NOAA Technical Memorandum
NWS HYDRO 41

PROBABLE MAXIMUM PRECIPITATION ESTIMATES FOR THE DRAINAGE ABOVE DEWEY DAM, JOHNS CREEK, KENTUCKY

Water Management Information Division
Office of Hydrology
Silver Spring, Md.
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U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Weather Service

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UNITED STATES DEPARTMENT OF COMMERCE
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National Weather Service
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C	In this report, it is FAFP evaluated by use of the 1-percent chance precipitation event for the given duration.
D_h, D_r	The depth of PMP for a duration of h or r hours for a fixed, small (usually $10\ mi^2$) area size that results when there is no terrain feedback into or terrain interaction with the atmospheric forces producing precipitation.
FAFP	An acronym for free atmospheric forced precipitation. It is the depth of all precipitation occurring in areas where there is no terrain feedback into or terrain interaction with the atmospheric forces producing precipitation. In areas where terrain feedback or interaction occurs, it is that part of the total precipitation depth which remains when amounts attributable to orographic forcing have been removed. FAFP is a component of all precipitation events and can be evaluated for PMP, 100-yr, 2-yr or any other event of interest. It has been referred to as the convergence component in some Hydrometeorological Reports.
h	The duration of a general period of precipitation.
K	A dimensionless number representing the effect of broadscale orographic forcing on the precipitation process for a given (usually small) area size and given duration. At a duration of 24 hr, its value may range from less than 1.0, and usually, larger than 0.5, in areas of exceptional topographic sheltering, to approximately 1.0 in nonorographic areas. Values in excess of 2.0 are common in areas of relatively steep terrain slope. In highly orographic areas where strong storms tend to be climatologically recurrent, values of K exceeding 3.0 (at 24 hr) can be expected.
(L)	A symbol used to represent the lowland topographic classification.
M	A dimensionless number representing the percentage of FAFP occurring during the most intense or core precipitation event. It is defined by the ratio D_r/D_h. Its value may be between 0 and 1, inclusive.
r	The duration of a core, or most intense precipitation, event within a general period of precipitation of duration h where $r \leq h$; r may be expressed in hr or as a percent of h.
P	A dimensionless number representing the percentage of the orographic factor, T/C, effective during the period represented by r. It is defined as 1 - M in this report. Its value may be between 0 and 1, inclusive.
PMP	In nonorographic regions where K is equal to 1.0, PMP is equal to FAFP; in orographic regions it is the product of FAFP and K.

T	The total depth of precipitation for a given duration and area size. It includes both free atmospheric forced precipitation and that which results from terrain feedback or interaction. It is evaluated in this report by use of the 1-percent chance precipitation event for the given duration.
(T)	A symbol used to represent the transitional topographic classification.
T/C	A dimensionless number representing the broadscale orographic influence for a given (usually small) area size. In this report, it is evaluated by using the 1-percent events. Its range of values is comparable to that of K.
(U)	A symbol used to represent the upland topographic classification.

PROBABLE MAXIMUM PRECIPITATION ESTIMATES FOR THE DRAINAGE ABOVE DEWEY DAM, JOHNS CREEK, KENTUCKY

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ABSTRACT This report discusses estimates of probable maximum precipitation (PMP) for the drainage of Johns Creek, Kentucky above Dewey Dam. Estimates are given for durations from 1 to 72 hr for the drainage which is partly within a stippled region identified in Hydrometeorological Report (HMR) No. 51, thereby necessitating evaluation of terrain effects on precipitation.

Part of the procedure used to evaluate terrain effects required selection of proxy observations of precipitation since there were no reporting locations within the drainage. The remainder of the terrain evaluation procedure was the same as the one reported earlier in NOAA Technical Memorandum NWS HYDRO 39. As in the earlier report, the applications procedures of HMR No. 52 were used along with generalized PMP estimates from HMR No. 51 to obtain a drainage average depth of nonorographic PMP. The final, or total, PMP estimates are the products of the drainage average depth of nonorographic PMP and the orographic intensification factor representing the evaluation of terrain effects within the drainage.

1. INTRODUCTION

The U.S. Army Corps of Engineers requested in April 1984 that the National Weather Service (NWS) develop a probable maximum precipitation (PMP) estimate for the drainage of Johns Creek, Kentucky, above Dewey Dam, a basin which is identified by the acronym DDKY in this report. A portion of this 207-mi^2 basin is located within the stippled region of Hydrometeorological Report (HMR) No. 51, "Probable Maximum Precipitation Estimates, United States East of 105th Meridian" (Schreiner and Riedel 1978). In that publication, it is recommended that for basins within the stippled region the effects of topography on the precipitation process be evaluated for basin estimates of PMP. The starting point for the estimate is the generalized charts of HMR No. 51. The study produced estimates of total PMP, i.e., precipitation conceived to have orographic and nonorographic components, for DDKY at durations of 1, 6, 12, 24, 48 and 72 hr. This report describes the approach used to develop these (total) PMP estimates.

The PMP estimates were made by entering appropriate values for the independent variables in equation 1-1.

$$PMP = (FAFP)(K) \tag{1-1}$$

FAFP is an acronym for free atmospheric forced precipitation and represents the nonorographic component of total PMP (see list of variables, page vi). The term K represents the percentage increase (or decrease) in FAFP induced by topography as its value is greater (or less) than 1.

Equation 1-1 was used in an earlier report, "Probable Maximum Precipitation for the Upper Deerfield River Drainage Massachusetts/Vermont," NOAA Technical Memorandum NWS HYDRO 39 (Miller et al. 1984), to calculate an average depth of PMP. The term K represents a single orographic factor for the whole drainage. In HYDRO 39, the value of K was derived from precipitation data taken at several reporting locations within the drainage, whereas, in this report there are no reporting locations within DDKY. Since it is likely that there are numerous drainages within which there are no reporting locations, the method used here to acquire proxy values for the parameters used to calculate a drainage average value of K should have wider applicability than just at DDKY. The adopted methodology is discussed further in section 3.1.1.2.

Development of appropriate values for FAFP will be explained in section 2. Highlighted will be the application of HMR No. 52 "Application of Probable Maximum Precipitation Estimates - United States East of the 105th Meridian" (Hansen et al. 1982) to generalized PMP estimates from HMR No. 51 for the drainage. Based on the explicit transposition limits of storms used in HMR No. 51 to produce charts of nonorographic PMP at area sizes important (up to 5,000 mi^2) for this study, eleven of twelve storms were identified as having transposition limits close to DDKY. The original locations of these storms are shown in figure 1-1. The coded identification appearing above the storm location is a U.S. Army Corps of Engineers assignment number and indicates that a formal storm study has been completed and is published in Storm Rainfall in the United States (U.S. Army Corps of Engineers, 1945-), hereafter referred to as Storm Rainfall. These locations indicate that the storm type most likely to produce record setting precipitation at DDKY would be a Great Plains or Mid-west type thunderstorm or thunderstorm complex embedded in a more general, polar-front induced storm. Record-setting storms occurring south of DDKY typically have transposition limits not further north than 35°N at the longitude of DDKY. A twelfth storm at Altapass, NC is included in figure 1-1, since that storm site is closer to DDKY than the transposition limits associated with some storms north or west of DDKY. While the complete mechanism of the Altapass storm is not transposable across the Appalachians, the remnants of the upper tropospheric ventilation (divergence) field from such a storm could combine with the mechanism previously cited as most likely to produce record setting precipitation at DDKY to enhance already extreme precipitation. In section 3, the approach selected to determine K will be explained. Finally, section 4 contains the computations required by equation (1-1) to obtain total PMP estimates for this basin.

2. COMPUTING NONOROGRAPHIC PMP FROM HMR NO. 51 AND 52

2.1 Introduction

In developing PMP estimates for DDKY, nonorographic values of storm-centered, area-averaged PMP are obtained from generalized charts applicable at 1000 mb, or sea level. This technique is desirable because of the consistency in depth-duration and depth-area relations maintained in generalized charts, as well as consistency maintained from study to study. Thus, atmospheric behavior

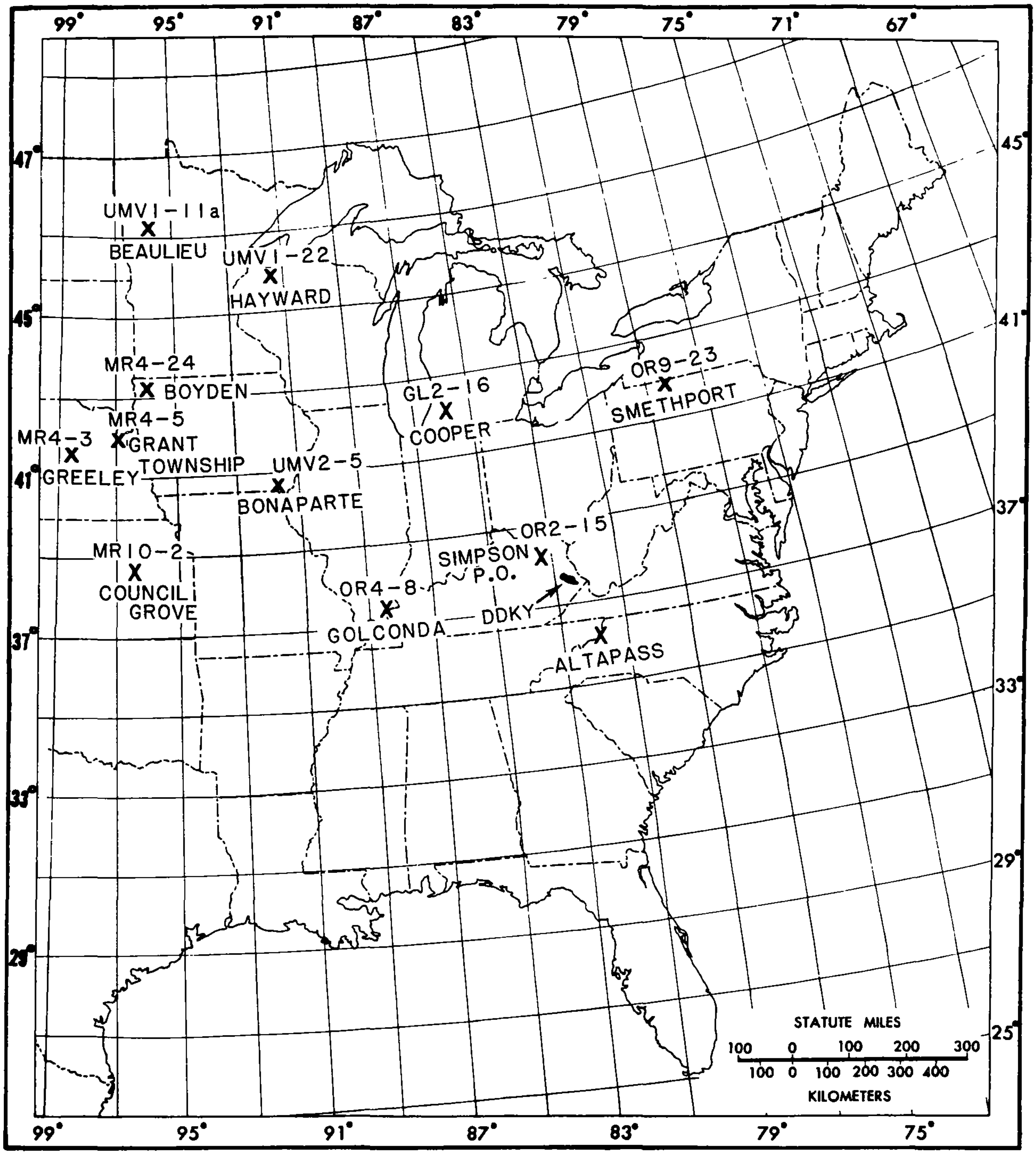

Figure 1-1.--Original storm locations important in setting levels of nonorographic PMP for DDKY.

inferred from precipitation amounts at a specific area size is consistent with observed atmospheric behavior in storms operating close to their peak capacity across area sizes both larger and smaller than that of DDKY. HMR No. 51 is the source for the level of nonorographic PMP (for various area sizes and durations) applicable in this study for DDKY. The procedures used to develop those analyses are documented in that publication. As in HYDRO 39, this report considers that isolines of PMP from charts in HMR No. 51, both inside, and outside stippled areas are of strictly nonorographic PMP at 1000 mb, assumed to be sea level.

Table 2-1.--PMP (in.) from HMR No. 51 for DDKY (37°36'N, 82°30'W). 1-hr PMP from HMR No. 52

Area mi^2	Duration (hr) 1	6	12	24	48	72
10	15.1	28.3	33.4	36.0	39.7	41.4
200	8.8	20.0	23.9	26.7	30.5	32.2
1000	5.0	14.7	18.4	21.4	24.0	25.7
5000	2.3	8.9	12.2	14.6	18.1	19.5
10000	1.7	6.8	9.8	12.3	15.5	16.8
20000	1.3	4.7	7.8	10.1	13.2	14.4

The methods employed in HMR No. 52 to transform smoothed, storm-centered, area-averaged PMP into drainage averaged PMP were used in this study. The results from HMR No. 52 were sets of durational storm isohyetal labels, or values for nonorographic PMP (at 1000 mb), as well as drainage-averaged depths (for needed durations) of nonorographic PMP, also at 1000 mb.

2.2 Basin-Centered, Nonorographic Estimates of PMP

Highlights of the steps taken to obtain basin-centered, nonorographic PMP estimates at 1000 mb and at the average barrier elevation applied at the centroid of DDKY, taken to be 37°36'N and 82°30'W, are presented in the following sections.

2.2.1 1000-mb Computations

From HMR No. 51 and 52, values (table 2-1) were read for each duration/area size from the PMP maps at the centroid of DDKY. These values were plotted and smooth depth-area-duration (DAD) lines fitted to them (fig. 2-1). Durational amounts from figure 2-1 for four standard isohyetal area sizes above and below the 207-mi^2 area of DDKY were extracted (table 2-2), plotted and fitted by smoothly varying depth-duration curves (fig. 2-2), from which values can be read at intermediate durations. Incremental differences for the first three 6-hr periods are then obtained.

The optimum orientation of the nonorographic storm pattern, in terms of including the largest number of closed isohyets within the basin, was found to be 315°, exactly normal to the optimum pattern orientation for PMP storms over eastern Kentucky shown in figure 8 of HMR No. 52. The isohyetal pattern from HMR No. 52 placed over the DDKY basin is shown in figure 2-3. In accordance with the procedures established in HMR No. 52, orientation adjustments were required only for the 450- 700- and 1,000-mi^2 storm area sizes, and all these were less than 4 percent. PMP for area sizes less than 300 mi^2 normally results from precipitation produced by convective cells either individually or as multi-celled complexes, which, in either case can have almost any orientation. If other orientations that did not require any reduction had been selected, a lesser total volume of precipitation over the basin would have been produced.

To determine the area size that would produce the maximum volume of precipitation for the first three 6-hr increments (out to 18-hr duration) at

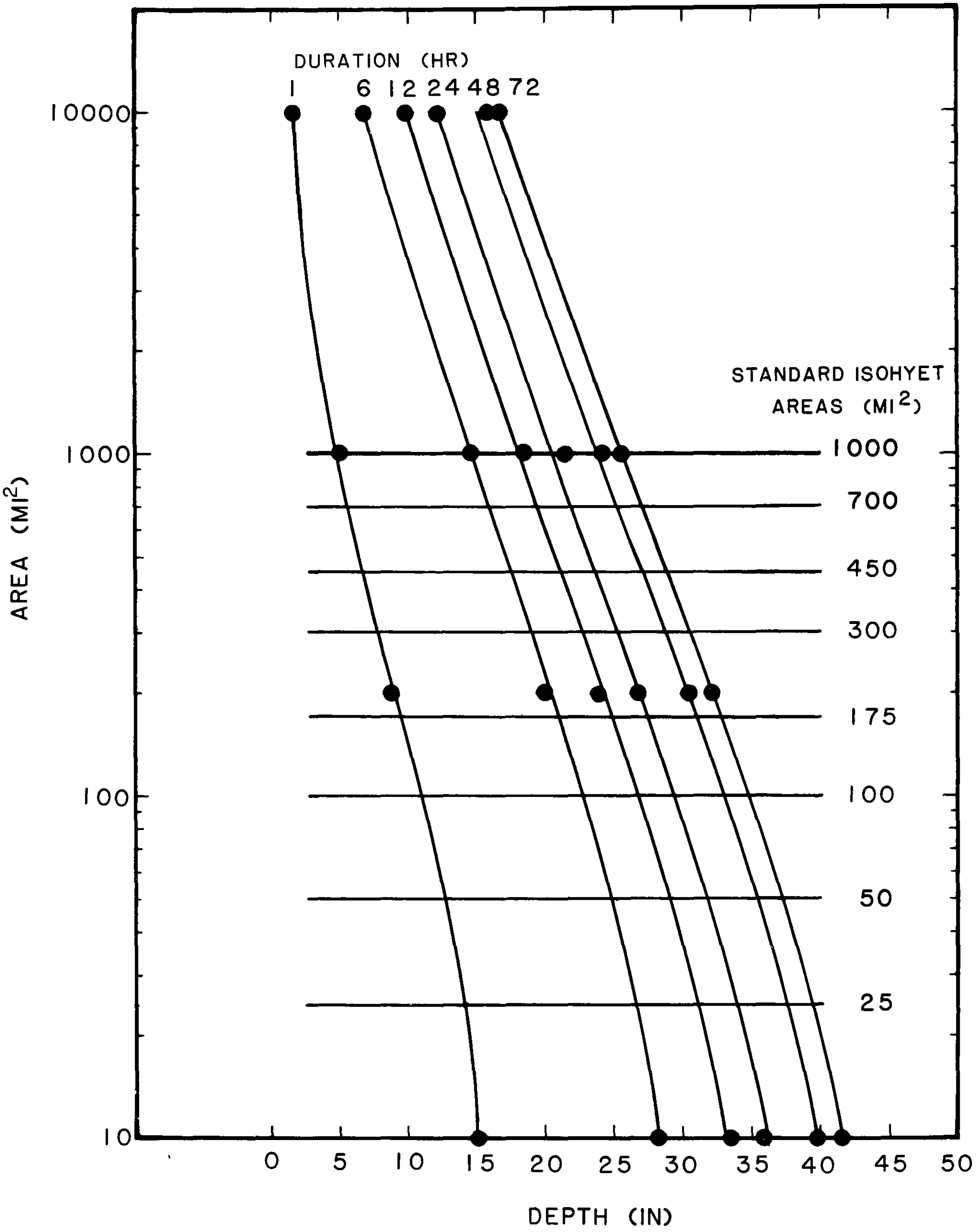

Figure 2-1.--Depth-area-duration data (heavy dots) plotted from HMR No. 52 (1 hr) and HMR No. 51 (6-72 hr) at the centroid of DDKY.

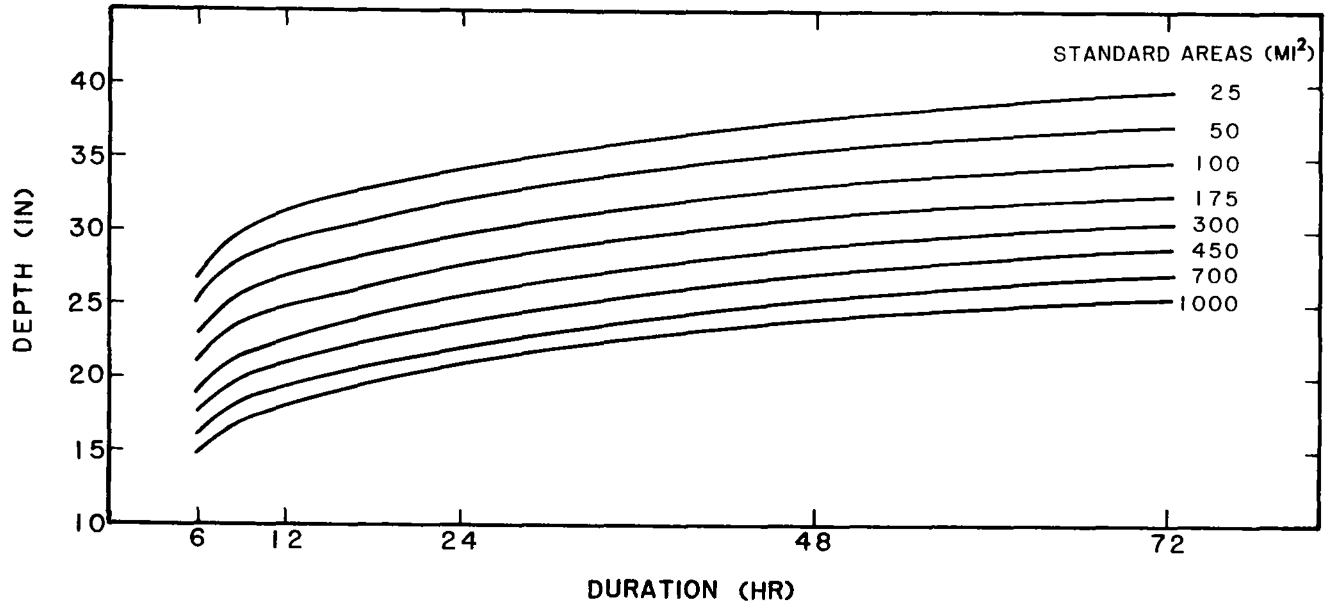

Figure 2-2.--Depth-duration curves for standard areas (25-1,000 mi^2) at the centroid of DDKY.

DDKY, a second degree polynomial function was used to fit the volumetric precipitation computations for the various area sizes listed in table 2-2. The function determined a non-standard storm area size of approximately 270 mi^2. The difference in the curve-fitted volume of precipitation at a 270-mi^2 area and at the standard storm area size of 300 mi^2 was less than 8/100 of one percent and less than 16/100 of one percent at the standard area size of 175 mi^2. In this instance, such small percentages indicate that when the area size that produces maximum volume is not selected by a curve fitting technique, only quite small errors are introduced. Therefore, subsequent computations of average depth of nonorographic PMP for DDKY were based on the 300 mi^2 storm area size. The values

Table 2-2.--PMP values (in.) from figure 2-1 for specific standard area sizes used in HMR No. 52 isohyetal label calculations

	Duration (hr)				
Area (mi^2)	6	12	24	48	72
25	26.6	31.2	34.0	37.7	39.5
50	25.0	29.1	31.9	35.5	37.3
100	22.8	26.8	29.6	33.1	34.8
175	21.0	24.7	27.5	31.1	32.6
300	19.0	22.5	25.4	29.0	30.6
450	17.7	21.1	23.7	27.2	29.0
700	16.0	19.4	22.0	25.3	27.1
1000	14.7	18.2	20.5	23.9	25.5

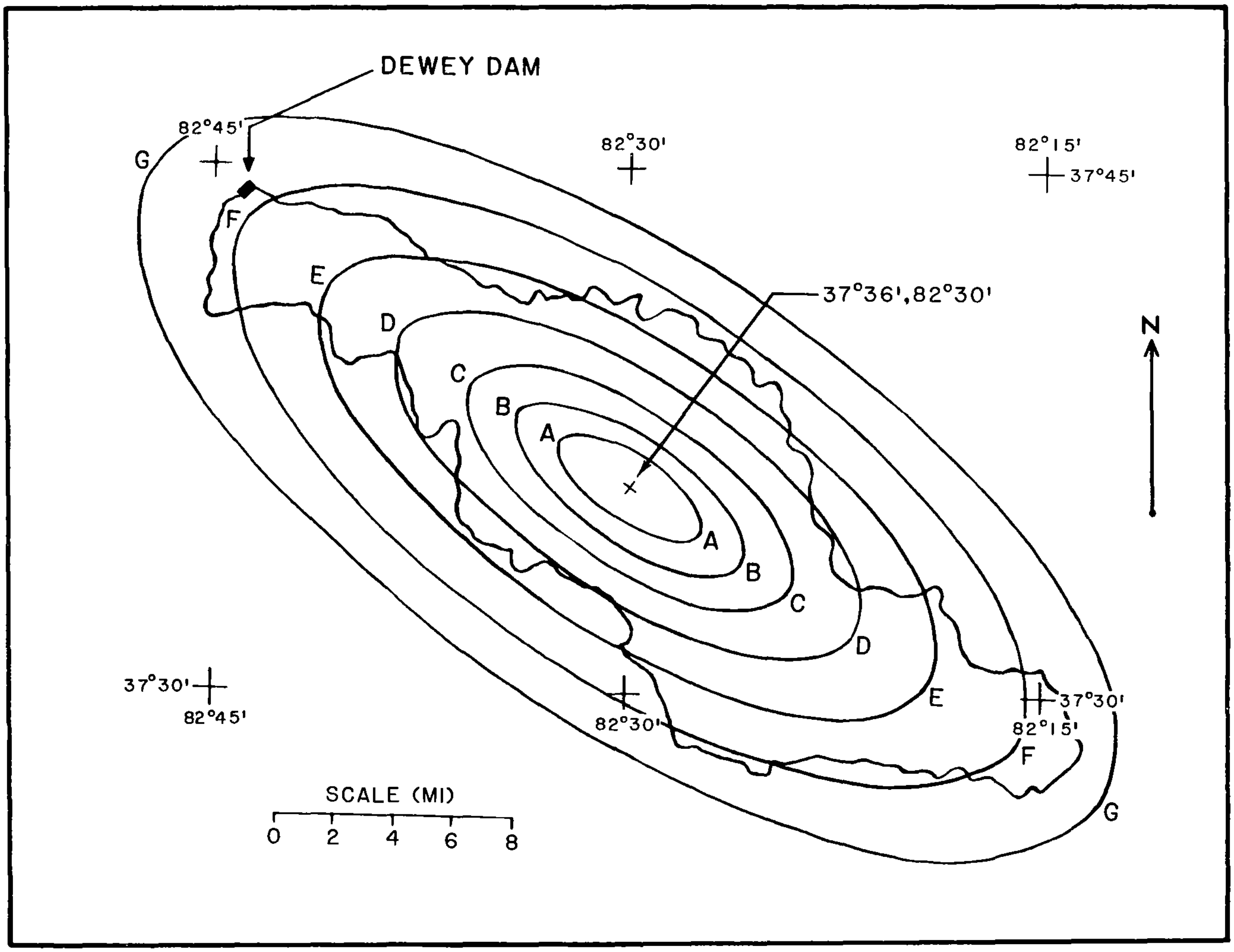

Figure 2-3.--Nonorographic isohyetal pattern placement at DDKY.

assigned to the isohyets for the desired storm area size and durations are shown in table 2-3.

Table 2-3.--Labels for isohyets of nonorographic PMP, for a storm area size of 300 mi^2, for a storm centered at DDKY. Values shown are to nearest tenth of an inch

Isohyetal label	Duration (hr)					
	1	6	12	24	48	72
A	9.7	23.8	27.8	30.7	34.2	35.7
B	9.0	22.2	26.1	28.9	32.4	33.9
C	8.4	20.8	24.5	27.3	30.8	32.3
D	7.8	19.4	23.0	25.8	29.3	30.8
E	7.2	18.1	21.6	24.4	27.9	29.4
F	6.6	16.5	20.0	22.8	26.3	27.8
G	4.9	12.4	15.3	17.7	20.7	22.0

Table 2-4.--Nonorographic PMP for DDKY (207 mi^2) applicable at 1000 mb

	Duration (hr)					
	1	6	12	24	48	72
1. Storm centered value (in.) from fig. 2-1, using HMR No. 51	8.80	20.30	24.30	26.80	30.40	32.00
2. Drainage-averaged value (in.) using HMR No. 52	7.72	19.21	22.83	25.62	29.11	30.61
3. Percent difference (line 2 - line 1 times 100)	88	95	94	96	96	96

Drainage-averaged PMP values obtained from applying the procedures of HMR No. 52 are shown on line 2 of table 2-4. The percentages on line 3 for 6- through 72-hr represent the differences between line 1 and line 2 and indicate reductions of nonorographic PMP attributable directly to basin shape.

2.2.2 Adjustments to 1000-mb Nonorographic PMP for Barrier Elevation

Nonorographic precipitation for DDKY must be adjusted for vertical moisture depletion due to the effects of barriers on inflow moisture for the PMP storm centered over the drainage. The most likely inflow direction for the prototype PMP storm for DDKY was determined to be from 300° to 220° based on the inflow direction of the four storms (Altapass being excluded) from figure 1-1 closest to DDKY. Another consideration was that low-level inflow to DDKY from a more southerly or easterly direction than those determined would be obstructed by the Appalachians.

Twenty three locations were sampled along the western edge of the drainage, each 2 mi apart, and an average barrier elevation of 1,360 ft for the basin was calculated. As in HMR No. 55 "Probable Maximum Precipitation Estimates - United States Between the Continental Divide and the 103rd Meridian" (Miller et al. 1984) and HYDRO 39, no change in precipitable water was allowed for the first 1,000 ft of elevation, i.e., from sea level to 1,000 ft. The basis for this decision came from the concept that moisture potential in any storm is equally likely within 1,000 ft of the elevation of storm occurrence. For elevation intervals above 1,000 ft, precipitation was decreased at the rate of the moisture decrease for a saturated pseudo-adiabatic atmosphere. This was the same procedure followed in HYDRO 39. In HMR No. 55, a moisture change of one-half the saturated pseudo-adiabatic was used beyond the 1,000-ft interval either side of a storm elevation. The reason for this slower moisture change was to avoid excessive increases when transposing storms vertically through the typically large elevation intervals found in the Rockies. Since the special circumstances that applied there do not generally apply in the Appalachians, the more conventional, full pseudo-adiabatic moisture change was selected for this report. A dew point temperature of 77°F, the maximum persisting 12-hr 1000-mb dew point upwind of DDKY, represented the moisture inflow for the time of year when the all-season PMP storm would be expected to occur. This resulted in a

Table 2-5.--Nonorographic drainage-averaged PMP (in.) for DDKY. Amounts are reduced for decreased moisture availability caused by inflow barriers.

	Duration (hr)					
	1	6	12	24	48	72
Drainage-averaged PMP (in.)	7.49	18.63	22.14	24.85	28.23	29.69

3-percent reduction to the values in line 2 of table 2-4, based on computations using the procedures cited. Table 2-5 shows the drainage average nonorographic PMP values reduced for the inflow barrier to the basin.

3. OROGRAPHIC MODIFICATION TO BARRIER ADJUSTED NONOROGRAPHIC PMP

Orographic modification of barrier adjusted nonorographic PMP in table 2-5 takes the same form reported in HYDRO 39. It is expressed as a single factor, K, which, it is assumed, can be applied at any point or assembly of points within the DDKY. The general expression for the orographic intensification factor, K, is:

$$K = M (1 + P ((T/C) -1)) + (1-M) (T/C) \tag{3-1}$$

Definitions of the variables used in equation 3-1 may be found in the list of variables at the front of this report. As in HMR No. 55 and HYDRO 39, in which the derivation of equation 3-1 may be found, the percentage, P, of T/C to be retained during the "most intense" precipitation period, has been estimated by the quantity (1-M) so that equation 3-1 reduces to:

$$K = M^2 (1 - (T/C)) + (T/C) \tag{3-2}$$

At this point, it is important to note that each term on the right side of equation 1-1 is a function of area size and duration so that when PMP is calculated, it is always for a specified area size and duration. In this study, FAFP as shown in table 2-5 represents the average depth of nonorographic PMP for the DDKY area, therefore, the K used in equation 1-1 and calculated using equation 3-2 must also apply to the same area size. Hence, values for the independent variables of equation 3-2 need to be derived for the area size of DDKY. This can be done for the variable M as will be seen in section 3.1.3, as well as for the variable C, discussed in section 3-2. However, only point or 10-mi^2 values are easily obtainable for T in areas where a thorough analysis of the 1-percent chance precipitation level is not available.

A crucial assumption made in this study, and also in HYDRO 39, is that at a given duration if M changes from its 10-mi^2 value with increasing area size, the value of T/C will also change such that K will remain constant across the range of area sizes of interest, in this study from 10 mi^2 to 207 mi^2. The assumption is made so that a value for K can be specified at the area size of the DDKY. As will be shown in section 3.2, K will remain constant if a reasonable areal decrease in the value of T is accepted. Since we do not know, however, what is the areal variability of T at DDKY, the correctness of the constancy of K assumption cannot be proved. The discussion in section 3.1.4 is required by acceptance of the constant K assumption.

The independent variables in equation 3-2 are evaluated initially for an area size of 10 mi^2 and a duration of 24 hr. The K for a specific terrain setting may be thought of as a quantitative estimate of the degree to which atmospheric processes, that were not initiated or influenced by such terrain, are changed (in their precipitation producing aspect) when such terrain interacts with or "feeds back" into them.

The term T/C has the same meaning in general terms as that for K. Both numerator, T, and denominator, C, represent depths of precipitation. In areas where topography has minimal interaction with atmospheric forces producing precipitation, the numerator and denominator should be considered equal in magnitude. In areas where topography should alter the depth of precipitation produced by an initial level of atmospheric forcing, the denominator stands for the precipitation depths associated with the initial level of atmospheric forcing and the numerator stands for the precipitation depths associated with the initial level of forcing, as altered through interaction with topography.

M is a dimensionless number representing the percentage of nonorographic precipitation which occurs in a "most intense" or "core" precipitation event (popularly, the "cloudburst" phase of a storm) for a given duration of interest. By "most intense" or "core" event is meant that within a given time interval, h, a very large percentage of total precipitation is accumulated in a small percentage of h; the length of this small percentage in hours being represented symbolically by r. The duration r is always a part of h; h is always uninterrupted and r is believed to be uninterrupted for the prototype PMP storm at DDKY, although r may be interrupted (two or more cores) in other storms. The reason why it is important to identify such "cloudbursts" is that it is believed there is a reduction in the percentage contribution of topographic interaction to precipitation production during the cloudburst phase of a storm. The basis for this belief is that (for a specified location and season) within a given volume of atmosphere and unit duration of time, there is a limit to the rate of increase of condensation which is closely approximated by atmospheric forcing unenhanced by topographic interaction; to try to exceed a given level of condensate production by adding on topographic forcing would be equivalent to asking the atmosphere to exceed a critical limit. At other times, however, when the unenhanced forcing is not close to approaching its upper limit, it is reasonable to permit terrain to interact at a proportionally greater level. Schematically, this is illustrated in figure 3-1, where the core duration, r, is about 25 percent of the duration of the precipitation interval, h. In this study, as in HYDRO 39 and HMR No. 55, M is represented by the ratio of depths, D_r/D_h, indicated in figure 3-1. In equation 3-2, M modulates the magnitude of the term for terrain feedback, i.e., M acts to diminish T/C when convection is an important component of the precipitation producing mechanism; the more intense the convection, the greater the degree of diminution. M also serves to define the magnitude of nonorographic precipitation caused by intense convection and is referred to as the storm intensification factor. Within the range of values possible for r for the h's of interest in this study, it is reasonable that as h increases for a particular storm, the value of r should either remain the same or increase. The magnitude of r is determined from available depth-area-duration information and mass curves of rainfall representative of prototype PMP storms.

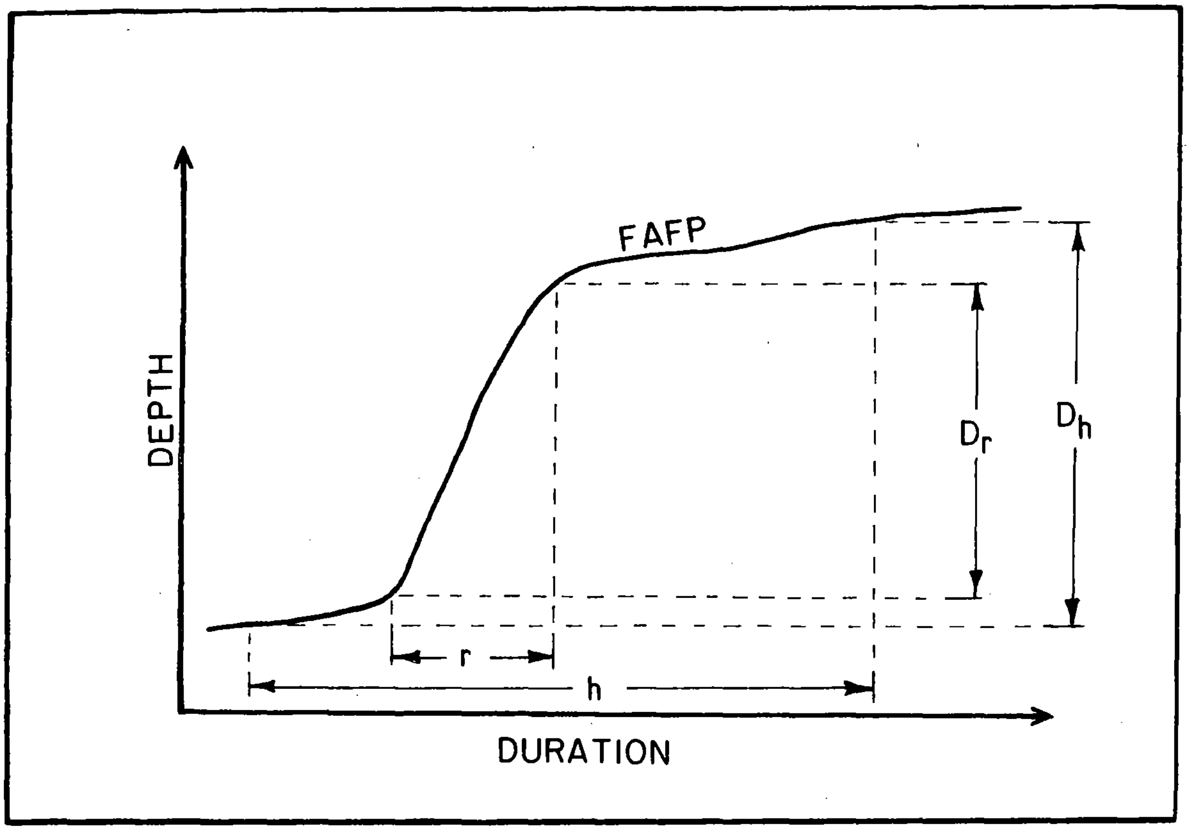

Figure 3-1.--Schematic representation of core duration, r, within fixed interval, h, and associated depths of nonorographic PMP, D_r and D_h, used in setting storm intensification factor.

3.1 Evaluation of the Variables Required to Estimate Orographic Intensification in DDKY

3.1.1 Evaluating T/C

The value of T/C was obtained for durations of 1, 6, 12, 24, 48 and 72 hr. As mentioned earlier, the areal variability of T/C was assumed to be such that, in combination with the observed areal variability of M, the value of K would be constant for all area sizes included within DDKY. In a relatively small area such as that encompassed by DDKY, this assumption is warranted.

Initially, T/C was evaluated at a point (over sizes up to 10 mi^2) and for 24-hr duration. The 1-percent level of precipitation (100-yr) was selected as the appropriate frequency interval to be used in determining the magnitudes of T and C.

3.1.1.1 Evaluating C. C was obtained by calculating the 100-yr precipitation depths at locations below 1,000 ft and outside the stippled area of HMR No. 51, within the rectangular region of figure 3-2. The period of record for the 37 stations used in the analysis ranged from 33 to 84 yr, with 28 of these stations having a period of record equal to, or greater than 75 yr. Twelve of the 28 "long" period of record stations had a period of record greater than 80 yr. The 37 stations were all of the stations available from Technical

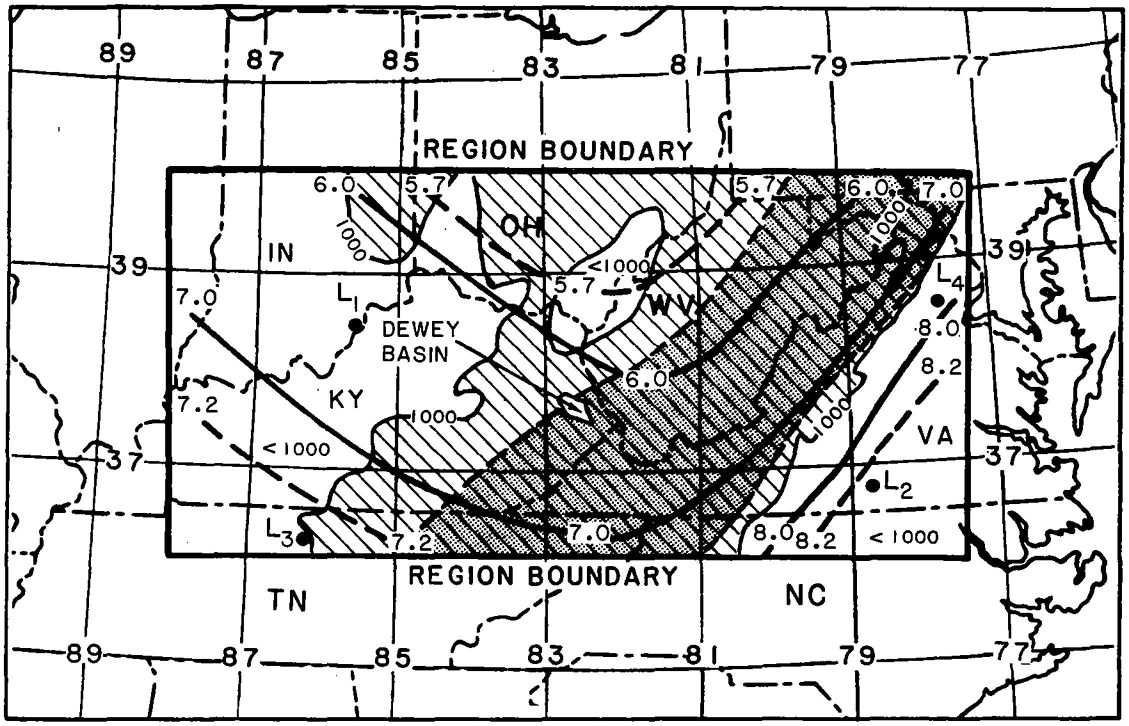

Figure 3-2.--Analysis region for parameter C (solid, heavy isolines in inches), evaluated at 100 yr and 24 hr. Solid, thin lines are of a generalized 1,000 ft MSL elevation contour (hatched region $\geq$ 1,000 ft).

Paper No. 29 (U.S. Weather Bureau, 1957-1960), as supplemented by the Daily Climatological Data Tapes in the Office of Hydrology format and other climatological data for the nonorographic portion of the rectangular area shown in figure 3-2. The supplementary data extended the period of record from 1956-1957 to 1980.

Even with a relatively long period of record, the plotted data in certain portions of the analysis region indicated large variability in C. At locations identified by L_1 and L_2, both in nonorographic regions in figure 3-2, each location was considered as the center of a circle within which the minimum period of record for precipitation records was 75 yr. The extreme value of the parameter C within these circles exceeded the average value by 13 percent for the circle with L_1 as the center and by 19 percent for the circle with L_2 as the center. Both circles were of 22 mi radius, and variation of elevation among reporting locations within each circle was a maximum of only 218 ft. One would not expect the atmosphere to produce and maintain gradients of convergence/divergence of this magnitude within such relatively small circular areas year after year, so that sampling variability is the likely cause for the differences in C. Sampling variability was not this large everywhere, however. At locations L_3 and L_4 where the circle radii were 20 and 19 mi and the minimum period of record 76 and 73 yr, respectively, the variability was 3.4 and 2.2 percent, respectively.

As a result of the ranges in the value of C in some parts of the nonorographic sections of the analysis region, a range of choices for the orientation and magnitude of the isoline analysis was possible. In the analysis depicted in figure 3-2, the orientation of the C isolines west of the stippled area was made to reflect the orientation of isodrosotherms of maximum persisting 12-hr 1000-mb dew points as shown in the Climatic Atlas of the United States (Environmental Science Services Administration 1968). East of the stippled area, the analysis gives weight to the fact that 10 of the 14 observations there (east of the 1,000-ft contour) were equal to or greater than 7.5 in., and 7 of these 10 exceeded 8 in. Isoline segments first drawn in each of the nonorographic areas were connected with smooth isolines. The resulting analysis, based on all available data through 1980 was found to be consistent with the analysis of 100-yr 24-hr precipitation depths reported in "Rainfall Frequency Atlas of the United States," U.S. Weather Bureau Technical Paper No. 40 (TP No. 40) (Hershfield 1961) in terms of isoline orientation. Note that the variability of C across DDKY is quite small, about 0.1 in., or between 1 and 2 percent.

As will be seen, subsequently, T will be determined at the centroids of three topographic subdivisions of DDKY. Hence, three distinct values of C, each adjusted for barrier elevation, will be needed to form three separate values of T/C, each applicable to a unique subdivision. Based on the size of each subdivision, a weighted value of T/C will then be obtained and assigned to the basin centroid. The derived values of C may be found on line 4 of table 3-2 in the section which follows, as does a discussion of the procedure followed to adjust a 1000 mb value of any 100-yr 24-hr precipitation depth to a given elevation MSL.

3.1.1.2 Evaluating T. There were no stations for which precipitation records were available within DDKY. The nearest gage is located on the edge of the drainage at Dewey Dam. The strategy adopted under these circumstances was to search for proxy observations for the drainage. If the drainage was topographically uniform, only one set of proxy observations would need to be found; if more than one topographic regime could be identified in a drainage, one group of proxy observations for each subdivision might be needed; and all proxy observations would "come from" or be "found in" places where the topographic settings were similar to the single or multiple topographic settings of the drainage. Figure 3-3 shows the outline of DDKY along with the proxy locations from which precipitation records were considered in determining the levels of the 100-yr precipitation level, T, for the selected topographic subdivisions of DDKY (see fig. 3-4 for these subdivisions).

The DDKY consists of a series of ridge-valley-ridge combinations oriented generally southeast to northwest with additional, shorter valleys oriented somewhat more south to north. At first estimate, the topographic variability in this generally uniform, corrugated setting was considered to be insignificant enough so that the drainage could be classified as homogeneous in its interaction with atmospheric processes. However, examination of all 100-yr 24-hr precipitation depths available for this study and within the analysis region from the Cumberland Plateau northeastward to the Kanawha River and from the crest of the Alleghenies northwestward for about 90 mi, indicated a gradient of 100-yr 24-hr T existed with higher values (7-8 in.) near the crest decreasing to lower values (5-6 in.) at the lower elevations to the northwest. This suggested a topographic classification for the drainage consisting of uplands and lowlands (heightened topographic feedback vs. diminished topographic feedback) with a transition or buffer area as shown in figure 3-4.

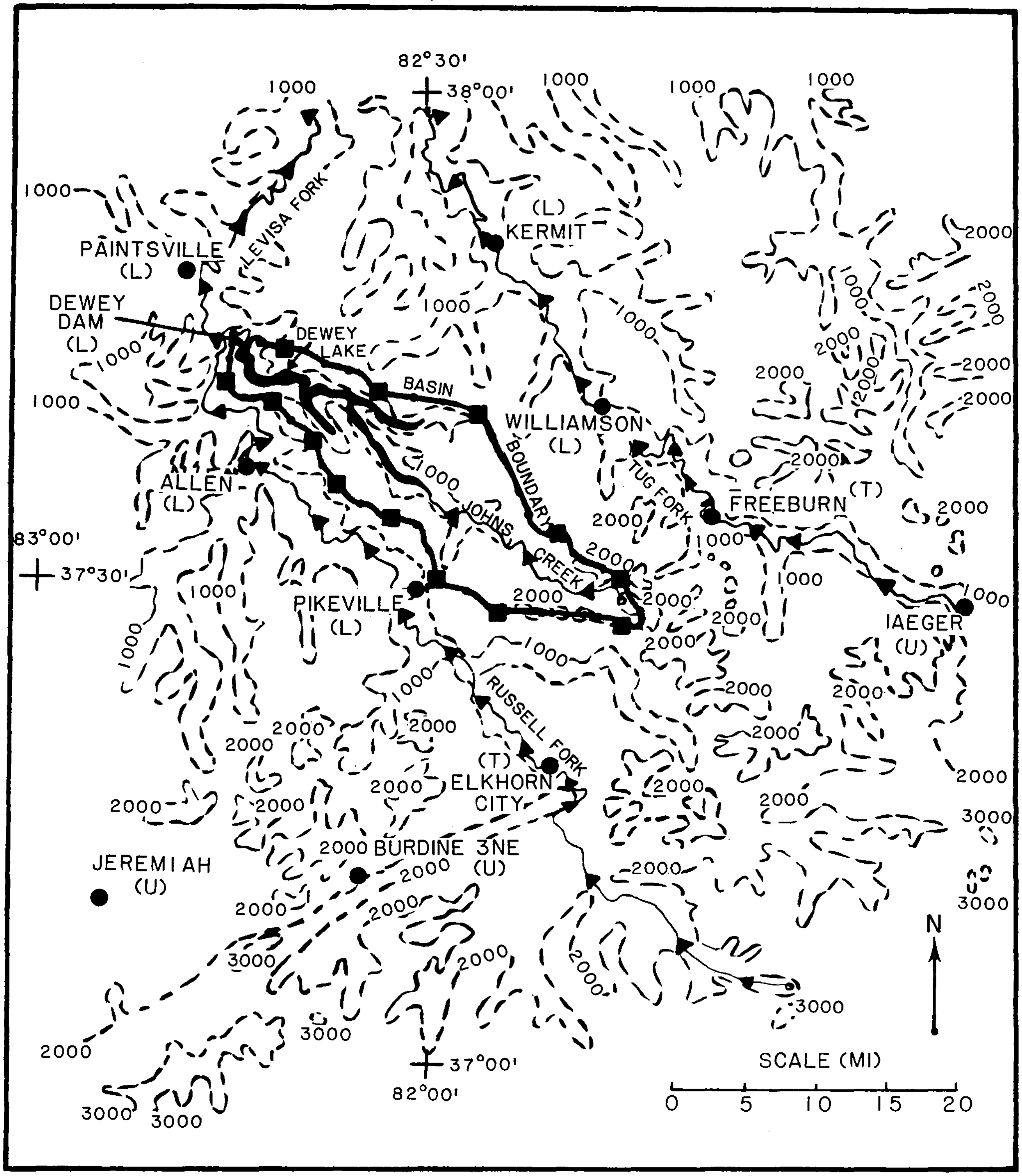

Figure 3-3.--Drainage above DDKY (solid line with filled squares) showing 1,000-ft elevation contours (dashed lines). Locations of proxy locations and associated topographic setting designator in parentheses (L) = lowlands; (U) = uplands; (T) = transition are indicated by filled circles. Selected streams are shown by thin, solid lines with arrowheads indicating direction of streamflow.

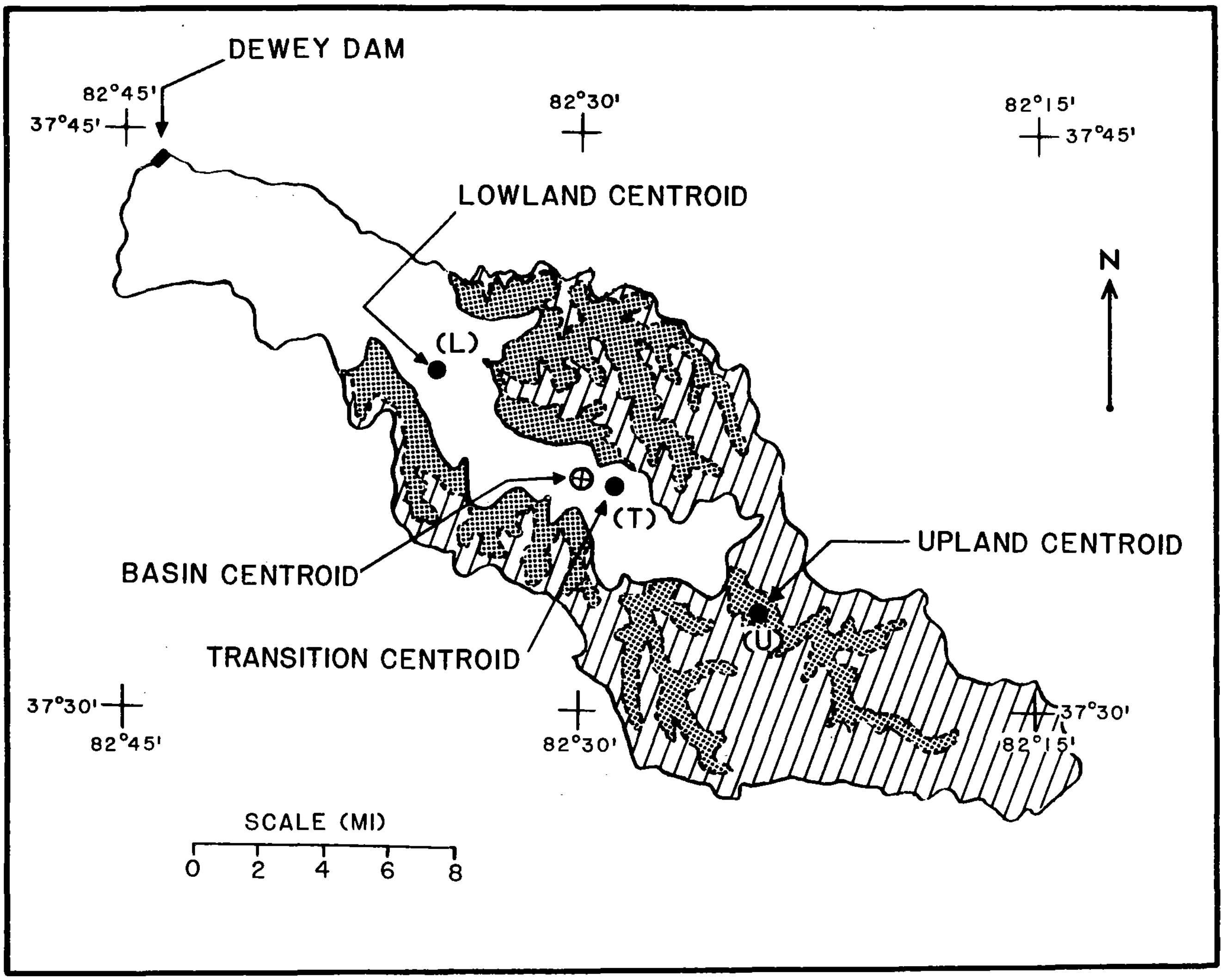

Figure 3-4.--Topographic subdivisions for DDKY with locations of centroids (filled circles) for each subdivision and for the drainage as a whole (open circle). Lowlands are unshaded; uplands are hatched; and transition areas are stippled.

The adopted subdivision of DDKY specified that lowlands would consist of valleys whose floors were below 700 ft MSL, while the valley floors of upland areas would be above 1,000 ft MSL; in both subdivisions the tops of adjacent ridges could have any value. The transition subdivision contained the remaining ridge-valley-ridge areas. A different topographic characterization of DDKY might have produced a value of T comparable to the one using the adopted characterization.

Besides the elevation-only criterion adopted for this report, features such as change in terrain slope, sheltering ridge lines, proximity to ridge lines, or roughness of terrain are useful in establishing the limits of topographic classifications. What is important in application of the techniques used in this study is that where there is significant spatial variability in precipitation, some relevant physiographic feature be selected to characterize each subdivision in the drainage and that proxy locations be sought in places nearby where topography has the selected characteristics. It would be futile to establish topographic subdivisions within which it is unlikely that hourly or daily precipitation records would be found. The selection of the topographic feature or features characteristic of a subdivision will depend on how well a given physiographic feature corresponds with significant spatial variability of the precipitation parameter of interest.

It is not intended in this section to attempt to recommend a "best way" to classify, categorize or subdivide topography in general in the Appalachians or to assert that the scheme adopted in this report at DDKY is in itself superior to some other scheme. It is desirable to keep the specification of topographic characteristics flexible or open-ended since there are a variety of settings in the Appalachians. A consequence of this flexibility, however, is that different analysts may assign different classifications and specification of their limits to a given setting, and if the depths of precipitation within this setting happen to be highly variable for a given frequency of occurrence, quite different values of T may be assigned to the same area. If the procedures of this section are followed, an average value for T for a drainage or portion of a drainage will be obtained, but they do not guarantee that it will be reproducible. A condition for deriving a singular average value of T for a drainage is a detailed analysis of precipitation data in orographic areas such as those analyses in NOAA Atlas 2 (Miller et al. 1973). The merit of a particular topographic classification and specification of its limits must be judged in part by the results it engenders; specifically, how well the resulting average value of T/C corresponds with T/C derived in other places having similar features.

Initially, all stations within or adjacent to the stippled area of figure 3-2 were considered as candidate proxy stations for this study since DDKY straddles the western edge of the stippled area. There is no upper limit to the initial number of proxy stations if all such stations could experience the same prototype PMP storm as the drainage of interest. The candidate stations were reduced to those in figure 3-3 by using the following guidelines:

A. Only those closest to the drainage or drainage subdivision were retained. Note: Because the placement of reporting stations can vary widely, an unequivocal rule for selecting which or how many proxy stations are closest cannot be formulated. In this study, from 2 to 6 of the closest proxy stations were considered sufficient to represent the parameter T for each 100 mi^2 of topographically homogeneous area.

B. Of those stations remaining after guideline A was applied, those with a period of record less than 15 yr were eliminated.

C. If, among the remaining stations, there were two or more within a circle of 2 mi radius, all of which were within an elevation interval of 500 ft, then only that station with the longest period of record from among them was retained. If the longest period of record station should have an unrepresentatively high or low precipitation depth for its topographic setting and in relation to the shorter period of record data, the more representative value having the next longest period of record would have been selected.

The topographic setting at Burdine 3NE did not have the general characteristics of the upland subdivision. Burdine 3NE is described in the Substation History

Table 3-1.--Relevant information for selected proxy locations of figure 3-2. The location prefix designates topographic classification as (L)owland, (U)pland or (T)ransition

Location	Elevation (ft MSL)	100-yr 24-hr depth (in.) (observation day)	POR (yr)
(L) Kermit, WV	620	4.76	26
(L) Williamson, WV	670	4.56	29
(L) Paintsville, KY	620	6.05	26
(L) Dewey, KY	690	3.65	21
(L) Pikeville, KY	690	4.07	26
(L) Allen, KY	640	3.88	16
(T) Elkhorn City, KY	800	6.28	21
(T) Freeburn, KY	730	5.00	22
(U) Jeremiah, KY	1,160	7.45	26
(U) Iaeger, WV	1,080	7.79	26

for Kentucky, Key to Meteorological Records Documentation No. 1.1 (U.S. Weather Bureau 1966), as a station in a "narrow valley, (with) high mountains all around." As such it is a typically "sheltered" location. While such settings are present in DDKY, they constitute a negligible portion of the upland subdivision. Inclusion of the 100-yr 24-hr precipitation depth from Burdine 3NE with the other proxy locations at Jeremiah and Iaeger would misrepresent the enhancement of nonorographic precipitation by upland topography by giving undue weight to a precipitation value affected by sheltering.

All the locations finally selected are listed in table 3-1. At Williamson, West Virginia where two reporting locations were within 4 mi and 100-ft elevation of each other, the location with the slightly longer period of record was used and the other excluded. If both locations had been used, the orographic intensification factor K would not have changed.

When the subdivisions were planimetered, uplands constituted 43.2 percent of the drainage; lowlands constituted 31.7 percent and transition area 25.1 percent, respectively, of the drainage (table 3-2). The proxy locations shown in figure 3-3 have either an associated (L), (T) or (U) signifying a (L)owland, (T)ransition or (U)pland classification.

To transform the observation-day depths of table 3-1 to depths comparable with values for C already discussed, an "N-minute" adjustment should be made by multiplying each observation day depth by 1.13. As indicated in TP No. 40 (Hershfield 1961) and NOAA Atlas 2 (Miller et al. 1973), the "N-minute" adjustment is based on statistical-empirical relationships considered valid within the 48 conterminous United States.

A "fit by eye" procedure was used to locate a centroid for each topographic subdivision (see filled circles of fig. 3-4). Then in a manner similar to the way in which barrier elevations were set for the centroid of the <u>entire</u> drainage, barrier elevations were determined for each topographic <u>subdivision</u> (line 3 table 3-2).

Table 3-2.--Factors related to calculation of T/C (10-mi^2 24-hr values) for each topographic classification. Values on lines 4, 6 and 7 are at the elevation indicated on line 3

	Lowland	Transition	Upland
1. Percent of drainage	31.7	25.1	43.2
2. Subdivision centroid (latitude, longitude)	37°39' 82°35'	37°36' 82°29'	37°32' 82°24'
3. Barrier elevation (closest 10 ft)	1,180	1,330	1,460
4. C, at centroid (in.)	6.18	6.14	6.08
5. Number of proxy locations	6	2	2
6. T, at centroid (in.)	5.09	6.37	8.61
7. T/C, at centroid	.82	1.04	1.42

Using the assumptions about vertical depletion of water available for precipitation mentioned in section 3.1.1.1, and assuming that the 1000-mb dew point temperature associated with this process should be (for a 100-yr frequency of occurrence event) an average of the monthly maximum persisting 12-hr 1000-mb dew points for the centroid of each topographic subdivision, one can calculate the value of C for each centroid. Then using the average value of 100-yr 24-hr precipitation depth, T, determined from the proxy stations for each subdivision, the quantity T/C is obtained. Line 6 of table 3-2 shows the derived values of T for each topographic subdivision. Using the weights from line 1 and the T/C from line 7, a weighted average value for T/C of 1.13 was obtained at the 24-hr duration to be applied at the centroid for the whole DDKY basin.

The value of T/C for the transition subdivision of DDKY is much the same as the value of T/C near the orographic separation line (similar to the boundary of the stippled region of HMR No. 51) located close to the foothills of the Rockies (see HMR No. 55). The T/C at 24 hr for the upland subdivision at DDKY (1.42) is somewhat smaller than the comparable value (1.54) for the Deerfield River Drainage reported in HYDRO 39. The increase in orographic enhancement of precipitation between the transition and upland subdivisions, in spite of the Deerfield comparison, is intuitively too large. However, since the smaller than expected value of T in the lowland subdivision of DDKY compensates for this over enhancement when a drainage average value of T/C is calculated, it was decided to retain the proxy locations of table 3-1, rather than search further afield. The weighted average value of T/C (1.13) is realistic for a drainage partly within and without the stippled region of HMR No. 51, and consequently, the adopted topographic classification and specification in this report has merit.

3.1.2 Temporal Variability of T/C

Values of T/C for other durations were developed with the aid of the T/C analysis from HMR No. 55 for the region between the Continental Divide and the

Table 3-3.--Relevant information used to prepare proxy values of 100-yr 6-hr T/C for DDKY

Proxy Location	Location 1/ C (in.)	Location 2/ C (in.)	Interpolated C (in.) (100 yr 6 hr)	Interpolated (T/C)
1.) 20 mi NE Colorado Springs (COS)	25 mi WNW COS/ 2.4	Nr. Cheyenne Wells/ 5.0	3.08	1.14
2.) 10 mi SE Walsenburg (WAL)	27 mi WNW WAL/ 2.4	40 mi WSW Springfield/ 5.0	3.26	1.07
3.) 28 mi SSW Raton	53 mi SW Raton/ 2.4	Nr. Clayton/ 5.0	3.39	1.12

103rd meridian. It was necessary to go to the western states to obtain detailed orographic precipitation data available only in NOAA Atlas 2 (Miller et al. 1973). Three locations were selected where the 1-percent chance level of precipitation for the 6-hr duration had been thoroughly analyzed and where the 100-yr 24-hr value for T/C was 1.13. The locations selected were at approximately the same latitude as DDKY and at comparable distances from the Gulf of Mexico, considered the primary source of moisture for the PMP storm in both regions. The proxy locations for establishing the T/C versus duration relation for DDKY were in the foothills of the Front Range of the Rocky Mountains in Colorado and New Mexico, specifically, 20 mi northeast of Colorado Springs, CO; 10 mi southeast of Walsenburg, CO, and 28 mi south southwest of Raton, NM. At each location, the 24-hr values of T/C increased downwind along the preferred inflow direction for the PMP storm. While the topographic settings and the climatology of rainfall differ somewhat between the western foothills of the Appalachians and the eastern foothills of the Rocky Mountains, the PMP storm types are basically similar in both places, as should also be the physical interaction between the foothills and the atmosphere during upslope conditions. Values for C were derived following the practices mentioned in HMR No. 55. Two points were selected on either side of each proxy location where, from topographic considerations, the value of T/C should be approximately 1. A uniform gradient of C was assumed in order to establish the value of C at each proxy location. The relevant data used to derive 100-yr 6-hr values of T/C are shown in table 3-3.

The average value of T/C from the three locations in table 3-3 (1.11) was accepted as the proxy value of T/C for the 6-hr duration at DDKY. Since it is reasonable that the value of T/C would approach 1.0 as the duration becomes increasingly small, these three pairs of T/C and duration (1.0 and 0 hr, 1.11 and 6 hr and 1.13 and 24 hr) were joined by the smoothly varying curve shown in figure 3-5 and extrapolated to provide values of T/C at the other durations given in table 3-4.

Table 3-4.--Weighted values of T/C for 10 mi^2 at durations important for this study

h (hr)	1	6	12	24	48	72
T/C	1.04	1.11	1.12	1.13	1.14	1.15

3.1.3 Evaluating M

The first step in evaluating M is to define the length of the core event, r, for the durations, h, of interest in this study. Definitions of r and h may be found in the list of variables at the front of the report and these terms are also discussed at the beginning of section 3. Depth-duration relations within important storms of record, transposable to or near DDKY are the starting point in the evaluation. Depth-duration information from Storm Rainfall for nine of the eleven storms transposable to or near DDKY (see fig. 1-1) is available for just 6-hr intervals. For one of the remaining storms, Bonaparte, there is hourly information out to 8 hr; and three hourly information is available for the other (Grant Township) storm. The large interval between the depth-duration data for most of these storms makes it difficult to define properly an hour-by-hour relationship for r and h.

However, hourly data at individual stations within the storm were on hand for four storms: Smethport, Council Grove, Grant Township and Hayward. Examination of these data provided insight into the relationship between r and h on the hourly timescale. The DDKY was completely enclosed by the transposition limits for only the Smethport storm from among the five storms (the four just mentioned, plus Bonaparte) for which hourly precipitation information was on hand. The eastern transposition limits for the Bonaparte, Grant Township and Hayward storms were within 65 mi of the centroid of DDKY, while the limits for the Council Grove storm were approximately 175 mi from the DDKY centroid. For this reason, only the Smethport, Bonaparte, Grant Township and Hayward storms were considered as candidates for examining the r versus h relationship. Of the four candidate storms, Smethport dominates the others in depth of precipitation produced at 10 mi^2 and 200 mi^2 within its transposition limits, which includes DDKY. Cumulative hourly rainfall data, normalized with respect to the cumulative amount at a given duration, and the averages of these amounts at four locations close

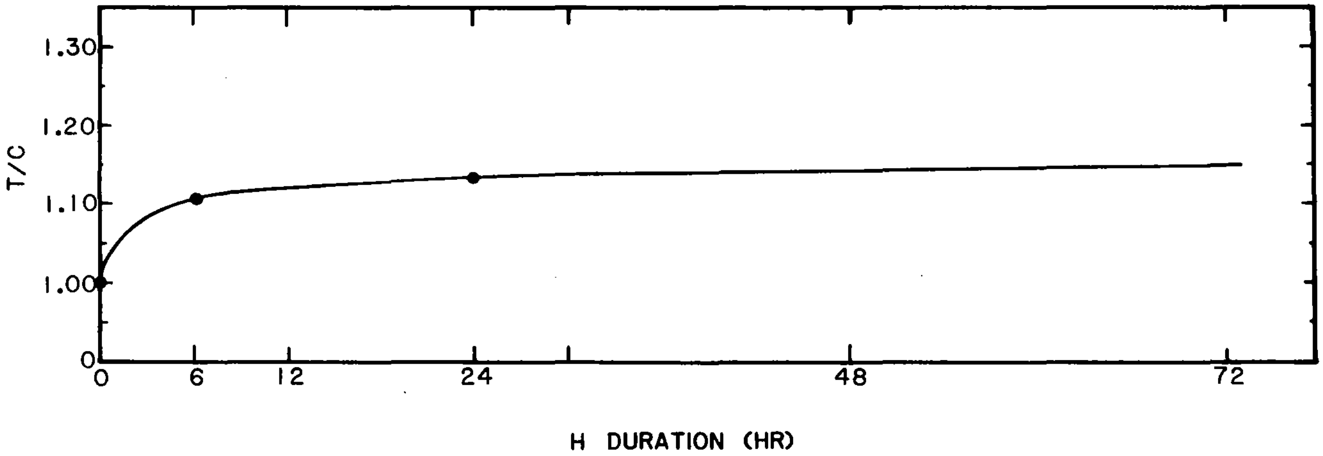

Figure 3-5.--Orographic factor T/C as a function of duration at DDKY.

Table 3-5.--Normalized cumulative 24-hr precipitation amounts, in percent, for four stations within the Smethport, PA storm of July 17-18, 1942 and averages therefrom at durations, h, of 24 hr (line 5), 18 hr (line 6), 15 hr (line 7), 12 hr (line 8), 9 hr (line 9), 6 hr (line 10) and 3 hr (line 11)

Location r(hr)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Raymond	42	50	54	55	56	63	85	86	86	91	97	98	99	99	99	99	100	100
2. Smethport	25	39	43	46	66	66	66	66	67	67	68	77	91	100	100	100	100	100
3. Carter Camp	37	43	47	49	51	66	82	86	87	90	93	96	98	99	99	100	100	100
4. Emporium	16	31	43	50	55	56	56	56	57	61	76	77	78	86	99	99	99	99
5. Average (24 hr)	30	41	47	50	57	63	72	74	74	77	84	87	92	96	99	100	100	100
6. Line 5 as percent of its 18-hr value	30	41	47	50	57	63	72	74	74	77	84	87	92	96	99	100	100	100
7. Line 5 as percent of its 15-hr value	30	41	47	50	58	64	73	75	75	78	85	88	93	97	100			
8. Line 5 as percent of its 12-hr value	34	47	54	57	66	72	83	85	85	89	97	100						
9. Line 5 as percent of its 9-hr value	41	55	64	68	77	85	97	100	100									
10. Line 5 as percent of its 6-hr value	48	65	75	79	90	100												
11. Line 5 as percent of its 3-hr value	64	87	100															

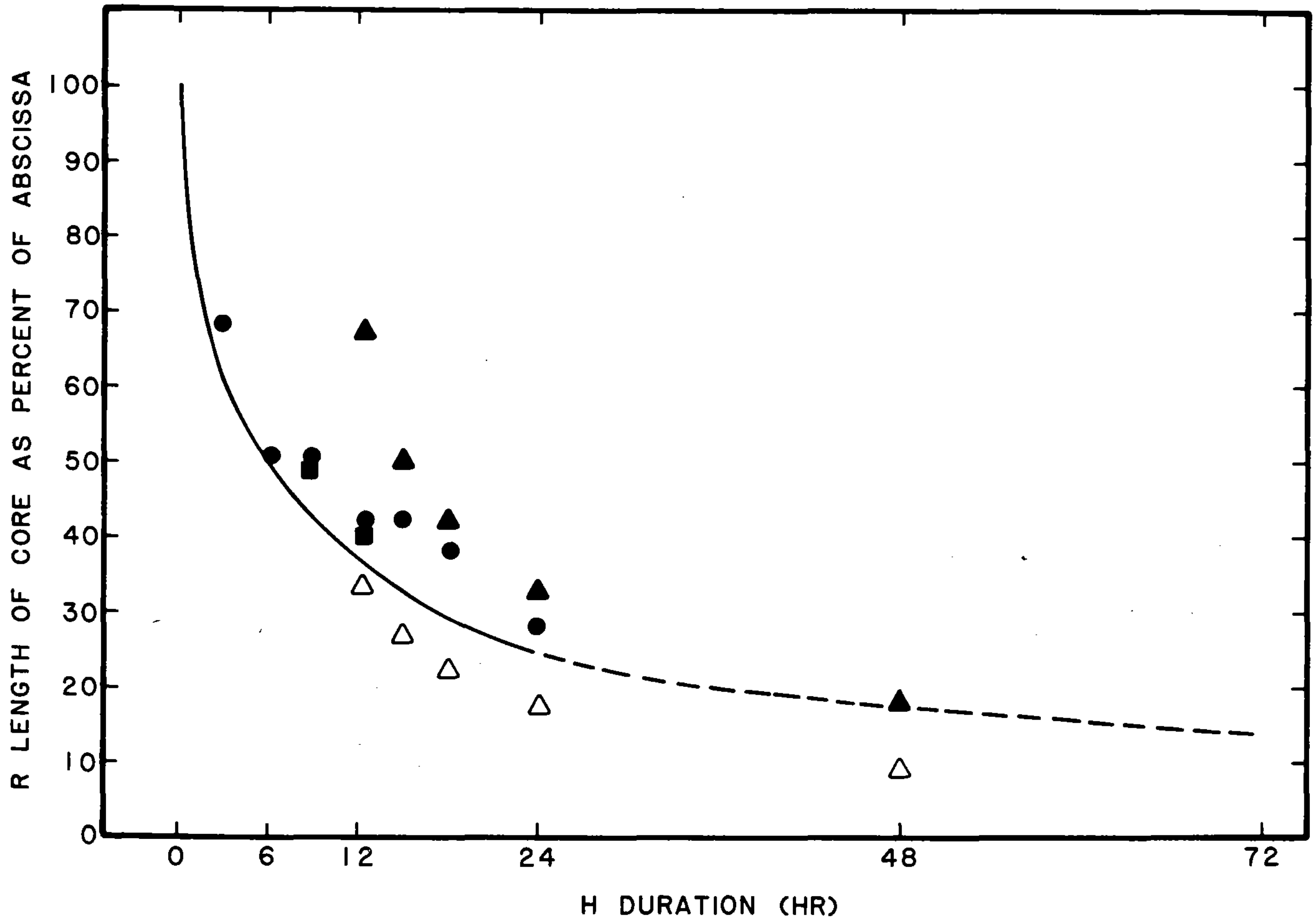

Figure 3.6.--Relation of length of core event, r (ordinate), to a duration of equal or greater length, h, for area sizes not larger than 10 mi^2 at DDKY. Units of ordinate are expressed as a percent of the given h. Values from storms at Smethport and Bonaparte are shown by filled circles and filled squares. The data for Hayward are shown by triangles - open for the 4-hr core and filled for the 8-hr core.

(all within 28 mi) to the Smethport storm center are presented in table 3-5. Each cumulative hourly amount in table 3-5 is expressed as a percentage of the cumulative hourly amount at a longer duration.

It was assumed in this study that the ending of the core event was indicated by a slackening in the rate of accumulated precipitation, given that a significantly large amount of precipitation had already accumulated in a relatively short amount of time. It was judged that the slackening occurred at 7 hr during the most intense 24 hr (line 5); and at 7, 6.5, 5, 4.5, 3 and 2 hr during the most intense 18, 15, 12, 9, 6 and 3 hr, respectively. In line 11, it is unclear where the core precipitation ends, however, three of the four stations show a significant lessening in rate of precipitation accumulation between 1 and 2 hr, while there appears to be no core at the fourth station (Emporium). These data, where r is expressed as a percentage of h, are shown in figure 3-6 as filled circles.

It was recognized that since the four locations referenced in table 3-5 are in an orographic setting, the data there contain some amounts of precipitation coming from topographic interaction with the atmosphere and, therefore, the derived relationship between r and h does not describe a purely nonorographic relationship as desired. However, examination of the isohyetal analysis for total storm duration, U.S. Department of Commerce (undated), indicated that relative isohyetal maxima and minima in the Smethport storm were poorly correlated with terrain features such as those mentioned in section 3.1.1.2 in this report. It was concluded that the poor level of correlation indicated that terrain interaction contributed in only a minor way to the production of the recorded amounts of precipitation and, therefore, that the percentages of table 3-5 were acceptable for portraying the strictly nonorographic relationships desired.

There is some risk in using average values from those gage records near the storm center as indicators of core-like precipitation viz., a strong indication at one gage could be submerged by weak or no indication at the other gages. The risk should be small, though, since the atmospheric forcing responsible for the core event should operate during its lifetime across areas much more encompassing than that of a single gage. If, nonetheless, the data sample is clearly bifurcated with respect to such forcing at the available gage locations, only those in which the forcing is apparent would be used to obtain the average value; and, sometimes, values from a single gage would be sufficient.

Data for three locations near the Hayward storm center are shown in table 3-6, which is in the same format as table 3-5, except that the 48-hr period of most intense precipitation, rather than the most intense 24-hr period, are used since Hayward was a longer duration storm than Smethport. The data for durations beyond 12 hr suggest two cores in this storm, one ending at r equal about 4 hr and the other ending at r equal about 8 hr. Data from lines 8 through 11 indicate that during the most intense 9, 6 and 3 hr, there is not sufficient intensity of precipitation to support a single core. Because of the ambiguity of whether to plot the 4- or 8-hr core values at durations of 12, 15, 18, 24 and 48 hr, both values were plotted; the open triangles representing the 4-hr core and the filled triangles the 8-hr core. Since the PMP storm at DDKY is considered to contain just a single core, such as shown in the data for Smethport, the data points for the Hayward storm in figure 3-6 for durations less than 48 hr were given relatively small weight when estimating the r versus h relationship for DDKY.

Acceptable ranges for the intensity and absolute level of precipitation accumulation during core-like events are still being discussed and formulated by hydrometeorologists. When the formulation becomes final, the Hayward storm may be excluded from those other storms considered to have cores. The data of table 3-6 and plotted values therefrom in figure 3-6 are included so that comparison may be made with the data from the other storms.

Data from the Bonaparte storm appear in table 3-7. Although the individual station records in the storm area were not available, information in Storm Rainfall indicates that data from Bonaparte, Iowa are the basis for the depth-duration relations of this storm. The slackening occurs during the most intense 12 and 9 hr of this storm for an r equal to 4.5 hr for each of the durations. These two r's, converted to percent of h, are shown as filled squares in figure 3-6. The ending of the core is not indicated in the data on lines 3 and 4.

Table 3-6.--Normalized cumulative 48-hr precipitation amounts for three stations within the Hayward, WI storm of August 26-31, 1941 and averages therefrom at durations, h, of 48 hr (line 4), 24 hr (line 5), 18 hr (line 6), 15 hr (line 7), 12 hr (line 8), 9 hr (line 9), 6 hr (line 10), and 3 hr (line 11)

r(hr) Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1. Couderay	17	18	25	32	32	46	51	61	67	69	69	69	70	70	70	70	70	70	73	73	73	73	73	73
2. Minona	13	14	23	24	28	29	29	37	37	38	40	50	58	68	74	75	75	75	75	75	75	75	75	75
3. Spooner	21	26	29	30	30	31	34	39	46	47	47	48	48	48	48	48	48	48	48	48	48	48	48	48
4. Average (48 hr)	17	19	26	30	30	35	38	46	50	51	52	56	59	62	64	64	64	64	65	65	65	65	65	65
5. Line 4 as % of its 24-hr value	26	29	40	46	46	54	58	71	77	78	80	86	91	95	98	98	98	98	100	100	100	100	100	100
6. Line 4 as % of its 18-hr value	27	30	41	47	47	55	59	72	78	80	81	88	92	97	100	100	100	100						
7. Line 4 as % of its 15-hr value	27	30	41	47	47	55	59	72	78	80	81	88	92	97	100									
8. Line 4 as % of its 12-hr value	30	34	46	54	54	63	68	82	89	91	93	100												
9. Line 4 as % of its 9-hr value	34	38	52	60	60	70	76	92	100															
10. Line 4 as % of its 6-hr value	49	54	74	86	86	100																		
11. Line 4 as % of its 3-hr value	65	73	100																					

Table 3-7.--Normalized cumulative 24-hr precipitation amounts for the Bonaparte, IA storm of June 9-10, 1905 at durations, h, of 12 hr (line 1), 9 hr (line 2), 6 hr (line 3), and 3 hr (line 4). Values in parentheses are interpolated values

r(hr)	1	2	3	4	5	6	7	8	9	10	11	12
Cumulative depth as percent of												
1. 12-hr amount	17	33	49	66	81	85	90	95	(97)	99	(99)	100
2. 9-hr amount	18	34	51	68	84	88	93	78	100			
3. 6-hr amount	20	39	58	78	95	100						
4. 3-hr amount	35	67	100									

The hourly reports from Sioux City, IA are the only ones available of sufficient duration and proximity to the Grant Township storm center. The significant precipitation at Sioux City lasted for only 13 consecutive hours. These data (not shown) indicated a much shorter core length prevailed at durations of 12, 9 and 6 hr (2.5, 2 and 2 hr, respectively) than was the case in the other three storms. Sioux City is approximately 38 mi from the Grant Township storm center. Since all hourly reports used in the previous three storms were within 28 mi of the respective storm centers, it was decided that the Sioux City observations, because of their greater distance from the storm center, were not representative of conditions near the storm center; therefore, they were not included with those from the other storms.

The smooth curve of figure 3-6 represents the r versus h relationship at a point or for a 10-mi^2 area for the PMP storm within DDKY. This curve envelops the plotted data for the three storms selected (excluding the shorter duration core at Hayward) in such a way that the length of the core event at DDKY at most durations is somewhat shorter than the plotted data indicate. For the durations of 12, 15, 18 and 24 hr, the envelopment is in line with the progressively shorter r's between the 8-hr core at Hayward and the dominant Smethport storm.

The smaller the value of r, the smaller the value of D_r and so too the value of M. From equation 3-2, it can be seen that the smaller the value of M, the larger the amount of T/C that is retained and, consequently, the larger the value of K. The envelopment in figure 3-6 has the consequence of making orographic precipitation slightly larger at DDKY than the data from the three selected storms indicate. If the data from Sioux City had been used to characterize the Grant Township storm, the envelopment could have been greater and the resulting K factor larger than the one used.

The curve of figure 3-6 states that the core event for the PMP storm at DDKY is up to 20 percent shorter at various durations than was the core event near the dominant Smethport storm. This level of envelopment was considered reasonable. If more than one dominant storm (for the area size and durations of interest) were plotted, with each storm given equal weight, then the mean value of the r values from these storms would be the reference point for the r versus h relationship for the basin of interest.

The values for the duration of the core beyond 24 hr in figure 3-6 come from the pair of points at 48 hr from the Hayward storm and extrapolation of the data for the first 24 hr, which is why this part of the curve is dashed. It is important to remember that the relationship of figure 3-6 is meant to apply to the PMP storm for DDKY and it may or may not apply to any other storm that has occurred or could occur there. This study assumes the function depicted in figure 3-6 is continuous for all durations.

The 10-mi^2 depth-duration curve of nonorographic PMP for DDKY from figure 2-1 is shown in figure 3-7. This curve is employed in combination with the r versus h relationship of figure 3-6 to produce the 10-mi^2 values of M shown in table 3-8. For a duration of 12 hr, the value of r on line 1 of table 3-8 is obtained from figure 3-6 by moving perpendicularly upward from the abscissa at h = 12 hr until the curve is intersected and then moving horizontally until the ordinate is intersected at r equals 37.5 percent, approximately. The value of r for 4.5 hr is obtained by multiplying the h for 12 hr by 0.375. The 12-hr value of M at 10 mi^2 (.78) from table 3-8 is the result of dividing the 4.5-hr depth of precipitation in line 2 (25.8 in.) by the 12-hr depth of precipitation in line 3 (33.2 in.). The values of 25.8 and 33.2 in. are obtained by finding 4.5 and 12 hr on the abscissa of figure 3-7, moving vertically upward until the smooth curve is intersected and then moving horizontally until the depths D_r and D_h are read on the ordinate as 25.8 and 33.2 in., respectively. The same procedure is used for all other durations.

Curves similar to that of figure 3-7 were not constructed for the centroids of the topographic subdivisions since they are too close to each other to provide distinct readings of D_r and D_h (fig. 3-1). The ratios of D_r/D_h at two locations (37°N, 83°W and 39°N, 83°W) nearby DDKY were within a few percent of D_r/D_h at the basin centroid, indicating that similar variability should be expected at the centroids of the topographic subdivisions. Hence, a weighted value of M for DDKY was not calculated as was done for the T/C parameter in table 3-2.

3.1.4 Temporal and Areal Variability of M

In the same manner that was used to obtain the durational variability of M at 10 mi^2 in table 3-8, data from table 2-1 were fitted with a smoothly varying depth-duration curve as shown in figure 3-8 for the 200-mi^2 area size centered within DDKY. Data derived from the depth-duration curves of figures 3-7 and 3-8 are shown in lines 1 and 2 of table 3-9, where M is calculated to the nearest hundredth and then multiplied by 100. The values of M in line 2 are based on the assumption that the r versus h relationships of figure 3-6, developed for a point or 10-mi^2 area size, also apply at 200 mi^2. If the forcing of intense convection were of shorter duration (smaller value of r) at larger area sizes, the resulting values of M would also be smaller and vice versa. The varying rates of precipitation accumulation at the several individual stations seen in tables 3-5 and 3-6 do not provide enough direct evidence to state unequivocally whether the value of r at 200 mi^2 should be greater than, equal to, or less than, its values at 10 mi^2. Discounting the forcing provided by interaction among individual thunderstorms within a 200-mi^2 area, and concentrating solely on forcing at the synoptic- and planetary- to meso-scales, as proposed by Orlanski (1975), it is intuitively reasonable that the duration of

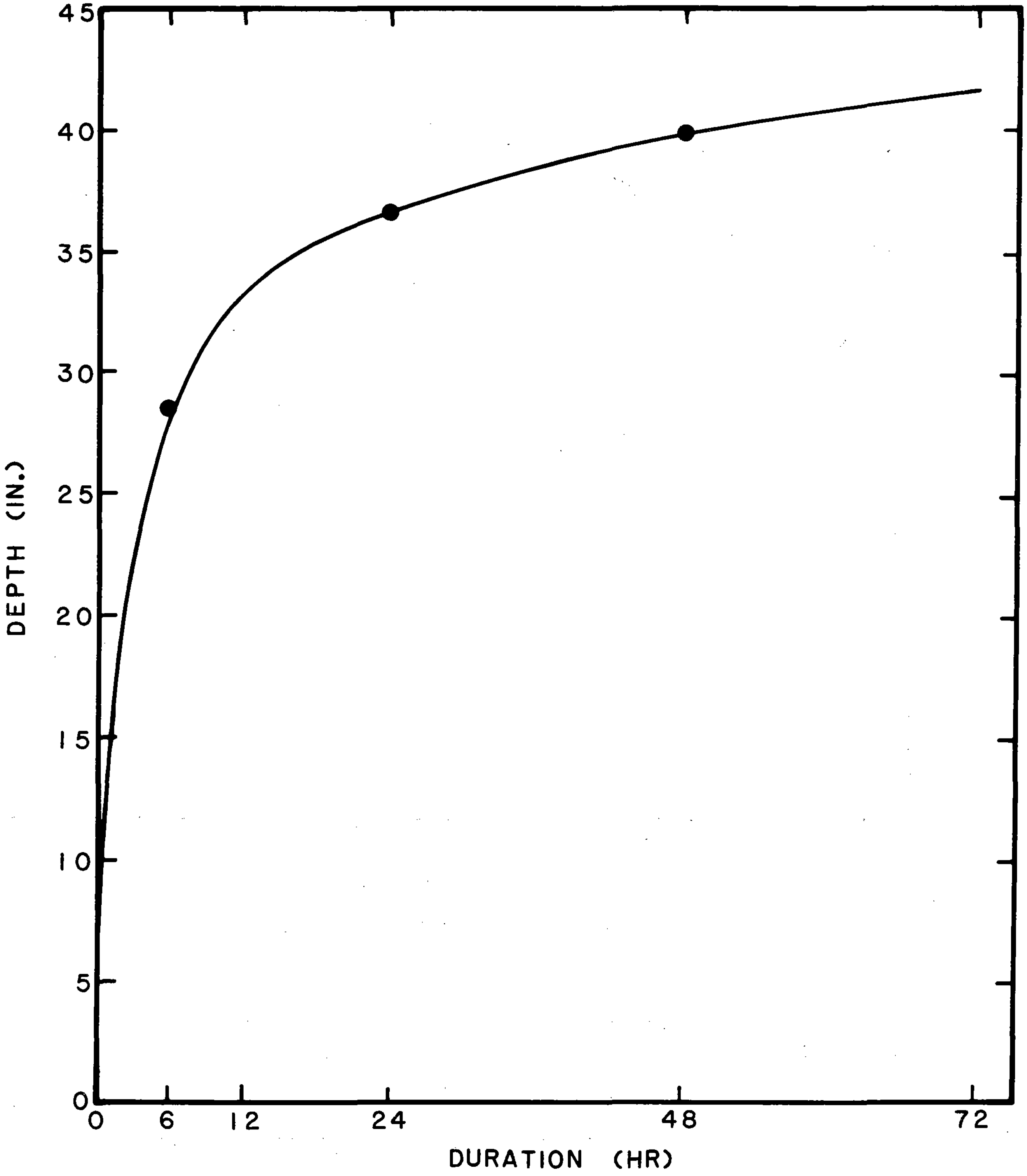

Figure 3-7.--Depth of nonorographic PMP at 10 mi^2 as a function of duration at DDKY. Values shown as filled circles are taken from figure 2-1.

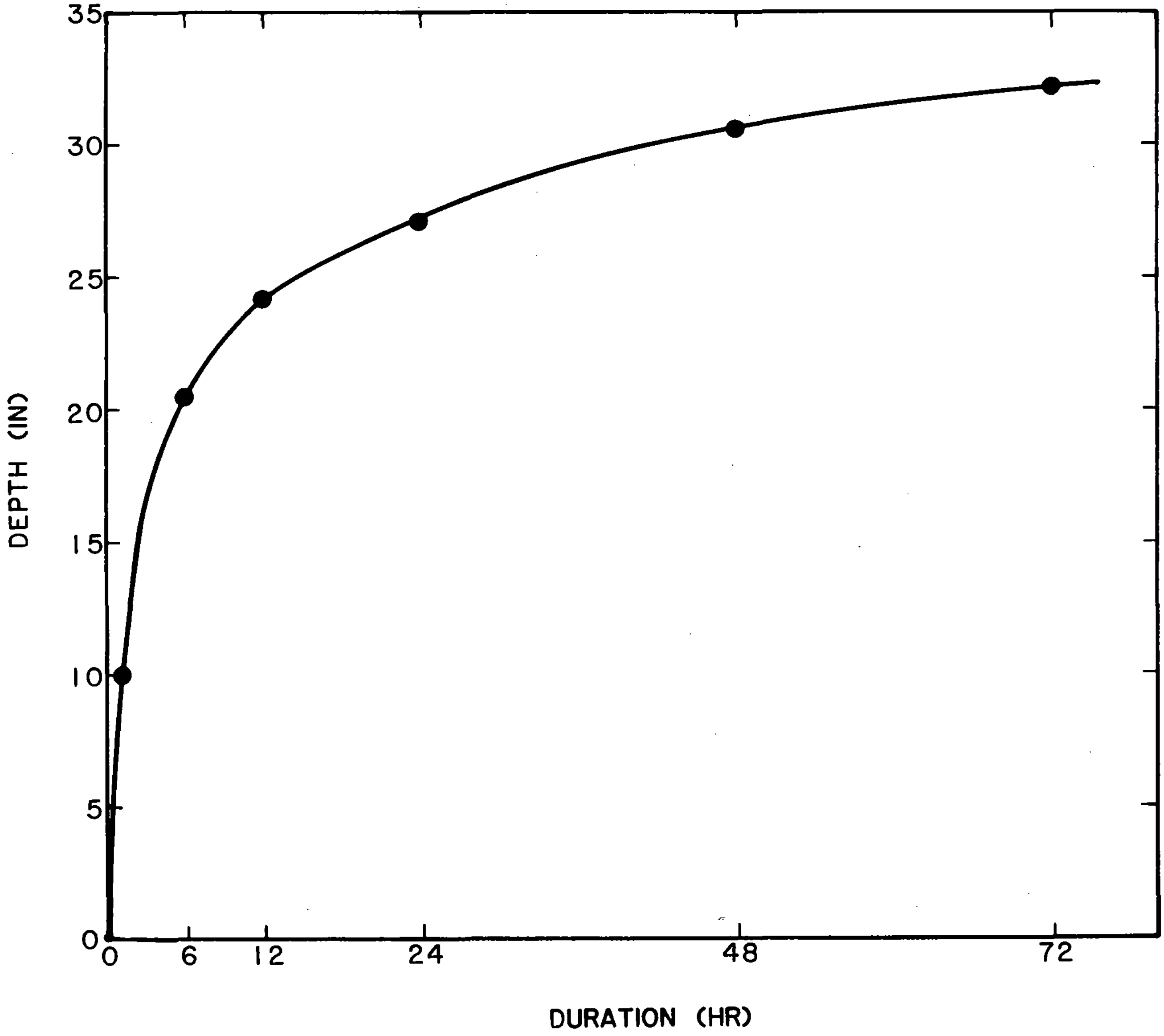

Figure 3-8.--As in figure 3-7, but for the area size of 200 mi^2.

Table 3-8.--Values of M corresponding to a 10-mi^2 precipitation area size and for selected durations, h

h (hr)	1	6	12	24	48	72
1. r (hr)	.75	3	4.5	6	8.5	10.5
2. D_r (in.)	13.3	22.3	25.8	28.2	30.9	32.2
3. D_h (in.)	15.1	28.2	33.2	36.5	40.0	41.7
4. M	.88	.79	.78	.77	.77	.77

Table 3-9.--Values of M at the centroid (37°36'N, 82°30'W) of DDKY for selected durations from values in figures 3-7 and 3-8

h (hr)	1	6	12	24	48	72
1. M (10 mi^2) times 100	88	79	78	77	77	77
2. M (200 mi^2) times 100	89	80	79	76	73	73
3. line 2 - line 1	1	1	1	-1	-4	-4

atmospheric forcing would not be preferential between the 10-mi^2 and 200-mi^2 area sizes. The forcing should be of equal duration for the 10-mi^2 subunit receiving the heaviest precipitation, as well as for its nineteen 10-mi^2 "neighbors," even though the chronological beginning and ending of core-like precipitation at the western and eastern edges of the 200-mi^2 area, for example, might be different. It is on this basis that the stated assumption was made.

The observed variation of M for either the 10-mi^2 or 200-mi^2 area size makes sense, if the difficulty of maintaining atmospheric structures capable of producing intense, "core-like" precipitation within a fixed area for a long period of time is assumed. What is somewhat surprising at first glance is the variability of M at 200 mi^2 versus its variability at 10 mi^2 at 48 hr and 72 hr (see line 3, table 3-9). The size of the difference is rather small in each case, so that the differences may have arisen from the way in which data were extracted, curves fitted, and values read therefrom. Such comparisons would have to be made at a number of other locations before one could verify this possibility. Notwithstanding these possibilities, the results in line 3 are reasonable if one accepts the point of view that early in a storm's history the most intense cells are as likely to be found in any 10-mi^2 subunit of a 200-mi^2 area as they are within any other 10-mi^2 subunit of the 200-mi^2 area. In contrast, later, storm structures will have evolved at the randomly "selected" initial 10-mi^2 subunit making it more likely that only a specific contiguous minority of the 10-mi^2 subunits around it will receive the most intense precipitation (from among all possible minorities), while the intensity drops off for the remainder of such subunits. In other words, the 10-mi^2 subunit which early in the storm's history received the heaviest precipitation is likely to be the same one which subsequently continues to receive the heaviest precipitation. Consequently, the intensity factor drops off more slowly there than at the remaining nineteen 10-mi^2 subunits in a 200-mi^2 area and, thus, the widening difference in M factors between 200 and 10 mi^2 at 48 and 72 hr shown in table 3-9. The important point to note here is that if random numerical sampling errors are discounted, the charts of storm-centered, area-averaged PMP from HMR No. 51 indicate that the prototype PMP storm for DDKY likely has the storm structures as speculated above, as also did the storms upon which the HMR No. 51 analyses are based.

3.2 Computation of K for DDKY

Values from table 3-4 and 3-8 are used in equation 3-2 to produce the values of K found in table 3-10, to be applied at the centroid of DDKY. If the same calculations are made using 200-mi2 values for M (table 3-9, line 2) and K

Table 3-10.--Values of K for precipitation area sizes between 10 mi^2 and 207 mi^2 for selected durations, h, at DDKY

h (hr)	1	6	12	24	48	72
K	1.01	1.04	1.05	1.05	1.06	1.06

(table 3-10), but this time solving for T/C, it is found that the hypothetical 200-mi^2 value for T/C will have to change (from its 10-mi^2 value) by less than 2 percent for K to remain constant for all durations of interest in this study. Studies (U.S. Weather Bureau, 1957-1960) based on observations from the NWS regular cooperative network of closely spaced recording rain gages indicate that values of C decrease by about 7 percent from 10 mi^2 to 200 mi^2 at a duration of 24 hr, so that T would need to decrease by about 9 percent. A 9-percent decrease in T which results in a 2-percent decrease in T/C for DDKY is reasonable.

4. COMPUTING TOTAL PMP FOR DDKY

Drainage averaged total PMP for DDKY is calculated from the relationship stated in section 1:

$$PMP = (FAFP)\ (K) \qquad (1\text{-}1)$$

where FAFP is equivalent to the nonorographic drainage-averaged PMP shown in table 2-5, and (K) comes from table 3-10. For the durations, h, considered in this study the results of the computations may be found in table 4-1 on line 7.

Table 4-1.--Total PMP and related parameters for DDKY

	Duration (hr)					
	1	6	12	24	48	72
1. Nonorographic PMP, sea level (in.)	7.72	19.21	22.83	25.62	29.11	30.61
2. Nonorographic PMP-barrier elevation (in.)	7.49	18.63	22.14	24.85	28.23	29.69
3. T/C	1.04	1.11	1.12	1.13	1.14	1.15
4. Length of core event (hr.), r	.75	3.0	4.5	6.0	8.5	10.5
5. M	.88	.79	.78	.77	.77	.77
6. K	1.01	1.04	1.05	1.05	1.06	1.06
7. Total PMP (in.) (line 2 x line 6)	7.56	19.38	23.25	26.09	29.92	31.47

Values for variables directly related to the computation of total PMP for DDKY are summarized on the first 6 lines of table 4-1.

The basin-centered results of line 7, table 4-1 may now be compared with the earlier formulated storm-centered PMP, but this time for a "generic" 207-mi^2 area size at the barrier elevation of DDKY. The percentages in table 4-2 are obtained by first multiplying the depths of table 2-4, line 1, by the ratio of corresponding values in table 2-5 to table 2-4, line 2; then dividing table 4-1, line 7, by the product; and finally, multiplying this result by 100. The resulting percentages indicate that for durations less than 24 hr, topographic interaction with atmospheric forces producing nonorographic precipitation within the DDKY, as represented by the K factors of table 4-1, line 6, are not sufficient to overcome the reduction of storm-centered, nonorographic PMP brought about by optimum fitting of isohyetal patterns to the DDKY basin shape. At durations beyond 24 hr, the effects of topographic interaction are only 1 percent larger than the effects of basin shape. Values comparable to those of table 4-2 at 6, 12, 24 and 48 hr for the Deerfield River Drainage (HYDRO 39) are 110, 114, 117 and 121 percent, respectively. Whereas the basin shape reduction of nonorographic PMP is smaller at Deerfield than at DDKY, it is mainly the heightened influence of orographic interaction there that accounts for these larger percentages.

Sheltering at some of the locations of the proxy observations used to derive the orographic factor T/C at DDKY, could produce some underestimation of the level of interaction between terrain and atmosphere there. However, the percentages of table 4-2 are within a range of percentages reasonable for a basin as close to a boundary separating areas of none and some orographic modification to nonorographic PMP, as is the DDKY.

Table 4-2.--Basin-centered total PMP at the centroid of DDKY as a percent of storm-centered, nonorographic PMP reduced for barrier elevation

Duration (hr)	1	6	12	24	48	72
PMP (Percent)	89	98	99	100	101	101

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