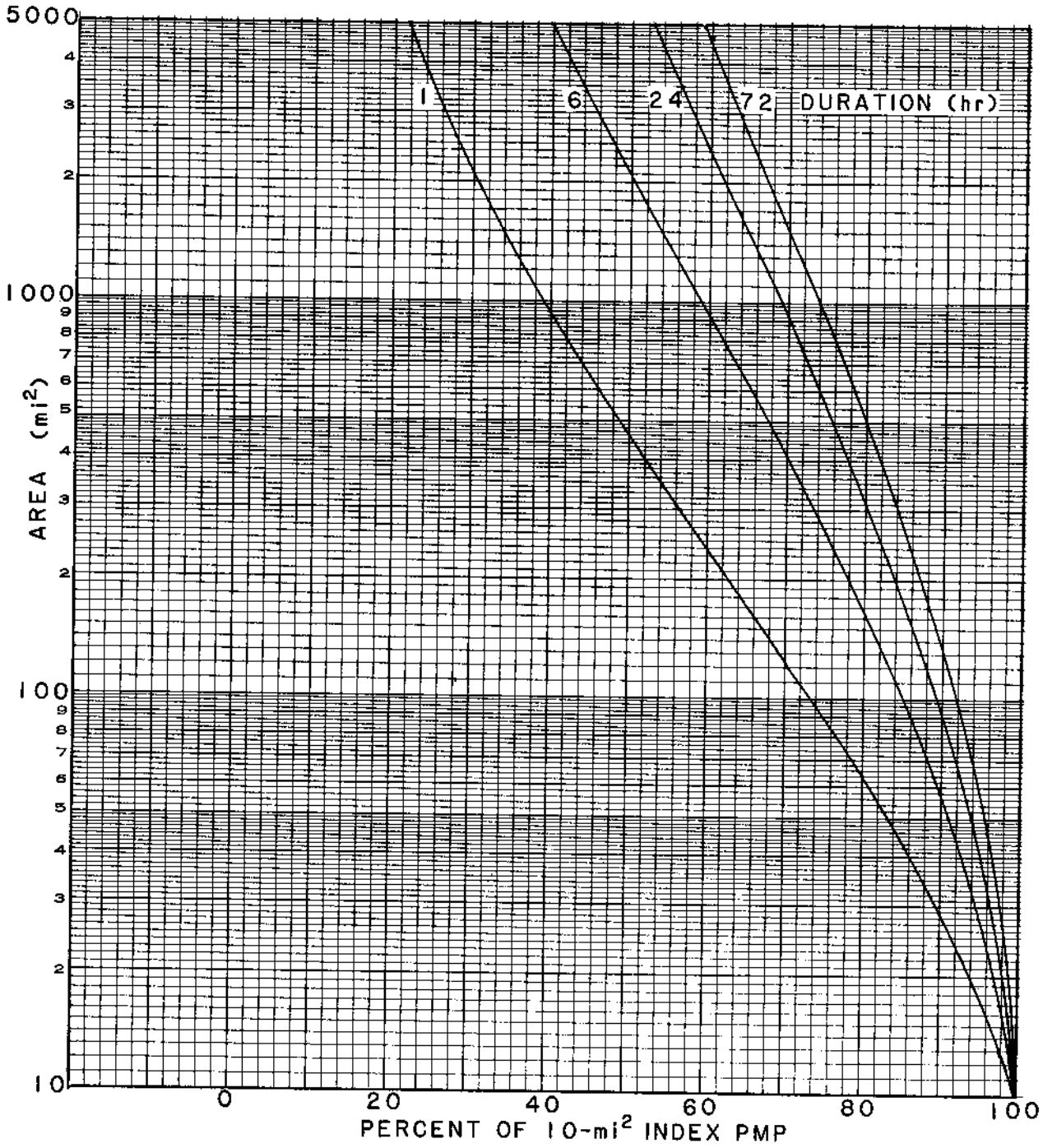

Figure 11.12.—DAD relation, B orographic subunit.

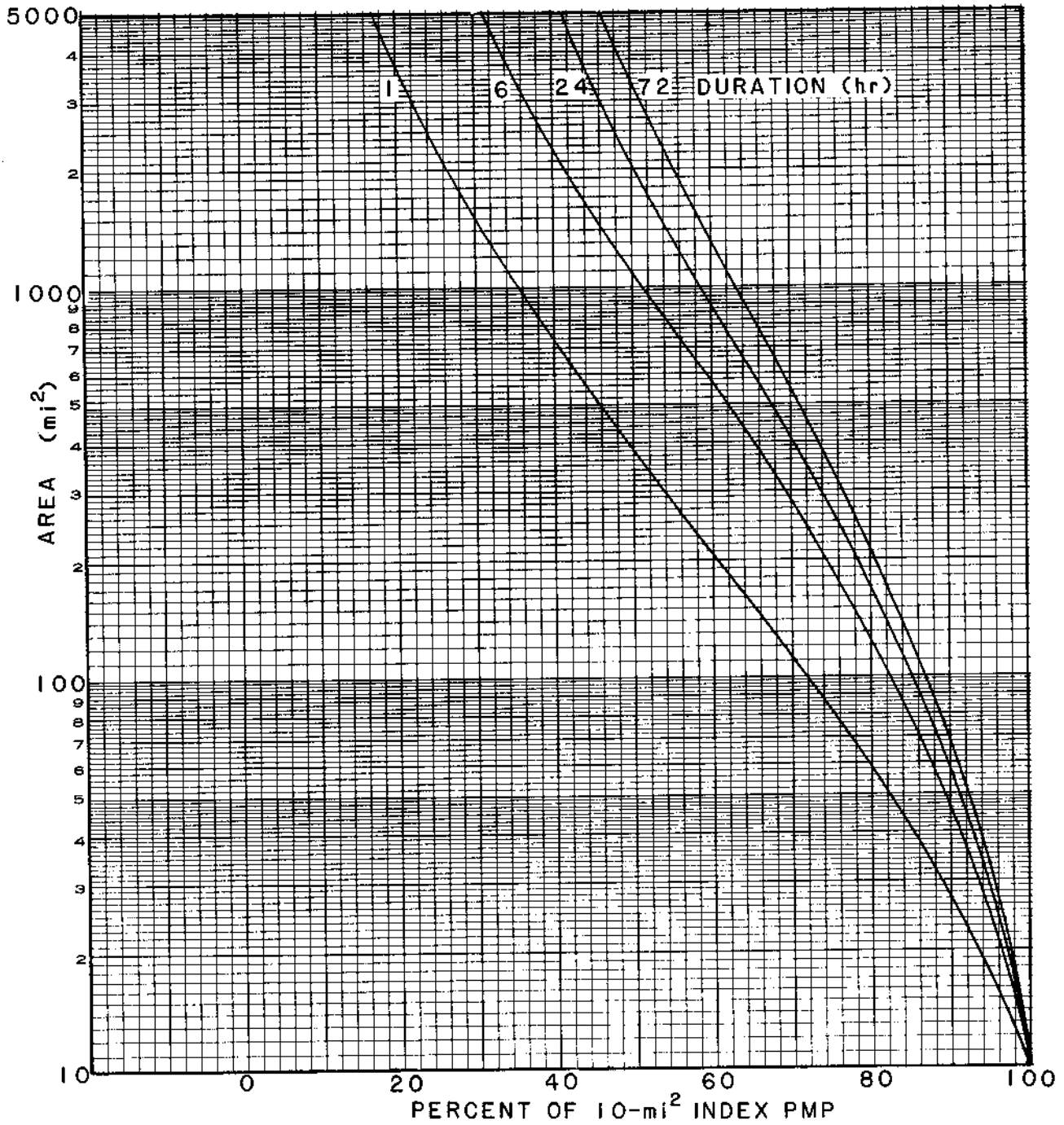

Figure 11.13.—DAD relation, D orographic subunit.

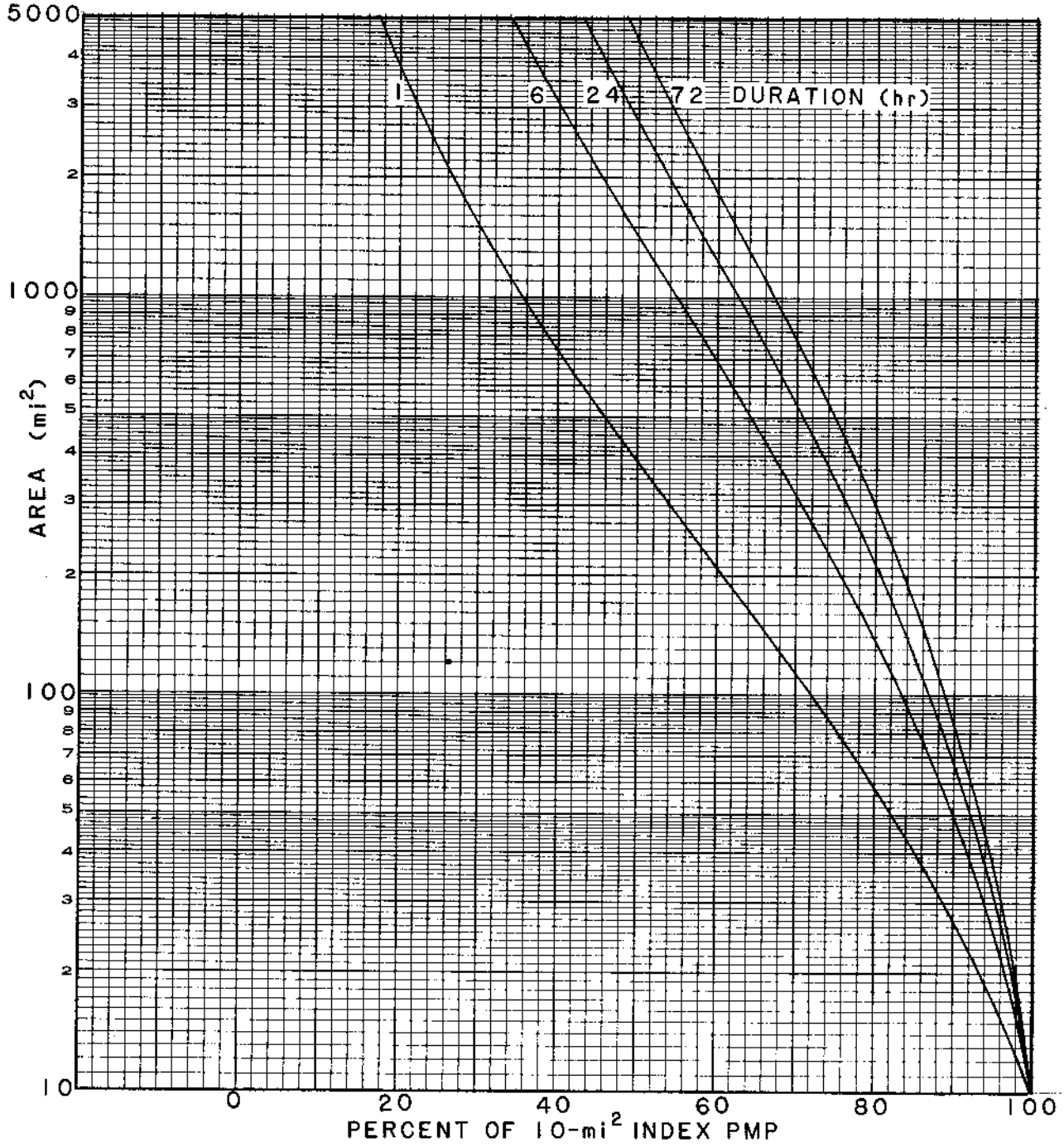

Figure 11.14.—DAD relation, A sheltered least orographic subunit.

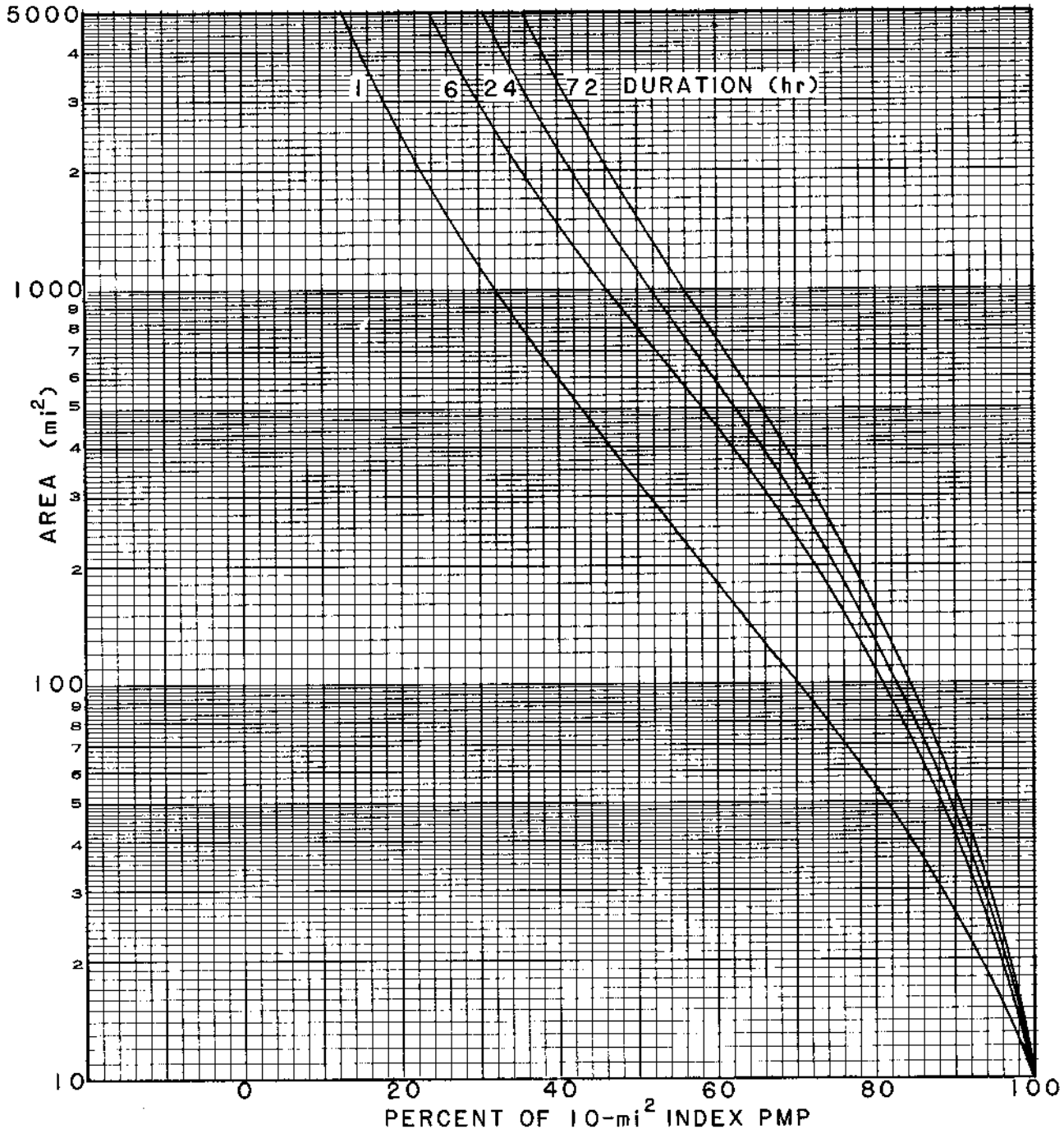

Figure 11.15.—DAD relation, E sheltered least orographic subunit.

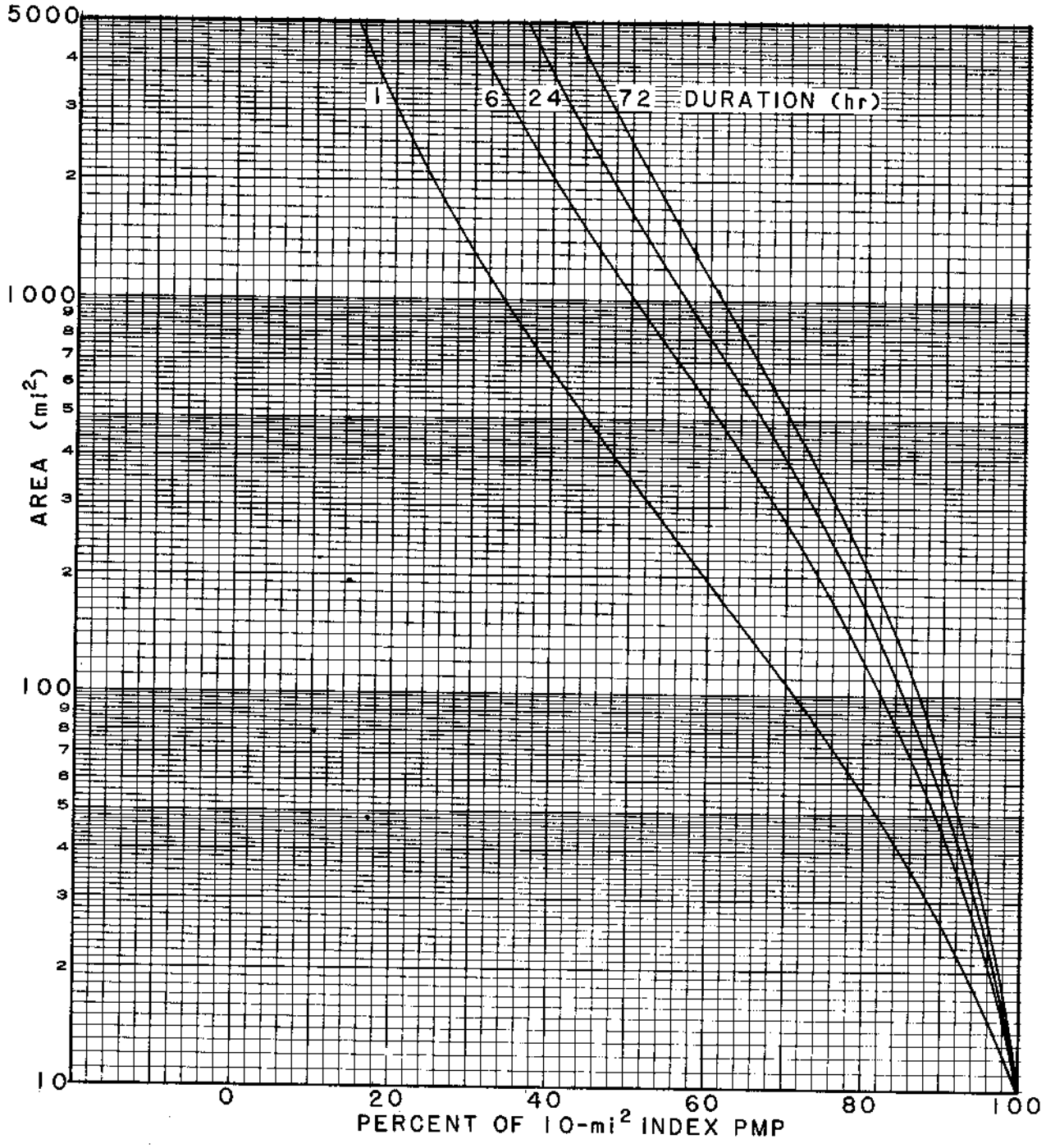

Figure 11.16.—DAD relation, C sheltered least orographic subunit.

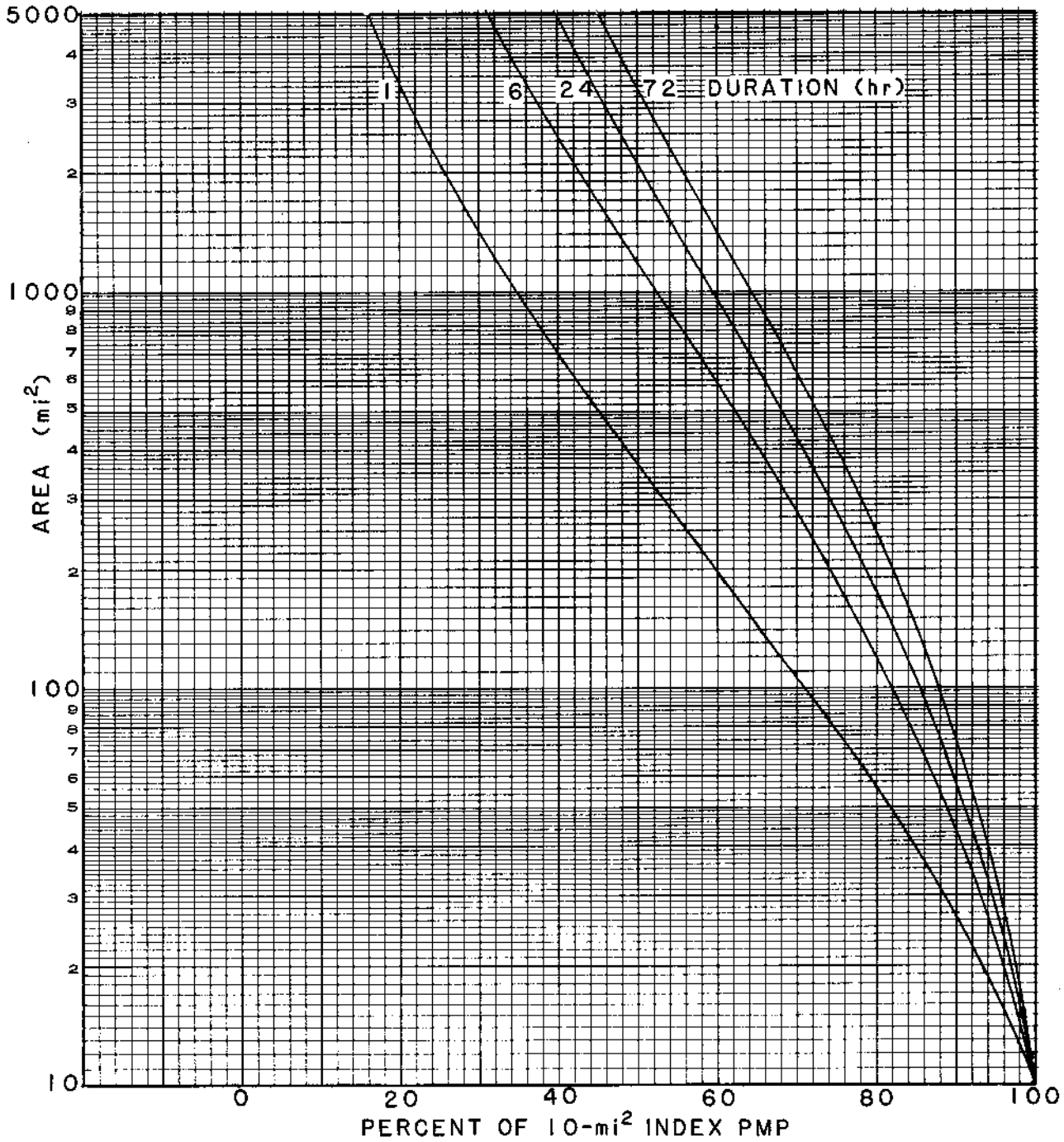

Figure 11.17.--DAD relation, B sheltered least orographic subunit.

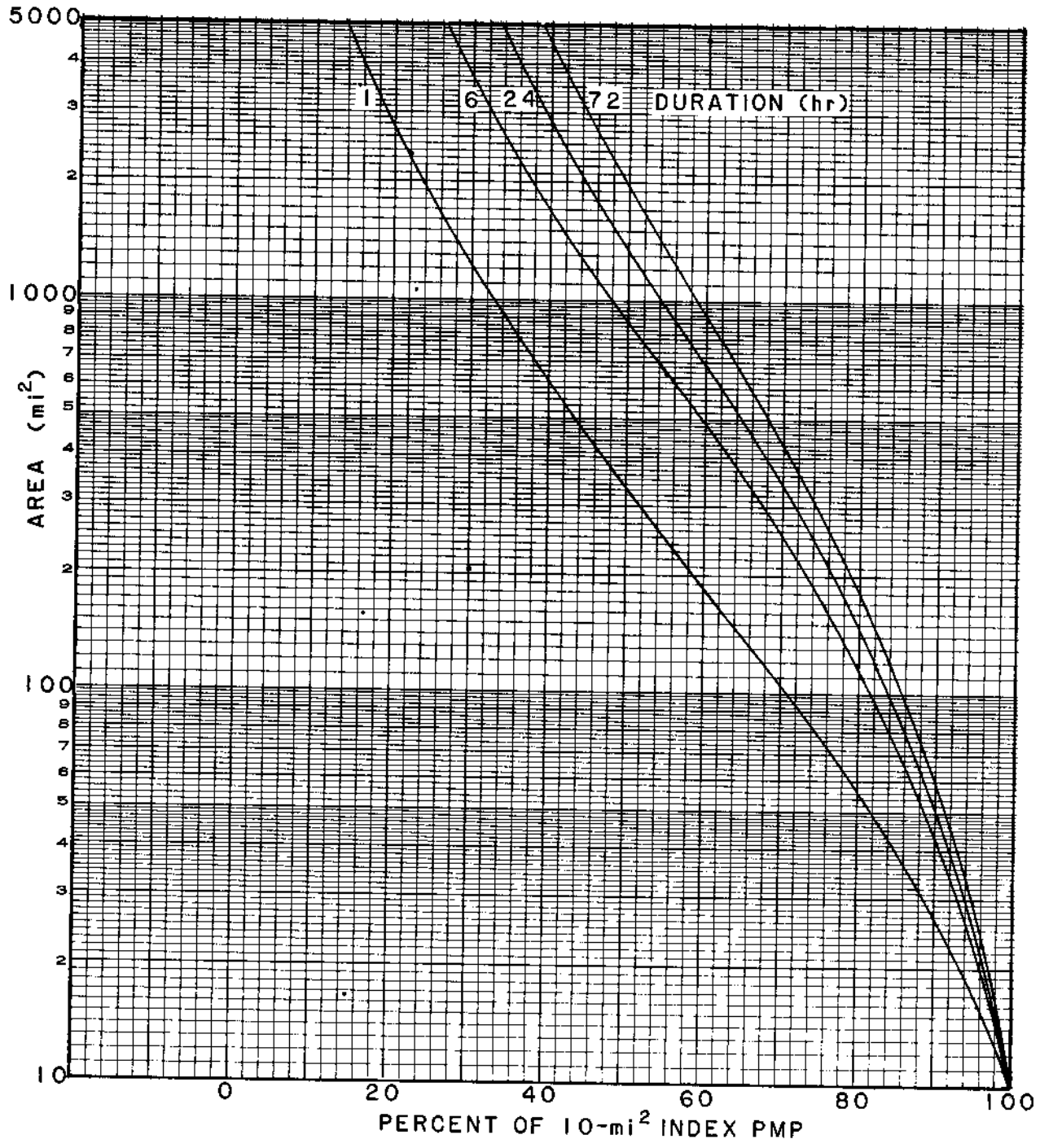

Figure 11.18.—DAD relation, D sheltered least orographic subunit.

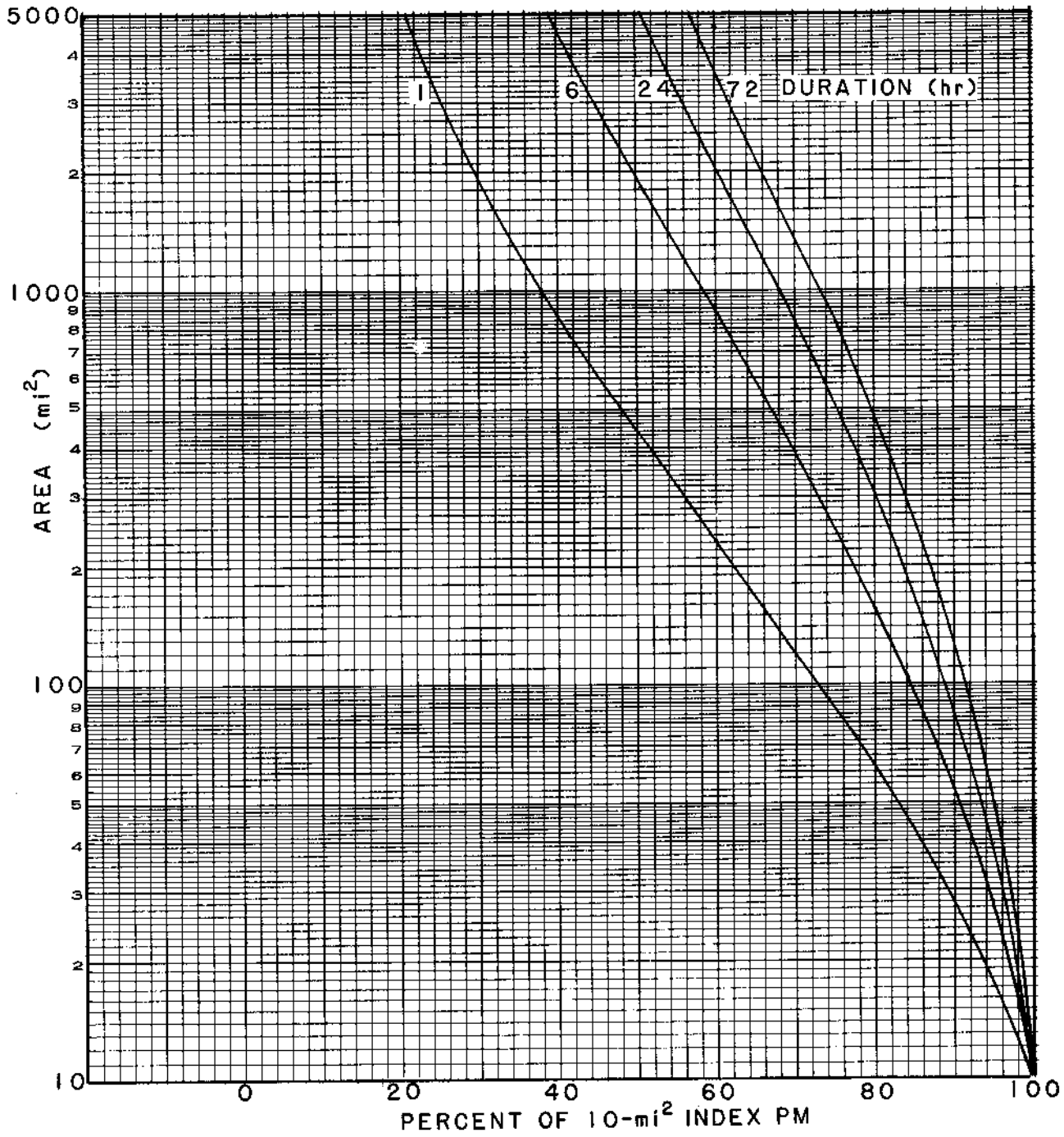

Figure 11.19.—DAD relation, A sheltered orographic subunit.

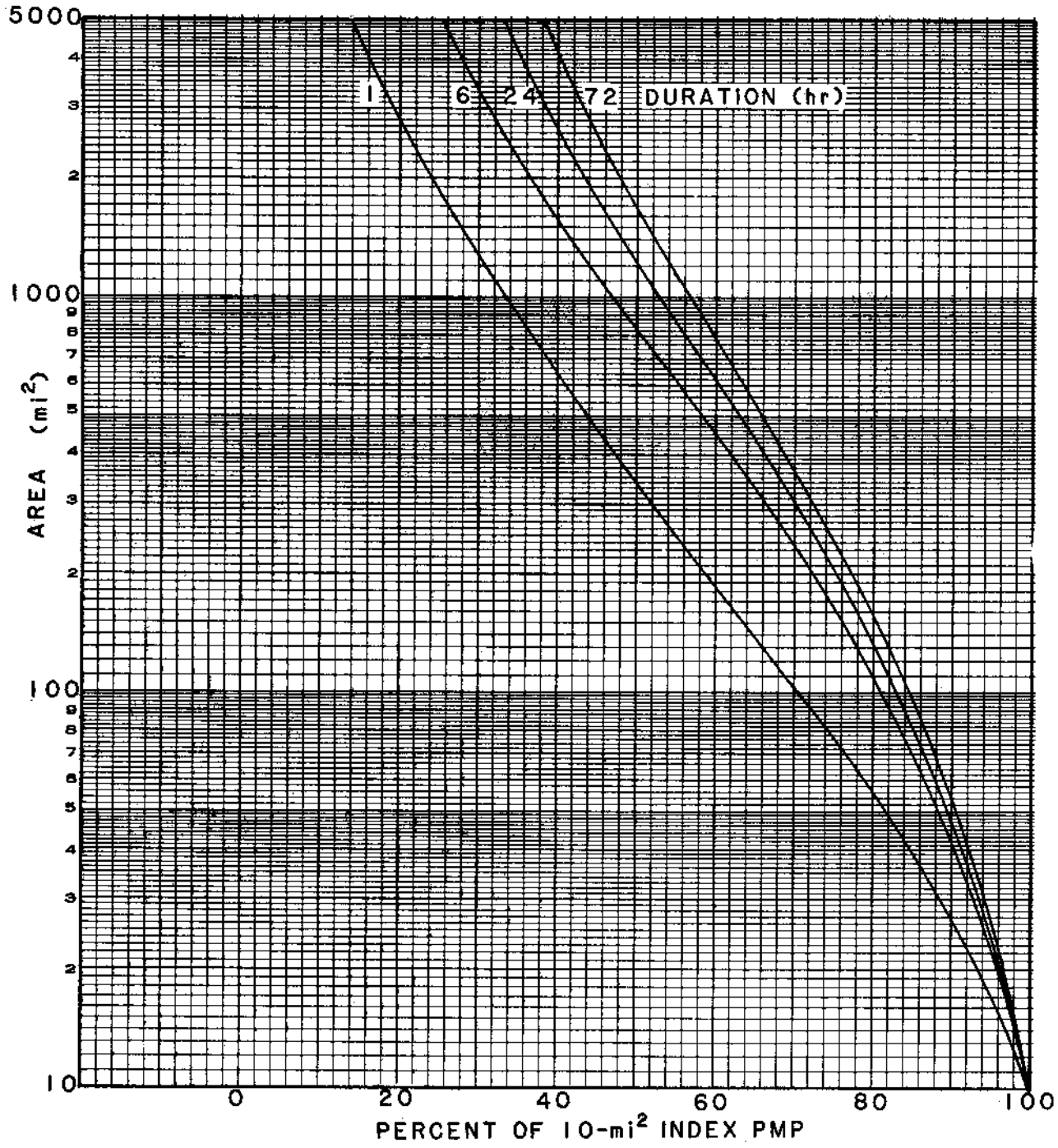

Figure 11.20.—DAD relation, E sheltered orographic subunit.

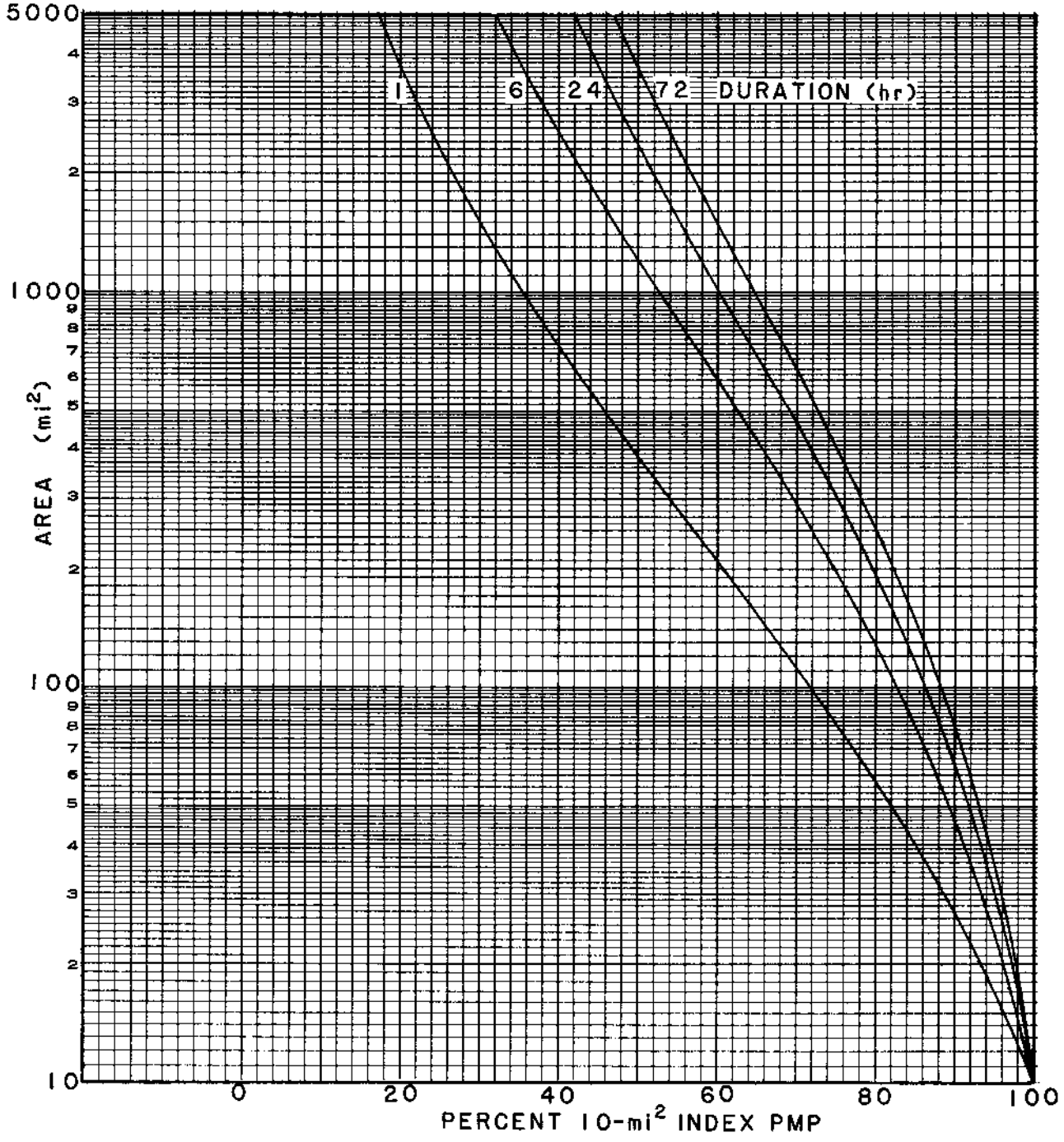

Figure 11.21.--DAD relation, C sheltered orographic subunit.

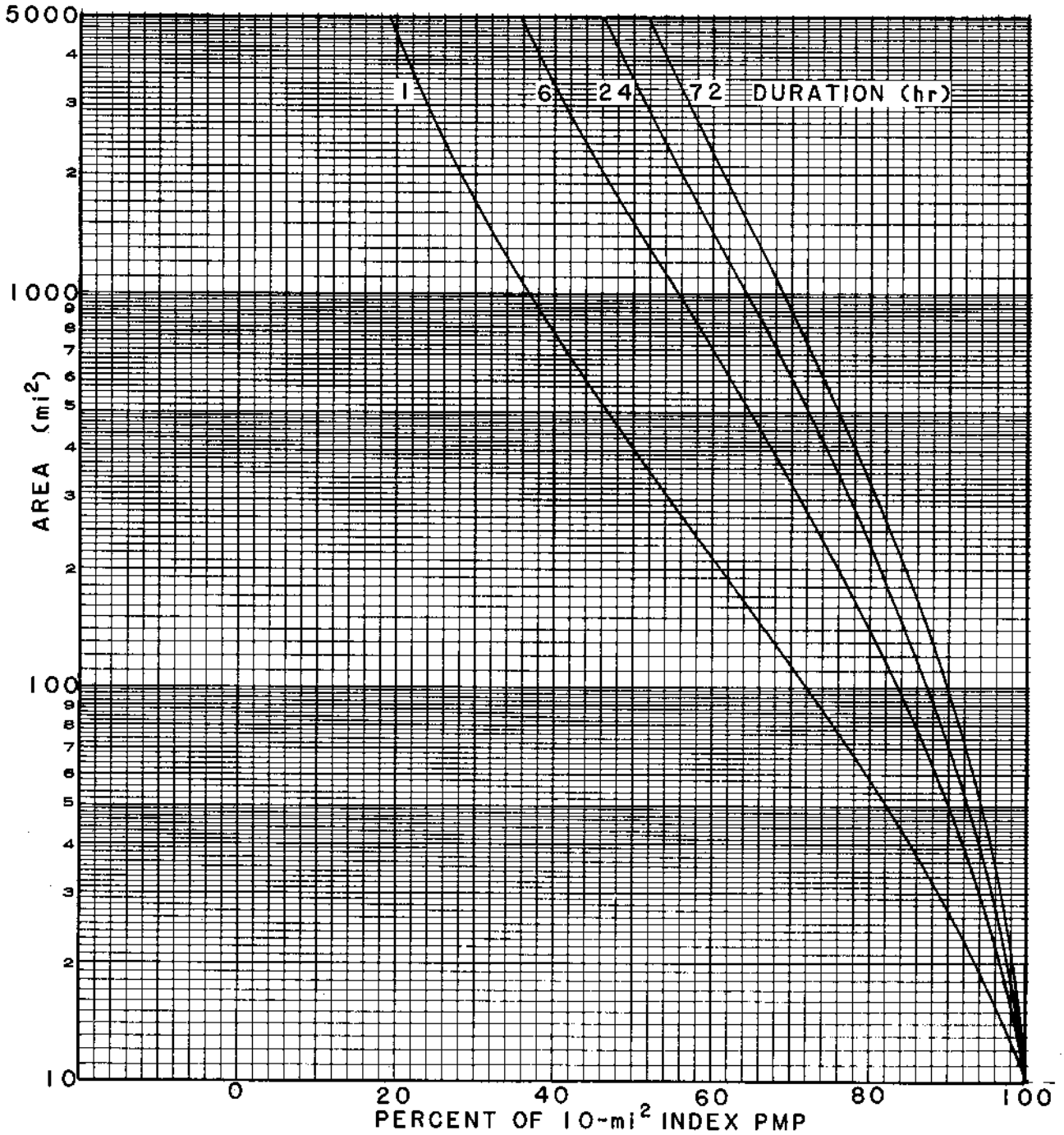

Figure 11.22.—DAD relation, B sheltered orographic subunit.

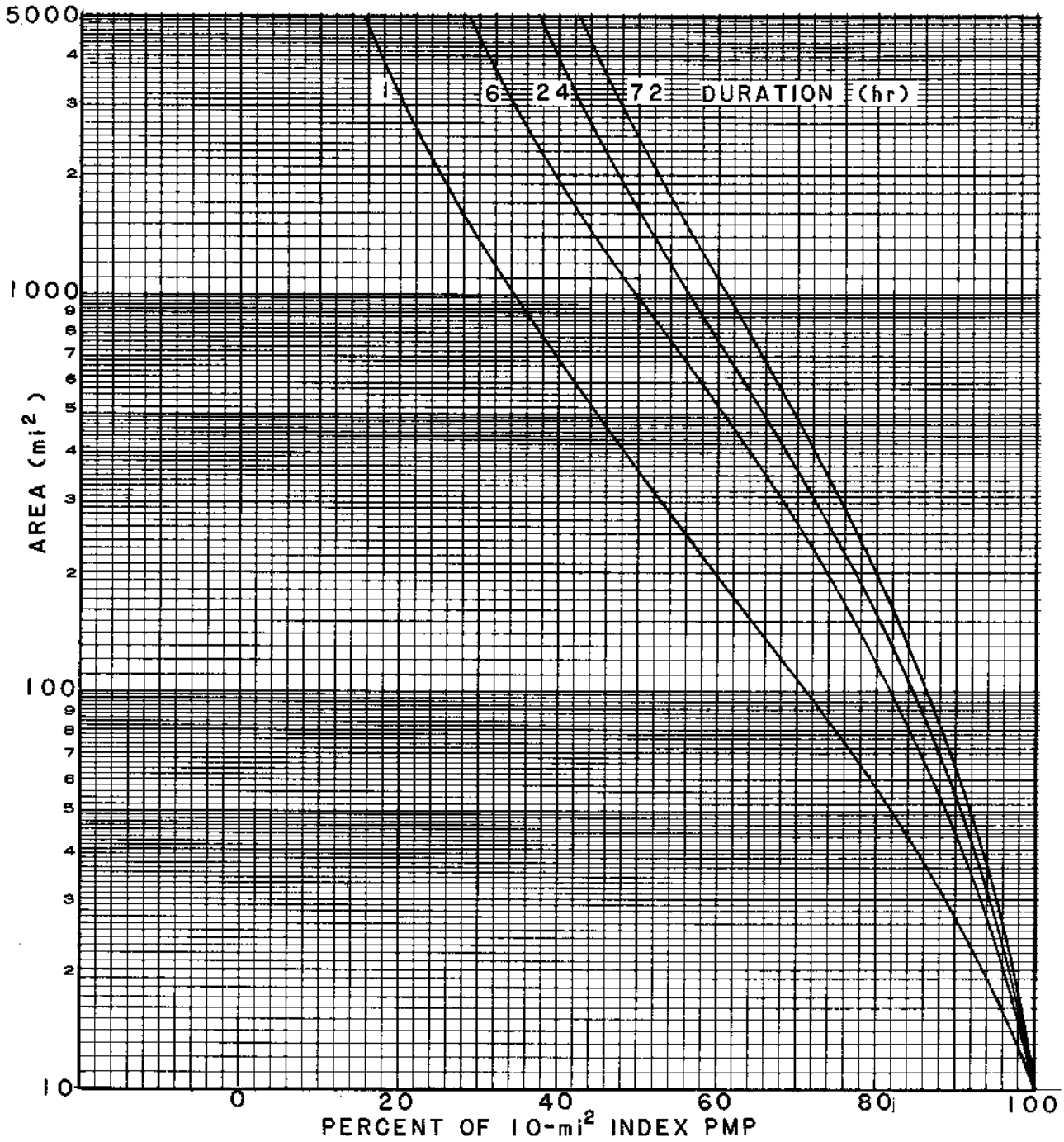

Figure 11.23.—DAD relation, D sheltered orographic subunit.

3. Cherry Creek (47). The 24-hr moisture-maximized data for this storm comes within 10 percent or less of the weighted relations in figures 11.7 and 11.11 for areas up to 100 mi^2. At 6 hr, moisture-maximized values for areas less than 100 mi^2 are undercut, although observed data are enveloped. Envelopment by 10 percent or less occurs between 100 and 200 mi^2.

4. McColleum Ranch (58). Weighted DAD from figures 11.8, 11.15 and 11.20 appear to well envelop the moisture-maximized data at 6, 24 and 72 hr for this storm at areas less than 5,000 mi^2. However, the trend is such that envelopments of 10 percent or less may occur at larger areas had such information been available.

5. Vic Pierce (112). This storm was transposed without rotation to 35°N 105°W. The 24-hr moisture-maximized values are enveloped by 10 percent or less for areas between 1,000 and 3,000 mi^2, and at 72 hr between 300 and 5,000 mi^2. At 6 hr for all areas envelopment exceeds 10 percent (fig. 11.8 and 11.10).

11.5 Conclusions on DAD Relations

A system for developing DAD relations for 21 subunits of the CD-103 region is described in this chapter. The system is based on available storm data used in a semi-objective methodology. It is substantiated by how well the derived PMP values compare with moisture-maximized storm values. The sets of DAD relations provided in figures 11.3 to 11.23 represent the best available set of DAD relations for the CD-103 region. The use of these procedures will be discussed in chapter 14.

12. LOCAL-STORM PMP

12.1 Introduction

The objective of this chapter is to develop the probable maximum precipitation (PMP) for local storms in the CD-103 region and to provide generalized estimates of these values. Local storms, because of their intense short-duration nature, are believed to be potentially significant when judging the level of PMP for areas less than 500 mi^2 and durations less than 6 hr. Major local storms of record and the method used to determine the magnitude of local-storm PMP are discussed. An index map (Plate VI) is provided for the 1-hr 1-mi^2 PMP, along with relations to obtain PMP for other durations and area sizes.

Previous generalized PMP studies have found regional differences in the environment that produces intense convective storms. In HMR No. 49 (Hansen et al. 1977), which covers an area of substantial topographic relief and sheltering, local storms were shown to be strongest when not embedded within general type storms. Conversely, in the region covered by HMR No. 51 (Schreiner and Riedel 1978), an area of relatively little topographic relief, convective storms were strongest when embedded in general type storms.

In the CD-103 region, HMR No. 55 considered the single-storm (general storm that included significant short-duration convection) and the two-storm (local and general storm are independent) approaches. A decision was made in HMR No. 55 to restrict the two-storm approach to three sheltered regions along the Continental Divide. This restriction brought about some difficulty along boundary zones that

was resolved at the time by manual smoothing. This smoothing produced some artificially higher levels of general-storm PMP than would otherwise have been obtained at these locations.

During the review of HMR No. 55, one consideration tested was to determine the consequences of providing local-storm PMP throughout the CD-103 region. The feasibility and advantages of this modification were discussed by the various federal agencies involved with this study, and it was agreed that the local-storm PMP should be determined everywhere in the region. The following sections describe the process used to obtain local-storm PMP for HMR No. 55A. Comparisons of some major local storms are presented in chapter 13.

12.1.1 Local-Storm Definition

The local storm is a small, isolated cell or group of cells commonly referred to as a thunderstorm. When a local storm becomes highly developed through convective uplifting of unusually moist air, it is capable of producing high rainfall intensities and excessive precipitation amounts over small areas in short periods of time.

For the purpose of this study, the duration of these extreme local storms is usually thought of as being less than 3 hr; however, they may extend to 6 hr, or slightly more with the merging of individual cells. A lower threshold of 3 in. of precipitation in 1 hr was placed on all extreme local storms considered. This is an arbitrary limit designed to screen out less important storms. For some of the observed storms the 1-hr amount was not explicitly given. In those cases reasonable judgment based on accepted durational relations was applied to obtain an estimate.

To apply the above definition to storms in the CD-103 region, a set of criteria was developed to classify storms as local. These criteria were:

1. The duration of the storm is short (less than 6-hr).

2. The area of the rainfall pattern is limited (<500 mi^2) with little or no surrounding rain where the reports could be grouped into clusters. This was to ensure that the storm was indeed isolated. A clear case of isolation would be one where there is a large point rainfall amount with no surrounding rain. However, because of the sparse network of observing stations it was decided to allow no more than 50 percent of the stations in an area of about 70,000 mi^2 surrounding the local storm to be reporting rain. Data sources were primarily Climatological Data (U.S. Weather Bureau 1899 -), and Hourly Precipitation Data (National Climatic Data Center 1951 -).

3. There is no apparent correlation between the storm and distinguishable rain-producing synoptic weather features. This was to ensure that the storm was not embedded in a larger, general type of storm. Generally, fronts and low-pressure systems were not closer than 200 mi from a candidate local storm. However, this distance was sometimes modified, depending on the particular characteristics of the synoptic situation. Such characteristics may include the moisture content, strength of feature, and rate at which a feature propagated downstream, among others.

These three basic criteria were used to evaluate candidate storms for classification as local storms in the CD-103 region.

12.1.2 Meteorology of Local Storms

The source of moisture for the CD-103 region, and therefore for the local storms of the region, is the Gulf of Mexico. Large, high pressure centers over the central United States work in conjunction with the thermal low pressure, which forms over northern Mexico, to pump Gulf of Mexico air into the region. The southeasterly flow into the region carries moisture-laden air, which, when it meets the cooler drier mountain air, increases the degree of conditional instability. As low level air is heated during the day, and, in some instances, forced upwards by the mountains, the conditional instability is released, causing frequent local storms during the late afternoon and early evening. This suggests that insolation plays an important role in the release of the conditional instability. Because identification of the track of moisture to a specific local event is difficult, the actual moisture source for most local storms is somewhat less certain than for generalized type storms.

There appears to be no clear pattern at the 500-mb level indicative of the outbreak of strong local storms. Often times at 500 mb there is a ridge over the area where an extreme local storm has occurred; however, ridges at this altitude (approximately 20,000 ft) are broad, large-scale features, covering tens of thousands of square miles; their importance is, therefore, difficult to assess relative to the much smaller (<500 mi^2) local storm.

12.2 Record Storms

12.2.1 Introduction

PMP is based on significant storms of record. Such storms provide a basis for the determination of the PMP level by presenting realistic weather situations to be analyzed. There are only a few examples of severe local storms in the CD-103 region among the storms for which data were available in the National Weather Service (NWS) Hydrometeorological Branch. Primarily this is because of the small spatial coverage of local storms and the sparsity of population in the region. Only a few local storms in the region have been documented. An extensive search was conducted for storms from other sources that might supplement the established storm record. From a group of 12 candidate extreme storms, four were selected as shown in table 12.1. Some of the other candidates have been listed under general storms because they could not be shown to be isolated from surrounding precipitation (see sec. 12.1.1). Three of these extreme local storms are listed along with additional pertinent data in table 12.2. In addition to the three storms from the CD-103 region listed in table 12.2, data on the local storm that occurred at Morgan, UT on August 16, 1958 is provided and used in this study for comparison purposes.

The storms shown in table 12.2 are from a period of record which covers roughly 90 years. The last 48 years provided all three of the extreme local storms that occurred in the CD-103 region. This is probably due to better documentation and

Table 12.1.--Candidate local-storm list

Storm No.	Storm name	Lat. (°) (')	Long. (°) (')	Elev. (ft)	Date	Duration (Hr)	Amt.	Ref*
48.	Las Cruces, NM	32 19	106 47	3900	8/29-30/35	9	10.0	5
51.	Leadville, CO	39 15	106 18	10200	7/27/37	.75	4.25[A]	3, 4
55.	Masonville, CO	40 26	105 13	6000	9/10/38	1	7.0	1
67.	Golden, CO	39 44	105 14	5993	6/7/48	2[B]	6.0	2

*Reference

1. Water supply paper 997
2. From Storm Rainfall in the U.S. (Corps of Engineers)
3. Climatological Data
4. Station Report, station history
5. Hydrometeorological Branch files

Notes:

A. Questionable amount, see discussion p. 183
B. Two-hour storm, but at 1 mi^2 the 1- and 2-hr values were the same.

increased observation potential as population increased in the region. This may, at first glance, not appear to be well supported in table 12.2, since only one local storm (Morgan, Utah) listed in the table occurred later than 1948. However, there were also storms of a local nature that do not appear in table 12.1 or table 12.2, because they did not meet the lower limit rainfall criteria in the local-storm definition. The majority of these smaller "local storms" occurred within the last 20 years of the period of record.

All major occurrences of local storms (sec. 12.1.1) that were known were considered. Some storms of possible local nature were excluded because of a lack of critical data. The Sweetwater, CO storm of July 12, 1976 was such a storm. Although an amount exceeding 10 in. was claimed, investigation showed this to be only an estimate not based on supportable data. Therefore, the Sweetwater, CO storm was not included in table 12.1.

The Leadville, Colorado, storm (51) of July 27, 1937, is an interesting situation. Leadville, at an elevation of 10,200 ft, experienced a significant local storm that was recorded as 4.25 in. in about 45 minutes, having started about 1:15 in the afternoon. Only rarely has any appreciable rainfall been recorded at such elevation (see for example discussion of Chiatovich Flat event (Hansen and Schwarz, 1981)). The local newspaper described the storm as being one of the worst in many years, while noting some of the damage to rail lines and the debris deposited at the alluvial outflow.

Table 12.2.—Extreme local storms in CD-103 region*

Storm no.	Location of storm center	Storm date and time	Lat. (°) (')	Long. (°) (')	Elev. (ft.)	Storm duration and amount Amt/Dur (in.)/(hr.)	1-hr amt. (in.)	Persisting 12-hr 1000-mb dew point Storm (°F)	Persisting 12-hr 1000-mb dew point max. (°F)	Storm dew point location
48	Las Cruces, NM	8/29-30/35 11:05 p.m. -8:05 a.m.	32 19	106 47	3900	10/9	4.2	71	78	El Paso, TX
55	Masonville, CO	9/10/38	40 26	105 13	6000	7/1	7	65	74	Akron, CO
67	Golden, CO	6/7/48 12 mid-2 a.m.	39 44	105 14	5993	6/2#	6#	65	75	310 mi. SE of storm location
	Morgan, UT*	8/16/58 4-5 p.m.	41 03	111 38	5115	6.75/1	6.75	67	75	Salt Lake City, UT

*The Morgan, UT storm has been included for comparison in the local storm evaluations, since the type of terrain features and synoptic conditions for this storm were believed similar to those of local storms in the CD-103 region.

#See footnote B, table 12.1

Crow* analyzed the Leadville record of precipitation data in considerable detail and showed evidence that the extreme amount was likely to be erroneous due to improper design and/or installation of a wind shield on the gage for a period of time that included this major storm event. We accept Crow's conclusion and have chosen therefore not to use these data in this study (thus it does not appear in table 12.2). Nevertheless, we acknowledge that an unusual local-storm event did occur at this elevation on this date although the magnitude of the amount is questionable.

It is noteworthy that none of the accepted extreme local storms listed in table 12.2 occurred in the northern half (north of 41°N) of the study region. This does not necessarily reflect a lack of local-storm occurrence in this portion of the region. The sparsity of the population in the northern half reduces the chance that local-storm events will be reported. The aerial survey of this northern portion of the region (sec. 1.6) showed it to contain some of the most desolate terrain. It is believed, however, that sufficient meteorological potential exists for the occurrence of local storms in this portion of the region.

*L. Crow, "The case of invalid summer precipitation data at Leadville, 1919-1938 and evidence that snowmelt is the overwhelming source of peak stream flow." (Unpublished manuscript, believed to be 1984).

12.2.2 Local Storms

In the following sections, a brief description is given of each of the local storms listed in table 12.2. Information regarding the storm occurrence and the factors considered in satisfying the conditions for local storms are discussed. Some information is also given about significant storms that were not regarded as local storms. The dew points referred to in this section have all been reduced to the equivalent 1000-mb value.

12.2.2.1 Las Cruces, New Mexico - 8/29-30/35 (48). During a heavy storm over Las Cruces, NM, 6.46 in. of rainfall was measured between the hours of 11:05 p.m. and 8:05 a.m. on August 29-30, 1935, at a local cooperative observation station, Agricultural College. This station is located about 2 mi southeast of Las Cruces, and about 8 mi west of the Organ Mountains which rise to about 9,000 ft. The elevation at Las Cruces and at Agricultural College is about 4,000 ft. Precipitation records in Climatological Data (U.S. Weather Bureau 1899 -) were accessed for the period of the storm. Many stations reported precipitation on the 30th, making the Las Cruces storm a marginal case; however, no data are available on the timing of other station rainfall. This, coupled with the lack of an apparent surface synoptic feature which could be related to the precipitation, led to acceptance of the storm as an extreme local storm.

The most unusual characteristic of this storm was its length. As a 9-hr storm, it represents an exception to the previously stated 6-hr duration limit imposed on local storms. It is important to recognize that most of the rain at the observation site (5.85 in.; 90%) fell within the first 3.5 hr. Subsequent rainfall was probably from lingering storm cells in the area.

An estimate of maximum point rainfall for this storm is 10 in. in 9 hr (U.S. Corps of Engineers 1945). This amount was accepted based on consideration of other recorded rainfall amounts from unpublished supplementary precipitation surveys, published rainfall amounts, and the resulting isohyetal pattern.

Storm dew points were determined from persisting 12-hr dew points for stations surrounding the storm area. Dew-point data were generally checked for the 24-hr period leading up to, and including, the storm period. This procedure was followed for all the storms considered in this portion of the study. The representative storm dew point for the Las Cruces storm (48) was based on dew-point data from El Paso, TX. This station lies along a moisture inflow path that reaches Las Cruces from the Gulf of Mexico. The representative persisting 12-hr 1000-mb storm dew point was 71°F.

Northern Hemisphere synoptic surface weather maps (Environmental Data Service, 1899 -) for August 29 and 30, 1935, are shown in figure 12.1. The August 30 chart depicts the synoptic surface situation about 2 hr before the end of the storm. Of particular interest are the thermal low pressure center over Mexico, and the high pressure center over the Plains States. These two features pumped moisture-rich air from the Gulf of Mexico into New Mexico. This process is noted as being prevalent in local storms in section 12.1.2. The result was an outbreak of storms on the night of the 29th and early morning of the 30th, the largest recorded precipitation amount was from the Las Cruces storm (48).

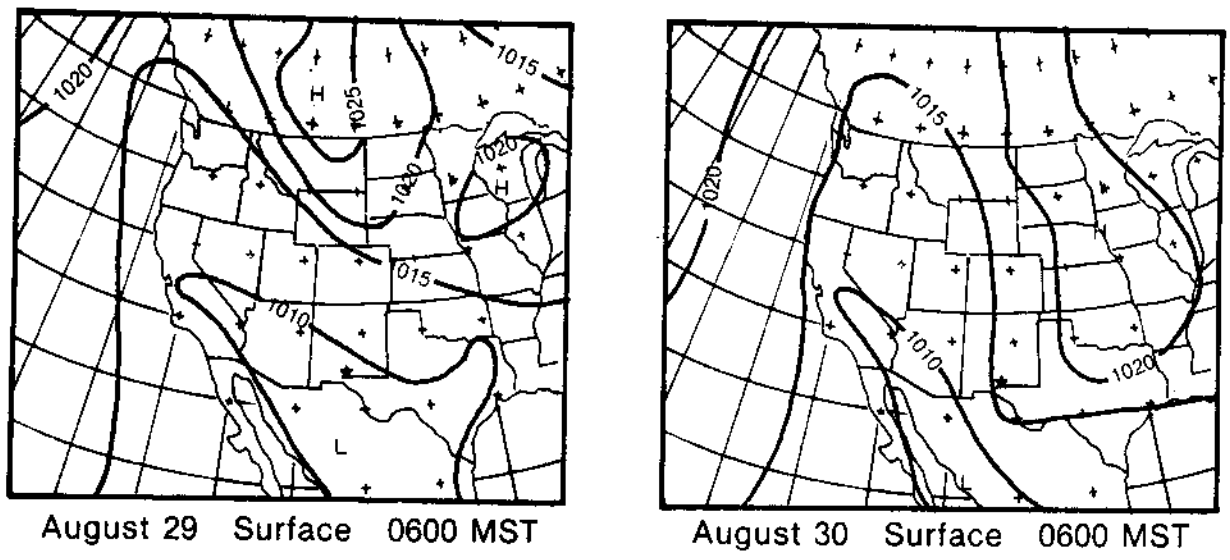

Figure 12.1.--Synoptic surface weather maps for August 29 and 30, 1935 - the Las Cruces, NM storm (48).

A lack of surface weather fronts in the entire western United States suggests that the storm was not related to any particular synoptic weather feature. Upper air data to support this observation were not available. The storm was probably accompanied by the passage of a trough at the 500-mb level (U.S. Weather Bureau 1967).

The Las Cruces storm does not play a significant role in the determination of 1-hr 1-mi^2 PMP in the CD-103 region. Moisture-maximized transposed amounts were generally less than 50 percent of those of the controlling storm at each transposed location. Since the storm is of little significance, no precipitation pattern for the storm is included.

12.2.2.2 Masonville, Colorado - 9/10/38 (55). The Masonville, CO storm on September 10, 1938 is the most important local storm in this study. This is because of the large amount of precipitation (7 in.) that fell in a relatively short period of time (1 hr) in this storm.

The storm actually occurred about 3 mi south of Masonville, near the Missouri Canyon in northern Colorado at an elevation of about 6,000 ft. It has been referred to as the Missouri Canyon storm in other literature (Hansen et al. 1978). The only records of this storm came from a handful of ranchers in the area. Of these, one rancher reported "...about 7 in. within a half hour." Another rancher, approximately one-half mile from the first, reported "...about 5 in., which occurred between 6 and 7 p.m., most of it within 20 minutes..." (Follansbee and Sawyer 1948). Words such as "about" and "most" make evaluating these reports difficult. In light of the fact that rain lasted approximately 1 hr only one-half mile from the 7-in. report and the vagueness surrounding the 7-in. amount, it was decided to accept the Masonville storm as 7 in. in 1 hr. The 1- to 30-min ratio from typical local storms in HMR No. 49 (see table 12.4) is 1.16 (1.0/0.86). On this basis, if the 7-in. depth actually accumulated in 30 min, a typical value for the 1-hr depth would be 8.1 in. This is 14 percent greater than the 1-hr value of 7 in. chosen for this storm. This would suggest that the decision to use 1 hr for this storm amount is not excessively conservative.

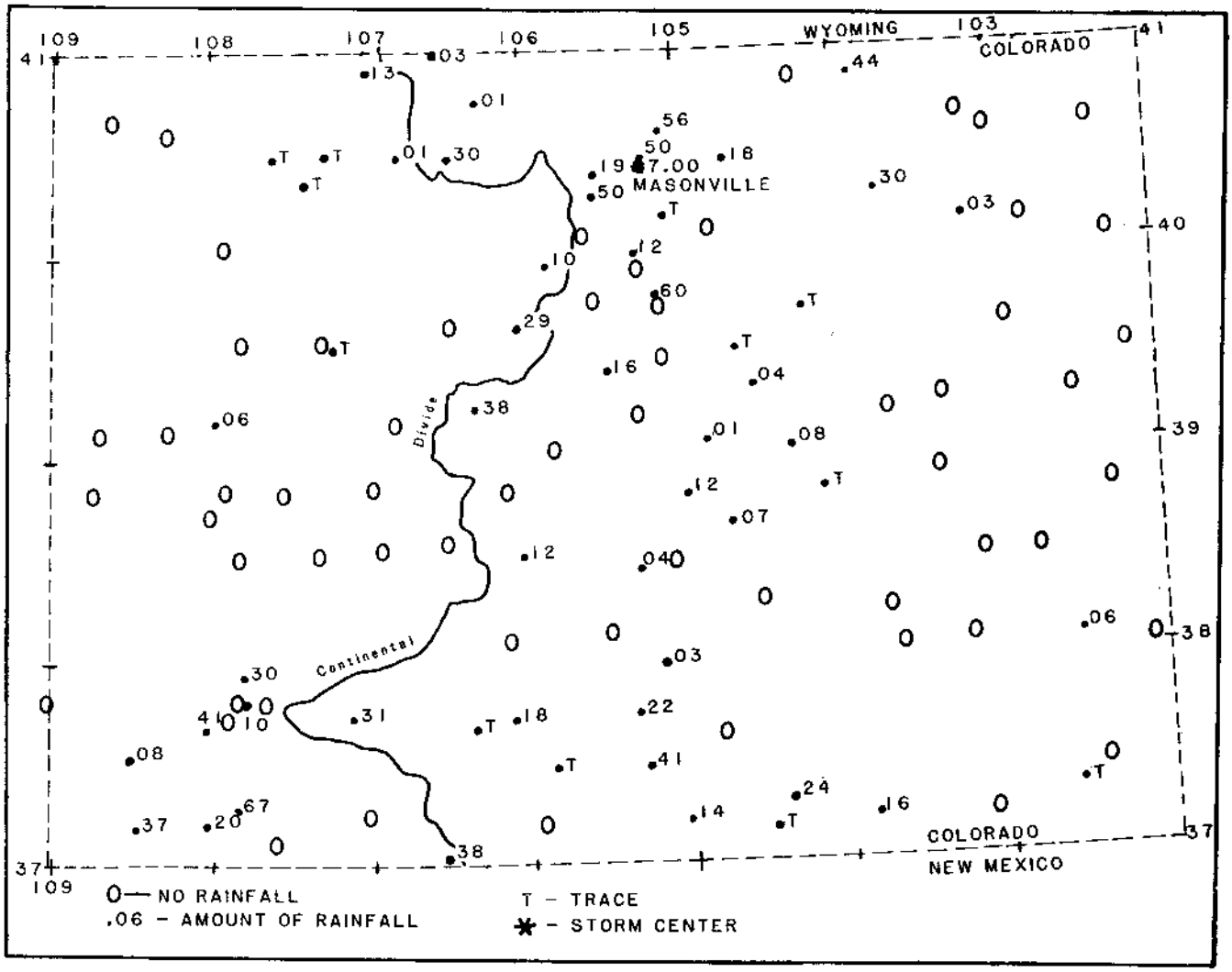

Figure 12.2.--Precipitation map, Masonville, CO storm (55) - September 10, 1938.

The representative persisting 12-hr storm dew points for the Masonville storm were sought using dew-point data from first-order reporting stations. Dew points were checked at Denver and Pueblo, CO, and Cheyenne, WY. Low representative storm dew points obtained from these cities prompted further investigation. Supplemental storm data were obtained for stations at Akron, Dover, Greeley, and Fort Collins, CO. All of these locations except Akron are within 50 mi of Masonville (Akron is about 100 mi east). Dew points at Fort Collins and Akron, CO, on the morning and afternoon of September 10 were several degrees (F) higher than those at other locations. Unfortunately, a gap of about 8 hr occurred in the Fort Collins data for the 10th. In light of this fact, and the favorable wind direction at Akron for advecting moisture towards the storm location, the Akron dew point (65°F) was accepted as most representative of the Masonville storm moisture. The Fort Collins dew point (64°F) supports the Akron dew point.

The geographic distribution of the rainfall surrounding the Masonville storm is shown in figure 12.2. The plotted data show the pattern as mostly disorganized on the 10th. Rainfall was scattered around the state in the form of numerous isolated storms, as shown by the large number of stations that reported no rainfall on the 10th. There were no reports of extreme or unusual amounts of rainfall other than for the Masonville storm (55).

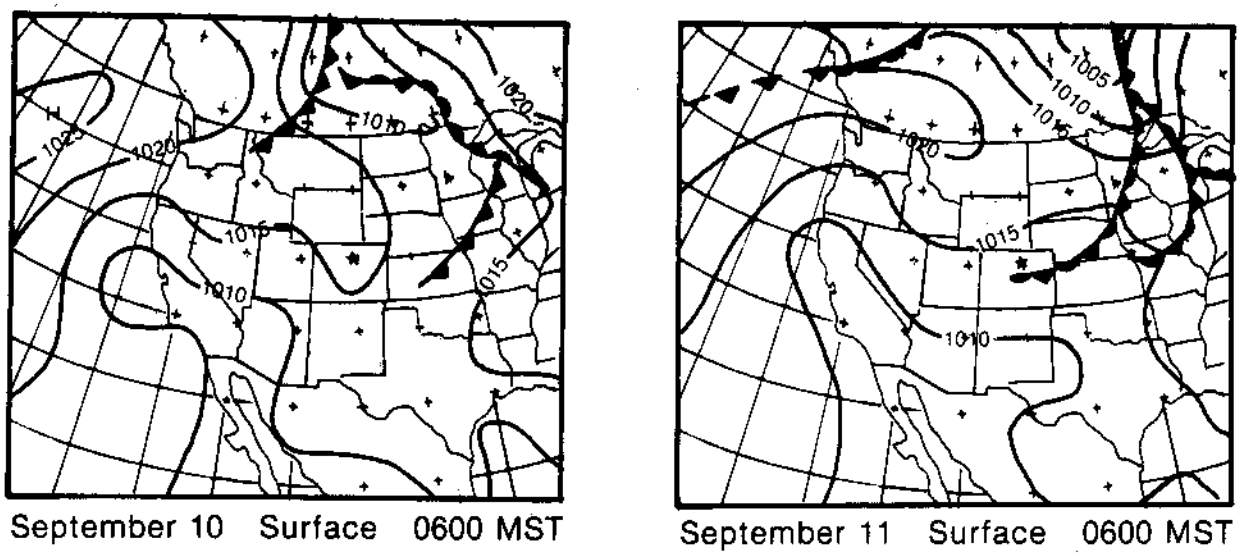

Figure 12.3.—Synoptic surface weather maps for September 10 and 11, 1938 - the Masonville, CO storm (55).

Only daily synoptic surface weather maps were produced in 1938. The 6:00 a.m. synoptic charts are shown in figure 12.3 for September 10 (approximately 12 hr prestorm) and September 11 (approximately 12 hr post storm). The analysis shows a front propagating rapidly southeastward from the northwest on the 10th to a position almost directly over Denver, CO, on the morning of the 11th. A linear interpolation between the two surface weather maps led to the conclusion that the Masonville storm occurred ahead of the approaching front. The interpolation shown in figure 12.4 is for 6:00 p.m. on the 11th, or about the time the Masonville storm ended. As can be seen in figure 12.4, the front was still a good distance to the northwest at the end of the storm, far enough away to conclude that the Masonville storm precipitation was not frontal in nature.

12.2.2.3 Golden, Colorado - 6/7/48 (67). The Golden, CO storm occurred early on the morning of June 7, 1948, and plays a supporting role in this study. Golden is located just west of Denver on the first upslopes of the Rocky Mountains. The storm elevation was 6,000 ft. The storm amount was reported as 6 in. in 2 hr by the Corps of Engineers (1945 -).

A representative storm dew point of 65°F was obtained as the result of the averaging of dew-point data from reporting stations approximately 310 mi southeast of the storm location. Dew-point data from several closer stations (Denver and Pueblo, CO; Cheyenne, WY) were also examined. These dew points were found to be unrealistically low. Based on available information, the storm dew point of 65°F for the Golden, CO storm (67) was accepted.

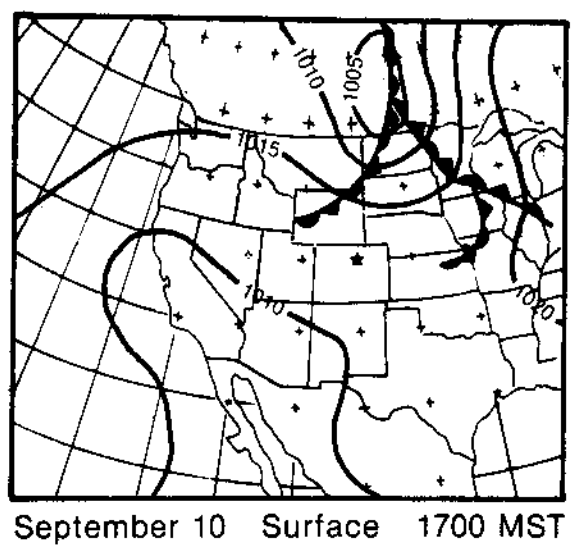

Figure 12.4.—Linearly interpolated synoptic surface weather map for 1800 GMT - September 11, 1938.

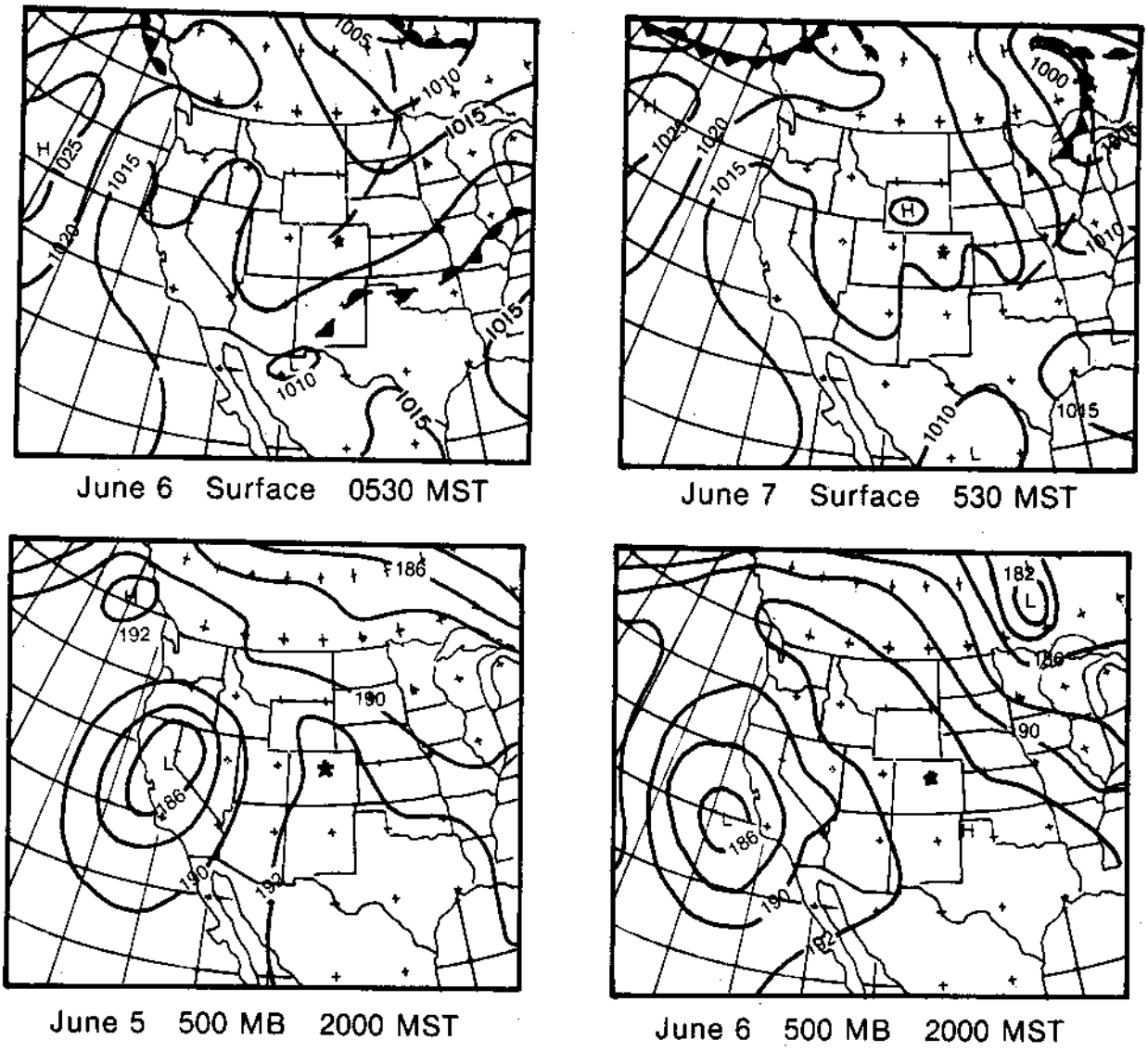

Figure 12.5.--Synoptic surface weather maps and 500-mb charts for June 6 and 7, 1948 - the Golden, CO storm (67).

The storm occurred between midnight and 2:00 a.m. on the morning of June 7. Surface weather maps in figure 12.5 for June 6th show a low pressure center in central Canada with an associated trough extending into the Rocky Mountain region of Colorado about 20 hr prior to the storm. The trough passed through the storm area and continued eastward into Kansas. Available data suggest that this trough passed over the storm area approximately 12 hr prior to the actual storm occurrence. This period of time is believed sufficiently long to disassociate the storm from the trough.

The isobaric gradient over the Colorado region was weak. A small area of high pressure was shown in the analysis for the 7th (fig. 12.5). The thermal Low over northern Mexico, a seasonal occurrence, caused onshore flow from the Gulf of Mexico. This type of flow is prevalent during many less intensive storms in the CD-103 region, as mentioned in section 12.1.2. However, significant moisture

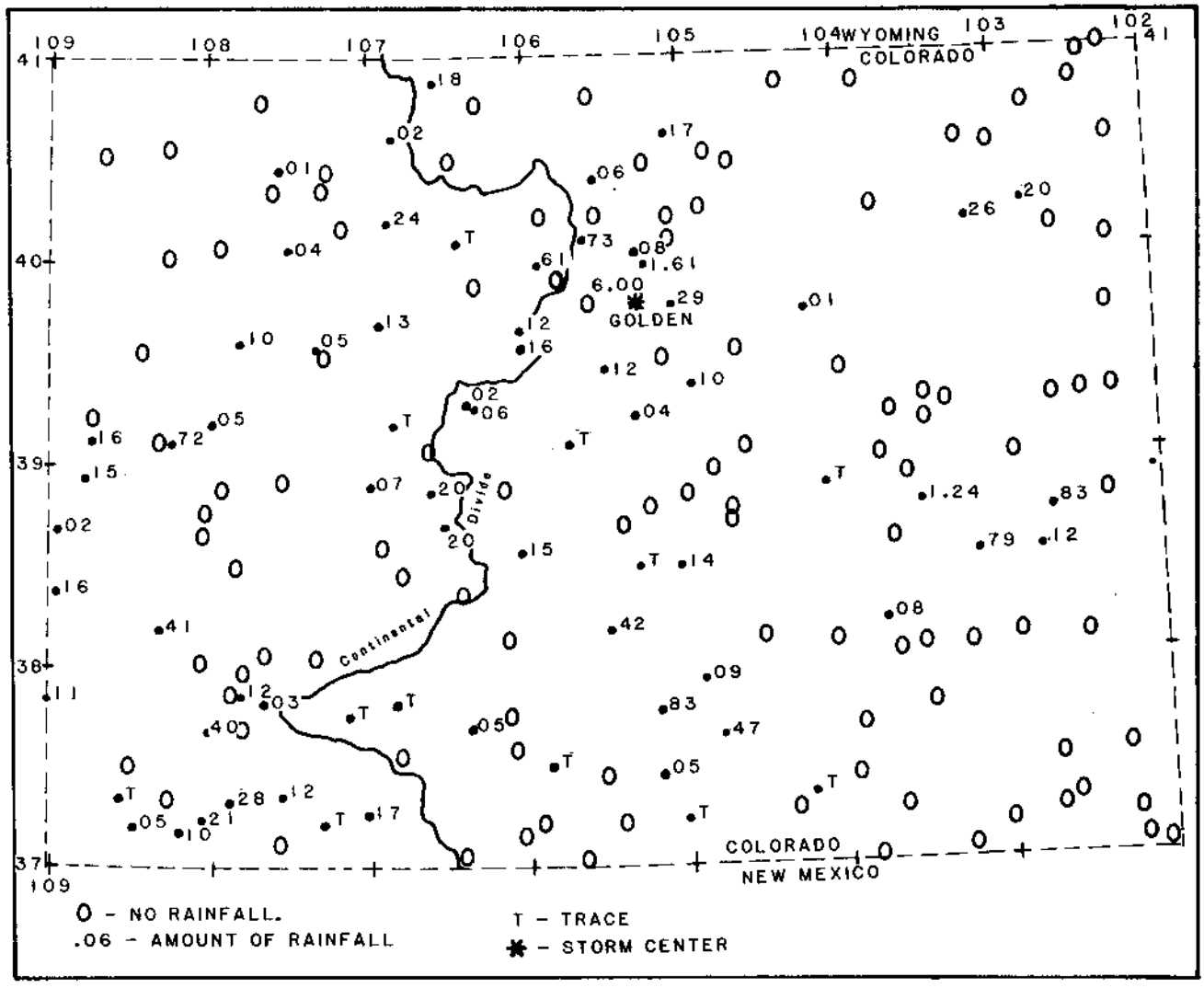

Figure 12.6.--Precipitation map, June 7, 1948 - the Golden, CO storm (67).

input to the storm is not well supported by the weak isobaric gradient over the Southwestern region. This fact may account for the low dew points that were observed at some stations.

At the 500-mb level, a ridge occurred over the region with a closed Low off the coast of California. Winds were generally light in the ridge showing little synoptic scale organization. However, it should be pointed out that a lack of upper air data for many of the storms in this study has made it difficult to derive any meaningful generalized relations between upper air data and local-storm occurrence.

The geographic rainfall distribution pattern on the day of the storm is shown in figure 12.6. The data are taken from the Climatological Data (U.S. Weather Bureau 1899-) for the 24-hr period, primarily from sunset (approximately 7:30 p.m.) June 6th to sunset June 7th, encompassing the storm occurrence. The rainfall distribution is generally disorganized with spotty precipitation scattered around the state. The 6-in. report at Golden, CO stands far above any other report for the period. This pattern provided strong evidence that the Golden, CO storm is an extreme local storm event.

12.2.2.4 Morgan, Utah - 8/16/58. The Morgan, UT storm of August 16, 1958, occurred outside the CD-103 region at an elevation of 5,115 ft and dumped 6.75 in. of rain between 4 and 5 p.m. This storm was used in the HMR No. 49 study as an extreme local storm. Upon review, it was decided to include this local storm for comparison purposes within the CD-103 study. This decision was based on terrain and related moisture inflow considerations. First of all, the terrain of a significant part of the CD-103 study area is very similar to that of the HMR No. 49 study. Secondly, the Continental Divide east-northeast of Morgan is less abrupt and lower in elevation than along other portions of the Divide. The Continental Divide east of Morgan does not represent the major barrier to moisture from the east-northeast that other portions of the Divide represent. Based on these arguments, the Morgan storm was transposed into the CD-103 region.

The meteorology of the Morgan storm has been discussed in HMR No. 50 (Hansen and Schwarz 1981); therefore, a lengthy discussion is not included here. Synoptic surface weather maps and 500-mb charts, and the geographic rainfall distribution for the day of the storm appear in figures 12.7 and 12.8, respectively. A weak isobaric gradient is apparent upon review of the surface charts, as was the case in the Golden, CO storm (sec. 12.2.2.3). No weather fronts were in the vicinity of the storm. At the 500-mb level, a ridge over the western United States showed generally light winds. This was also present in the Golden, CO storm.

The rainfall pattern, taken from Climatological Data for the 24-hr period generally ending around 8:00 p.m., shows a disorganized scattering of rain around the state. The 6.75 in. report stands far above all other reports for that day. A report of 7 in. was not accepted in this storm.

The synoptic conditions for the Morgan, UT storm parallel in many respects those for the Golden, CO storm. This may suggest a general environment that is receptive to the development of extreme local storms. It also suggests some degree of uniformity between local storms in the CD-103 region and those in the HMR No. 49 region. This similarity supports transposition of the Morgan, UT storm into the CD-103 region.

The Morgan storm plays a comparative and supportive role in the determination of local-storm PMP in the CD-103 region. Its moisture-maximized transposed amounts are slightly less than the corresponding values for the Masonville storm. These supporting values lend credibility to the levels of PMP dictated by the Masonville storm.

12.2.3 Important Non-local Storms

Some discussion is warranted of three storms, which were investigated as being local storms but were found to be embedded in general storms. These storms were considered to be potentially important storms to the CD-103 region. It is important to keep in mind the local-storm definition discussed in section 12.1.1.

12.2.3.1 Virsylvia, (Cerro), New Mexico - 8/17/22 (35). This storm occurred over a 4-hr period on August 17, 1922 at Virsylvia, NM where 7.5 in. of rain was observed. The station is located in the San Luis Valley in extreme northern New Mexico at an elevation of 7,500 ft near the present town of Cerro.

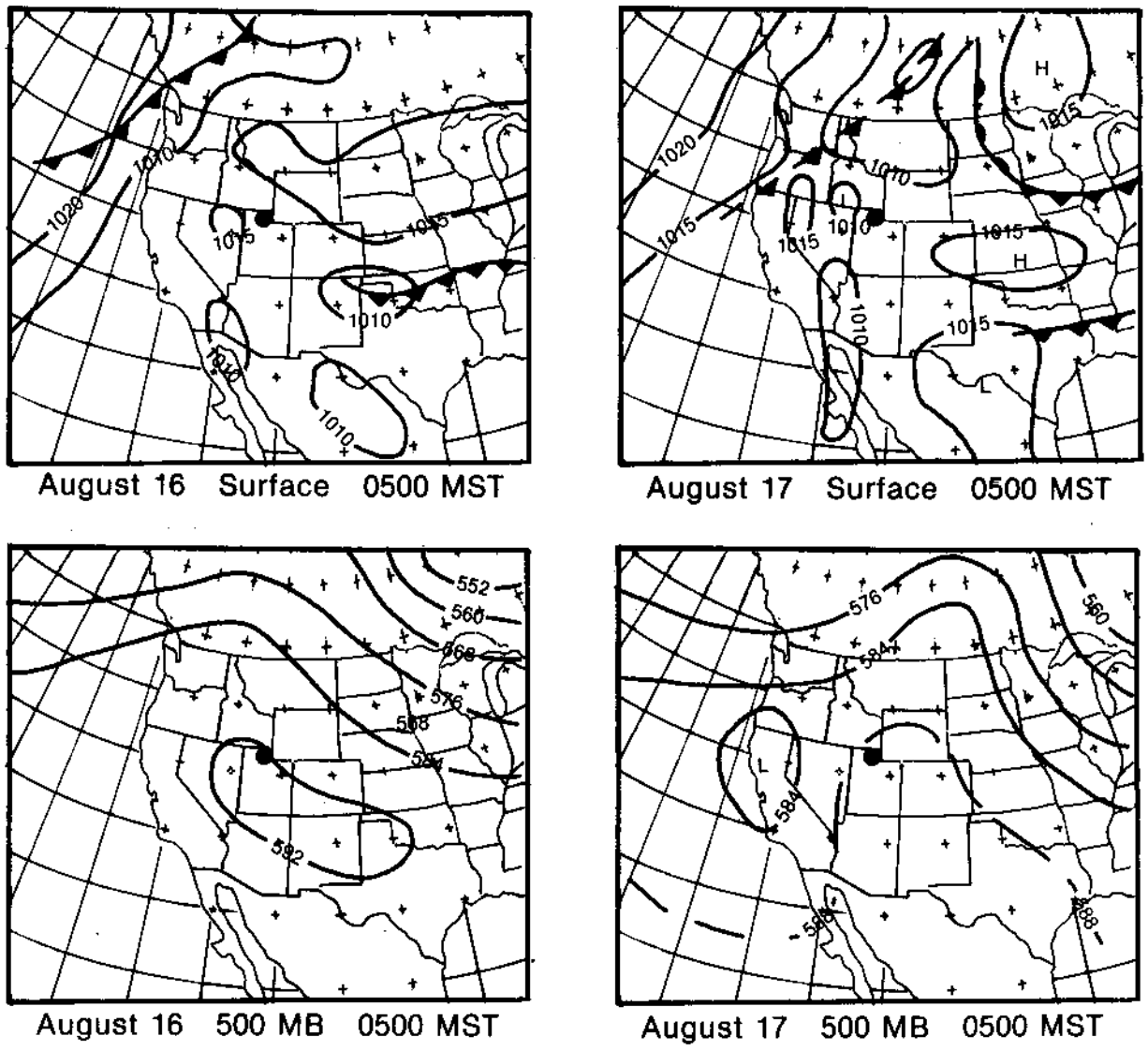

Figure 12.7.—Synoptic surface weather maps and 500 mb charts for August 16 and 17, 1958 - the Morgan, UT storm.

The observed rainfall was taken from a station report as having occurred between the hours of noon and 4:00 p.m. on the 17th. A review of the surface synoptic situation in the Northern Hemisphere Synoptic Weather Map series (Environmental Data Service 1899-) revealed that a front that had been semistationary over Colorado early on the morning of the 17th started drifting slowly southward to a position across central New Mexico on the morning of the 18th. Although the exact time of frontal passage at the Virsylvia (Cerro) station is unknown, it is highly likely that the front, based on an interpolated position, was very close to the station on the afternoon of the 17th. This implies a close relationship between the storm and the cold front. Because of this relationship, the Cerro storm was not accepted as an isolated local storm.

12.2.3.2 White Sands, New Mexico - 8/19/78 (82). A heavy line of thunderstorms dumped 10 in. of rain in 4 hr (5:00 p.m. to 9:00 p.m.) at White Sands, NM (elevation 4,000 ft.) on August 19, 1978. The storm caused locally heavy flash flooding that resulted in the deaths of five people.

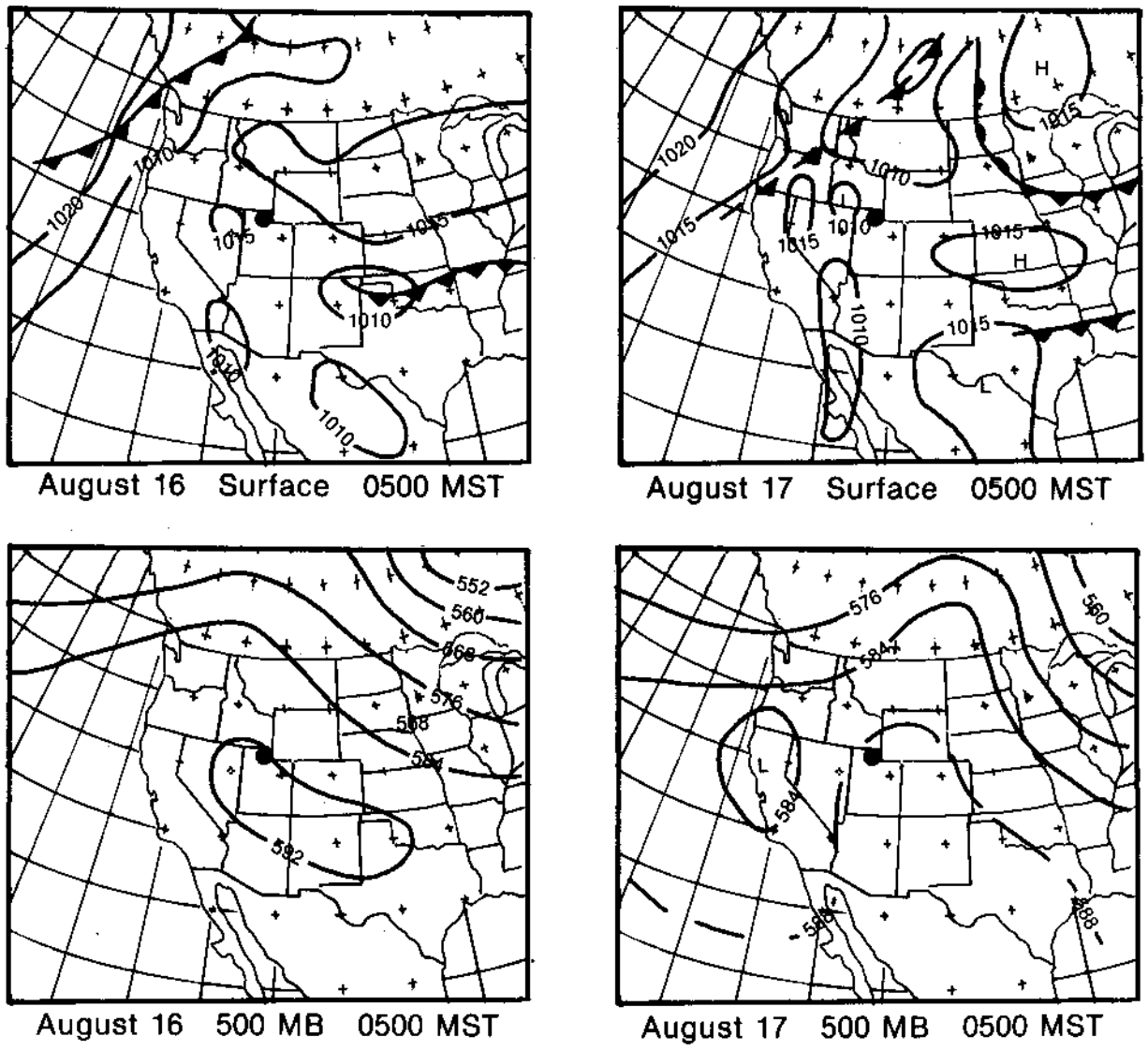

Figure 12.7.—Synoptic surface weather maps and 500 mb charts for August 16 and 17, 1958 - the Morgan, UT storm.

The observed rainfall was taken from a station report as having occurred between the hours of noon and 4:00 p.m. on the 17th. A review of the surface synoptic situation in the Northern Hemisphere Synoptic Weather Map series (Environmental Data Service 1899-) revealed that a front that had been semistationary over Colorado early on the morning of the 17th started drifting slowly southward to a position across central New Mexico on the morning of the 18th. Although the exact time of frontal passage at the Virsylvia (Cerro) station is unknown, it is highly likely that the front, based on an interpolated position, was very close to the station on the afternoon of the 17th. This implies a close relationship between the storm and the cold front. Because of this relationship, the Cerro storm was not accepted as an isolated local storm.

12.2.3.2 White Sands, New Mexico - 8/19/78 (82). A heavy line of thunderstorms dumped 10 in. of rain in 4 hr (5:00 p.m. to 9:00 p.m.) at White Sands, NM (elevation 4,000 ft.) on August 19, 1978. The storm caused locally heavy flash flooding that resulted in the deaths of five people.

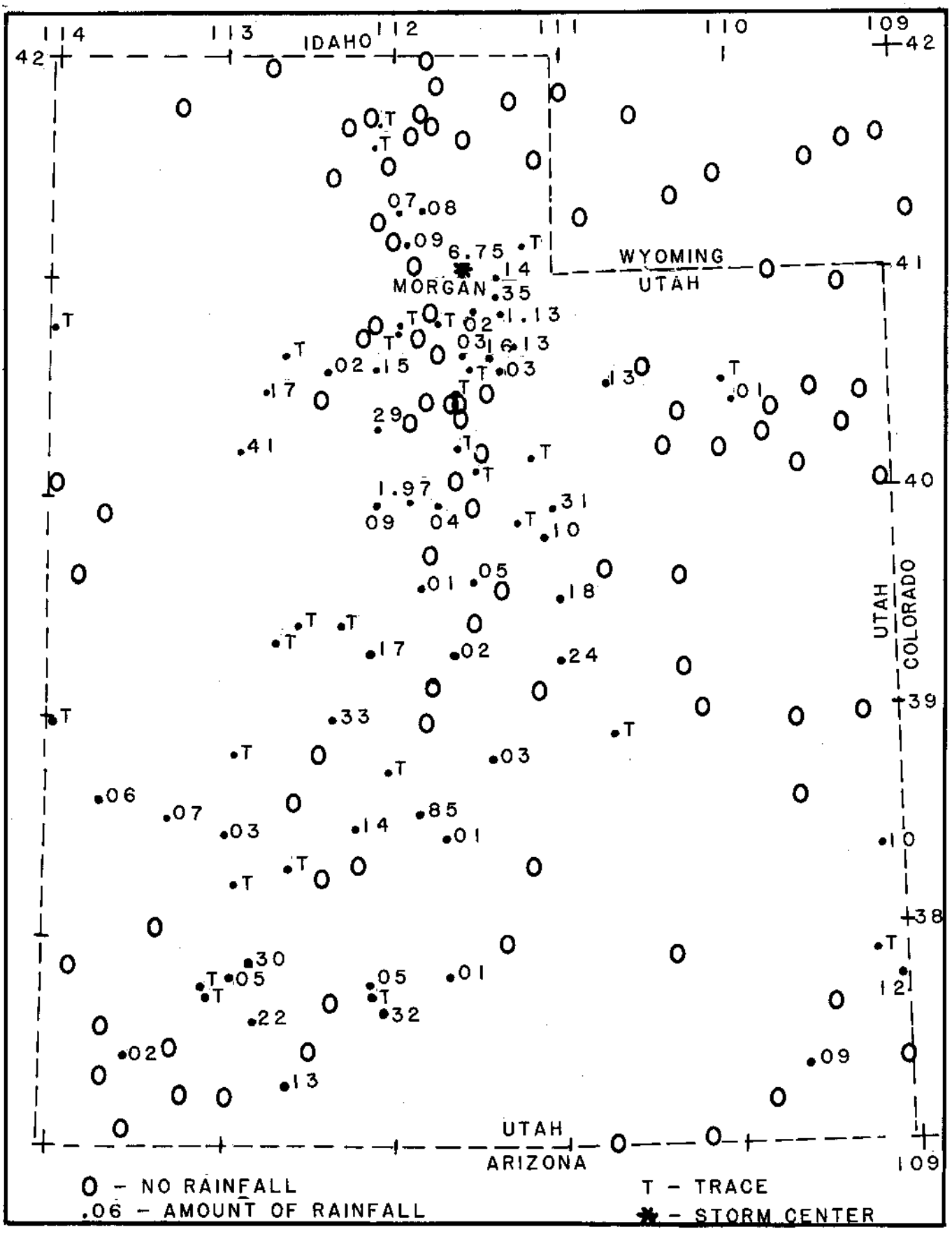

Figure 12.8 .--Precipitation map, Morgan, UT storm - August 16, 1958.

The 0600 surface synoptic analysis for August 19 and August 20 showed no apparent correlation between the rainfall and any fronts. A weakening cold front was located in southern Texas; however, it was believed that this front, having already passed White Sands prior to the storm, was not responsible for the storms.

The rainfall pattern indicated that an organized line of severe thunderstorms, possibly a squall line, had moved from southwestern New Mexico to the northeast past White Sands. Rain amounts from Hourly Precipitation Data (National Climatic Data Center 1951-) showed several significant rainfalls throughout the southwestern portion of the state that occurred at the same time as the White Sands storm. Many of these rainfalls were in excess of 1 in. in less than 2 hr. The magnitude and intensity of the rains concurrent with the White Sands storm, along with the apparent organization of a squall line of severe thunderstorms, led to the rejection of the White Sands storm as a local storm.

12.2.3.3 Big Thompson Canyon, Colorado - 7/31/76 (81). The Big Thompson Canyon storm of July 31, 1976, is discussed in section 2.4.1.9. The Big Thompson storm was not accepted as a local storm because of the stationary cold front that prevailed through the middle of Colorado. The storm developed very near this front, and, therefore, the extreme short duration rainfall event is considered to be part of a general storm.

12.3 1-hr 1-mi^2 PMP Approach

12.3.1 Introduction

As was stated in section 12.1, the local-storm PMP was derived for the entire CD-103 region in this revised study. This decision was a significant change from that followed in HMR No. 55, as discussed in that section. The present approach is similar to that used in developing the local-storm PMP in HMR No. 49 (Hansen et al. 1977). In this approach one of the first indices considered was an analysis of maximum 1-hr point rainfall. These data, obtained from a search of the hourly precipitation data tapes* (period 1948-1978), were plotted and analyzed to establish an approximate pattern and gradient. Extreme local-storm data was maximized and transposed throughout the region to set the level of magnitude of PMP. For convenience, a common-level index map was set at 5,000 ft and the results smoothed and manually adjusted to blend into the analysis west of the Divide. Cross-Divide comparisons of these results are discussed in chapter 13.

12.3.2 Data

Data tapes available to the Office of Hydrology contain hourly precipitation for the period 1948 to 1978. Data were processed for recorder stations in the region that had a minimum of 15 years data. Maximum 1-hr values were listed for each station and synoptic maps and original records reviewed to verify the reports as well as to determine which data most closely met the conditions of the local-storm definition. The maximum station values were then adjusted to

---

* Hourly precipitation tapes maintained by the Office of Hydrology.

5,000 ft by use of the saturated adiabatic equivalent ratio of precipitable water (U.S. Weather Bureau 1951). A rough analysis was made of the 5,000 ft data to establish the basic gradient.

The four major local storms listed in table 12.2 were adjusted for duration and elevation, and moisture maximized to obtain 1-hr moisture-maximized 5,000-ft amounts. These were transposed within rather liberal north-south transposition limits to set the level of PMP throughout the region. Smoothing was then done where necessary to tie into 1-hr local-storm 5,000-ft analyses west of the Divide. Each adjustment, along with any restrictions, is discussed separately in the following sections.

12.3.2.1 Adjustment for Duration. An adjustment for duration was applied to those extreme local storms that did not explicitly have a 1-hr amount. One-hr amounts were available for the Golden (67) and Masonville (55), CO, and Morgan, UT storms. Therefore, it was not necessary to adjust those storms. However, 1-hr amounts were not reported for the Las Cruces, NM (48) storm.

Depth-duration information, if it existed for a local storm, was considered of primary importance. Data are available for a mass curve of rainfall only for the Las Cruces, NM storm (48). From this, a depth-duration relation was constructed from the record at the Agricultural College and is shown in figure 12.9. From this relation, a 1-hr percentage of total-storm amount (42 percent) was obtained. From field survey measurements, it was estimated that the maximum point rainfall in the Las Cruces, NM storm was 10 in. Applying the 1-hr to total-storm percentage from the Agricultural College record to this estimated amount produced a 1-hr value of 4.2 in.

12.3.2.2 Adjustment for Maximum Moisture. The adjustment for maximum moisture is the ratio of precipitable water for the maximum persisting 12-hr 1000-mb dew point to that for the representative persisting 12-hr 1000-mb storm dew point. The adjustment is basically the same as that for the general storm discussed in chapter 8. Representative storm dew points for local storms are preferably taken from stations within close proximity (<50 mi) to the storm location. These stations are considered to be the most representative of the moisture situation at the storm location because the localized nature of the storm precludes a well organized inflow of moisture. In reality, close proximity dew points are not always available. In their absence, dew points were accepted from more distant locations, with some loss in reliability.

For the local storm, it is permissible to proceed in any direction from the storm location to find a representative storm dew point. This is in contrast to the general storm where the representative dew point must be located in the moisture inflow direction for the storm. The multidirectional approach is considered satisfactory for the local storm because the local storm is assumed to occur independent of any sustained moisture inflow.

Representative storm dew points must persist for 12 hr or more at a station. This is required to remove any aberrations in the station dew-point data. Dew points that occur in a reported rainfall situation are also generally not accepted. The representative storm dew points for each of the local storms appear in table 12.2 and are discussed for each local storm in section 12.2.2.

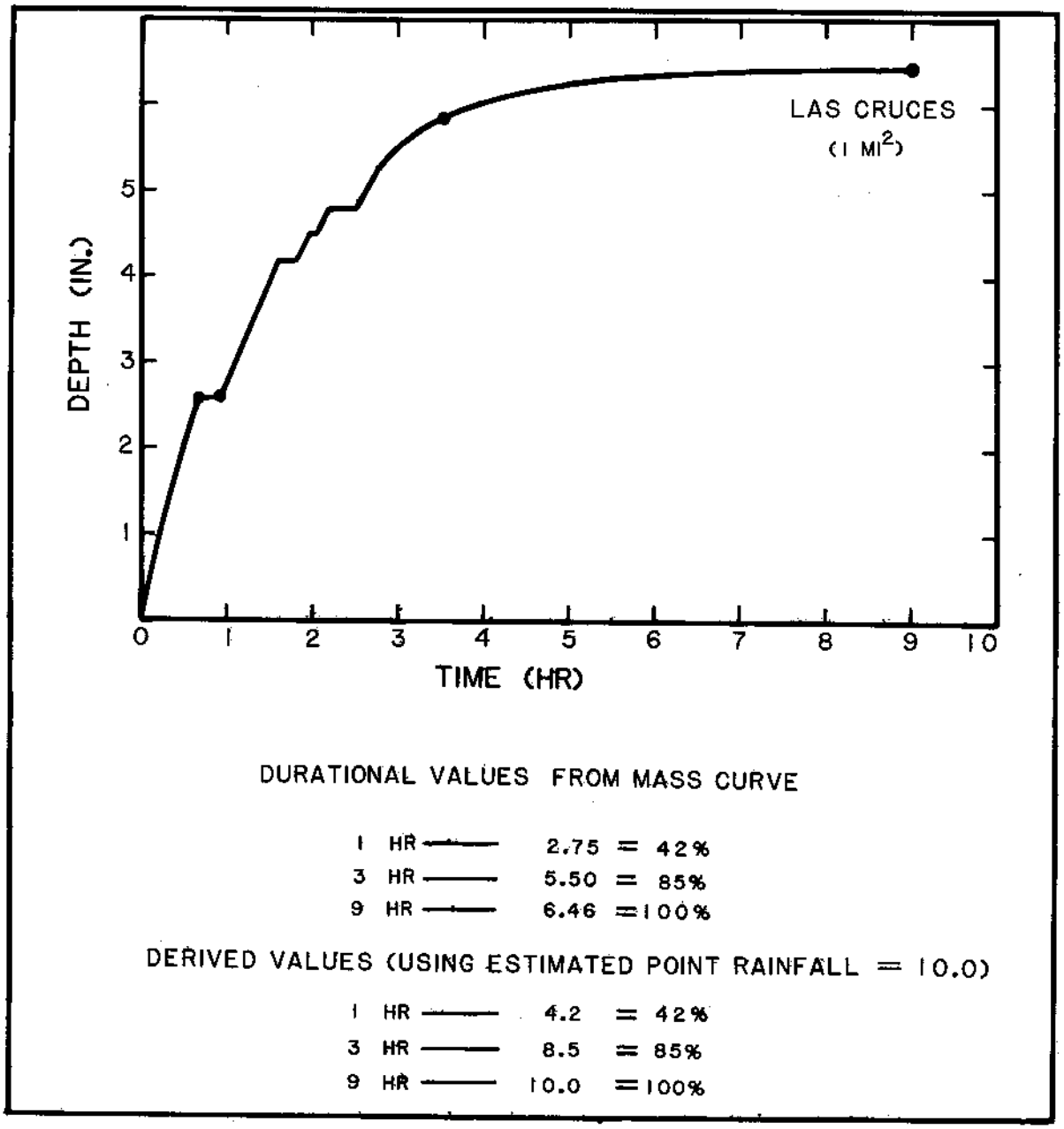

Figure 12.9.--Mass curve of rainfall for Agricultural College - the Las Cruces, NM storm (48).

Maximum persisting 12-hr 1000-mb dew points were taken from the revised dew-point charts prepared for this study (chapt. 4). The local-storm maximum persisting 12-hr 1000-mb dew point is read 15 days into the warm season at the location of the storm, not at some reference distance from the storm, as is done for the general storm. This should provide a better representation of maximum moisture available for the local storm.

Moisture maximization of extreme local storms is done in-place, that is, at the storm site location. An upper limit restriction of 1.5, or 150 percent, was placed on the in-place moisture-maximization adjustment. This restriction has the effect of reducing the allowable moisture difference between precipitable water obtained from the representative storm dew point, and precipitable water obtained from the maximum persisting 12-hr 1000-mb dew point. The restriction is

Table 12.3.--In-place local-storm moisture maximizations

Storm no.	Storm	Unrestricted in-place moisture adjustment (percent)	Restriction applied moisture adjustment (percent)
48.	Las Cruces, NM	148	148
55.	Masonville, CO	183	150
67.	Golden, CO	185	150
-	Morgan, UT	158	150

intended to minimize excessive adjustments. The limitation is lower than was used for the general storm in orographic regions for two reasons. First, extremely large changes in moisture supply for these isolated events may result in a change to the storm structure. Second, the ability of available moisture to be adequately sampled by the limited observational network was a concern. Low representative storm dew points produce unreasonably high adjustments for moisture maximization. This is more of a problem with local storms where there is no sustained moisture inflow, and where dew points must be selected within a relatively small region, than with general storms where observations at a considerable distance may be used.

The restriction of 150 percent on the adjustment for moisture maximization affected three out of the four extreme local storms in table 12.2. The only storm not affected was the Las Cruces, NM storm (48). Table 12.3 lists the unrestricted in-place moisture-maximization adjustment and the restricted adjustment that was used in PMP calculations.

12.3.2.3 Horizontal Transposition. Transposition, as for the general storm, refers to the process of taking storm precipitation amounts from one location to another location. The amount is adjusted for differences in the moisture available between the storm location and the transposed location.

Numerous transposition locations were chosen in the CD-103 region. Some locations were chosen because of their low elevations in valleys, canyons, etc. Other locations were chosen to represent middle and high elevations as well as nonorographic and minimum nonorographic areas. Locations were chosen to provide adequate representation for northern, as well as southern areas.

The necessary climatic ingredients for the development of extreme local storms are potentially present throughout the CD-103 region during the May to September season. The four extreme local storms in table 12.2 occurred during this season. A survey of clock-hour rainfall showed that short-duration maximum 1-hr rainfall most likely occurs during this season (see discussion in sec. 12.8).

Some areas, due to moisture availability, terrain considerations, etc., are likely to produce more local storms than other areas. The question of frequency of local-storm occurrences is not relevant to estimating the level of local-storm PMP, as long as it is concluded that local storms do indeed occur.

In transposing local storms from one location to another, the same upper restriction of 1.2, or 120 percent, was used as in transposing general storms. In reality, this restriction turned out to have no effect, as no horizontal moisture adjustment for any of the local storms considered exceeded 1.2.

12.3.2.4 Adjustment for Elevation. The adjustment for elevation is an adjustment for the differences in available moisture at different elevations. Discussion of this adjustment is also given relative to general storms in section 8.4.2.2.

No adjustment to moisture was imposed on local storms within the first 1,000-ft elevation change, as was also the case for general storms. However, unlike the general storms, the traditional full moisture adjustment was used for differences beyond the first 1,000 ft in local-storm transposition considerations. Use of the full moisture adjustment resulted in significant decreases to some of the high-elevation local-storm PMP estimates.

The traditional moisture adjustment was used because we find no evidence that local storm events are sustained by inflow moisture advected over long distances in the sense that general storms are. Initiation of local-storm convection derives its moisture from that available in the immediate vicinity, possibly accumulated from evaporation of prior rainfall.

Regarding the difference in vertical adjustments applied to local- and general-storm amounts in this study, the precedent has already been established in HMR No. 43 and 49. However, the adjustments used in the present study are in accord with those described in most previous hydrometeorological studies.

An overall upper restriction of 1.2, or 120 percent, was placed on the adjustment of moisture due to elevation. The transposition adjustments for the four storms were well within the 1.2 restriction.

It was decided not to include an adjustment for the effect of barrier elevations on moisture. This agrees with WMO procedures (1973) and with HMR No. 49.

12.4 1-hr 1-mi^2 Local-Storm PMP Map (Revised)

12.4.1 Introduction

All extreme local storms were transposed to a random selection of grid locations in the region. The 1-hr 1-mi^2 values are for a constant elevation of 5,000 ft. This was so the gradients of PMP would not be obscured by elevation changes, and is consistent with the local-storm PMP analysis produced in HMR No. 49 (Hansen et al. 1977).

12.4.2 Analysis of 1-hr 1-mi^2 Local-Storm PMP Map

Evaluating the 1-hr 1-mi^2 map at a constant elevation of 5,000 ft reduced the amount of detail necessary in the analysis, and also served to point out the nature of the 1-hr PMP gradient across the region. The constant elevation of 5,000 ft also facilitated smoothing between the local-storm PMP for the CD-103 region and the local-storm PMP west of the Continental Divide (Hansen et al. 1977).

With elevation removed as an influence upon the analysis of the 1-hr 1-mi^2 PMP map, moisture availability played a major role in the analysis. Moisture manifested itself in two ways in the analysis. First of all, maximum persisting 12-hr 1000-mb dew points had a strong influence on the transposed values at each location. Second, the dew point gradients were used to provide additional guidance on how isopleths of PMP should be oriented on the 1-hr 1-mi^2 PMP map. This guidance was obtained through observing the gradient of isolines of maximum persisting 12-hr 1000-mb dew points on the charts for the months of May-September (fig. 4.9 to 4.13). These are the months of local-storm occurrence (see table 12.7).

The transposed and adjusted storm values showed that the Masonville storm dominated throughout almost all of the region. In Wyoming and southwestern Montana, the Masonville amounts were matched or slightly exceeded by the transposed Morgan, Utah storm values. This was viewed as support for the overall level established by this process.

The enveloping analysis of maximized 5,000 ft station data drawn for 1 hr and 1 mi^2 was then smoothed to tie into the local-storm analysis from HMR No. 49 as closely as possible. The need to tie into the local-storm results in HMR No. 43 were considered less important since this report is presently being revised and the published local-storm results may change. Nevertheless, quite close agreement to HMR No. 43 values was not difficult to obtain (see discussion in section 13.6)

12.4.3 1-hr 1-mi^2 PMP Index Maps

The results of the procedure described above appear in plates VI a-c. As stated in an earlier section, significant barriers were given little attention in this study, since it was assumed local storms are not inflow dependent. Lowest values of local-storm PMP occur in northwestern Montana and increase in a generally uniform manner to the southeast, reaching a maximum of 13.0 in. in western Texas.

Although local-storm PMP is analyzed throughout the region, nowhere east of the 105th meridian were we able to find a location where the local-storm value exceeded the 1-hr general-storm value.

12.5 Durational Variation

Since it is assumed that a local storm exists independent of sustained inflow, it is reasonable that the duration of a PMP-type local storm would be unlikely to exceed 6 hr. It is also reasonable to expect that most of the rain and, therefore, the greatest intensities of rainfall would occur in the first 1-3 hr, and then decrease as the storm depleted its moisture.

12.5.1 Data and Analysis for PMP for Longer Than 1 hr

With the above considerations in mind, a study of 6-/1-hr rainfall ratios was undertaken to determine how local-storm PMP would vary with duration. Recorder station maxima were accessed for 1- and 6-clock-hour monthly maximum amounts. The following restrictions were placed on the data.

1. The maximum 1-hr rainfall for each month was determined.

2. The maximum 6-hr amount surrounding the 1-hr value was determined.

3. Rainfall adjacent to the 6-hr rainfall period was tested to determine if the storm was isolated in time at this station.

The process was accomplished in the following manner. First, a 1-hr maximum was found, then the maximum 6-hr amount around the 1-hr maximum was determined. Three-hour periods were then checked on both sides of the 6-hr amount for precipitation amounts (>.1 in.). If there was no precipitation in excess of the criterion, the rainfall was accepted as short duration. If larger precipitation amounts were present, then the 6-hr period around the 1-hr maximum was shifted by 1 hr and the 3-hr periods on both sides of the new 6-hr period were checked. This process continued until an acceptable 6-hr period could be found, or until all 6-hr periods were tested and were considered unacceptable. In the former case, the 1-hr maximum and acceptable surrounding 6-hr period were recorded. In the latter case, the 1-hr maximum was eliminated and the next highest 1-hr period for that month was tested in the same manner. In most cases, if the maximum 6-hr amount surrounding the 1-hr maximum was determined to be unacceptable, attempts to find an acceptable 6-hr period around that 1-hr maximum also proved fruitless. However, in some cases, when short burst storms occurred within a short time of each other, an acceptable 6-hr period could be found where the 1-hr maximum occurred.

Corresponding monthly 1-hr maxima from different years (May 1948, May 1949, May 1950, etc.) were compared to obtain a period-of-record 1-hr maximum for each month of the year at each station. The highest 1-hr amount of record was then selected at each station and compared with its surrounding 6-hr amount to obtain a 6-/1-hr within-storm ratio for the station. In this manner 6-/1-hr within-storm ratios were obtained for all the stations within the local-storm areas of the CD-103 region. These ratios were, by definition of the selection criteria previously outlined, taken from short-duration type precipitation events.

The ratios were grouped according to proximity, similarity of topographical characteristics, and position with respect to geographical boundaries. The ratios range from around 1.1 to around 1.2. On a comparative basis, average 6-/1-hr ratios in HMR No. 49 ranged from 1.1 to 1.8, with ratios to the east of the Sierra Nevada ranging from 1.1 to 1.4. Near the Rocky Mountains, ratios tended to be between 1.2 and 1.3. The lack of range in the averaged 6-/1-hr ratios for the CD-103 region and for the adjacent eastern portion of HMR No. 49, suggests a homogeneity of the local-storm depth-duration characteristics, both within the CD-103 region, and between the CD-103 region and the adjacent eastern portion of HMR No. 49. The Las Cruces, NM storm (48) was the only local storm in the region for which depth-duration estimates could be made. The 6-/1-hr ratio for this storm was approximately 2.4, significantly larger than suggested by the hourly precipitation data.

It was decided that the entire CD-103 region could be represented by a single 6-/1-hr ratio. The ratio chosen was 1.35, for which a smooth depth-duration curve is shown in figure 12.10, and appropriate ratios for durations between 1 and 6 hr are given in table 12.4. The 1.35 ratio is skewed towards the higher 6-/1-hr ratios within the CD-103 region to provide a reasonable envelopment of the 6-/1-hr ratios shown. The use of the ratio of the Las Cruces storm would have resulted in unreasonable 6-hr 1-mi^2 local-storm PMP.

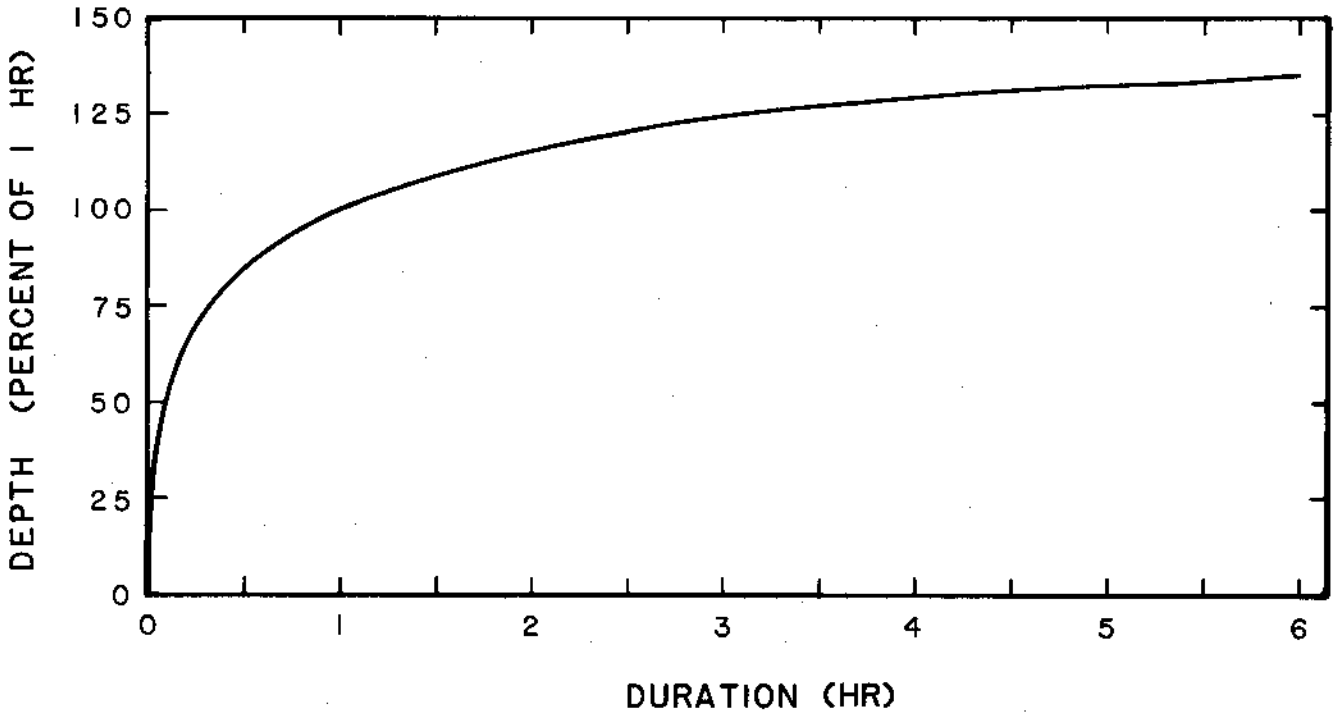

Figure 12.10.--Depth-duration curve for 6-/1-hr ratio of 1.35.

Table 12.4.--Percent of 1-hr local-storm PMP for selected durations for 6-/1-hr ratio of 1.35 (HMR No. 49)

Duration (hr)	Percent of 1 hr
1/4	.68
1/2	.86
3/4	.94
1	1.00
2	1.16
3	1.23
4	1.28
5	1.32
6	1.35