NOAA Technical Memorandum NWS HYDRO 39

PROBABLE MAXIMUM PRECIPITATION FOR THE UPPER DEERFIELD RIVER DRAINAGE MASSACHUSETTS/VERMONT

Water Management Information Division
Office of Hydrology
Silver Spring, Md.
June 1984

U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Weather Service

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WBTM HYDRO 2 Annotated Bibliography of ESSA Publications of Hydrometeorological Interest. J. L. H. Paulhus, February 1967, 20 pp. (Superseded by WBTM HYDRO 8)

WBTM HYDRO 3 The Role of Persistence, Instability, and Moisture in the Intense Rainstorms in Eastern Colorado, June 14-17, 1965. F. K. Schwarz, February 1967, 21 pp. (PB-174-609)

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WBTM HYDRO 9 Elements of River Forecasting (Revised). Marshall M. Richards and Joseph A. Strahl, March 1969, 57 pp. (PB-185-969)

WBTM HYDRO 10 Flood Warning Benefit Evaluation--Susquehanna River Basin (Urban Residences). Harold J. Day, March 1970, 42 pp. (PB-190-984)

WBTM HYDRO 11 Joint Probability Method of Tide Frequency Analysis Applied to Atlantic City and Long Beach Island, N.J. Vance A. Myers, April 1970, 109 pp. (PB-192-745)

NOAA Technical Memorandums

NWS HYDRO 12 Direct Search Optimization in Mathematical Modeling and a Watershed Model Application. John C. Monro, April 1971, 52 pp. (COM-71-00616)

NWS HYDRO 13 Time Distribution of Precipitation in 4- to 10-Day Storms--Ohio River Basin. John F. Miller and Ralph H. Frederick, July 1972, 41 pp. (COM-72-11139)

NWS HYDRO 14 National Weather Service River Forecast System Forecast Procedures. Staff, Hydrologic Research Laboratory, December 1972, 7 chapters plus appendixes A through I. (COM-73-10517)

NWS HYDRO 15 Time Distribution of Precipitation in 4- to 10-Day Storms--Arkansas-Canadian River Basins. Ralph H. Frederick, June 1973, 45 pp. (COM-73-11169)

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Nuclear Regulatory Commission
Contract No. NRC-03-83-102

UNITED STATES DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary
/ National Oceanic and Atmospheric Administration
John V. Byrne, Administrator
/ National Weather Service
Richard E. Hallgren, Assistant Administrator

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Definitions

Concurrent Precipitation. That portion of precipitation, coming from the PMP storm centered in a basin being analyzed for the probable maximum flood, which falls concurrently in an adjacent basin (sec. 3.2).

Drainage-averaged PMP. After the PMP storm pattern has been distributed across a specific drainage and the computational procedure of HMR No. 52 applied, the resulting average depth is referred to as the drainage-averaged PMP estimate. The values include that portion of the PMP storm pattern that occurs over the drainage, both PMP and residual (sec. 3.1).

Probable Maximum Precipitation (PMP). Theoretically the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location at a certain time of the year. (This definition is a 1982 revision to that used previously (American Meteorological Society 1959) and results from mutual agreement among the National Weather Service, the U.S. Army Corps of Engineers, and the Bureau of Reclamation) (sec. 2.).

Residual Precipitation. When computing drainage-averaged PMP, the precipitation that occurs outside the area of the PMP pattern placed on the drainage, regardless of the area size of the drainage. Because of the irregular shape of the drainage, or because of the determination of a PMP pattern smaller in area than the area of the drainage, some of the residual precipitation can fall within the drainage (sec 3.2).

Standard Isohyet Area Sizes. In HMR No. 52, the standard isohyet area sizes correspond to the area enclosed by isohyets of the recommended PMP storm pattern, i.e., 10, 25, 50, 100, 175, 300, 450, 700, 1,000, 1,500, 2,150, 3,000, 4,500, 6,500, 10,000, 15,000, 25,000, 40,000, and 60,000 mi^2 (sec. 3.1).

List of Variables

A — The component of FAFP occurring during the most intense or core precipitation event.

B — The component of FAFP occurring outside of the core precipitation event.

C — The portion of T which results when there is no terrain feedback into or terrain interaction with the atmospheric forces producing precipitation. This is frequently referred to as as convergence precipitation. It is evaluated in this report 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.

K_1 The value of K during the period of most intense rainfall or core precipitation event.

K_2 The value of K during the period outside the core precipitation event.

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.

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 when A occurs. It is defined as 1 - M.

PMP In nonorographic regions, K is equal to 1.00 and total PMP is equal to FAFP.

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/C A dimensionless number representing the broadscale orographic influence for a given (usually small) area size during the period when B occurs. In this report it is evaluated by using the 1-percent chance precipitation events.

PROBABLE MAXIMUM PRECIPITATION FOR THE UPPER DEERFIELD RIVER DRAINAGE MASSACHUSETTS/VERMONT

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ABSTRACT The Hydrometeorological Branch has prepared an independent estimate of probable maximum precipitation (PMP) for the Upper Deerfield River drainage in response to a request by the Nuclear Regulatory Commission Hydrologic and Geotechnical Engineering staff. Estimates are given for durations from 1 to 48 hr for basins above Sherman Dam, above Harriman Dam, above Somerset Dam, and between Sherman and Harriman Dams.

This report describes the approach used to develop the PMP estimates from the results of applying Hydrometeorological Report (HMR) No. 52 to generalized PMP estimates of HMR No. 51 for the drainage. The results from this application are modified for orographic intensification through an adaptation of a method recently developed for orographic regions within the Rocky Mountains. Included in this report is a discussion of the major storms considered for transposition through the region and which controlled the level of PMP established in New England in HMR No. 51.

1. INTRODUCTION

The Nuclear Regulatory Commission (NRC) requested that the National Weather Service (NWS) prepare an independent site-specific estimate of the Probable Maximum Precipitation (PMP) for various areas of the Upper Deerfield River drainage. This request was formalized in Interagency Agreement No. NRC 03-83-102 between NRC and NWS, dated March 9, 1983. The specific requirements of this agreement are summarized as follows:

(1) Review pertinent information regarding previous studies of PMP for the region as provided by NRC.

(2) Determine PMP estimates for the Upper Deerfield River basin above Sherman Dam (236 mi^2), above Harriman Dam (184 mi^2), above Somerset Dam (30 mi^2), and for the subbasin between Sherman and Harriman Dams (52 mi^2). One-hour PMP was requested only for the latter subbasin, and concurrent precipitation for the remaining basin area was desired for each of the last three estimates.

(3) Prepare a draft and final report documenting the development of estimates given in (2).

The Upper Deerfield River drainage above Sherman Dam (236 mi^2) is located in northwestern Massachusetts and southwestern Vermont, roughly 100 mi north of the Connecticut coast as shown in figure 1. Also shown in this figure are the locations of the centers of major storms that will be discussed later in this report. Figure 2 shows the outline of the drainage as well as the position of Sherman, Harriman and Somerset Dams. Figure 2 also presents an indication of the terrain roughness as shown by the elevation contours. Elevations exceeding 3,000 ft occur on the northeast and northwest boundaries of the drainage as well as within the drainage just east of the Upper Deerfield River in the vicinity of Somerset. Otherwise, most of the drainage lies between 2,000 and 2,500 ft.

2. BACKGROUND

Historically, the first attempts at preparing design criteria for dams involved envelopment of the discharge record on an individual stream. As this criteria proved inadequate, regional streamflow records were used. At times statistical analysis of discharge records, either for an individual stream or over a region, were conducted. After some major floods occurred in the New England states, the Boston Society of Civil Engineers (1942) examined the adequacy of this approach. They concluded it would be very difficult and the results would be questionable to extrapolate to the long return periods required for a spillway design flood for significant structures. The need still existed, however, to develop adequate design criteria. The PMP concept evolved from this need. PMP is an estimate of the theoretical upper limit of rainfall, and thus maximum flood potential. The meteorologist considers the factors important to producing precipitation and determines their optimum combination to estimate an upper limit of rainfall for a basin or a region. Within the NWS, PMP studies have always been done by personnel of the Water Management Information Division (WMID).

The Hydrometeorological Branch, WMID, was asked by NRC to provide a site-specific determination of PMP for the Upper Deerfield River basin using the latest available techniques and information. The Hydrometeorological Branch has originated many PMP studies in support of hydrologic design requirements for Federal agencies. In particular, applicable to the subject drainage are Hydrometeorological Reports No. 33 (Riedel et al. 1956), No. 51 (Schreiner and Riedel 1978), and No. 52 (Hansen et al. 1982). For brevity, these reports will be referred to hereafter as HMR No. 33, 51, and 52. Briefly summarizing, HMR No. 33 provided monthly generalized PMP estimates for the eastern United States for areas between 10 and 1,000 mi^2 and durations between 6 and 48 hr. In HMR No. 51, the values for the all-season PMP were expanded to cover areas to 20,000 mi^2 and durations to 72 hr, and updated to include recent advances in procedures and storm data. HMR No. 51 provides generalized storm area-averaged all-season PMP estimates. HMR No. 52 was prepared to provide a procedure whereby storm PMP from HMR No. 51, or from other similar generalized studies for this region, could be applied to a specific drainage and drainage-averaged PMP determined.

HMR No. 52 offers a technique that converts generalized PMP estimates to site-specific estimates. The Hydrometeorological Branch has elected to use this technique in the present study. A significant fact concerning this approach is that neither HMR No. 51 nor 52 account for orographic effects. The Upper Deerfield River drainages are entirely within a broad region that has been

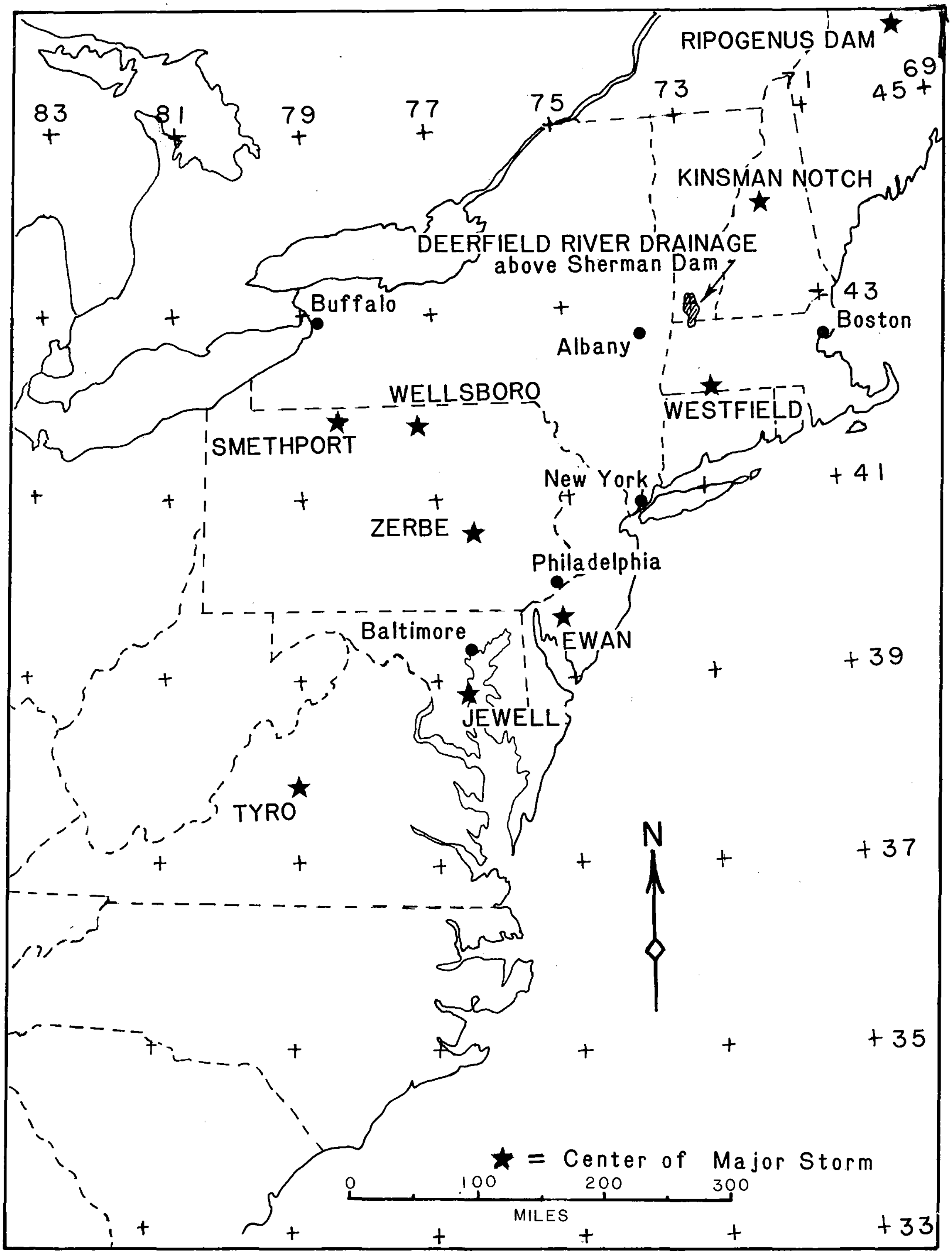

Figure 1.--Map showing location of Upper Deerfield River drainage above Sherman Dam, relative to New England States and the locations of major storm centers.

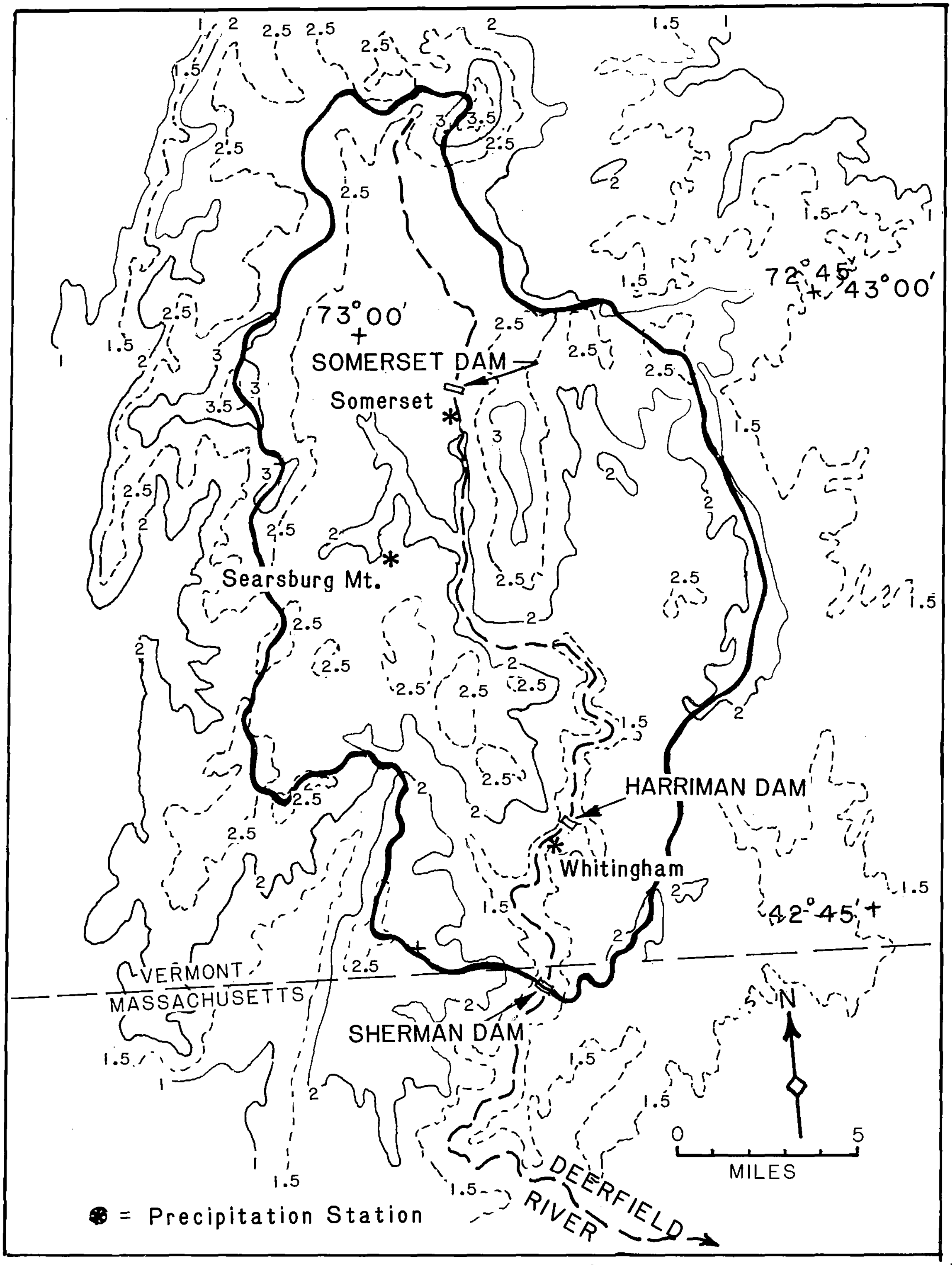

Figure 2.--Upper Deerfield River drainage above Sherman Dam (heavy, solid line) showing 500-ft elevation contours (labeled in 1,000's of feet). Locations of Harriman and Somerset Dams and precipitation stations referenced in text are indicated.

designated in these documents as possibly affected by orographic influences. As a result, it is a necessary consequence that a method be developed that will allow the orographic modification to HMR No. 51 and 52 results to be determined. Such a procedure has been included in this report. The basis for the orographic procedure was derived from current studies of PMP for the United States between the Continental Divide and the 103rd meridian. This region is predominantly orographic. A report (Miller et al. 1984) covering this study is currently being published.

2.1 Review of Previous PMP Studies

As part of the effort to develop a PMP estimate for the Upper Deerfield River basin, the Hydrometeorological Branch was asked by the NRC to review the three relatively recent reports that include PMP determination for these basins. We will summarize the procedure used in these studies and give some of the results.

2.1.1 Yankee Atomic Electric Company

The Yankee Atomic Electric Company (Yankee Atomic) issued a report (1980) that covered a Design Basis Flood Analysis for their nuclear facility at Rowe, MA. To obtain a site-specific estimate of PMP, this study surveyed storms east of the Appalachian Mountains and selected seven it considered significant relative to the Upper Deerfield River basin. These storms were then moisture maximized, transposed to the Upper Deerfield River drainage, adjusted for elevation and orographic intensification, and enveloped by a smooth depth-duration curve to obtain a 200-mi^2 24-hr PMP estimate of 14.3 in. In this study, it is stated the adjustment for orographic effects is approximately equal to the adjustment for elevation. The reduced amount of moisture available at higher elevations is equivalent to the adjustment for orographic effects and was "... the only orographic correction applied." Their report stated that PMP estimates determined by use of statistical procedures developed by Hershfield (1961, 1965) provided support for their estimate of PMP.

2.1.2 Nuclear Regulatory Commission (Nuclear Reactor Regulation Staff)

Nuclear Reactor Regulation staff (NRC) members developed PMP estimates for the Upper Deerfield River basin from HMR No. 33 (Riedel et al. 1956), in a study completed in January 1981 (NRC 1981). At that time, HMR No. 51 had been released some two and a half years previously, but NRC staff (among other Federal agencies) stated they had not completed their reviews prior to preparation of their report on the Upper Deerfield River basin. The NRC staff also evaluated the transposition of the Westfield, MA, storm (8/17-20/55) to the drainage, and allowed an orographic adjustment increase of 20 percent. The NRC staff concluded that PMP for the Upper Deerfield River drainage should be between the 16.6 in. obtained by transposing the Westfield, MA, storm and the 18.9 in. obtained from HMR No. 33. For their evaluation of the Upper Deerfield River basin, the NRC staff nevertheless used the results of HMR No. 33 as their design basis rainfall.

Subsequent review of HMR No. 51 by the NRC staff (1982) derived a 236-mi^2 24-hr value of PMP of 21.9 in. for the Upper Deerfield River basin. This roughly 16 percent increase of values from HMR No. 51 over those from HMR No. 33 is more than the typical increase throughout the New England region, and reflects increases that evolved from inclusion of data from Hurricanes Camille and Agnes, as well as smoothing in extending PMP to longer durations and larger areas. NRC

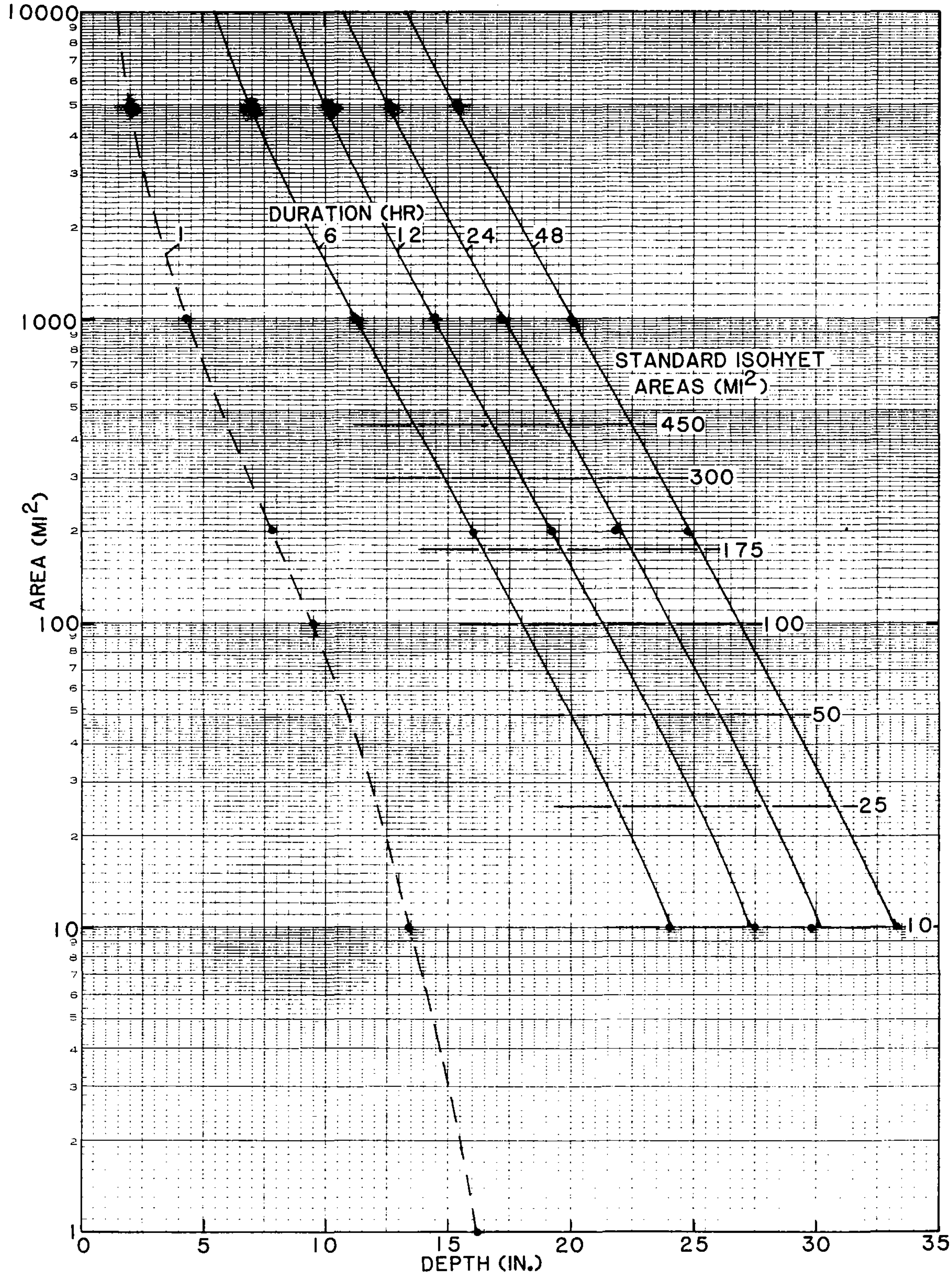

Figure 3.--Depth-area-duration data plotted from HMR No. 51 and 52 for 42°54'N, 72°57'W representing Upper Deerfield River drainage above Sherman Dam. Selected standard areas (10 to 450 mi^2) indicated for input to HMR No. 52 procedures. See text for explanation of dashed curve.

staff continued to base their design evaluation study on the HMR No. 33 PMP criterion, however, recognizing the subsequent increase values given in HMR No. 51.

2.1.3 Franklin Research Center

The Nuclear Regulatory Commission funded the Franklin Research Center (FRC) to review the Yankee Atomic report and the NRC staff study. In their review (Scherrer 1982), the FRC considered using the additional storms at Ewan, NJ, and Smethport and Zerbe, PA. Although the study found that the transposed values of the Ewan, NJ, and Smethport, PA, storms exceeded the enveloping PMP curve recommended by Yankee Atomic, FRC questioned the validity of transposing these storms to the drainage. Otherwise, their findings tended to accept the results of the Yankee Atomic study. One exception cited was that they believed the critical duration should be 12-18 hr rather than 24 hr. As a result, they recommended a modification to the Yankee Atomic PMP enveloping curve that consequently gave a 200-mi^2 24-hr PMP of 14.7 in. for the Upper Deerfield River drainage.

Although much of the FRC evaluation discusses the effect of tropical storm precipitation in the region of the Upper Deerfield River, and concludes that a storm of this type is likely to produce the PMP over the drainage, it also makes a cautionary statement concerning the possibility of a nontropical type storm of the Smethport, PA, character. However, this concern did not influence their conclusions. Regarding the orographic adjustment of a 20 percent increase applied by the NRC staff to the transposed Westfield, MA storm, the FRC believes this to be about twice as large as their determination based on considerations derived from relations presented in Hawaiian PMP studies (Schwarz 1963).

3. PMP FROM HMR NO. 51 AND 52

PMP estimates for individual drainages can be developed either from moisture maximization and transposition of major storms of record through the region, or by use of generalized studies with appropriate modifications, if any are needed. In keeping with recent Hydrometeorological Branch practice, the procedure chosen to develop the individual drainage PMP estimate for the Upper Deerfield River drainage is to derive this estimate first from the generalized PMP maps presented in HMR No. 51 using the procedures described in HMR No. 52. The methodology provided in HMR No. 52 gives both the PMP over the basin and the precipitation that occurs at the same time over adjacent basins. Then as a necessary next step, we developed a method to modify these results for the terrain effects in this drainage.

The procedures used to develop HMR No. 51 are adequately described in the publication. However, an appendix to this report adds some additional material specifically directed toward the New England region.

3.1 Basin PMP Estimates

From HMR No. 51, values (table 1) were read for each duration/area size on the PMP maps at the centroid of the Upper Deerfield River basin (taken to be 42°54'N and 72°57'W). These values were plotted and smooth depth-area-duration (DAD) lines fit to the data (fig. 3). From these curves, values of generalized PMP estimates can be read for an area of 236 mi^2 and compared with similarly obtained

Table 1.--PMP (in.) from HMR No. 51 for the Upper Deerfield River drainage (42°54, 72°57). 1-hr PMP from HMR No. 52

Area (mi^2)	Duration (hr) 1	6	12	24	48
1	16.2	-	-	-	-
10	13.4	24.0	27.5	29.8	33.3
200	7.8	16.0	19.2	21.8	24.7
1000	4.3	11.2	14.5	17.2	20.0
5000	2.0	7.0	10.2	12.6	15.4
10000	1.5	5.3	8.4	10.6	13.0

values from HMR No. 33 as shown in table 2. The minor differences between table 2 values and those obtained by NRC staff (sec. 2.1.2) can be expected to result from reading data from generalized PMP maps and plotting and smoothing of DAD curves.

Table 2.--Comparison of PMP values (in.) for 236 mi^2 between HMR No. 51 and 33

	Duration (hr) 6	12	24	48
HMR No. 51	15.6	18.7	21.5	24.4
HMR No. 33	14.3	17.0	19.2	20.2
% increase	9	10	12	21

The procedure given in HMR No. 52, to apply the PMP from HMR No. 51 to a specific basin, is lengthy and complex. We will attempt to highlight sufficient key steps so that the intermediate steps can be traced. The procedure begins by obtaining durational amounts at specific area sizes from the PMP depth-area-duration curves from HMR No. 51 at the location of interest. These initial values from figure 3 are listed in table 3. The values are plotted as depth-duration curves and fit by smooth lines from which values can be read off at intermediate durations (fig. 4).

In HMR No. 52, an idealized elliptical isohyetal pattern (2.5 to 1 axial ratio) is given as being the most representative shape for generalized PMP applications. The orientation at which this pattern is placed on a drainage is important, since HMR No. 52 discusses the concept of preferred orientations for PMP type storms. This concept says that if placement of the isohyetal pattern is for an orientation outside a range of ±40° about the preferred PMP orientation, a reduction is required for storm pattern areas larger than 300 mi^2. For areas equal to or less than 300 mi^2, experience supported no adjustment for pattern orientation, since small area storms appear equally intense regardless of orientation. The isohyetal pattern from HMR No. 52 was placed over the Upper Deerfield River drainage using a number of different orientations and the procedure followed to determine the placement that resulted in the maximum volume of precipitation within the drainage. This process also establishes the PMP storm area size relative to each placement. This process resulted in the final pattern placements shown in figures 5-8. PMP storm areas and final orientations are summarized in table 4.

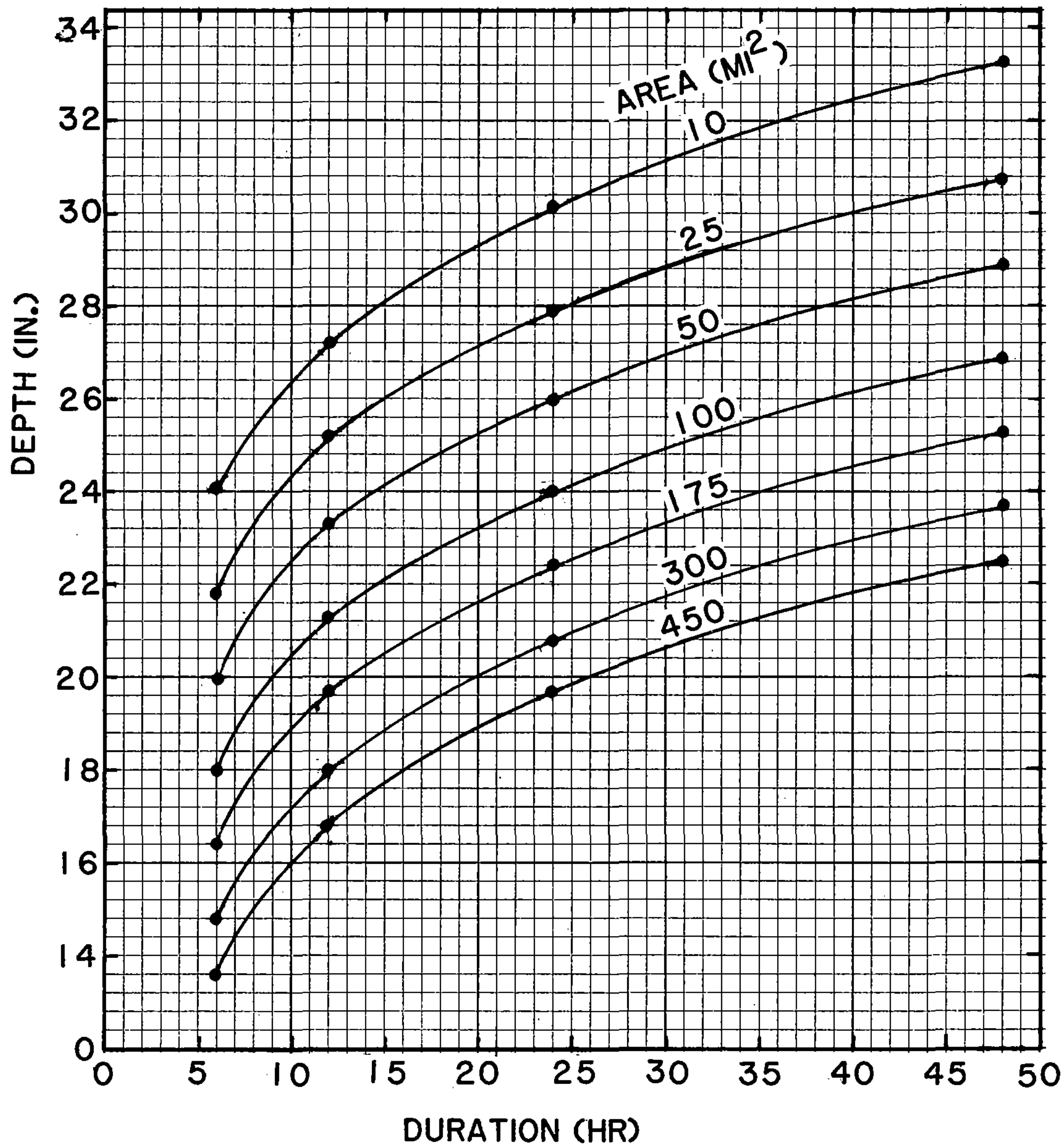

Figure 4.--Depth-duration curves for standard areas (10 to 450 mi^2) for 42°54'N, 72°57'W representing Upper Deerfield River drainage above Sherman Dam.

Table 3.--PMP values (in.) from figure 3 for specific standard area sizes used in HMR No. 52 isohyetal pattern

Standard isohyet area size (mi^2)	Duration (hr) 6	12	24	48
10	24.1	27.2	30.2	33.3
25	21.8	25.2	27.9	30.7
50	20.0	23.3	26.0	28.9
100	18.0	21.3	24.0	26.9
175	16.4	19.7	22.4	25.3
300	14.8	18.0	20.8	23.7
450	13.6	16.8	19.7	22.5

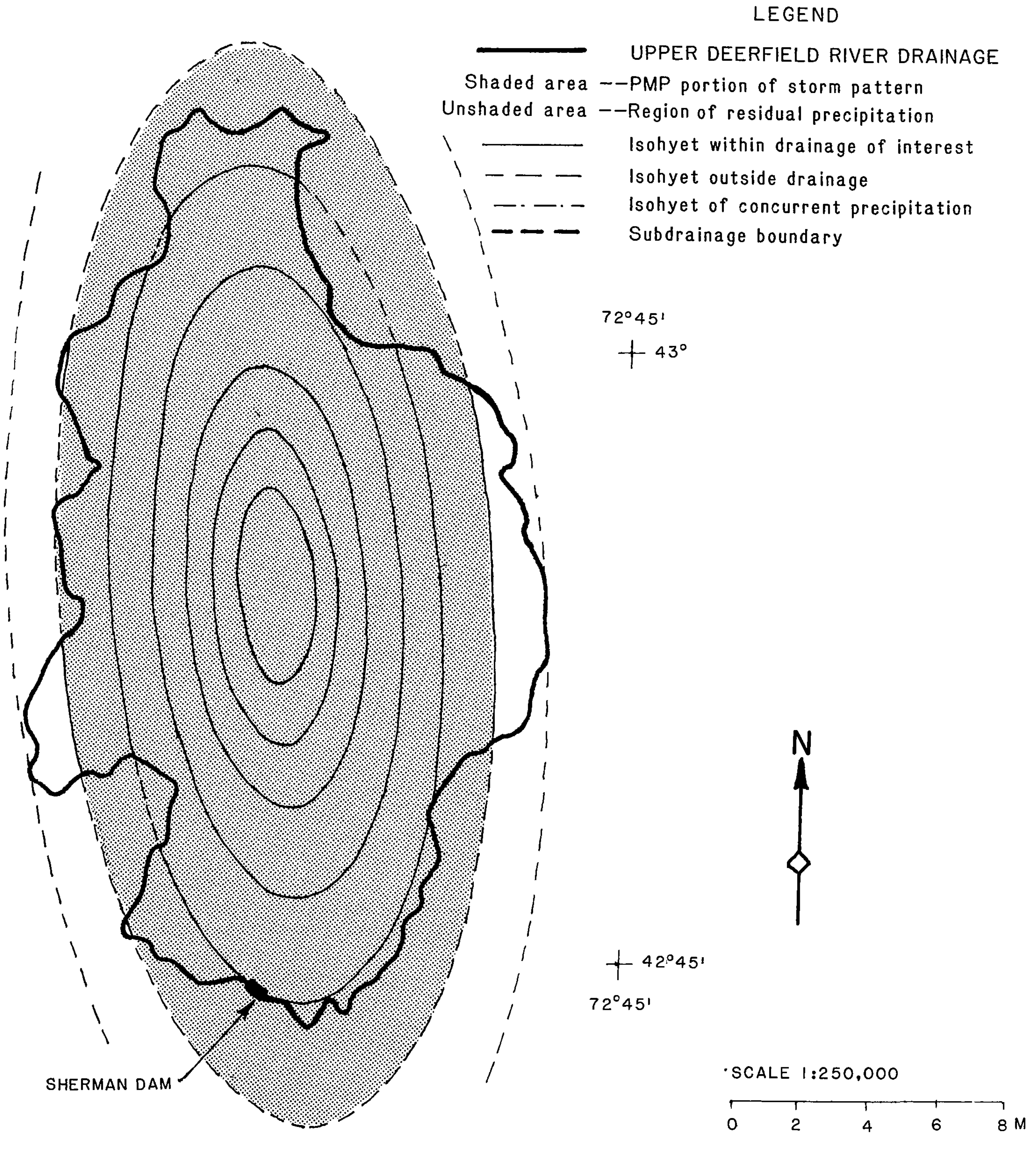

Figure 5.--Isohyetal pattern placement over entire Upper Deerfield River drainage (236 mi^2).

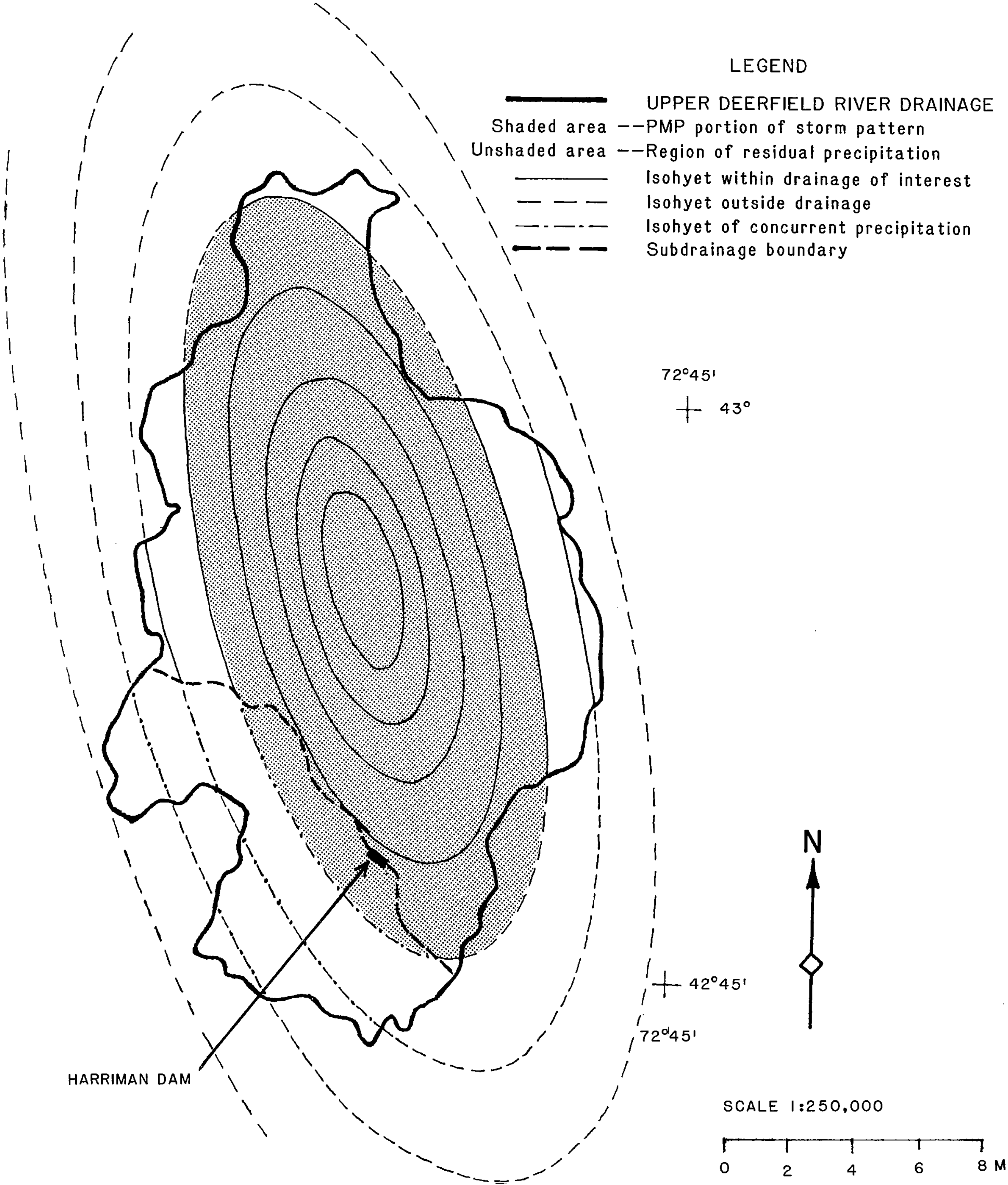

Figure 6.--Isohyetal pattern placement over Upper Deerfield River drainage above Harriman Dam (184 mi^2).

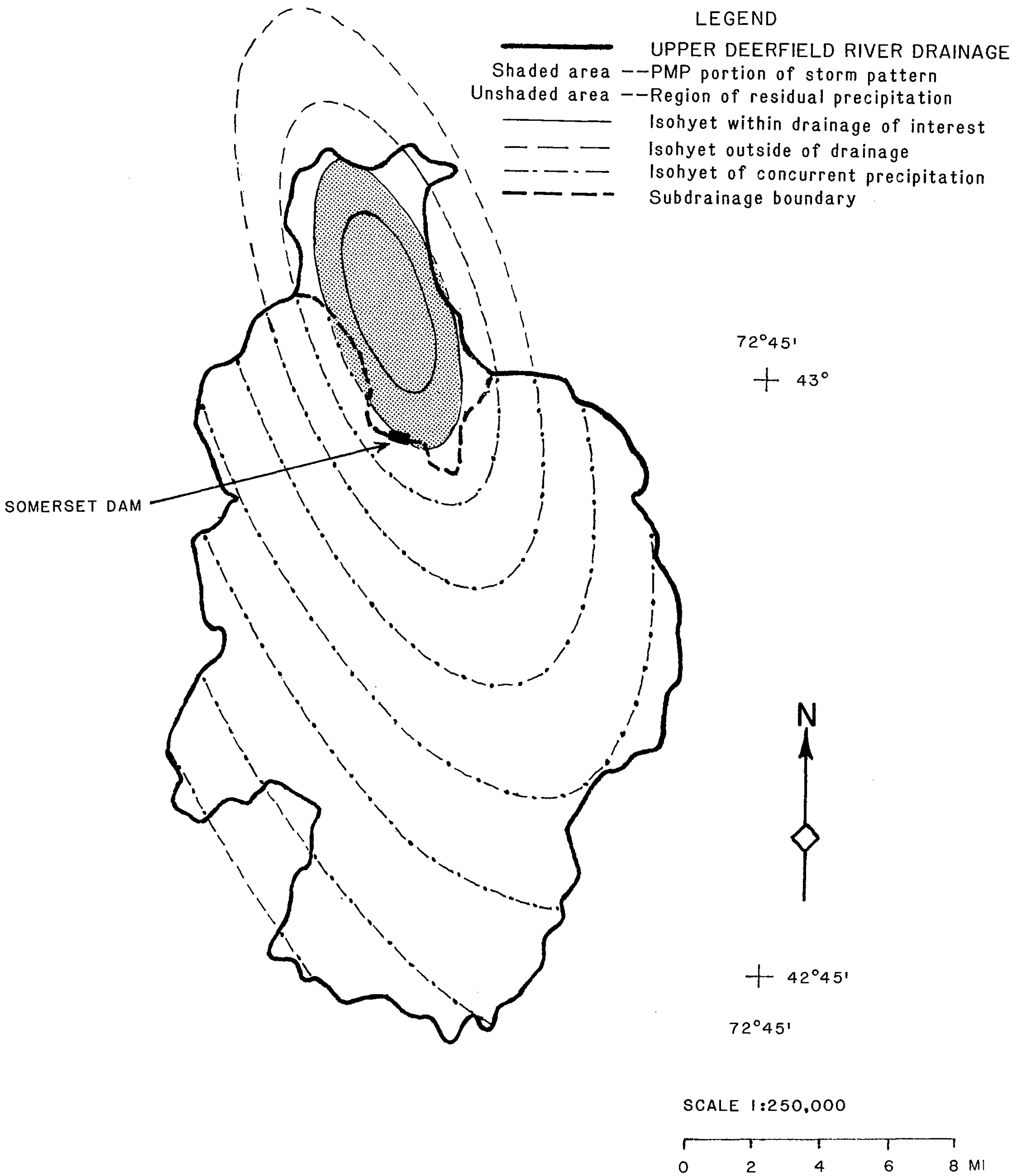

Figure 7.—Isohyetal pattern placement over Upper Deerfield River drainage above Somerset Dam (30 mi^2).

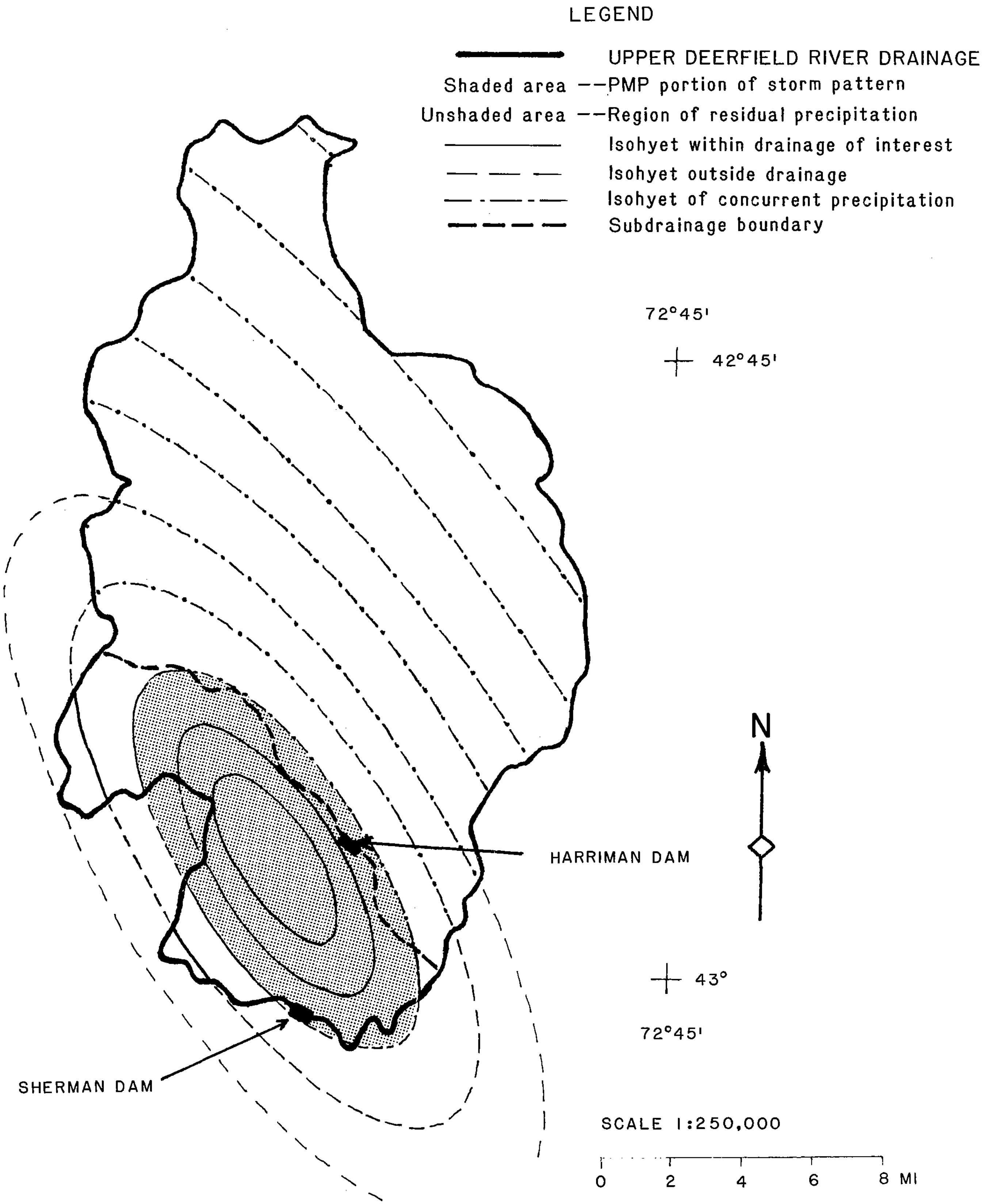

Figure 8.--Isohyetal pattern placement over Upper Deerfield River drainage between Sherman and Harriman Dams (52 mi^2).

Table 4.--PMP storm area and pattern orientation for each subbasin in the Upper Deerfield River drainage

Basin over which isohyetal pattern is centered	Basin area (mi^2)	Storm area (mi^2)	Orientation (deg.)
Above Sherman Dam	236	300	175°/355°
Above Harriman Dam	184	175	163°/343°
Above Somerset Dam	30	25	159°/339°
Between Sherman and Harriman Dams	52	50	146°/326°

It should be mentioned that inherent in determining the maximum volumes in each pattern placement is evaluation of the values for each isohyet. This lengthy process is described in detail in HMR No. 52 and will not be further described here.

Having determined the maximum volume patterns as shown in figures 5-8, each volume was divided by the area of the subbasin to obtain basin-averaged PMP estimates given in table 5. In this table, we have provided an estimate of the 1-hr PMP for the subbasin between Sherman and Harriman Dams in response to the NRC request. The estimate was obtained by first interpolating between the 1-hr PMP maps at selected areas sizes given in chapter 6 of HMR No. 52 (dashed curve in fig. 3). These maps were developed to supplement HMR No. 51 for the shorter durations (less than 6 hr). Procedures in HMR No. 52 were then used to obtain the basin-averaged values in table 5.

Table 5.--Drainage-averaged PMP estimates (in.) for Upper Deerfield River drainage and subbasins from HMR No. 52, applicable at sea level

Drainage	Duration (hr)				
	1	6	12	24	48
Above Sherman Dam ($236\ mi^2$)	*	15.17	18.45	21.17	24.06
Above Harriman Dam ($184\ mi^2$)	*	15.89	19.16	21.91	24.76
Above Somerset Dam ($30\ mi^2$)	*	20.67	24.00	26.70	29.39
Between Sherman and Harriman Dams ($52\ mi^2$)	10.20	18.94	22.26	24.98	27.70

* Not requested in interagency agreement.

The PMP estimates given in table 5 are representative of PMP at sea level as typically available in HMR No. 51, but which have been applied to a specific drainage, and therefore, include consideration for the shape of the basin in each case. Comparison of the results in table 5 with the values in table 2 which were obtained from HMR No. 51 for the 236-mi^2 drainage above Sherman Dam, indicates that a reduction of about 2 percent occurred in the application of HMR No. 52. Since orientation was not a part of the consideration, because the storm areas are all equal to or less than 300 mi^2, the small reduction represents the effects of basin shape. The fact that the reduction is so small indicates that the basins are generally elliptical in shape and well covered by the elliptical rainfall patterns.

3.2 Residual and Concurrent Precipitation

Another feature of the procedure in HMR No. 52 is the concept of residual precipitation. This concept recognizes that precipitation does not stop at the edge of the PMP storm area. Residual precipitation is defined as the precipitation that lies outside the PMP storm area, eventually becoming zero at some larger area size. In figure 9, the PMP storm area is assumed to be represented by the "D" isohyet in this schematic diagram of a drainage, where the pattern is placed over one of two designated subbasins (separated by the dashed line), for which an estimate of PMP is required. In this figure, the area covered by residual precipitation that falls within the entire drainage is shown by vertical cross hatching.

The concept of residual precipitation allows determination of the amount of precipitation that falls within a drainage, but outside the PMP storm area pattern. These contributions have been included as a normal consequence of the HMR No. 52 procedure to develop the individual-drainage PMP estimates shown in table 5.

In figure 9, we see that subbasin 2 is covered by residual precipitation and a small portion of the PMP storm area. When analyzing the probable maximum flood, it is of hydrologic interest to know the precipitation from the PMP storm that falls in an adjacent subbasin. We refer to this quantity as the concurrent precipitation; i.e., the precipitation that falls in one subbasin concurrently to the PMP storm centered over an adjacent subbasin. We can determine the concurrent precipitation rather easily from the storm pattern and isohyet information developed from application of HMR No. 52. In figure 9, the concurrent precipitation has been designated by the horizontal cross hatching. It should be pointed out that concurrent precipitation may, or may not, be made up of both PMP and residual precipitation, as shown in the example in figure 9.

Concurrent precipitation for the three subbasins of the Upper Deerfield River drainage is given in table 6. The concurrent precipitation for the 1-hr duration was only requested for one case, the PMP pattern centered over the area between Sherman and Harriman Dams. This estimate was not obtained as were the values for durations from 6 to 48 hr, because HMR No. 52 does not provide 1- to 6-hr ratios for residual precipitation. This 1-hr value was determined by plotting the durational values for 6 to 48 hr, and drawing a smooth curve to enable interpolation of this amount as shown in figure 10.

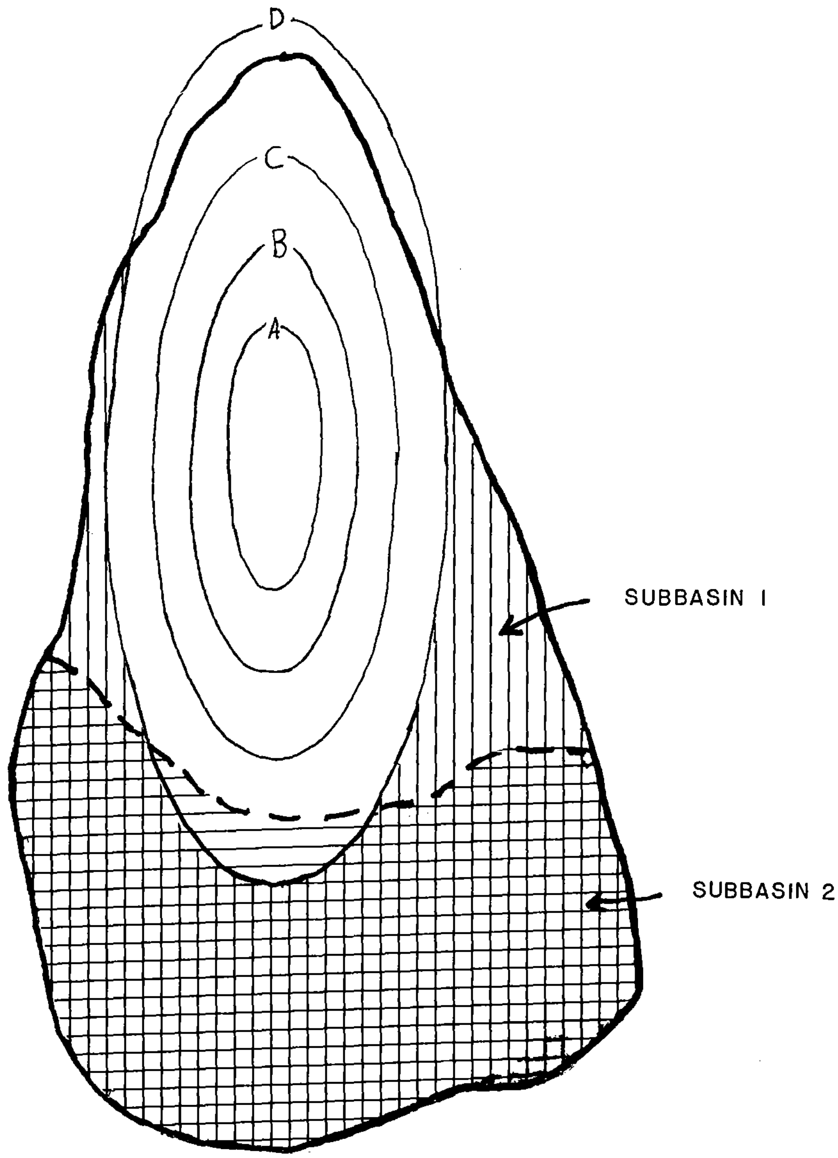

Figure 9.--Schematic drainage to demonstrate the area covered by the PMP storm placement (isohyets A to D), the residual precipitation (vertical cross hatching), and concurrent precipitation (horizontal cross hatching).

4. OROGRAPHIC MODIFICATION

In developing our individual-drainage PMP estimate for the Upper Deerfield River basin, we have chosen a two-stage procedure. First, we have developed a convergence, or nonorographic, estimate of PMP for this basin. This was done by applying the procedures of HMR No. 52 to the results from HMR No. 51. In the second stage, consideration must be given to the effects of orography. In an orographic region, the estimate obtained should be adjusted upward or downward, or not at all, by orographic modifications. The Hydrometeorological Branch is

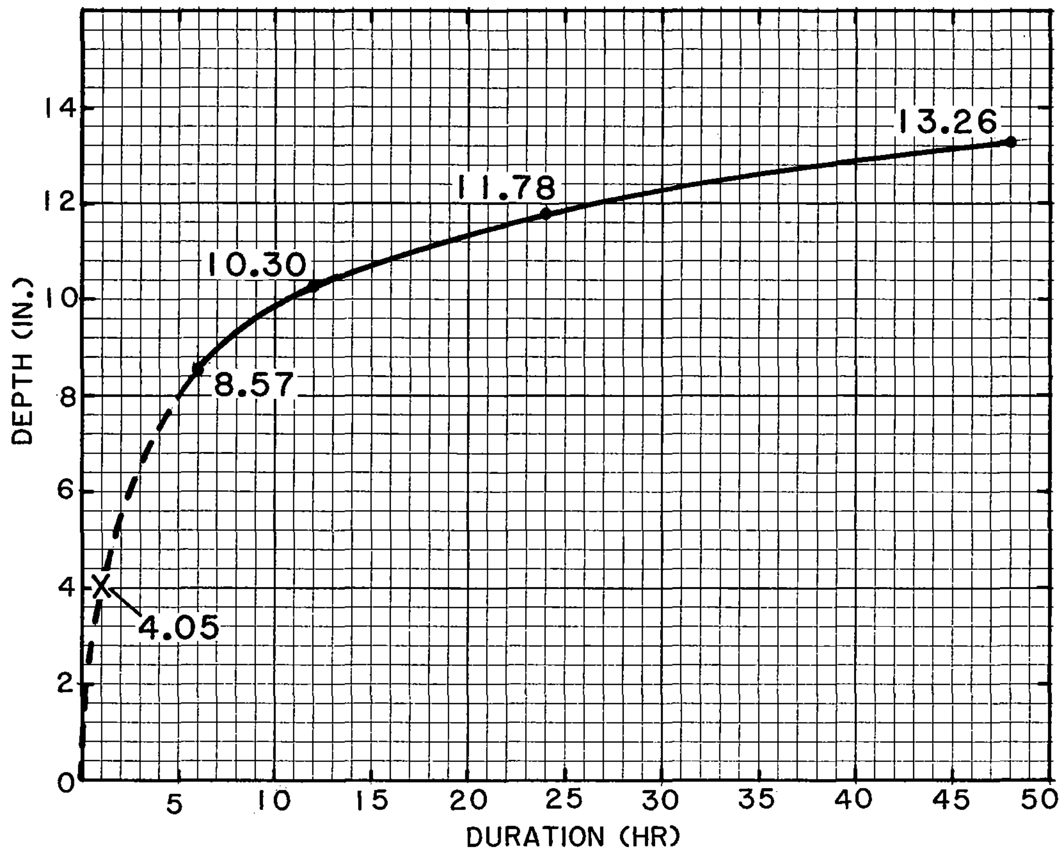

Figure 10.--Depth-duration curve used to interpolate 1-hr concurrent precipitation for subbasin between Sherman and Harriman Dams. The "X" indicates the interpolated value.

Table 6.--Concurrent sea-level precipitation (in.) from HMR No. 52 procedures for subbasins of the Upper Deerfield River drainage

Basin where PMP centered	Basin covered by concurrent precipitation	Duration (hr)				
		1	6	12	24	48
Above Harriman Dam (184 mi^2)	Between Sherman and Harriman Dams (52 mi^2)	*	11.79	14.52	16.92	19.42
Above Somerset Dam (30 mi^2)	Between Sherman and Somerset Dams (206 mi^2)	*	8.68	10.22	11.50	12.79
Between Sherman and Harriman Dams (52 mi^2)	Basin above Harriman Dam (184 mi^2)	4.05	8.57	10.30	11.78	13.26

* Not requested in interagency agreement

currently studying such procedures, and has recently completed a comprehensive study of PMP for the United States between the Continental Divide and the 103rd meridian (Miller et al. 1984). As the region covered in that study is primarily orographic, we have opted to use some of the concepts and considerations from that study to develop the orographic modification factors applicable to the Upper Deerfield River drainage.

The approach is based on the concept that total PMP is comprised of both orographic and convergence, or nonorographic, components. This total PMP can be developed as a product of an orographic factor and the convergence component. The convergence component of PMP is equivalent to the nonorographic PMP and, as such, is given by results derived from HMR No. 51 and 52. This interpretation of the HMR No. 51 PMP is consistent with other hydrometeorological studies by the NWS (U.S. Weather Bureau 1961, 1966, and Miller et al. 1984).

The problem becomes one of determining the orographic factor, which we will refer to as K. The convergence component is designated as FAFP (for free atmospheric forced precipitation) to signify the absence of the terrain feedback mechanism which is characteristic of the orographic component of precipitation. The orographic influence factor, K, will be used in conjunction with the depths of convergence precipitation from HMR No. 51 and 52 for given area sizes and durations to produce total PMP according to equation 1:

$$PMP = FAFP*K \qquad (1)$$

The value of FAFP in equation 1 for the Upper Deerfield River basin must be adjusted for the elevation barrier to moist air inflow. A standard procedure is to compute the reduction based on the loss in available precipitable water as a result of the barriers to the moist air inflow. At the Upper Deerfield River basin, we determined from a review of candidate storms over the region that the low level inflow of moisture into the prototype PMP storm should be from the west through the south. Inflow from directions other than these would introduce unacceptable modifications to the storm mechanism of the various critical storms listed in the appendix to this report. The average barrier elevation for inflow from these directions is about 2,200 ft. Under such conditions a maximum persisting 12-hr 1000-mb dew point of 74°F is appropriate for the PMP storm, and we elected to make no change in precipitable water within the first 1,000 ft of elevation change based on procedures followed in HMR No. 51. These decisions translate into an 11 percent reduction in the FAFP values obtained from HMR No. 51 and 52 applications.

The K factor is composed of terms representing the broadscale effect of topography. The approach taken in equation 1 will work well only where a single value of K is appropriate. In a large basin of complex topography, equation 1 must be modified or the basin subdivided into smaller topographically homogeneous areas. The Upper Deerfield River basin is considered to be sufficiently homogeneous that a single value of K is appropriate.

4.1 Relation of Orographic Factor (K) to Storm Intensity

Before we discuss the terms chosen to represent the broadscale effects of topography, however, we must introduce two important concepts. These concepts apply to the prototype PMP storm for the Upper Deerfield River basin and bear on the development of equation 1. The first concept is that the PMP storm is composed of a most intense, or core, precipitation event surrounded by precipitation of significantly lesser, though not necessarily constant, intensity. This concept arose from our examination of the original manuscript mass curves of rainfall used to develop "Storm Rainfall in the United States" (U.S. Army Corps of Engineers 1945-) for important, record setting storms. From these curves one could clearly distinguish periods when the intensity of precipitation significantly exceeded an average value over a longer duration. We associated the core event with this greater-than-average precipitation intensity period. We next looked at DAD data for individual storms to get an idea of the typical length of such core events.

The DAD data for the storms at Smethport, PA; Tyro, VA; Zerbe, PA; and Ewan, NJ, show at a duration of 24 hr and for an area size of 200 mi^2 that 66, 60, 49, and 91 percent, respectively, of the 24-hr depth of precipitation in these storms fell in only 25 percent (6 hr) of the time. At 24 hr for the smaller area size of 10 mi^2, the percentages the 6-hr amount is of the 24-hr value for the four storms are: 85, 56, 56, and 89 percent, respectively. For comparison, HMR No. 45 (Schwarz and Helfert 1969) shows that 86 percent of the 10-mi^2 24-hr rainfall occurs in 25 percent of the time. This is the mean ratio from five intense storms (Smethport, PA; Cherry Creek, CO; Simpson, KY; Ewan, NJ; and Rock House, NC). These results led us to conclude that the duration for the core event for 24-hr PMP duration should be 6 hr or 25 percent of the total duration.

To find an appropriate core time for shorter durations, it is necessary to use hourly rainfall values. Hourly data are available only for the more recent storms. Hourly data in the vicinity of the storm centers at Smethport, PA; Tyro, VA; Zerbe, PA; and Ewan, NJ, continue to show the presence of a core event within the six consecutive most intense hours of precipitation. By considering different fractions of the 6-hr interval, we found that in 50 percent of this time interval (3 hr) the average percentage of 6-hr precipitation was 66, 54, 63, and 80 percent, respectively. In the Westfield, MA, storm of 1955, the equivalent percentage was 69 percent. These percentages suggest a core event of about 3 hr in the six consecutive most intense hours of precipitation within the general storm.

The DAD data has shown that an average of 67 percent for 200 mi^2 and 72 percent for 10 mi^2 of the maximum 24-hr precipitation occurred in 25 percent of the time interval. Using the same approximate percentages as for the 24-hr duration, it was determined that it took 50 percent of the time for these same percentages to occur at 6 hr. As the period of rainfall examined becomes increasingly small, it is expected that the core event will occur in an increasingly larger percentage of the total time, approaching 100 percent of the time as the interval becomes less than 1 hr. These data support the concept of the presence of an intense, relatively short duration event at the core of the general storm that produces PMP at longer durations. Thus, FAFP can be expressed as the sum of two parts;

$$FAFP = A + B \qquad (2)$$

where A represents the precipitation during the core event, and B represents the precipitation during the remaining portion of the storm.

The second concept is the assumption that there is a smaller influence on the precipitation process from the terrain during the most intense or core event just described than during the period of the surrounding precipitation. Based on studies of outstanding point rainfalls at 56 locations in or near the Tennessee

River basin, along with a survey of several hundred storm studies for the eastern half of the United States, it was concluded that PMP-type storms of 1-hr duration or less would show little orographic effect (Schwarz and Helfert 1969). For longer durations, storms would be likely to produce more rainfall on slopes and adjacent valleys than over flat areas with no nearby slopes. The small effect of terrain on extreme precipitation events during the first hour is attributed to storm dynamics overwhelming terrain feedback. For this study, we assumed that the core event, which for longer durations will increase beyond 6 hr in length, is also generated primarily, though not completely, by storm dynamics. This is to say that the orographic factor is composed of two parts, a value K_1, associated with the most intense portion of the storm and the value K_2 for the remaining time period.

These two concepts lead to the conclusion that equation 1 should be rewritten to show different orographic influences acting on FAFP during the core portion and on the surrounding portion of the FAFP event. Substituting equation 2 in equation 1 and using the concepts relating to K discussed in the preceding paragraph, equation 1 becomes:

$$PMP = (A * K_1) + (B * K_2) \qquad (3)$$

We define the amount of FAFP in the core event by A, where:

$$A = FAFP * M \qquad (4)$$

and the amount of FAFP for the surrounding precipitation by B, where:

$$B = FAFP * (1 - M) \qquad (5)$$

In these formulas, M is the percent of FAFP produced by the core event. M is defined as the ratio D_r/D_h (see fig. 11). D_h is the depth of precipitation in the PMP storm accumulated over the interval h, the period of time of particular interest, but arbitrary length. D_r is the depth of precipitation caused by the core event operating in the interval h and of duration r hours where $r \leq h$. The duration depends on the climatology of intense rainfall events occurring in, or transposable to the region of concern. In areas where no core event is expected to occur, r would be zero for all values of h selected, D_r would be zero as a consequence and, hence, M would be zero. These ideas are depicted schematically in figure 11, where the ordinate is depth and the abscissa is duration. The solid line labeled FAFP is a hypothetical mass curve of accumulated FAFP in the PMP storm.

Based on an examination of mass curves of rainfall and hourly precipitation records from important storms occurring in, or transposable to central New England, the values of r expressed as a percent of h, for h of 24 and 6 hr, were 25 and 50 percent, respectively. It is apparent that for extremely short intervals of h the influence of orography is minimized so that as h approaches 0, r expressed as a percent of h approaches 100. Therefore, the value of r expressed as a percent of h for the short interval of 1 hr should be between 100 and 50 percent. It is our judgment that an estimate of 75 percent should be used. A smooth curve (fig. 12) was drawn through these four pairs of r and h (24 hr and 25 percent, 6 hr and 50 percent, 1 hr and 75 percent and 0 and 100 percent). The final values for r, in percent and number of hours, are shown in table 7.

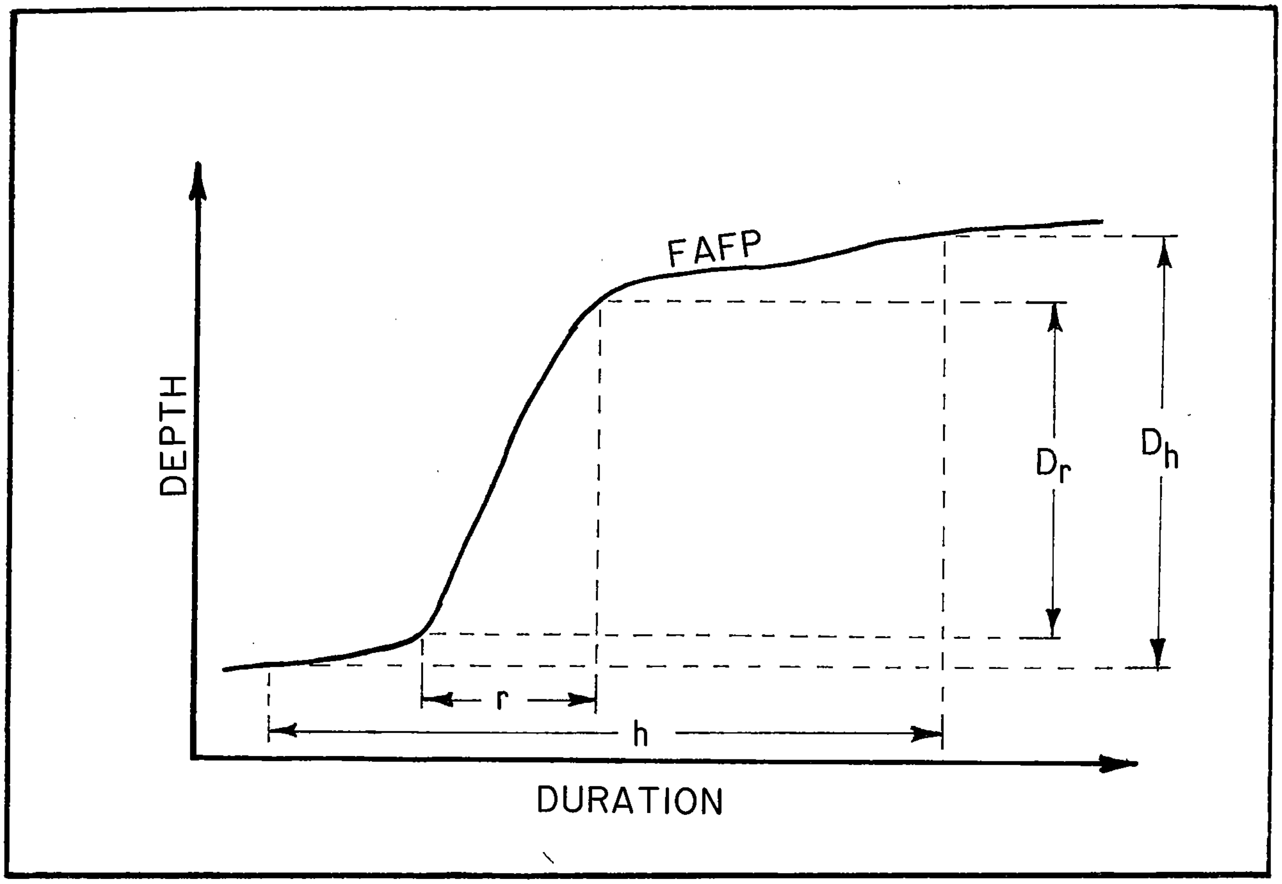

Figure 11.--Schematic representation of D_r and D_h.

Table 7.--Estimated length of intense precipitation (r) for selected total precipitation period (h)

h (hours)	1	6	12	24	48
r as a percent of h	75	50	35	25	21
r (hours)	.75	3	4.2	6	10

4.1.1 Derivation of Relations for Orographic Factors

It is necessary to develop relations which will permit us to evaluate the orographic effect during the core period and the remaining time interval of the PMP storm. These two factors are required to compute total PMP using this approach. These factors are developed conceptually and then must be evaluated for each basin and duration of interest.

4.1.1.1 Derivation of Relation for K_2.

The maximum orographic influence on FAFP occurs during the period of less intense rainfall (B). This influence can be represented by a ratio between the total precipitation (T), and the amount of convergence precipitation (C), or free atmospheric forced precipitation (FAFP) at that location:

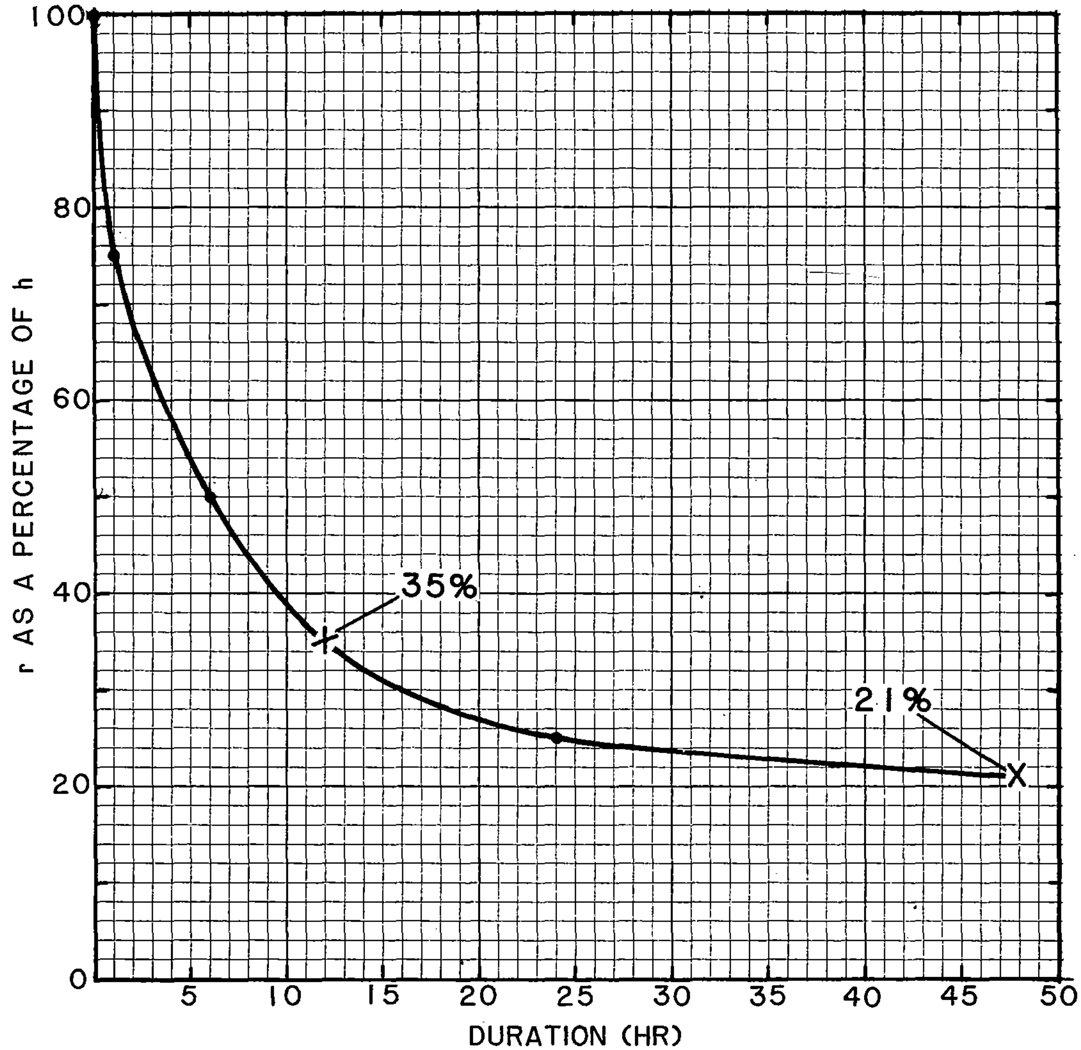

Figure 12.--Relation of length of core event (r) to a duration of greater or equal length (h) for the Upper Deerfield River basin. The "X's" indicate the interpolated and extrapolated values.

$$K_2 = T/C \tag{6}$$

In our evaluation, we use the 1-percent chance event to evaluate T and C. Thus, the symbol T represents that fitted value from an observed series of annual maximum precipitation depths which should be equaled or exceeded 1 percent of the time. The symbol C stands for the portion of this value T, which would have resulted if there had been no terrain feedback into the precipitation processes producing the depths comprising the series. Values of T observed in flat areas such as the Atlantic coastal plain or in broad, interior valleys are considered to represent values of C and the value of T/C in such places is 1. If the effect of terrain is to increase FAFP, then $(T/C) > 1$. In a few sheltered regions, where terrain-induced downslope flow acts to decrease FAFP, $(T/C) < 1$.

4.1.1.2 Derivation of Relation for K_1.

We represent K_1 by the expression:

$$K_1 = 1 + P\ ((T/C) - 1) \qquad (7)$$

where $0 \leq P \leq 1$.

The symbol P stands for the assumed percentage of T/C effective during r. We found from our study of PMP between the Continental Divide and the 103rd meridian that the value of P depends on r, the duration of the core event. P is represented by the expression:

$$P = 1 - M \qquad (8)$$

where M is defined as the ratio D_r/D_h.

4.2 Evaluation of Parameters Required for Orographic Factors for the Upper Deerfield River Basin

The equations for computation of K_1 and K_2 require the evaluation of M and T/C for the Upper Deerfield River basin. These two factors vary with duration and must be evaluated for the range of durations of interest.

4.2.1 Evaluation of M for the Upper Deerfield River Basin

D_r and D_h were determined by obtaining (from HMR No. 51 and 52) values of PMP for 10 mi^2 at the centroid of the drainage at 42°54'N 72°57'W (vicinity Somerset, VT), at 30 min, 1, 6, 12, 24, and 48 hr, and connecting these values with a smooth curve shown in figure 13, from which values at 0.75, 3, 4.2, and 10 hr were interpolated. The values plotted in figure 13 for 6, 12, 24, and 48 hr are those given in table 3, and those for 30 min and 1 hr are from HMR No. 52. The values of D_r, D_h, and the resulting ratio M at 42°54'N 72°57'W for various h at 10 mi^2, are given in table 8.

4.2.2 Evaluation of T/C for the Upper Deerfield River Basin

The initial determinations of T and C were made for the 24-hr duration. Calculations of the 1-percent chance event were made from the longest available periods of record for stations in the northeastern United States. These plotted 1-percent chance events were used as our estimate of T. In regions where there are negligible orographic influences, values of T and C are the same. If the plotted values for this region are examined, a general south to north decrease is seen for those subregions of negligible orographic influences (where T and C are considered equivalent). The values of T or C of about 8-10 in. (at 24 hr) near the southeastern New England coast decrease to between 4 and 5 in. around 100 mi inland from the coast in areas of negligible orographic influence. The orientation of isolines of C which could be drawn from these data is generally southwest to northeast. To illustrate this orientation, the short line segments with arrowheads in figure 14 were drawn. Thus, the isolines which would result from a complete analysis would be parallel to the line segments with lower values of C to the left of the "arrows."

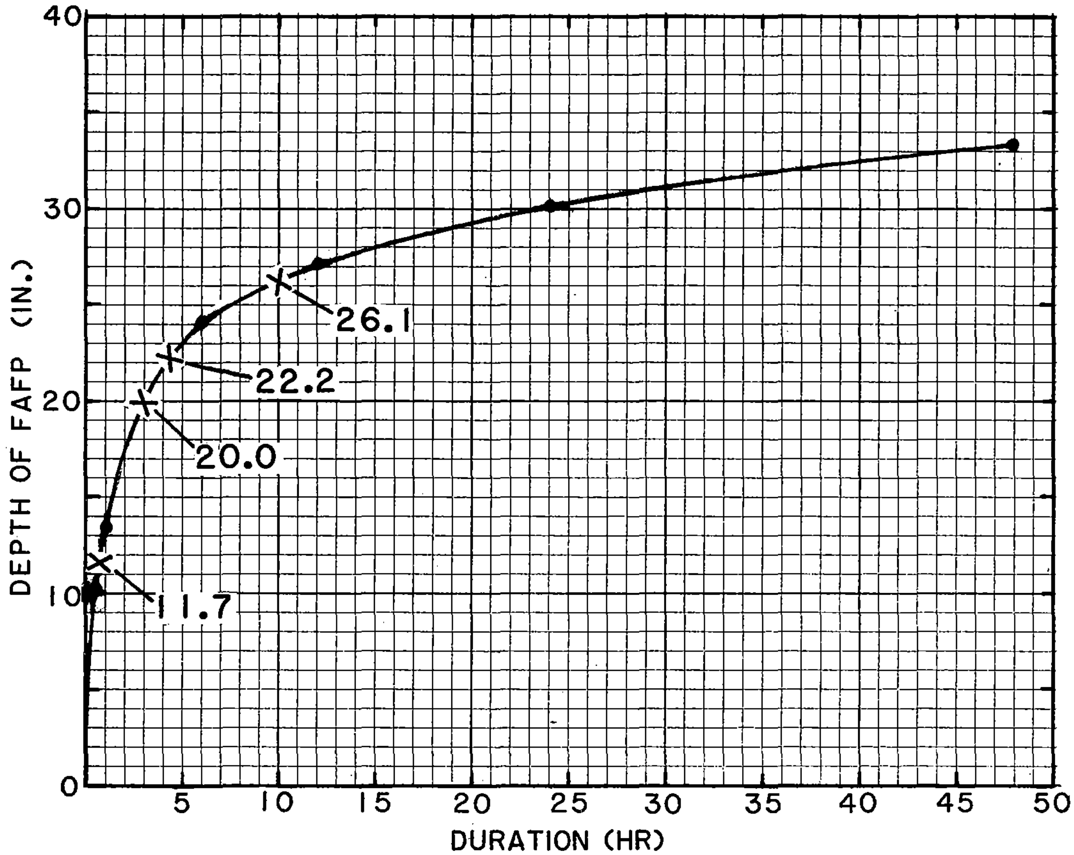

Figure 13.--Depth of FAFP as a function of duration at 42°54'N, 72°57'W near Somerset, VT. The "X's" indicate the interpolated values.

Table 8.--Values for M corresponding to selected 10 mi² precipitation periods, h, for the Upper Deerfield River drainage (42°54'N, 72°57'W)

h (hr)	1	6	12	24	48
D_r	11.7	20.0	22.2	24.1	26.1
D_h	13.4	24.1	27.2	30.2	33.3
M (percent)	.87	.83	.82	.80	.78

Our interest in this study was to evaluate T and C only to the extent necessary to determine the orographic effects over the Upper Deerfield River basin above Sherman Dam. For this reason, a comprehensive analysis was not undertaken. While the line segments shown in figure 14 represent an appropriate orientation, they do not provide any information on magnitude or gradients of the field of C.

To evaluate C over the Upper Deerfield River basin, it is necessary to determine specific values of C in regions of negligible orographic influence. The area at the confluence of the Mohawk and Hudson Valleys (in the vicinity of Albany, NY, indicated by the X in fig. 14) is one such region. Here, the calculated value of T is regarded as the value of C, i.e., the value of T/C = 1. The value of T at this location was obtained by averaging the values of T at Albany Airport and Mechanicville, NY. The longest available period of

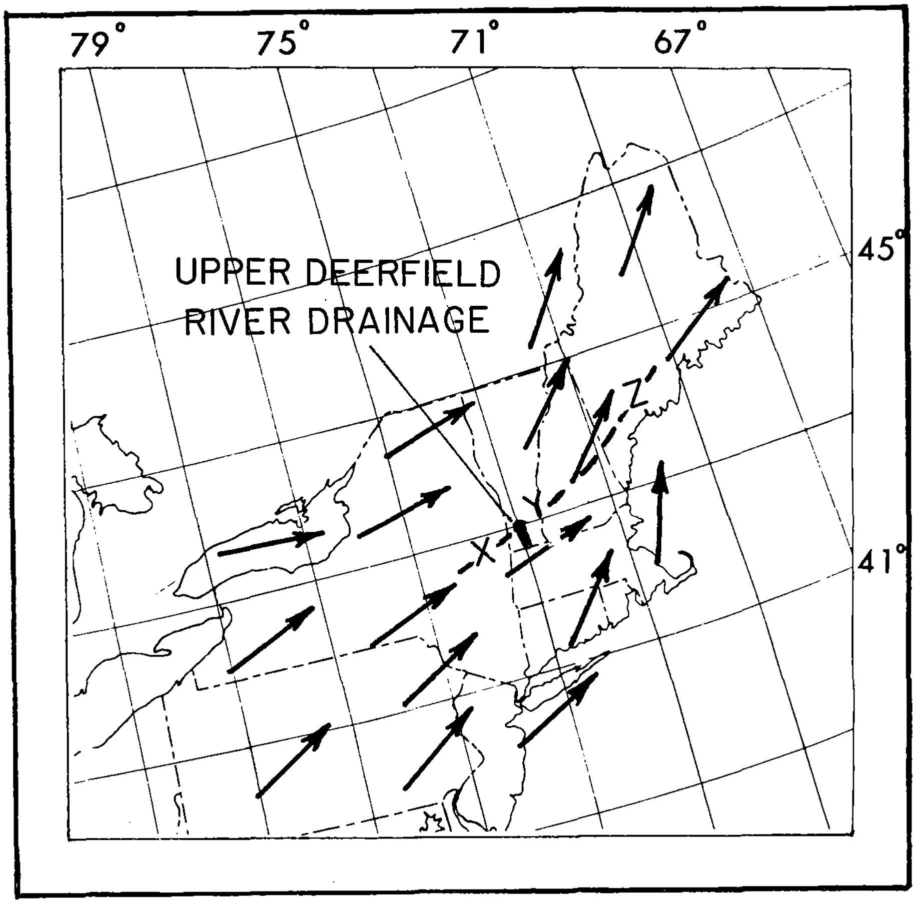

Figure 14.--Arrows depicting generalized orientation of isolines of "C." Locations at X, Y and Z are described in text. The dashed line suggests the isoline of C that would pass through the Upper Deerfield River basin.

record was used at each station, and the average value was 4.75 in. The value of T for the Connecticut River Valley from near Northfield, MA, to White River Junction, VT, is in the range of 4 to 5 in. (symbol Y in fig. 14). In Maine, between Lewiston and Waterville (Z in fig. 14), the value of T or C is also in the range of 4 to 5 in. The basic assumption that the field of C is relatively smooth and continuous, allows connection of values at X, Y, and Z. The 4.75 in. isoline of C through the Albany-Mechanicville area is, therefore, drawn through these three locations (X, Y, and Z connected by dashed line in the figure). This analysis of the 4.75 isoline of C puts it through the Upper Deerfield River basin. This value (4.75 in.) is, therefore, regarded as an appropriate value of C at 24 hr and 10 mi^2 for the basin at an elevation of 250 ft MSL (the approximate elevation of the region around Albany, NY, and Lewiston and Waterville, ME). A moisture adjustment of 89 percent was determined using an average barrier elevation of 2,200 ft. This adjustment assumes no vertical moisture change in the first 1,000 ft (as was done for the FAFP adjustment) and a dew point of 60°F. This dew point was based on the average of the 12 monthly maximum persisting 12-hr 1000-mb dew points and is considered representative of the storms contributing to the annual series of 24-hr precipitation events. Application of this adjustment to the 4.75-in. amount results in a "C" of 4.2 in. for the inflow elevation of the Upper Deerfield River drainage.

Values of T at 24-hr in the drainage are 5.95, 6.47, and 6.93 in., respectively, for long-record stations at Whitingham, Searsburg Mountain, and Somerset (fig. 2), based on the annual series. The average of these three depths is the best approximation for the value of T at any point in the drainage. The average value of 6.45 in. combines with the calculated C of 4.2 in., both at 24 hr, and 10 mi^2 for a T/C of 1.54. Using procedures and relations developed for the study of orographic influence in the region between the Continental Divide and the 103rd meridian, a value of T/C at 6 hr for the Upper Deerfield River drainage was determined to be 1.42. Assuming that the value of T/C should be 1 shortly after precipitation begins, we fitted the three pairs of T/C and duration (1.54 and 24, 1.42 and 6, 1.0 and 0) with a smooth curve, as seen in figure 15, to produce the values in table 9.

It is important to note that whenever T/C and M are used for a duration, h, their values are based on accumulated precipitation amounts from storms of record. Hence, the FAFP value to which they are applied must be an accumulated amount rather than an incremental amount. For example, the T/C and M at 48 hr are applied to 48 hr of accumulated FAFP and not to the FAFP recorded during the 48th hour of the storm.

4.3 Development of Final Equation for Computing Total PMP

The information developed in the preceding sections can be used to compute total PMP in an orographic region where the convergence component (FAFP) is known. A primary assumption used in this report, as well as in other HMR reports (e.g., 49 and 55), is that the ratio of T/C, developed from the 1-percent precipitation, applies equally for PMP. Substituting equations 4, 5, 6, and 7 into equation 3 we get:

$$PMP = FAFP \left\{ M[1 + P\ ((T/C) - 1)] \right\} + FAFP \left\{ (1 - M)(T/C) \right\} \qquad (9)$$

Remembering that P = 1 - M, equation 9 reduces to:

$$PMP = FAFP\ [M^2(1 - (T/C)) + (T/C)] \qquad (10)$$

The K factor of equation 1 for the Upper Deerfield River drainage is the expression in the squared brackets of equation 10.

In computing PMP using K, we will assume that for a given duration as M decreases with increasing area size, the value of T/C will also decrease such that K will remain constant across the relatively small range of area sizes of interest in this study. At 24 and 48 hr in central New England, M will decrease about 7 percent for an increase in area size from 10 to 200 mi^2. For K to remain constant with this change in the value of M, T/C would have to decrease about 3 percent. Smaller decreases in M at h = 1, 6 or 12 hr would require smaller decreases in T/C to keep K constant. Studies 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 10 percent for our assumption to be correct. A 10 percent decrease in T could occur.

The K factors for the Upper Deerfield River drainage in table 10 are produced by evaluating the expression inside the brackets of equation 10.

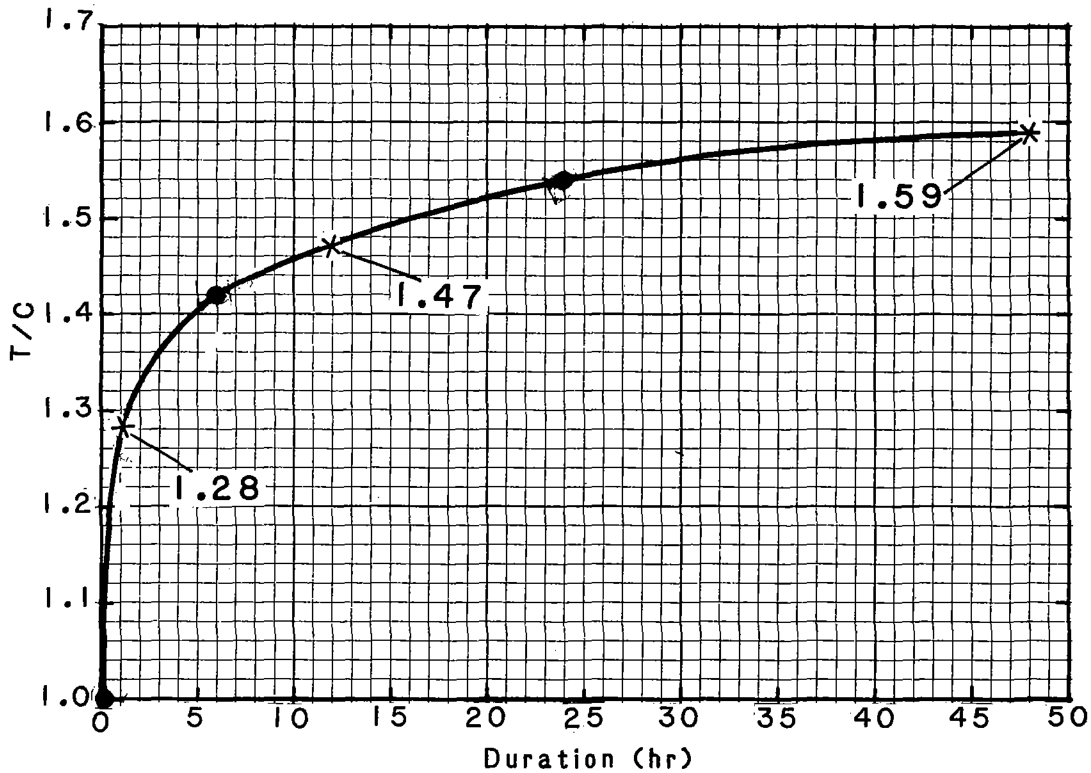

Figure 15.--Orographic factor (T/C) as a function of duration for the Upper Deerfield River basin. The "X's" indicate interpolated/extrapolated values.

Table 9.--Values of T/C for selected durations applicable to the Upper Deerfield River basin for 10 mi^2

h (hr)	0	1	6	12	24	48
T/C (percent)	1.00	1.28	1.42	1.47	1.54	1.59

An orographic factor of 19 percent at 24 hr appears reasonable in view of the terrain and meteorological conditions prevailing in this drainage. These K factors apply to all area sizes considered in the Upper Deerfield River drainage.

Table 10.--Values of orographic modification factor, K, for selected durations applicable to the Upper Deerfield River basin and all area sizes $\leq$236 mi^2

h (hr)	1	6	12	24	48
K (percent)	1.07	1.13	1.15	1.19	1.23

5. FINAL PMP ESTIMATES FOR THE UPPER DEERFIELD RIVER BASIN

The total PMP, resulting from application of the orographic factors (K) at each duration to equation 1, is given in table 11. Note that FAFP values in table 11 are taken from table 5 and are first adjusted by 89 percent to account for barrier elevation. We adjusted the concurrent precipitation from table 6 by the same orographic and moisture factors to obtain the adjusted values given in table 11.

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The authors wish to express their appreciation for the efforts of the following individuals. Miss Agnes Takacs, visiting scholar from the Meteorological Service of the Hungarian People's Republic, who performed some of the initial studies on storms affecting the region surrounding the Upper Deerfield River drainage, and the application of HMR No. 52 procedures to the drainage. Verification of these results, as well as preparation of the figures for the isohyetal patterns and determination of the concurrent precipitation, was completed by Mr. Chris Moeller, Meteorologist, Hydrometeorological Branch. Mrs. Helen Rodgers, for her typing the many drafts and final report.

Table 11.--Total PMP and concurrent precipitation (in.) for Upper Deerfield River basin modified by orographic factor

PMP							Concurrent Precipitation					
Basin (area mi^2)		Duration (hr) 1	6	12	24	48	Basin covered by concurrent precipitation (area mi^2)	Duration (hr) 1	6	12	24	48
Upper Deerfield River above Sherman Dam (236)	FAFP	*	13.50	16.42	18.84	21.41	None					
	PMP		15.26	18.88	22.42	26.33	None					
Upper Deerfield River above Harriman Dam (184)	FAFP	*	14.14	17.05	19.50	22.04	Between Sherman and Harriman Dams (52 mi^2)					
	PMP		15.97	19.61	23.21	27.11		*	11.86	14.86	17.92	21.26
Upper Deerfield River above Somerset Dam (30)	FAFP	*	18.40	21.36	23.76	26.16	Between Sherman and Somerset and Dams (206 mi^2)					
	PMP		20.79	24.56	28.27	32.18		*	8.73	10.46	12.18	14.00
Upper Deerfield River between Sherman and Harriman Dams (52)	FAFP	9.08	16.86	19.81	22.23	24.65	Above Harriman Dam (184 mi^2)					
	PMP	9.72	19.05	22.78	26.45	30.32		3.86	8.62	10.54	12.48	14.52

* Not requested in interagency agreement

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APPENDIX

Discussion of HMR No. 51 Controlling Storms

PMP given in HMR No. 51 is the result of an extensive study of major storms of record. That report adequately documents the developmental process in which storms are transposed and moisture maximized within geographical limitations of meteorological homogeneity. It is, however, not entirely clear in the report which major storms are controlling (closely enveloped by the level of PMP) in a particular region. We have, therefore, reviewed this aspect of HMR No. 51 and prepared a summary of the storms that support the level of PMP throughout the New England States (table A-1). From this table, it is apparent that three storms

Table A.1.--Controlling storms in New England (composite of locations) for all areas/durations

Area (mi^2)	Duration (hr) 6	12	24	48	72
10	OR 9-23* NA 1-7B	NA 1-7B OR 9-23	OR 9-23	-	-
200	NA 1-7B NA 2-4	NA 1-7B	-	-	-
1000	NA 1-7B SA 1-1 NA 1-17	-	-	-	-
5000	SA 1-1	-	NA 2-24A	NA 2-24A	NA 2-24A
10000	SA 1-1 NA 1-20B	NA 1-20B	NA 2-24A	NA 2-24A	NA 2-24A
20000	NA 2-24A	NA 2-24A	NA 2-24A	NA 2-24A	NA 2-24A

*Storm identification:

OR 9-23	Smethport, PA	7/17-18/42
NA 1-7B	Jewell, MD	7/26-29/1897
NA 1-17	Kinsman Notch, NH	11/2-4/27
NA 1-20B	Ripogenus Dam, ME	9/16-17/32
NA 2-4	Ewan, NJ	9/1/40
NA 2-24A	Zerbe, PA	6/19-23/72
SA 1-1	Wellsboro, PA	5/30-6/1/1889

Notes: Dashes in this table are durations and areas for which smoothing and consistency procedures used in HMR No. 51 result in PMP which envelopes maximized storm data more than a few percent.

Numbers provided for storm identification are U.S. Army Corps of Engineers Assignment Numbers and indicate formal storm studies completed and published in Storm Rainfall in the United States (U.S. Army Corps of Engineers 1945-).

are important for setting the level of PMP for small areas (<200 mi^2) and short durations (<12 hr). Table A.2 shows information that indicates the degree of envelopment of the maximized, transposed observed amounts for these three storms (Smethport, PA; Jewell, MDV erx Ewan, NJ), as well as two other storms, Westfield, MA; and Zerbe, PA. The Zerbe, PA, storm controls at larger areas and durations. The Westfield storm has been included for comparison, since it represents the largest observed rainfall close to the drainage. These data were derived from the work papers used in the development of HMR No. 51 and are representative of selected locations that surround the Upper Deerfield River basin. Table A.2 indicates that the degree of envelopment is smaller at 6 hr than at 24 hr for the area sizes shown. It also shows that HMR No. 51 includes small amounts of undercutting of 6-hr transposed values. The Wellsboro, PA, (SA 1-1) storm, listed in Table A-1, is closely enveloped at larger areas (>200 mi^2) for 6 hr throughout this region.

Because the number of storms considered transposable through any region is a limited sample of a total historical storm experience, HMR No. 51 relies (as do other generalized studies) on smoothing geographically, areally, and durationally, as well as on consistency checks, to control the degree of envelopment. The degree to which smoothing is done also can be interpreted as representing implicit transposition. Acceptance of implicit transposition or smoothing, is based on the understanding that there are no discontinuities observed in tracks of intense storms. Regional smoothing takes into account the effect of an extreme storm beyond the explicit limits of its area of transposability. Smoothing and consistency checks are an advantage in the generalized approach as compared to the traditional site-specific PMP study. In the latter, storm data that are maximized and transposed to the basin may be considered within areal and durational limits applicable to the scale of the basin. These values may or may not be consistent with similar results for different scales derived as part of a larger more comprehensive study. We believe that a generalized PMP analysis, when available, is more representative over a specific site than a site-specific study.

The concept of implicit transposition related to this region can be illustrated by consideration of the Smethport, PA, storm of July 17-18, 1942. This storm is one of the most extreme storms that has occurred in the Drainx States and is a key element in determining appropriate levels of PMP in the eastern United States. The direct transposition limits for the storm used in HMR No. 51 are shown in figure A-1. These limits restrict the transfer of this storm to the enclosed region. A consequence of this could be a sharp discontinuity in the precipitation analysis along this boundary. It is unlikely that meteorological reasoning would support a significant decrease in precipitation potential as one progresses eastward across the Appalachians, a direction that approaches a moisture source. There are two solutions to this problem. The first would be to develop adjustment techniques which permit the explicit transposition of these storm values across the ridge. These procedures would account for differing moisture sources and orographic effects. A second procedure, and the one chosen for use in HMR No. 51, is implicit transposition. By this we mean, allowing values computed for points at the edge of the region of explicit transposition to influence the placement of the isohyets in the adjoining region, taking into consideration varying moisture sources, storm types, storm tracks, and other factors which can influence the total amount of precipitation for a storm. Another factor influencing isohyets drawn in a particular region based on implicit transposition is the interdurational and interareal relations. Thus,

Table A.2.--Storms that control PMP in HMR No. 51 at specific area sizes and durations

Assignment No.° (1)	Obs. Amt.+ (in.) (2)	Max. Amt.# (in.) (3)	Transposition Amt.† (in.) (4)	Transposition Location (5)	HMR No. 51 (in.) (6)	Percent envelopment* (7)
6 hr 10 mi²						
NA 2-4	20.0	24.5	21.1	SE N.H.	24.4	+15.6
NA 1-7B	13.0	18.3	13.7	N Maine	14.0	+ 2.2
OR 9-23	24.7	27.1	24.7	E Cent. NY	24.2	- 2.0
24 hr 10 mi²						
NA 2-4	22.7	27.7	23.8	SE N.H.	30.0	+26.0
NA 1-7B	14.7	20.7	15.4	N Maine	17.2	+11.7
OR 9-23	29.2	32.1	29.2	E Cent. NY	29.2	0
NA 2-22A	16.4	18.0	14.8	NE Maine	22.5	+52.0
NA 2-24A	14.3	17.3	14.4	NE Maine	22.0	+52.8
6 hr 200 mi²						
NA 2-4	15.0	18.3	15.7	SE N.H.	16.0	+ 1.9
NA 1-7B	9.4	13.3	9.9	N Maine	9.7	- 2.0
OR 9-23	13.1	14.4	13.1	E Cent. NY	15.8	+20.6
24 hr 200 mi²						
NA 2-4	16.5	20.1	17.3	SE N.H.	22.0	+27.2
NA 1-7B	10.6	14.9	11.1	N Maine	13.0	+17.1
OR 9-23	19.9	21.9	19.9	E Cent. NY	21.0	+ 5.5
NA 2-22A	14.2	15.6	12.8	NE Maine	17.0	+32.8
NA 2-24A	13.4	16.2	13.4	NE Maine	15.7	+17.2

°Storms:

NA 2-4	Ewan, NJ	9/1/1940
NA 1-7B	Jewell, MD	7/26-29/1897
OR 9-23	Smethport, PA	7/17-18/1942
NA 2-22A	Westfield, MA	8/17-20/1955
NA 2-24A	Zerbe, PA	6/19-23/1972

See storm identification table A-1 for explanation of assignment numbers

+ Observed precipitation at location of storm occurrence (fig. 1). Amounts are from DAD data in Storm Rainfall in the United States (U.S. Army Corps of Engineers 1945-).

Precipitation amount shown has been moisture maximized by procedures used in HMR No. 51.

† Precipitation amount shown has been adjusted by transposition adjustments used in development of HMR No. 51.

* The percentage shown is the deviation from the transposed storm amount. It is determined from the equation:

$$\frac{\text{Col 6} - \text{Col 4}}{\text{Col 4}} \times 100$$

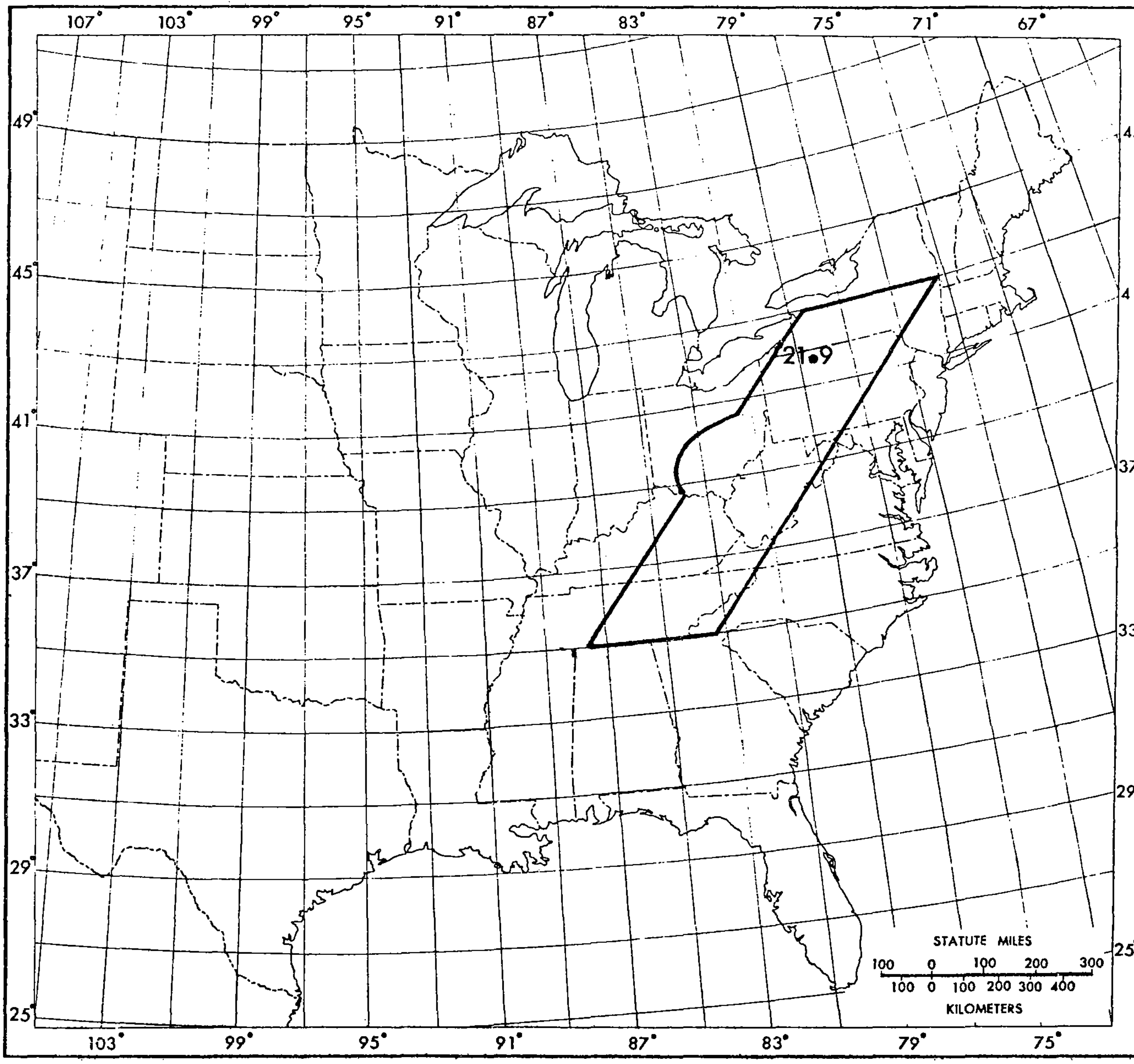

Figure A-1.--Transposition limits for the Smethport, PA, storm - July 17-18, 1942. Maximized 200 mi² 24-hr in-place amount shown.

when smooth depth-duration curves are drawn for a region, there must be direct support for the enveloping curves at some area sizes and duration from storms directly transposed to a region. If direct transposition of the Smethport, PA, amount were made using a barrier elevation of 2,500 ft and traditional methods of transposition, the 24-hr 200-mi² Smethport observed amount of 19.9 in. is reduced by 9 percent to 18.2 in. at the site of Harriman Dam. This is compared to a value of 21.5 in. from HMR No. 51 (our value differs slightly from that computed by NRC only in the minor differences expected to result from reading data off the generalized PMP maps, plotting and smoothing of depth-area-duration curves). Our determination of barrier elevation is relative to the mountains west of the drainage. If we follow the current practice of no elevation adjustment for the first 1,000 ft difference in elevation, when transposing storms, the Smethport, PA, value would be 19.9 in. at Harriman Dam.

It appears from our review of HMR No. 51 that the controlling storm for the vicinity of the Upper Deerfield River drainage is likely to be from one of two types of storms. The first is a storm with extratropical characteristics similar to that which occurred at Smethport, PA, in 1942. This storm, with a more optimum set of conditions than those that did occur, could produce even larger amounts of precipitation. A second type of storm is believed possible as the result of considering tropical storms that have occurred near the Upper Deerfield River drainage. Hurricane Agnes is one of the most prominent storms in our present record; however, an unusual storm produced unprecedented precipitation at Tyro, VA, (8/19-20/69) from the remnants of Hurricane Camille. This intense short-duration event produced 19.6 in. of rainfall in 18 hr over a 200 mi^2 (almost one-third larger than occurred in Hurricane Agnes). Even though the Tyro, VA, storm was not transposed beyond Pennsylvania in HMR No. 51, we believe that a hurricane with an imbedded center of intense precipitation is a candidate storm type for consideration over the Upper Deerfield River basin.

(Continued from inside front cover)

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