Using the data from a large storm, that of hurricane Connie, (Aug. 11-15, 1955) a 24-hr. time interval was chosen wherein most stations in the drainage area experienced one inch or more of rain. Again the associated diagram of rain vs. station elevation indicated no significant correlation.

Relations involving distance from coast

Maximum 24-hr. station precipitation on the Susquehanna Basin, station elevation and shortest distance of each station from the generalized coastline were plotted on scatter diagrams in various combinations. These plots and those of residual variation against elevation ("distance-from-coast" factor removed) showed no significant trends.

Comparisons of isohyetal maps with topography

Isohyetal maps of the 10 largest rainstorms over the basin were examined by overlaying them on a topographic chart. No well-defined or consistent topographic variation could be found. Centers of maximum rainfall were scattered over valleys as well as ridges, although there appeared to be some trend for a maximum along the southeast drainage divide, which is a comparatively slight ridge.

Precipitation deviation vs. elevation differences

The most common feature observed on an isohyet chart is, naturally, a diminishing of rainfall with distance from the maximum value or rainfall center. Since variation of precipitation with distance from precipitation center is large it is possible that within a storm this feature overshadows the variation with altitude.

To test this, the rainfall of two storms was analyzed. These were the storms of August 13, 1955 (Connie) and August 20-24, 1933 both of which affected a large portion of the Susquehanna drainage basin. In each case a 24-hr. period was selected in which most of the stations in the basin had major precipitation. These data were plotted on a map and several primary centers of precipitation singled out. Figures 8 and 9 show these isohyetal maps. The primary centers of rain are labeled A, B, C, D, and E. A simple graph of precipitation vs. elevation of station yielded no useful information.

The next step was to measure the distance from every station to the nearest rain center; this was plotted against precipitation amount. An eye-fitted curve (figure 10) is presented for the 1955 case. The deviation of precipitation from this curve for each station was then plotted against difference in elevation between the station and elevation of the nearest rainfall center. Results are shown in figure 11 for the August 1955 storm. The least squares regression line shows an increase of near .51 inch per 1000 feet increase in elevation. Treating the data in the storm of August 20-24, 1933 in similar fashion yields a result of .43 inch per 1000 feet increase in elevation.

It is suggested that an average increase of 0.5 inch per 1000 feet in 24 hours be applied as an adjustment to the rain distribution in the probable maximum storm for any sub-basin in the Susquehanna drainage. Details regarding how this adjustment is used to change proposed storm isohyetal patterns are given in section VI.

Because this relationship was developed with storms in the Susquehanna drainage there is no assurance that it holds at other places. It is recommended that it be used only to adjust precipitation amounts within a particular storm in the basin, and is not intended as an adjustment factor among storms or when transposing storms.

VI. TIME AND AREAL DISTRIBUTIONS OF PMP WITHIN BASIN

Introduction

Enveloping DDA curves of PMP, like figure 2, for the region of a basin constitute only a portion of the precipitation criteria necessary for determining a flood hydrograph. Two other aspects of the problem related to storm characteristics are a concern of the hydrometeorologist. The first is appropriate time distribution of the probable maximum rain and the second is its areal distribution over a basin. Decisions on these items could involve hydrologic characteristics of a basin and the objective of a design hydrograph. The hydrometeorological analysis should provide storm distribution criteria sufficiently general to satisfy a variety of hydrologic requirements, and should be meteorologically sound and consistent with the PMP. One additional consideration is that the recommended criteria are not unduly complicated and do not involve time-consuming refinements unwarranted by the available basic data.

Time Distribution

After the PMP for the total duration of the probable maximum storm has been determined, one is yet confronted with the problem of how to distribute this volume of rain in time. The problem can be separated into two component parts. First, how much of this total rain should be concentrated in the maximum (1st) 6-hr. increment, the next highest (2nd) 6-hr. increment, 3rd, 4th, etc., (time concentration); and secondly, what should be the sequence of these increments, ranked by magnitude from 1 to 12, during the probable maximum storm (sequence of increments)?

Time concentration

It is recommended that the volume of PMP for the total basin area be distributed proportional to the 6-hr. incremental values from the PMP depth-duration curve for the area of the basin. Thus the maximum (1st) 6-hr. increment is the 6-hr. PMP at the area of the basin, the next highest (2nd) 6-hr. increment is the difference between 12-hr. and 6-hr. PMP, etc. Some considerations in this recommendation are first, that the procedure is easy to apply. For example, PMP values such as those on table 1, need only be subtracted successively from the next highest value in order to obtain basin average PMP increments. Second, the procedure is conservative in that it combines PMP for all durations in one storm event. That this is not unduly conservative, however, is shown by the Wellsboro, Pa. storm which controls for several durations at some areas (see table 3).

Sequence of increments

In the foregoing, the recommended magnitudes of 6-hr. incremental rains during the probable maximum storm were set forth. How these 6-hr. increments (from maximum, or 1st, to lowest, or 12th), should be arranged in sequence during the 3-day storm is now discussed.

One consideration is rain sequences as observed in major storms. These are quite varied, with little consistency from storm to storm with two exceptions. It is more usual to find the highest two or three 6-hr. increments occurring adjacent to each other and, there is a tendency for several bursts in a 3-day period.

The PMP values themselves are another consideration. Should the 6-hr. increments of PMP be randomly scattered there would be little assurance that PMP magnitude would be maintained. That is, to maintain PMP for a 12-hr. duration, the two highest increments must be adjacent, for 18-hr. PMP the three highest must be adjacent, and so forth.

Time sequences which show characteristic storm behavior and which conform to the sequential requirement described in the preceding paragraphs within practical limits, though not strictly adhering to it 6-hr. period by 6-hr. period, are obtained by applying the following rules:

(a) 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.

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

(c) Arrange the three 24-hr. periods in accordance with the sequential requirement, that is, the second highest 24-hr. period next to the highest with 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

The areal distribution of rain in the probable maximum storm needs to be specified in order to compute the flood hydrograph. One aspect of areal distribution is the shape, orientation and placement of isohyets in a basin. These items are determined by selection and placement of an isohyetal pattern. The other feature of areal distribution is the concentration of rain in a basin. This latter deals with how sharply the PMP for the area of a basin is peaked. Values of isohyets in a pattern storm determine this peakedness or concentration.

Pattern storms

Ideally, the isohyetal pattern of an actual major storm over a basin would determine the shape, orientation and placement for the probable maximum storm. The few extreme storms of record in the Susquehanna Basin hardly permit this without some modifications. Study of the major rains of record over the Susquehanna drainage above Harrisburg does not reveal a consistent preference for placement or shape of rain centers, therefore a generalized elliptical-shaped isohyetal pattern is suggested for any sub-basin. This pattern, shown on figure 12, may be centered over a basin to produce a critical flood hydrograph. It may be oriented so as to give best fit to a basin outline.

A separate pattern storm has also been determined for each of the eight assigned sub-basins. These are shown in figures 13a to h. Each has one or more actual isohyetal patterns as prototypes which were selected from storms over the Susquehanna drainage that are contained in Storm Rainfall (1). An exception to this is a pattern determined for the entire drainage above Harrisburg. A short description of the patterns suggested for each of the eight assigned areas giving the prototypes and changes made are as follows:

Susquehanna River at Conklin, N. Y. Prototype is June 29-July 5, 1915 (GL 4-11, center B of Storm Part II isohyetal map.) Transposition about 30 miles to east, 30° counterclockwise rotation, and minor smoothing of isohyets results in pattern given in figure 13a. The dashed lines on this and other patterns are the topographic modifications discussed subsequently.

Susquehanna River near Waverly, N. Y. Prototype same as above. Minor changes in shape of isohyets, in place of occurrence, for better fit to basin. Pattern given in figure 13b.

Chemung River at Chemung, N. Y. Prototypes are September 8-13, 1890 (GL 4-1), June 29-July 5, 1915 (GL 4-11), and May 30-June 1, 1889 (SA 1-1) storm isohyets. The September 1890 storm has a 9-inch center about 15 miles to the northwest of the center of the basin, with the isohyets elongated in the W-E direction. The May-June 1889 storm was approximately 30 miles to the south with N-S elongation. Over 5 inches occurred in the June-July 1915 storm near the center of the basin with isohyets oriented almost E-W. These storms demonstrate that large centers have occurred near the basin, justifying the idealized better fitting pattern given for the basin in figure 13c.

Susquehanna River at Wilkes-Barre, Pa. Prototype is June 29-July 5, 1915 (GL 4-11, centers A and B of Storm Part II isohyetal map.) Center A was shifted to the northwest about 10 miles and rotated approximately 50° clockwise. The western end of center B was rotated approximately 30° counterclockwise. Other changes were smoothing and changing shape of isohyets to better fit the basin. Figure 13d shows resulting pattern.

Susquehanna River at Danville, Pa. Same prototype as above. Essentially the same changes as for the previous basin. Reshaping of isohyets for southern end of drainage is major difference. Figure 13e shows resulting pattern.

West Branch Susquehanna at Lewisburg, Pa. Prototypes are the May 17-22, 1894 (NA 1-4) and July 22-23, 1927 (NA 1-16A) storm. The

May 17-22, 1894 storm 8-inch center E is about 15 miles to the north of the center of the basin, but it does not have east-west orientation of isohyets to fit the basin. There exist other storms with centers which have orientation and shape, similar to the basin, such as the 8-inch center of the July 22-23, 1927 storm, although farther removed. It is believed that this sufficient evidence for the idealized pattern, for the probable maximum storm, given in figure 13f.

Juniata River at Newport, Pa. The 8-inch center of the July 22-23, 1927 storm (NA 1-16A) is used as the prototype considering that such a storm could occur approximately 50 miles to the west with the same isohyetal orientation. Isohyets were reshaped to better fit the basin. See figure 13g.

Susquehanna River at Harrisburg, Pa. Since there has been no storm which adequately covers this large basin that could be increased to PMP magnitude, an idealized pattern was developed. This pattern has 4 centers which were determined from a map showing locations of storm centers from Part II data. It thus favors locations of centers of heavy rains. Figure 13h shows the pattern.

Rain concentration

Concentration of rain within a basin can be defined by depth-area relations. For the Susquehanna drainage it is recommended that the depth-area relation be patterned after observed major storms over or near the basin. This means that something less steep than the PMP depth-area relation of figure 2 be used for obtaining the PMP within sub-basin boundaries. This may be termed within-basin PMP distribution.

Within-basin depth-area curves were derived for selected durations and sizes of areas. An interpolation method is then given to obtain within-basin depth-area values for basins of any other sizes and for any other increment of PMP. The interpolation method goes directly from basin-average PMP values to the values of isohyets which will be consistent with within-basin depth-area curves.

Basic within-basin depth-area curves. Recommended within-basin depth-area curves for a 24,000-sq. mi. and a 1000-sq. mi. basin, both for 6-hr. and 72-hr. PMP were derived from major storms which were either controlling or near controlling at the stated area sizes and durations of PMP. These are shown by dashed lines in figure 14. They encompass the basin sizes being studied.

The 72-hr., 24,000-sq. mi. within-basin curve is a slight adaptation of the depth-area relation of the Buck, Conn. storm (NA 2-2) of September 19-21, 1938. The 72-hr., 1000-sq. mi. curve is patterned after the Big Meadows, Va. storm (SA 1-28A) October 11-18, 1942. The 6-hr., 24,000-sq. mi. curve is based on the New Brunswick, N. J. storm (NA 2-16) of September 12-15, 1944. For 6-hr., 1000-sq. mi. the curve is derived from the Wellsboro, Pa. storm (SA 1-1) of May 30-June 1, 1889.

Isohyet-area curves based on within-basin depth-area curves. The within-basin depth-area curves are to define rain concentration within a basin. In order to do this the within-basin depth-area curves were converted into isohyet-area curves. An isohyet-area curve is a profile, from the center of a storm outward, in which the value of each isohyet is plotted against the total area enclosed by the isohyet. This quite directly gives isohyetal values within a basin. It may also be called a rain profile. The computation of isohyet-area curves from conventional depth-area curves is the exact inverse of developing DDA curves from an isohyetal chart. A set of isohyet-area curves for 24,000 square miles is shown in figure 15. The 72-hr. and 6-hr. curves (A and B) are converted from the corresponding within-basin depth-area curves of figure 14 (dashed lines). The other curves are for the intervening time increments listed. Their construction by interpolation is explained in subsequent paragraphs.

Isohyet-area curves expressed as ratios. The purpose of the isohyet-area curve is to distribute within-basin PMP. Therefore a fundamental property of each isohyetal curve, like those of figure 15, is that the precipitation averaged along the curve must equal the basin average PMP. To average properly equal increments of area are given equal weights, from the formula:

$$\overline{P} = \frac{1}{(A_2 - A_1)} \int_{A_1}^{A_2} P dA$$

where P is precipitation and A is area. Visual averaging on the graphs is not easy because of the compression of the area scale. Thus the average ordinate of curve B is 3.4 inches, the 24,000-sq. mi. 6-hr. PMP from figure 2. That of curve A must be 12.7 inches.

The foregoing property of isohyet-area curves is most readily maintained by expressing them as ratios to the basin-average PMP rather than in inches. The ratio will be greater than 1.0 at the isohyetal center and will decrease to less than 1.0 at the periphery. The average ordinate on this kind of isohyet-area curve must be 1.0 ("average" defined as in preceding paragraph).

Thus, final working nomograms (figures 16a-d), the complete explanation of which follows, are isohyet-area curves expressed as ratios. The 24,000-sq. mi. curve of figure 16a for the 72-hr. storm duration and of figure 16b for 6 hours are converted from curves A and B, respectively, of figure 15 by dividing the ordinates of the latter by 12.7 and 3.4 inches.

Basin-size interpolation of isohyet-area diagrams. The four within-basin depth-areal curves (dashed) of figure 14 for two durations and two basin sizes were converted to isohyet-area curves expressed as ratios. These are the bounding 1000- and 24,000-sq. mi. curves of figure 16a (for total storm duration of 72 hrs.) and figure 16b (for 6 hrs.). The lines for other sizes of basins are interpolated.

Duration interpolation of isohyet-area diagrams. The duration interpolation of the isohyet-area curves was somewhat more complex than for area. A transition was desired from the peaked 6-hr. curve (for example curve B, figure 15) to the flatter curves of other duration increments. The first objective was a characteristic isohyet-area curve for 24,000 sq. mi. for the 2nd 6-hr. storm increment. The following procedure was adopted.

Subtracting curve B of figure 15 from curve A yields an isohyet-area curve, (not shown) in inches, for the 66 hours of the storm excluding the maximum 6 hours. This is converted to a ratio curve for 66 hours. The 24,000-sq. mi. isohyet-area ratio curve for the 2nd 6-hr. storm increment is now laid out by eye, intermediate between the 66-hr curve and the ratio curve for the maximum 6 hours, but closer to the former. This new ratio curve is the upper bound of the nomogram of figure 16c for the 2nd 6-hr. storm increment. Converted back to inches, the 2nd 6-hr. isohyet-area curve is shown as C in figure 15.

Next, curves C and B, figure 15, are subtracted from curve A to obtain the isohyet-area curve for 60 hours (not shown). This curve, converted to ratios, becomes the upper bound for nomogram 16d. These ratios apply to all time increments through 60 hours, that is, from the 3rd 6-hr. increment to the 12th, in descending order of magnitude.

Multiplying the ratios thus obtained by the appropriate 24,000-sq. mi. basin-average increments of PMP from table 1 yields curves D through G of figure 15, completing the set.

Similar procedure at 1000 square miles and areal interpolation completes nomograms 16c and 16d.

The full set of ratio nomograms were checked for smoothing and spacing by converting into isohyet-area profiles in inches and to within-basin depth-area curves (as in figure 14).

Note that the curves in figures 16a through 16d are solid lines from 10-sq. mi. areas up to the isohyet area value that corresponds to the area of the basin. (The curves are drawn for basin areas ranging from 1000 to 24,000 square miles.) This is the upper limit of the computations possible using the within-basin curves of figure 14. But, normally, a pattern-storm designed to fit a particular sub-basin will have at least one isohyet that encloses an area larger than the sub-basin (usually only the last outer one).

To provide values for these larger-area isohyets the ratio lines were extended to the left (and upward to higher areas), and are shown as dashed curved lines. For these extensions it was assumed that the four basic within-basin curves of figure 14 follow the PMP curves if extended upward a short distance. This insures that the last isohyet in a pattern storm does not enclose a rain volume that exceeds that specified by the PMP curve for that particular area and duration.

Using isohyet-area ratio nomograms in combination with pattern storms. Figures 16a through d provide the full set of within-basin isohyet-area relations recommended for the Susquehanna Basin.

Each of the four nomograms is entered with the area of each isohyet of the pattern storm, horizontally from the left-hand scale. Ratios are then read off at the sloping line corresponding to the basin size, interpolating as necessary. Time increments of PMP (geographically adjusted) for the area equal to the basin are then multiplied by the ratios to obtain the isohyetal labels for each time increment. Details of this procedure are contained in section VII.

Isohyetal labels for eight sub-basins. The procedure of the preceding paragraph has been carried through for eight sub-basins. The isohyetal labels at the heads of the columns in tables 6a-6h refer to the uppercase letters on figures 13a-13h. The lowercase letters (a-h) identify individual sub-basins (figure 1).

Instead of listing separate labels for the 5th, 6th, 7th, and 8th 6-hr. periods in these tables, a single set of labels is given, total for the sum of these four increments, or "2nd" day. The resulting 24-hr. values, after being evaluated for sub-areas of interest within the basin, are then divided into four 6-hr. increments (if required) by the percentages at the bottom of the tables. Similar treatment is given the four 6-hr. increments of least magnitude, or "3rd" day.

Adjustment of isohyets in pattern storms for elevation differences within basin

A study of variation of precipitation with elevation over the Susquehanna River drainage was discussed in section V. It recommends that the volume of rain in a probable maximum storm for any basin be distributed to show a variation of 0.5 inch per 1000-ft. elevation difference. Such distribution was found to be most conveniently done by modifying pattern storm isohyets.

Application of elevation adjustment. The increase of 0.5 inch per 1000-ft. elevation difference, based on observed intense 24-hr. rains, is considered applicable to the maximum 24-hr. increment of PMP. It will be seen that for pattern storms centered over a basin modifications are necessary only for isohyets at fringes of the pattern. Here probable maximum storm values are about of the magnitude of 24-hr. amounts used in developing the elevation adjustment. For other durations of PMP the adjustment is proportional to the ratio of PMP for that duration to the PMP for 24 hours. Since the 1st (maximum) 6-hr. PMP increment will usually be considered, and not necessarily that for 24 hours, a method follows for determining the adjustment for 1st 6-hr. PMP increment.

Elevation adjustment for 1st (maximum) 6-hr. PMP increment. The elevation adjustment for the 1st 6-hr. PMP increment is proportional to the ratio of 1st 6-hr. PMP to 24-hr. PMP. This ratio varies with the size of the basin, and may be expressed by the formula

$$C_6 = 0.5 \left(\frac{P_6}{P_{24}} \right)$$

where C_6 = increase in precipitation with elevation, in inches per 1000 ft., for 1st 6-hr. PMP

P_6 = 1st 6-hr. PMP increment, read from PMP DDA curve at basin area

P_{24} = 24-hr. PMP increment, read from PMP DDA curve at basin area

Figure 17 is a graph of C_6 computed from the PMP DDA curves (figure 2). As an example, the elevation adjustment to modify a pattern storm for the 1st 6-hr. PMP increment centered over a basin of 10,000 square miles is 0.255 inch per 1000 ft.

<u>Modification of pattern storm isohyets for elevation differences</u>. In relatively broken terrain as in the Susquehanna it is suggested that the elevation adjustment be applied in a generalized fashion to pattern storm isohyets. After isohyetal values have been determined for the 1st 6-hr. PMP increment for the generalized pattern and the elevation adjustment factor selected from figure 17, center the generalized pattern over a topographic map (figure 1) of the basin. In this position it will be seen that almost all significant elevation differences along any particular isohyet are near the outer edge of the basin. Using the applicable elevation adjustment, sketch each isohyet outward (beyond the basin if necessary) to where the terrain is higher. The distance is estimated by interpolation between adjacent isohyets. For example, if the adjustment is 0.30 inch per 1000 ft., then over a portion of the basin that averages 1000 feet higher than over another portion and where two neighboring isohyets differ by 3 inches, the isohyets are sketched outward in such a manner that the higher-valued one is one-tenth of the way toward the original position of the next isohyet. Each isohyet that has been adjusted outward must then be sketched inward over lower elevations to keep the same area within each isohyet, and therefore retain the initial rain volume.

These isohyets sketched for the 1st 6-hr. PMP increment can then be used for any other PMP increment without significant loss of accuracy. The isohyet <u>labels</u> of course will differ for the other increments.

<u>Elevation adjusted isohyet patterns for eight sub-basins</u>. The procedure just outlined has been carried out for eight sub-basins. Sketched changes in the patterns are shown by dashed lines. An example of application of the elevation adjustment is contained in the summary of section VII.

VII. SUMMARY OF PROCEDURES FOR OBTAINING PROBABLE MAXIMUM STORM RAINFALL FOR A BASIN

Procedures and calculations for obtaining probable maximum storm rain for a basin are summarized and illustrated in this section. The general case is dealt with first--a basin of 1000 square miles or more in area. A stepwise procedure is given with an example of calculations. Then steps are given for handling eight assigned basins. This is followed by the procedure for obtaining probable maximum storm rain for a small basin (say less than 1000 square miles in area) where areal distribution may not be needed.

These summaries include all techniques that are presented. Hydrologic experience may indicate that certain portions, such as redistribution for elevation within a basin, may not be significant for a particular problem. Such portions could then be omitted.

An outline of the PMP procedure is presented in schematic form on the opposite page.

A. SUMMARY FOR A BASIN GREATER THAN 1000 SQUARE MILES IN AREA

1. Enveloping PMP

   a. Enter figure 2 with total area of basin to obtain PMP for 6, 12, 24, 48, and 72 hours.

   b. Determine geographic adjustment (in%) at center of basin from figure 1.

   c. Multiply values of (a) by adjustment from (b).

   d. Construct a smooth depth-duration curve from values of step (c). From this determine 6-hr. increments (or other desired increments, see step 5).

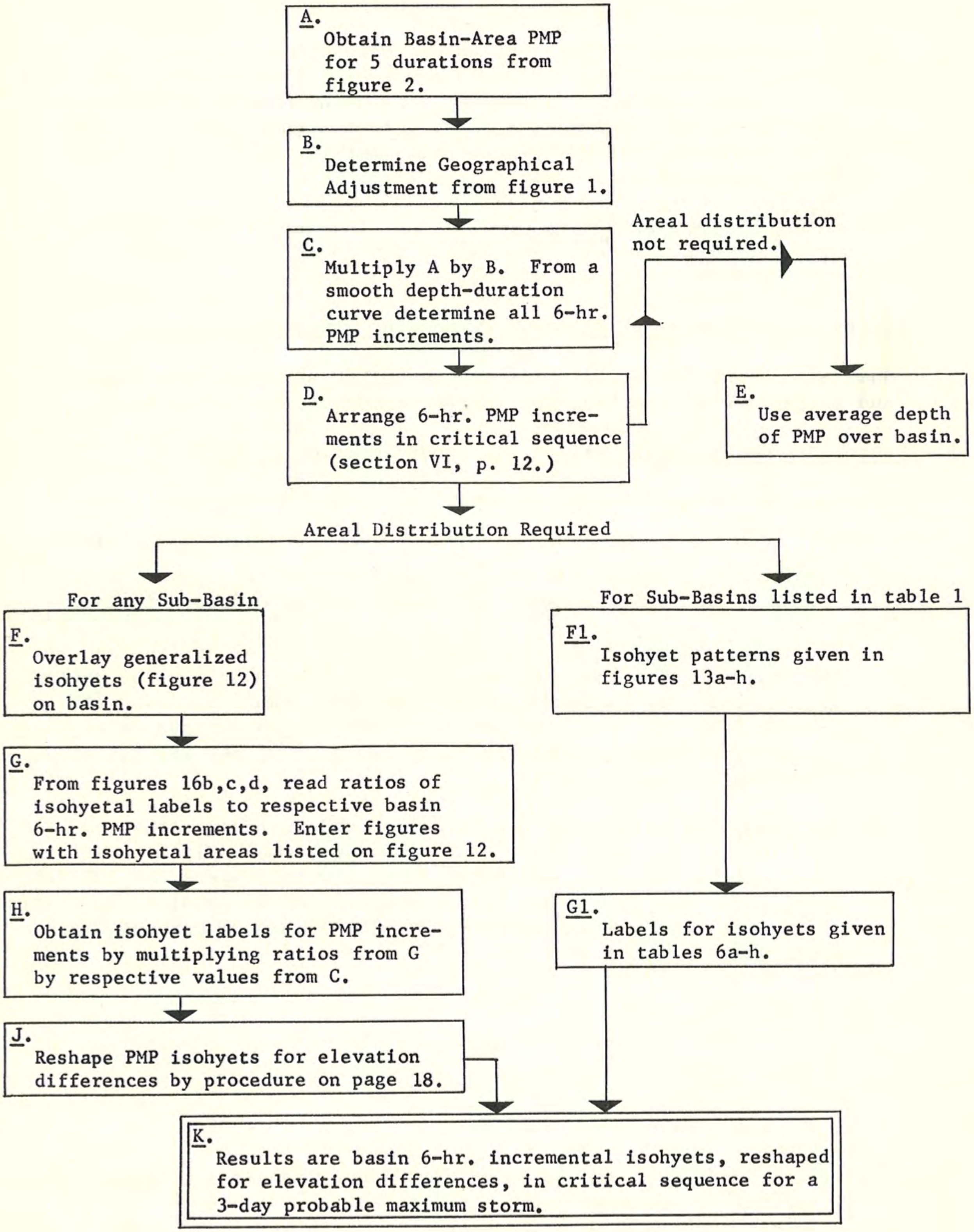
      Note: If isohyetal patterns (areal distribution) are not required, omit paragraphs 2 through 6.

2. Pattern storm isohyets and areas

   a. Overlay basin with generalized pattern storm isohyets, figure 12. Rotate for best fit of isohyets to basin outline.

   b. Note the areas of the isohyet that encloses the sub-basin and those that are within. The areas of the isohyets are listed on figure 12.

DIAGRAM OF PMP PROCEDURE



3. Pattern storm isohyetal values for 1st (maximum) 6-hr. increment of PMP

   a. Enter nomogram of figure 16b on ordinate scale with area of each isohyet from step 2-b. Proceed horizontally to sloping basin area line, interpolating if necessary. Read ratio on abscissa corresponding to this basin size. The largest isohyet will be larger than the basin. Also obtain a ratio for 10 square miles, the assumed maximum point value.

   b. Multiply these ratios by the maximum (1st) 6-hr. PMP increment obtained in 1-d. Results are values of isohyets for pattern storm for 1st 6-hr. increment of PMP.

4. Pattern storm isohyetal values for 2nd 6-hr. increment of PMP

   Same as 3-a and 3-b except that ratios to PMP are read from figure 16c and multiplied by 2nd 6-hr. increment of PMP obtained in 1-d.

5. Pattern storm isohyetal values for other increments of PMP

   a. Same as 3-a and 3-b, except that ratios to PMP are read from figure 16d.

   b. For isohyetal values for the 3rd and 4th 6-hr. increment, multiply ratios by 3rd and 4th 6-hr. increments of PMP obtained in 1-d.

   c. For isohyetal values for the "2nd" day PMP increment (the sum of the 5th, 6th, 7th, and 8th 6-hr. increments), multiply the ratios by the "2nd" day increment of PMP obtained from 1-d. Isohyets for the 5th, 6th, 7th, and 8th 6-hr. PMP increments can be obtained by multiplying the "2nd" day isohyets by 34, 28, 21, and 17 percent, respectively*.

   d. For isohyetal values for the "3rd" day PMP increment (the sum of 9th, 10th, 11th, and 12th 6-hr. increments), multiply the ratios by "3rd" day increment of PMP obtained in 1-d. Isohyets for the 9th, 10th, 11th, and 12th 6-hr. PMP increments can be obtained by multiplying the "3rd" day isohyets by 29, 26, 23 and 22 percent, respectively*.

---

*After deriving "2nd" day (5th-8th) and "3rd" day (9th-12th) isohyetal values and making elevation adjustments (see 6-a to c), the volume of rain for any particular 6-hr. increment in a sub-area of a basin may be obtained by multiplying by the appropriate percent.

6. Adjustment for elevation

   a. Obtain factor for elevation adjustment from figure 17, dependent on basin size.

   b. Overlay isohyetal pattern with isohyets labeled for 1st 6-hr. PMP increment on figure 1.

   c. Adjust isohyet shape for the generalized topography by the factor obtained in 6-a, as described at the end of section VI.

7. Sequence of 6-hr. increments during the probable maximum storm

   Arrange precipitation in accordance with rules a-c given in section VI.

EXAMPLE FOR A BASIN GREATER THAN 1000 SQUARE MILES IN AREA

Sub-basin: Susquehanna River drainage between Wilkes-Barre and Danville, Pa. (See figure 18.)

Area: 1200 square miles

(Lettered and numbered headings that follow correspond to those in preceding summary)

1. Enveloping PMP

   a. PMP for 6, 12, 24, 48, and 72 hours: 11.2, 13.6, 16.5, 19.5 and 20.7 inches (figure 2).

   b. Geographic adjustment: 100% (figure 1)

   c. Geographically adjusted PMP: Same as 1-a.

   d. Duration (hrs.)

Duration (hrs.)	6	12	18	24	30	36	42	48	54	60	66	72
PMP (inches)	11.2	13.6	15.1	16.5	17.6	18.4	19.0	19.5	19.9	20.2	20.5	20.7
6-hr. incremental PMP (inches)	11.2	2.4	1.5	1.4	1.1	0.8	0.6	0.5	0.4	0.3	0.3	0.2

2. Pattern storm isohyets and areas

(See figure 12)

Isohyet	Area (Sq. Mi.)
A	98
B	391
C	1002
D	2446

3. Pattern storm isohyet values for 1st (maximum) 6-hr. increment of PMP

   a. Read ratios for isohyetal areas from interpolated basin area lines of figure 16b.

   b. Multiply these ratios by basin average 1st 6-hr. PMP (see 1-d) to obtain isohyet values (4th column in following table).

Isohyet	Area (Sq. Mi.)	Ratio to Basin PMP (from fig. 16b)	Basin Average PMP (in.)	Isohyet Value (in.)
Maximum Value	10	1.43	11.2	16.0
A	98	1.22	11.2	13.7
B	391	1.05	11.2	11.8
C	1002	0.87	11.2	9.7
D	2446	0.49	11.2	5.5

4. Pattern storm isohyet values for 2nd 6-hr. increment of PMP

   Same as above except use figure 16c for ratios to PMP and multiply them by 2.4 inches (the 2nd 6-hr. basin average PMP from 1-d).

5. Pattern storm isohyet values for other increments of PMP

   The 3rd-12th 6-hr. increments are obtained as above using figure 16d. This example demonstrates the procedure for the 5th-8th ("2nd" day) 6-hr. increments.

Isohyet	Area (Sq. Mi.)	Ratio to Basin PMP (from fig. 16d)	Basin Average "2nd" Day PMP Increment (in.)	Isohyet Value for "2nd" Day PMP Increment (in.)
Maximum Value	10	1.27	3.0	3.8
A	98	1.15	3.0	3.5
B	391	1.01	3.0	3.0
C	1002	0.94	3.0	2.8
D	2446	0.78	3.0	2.3

After determining isohyetal values for "2nd" day PMP increment multiply by 34, 28, 21, and 17 percent respectively for 5th, 6th, 7th, and 8th 6-hr. PMP incremental isohyetal values.

6. Adjustment for elevation

No adjustment for elevation is recommended for this basin due to the balance of low and high elevations in close proximity. However, in this example, adjustments have been made to demonstrate the process.

a. Figure 17 shows a 0.34 inch increase in precipitation per 1000 feet difference in elevation. (Read at basin area.)

b. Overlay isohyets (figure 18) labeled with 1st 6-hr. increment on the generalized topography. Draw the increase and balance this with the same areal decrease. Results are the dashed lines shown on figure 18.

7. Sequence of 6-hr. increments during the probable maximum storm

Example:

Time from beginning of storm (hrs.)

6	12	18	24	30	36	42	48	54	60	66	72

Sequence of 6-hr. increments (1st=highest increment, 2nd=next highest increment, etc.)

7th	5th	6th	8th	3rd	2nd	1st	4th	12th	10th	9th	11th

6-hr. PMP increments (in.)

0.6	1.1	0.8	0.5	1.5	2.4	11.2	1.4	0.2	0.3	0.4	0.3

B. SUMMARY FOR EIGHT SUB-BASINS (See table 1)

1. Enveloping PMP

Determine 6-hr. incremental PMP (1st to 12th) by successive subtraction of values in table 1.

2. Pattern storms and isohyetal values

Tables 6a-h provide isohyetal values for pattern storms (figures 13a-h) for each basin for 72 hrs.; 1st, 2nd, 3rd, and 4th 6-hr. increments and "2nd" and "3rd" day PMP increments.

3. Adjustment for elevation

Basin rain volume has been distributed with elevation differences as described near end of section VI. Resulting isohyetal changes are indicated by dashed lines on figures 13a-h. The new isohyetal configurations apply equally to any increment of PMP.

4. Volume of rain in 5th-12th 6-hr. period for a sub-area of basin

If the rain for the 5th-12th 6-hr. period in a sub-area of a basin is desired by 6-hr. increments, it may be obtained by applying the percents listed in tables 6a-h to the "2nd" and "3rd" day volumes.

5. Sequence of 6-hr. increments during the probable maximum storm

Arrange in accordance with rules a-c given in section VI.

C. SUMMARY FOR SMALL BASINS LESS THAN 1000 SQUARE MILES IN AREA

Where areal distribution of rain in the probable maximum storm is not needed for a small basin the steps for determining the basin rain are:

1. From figure 2 obtain 6-, 12-, 24-, 48-, and 72-hr. PMP for the area of the basin.

2. Determine geographic adjustment at center of basin from figure 1.

3. Multiply values of step 1 by adjustment percent from step 2.

4. Construct a smooth depth-duration curve from values of step 3. From this determine 6-hr. increments of PMP.

5. Arrange 6-hr. increments in accordance with rules a-c given in section VI.

ACKNOWLEDGMENTS

The authors appreciate the many helpful suggestions and contributions of Vance A. Myers, Head of Hydrometeorological Branch. Their gratitude is also extended to Dwight E. Nunn, of the Office of Chief of Engineers, Corps of Engineers, for advice and consultation, and to Sydney Molansky for editorial assistance.

REFERENCES

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

2. 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, Washington, 1956.

3. U. S. Weather Bureau, "Rainfall Associated with Hurricanes," National Hurricane Research Project Report No. 3, Washington, 1956.

4. U. S. Weather Bureau, Monthly Weather Review, Washington, D. C.

5. U. S. Weather Bureau, "North Atlantic Tropical Cyclones," Technical Paper No. 36, Washington, 1959.

6. U. S. Weather Bureau, "Maximum Station Precipitation for 1, 2, 3, 6, 12, and 24 Hours," Technical Paper No. 15, Part VI: New England, 1953, and Part XVI: Pennsylvania, Washington, 1956.

Table 1

PMP VALUES, IN INCHES, FOR SUB-BASINS OF SUSQUEHANNA RIVER DRAINAGE

(Geographically adjusted)

Sub-Basin	Basin Ident.	Area (Sq.Mi.)	Geog. Adj.	Duration (hours) 6	12	18	24	30	36	42	48	54	60	66	72
Susquehanna R. at Conklin, N. Y.	a	2240	.90	8.2	10.3	11.8	13.0	14.0	14.8	15.4	16.0	16.4	16.7	17.0	17.2
Susquehanna R. at Waverly, N. Y	b	4780	.91	6.3	8.3	9.9	11.1	12.2	13.0	13.7	14.2	14.7	15.1	15.3	15.5
Chemung R. at Chemung, N. Y.	c	2530	.98	8.5	10.8	12.5	13.8	14.9	15.7	16.4	17.0	17.5	17.9	18.2	18.4
Susquehanna R. at Wilkes-Barre, Pa.	d	9960	.94	4.9	6.8	8.4	9.6	10.6	11.4	12.2	12.8	13.3	13.7	14.0	14.2
Susquehanna R. at Danville, Pa.	e	11,220	.95	4.7	6.6	8.2	9.4	10.4	11.2	11.9	12.5	13.1	13.5	13.7	14.0
West Branch, Susquehanna R. at Lewisburg, Pa.	f	6847	1.02	6.2	8.5	10.1	11.5	12.6	13.5	14.3	14.9	15.5	15.9	16.2	16.4
Juniata R. at Newport, Pa.	g	3354	1.04	8.3	10.6	12.3	13.8	15.0	15.9	16.6	17.3	17.8	18.3	18.6	18.8
Susquehanna R. at Harrisburg, Pa.	h	24,100	1.00	3.4	5.2	6.6	7.8	8.9	9.8	10.5	11.2	11.8	12.2	12.5	12.7

Table 2

MAJOR STORMS PROCESSED IN DEVELOPING PROBABLE MAXIMUM PRECIPITATION VALUES

Assignment Number	Date and Place
SA 1-1	May 30-June 1, 1889; Wellsboro, Pa.
SA 1-26	Sept. 3-6, 1935; Easton, Md.
SA 1-28a	Oct. 11-18, 1942; Big Meadows, Va.
SA 2-9	July 13-17, 1916; Altapass, N. C.
OR 9-23	July 17-18, 1942; Smethport, Pa.
GL 4-9	Oct. 7-11, 1903; Patterson, N. J.
NA 1-2	Oct. 1-5, 1869; Canton, Conn.
NA 1-7b	July 26-29, 1897; Jewell, Md.
NA 1-20	Sept. 16-17, 1932; Westerly, R. I.
NA 1-24a	Aug. 20-24, 1933; Peekamoose, N. Y.
NA 1-27	July 6-10, 1935; Hector, N. Y.
NA 2-2	Sept. 19-21, 1938; Buck, Conn.
NA 2-3	Aug. 19, 1939; Manahawkin, N. J.
NA 2-4	Sept. 1, 1940; Ewan, N. J.
NA 2-16	Sept. 12-14, 1944; New Brunswick, N. J.
NA 2-18	Dec. 29, 1948-Jan. 1, 1949; Berlin, N. Y.
NA 2-21a	Aug. 11-15, 1955; Slide Mtn., N. Y.
NA 2-21b	Aug. 10-15, 1955; New Bern, N. C.
NA 2-22a	Aug. 17-20, 1955; Westfield, Mass.

Table 3

STORMS CONTROLLING ENVELOPING PMP CURVES FOR STANDARD SIZE AREAS AND SELECTED DURATIONS

(Number in parenthesis is storm adjustment in percent)

Area (Sq.Mi.)	Duration (hrs.) 6	12	24	48	72
500	NA 2-4 (118)	NA 2-4 (118)	SA 2-9 (109)	SA 2-9 (109)	SA 2-9 (109) SA 1-28a (130)
1,000	SA 1-1 (160)	NA 2-3 (111)	SA 2-9 (109)	SA 2-9 (109)	SA 2-9 (109)
2,000	SA 1-1 (160)	SA 1-1 (160)	GL 4-9 (134)	SA 2-9 (109)	SA 1-28a (130)
5,000	SA 1-1 (160)	SA 2-9 (109)	GL 4-9 (134)	SA 2-9 (109)	NA 2-2 (138)
10,000	SA 1-1 (160)	SA 1-1 (160)	GL 4-9 (134)	SA 1-1 (160)	NA 2-2 (138)
20,000	SA 1-1 (160)	SA 1-1 (160)	GL 4-9 (134)	SA 1-1 (160)	NA 2-2 (138)
50,000	SA 1-1 (160)	SA 1-1 (160)	SA 1-1 (160)	SA 1-1 (160)	NA 2-2 (138)

Table 4

TROPICAL STORMS, SINCE 1894, GIVING SIGNIFICANT PRECIPITATION TO SUSQUEHANNA RIVER DRAINAGE ABOVE HARRISBURG, PA.

Date	Track No.	Name	Rain Center and Total Point Rain (in.)	Assignment No.
Sept. 18-30, 1894	1		Smith Corners, Pa. 9.3	SA 1-13
Sept. 22-Oct. 1, 1896	2		Bloomberg, W. Va. 7.2	SA 1-19
Oct. 5-10, 1903	3		Patterson, N. J. 15.0	GL 4-9
June 7-16, 1912	4		Johnstown, Pa. 5.0	OR 8-16B
Sept. 13-16, 1912	5		Spier Falls, N. Y. 3.5	
Aug. 5-25, 1915	6		Gordon, Pa. 4.9	SA 1-7
July 20-22, 1916	7		Reading, Pa. 5.3	
Sept.-Oct. 28-1, 1920	8		Mt. Pocono, Pa. 6.7	
Oct. 22-26, 1923	9		Setaupet, N. Y. 6.7	
Aug. 17-26, 1933	10		Peekamoose, N. Y. 15.6	NA 1-24A
Sept. 8-21, 1933	11		Provincetown, Mass. 12.3	NA 1-24B
			York, Pa. 14.0	
Sept. 10-22, 1938	12		Buck, Conn. 15.8	NA 2-2
Oct. 10-12, 1942	13		Big Meadows, Va. 18.9	SA 1-28A
Sept. 12-15, 1944	14		New Brunswick, N. J. 12.0	

Table 4 Cont'd

Date	Track No.	Name	Rain Center and Total Point Rain (in.)	Assignment No.
Sept. 13-18, 1945	15		Rockingham, N. C. 14.8	SA 5-27
Aug.-Sept. 25-2, 1952	16	Able	Chambersburg, Pa. 6.2	
Aug.-Sept. 25-1, 1954	17	Carol	Eagles Mere, Pa. 6.2	
Oct. 5-16, 1954	18	Hazel	Big Meadows, Va. 11.2	
Aug. 3-14, 1955	19	Connie	Slide Mtn., N. Y. 13.5	NA 2-21A
			New Bern, N. C. 12.7	NA 2-21B
Aug. 17-20, 1955	20	Diane	Westfield, Mass. 19.8	NA 2-22A
			Coaldale, Pa. 10.00	

Table 5

TROPICAL RAINSTORMS TRANSPOSED TO SUSQUEHANNA RIVER BASIN

Date	Track No.	Name	Rain Center and Total Point Rain (in.)	Assignment No.
July 13-17, 1916	21		Altapass, N. C. 23.7	SA 2-9
Aug. 19, 1939	22		Manahawkin, N. J. 17.8	NA 2-3
Sept. 1, 1940	23		Ewan, N. J. 24.0	NA 2-4

Table 6a

VALUES OF PATTERN STORM ISOHYETS (FIGURE 13a) FOR SUSQUEHANNA RIVER AT CONKLIN, N. Y.

Basin Size: 2240 Sq. Mi.

	Center	A	B	C	D	E
		Isohyet Values (inches)				
72 hours	24.8	21.0	17.4	14.6	10.3	
1st 6 hours	13.3	10.7	8.4	6.5	2.5	
2nd 6 hours	2.8	2.4	2.1	1.9	1.4	
3rd 6 hours	2.1	1.8	1.6	1.4	1.1	
4th 6 hours	1.6	1.4	1.2	1.1	0.8	
* 2nd day	3.9	3.4	2.9	2.6	2.1	
∇ 3rd day	1.6	1.5	1.2	1.1	0.8	
Total area of Isohyet (sq. mi.)	10	155	850	2252	5241	

*For successive 6-hr. values use 34, 28, 21, and 17% of 2nd day values

∇For successive 6-hr. values use 29, 26, 23, and 22% of 3rd day values

Table 6b

VALUES OF PATTERN STORM ISOHYETS (FIGURE 13b) FOR SUSQUEHANNA RIVER AT WAVERLY, N. Y.

Basin Size: 4780 Sq. Mi.

	Center	A	B	C	D	E
		Isohyet Values (inches)				
72 hours	24.1	21.2	17.5	13.0	9.8	
1st 6 hours	12.1	9.9	7.4	4.8	2.6	
2nd 6 hours	2.8	2.5	2.2	1.7	1.4	
3rd 6 hours	2.1	2.0	1.7	1.4	1.2	
4th 6 hours	1.8	1.6	1.4	1.2	0.9	
* 2nd day	4.2	4.0	3.4	2.7	2.3	
∇ 3rd day	1.8	1.7	1.4	1.2	1.0	
Total area of Isohyet (sq. mi.)	10	113	871	3779	9025	

*For successive 6-hr. values use 34, 28, 21, and 17% of 2nd day values

∇For successive 6-hr. values use 29, 26, 23, and 22% of 3rd day values

Table 6c

VALUES OF PATTERN STORM ISOHYETS (FIGURE 13c) FOR CHEMUNG RIVER AT CHEMUNG, N. Y.

Basin Size: 2530 Sq. Mi.

	Center	A	B	C	D	E
		Isohyet Values (inches)				
72 hours	26.8	23.7	20.2	15.7	12.5	
1st 6 hours	14.2	11.9	9.7	6.8	3.3	
2nd 6 hours	3.1	2.8	2.4	2.1	1.7	
3rd 6 hours	2.2	2.0	1.8	1.5	1.3	
4th 6 hours	1.8	1.6	1.4	1.2	1.0	
* 2nd day	4.3	4.0	3.5	2.9	2.4	
∇ 3rd day	1.8	1.7	1.5	1.2	1.1	
Total area of Isohyet (sq. mi.)	10	89	514	2076	5117	

*For successive 6-hr. values use 34, 28, 21, and 17% of 2nd day values

∇For successive 6-hr. values use 29, 26, 23, and 22% of 3rd day values

Table 6d

VALUES OF PATTERN STORM ISOHYETS (FIGURE 13d) FOR SUSQUEHANNA RIVER AT WILKES-BARRE, PA.

Basin Size: 9960 Sq. Mi.

	Center	A_1	A_2	B_1	B_2	C_1	C_2	D	E
		Isohyet Values (inches)							
72 hours	23.1	21.4	20.3	18.4	17.0	15.8	14.3	12.2	9.2
1st 6 hours	10.5	8.8	8.4	6.9	6.4	5.5	5.0	3.9	2.1
2nd 6 hours	2.9	2.7	2.6	2.4	2.2	2.2	2.0	1.7	1.3
3rd 6 hours	2.2	2.2	2.1	2.0	1.8	1.7	1.6	1.4	1.2
4th 6 hours	1.7	1.7	1.6	1.5	1.4	1.3	1.2	1.1	0.9
* 2nd day	4.4	4.4	4.2	4.0	3.7	3.5	3.2	2.9	2.3
∇ 3rd day	1.9	1.9	1.8	1.7	1.6	1.5	1.4	1.2	1.0
Total area of Isohyet (sq. mi.)	30	52	129	311	728	1024	1984	7940	17,070

*For successive 6-hr. values use 34, 28, 21, and 17% of 2nd day values

∇For successive 6-hr. values use 29, 26, 23 and 22% of 3rd day values

Table 6e

VALUES OF PATTERN STORM ISOHYETS (FIGURE 13e) FOR SUSQUEHANNA RIVER AT DANVILLE, PA.

Basin Size: 11,220 Sq. Mi.

	Center	A_1	A_2	B_1	B_2	C_1	C_2	D	E
		Isohyet Values (inches)							
72 hours	23.0	21.3	20.4	18.5	17.1	16.0	14.4	12.2	9.2
1st 6 hours	10.3	8.6	8.2	6.8	6.3	5.1	4.9	3.8	2.1
2nd 6 hours	3.0	2.7	2.6	2.4	2.3	2.2	2.0	1.7	1.3
3rd 6 hours	2.2	2.2	2.1	2.0	1.9	1.8	1.6	1.4	1.2
4th 6 hours	1.7	1.7	1.6	1.6	1.4	1.4	1.2	1.1	0.9
* 2nd day	4.3	4.3	4.1	4.0	3.7	3.5	3.2	2.8	2.3
∇ 3rd day	2.1	2.1	2.0	1.9	1.8	1.7	1.5	1.4	1.1
Total area of Isohyet (sq. mi.)	30	52	129	311	728	1024	2104	8421	18,380

*For successive 6-hr. values use 34, 28, 21, and 17% of 2nd day values

∇For successive 6-hr. values use 29, 26, 23 and 22% of 3rd day values

Table 6f

VALUES OF PATTERN STORM ISOHYETS (FIGURE 13f) FOR WEST BRANCH SUSQUEHANNA RIVER AT LEWISBURG, PA.

Basin Size: 6847 Sq. Mi.

	Center	A	B	C	D	E
		Isohyet Values (inches)				
72 hours	26.4	24.6	21.6	18.6	15.2	11.5
1st 6 hours	12.6	11.2	9.1	7.3	5.5	3.2
2nd 6 hours	3.3	3.0	2.8	2.5	2.1	1.7
3rd 6 hours	2.3	2.3	2.1	1.9	1.6	1.2
4th 6 hours	1.9	1.9	1.7	1.5	1.3	1.1
* 2nd day	4.8	4.7	4.3	3.8	3.3	2.6
∇ 3rd day	2.1	2.0	1.9	1.6	1.4	1.2
Total area of Isohyet (sq. mi.)	10	58	327	1228	4202	10,448

*For successive 6-hr. values use 34, 28, 21, and 17% of 2nd day values

∇For successive 6-hr. values use 29, 26, 23, and 22% of 3rd day values

Table 6g

VALUES OF PATTERN STORM ISOHYETS (FIGURE 13g) FOR JUNIATA RIVER AT NEWPORT, PA.

Basin Size: 3354 Sq. Mi.

	Center	A	B	C	D	E
		Isohyet Values (inches)				
72 hours	28.2	25.5	20.9	17.9	13.3	
1st 6 hours	14.6	12.7	9.6	7.7	4.7	
2nd 6 hours	3.3	3.0	2.5	2.2	1.8	
3rd 6 hours	2.4	2.2	1.9	1.7	1.4	
4th 6 hours	1.9	1.8	1.6	1.4	1.2	
* 2nd day	4.7	4.4	3.8	3.4	2.8	
∇ 3rd day	2.0	1.9	1.6	1.4	1.2	
Total area of Isohyet (sq. mi.)	10	62	628	1836	5297	

*For successive 6-hr. values use 34, 28, 21, and 17% of 2nd day values

∇For successive 6-hr. values use 29, 26, 23, and 22% of 3rd day values

Table 6h

VALUES OF PATTERN STORM ISOHYETS (FIGURE 13h) FOR SUSQUEHANNA RIVER AT HARRISBURG, PA.

Basin Size: 24,100 Sq. Mi.

	Centers		A_1	A_2	A_3	B_1	B_2	B_3	B_4	C_2	C_3	C_4	D	E
	M	N	Isohyet Values (inches)											
72 hours	23.0	19.9	19.6	19.9	19.6	16.5	16.9	16.1	16.8	13.0	12.3	14.6	10.1	7.6
1st 6 hours	9.1	7.8	6.7	6.8	6.7	4.9	5.1	4.9	5.1	3.4	3.2	3.8	2.3	1.4
2nd 6 hours	3.0	2.6	2.5	2.5	2.5	2.2	2.2	2.1	2.2	1.9	1.8	2.1	1.5	1.2
3rd 6 hours	2.0	1.8	1.9	1.9	1.9	1.7	1.7	1.7	1.7	1.4	1.4	1.6	1.2	0.9
4th 6 hours	1.8	1.6	1.7	1.8	1.7	1.5	1.6	1.5	1.6	1.3	1.2	1.4	1.0	0.8
* 2nd day	4.9	4.2	4.6	4.7	4.6	4.2	4.2	4.0	4.2	3.4	3.3	3.9	2.8	2.3
∇ 3rd day	2.2	1.9	2.1	2.1	2.1	1.8	1.9	1.8	1.9	1.5	1.4	1.7	1.2	1.0
Total area of Isohyet (sq. mi.)	10	10	114	87	124	654	471	859	196	3389	4645	1092	22,990	41,760

*For successive 6-hr. values use 34, 28, 21, and 17% of 2nd day values

∇For successive 6-hr. values use 29, 26, 23 and 22% of 3rd day values

Note: Same value for all M centers

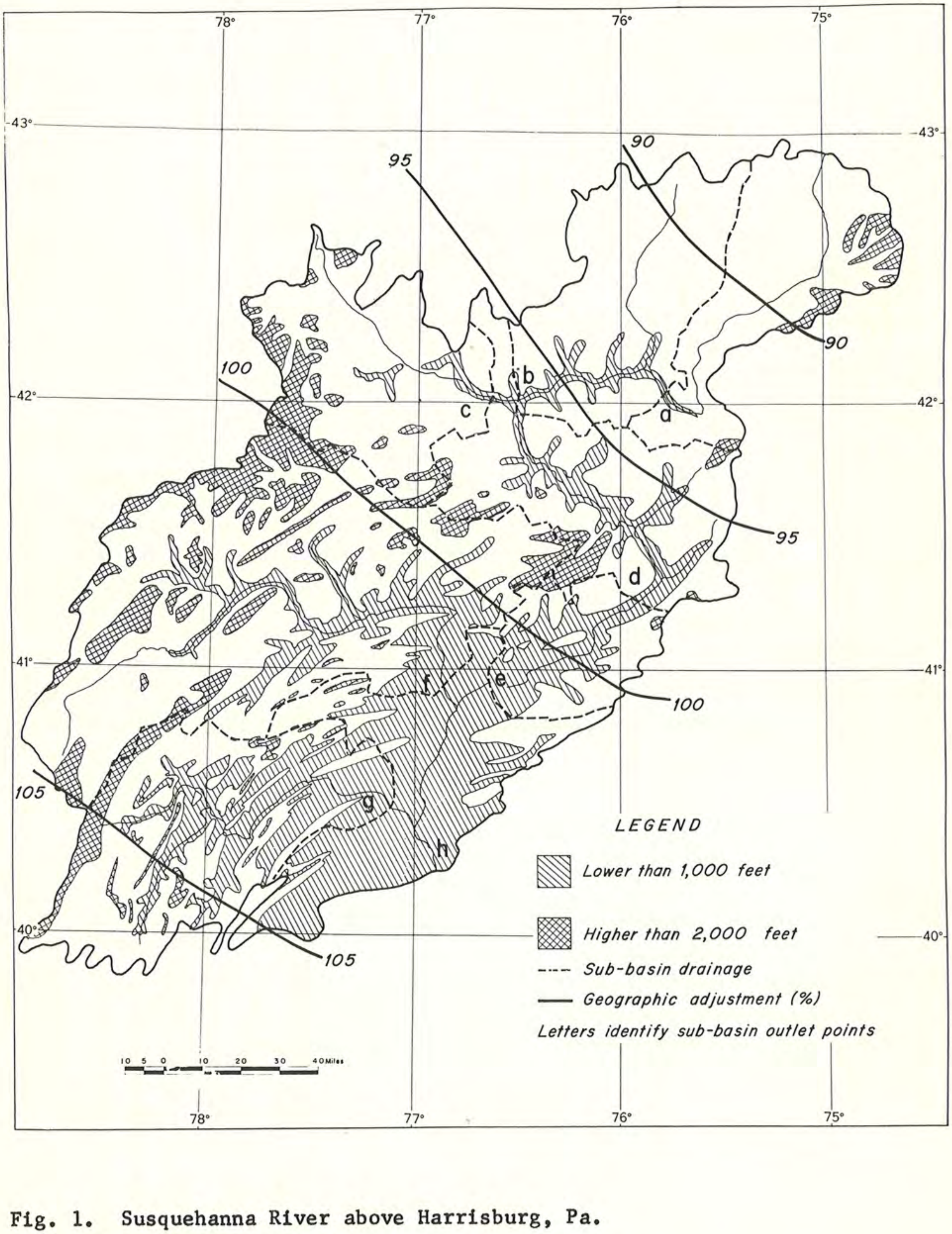
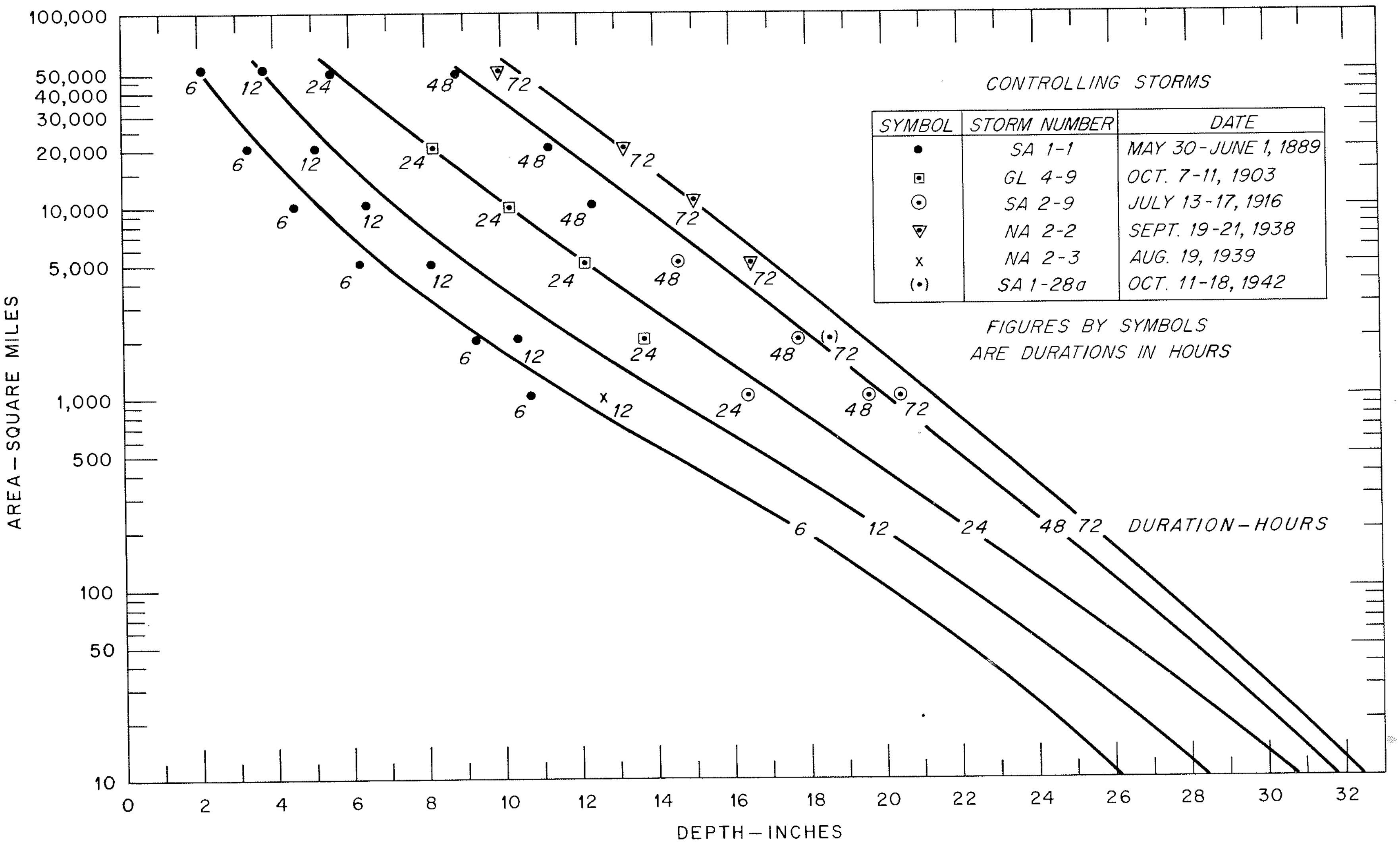


Fig. 1. Susquehanna River above Harrisburg, Pa.



CONTROLLING STORMS

SYMBOL	STORM NUMBER	DATE
●	SA 1-1	MAY 30-JUNE 1, 1889
▣	GL 4-9	OCT. 7-11, 1903
⊙	SA 2-9	JULY 13-17, 1916
▼	NA 2-2	SEPT. 19-21, 1938
x	NA 2-3	AUG. 19, 1939
(•)	SA 1-28a	OCT. 11-18, 1942

FIGURES BY SYMBOLS ARE DURATIONS IN HOURS

Fig. 2. Enveloping depth-duration-area values of PMP for Susquehanna River Basin

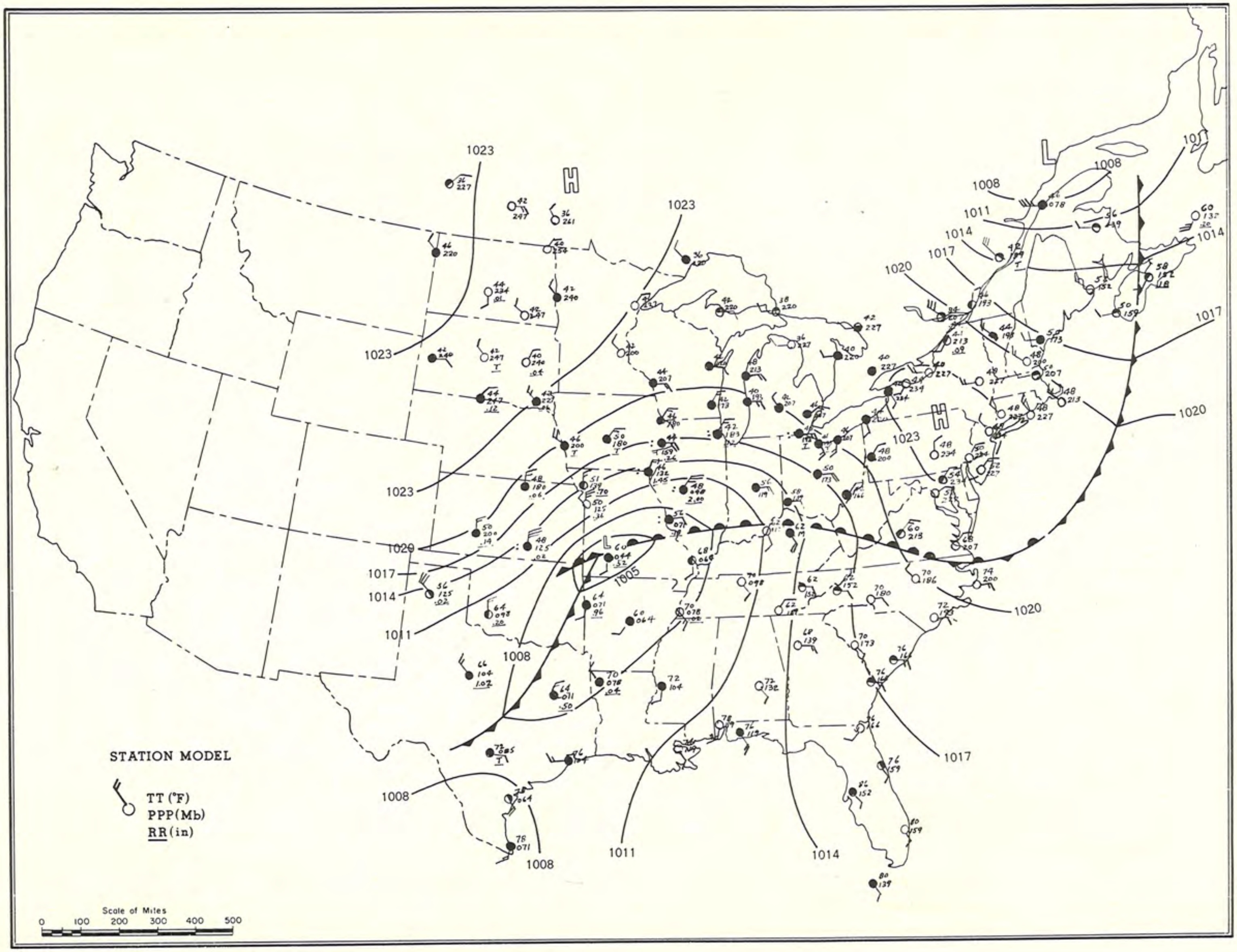


Fig. 3a. Surface chart 8 a.m. EST, May 29, 1889

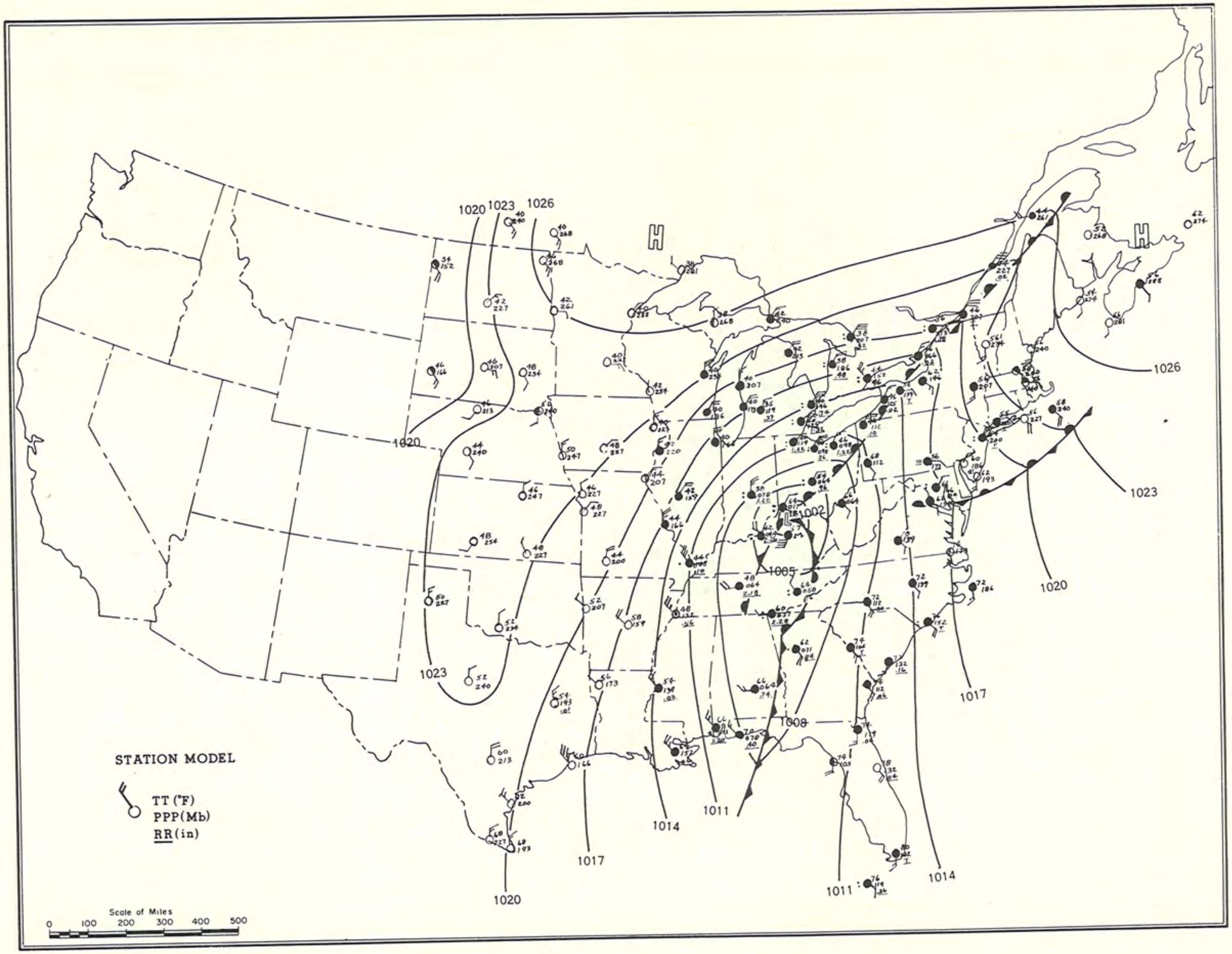


Fig. 3b. Surface chart 8 a.m. EST, May 30, 1889

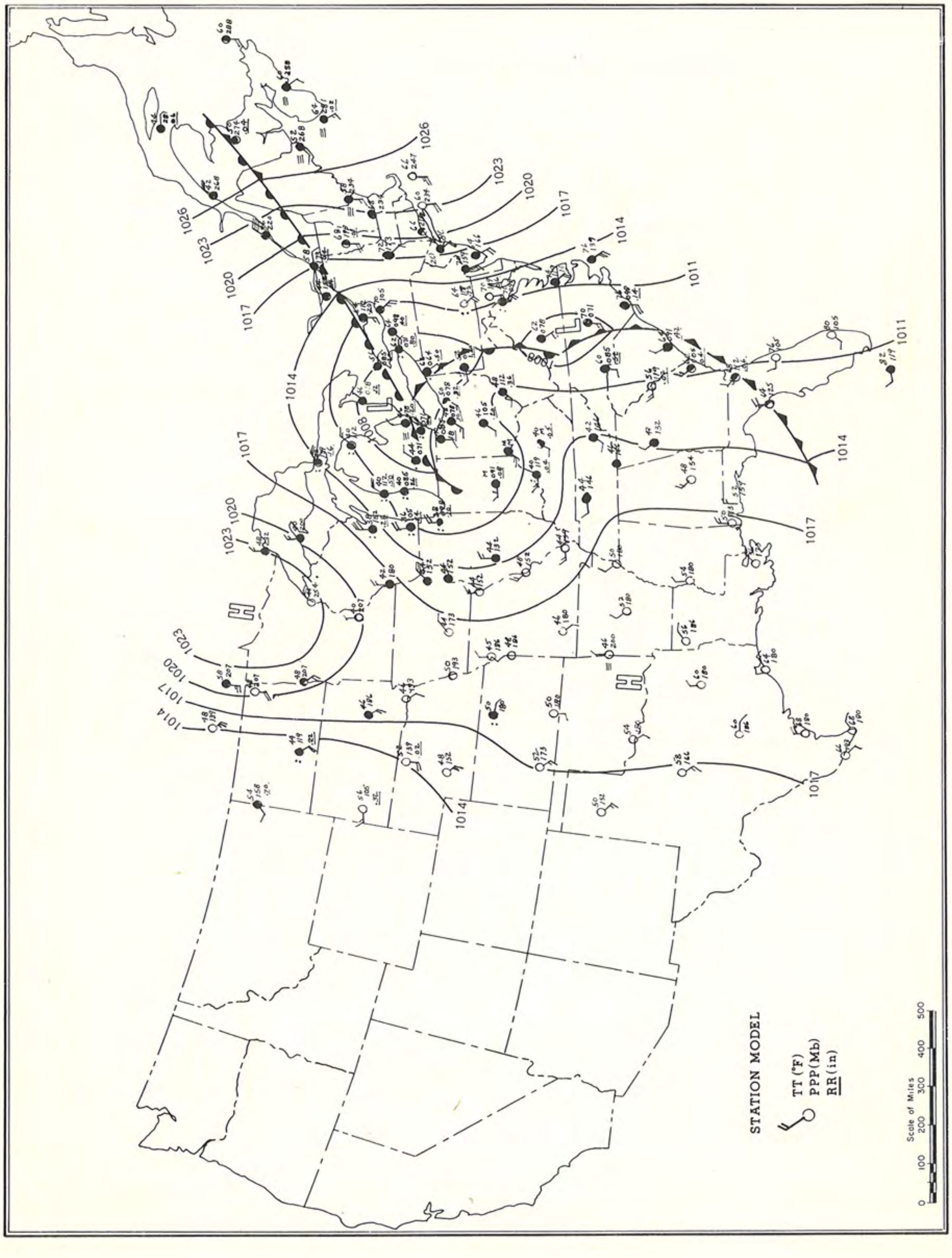


Fig. 3c. Surface chart 8 a.m. EST, May 31, 1889

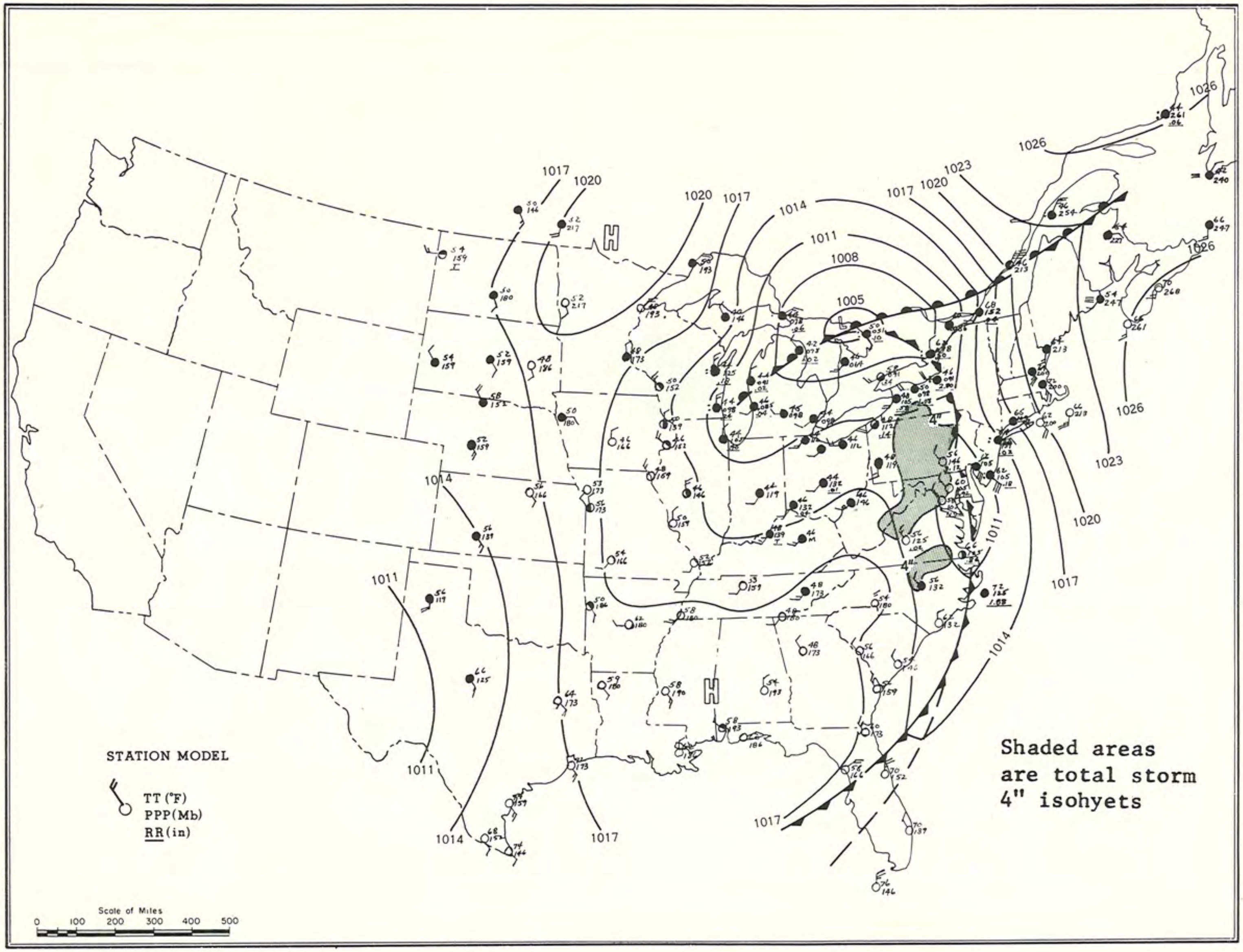


Fig. 3d. Surface chart 8 a.m. EST, June 1, 1889

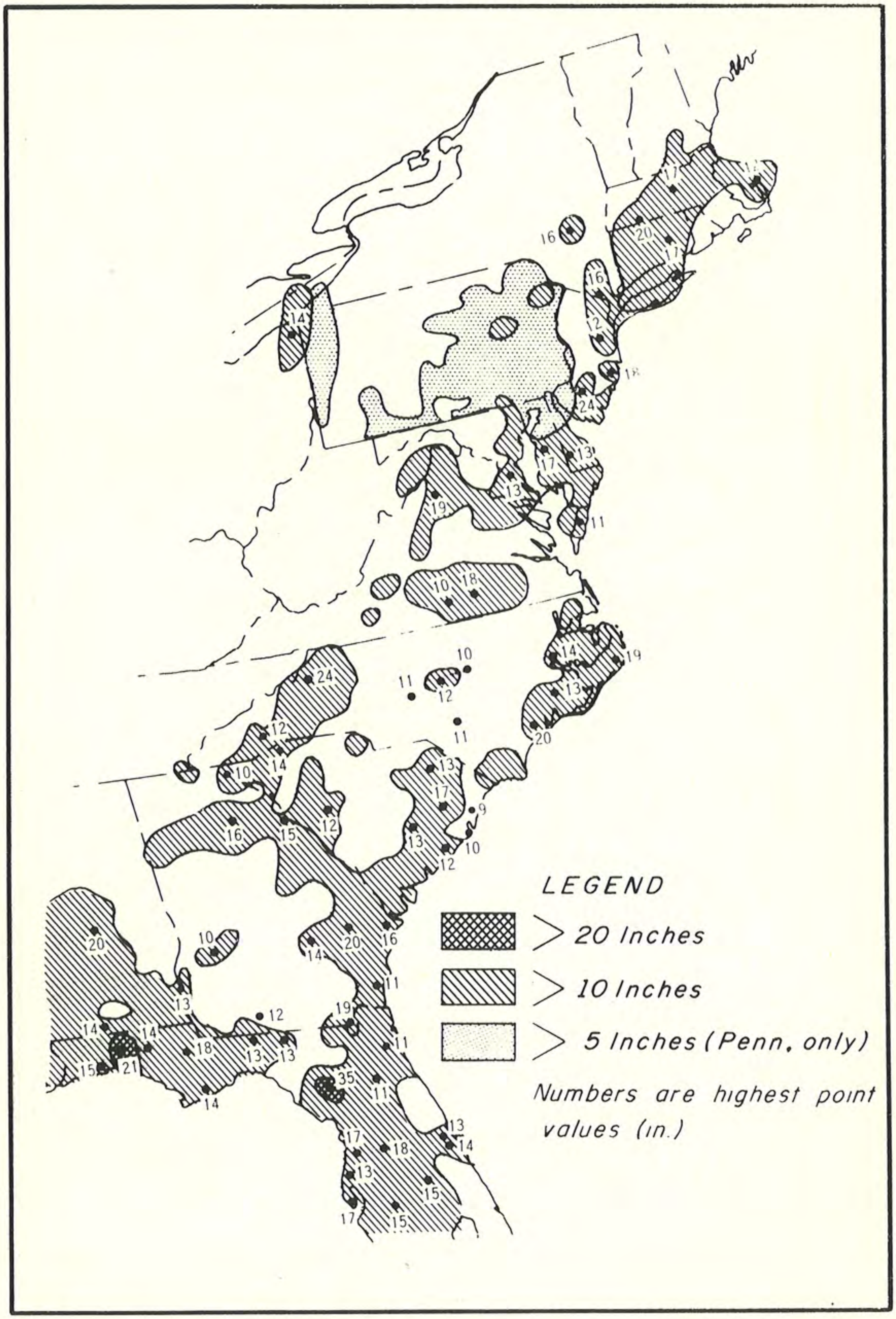


Fig. 4. Major rain from tropical storms

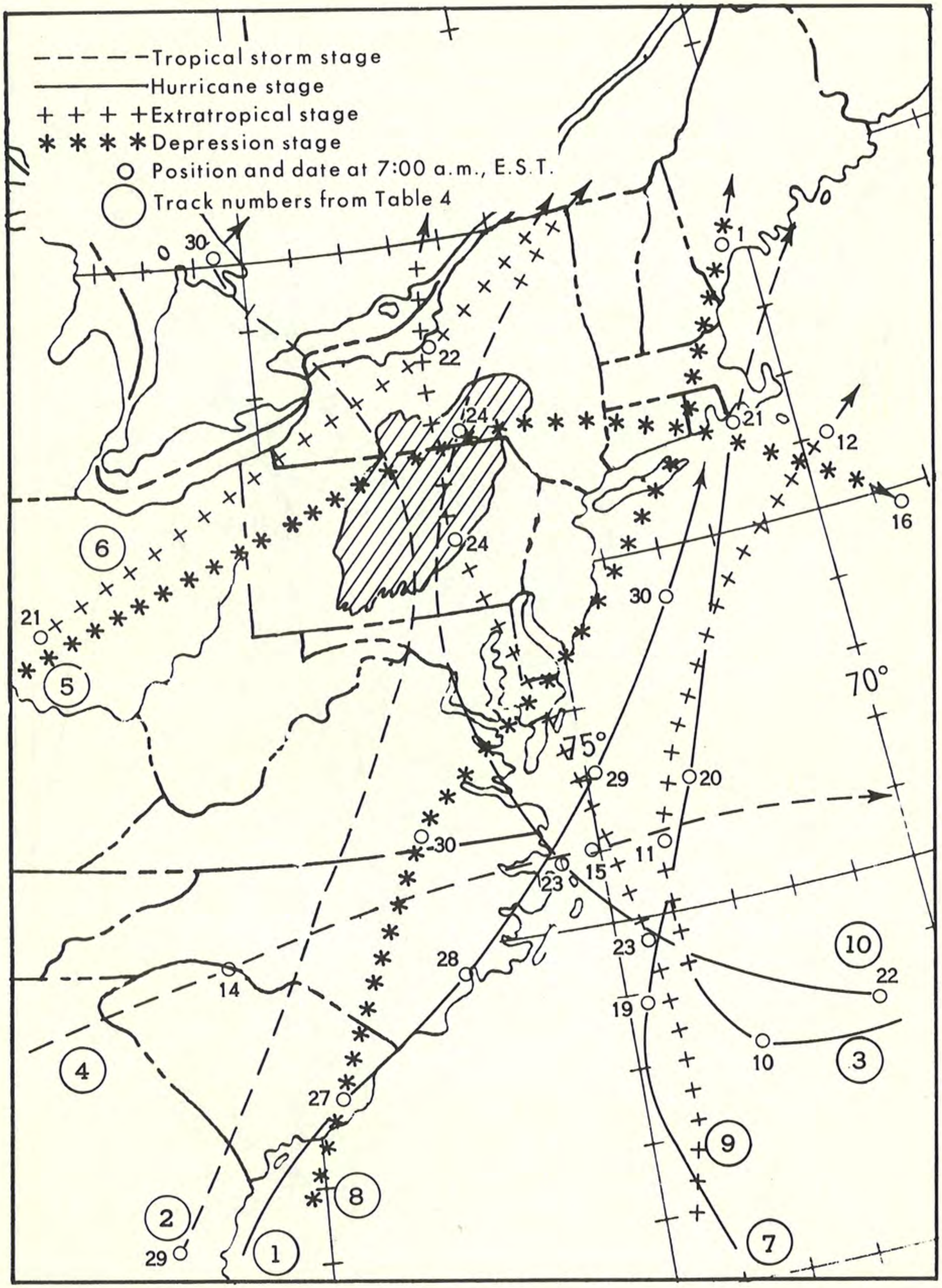


Fig. 5. Tracks of tropical storms associated with precipitation in the Susquehanna River Basin (shaded)

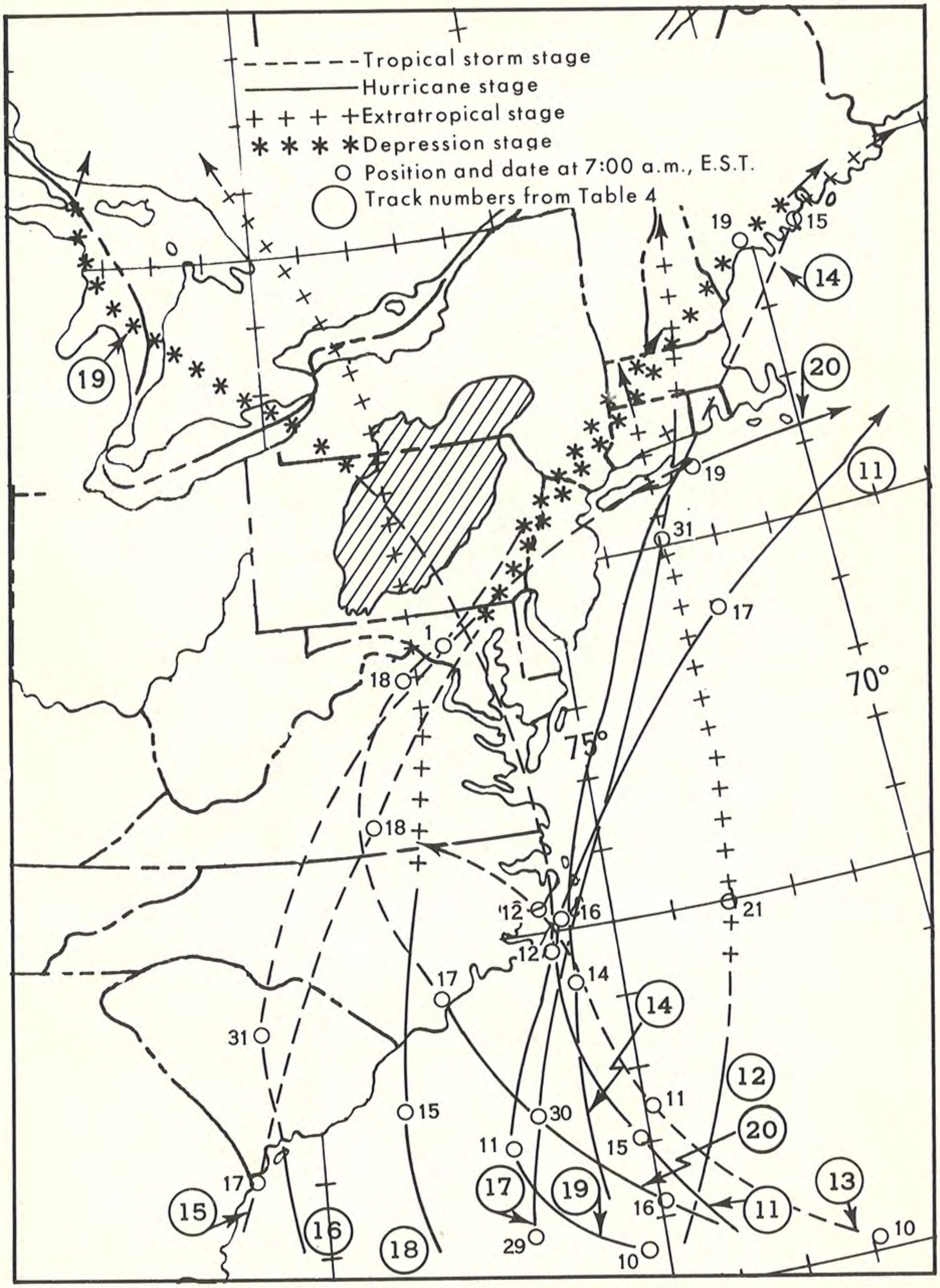


Fig. 6. Tracks of tropical storms associated with precipitation in the Susquehanna River Basin (shaded)

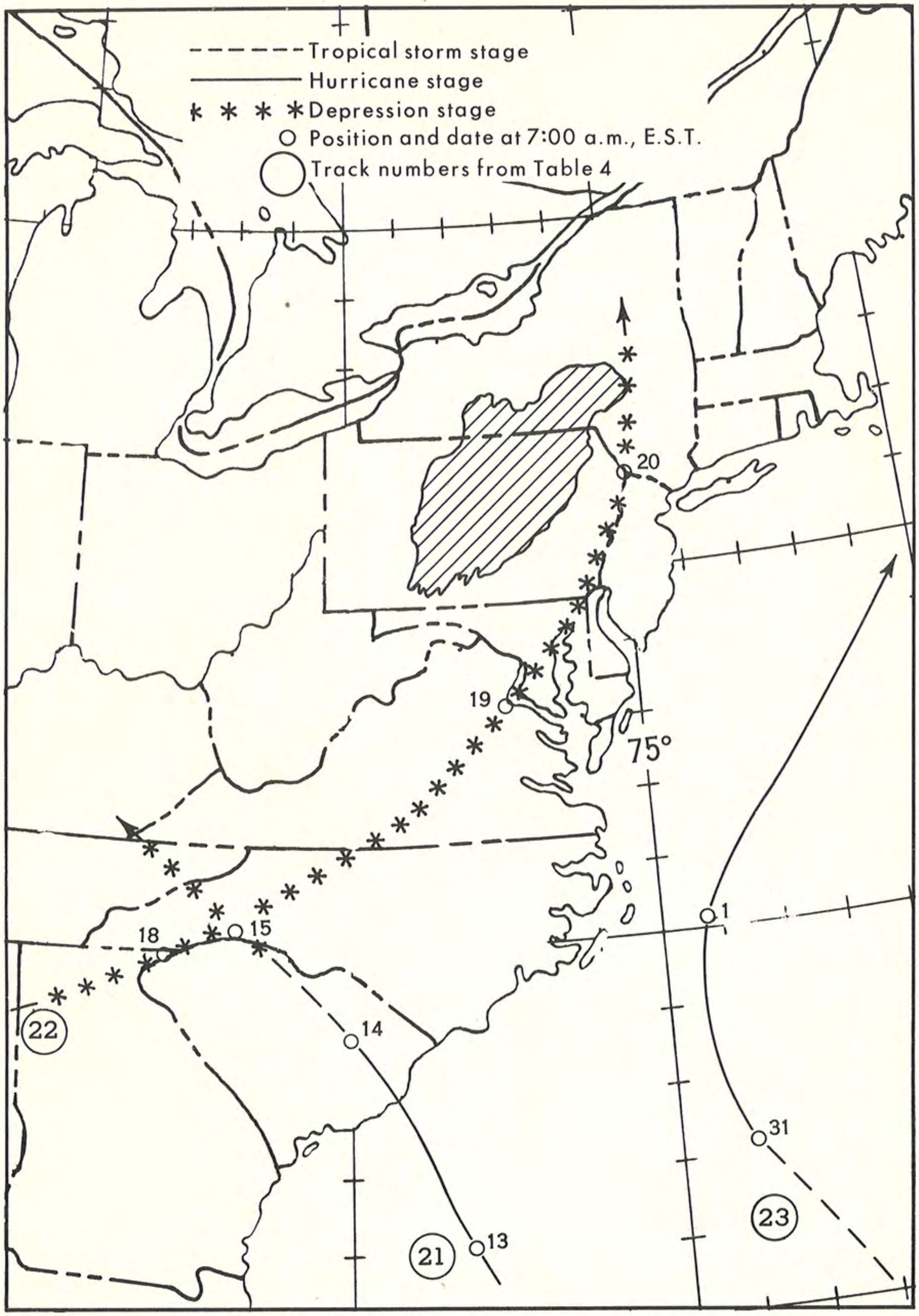


Fig. 7. Tracks of tropical storms associated with major rainstorms transposable to the Susquehanna River Basin (shaded)

132 663

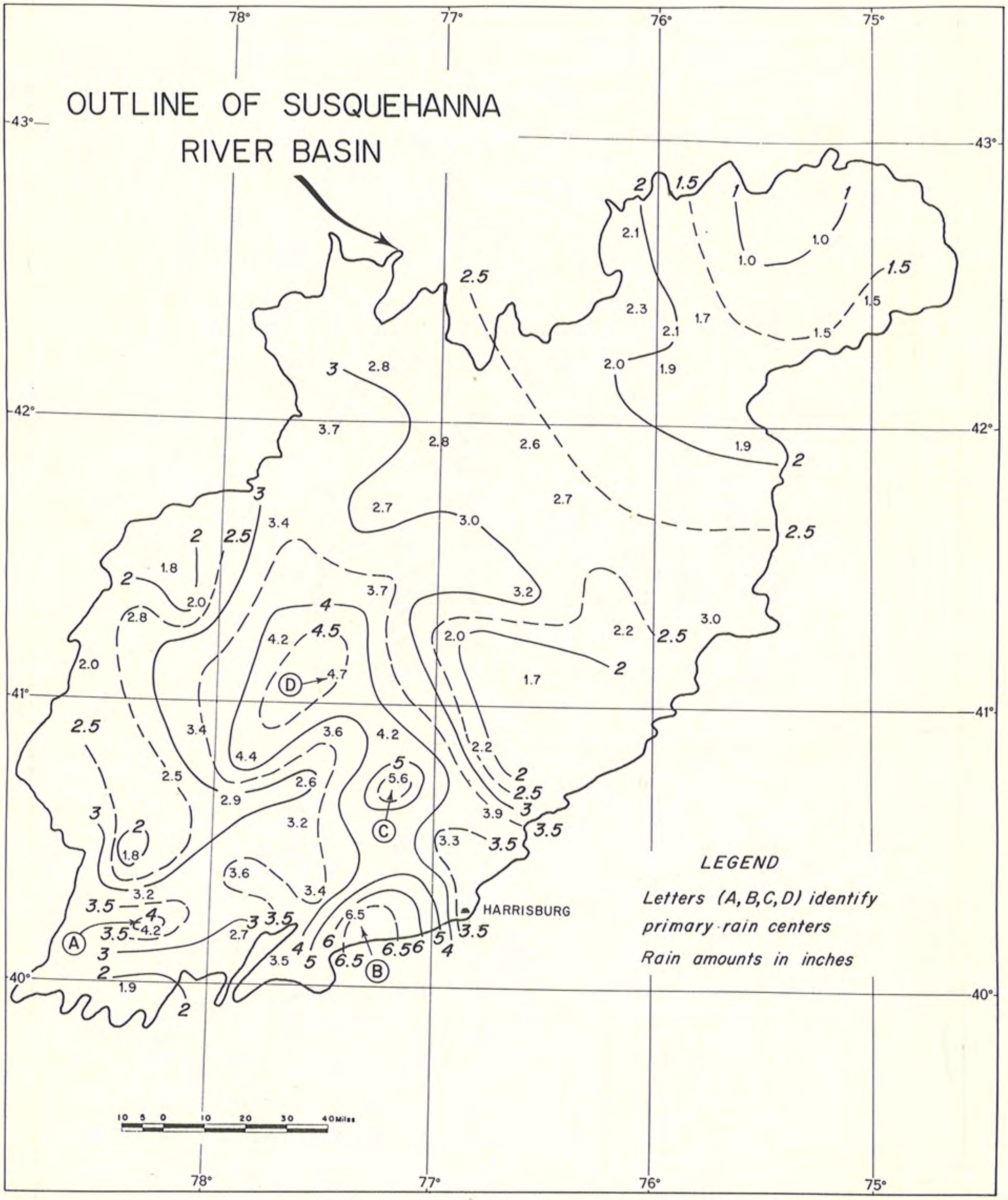


Fig. 8. 24-hr. rainfall ending 6 p.m. EST, August 13, 1955

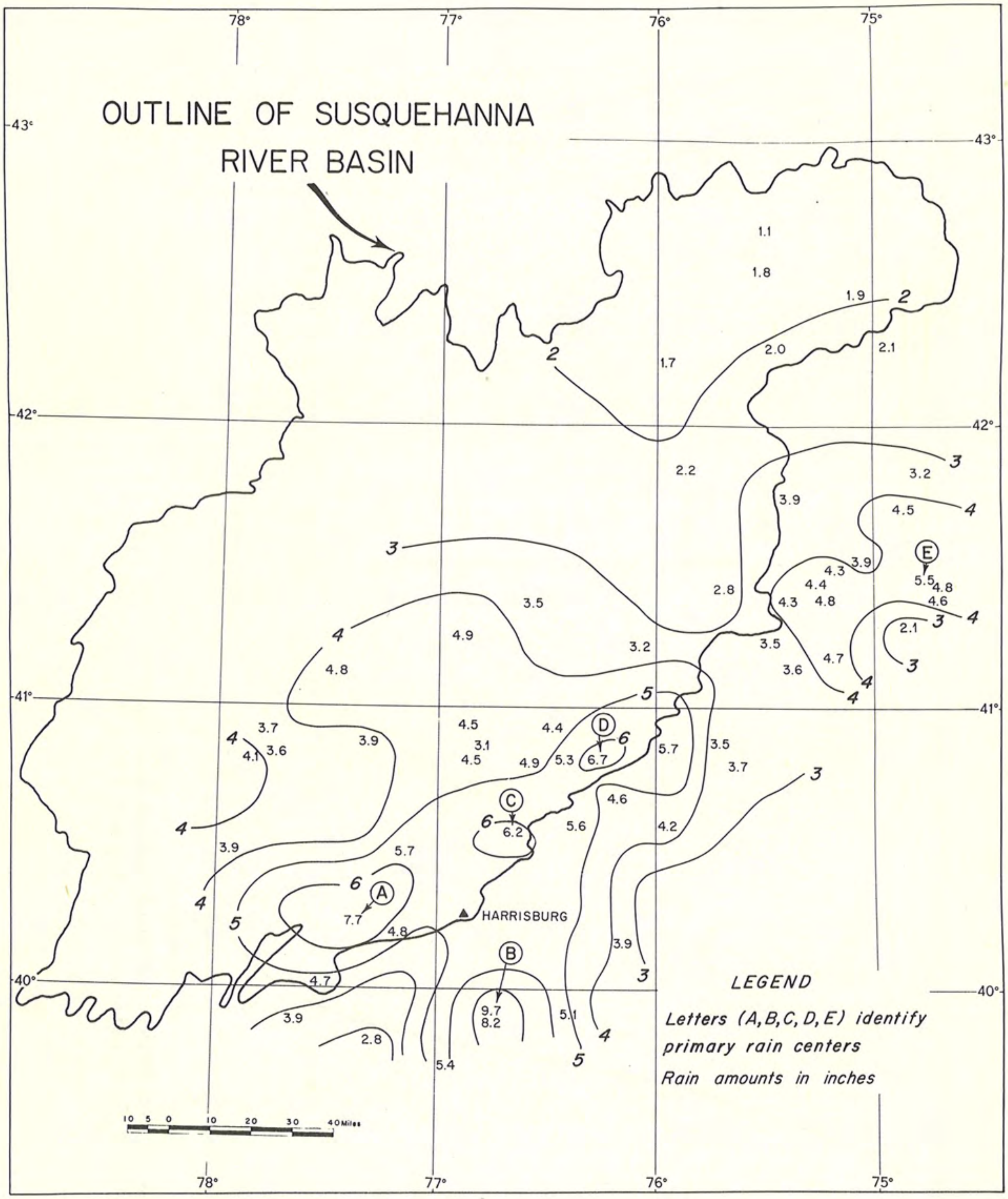


Fig. 9. 24-hr. rainfall ending 7 a.m. EST, August 24, 1933

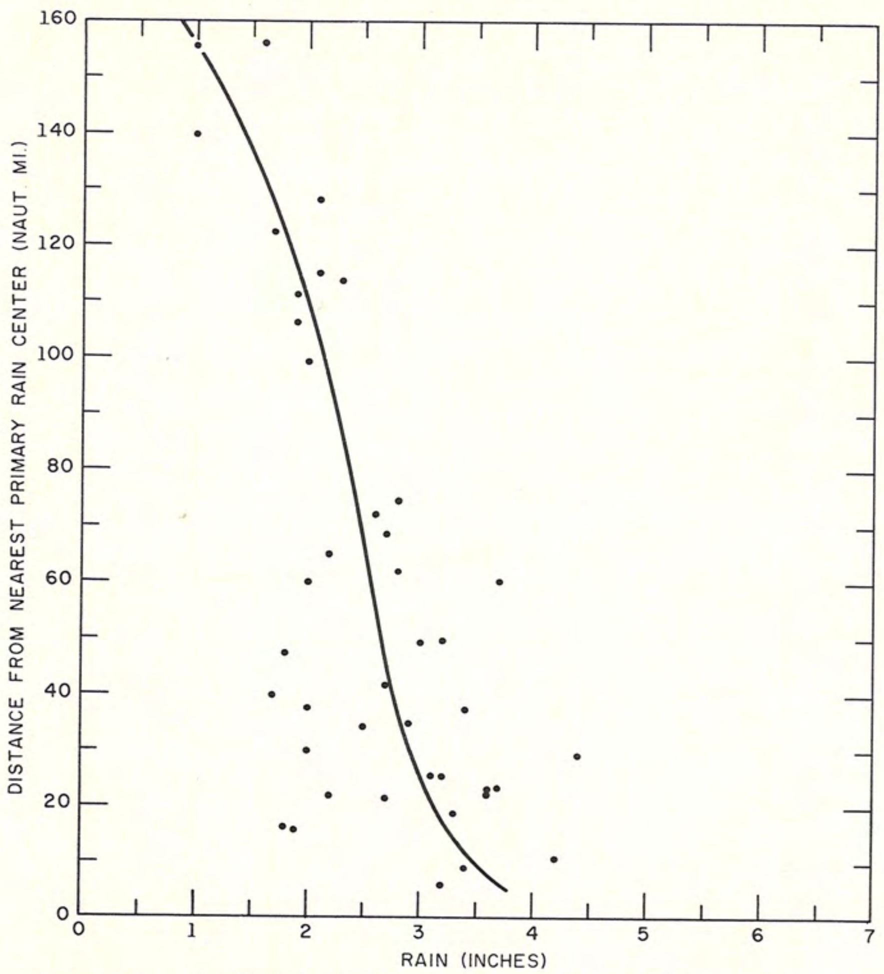


Fig. 10. Relation between precipitation and distance from rain center, August 13, 1955

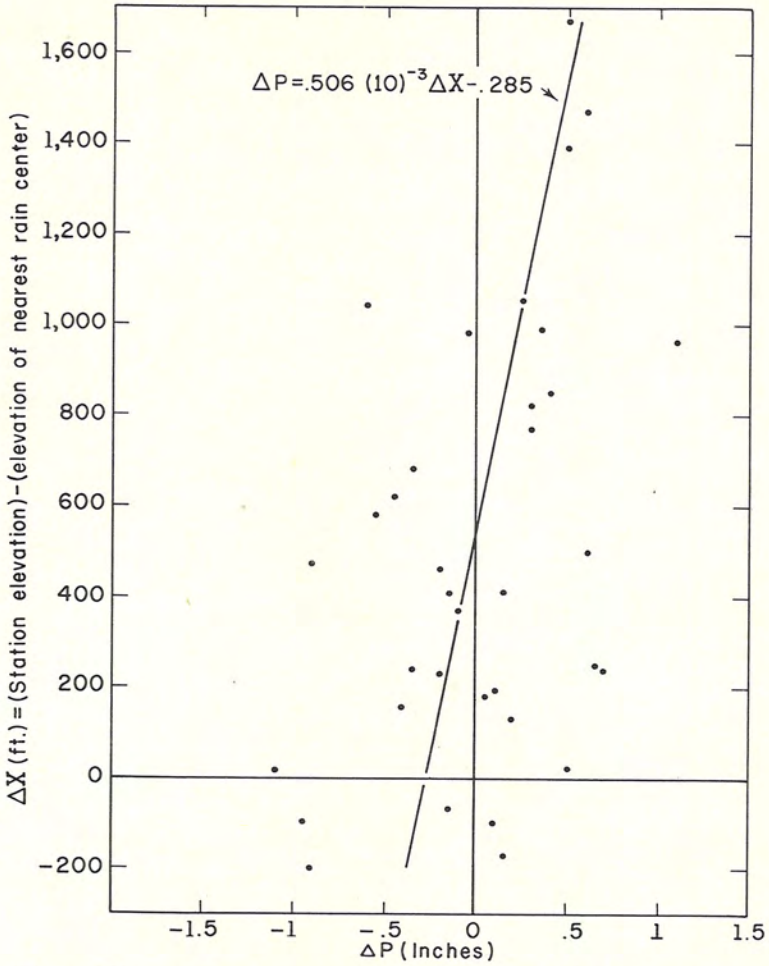
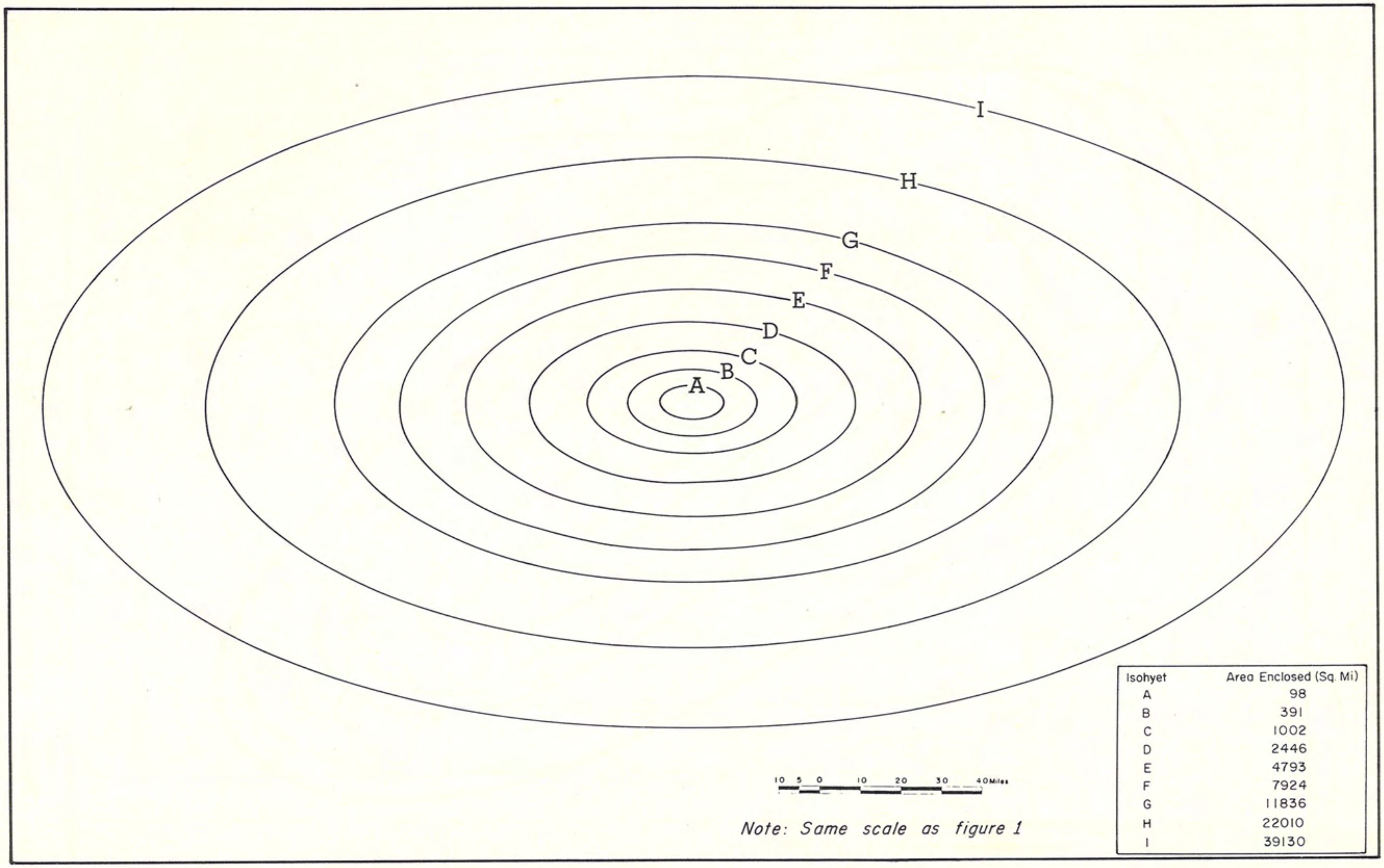


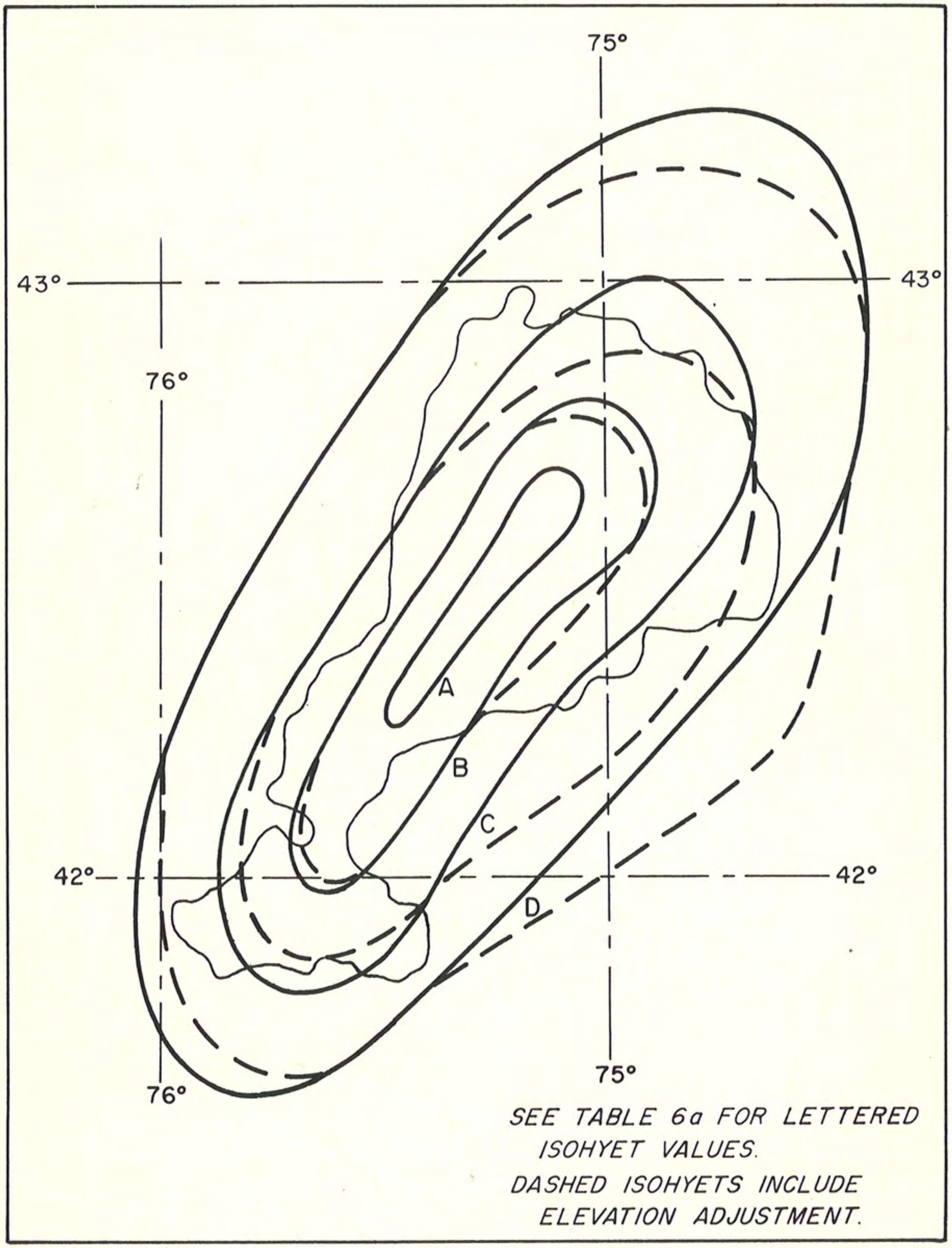
Fig. 11. Relation between deviations of precipitation from curve of figure 10 and elevation differences in August 13, 1955 storm



Note: Same scale as figure 1

Isohyet	Area Enclosed (Sq. Mi)
A	98
B	391
C	1002
D	2446
E	4793
F	7924
G	11836
H	22010
I	39130

Fig. 12. Generalized pattern storm



SEE TABLE 6a FOR LETTERED ISOHYET VALUES.

DASHED ISOHYETS INCLUDE ELEVATION ADJUSTMENT.

Fig. 13a. Pattern storm for Susquehanna River at Conklin, N. Y.

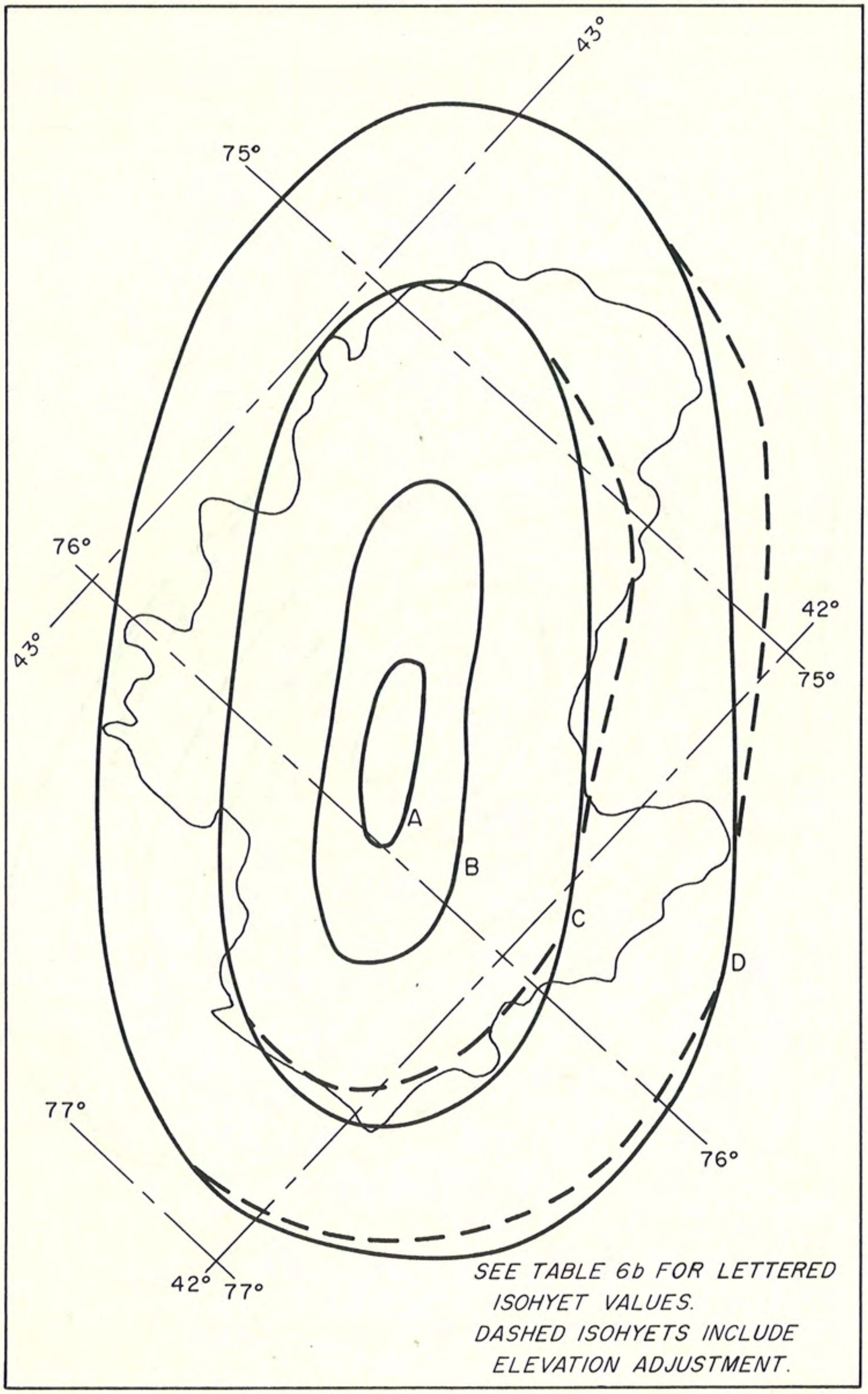


Fig. 13b. Pattern storm for Susquehanna River at Waverly, N. Y.

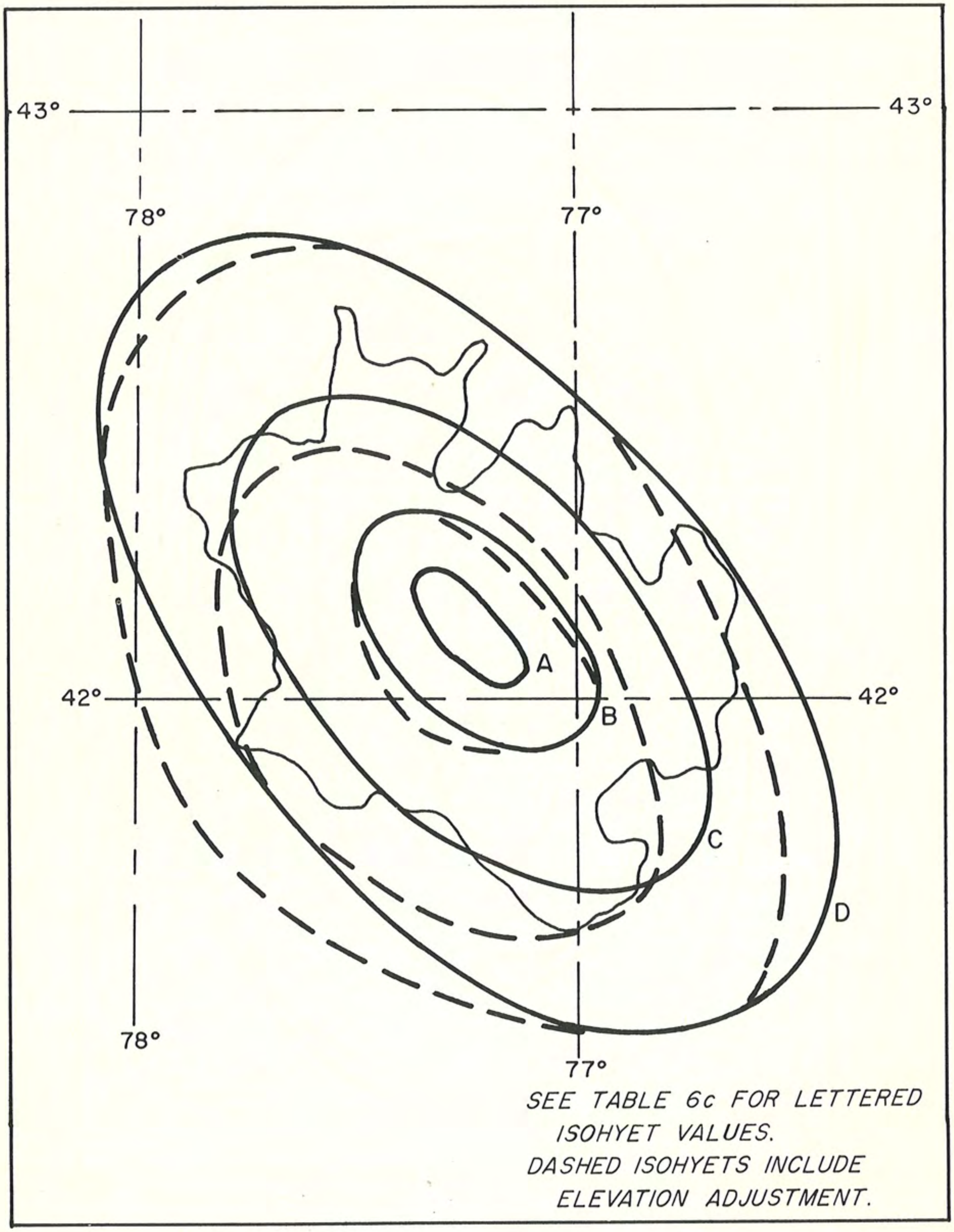
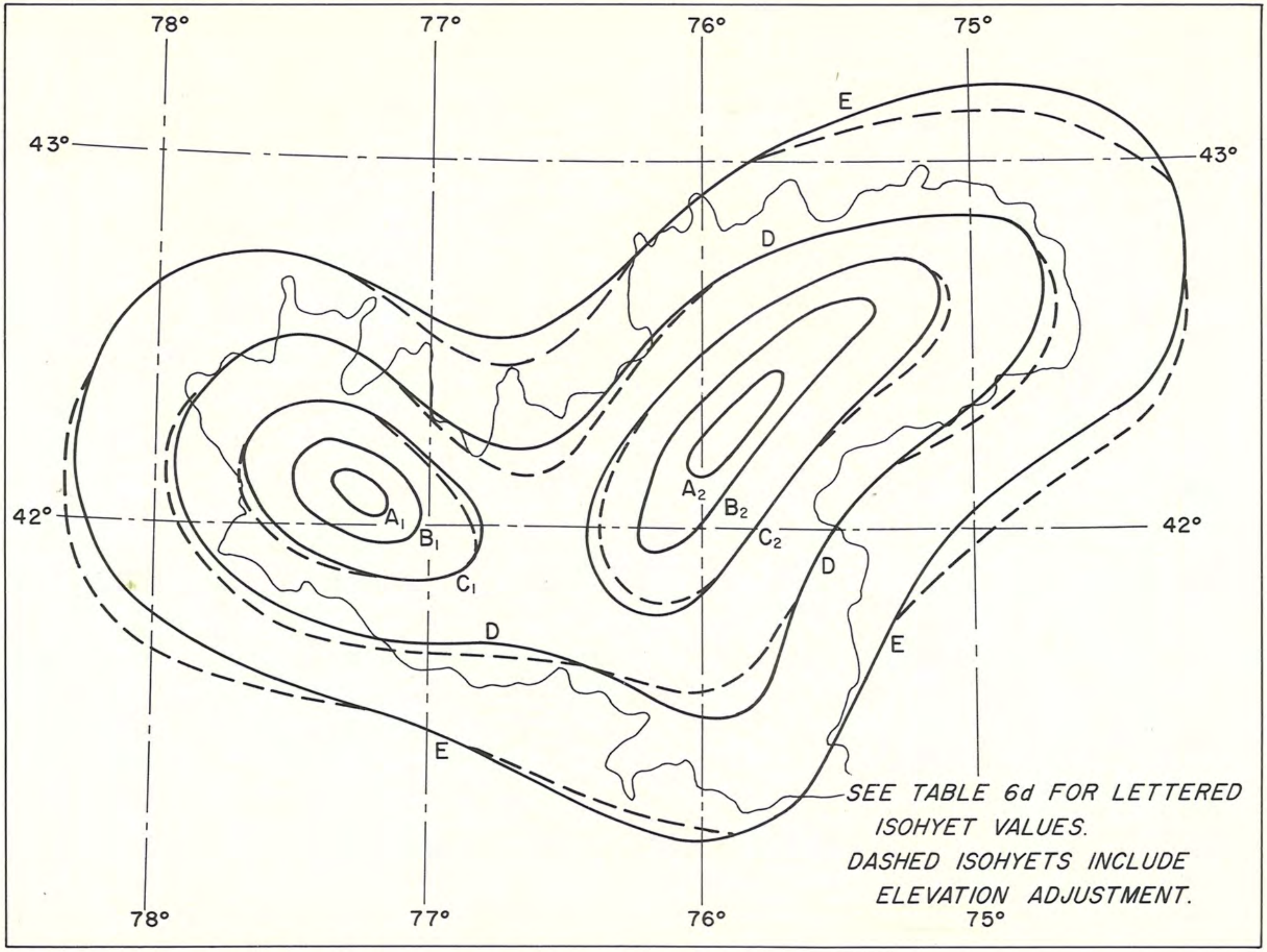
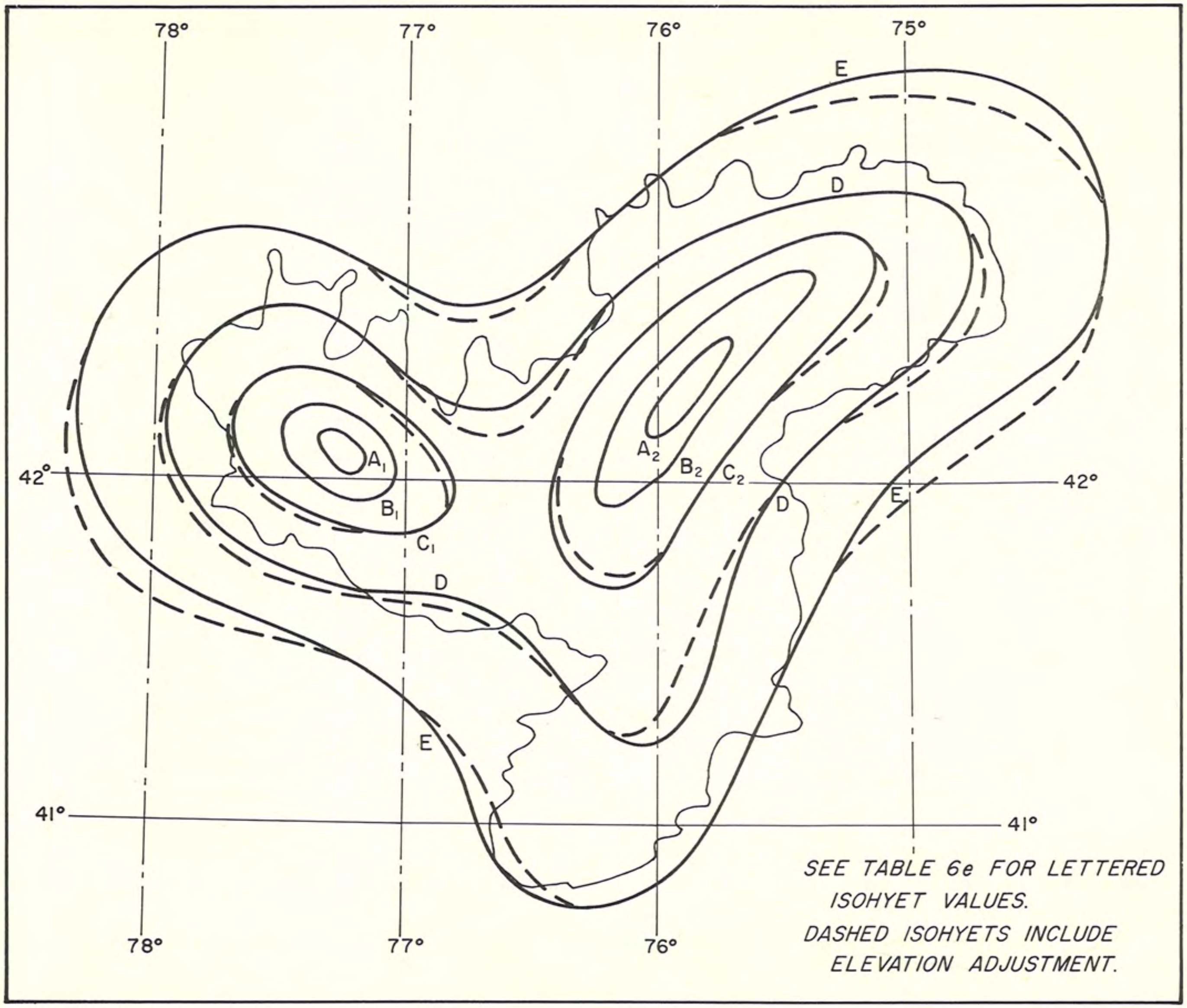


Fig. 13c. Pattern storm for Chemung River at Chemung, N. Y.



SEE TABLE 6d FOR LETTERED ISOHYET VALUES.
DASHED ISOHYETS INCLUDE ELEVATION ADJUSTMENT.

Fig. 13d. Pattern storm for Susquehanna River at Wilkes-Barre, Pa.



SEE TABLE 6e FOR LETTERED ISOHYET VALUES.
DASHED ISOHYETS INCLUDE ELEVATION ADJUSTMENT.

Fig. 13e. Pattern storm for Susquehanna River at Danville, Pa.

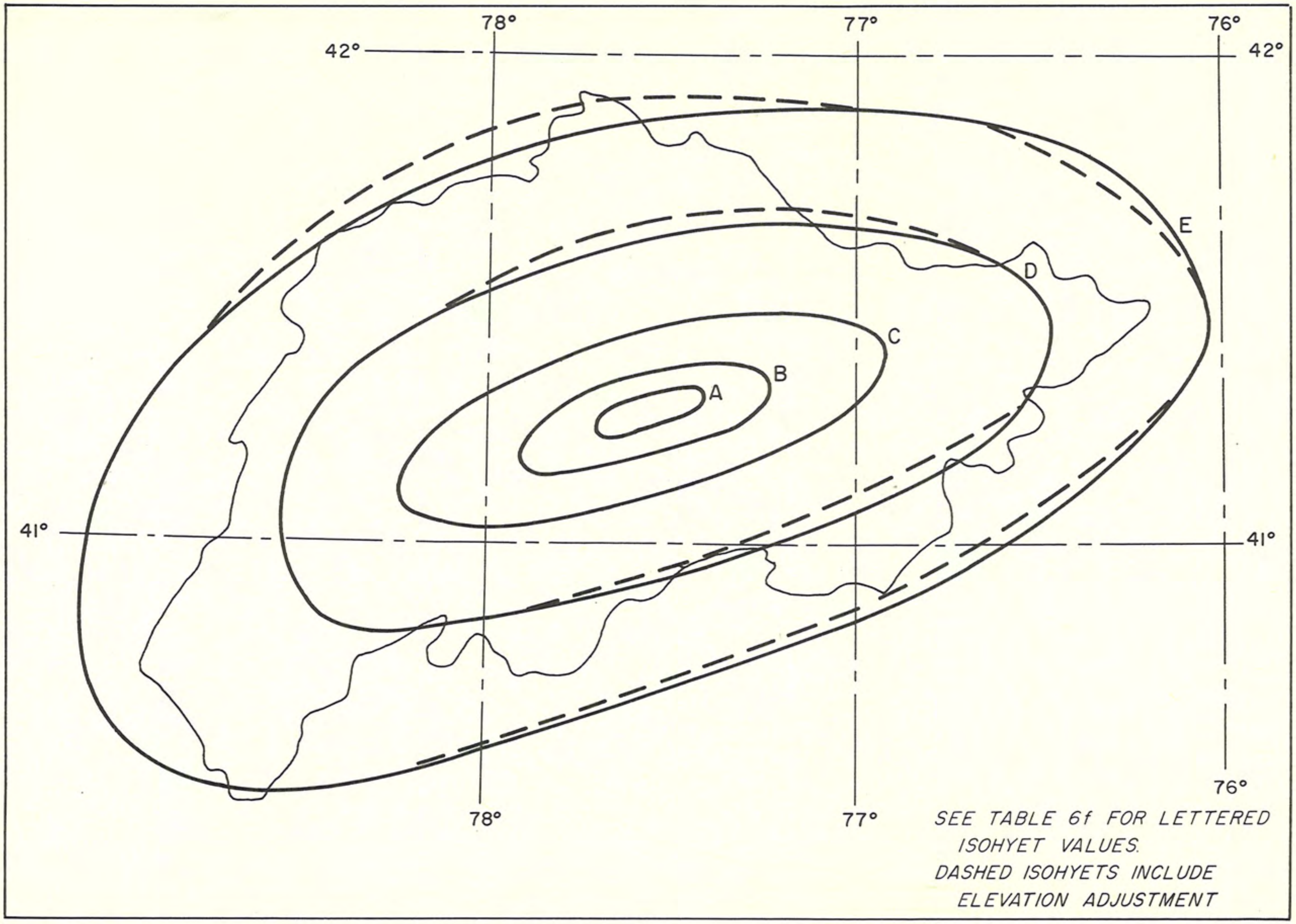


Fig. 13f. Pattern storm for West Branch Susquehanna River at Lewisburg, Pa.

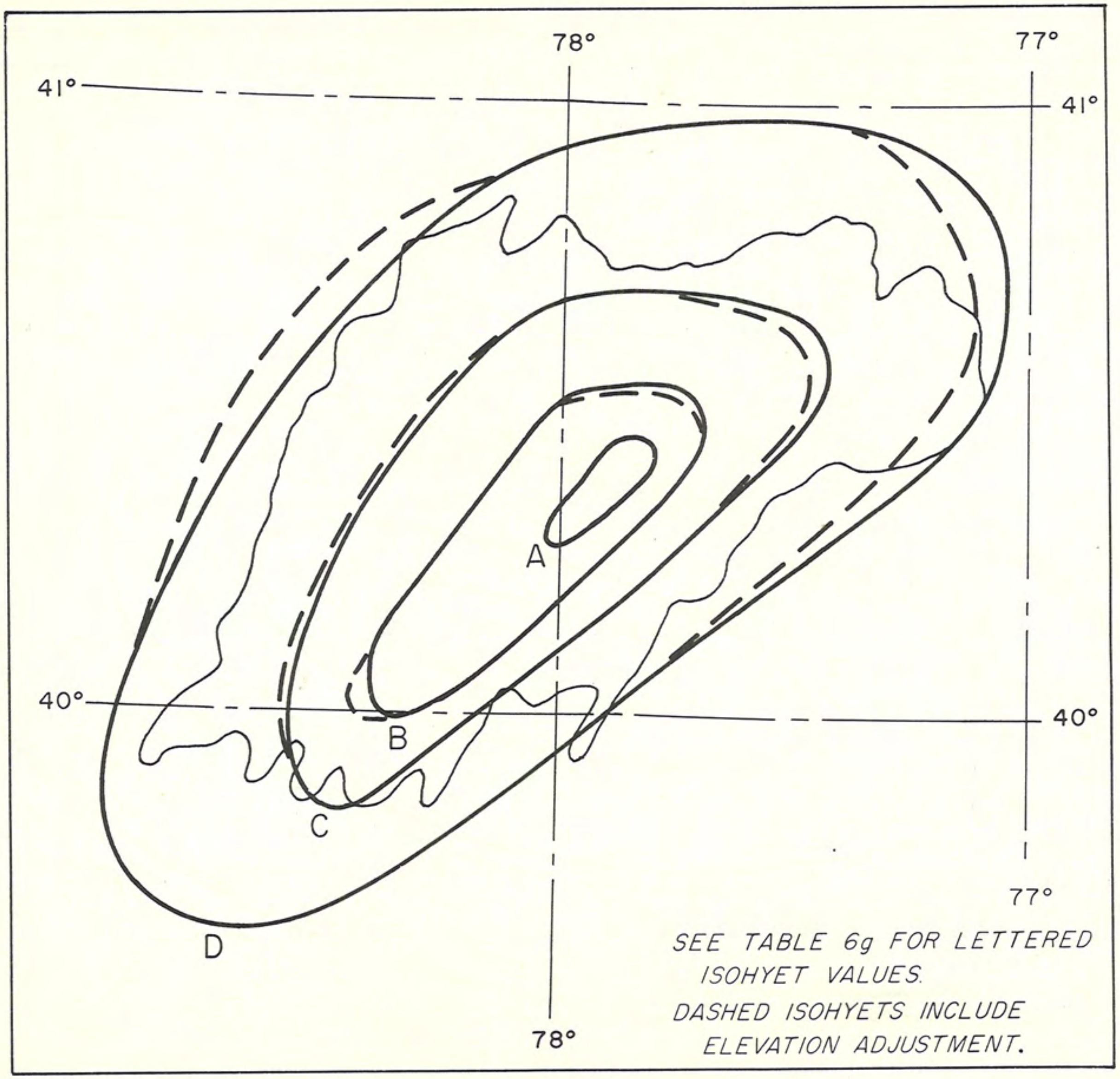


Fig. 13g. Pattern storm for Juniata River at Newport, Pa.

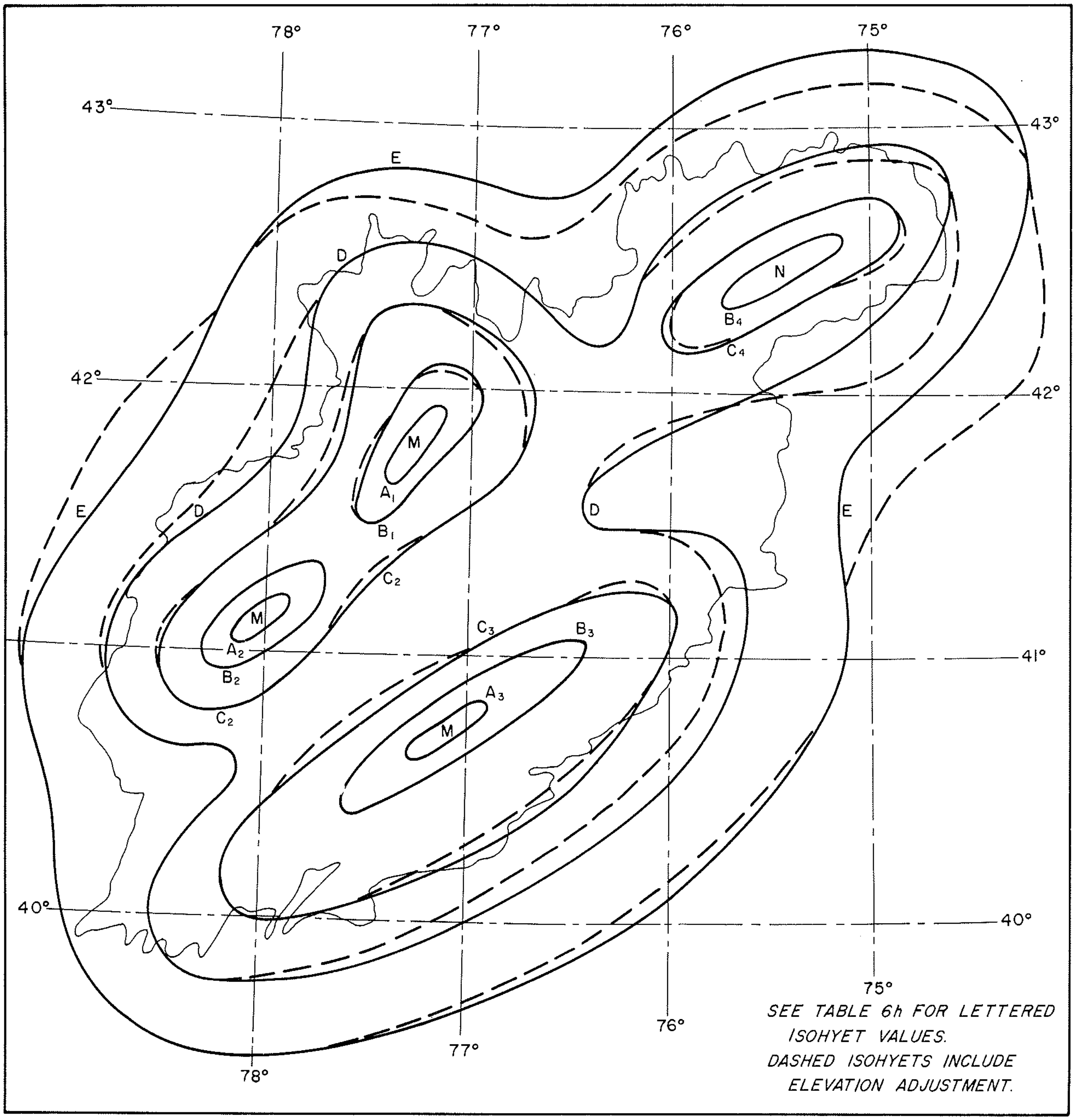


Fig. 13h. Pattern storm for Susquehanna River at Harrisburg, Pa.

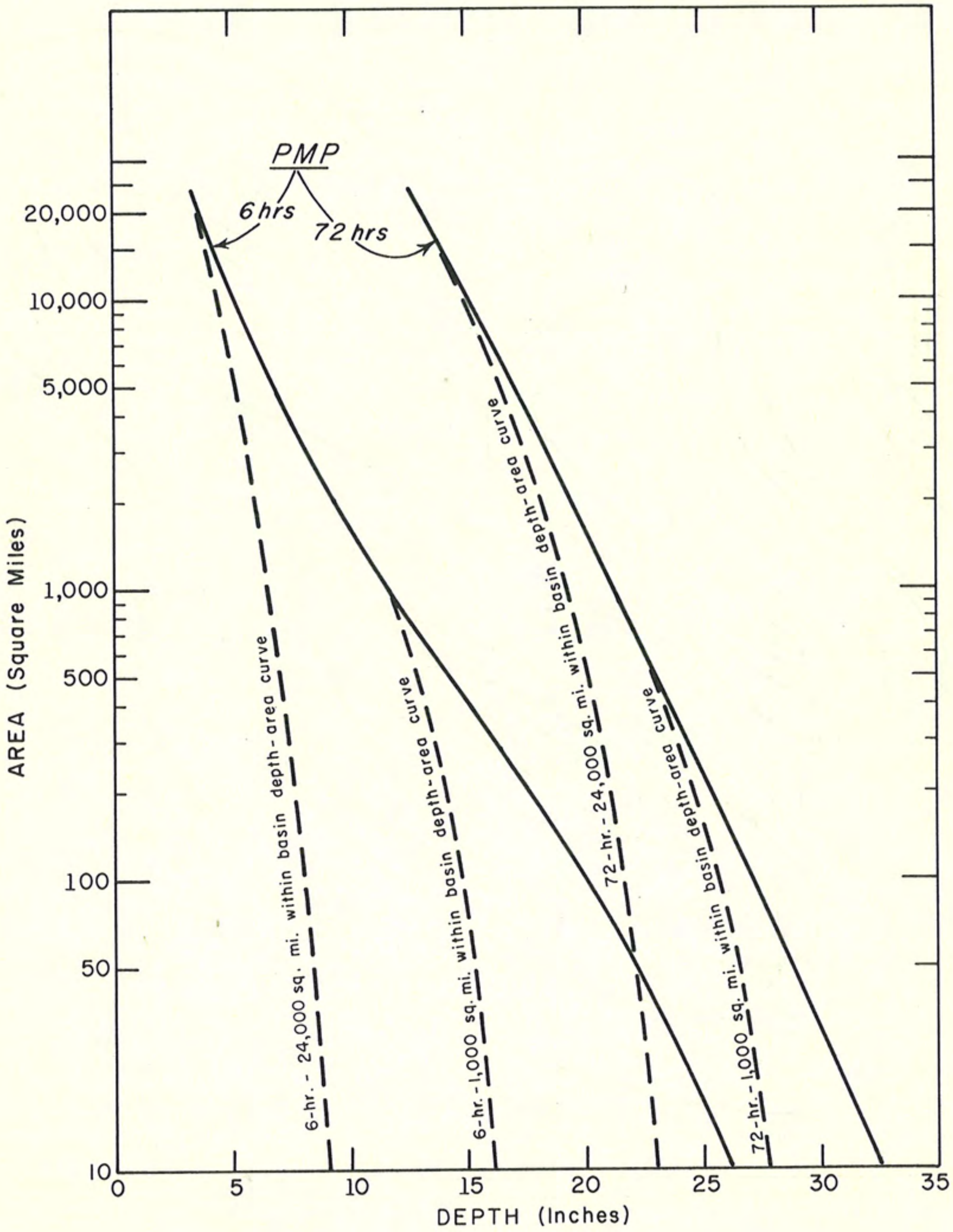


Fig. 14. PMP and within-basin depth-area curves

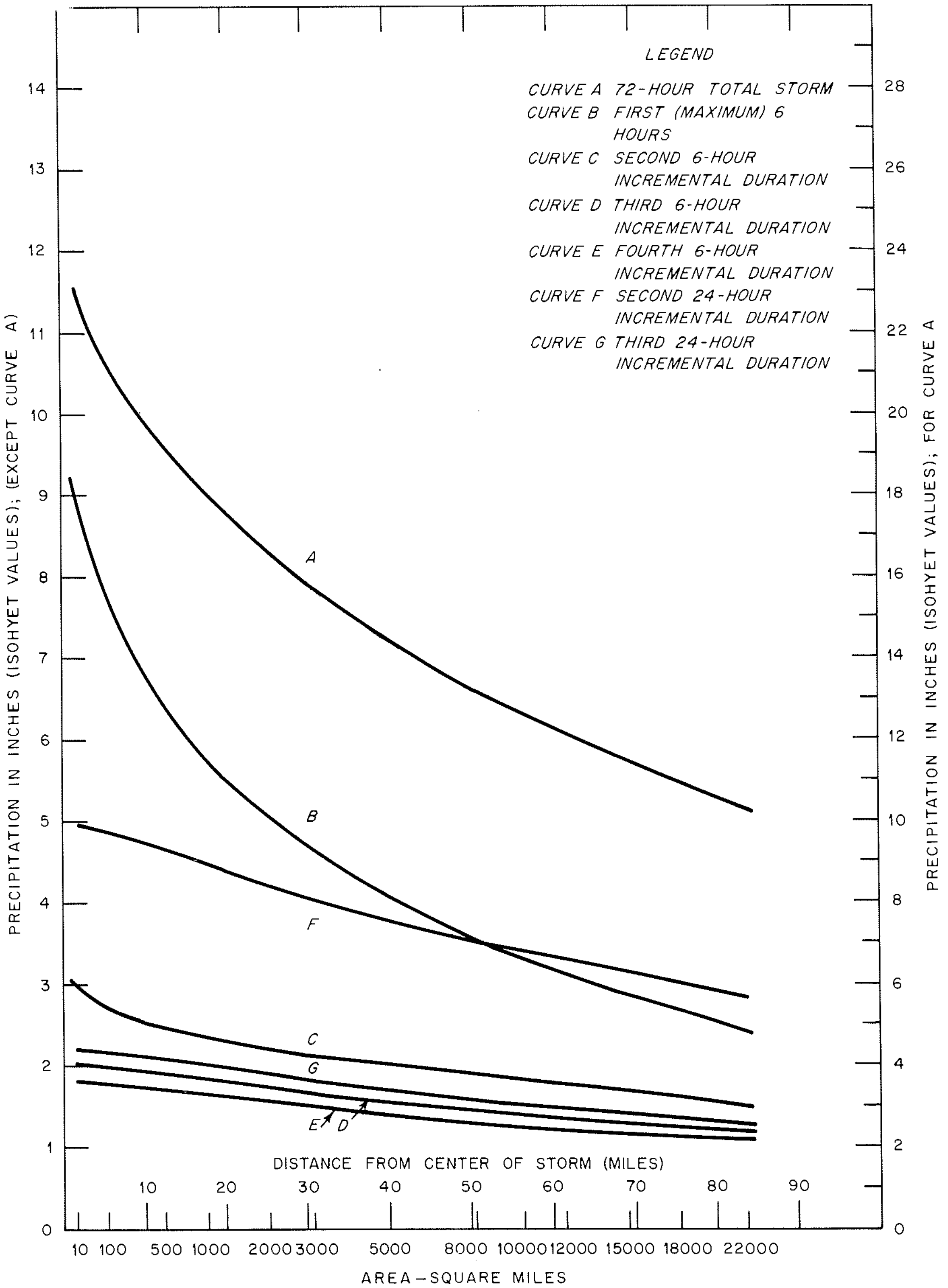


Fig. 15. Isohyet-area curves for 24,000-sq. mi. basin

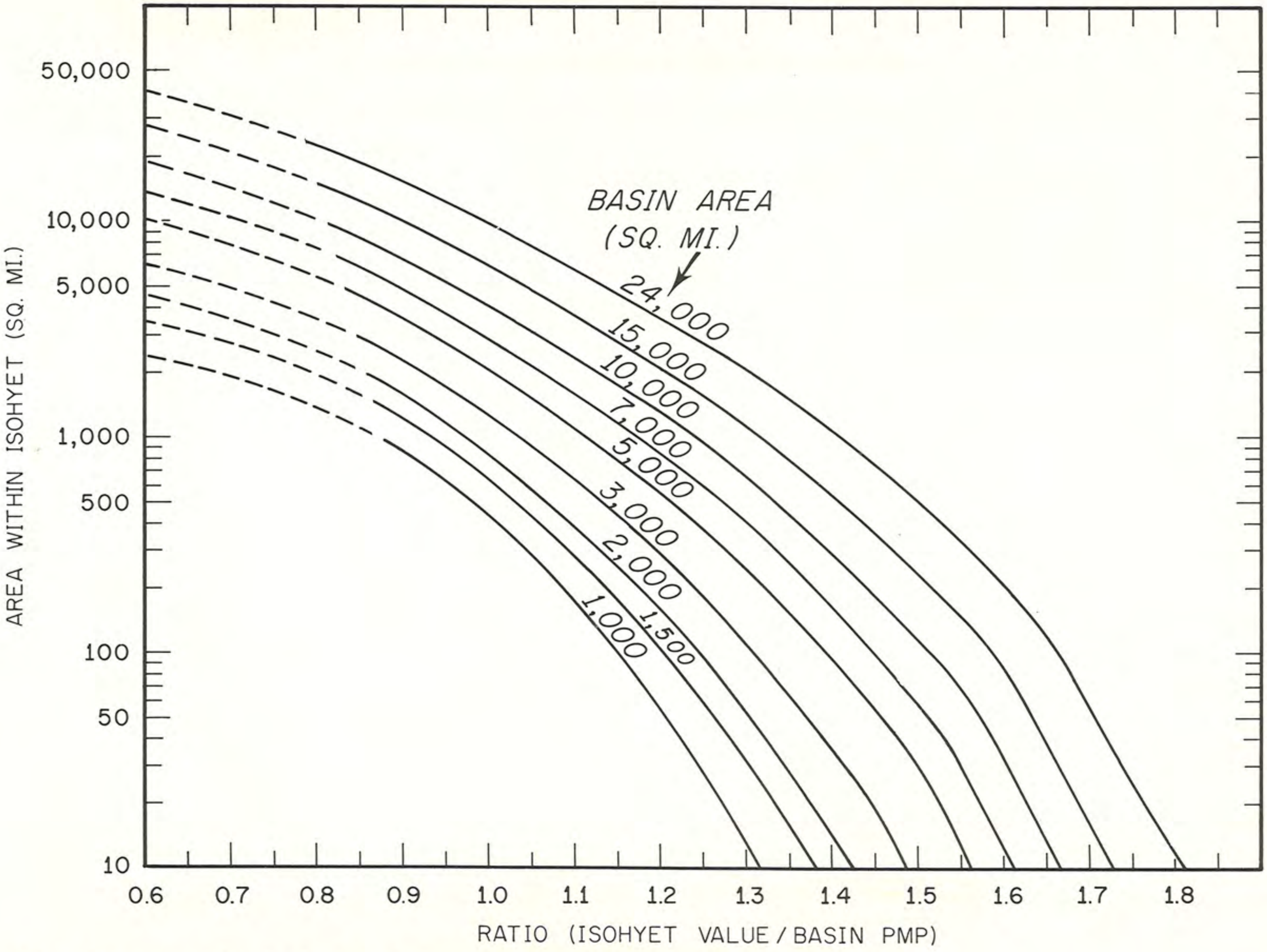


Fig. 16a. Nomogram for isohyet values in pattern storms (72-hr. duration)

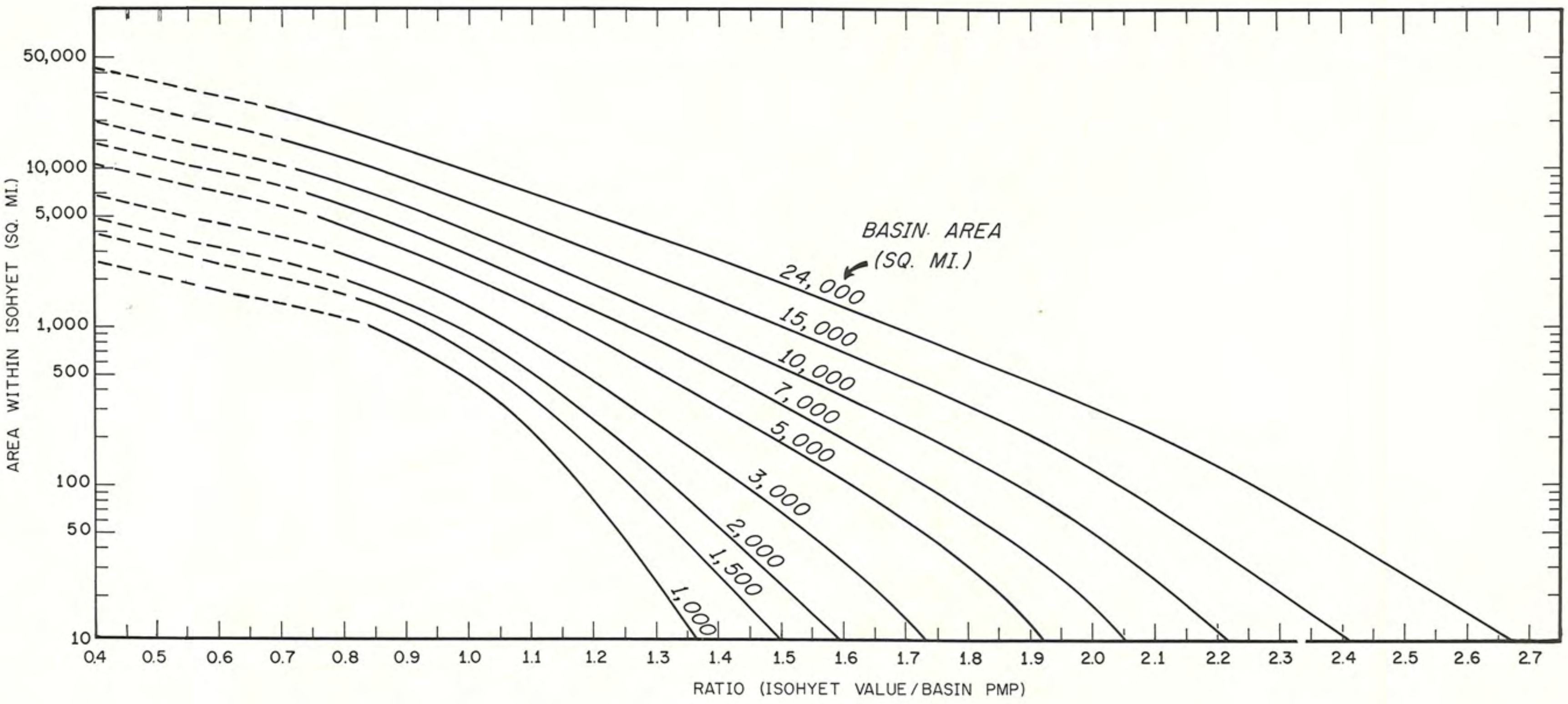


Fig. 16b. Nomogram for isohyet values in pattern storms (maximum 6-hr. increment)

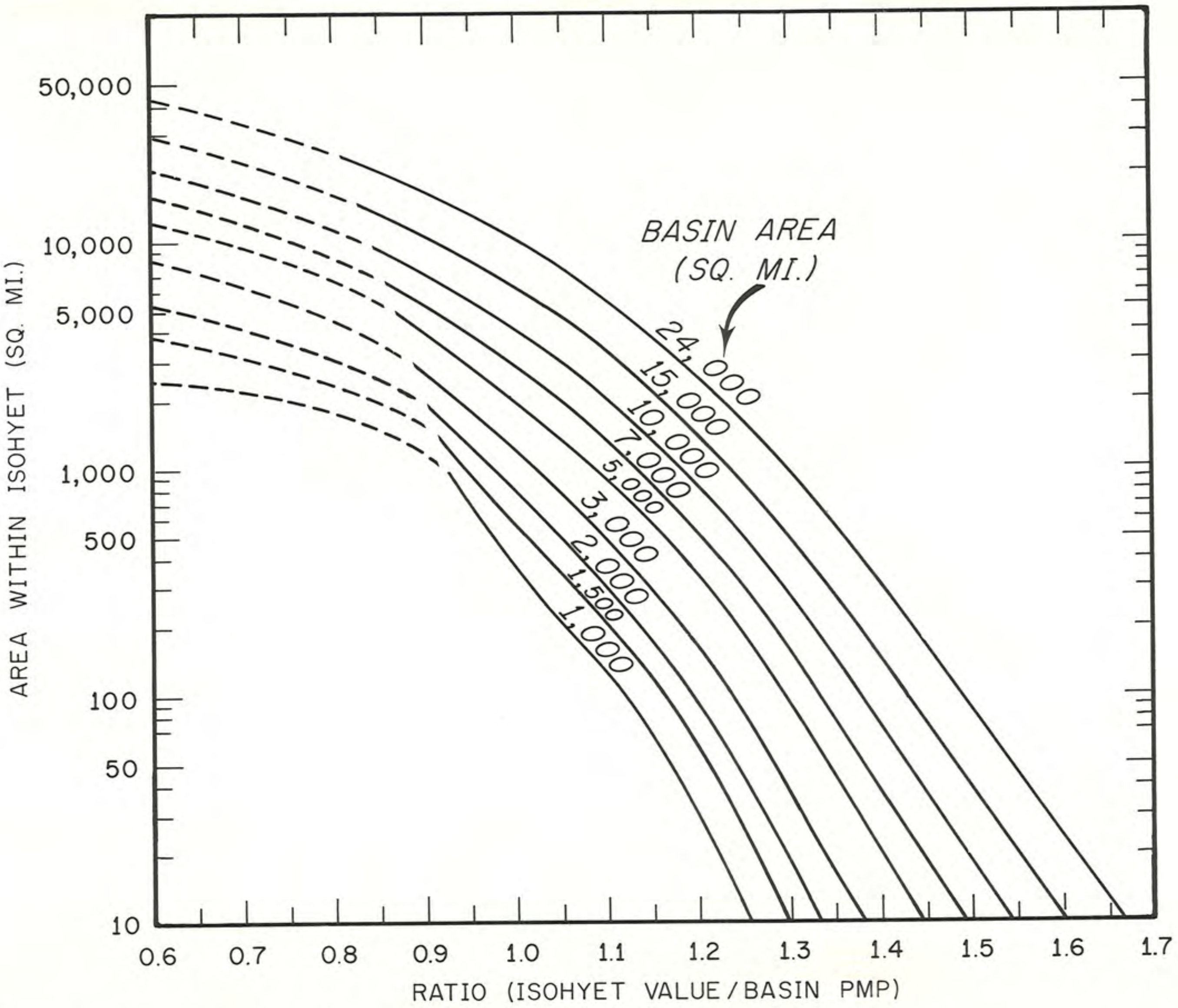


Fig. 16c. Nomogram for isohyet values in pattern storms (2nd 6-hr. increment)

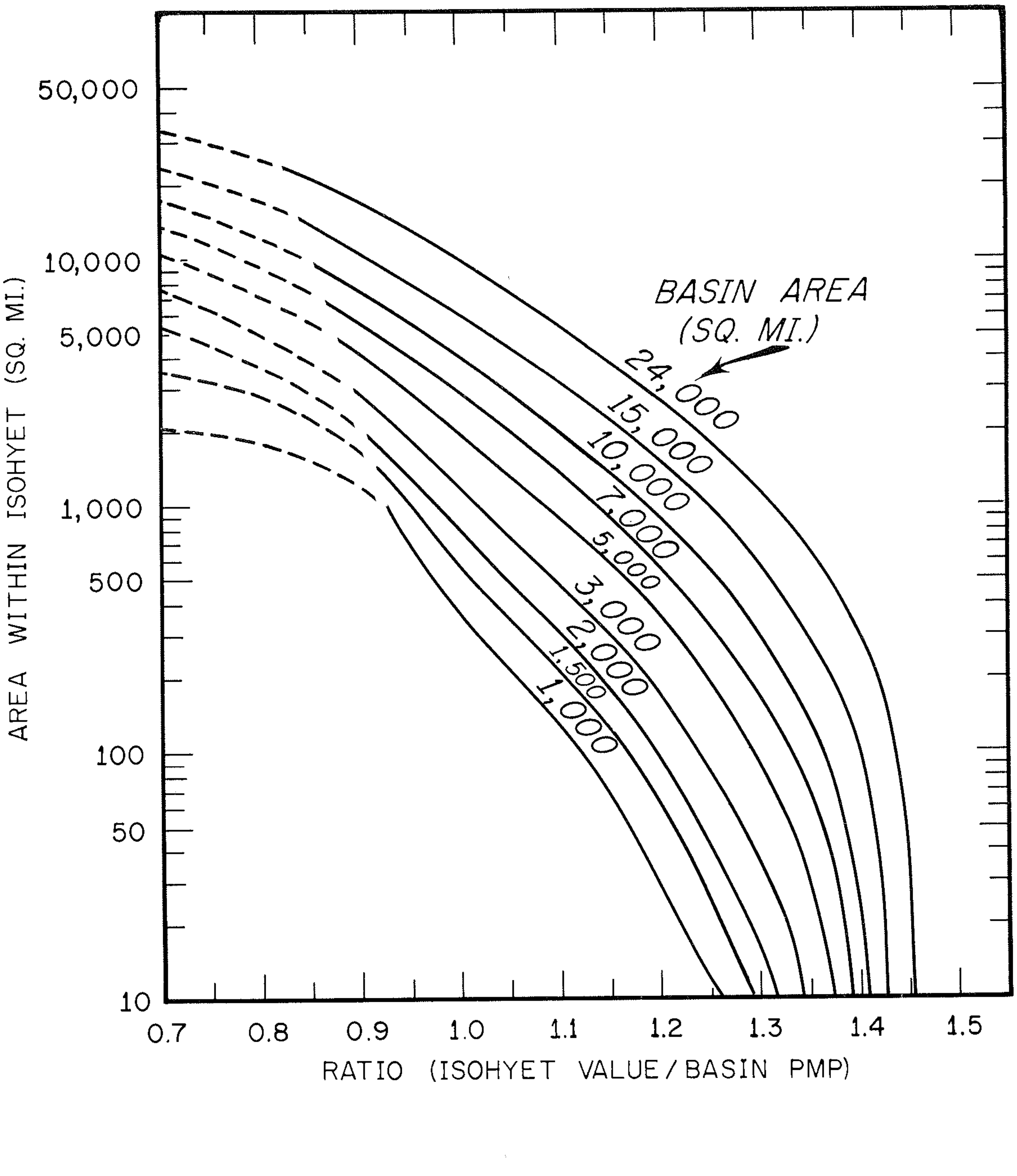


Fig. 16d. Nomogram for isohyet values in pattern storms (3rd-12th 6-hr. increments)

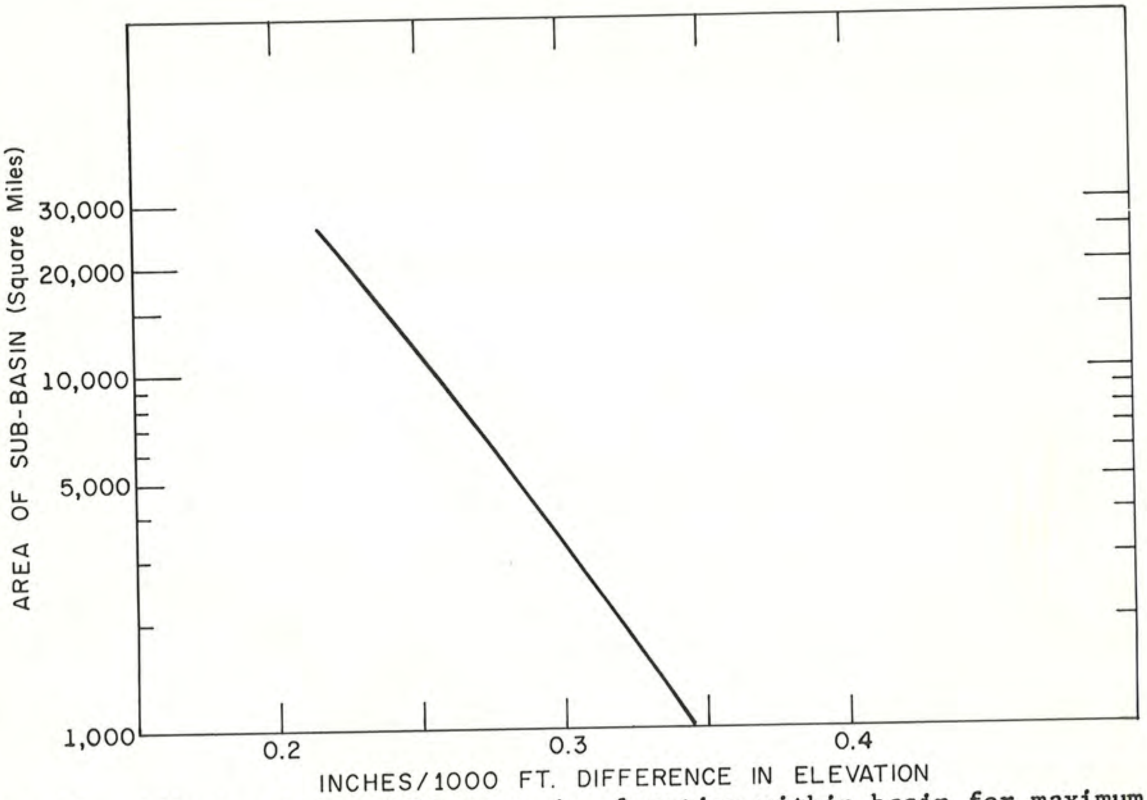
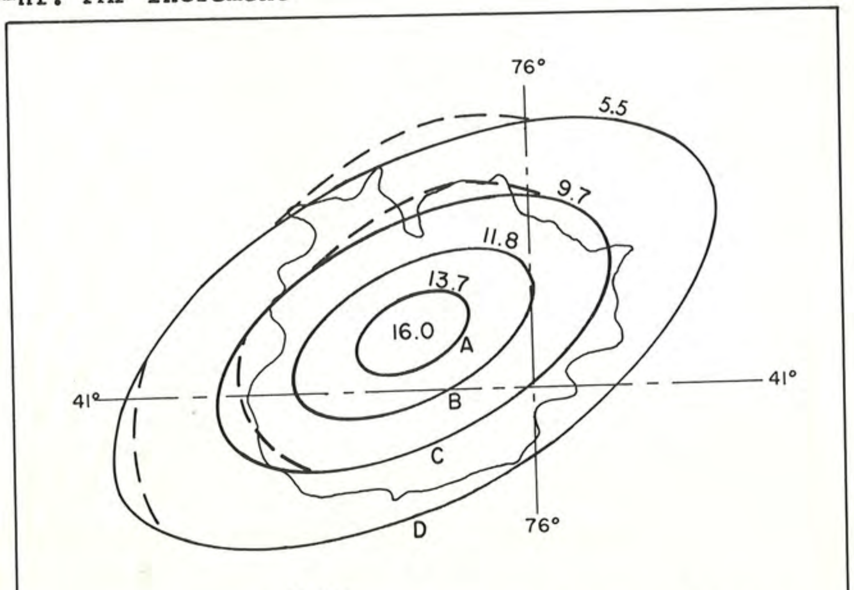


Fig. 17. Adjustment for difference in elevation within basin for maximum 6-hr. PMP increment



Notes:

1. Isohyet values (inches) for maximum 6-hr PMP increment.
2. Dashed Lines given as illustration of within-basin elevation adjustment. Not recommended for use in this basin.

Fig. 18. Isohyets for probable maximum storm. Susquehanna River between Wilkes-Barre and Danville, Pa.

☆ U.S. GOVERNMENT PRINTING OFFICE : 1965 O—776-542