NOAA Technical Report NWS 21

Interduration Precipitation Relations for Storms — Southeast States

Silver Spring, Md.
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NWS 13 The March-April 1969 Snowmelt Floods in the Red River of the North, Upper Mississippi, and Missouri Basins. Joseph L. H. Paulhus, Office of Hydrology, October 1970, 92 p. (COM-71-50269)

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Interduration Precipitation Relations for Storms — Southeast States

Ralph H. Frederick

Office of Hydrology
Silver Spring, Md.
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INTERDURATION PRECIPITATION RELATIONS FOR STORMS - SOUTHEAST STATES

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ABSTRACT. Annual maximum precipitation events for N = 1-, 2-, 3-, 6-, 12-, and 24-hr durations are identified. The precipitation event for each of M = 1-, 2-, 3-, 6-, 12-, and 24-hr durations (M≠N) concurrent with the N-hr event is then selected. The events are stratified according to magnitude (class intervals in terms of return period) and relations between the N-hr and M-hr event are studied by forming a ratio of shorter to longer duration precipitation totals. Accumulated frequency distributions of this ratio by duration and return period class interval are suggested as a tool to estimate precipitation increments in constructing precipitation mass curves. By analyzing the relative timing of the shorter duration within the larger duration event, a characteristic time distribution can be developed. Examples of applying this method are shown.

INTRODUCTION

When hydraulic engineers or designers lack sufficient runoff and/or streamflow data to define flow frequencies for a project of interest, they most often synthesize such data through use of the more abundant precipitation data and analyses. One common practice is to synthesize a design precipitation mass curve from available precipitation-frequency values and calculate a design hydrograph from it. This requires using precipitation-frequency values for more than one duration in order to estimate both peak discharge and volume of water involved. The precipitation-frequency values for the different durations are generally derived from independent data samples without consideration of the concurrence of the storms defining the precipitation-frequency values for the different durations. Thus, a precipitation-frequency value for a short (1 to a few hours) duration derived mostly from convective storms might be combined with a longer duration (12 to 24 hours) value derived from cyclonic storms of either tropical or extratropical origin. The probability of the concurrence of the two events is undefined and adds uncertainty to the probability (or frequency) of the design storm.

This study examines the time and magnitude relationships between concurrent precipitation events for 1, 2, 3, 6, 12, and 24 hours. It examines such relationships in terms of duration and how the relationships vary according to the magnitude (identified by frequency) of the various precipitation events. It then illustrates one approach to estimating incremental storm values and constructing a characteristic precipitation mass curve. The proposed method requires the engineer or designer to first determine the hydrologically critical storm in terms of duration and frequency and then to determine the critical probability for precipitation increments to be combined with the design storm for construction of the precipitation mass curve.

DEFINITION OF TERMS

The terminology used in this report requires that very specific definitions be given for the words "storm" and "rainfall." Although common usage may indicate otherwise, the words *"storm"* and *"rainfall"* as used in this report are defined in this section. Until their definitions are understood, subsequent sections of the report could be confusing to the reader.

The *annual maximum storm* at a station is the largest total precipitation event for N-consecutive hours (N = 1, 2, 3, 6, 12, 24) during a calendar year. The annual maximum storm is for an *independent duration* (ID). [No consideration is given to the concurrence of this precipitation event with events for other durations.] Independent duration events are henceforth referred to as *storms*.

For each annual maximum storm, five other precipitation values are abstracted. These are the largest concurrent precipitation totals for M-consecutive hours (M = 1, 2, 3, 6, 12, and 24, M ≠ N). These are the events which include (surround) or are contained within the annual maximum storm. These are called *dependent duration* (DD) events since they are dependent upon the occurrence of the ID storm. DD events are referred to as *rainfalls* in this study.

Both storms and rainfalls begin with measurable precipitation during the first hour. After the first hour, each other hour may, or may not, have measurable precipitation. Thus, an N-hr storm or rainfall may actually have precipitation for as little as 1 hour and can have, or not have, some precipitation in each of the other hours. When there is no measurable preciptation in the last hour(s) of a storm or rainfall, the hour(s) from the last hour with precipitation to the end of the period are filled with *trailing zeros*.

Some examples are given. At a station in a particular year, the largest 3-hr precipitation fell between 5 and 8 p.m. (table 1a) during a thunderstorm on a sultry summer evening. This is the annual maximum event for that station and that year and the 21.6 mm is the depth in the 3-hr *storm* (ID). On this day, however, some rain fell intermittently from mid-afternoon through the evening. The 6-hr *rainfall* (DD) associated with this storm was from 4 to 10 p.m. and the depth was 24.9 mm. Notice that there was no rain between 9 and 10 p.m. so the 6-hr rainfall had 1 *trailing zero*. At this same station during this same year, an intense winter storm (table 1b) brought the annual maximum 6-hr *storm*. Between the hours of 10 a.m. and 4 p.m., 29.8 mm of precipitation fell. The 6-hr *independent duration* storm for this year at this

Table 1.--Excerpts from hourly precipitation record - Someplace, SE, USA, 19XX.

a. A sultry summer evening

Hour Ending		Precipitation (mm)	
2 p.m.		0.3	
3		0.3	
4		0.0	
5		2.5	6-HR RAINFALL (5–10)
6	3-HR STORM (6–8)	5.6	
7		12.2	
8		3.8	
9		0.8	
10	TRAILING ZERO	0.0	
11		0.7	

b. A stormy winter day

Hour Ending		Precipitation (mm)	
10 a.m.		0.3	
11	6-HR STORM (11–4)	3.8	
12 noon		3.8	
1 p.m.		4.6	3-HR RAINFALL (1–3)
2		6.4	
3		7.6	
4		3.6	
5		0.5	
6		0.0	
7		0.5	

station has now been selected. The heaviest 3-hr precipitation during this storm is 18.6 mm from noon to 3 p.m. and defines the 3-hr *dependent duration* rainfall associated with the 6-hr storm.

Previous studies were concerned only with the values we have defined as storms. This study investigates the sequential and quantitative relation between what we have defined as storms and rainfalls.

AREA OF STUDY AND ITS PRECIPITATION CLIMATOLOGY

The area selected for this study is the Southeastern States south of 35°N from Arkansas and Louisiana eastward (fig. 1). In choosing the area for a study of this type, two opposing constraints must be compromised. The data sample must be 1) climatologically homogeneous for the elements studied; and 2) large enough to define time and magnitude patterns in the wide variety of precipitation distributions found in nature. If an area were truly "climatologically homogeneous," its climatology could be defined with only a single well-placed station with a long enough record. In the United States there are no stations with a "long enough" record and no reasonable size area that is strictly climatologically homogeneous. Therefore, for a study of this type climatological homogeneity must be viewed realistically so as to obtain the large data sample needed to fulfill requirement (2) above.

In the section "Storm/Rainfall Relations by Ratio," an analysis of the ratio of shorter to longer duration precipitation events is described. To test whether the study area is reasonably climatologically homogeneous with respect to this ratio, three stations were randomly selected between 34° and 35°N in each of the States of Arkansas, Mississippi, Alabama, Georgia and South Carolina. Likewise, three stations each south of 31°N were chosen in Louisiana, Mississippi, Alabama, Georgia and Florida. For each of these stations, the three largest 1- and 24-hr storms and their associated rainfalls were

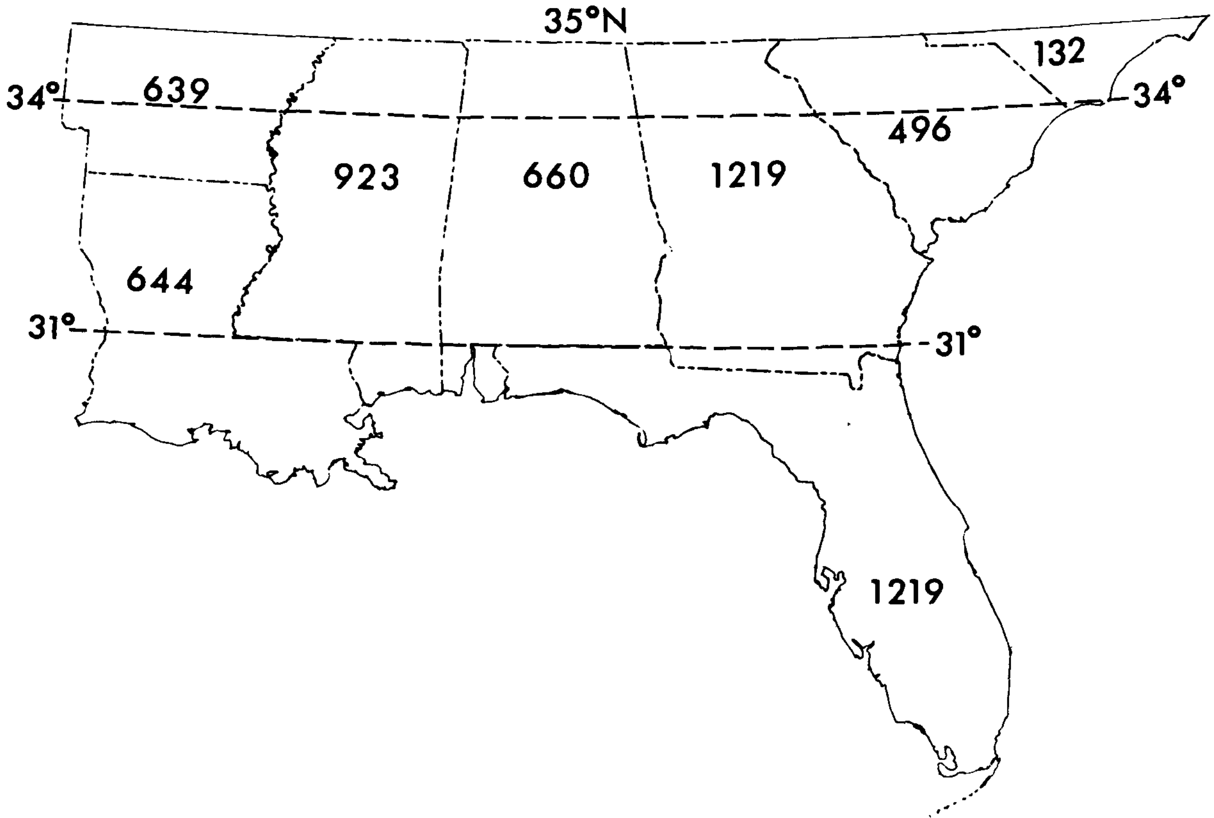

Figure 1.--Study area showing station years of data per state.

tabulated. The 1-hr to 24-hr ratio for both 1-hr storms and 24-hr storms was computed and averaged separately for the northern and southern station data samples. As shown in table 2, the mean ratios differed by only a fraction of a standard deviation from each other. A similar test comparing stations in eastern and western portions of the study area showed similar results. These tests support the concept that the climate of the area is sufficiently homogeneous in the elements under study that relations developed for the region as a whole will be meaningful.

Physiographically, the region is comprised of coastal plains and upland plateau with elevations under 600 m. The southeastern Appalachian Mountains extend into northern Georgia and extreme western South Carolina, but in each State the mountainous regions are less than 10% of the State's area. While there are some ridge and valley sections in the rest of the study area, the only other mountains are the Ouachita Mountains in Arkansas (highest just over 850 m). Thus, orography is important to the precipitation climatology in only a small portion of the study area. The physiographic feature of most importance to the precipitation is the long coast of the Gulf of Mexico and the Atlantic Ocean.

Table 2.--Results of climatological homogeneity test between northern and southern stations (N = 45).

	North		South	
	Mean	S. D.	Mean	S. D.
1-hr storm / 24-hr rainfall	0.721	0.197	0.682	0.212
1-hr rainfall / 24-hr storm	0.226	0.087	0.220	0.082

In the study area, normal annual precipitation (Environmental Science Services Administration 1968) ranges from 1525 to 1650 mm in some coastal and mountainous regions to 1145 to 1270 mm in South Carolina and portions of interior Georgia. It falls on an average of 100 to 120 days each year. Precipitation is well distributed throughout the year except for the pronounced summer and early fall maximum in Florida. Snowfall is not an important factor. Mean annual depths are 10 cm or less in northern sections and under 2.5 cm over about 60% of the area.

In the Southeastern States, intense rains of short duration (1 to a few hours) come mainly from convective showers and thunderstorms during the warmer portions of the year. As the duration of precipitation increases, the intense rains come from the passage of cyclonic disturbances of both tropical and extratropical origin. Many are associated with quasi-stationary fronts and inverted V isobaric patterns. Cry (1967) estimates that 10 to 15% of the June-to-October precipitation in the study area comes from tropical cyclones with as little as 5% in northeast Mississippi. While these percentages seem minor in terms of total precipitation, tropical cyclones contribute significantly to the study of intense rains (see section Comparative Seasonality of Storms). Hershfield and Wilson (1960) found no well-defined dichotomy between the hydrologic characteristics of hurricane or tropical storm rainfall vs. precipitation from other types of storms. Large precipitation amounts at long durations can also be caused by separate periods of convective activity following each other after several hours of no precipitation. This study does not separate precipitation events on the basis of their causative agent; i.e., a 24-hr precipitation event is not labeled as tropical, extratropical, or a series of convective events.

SELECTION AND PROCESSING OF DATA

The hourly precipitation observations published in *Climatological Data* (U.S. Weather Bureau 1948-51) and *Hourly Precipitation Data* (Environmental Data Service 1951-73) for the period 1948 (in most cases mid-1948) through 1972 were available on magnetic tape (Peck et al. 1977). For Louisiana, the data were available through 1973. The hourly precipitation record for each station year was read into a computer from these tapes. A computer program scanned the record to tabulate the number of hours listed as "missing" and "accumulated." Precipitation accumulations* representing time periods of 6 hours or less were assumed to have uniform distribution during the period of accumulation. Accumulations for over 6 hours were set to zero and treated as missing data. Each period of accumulated data and its disposition was printed out by the computer program.

Next, the 6 storms and 30 rainfalls and their times of occurrence were selected and listed for the station-year. This output was screened visually and compared with the list of accumulations and missing data to give reasonable assurance that the selected values were indeed the maximum values for that station for that year. If there were a likelihood that the largest storm for any of the durations for that year occurred when the data were missing or zeroed due to long accumulations, data for that station-year were eliminated from the station's series. As with any multi-million piece data set, a few (a small portion of 1%) erroneous values (punch errors, uncorrected observation errors, etc.) found on the data tapes caused enough ambiguity to require elimination of a year's data from the station series. The screened and edited data series were accepted for analysis.

Table 3 shows the distribution of station-years of data and the number of stations by length of record. The rule was that stations with less than 15 years of acceptable data were not used but one station with only 14 years of data managed to slip through the screening procedures. Two Louisiana stations had 26 years of acceptable record. Three-fourths of the stations used

Table 3.--Distribution of stations and station-years of data by length of record.

Length of record (years)	14	15	16	17	18	19	20	21	22	23	24	25	26
Percent of stations	0.4	6.5	3.2	5.1	5.8	4.0	9.0	9.7	10.5	12.6	15.2	17.3	0.7
Percent of station-years	0.2	4.5	2.4	4.0	4.9	3.5	8.4	9.6	10.8	13.6	17.0	20.2	0.9

had 20 or more years of data and over 80% of the sample came from stations with 20 or more years of record. Over 1/5 of the station-years of data in the sample came from stations with 25 (or 26) years of record (the total in

*Accumulated precipitation is a total for several hours which is recorded on the rain gage chart as falling during a short period. For instance, the clock drive stops so that the pen trace remains at the same time; or snow falls in the funnel of an unwinterized gage and melts at some later time.

table 3 is 100.1 percent because of rounding). Figure 1 shows the number of station-years for each State. The total number of station-years was almost 6,000 from 277 stations.

STRATIFICATION INTO FREQUENCY CLASSES

The Fisher-Tippett Type I extreme value distribution was fitted to each of the six ID sets for each station using the Gumbel (1958) fitting method. By reference to this distribution, each storm and rainfall for each station year was tagged with a return period (frequency) class. There was no cross reference of frequency values to those for neighboring stations, or to those in the literature. Thus, a storm or rainfall of X mm at one station might, or might not, be of the same frequency class as an equal X mm value at another station. At the same station, an X mm rainfall would be of the same frequency class as an X mm storm of the same duration. The classes and their terminology for this study are shown in table 4.

Table 4.--Frequency classes and terminology for storms and rainfalls.

Class interval limits	Terminology
Equal to or exceeding the 25-yr storm.	Class I
Equal to or exceeding the 10-yr but less than the 25-yr storm.	Class II
Equal to or exceeding the 5-yr but less than the 10-yr storm.	Class III
Equal to or exceeding the 2-yr but less than the 5-yr storm.	Class IV
Less than the 2-yr storm.	Class V

ANALYSIS OF JOINT FREQUENCY OF STORMS AND RAINFALLS

Two-way frequency distributions of each ID data set vs. each of its DD data sets were formed by the return period classes just defined. Table 5 is an example of one such distribution. Table 5 shows, for example, that 152 6-hr storms of class IV had 2-hr rainfalls of class III. No class I 2-hr rainfalls were associated with class V 6-hr storms. Joint frequency tables similar to table 5 for all 30 ID-DD combinations are presented in appendix I.

As expected, small storms and rainfalls in this area tend to co-occur, no matter what the durations involved. Table 6 shows the co-occurrence of class V storms and rainfalls (first column, first row) of all 30 tables similar to table 5, converted to percent; e.g., [3481/4005] X 100 = 86.9. The class V co-occurrence percentage exceeds 86 for all duration combinations. A rate of 90% co-occurrence is not uncommon.

Table 5.--Joint frequency distribution of 6-hr storms and 2-hr rainfalls.

Storm Class / Rainfall Class	V	IV	III	II	I	sum
			Number of events			
V	3481	577	144	57	6	4265
IV	452	285	94	82	13	926
III	64	152	63	59	23	361
II	8	85	79	64	47	283
I	0	9	10	34	44	97
sum	4005	1108	390	296	133	5932

Table 6.--Percent of co-occurrence of storms and rainfalls of class V.

ID / DD	1	2	3	6	12	24
1		99.0	87.5	87.5	88.6	89.3
2	89.9		93.1	86.9	86.3	87.3
3	88.7	94.4		89.7	87.0	87.1
6	89.1	90.8	92.4		91.2	88.8
12	89.6	89.5	90.0	92.2		91.8
24	90.2	89.9	89.2	90.5	93.5	

At the other end of the frequency scale, table 7 shows percent of class I storms accompanied by rainfalls of that class.

Although the percent of co-occurrence is as high as 75 (at ID = 2, DD = 3), the percentage falls off rapidly away from the table diagonal. The average for the 10 values adjacent to the diagonal is just over 55% of co-occurrence. Outward toward the corners of the table, the average percentage drops progressively to 34.7, 19.0, 11.5 and 7.4. In table 6, this average was just under 89% at the 2nd, 3rd, and 4th removals from the diagonal. While table 6 shows small storms and rainfalls tend to co-occur, table 7 shows large storms and rainfalls do not usually co-occur except at durations differing by only one to a few hours.

Table 7.--Percent of co-occurrence of storms and rainfalls of class I.

ID / DD	1	2	3	6	12	24
1		50.0	37.7	21.1	9.5	7.0
2	43.1		65.8	33.1	15.9	11.4
3	37.1	75.0		51.9	26.9	14.9
6	24.1	44.0	60.5		50.0	36.8
12	11.2	21.0	30.7	48.9		54.5
24	7.8	14.0	16.7	32.3	51.6	

STORM/RAINFALL RELATIONS BY RATIO

Concurrent storms and rainfalls were related to each other by forming a ratio of the shorter duration (either ID or DD) to the longer duration (either DD or ID) precipitation. This was done for each ID-DD combination by the frequency classes defined in table 4 and accumulated frequency distributions were formed of this ratio. For example, figure 2 shows the accumulated frequency distribution for three storm classes of the ratio of the 1-hr ID / 24-hr DD. The figure shows a systematic variation in the ratio as the rarity of the storm increases. As shown by the dashed line, class V 1-hr storms are 40% or more of the concurrent 24-hr rainfall 80% of the time while class III and I storms are 46.5% and 55% of the concurrent 24-hr rainfall 80% of the time. This means that there is a probability of 0.80 that the 24-hr

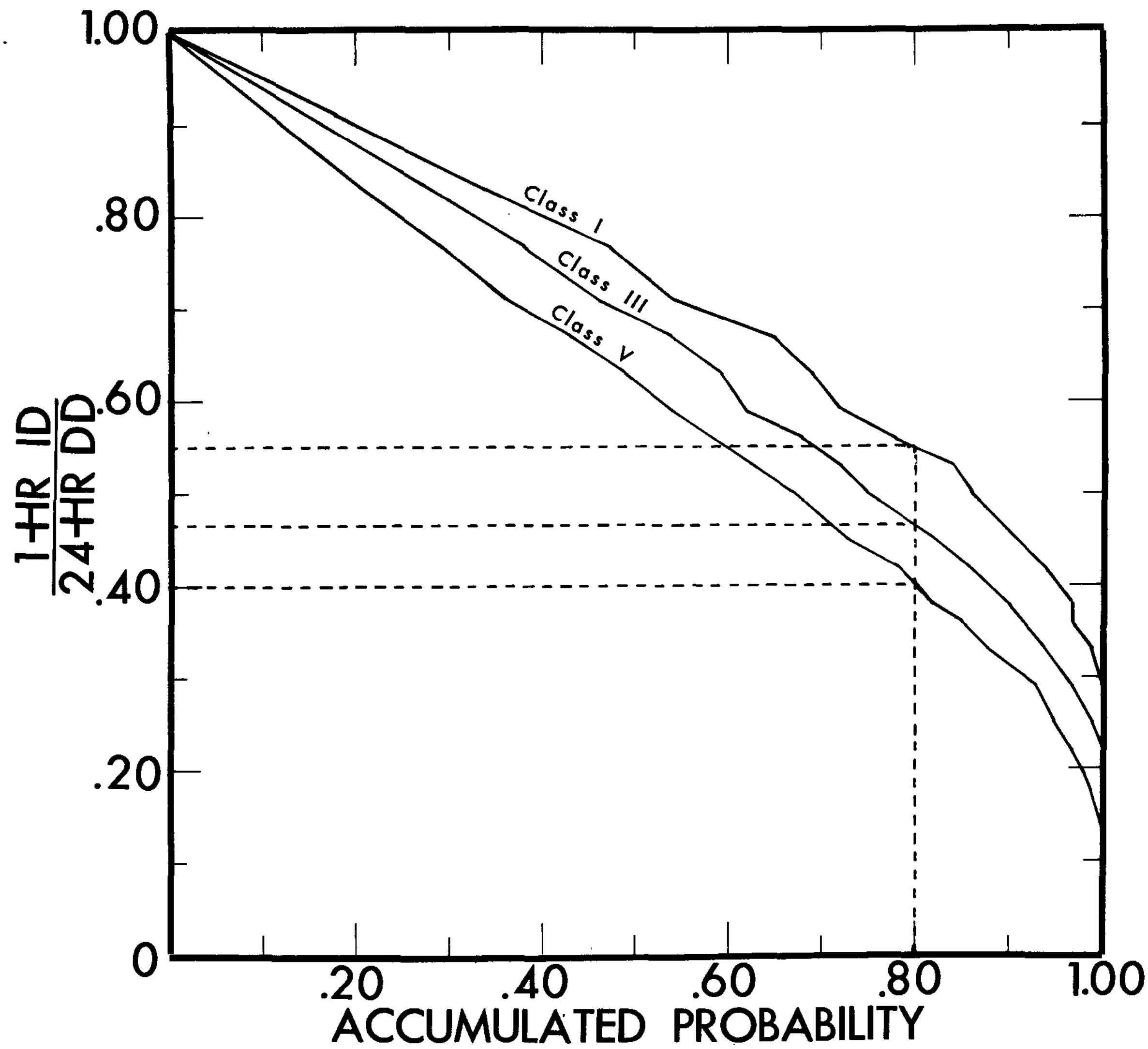

Figure 2.--Accumulated probability of percent of 24-hr rainfall concurrent with selected classes of 1-hr storms.

rainfall associated with a Class I 1-hr storm will be less than 1.82 times that 1-hr value (1.0/0.55 = 1.82). Likewise, there is only a 0.20 probability that the 24-hr rainfall will exceed 1.82 times the 1-hr value.

Appendix II contains accumulated probability figures for each storm duration and three storm classes. All DD possibilities are shown for each ID. The curves in the appendix have been smoothed by eye-fitting and have been checked for consistency both duration-wise and frequency-wise. Interpolation to obtain class II and IV relations is appropriate.

COMPARATIVE SEASONALITY OF STORMS

Tabulations were made of the month of occurrence of storms for each duration for each frequency class (shown as bar graphs in appendix III). Month of occurrence was defined as the month in which the first hour of precipitation fell. Inspection indicated no consistent differences among classes I, II, III, and IV and they were combined. For this analysis, therefore, the data were stratified into only two classes: 1) storms smaller than 2-yr, and 2) all others.

Figure 3, seasonal distribution of storms equal to or greater than the 2-yr storm shows a remarkably consistent variation with duration. From September through March, percent of storms for each month increases as duration increases with only two minor exceptions. In November the 1- and 2-hr storms have equal frequency and the 24-hr is slightly less frequent than the 12-hr storms. From May through August, frequency decreases as duration increases with the exception of June when there is a crossing of the 12- and 24-hr curves. Nearly 60% of the 1-hr storms are in June, July, or August against less than 25% of the 24-hr storms in these months. This illustrates the climatological fact that summer thunderstorms dominate the sample for short (1-, 2-, and 3-hr) durations. On the other hand, November through March have at least 2.5 times as many annual maximum 24-hr storms as 1- or 2-hr storms in each month. The 6-, 12- and 24-hr curves show a bimodel tendency with the major peak in September and minor peak in the spring. An investigation of the September peak using a random sample of 100 September 24-hr storms larger than the 2-yr storm showed something on the order of 40% of the annual maximum values in that month were associated with hurricanes. The remainder came from cold fronts, extra-tropical circulations, inverted V troughs, and air mass storms, with a few that were a combination of causes or did not really fit the above classes.

DIFFERENCES BETWEEN STORMS AND RAINFALLS OF THE SAME DURATION

In the Southeastern States storms and rainfalls of 6-, 12-, and 24-hr durations differ in the number of hours with measurable precipitation and in the number of trailing zeroes. Table 8 quantizes some of these differences.

The first part of the table addresses the question: How likely is it that a storm (or rainfall) has precipitation in each of the hours? As shown in the table, the answer is, not very likely especially at the 24-hr duration.

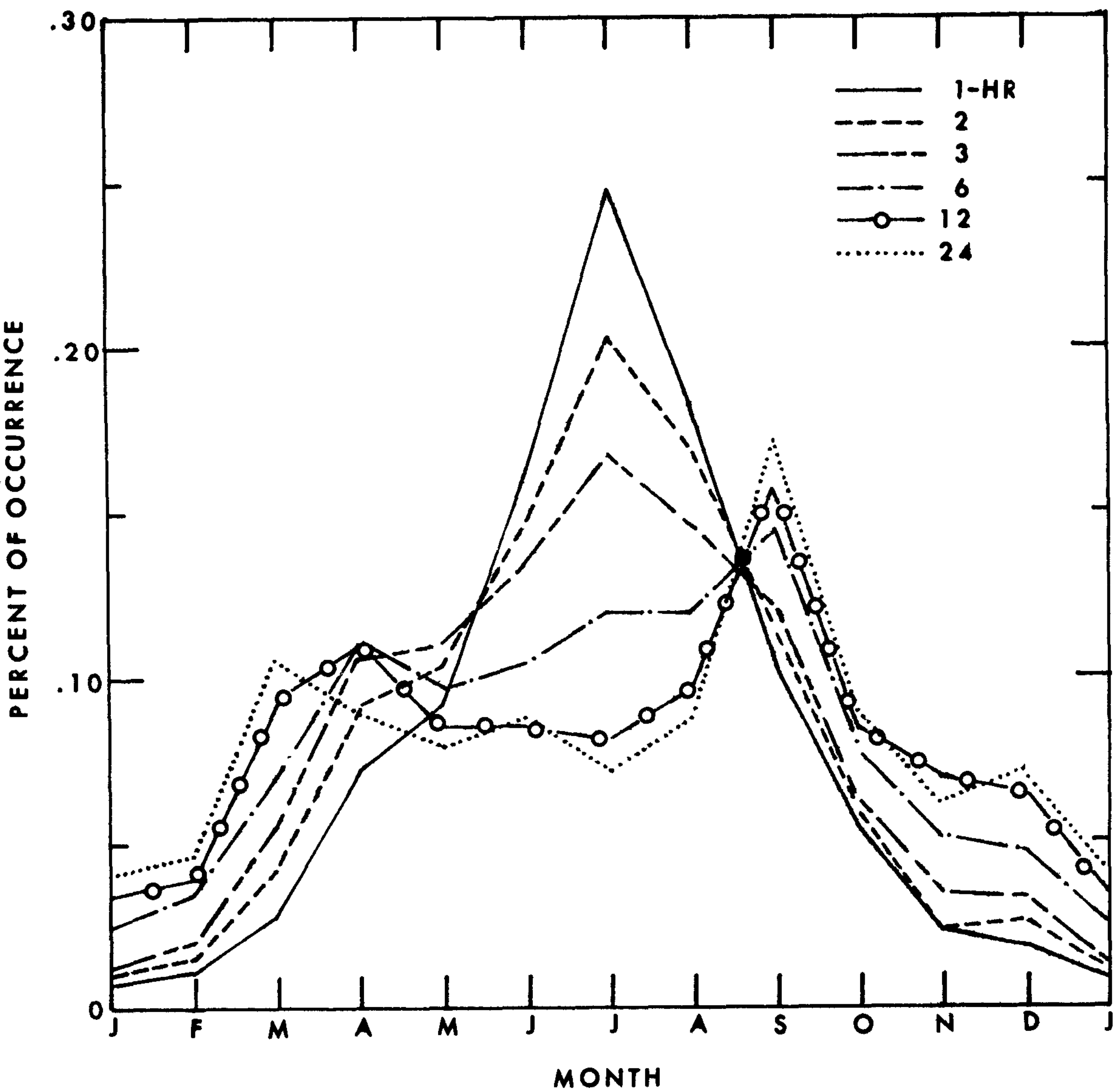

Figure 3.--Monthly distribution of annual maximum N-hr storms equal to or exceeding the 2-yr storm at station of observation.

The less frequent 24-hr storm (class I) is more likely to have 24 hours of precipitation but even then the probability is less than one-in-three. Rainfalls with precipitation in all 24 hours are rare. The likelihood of N-hours of precipitation increases as the duration decreases reaching around 80% in 6-hr storms of class I or III.

Since many, if not most, storms and rainfalls do not have precipitation in all N-hours, what percent of the storm or rainfall hours do contain measurable amounts of precipitation? The second section of table 8 illustrates this quantity. The table shows that 6-hr storms have about 90% or more hours

Table 8.--Differences between storms and rainfalls

			Storm Class I	Storm Class III	Storm Class V
Percent of storms - rainfalls with measurable precipitation in all of the N-hours	ID=24		32	17	5
	ID=1	DD=24	0	1	1
	ID=12		57	54	32
	ID=1	DD=12	9	7	9
	ID=6		82	79	64
	ID=1	DD=6	35	36	34
Precent of storm - rainfall hours with measurable precipitation	ID=24		84	76	60
	ID=1	DD=24	34	35	35
	ID=12		90	89	76
	ID=1	DD=12	51	51	51
	ID=6		95	94	88
	ID=1	DD=6	73	74	73
Percent of storms - rainfalls with no trailing zeros	ID=24		65	60	42
	ID=1	DD=24	17	28	26
	ID=6	DD=24	31	34	27
	ID=12		81	75	55
	ID=1	DD=12	26	25	26
	ID=6	DD=12	54	55	41
	ID=6		86	84	73
	ID=1	DD=6	47	44	46

with precipitation. 24-hr storms have from 60% to 84% (dependent upon relative frequency) of their hours with precipitation. N-hr rainfalls have more zeros (less hours with precipitation). At the 12-hr duration the likelihood is about 50/50 with more precipitation hours at the shorter duration and fewer such hours at the 24-hr duration.

The last section of table 8 examines the occurrence of trailing zeros. Once again the numbers depend upon frequency and duration and whether the event is a storm or rainfall.

Figure 4 shows the accumulated percent of 24-hr storms (class III) and rainfalls by count of hours without precipitation. Eighty percent of these 24-hr storms have less than 10 hours without precipitation (dash line, fig. 4). On the other hand (dot line, fig. 4) only 20% of the 24-hr rainfalls concurrent with class III 1-hr storms have less than 10 zero hours.

Table 8 and figure 4 show that although the percentages change, 6-, 12-, and 24-hr rainfalls have, on the average, more non-precipitation hours and more trailing zeros than do equal class 6-, 12-, and 24-hr storms.

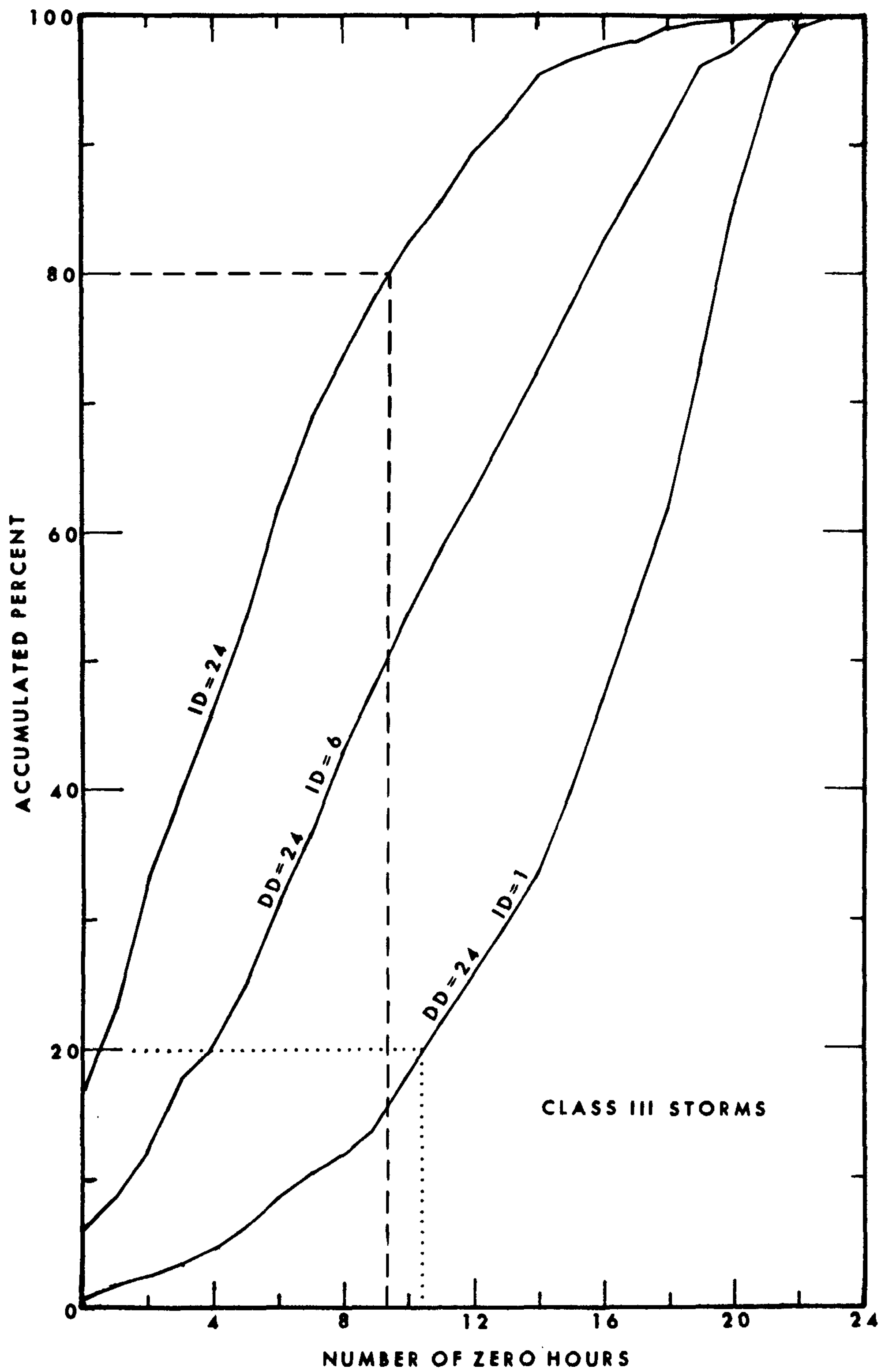

Figure 4.--Accumulated percent of 24-hr storms and rainfalls by count of hours without measurable precipitation.

ESTIMATION OF RAINFALL VALUES FOR STORM PRECIPITATION MASS CURVES

This section suggests a method of obtaining rainfall increments for use in the construction of design storm precipitation mass curves, once the basic design storm duration and frequency have been defined from hydrologic/economic/safety factors. The appropriate choice of the design storm and frequency are not the subject of this study. The incremental rainfalls can be estimated from the analysis of concurrent storm and rainfall events.

Curves similar to figure 2 showing accumulated probability for each rainfall duration at each storm duration for class I, III and V storms are presented in appendix II. Using the figure for the storm duration and frequency most pertinent to a project, the engineer or designer chooses what he/she considers the appropriate hydrologic risk factor for the needed rainfall durations. This risk can be the same for all rainfall durations or can vary according to the design requirements. It should be pointed out that there are numerous storm frequency-rainfall accumulated probability combinations which will result in the same combined probability. For example, a 50-yr storm (probability of occurrence in any given year is 0.02) and a rainfall at the 0.50 accumulated probability level have a combined probability of 0.01 per year. The 25-hr storm (0.04 probability of occurrence) and the 0.25 rainfall accumulated probability values likewise have a combined probability of 0.01. From among the combinations of equal meteorological probability the choice should be of the combination that tends to produce the most hydrologically critical result when this is known.

As an example, assume the 50-yr 1-hr storm is the basic design storm. The engineer or designer has decided that 0.80 is an appropriate risk factor for dependent duration rainfalls (DD's). From figure 2, the 24-hr rainfall at accumulated probability of 0.80 is 1.82 (1/0.55) times the 1-hr value. Using a 1-hr storm value from a published source (e.g., Frederick et al. 1977) and multiplying by 1.82, gives the 24-hr rainfall value for this example. Rainfalls for each other duration can likewise be estimated and all can be assembled into a precipitation mass curve after a decision on timing, discussed in the next section.

TIME DISTRIBUTION OF PRECIPITATION IN STORMS AND RAINFALLS

Construction of a precipitation mass curve requires a time sequence as well as the magnitude of the precipitation increments. For guidance on this, tabulations were made of the time of the beginning of the shorter duration precipitation event within the longer duration event for all ID-DD combinations by the 5 classes. Since not all storms and rainfalls had measurable precipitation in the last hour(s), we also tabulated the actual length of the precipitation.

To study the time distribution within storms and rainfalls, the first step is to delineate the observed frequency of hour of beginning of the short duration within longer duration precipitation events by simple conversion to percentages of occurrences for each hour. For example, of 3922 6-hr class V storms, 512 had the 1-hr rainfall during the 4th hour. Thus, 512/3922 = .1305 is the observed frequency for that hour as indicated in the line of table 9 labeled "observed."

To interpret these frequencies, we must isolate the statistical effects of the definition that zeros are trailing, not leading. For example, if the last two hours of a 6-hr storm have no precipitation, there is no possibility of the associated 1-hr rainfall during these particular hours. Continuing this example, we compute an expected frequency of timing of the 1-hr rainfall within 6-hr storms based on random (or uniform) distribution of the 1-hr rainfalls within the period during which precipitation actually occurred. The observed frequency and this theoretical random one are then compared. Table 9 illustrates this process for 1-hr rainfall within 6-hr storms of frequency class V. The second column of table 9 shows the fraction of storms of this subset having the number of trailing zeros indicated in the first column. If random distribution occurred, one-sixth of the 1-hr rainfalls in storms with no trailing zeros would be expected to occur in each of the six storm

Table 9.--Example of time distribution analysis using 1-hr rainfalls within 6-hr class V storms.

		Storm Hours					
Trailing zeros	Fraction of storms	1	2	3	4	5	6
		Random Probability					
0	0.729	.1215	.1215	.1215	.1215	.1215	.1215
1	0.112	.0224	.0224	.0224	.0224	.0224	
2	0.074	.0185	.0185	.0185	.0185		
3	0.056	.0187	.0187	.0187			
4	0.026	.0130	.0130				
5	0.003	.0030					
"Expected"	1.000	.1971	.1941	.1811	.1624	.1439	.1215
Observed		.2318	.2856	.1622	.1305	.1101	.0798
Ratio (O/E)		1.18	1.47	0.90	0.80	0.77	0.66

hours, or 0.729/6 = 0.1215 of the class V subset, as indicated in the table. Likewise, 0.112/5 = 0.0224 of the 1-hr rainfalls would occur in each of the first 5 hours when a storm had 1 trailing zero with no possibility, by definition, in the last hour. Listing each hour's possibilities and summing results in the "expected" figures shown at the bottom of the table (the expected" row total can sum to 1.0001 because of rounding). The observed frequencies are listed on the next line of the table, followed by a line showing the observed/expected (O/E) ratio. The highest ratio is interpreted as marking the most likely hour for the 1-hr rainfall in a 6-hr storm of this class with no trailing zeros, and likewise as a composite position that would result if the trailing zeros were replaced by small amounts of precipitation. This is the second hour in this example.

This same process was carried out for all ID-DD combinations involving the 6-, 12-, or 24-hr durations for class I, III, and V storms. Tables 10, 11, and 12 show the most probable beginning hour of the shorter duration DD or

Table 10.--Most likely beginning hour of shorter duration storm (ID) or rainfall (DD) within longer duration storm or rainfall - class V storms.

DD \ ID	1	2	3	6	12	24
			ID-DD Hour			
1		1	1 or 2	2	2	2
2	1		1	1	1	1
3	1	1		1	1	1
6	1	1	1		1	1
12	1	1	1	1		1
24	1	1	1	1	1	

Table 11.--Same as table 10, class III storms.

DD \ ID	1	2	3	6	12	24
			ID-DD Hour			
1		1	2	2	2	2
2	1		1	1 or 2	2	2
3	1	1		1	1	1
6	2	1	1		1	1
12	2	1	1	1		1
24	2	1	1	1	1	

Table 12.--Same as table 10, class I storms.

DD \ ID	1	2	3	6	12	24
			ID-DD Hour			
1		1 or 2	2	4	2	4
2	1		1	3	2	3
3	1 or 2	1		3	1	3
6	2	1	1		1	1
12	2	1	1	1		1
24	2	1	1	1	1	

ID within longer duration DD or ID class V, III, and I storms, determined in the above manner. The results for ID-DD combinations with both 3 hours or less are also included in the tables. In most cases here the observed data were overwhelming in pointing out the most likely beginning hour and normalization in the style of table 9 was unnecessary.

Tables 10, 11, and 12 are not based strictly on the computed O/E ratio values but also take other factors into account. In cases where the O/E ratio had a double peak, judgment was applied in choosing the peak rather than always accepting the largest. For example, in 24-hr rainfalls around class III 1-hr storms, the O/E ratio for the 23rd hour is 3.09 while the 2nd hour had a ratio of only 2.21. Hour 23 had only 4.25 percent of all observed occurrences but the 2nd hour had nearly 24 percent of the observed values. We felt the O/E ratio of 2.21 based on such a large quantity of observed data was more significant than the 3.09 ratio based on so few occurrences.

Also considered in choosing between peaks was the distribution of other duration storms or rainfalls. In the previous example, if the 1-hr storm were allowed to occur in the 23rd hour of the 24-hr rainfall, the 6-hr rainfall would have to have its 1-hr storm in the 5th hour (remember both 6-hr rainfall and 1-hr storm must be within the 24-hr rainfall). But the O/E ratio for class III 1-hr storms within 6-hr rainfalls was only 0.51 at the 5th hour. For the 2nd hour the O/E ratio was 1.55.

Tables 10, 11, and 12 contain a few entries "1 or 2." This indicates about equal probability and a synthesized storm using either hour would not be inconsistent with the data. The tables are constructed to represent one burst storms and rainfalls; i.e., the 1-hr event is within the 2- or 3-hr event and the 2-hr event includes the 1-hr and is, in turn, included within the 3-hr. Specifically when using the tables as guides to constructing mass curves of precipitation for a 6-hr storm or rainfall the 1-, 2-, and 3-hr events can all be placed as shown in the tables. Any hours not specifically assigned values, e.g., the 4th, 5th, and 6th hours of a 6-hr storm could have linear distribution of remaining amounts. That is, the remaining 3 hours could each have one-third of the difference between the 6-hr value and the 3-hr value. Despite the fact that storms and especially rainfalls typically contain non-precipitation hours and trailing zeros, the amounts resulting from this differing method are quite small and should not be hydrologically much different from zero once the steep portion of the precipitation mass curve or hydrograph is defined.

When hydrologically critical, precipitation mass curves using a time distribution somewhat different from "most likely" patterns listed would not be unrealistic. For instance, placing the maximum 1-hr event in the second or third hour instead of the suggested first hour so that it would have less infiltration and produce greater runoff to carry to a hydrograph would not be "untypical." In a study for Pennsylvania, Kerr, et al. (1974) suggest that a design precipitation mass curve should position the most intense portion of the storm immediately after the initial abstraction has occurred.

EXAMPLE OF CONSTRUCTION OF PRECIPITATION MASS CURVE

A project at 85°00'W and 32°30'N requires the 50-yr 6-hr storm as the critical design value. A precipitation mass curve for 24 hours which includes the 50-yr 6-hr storm must be constructed. The design engineer has determined that he should use an accumulated probability of 0.70 to relate the storm with its associated rainfalls. The use of an accumulated probability level of 0.70 in this example and of 0.80 in the discussion of figure 2 are for illustrative purposes only. They are not intended to be recommendations or proposed standards.

The first step is to estimate the design storm value. From Technical Paper No. 40 (Hershfield 1961) the 50-yr 6-hr value for the location in question is read as 142.2 mm. Storm rainfall ratios are read from the ID = 6, class I figure in appendix II. For the 1-, 2-, and 3-hr rainfalls, the abscissa scale at the top of the diagram is used (accumulated probability (DD < ID)). Reading down the 0.70 Accumulated Probability line the values are 0.86, 0.72, and 0.45 for the 3-, 2-, and 1-hr ratios, respectively. For 12- and 24-hr rainfalls, the bottom abscissa scale (accumulated probability (DD > ID)) is used and the ratios of 0.785 and 0.87 are read for 24 and 12 hours. The rainfall ratios are tabulated in column 3, table 13. Rainfall values for each increment are computed in column 4 by multiplying the ratios by 142.2. Using the ID = 6 column of table 12, the beginning hour for each rainfall increment is tabulated in column 5, table 13.

Table 13.--Construction of precipitation mass curve for 50-yr 6-hr storm at 85°00'W 32°30'N using accumulated rainfall probability of 0.70.

Column 1	Column 2	Column 3	Column 4	Column 5
Duration (hr)	ID Precip. (mm)	DD/ID at 0.70 Accum. Prob.	DD Precip. (mm)	Beginning Hour
1		0.45	64.0	4
2		0.72	102.4	3
3		0.86	122.3	3
6	142.2			
12		1/0.87	163.5	1
24		1/0.785	181.2	1

The precipitation mass curve constructed from table 13 is shown in figure 5. The 6-hr storm total of 142.2 mm begins in the 1st hour of the 181.2 mm 24-hr rainfall, the maximum 1-hr (64.0 mm) is in hour 4, etc.

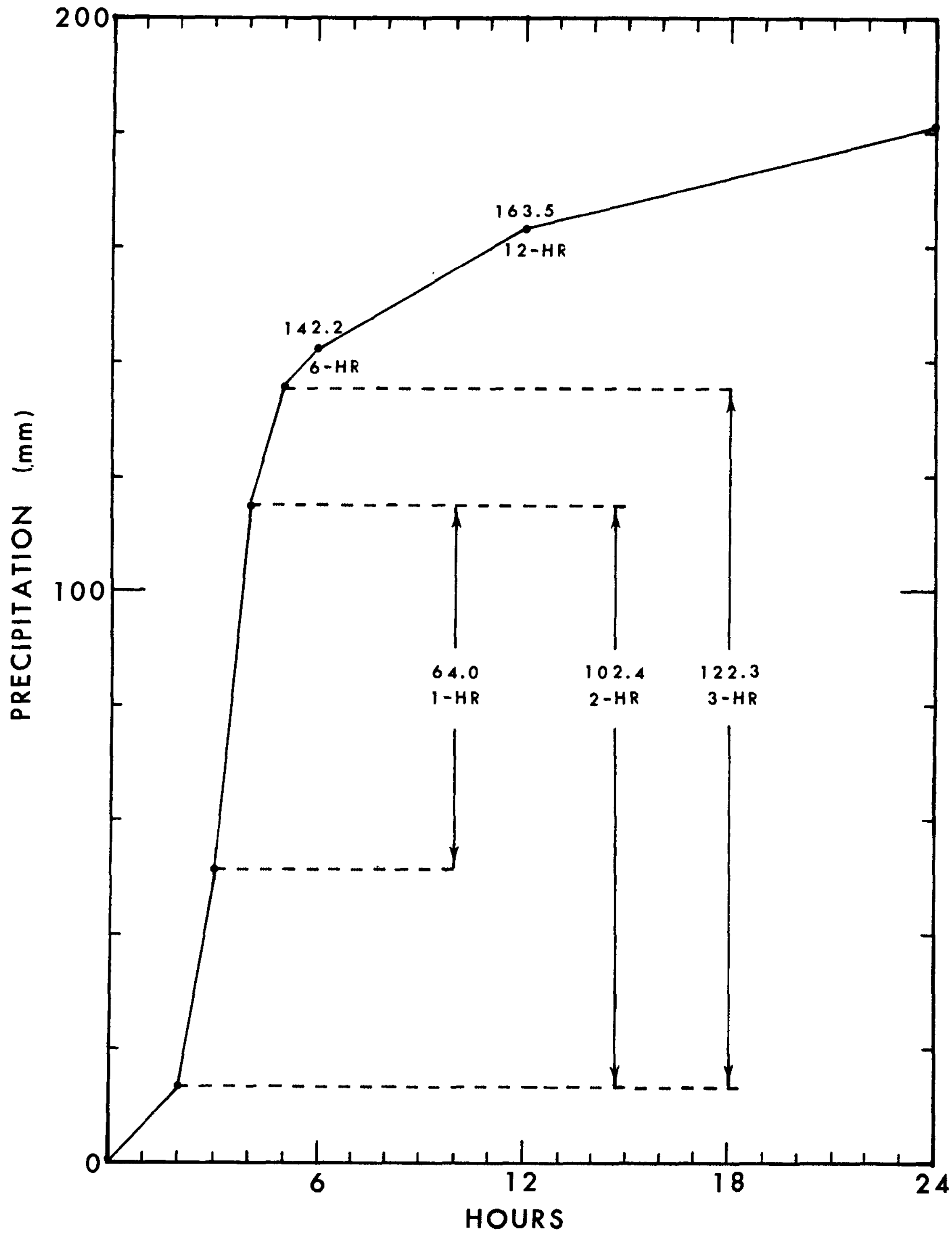

Figure 5.--24-hr precipitation mass curve using 50-yr 6-hr storm at 85°00'W and 32°30'N and N-hr rainfall probability 0.70.

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APPENDIX I. TABLES OF JOINT FREQUENCY DISTRIBUTION OF N-HR STORMS WITH M-HR RAINFALLS

TABLE I- 1 JOINT FREQUENCY DISTRIBUTION
OF 1-HR STORMS WITH 2-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3595	572	72	3	0	4242
IV	325	350	193	81	2	951
III	63	120	84	83	17	367
II	18	55	64	93	47	277
I	0	5	16	24	50	95
SUM	4001	1102	429	284	116	5932

TABLE I- 2 JOINT FREQUENCY DISTRIBUTION
OF 1-HR STORMS WITH 3-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3550	681	147	33	0	4411
IV	338	257	152	98	15	860
III	73	82	56	69	26	306
II	35	68	57	60	32	252
I	5	14	17	24	43	103
SUM	4001	1102	429	284	116	5932

TABLE I- 3 JOINT FREQUENCY DISTRIBUTION
OF 1-HR STORMS WITH 6-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3566	795	238	100	12	4711
IV	287	174	101	80	37	679
III	92	56	33	50	14	245
II	45	54	37	32	25	193
I	11	23	20	22	28	104
SUM	4001	1102	429	284	116	5932

TABLE I- 4 JOINT FREQUENCY DISTRIBUTION
OF 1-HR STORMS WITH 12-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3583	864	293	149	38	4927
IV	252	134	73	71	27	557
III	98	46	25	30	19	218
II	53	36	26	20	19	154
I	15	22	12	14	13	76
SUM	4001	1102	429	284	116	5932

TABLE I- 5 JOINT FREQUENCY DISTRIBUTION OF 1-HR STORMS WITH 24-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3609	901	309	181	57	5057
IV	233	107	59	61	28	488
III	90	44	30	15	9	188
II	50	36	21	20	13	140
I	19	14	10	7	9	59
SUM	4001	1102	429	284	116	5932

TABLE I- 6 JOINT FREQUENCY DISTRIBUTION OF 2-HR STORMS WITH 1-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3531	550	106	32	0	4219
IV	383	353	141	73	7	957
III	52	161	83	68	18	382
II	3	67	77	91	25	263
I	0	2	15	44	50	111
SUM	3969	1133	422	308	100	5932

TABLE I- 7 JOINT FREQUENCY DISTRIBUTION OF 2-HR STORMS WITH 3-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3747	335	1	0	0	4083
IV	203	666	190	11	0	1070
III	19	100	153	102	0	374
II	0	30	75	165	25	295
I	0	2	3	30	75	110
SUM	3969	1133	422	308	100	5932

TABLE I- 8 JOINT FREQUENCY DISTRIBUTION OF 2-HR STORMS WITH 6-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3602	689	103	13	0	4407
IV	273	294	176	100	9	852
III	68	76	65	86	11	306
II	23	66	58	64	36	247
I	3	8	20	45	44	120
SUM	3969	1133	422	308	100	5932

TABLE I- 9 JOINT FREQUENCY DISTRIBUTION
OF 2-HR STORMS WITH 12-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3552	806	213	72	8	4651
IV	278	207	112	117	18	732
III	84	64	44	44	28	264
II	44	41	31	49	25	190
I	11	15	22	26	21	95
SUM	3969	1133	422	308	100	5932

TABLE I-10 JOINT FREQUENCY DISTRIBUTION
OF 2-HR STORMS WITH 24-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3565	854	252	133	18	4822
IV	248	168	89	82	39	626
III	92	58	43	35	15	243
II	50	44	21	43	14	172
I	14	9	17	15	14	69
SUM	3969	1133	422	308	100	5932

TABLE I-11 JOINT FREQUENCY DISTRIBUTION
OF 3-HR STORMS WITH 1-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3479	668	153	64	11	4375
IV	389	259	101	87	16	852
III	87	121	56	65	20	349
II	23	76	63	60	24	246
I	0	14	22	31	43	110
SUM	3978	1138	395	307	114	5932

TABLE I-12 JOINT FREQUENCY DISTRIBUTION
OF 3-HR STORMS WITH 2-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3704	320	41	3	0	4068
IV	273	641	109	39	2	1064
III	1	167	148	81	6	403
II	0	10	97	159	31	297
I	0	0	0	25	75	100
SUM	3978	1138	395	307	114	5932

TABLE I-13 JOINT FREQUENCY DISTRIBUTION
OF 3-HR STORMS WITH 6-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3670	517	20	0	0	4207
IV	251	486	205	43	2	987
III	44	96	101	94	6	341
II	12	36	59	124	37	268
I	1	3	10	46	69	129
SUM	3978	1138	395	307	114	5932

TABLE I-14 JOINT FREQUENCY DISTRIBUTION
OF 3-HR STORMS WITH 12-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3580	706	132	23	3	4444
IV	267	281	157	114	11	830
III	79	83	55	71	28	316
II	39	56	32	70	37	234
I	13	12	19	29	35	108
SUM	3978	1138	395	307	114	5932

TABLE I-15 JOINT FREQUENCY DISTRIBUTION
OF 3-HR STORMS WITH 24-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3550	783	206	75	6	4620
IV	273	213	100	112	41	739
III	75	74	43	58	15	265
II	63	50	36	36	33	218
I	17	18	10	26	19	90
SUM	3978	1138	395	307	114	5932

TABLE I-16 JOINT FREQUENCY DISTRIBUTION
OF 6-HR STORMS WITH 1-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3506	759	232	131	29	4657
IV	329	174	68	66	30	667
III	107	83	31	44	23	288
II	55	62	47	31	23	218
I	8	30	12	24	28	102
SUM	4005	1108	390	296	133	5932

TABLE I-17 JOINT FREQUENCY DISTRIBUTION OF 6-HR STORMS WITH 2-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3481	577	144	57	6	4265
IV	452	285	94	82	13	926
III	64	152	63	59	23	361
II	8	85	79	64	47	283
I	0	9	10	34	44	97
SUM	4005	1108	390	296	133	5932

TABLE I-18 JOINT FREQUENCY DISTRIBUTION OF 6-HR STORMS WITH 3-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3591	424	77	25	1	4118
IV	400	467	121	54	5	1047
III	14	178	101	61	12	366
II	0	38	85	121	46	290
I	0	1	6	35	69	111
SUM	4005	1108	390	296	133	5932

TABLE I-19 JOINT FREQUENCY DISTRIBUTION OF 6-HR STORMS WITH 12-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3694	449	11	1	0	4155
IV	265	492	200	46	0	1003
III	35	121	100	121	8	385
II	9	44	66	90	60	269
I	2	2	13	38	65	120
SUM	4005	1108	390	296	133	5932

TABLE I-20 JOINT FREQUENCY DISTRIBUTION OF 6-HR STORMS WITH 24-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3624	613	101	9	2	4349
IV	287	312	152	130	11	892
III	63	100	61	66	29	319
II	31	67	57	66	48	269
I	0	16	19	25	43	103
SUM	4005	1108	390	296	133	5932

TABLE I-21 JOINT FREQUENCY DISTRIBUTION OF 12-HR STORMS WITH 1-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3488	880	308	181	62	4919
IV	262	135	46	48	26	517
III	97	61	26	30	13	227
II	68	53	28	20	13	182
I	21	20	17	17	12	87
SUM	3936	1149	425	296	126	5932

TABLE I-22 JOINT FREQUENCY DISTRIBUTION OF 12-HR STORMS WITH 2-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3398	758	237	132	39	4564
IV	372	191	79	58	18	718
III	116	95	44	33	23	311
II	43	89	42	51	26	251
I	7	16	23	22	20	88
SUM	3936	1149	425	296	126	5932

TABLE I-23 JOINT FREQUENCY DISTRIBUTION OF 12-HR STORMS WITH 3-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3424	651	182	88	23	4368
IV	410	266	97	72	20	865
III	83	134	57	33	19	326
II	17	89	65	68	31	270
I	2	9	24	35	33	103
SUM	3936	1149	425	296	126	5932

TABLE I-24 JOINT FREQUENCY DISTRIBUTION OF 12-HR STORMS WITH 6-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3591	469	75	17	2	4154
IV	338	471	136	64	4	1013
III	7	173	98	69	16	363
II	0	36	109	92	41	278
I	0	0	7	54	63	124
SUM	3936	1149	425	296	126	5932

TABLE I-25 JOINT FREQUENCY DISTRIBUTION
OF 12-HR STORMS WITH 24-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3680	423	4	0	0	4107
IV	230	576	218	26	0	1050
III	23	116	144	91	4	378
II	3	32	57	140	57	289
I	0	2	2	39	65	108
SUM	3936	1149	425	296	126	5932

TABLE I-26 JOINT FREQUENCY DISTRIBUTION
OF 24-HR STORMS WITH 1-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3492	938	320	212	71	5033
IV	252	107	51	41	17	468
III	71	60	29	23	11	194
II	67	54	13	20	7	161
I	27	21	8	12	8	76
SUM	3909	1180	421	308	114	5932

TABLE I-27 JOINT FREQUENCY DISTRIBUTION
OF 24-HR STORMS WITH 2-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3413	828	265	172	51	4729
IV	322	167	73	58	18	638
III	101	80	39	23	17	260
II	60	73	32	42	15	222
I	13	32	12	13	13	83
SUM	3909	1180	421	308	114	5932

TABLE I-28 JOINT FREQUENCY DISTRIBUTION
OF 24-HR STORMS WITH 3-HR RAINFALLS

ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3403	741	229	138	35	4546
IV	353	217	85	65	24	744
III	105	94	43	38	10	290
II	43	95	50	37	28	253
I	5	33	14	30	17	99
SUM	3909	1180	421	308	114	5932

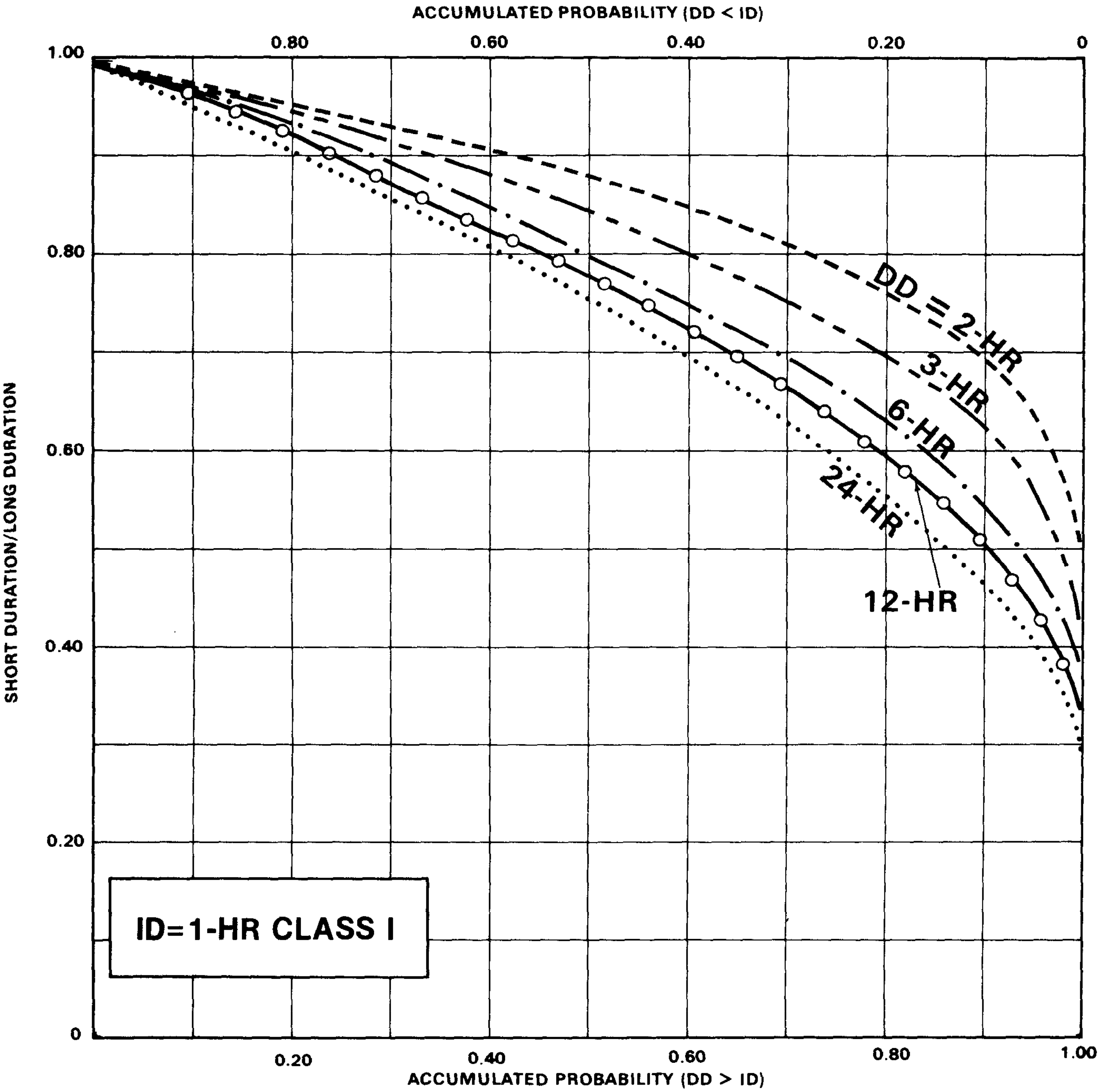
TABLE I-29 JOINT FREQUENCY DISTRIBUTION OF 24-HR STORMS WITH 6-HR RAINFALLS

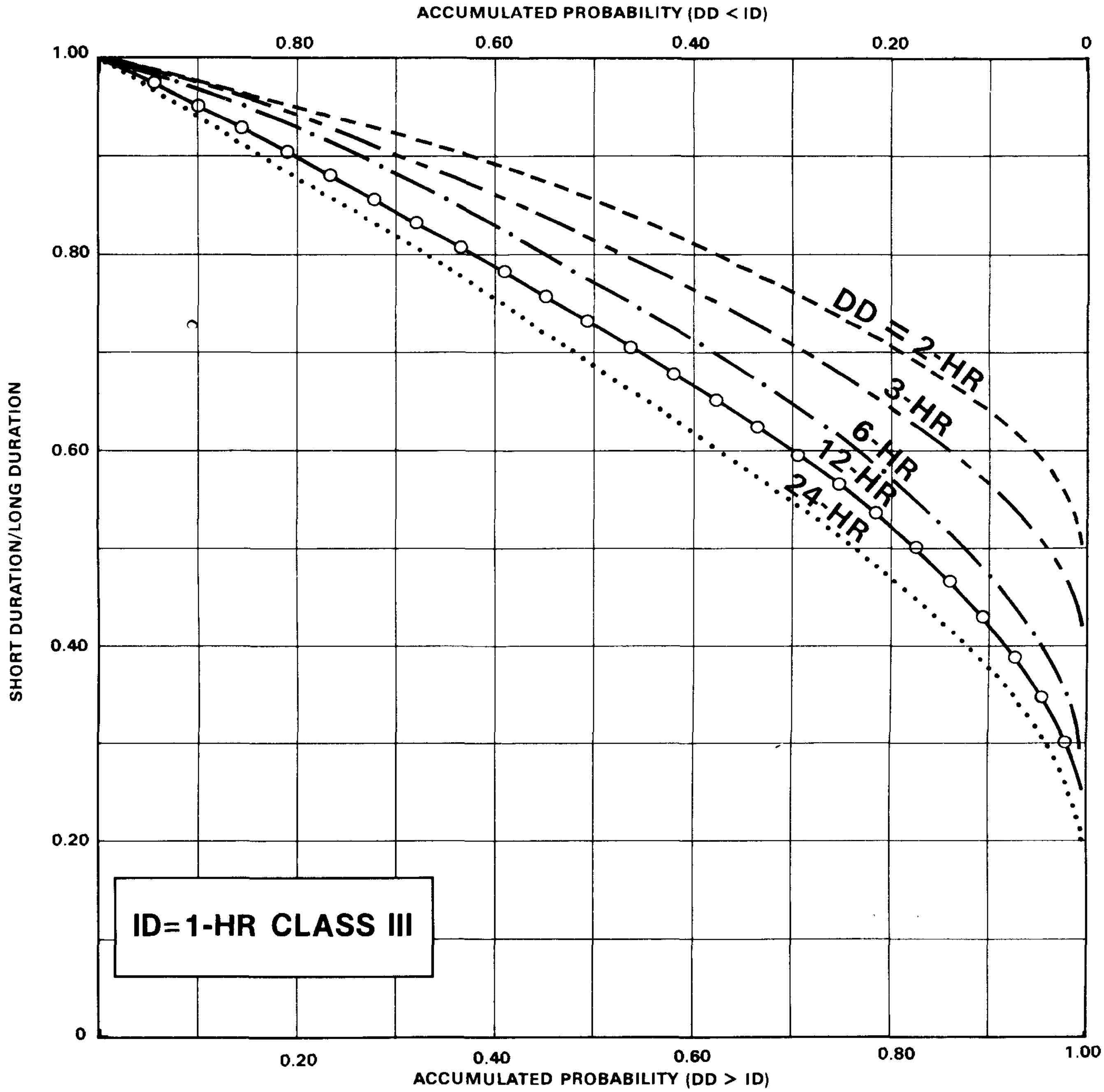
ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3472	636	154	56	2	4320
IV	368	295	119	81	23	886
III	61	134	60	59	22	336
II	6	106	61	66	25	264
I	2	9	27	46	42	126
SUM	3909	1180	421	308	114	5932

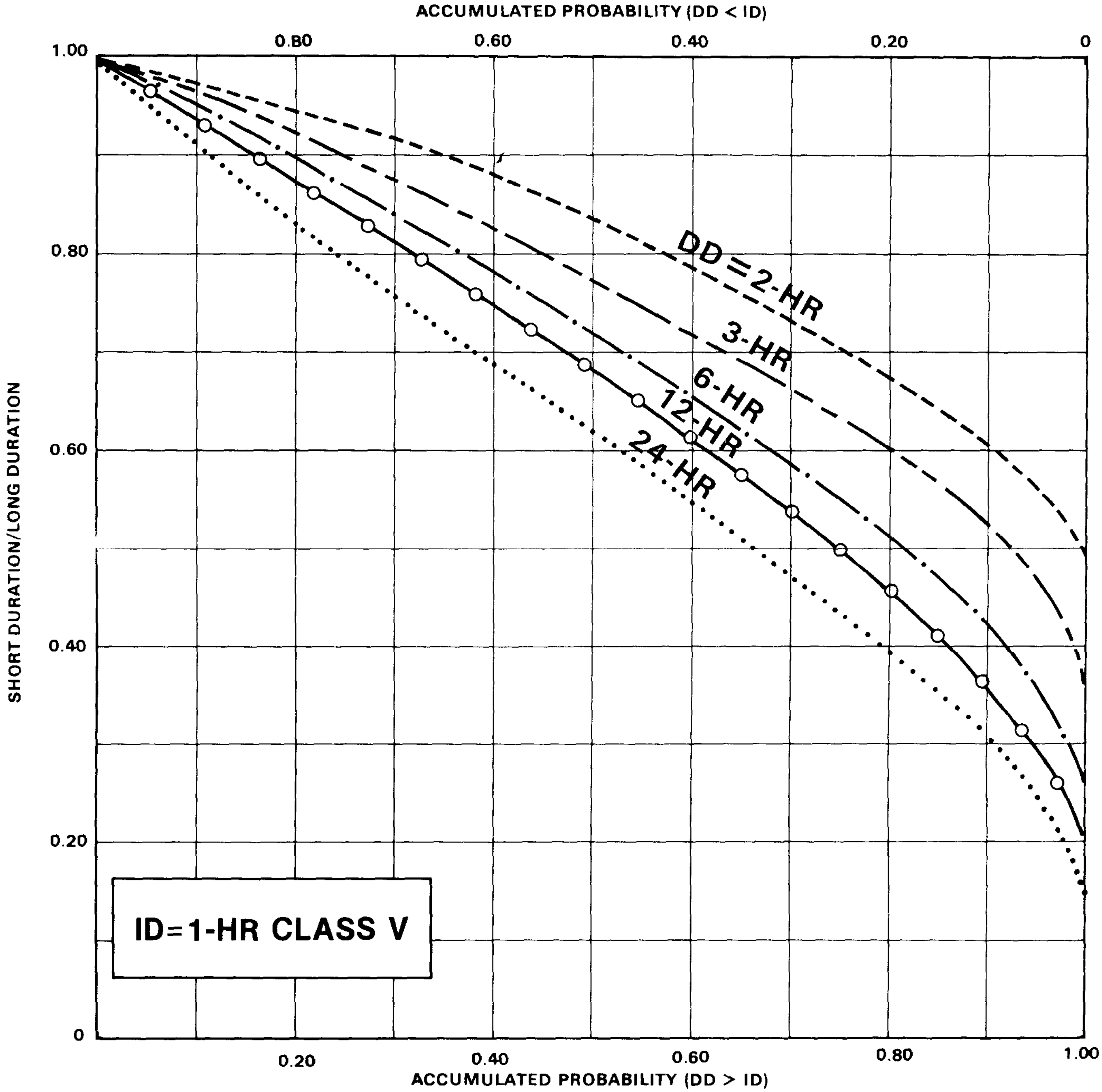
TABLE I-30 JOINT FREQUENCY DISTRIBUTION OF 24-HR STORMS WITH 12-HR RAINFALLS

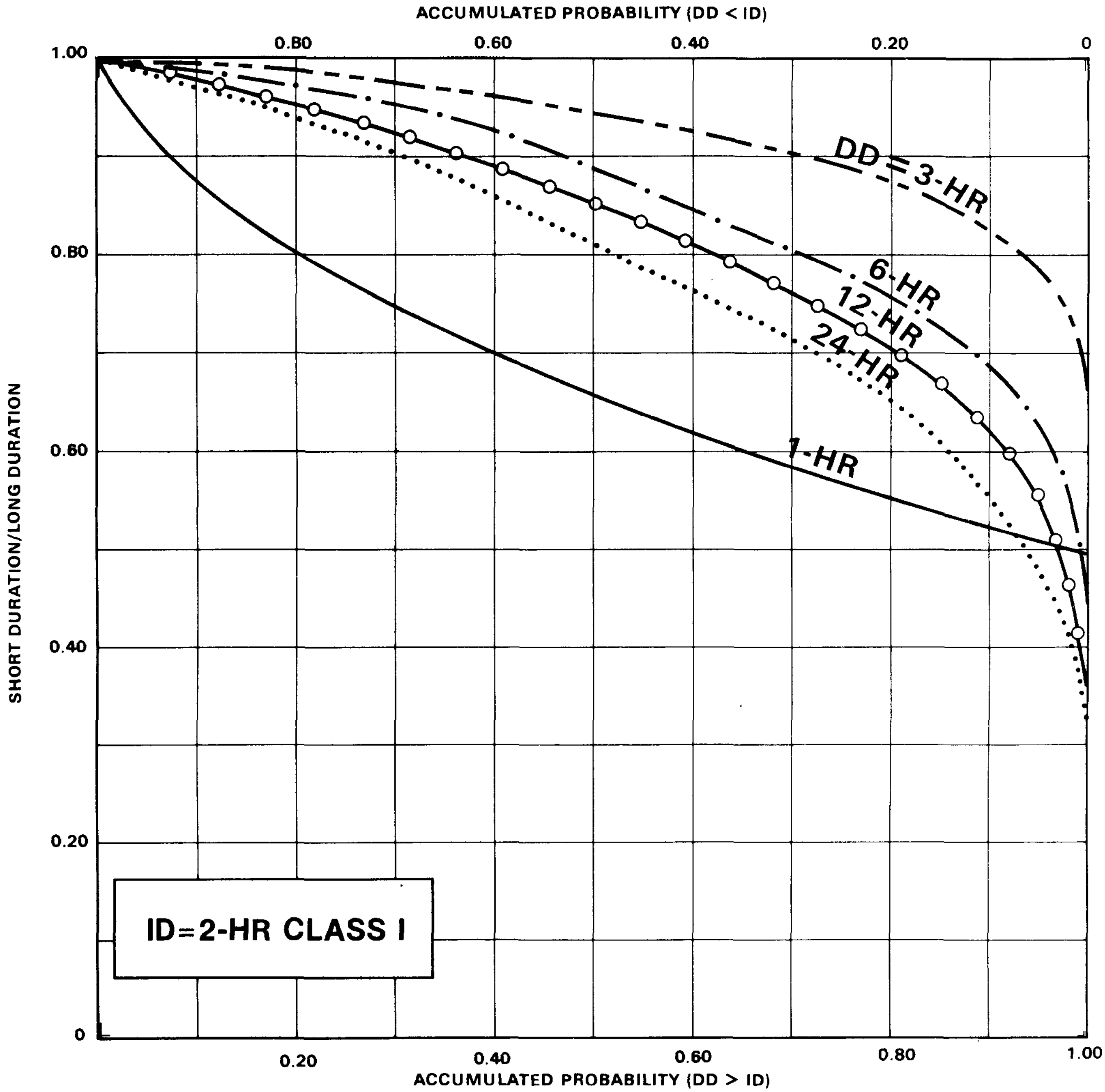
ID CLASS	V	IV	III	II	I	SUM
DD CLASS						
V	3588	414	53	10	0	4065
IV	317	553	137	43	4	1054
III	4	190	139	63	6	402
II	0	23	88	136	42	289
I	0	0	4	56	62	122
SUM	3909	1180	421	308	114	5932

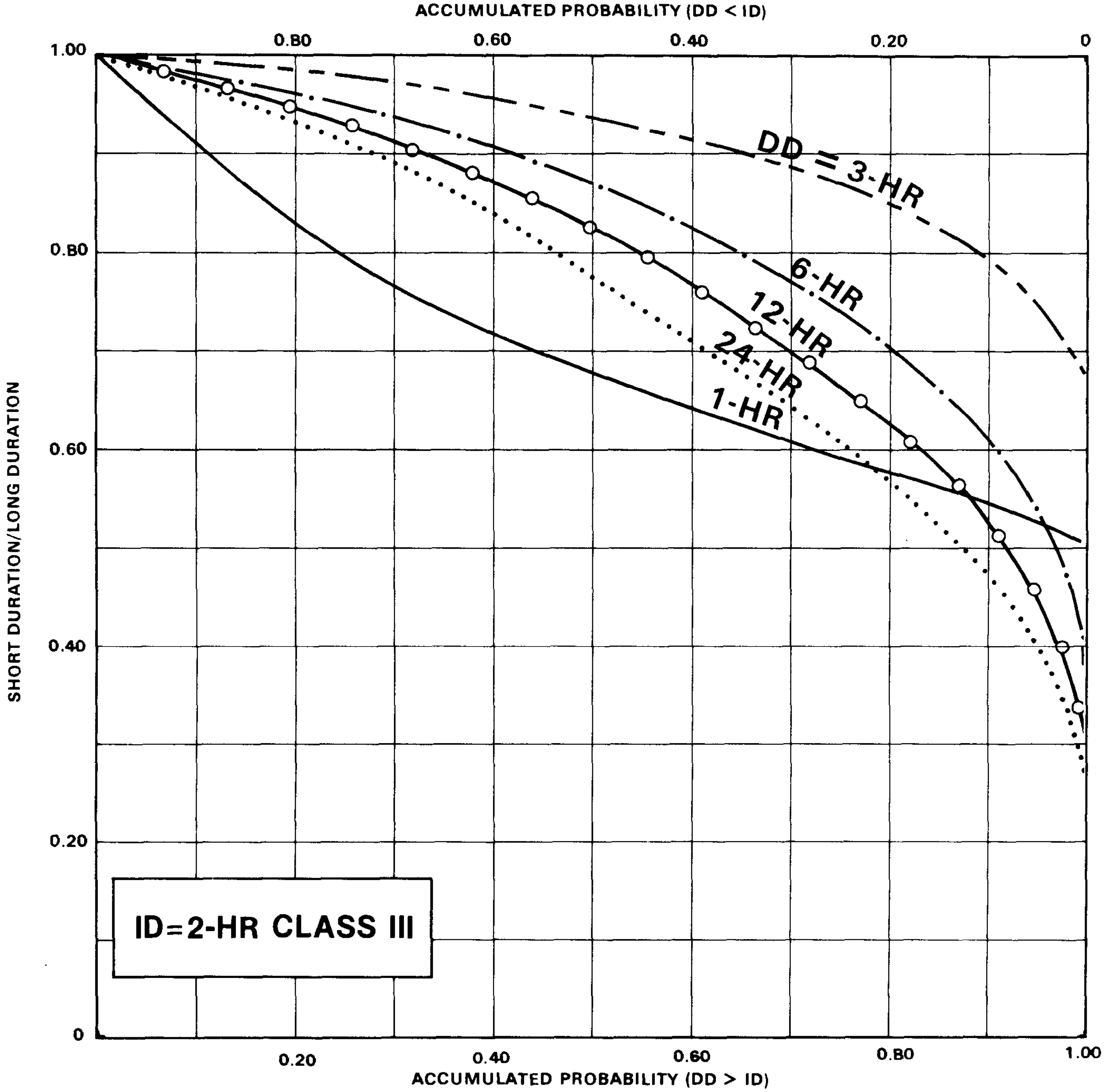
APPENDIX II. GRAPHS OF ACCUMULATED PROBABILITY FOR CLASS I, III, AND V N-HR STORMS

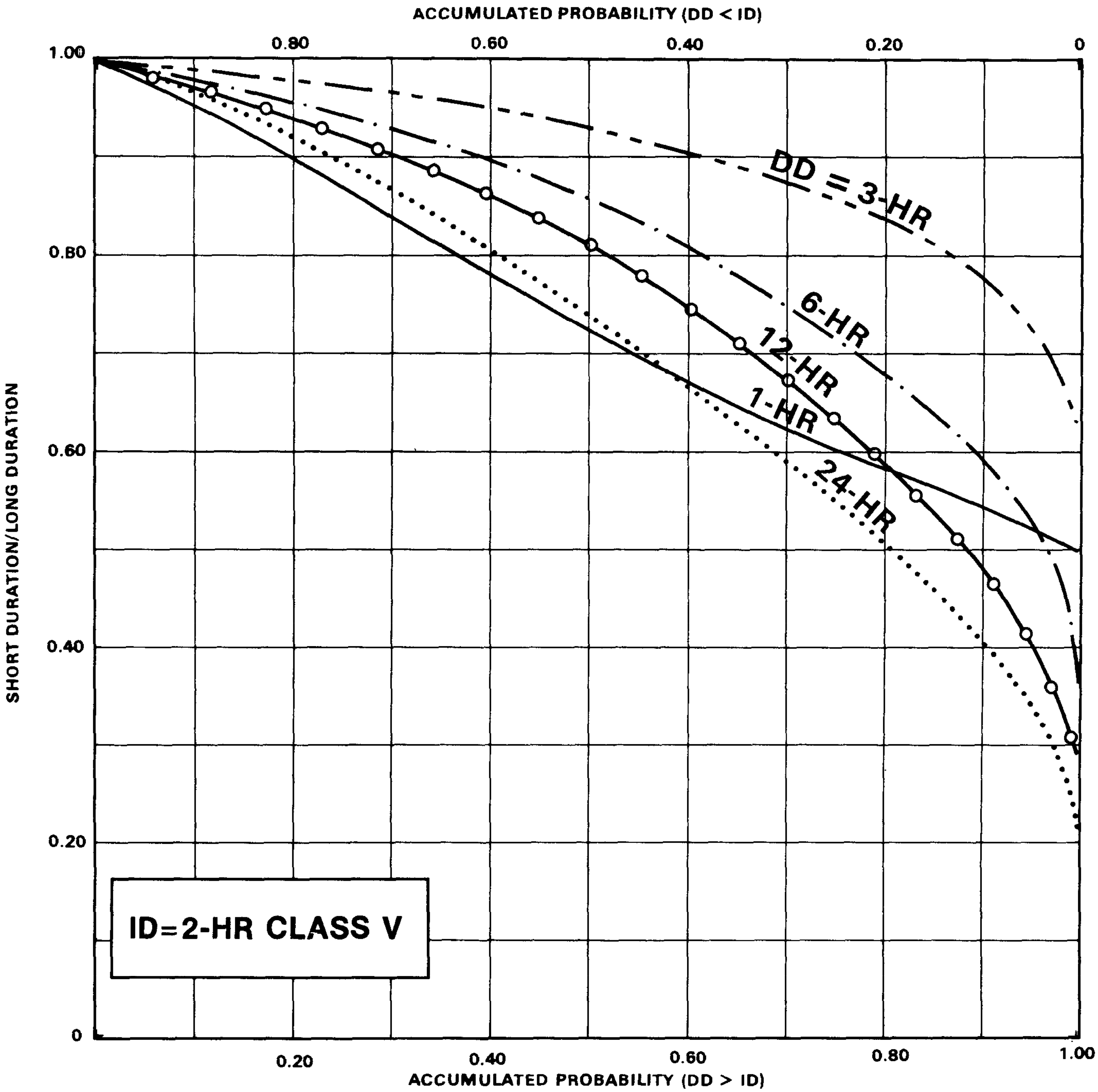

ACCUMULATED PROBABILITY (DD < ID)
0.80
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 2-HR
3-HR
6-HR
24-HR
12-HR
ID=1-HR CLASS I
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)

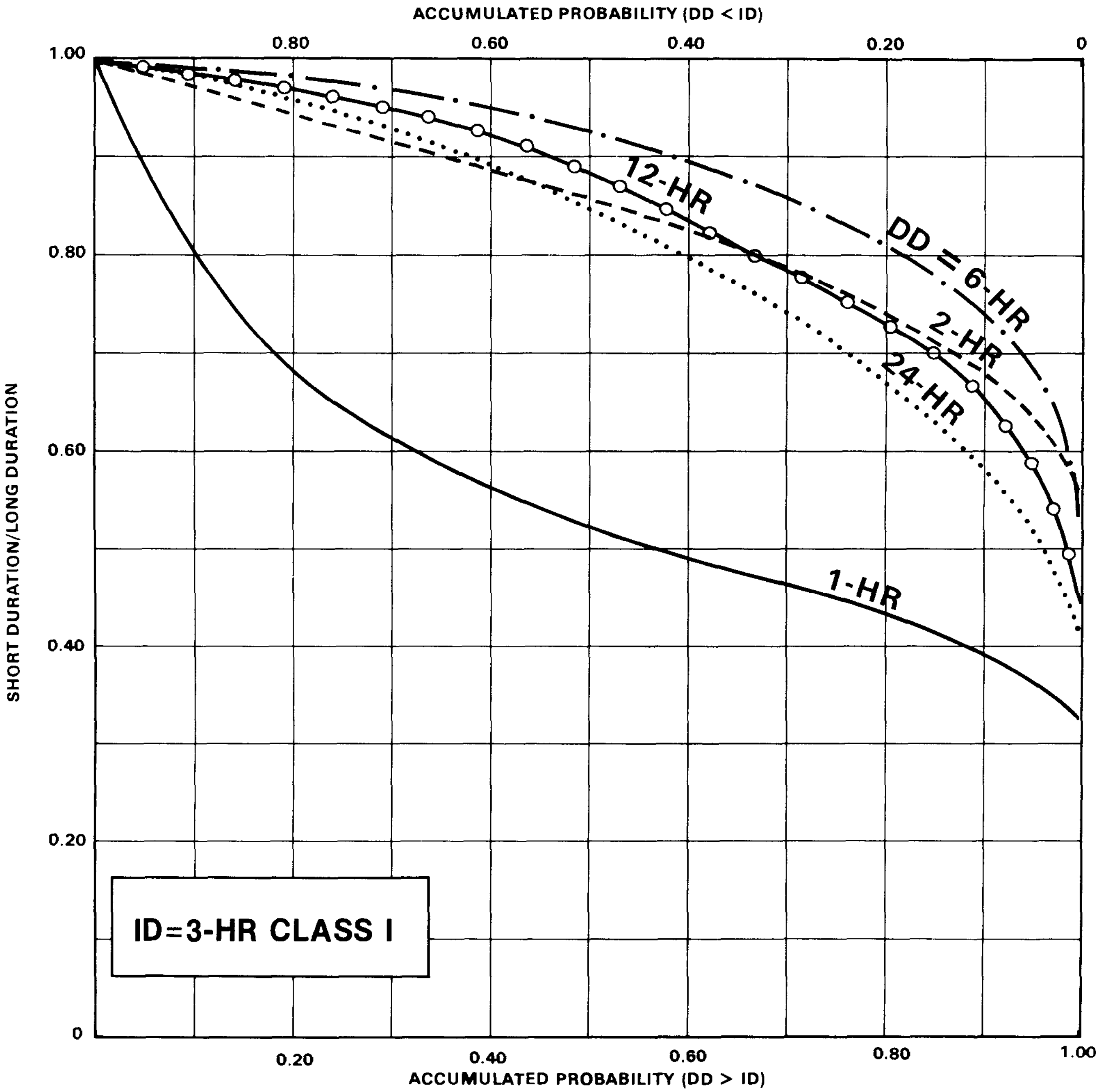

ACCUMULATED PROBABILITY (DD < ID)
0.80
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 2-HR
3-HR
6-HR
12-HR
24-HR
ID=1-HR CLASS III
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)

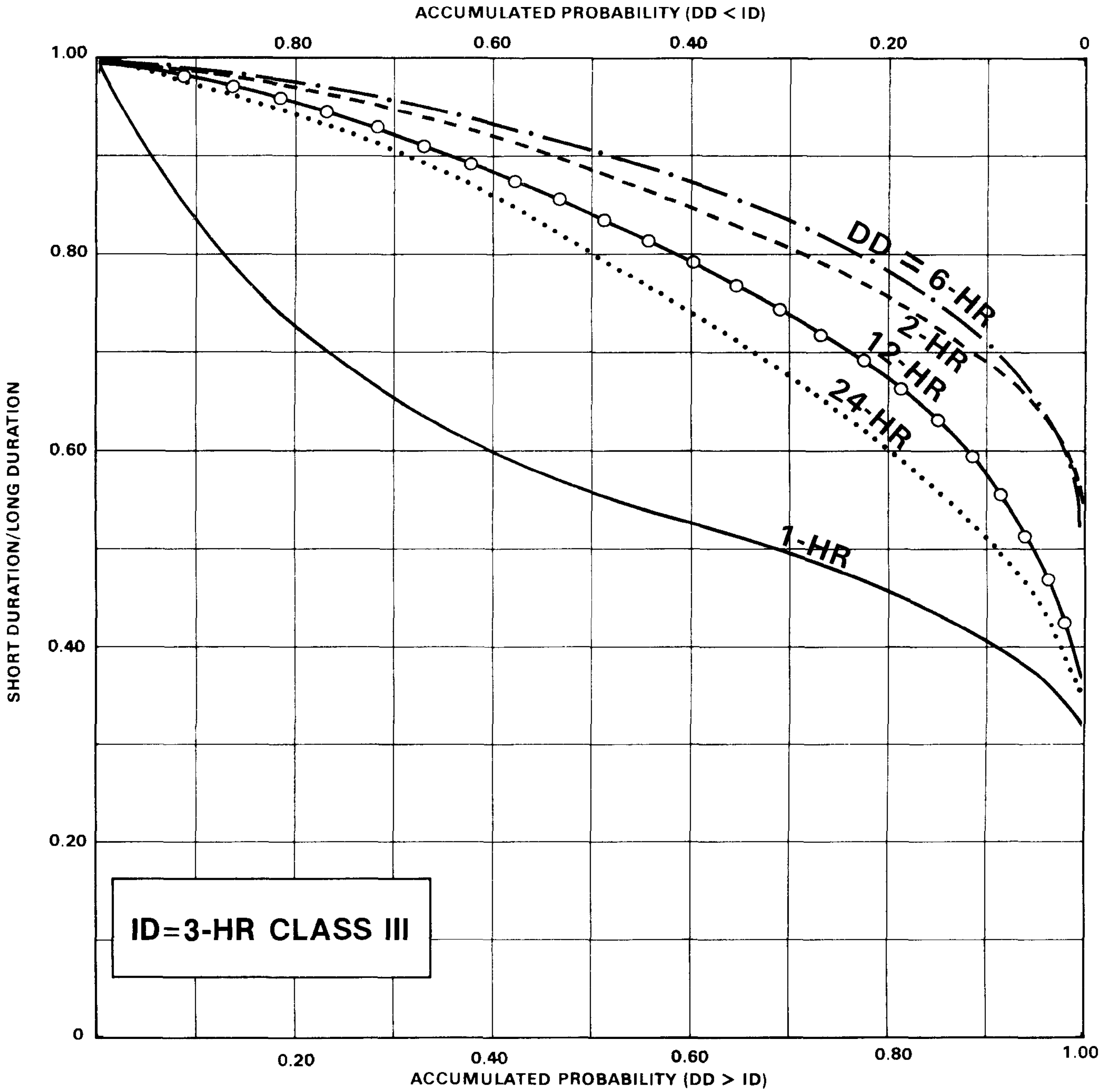

ACCUMULATED PROBABILITY (DD < ID)
0.80
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD=2-HR
3-HR
6-HR
12-HR
24-HR
ID=1-HR CLASS V
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)

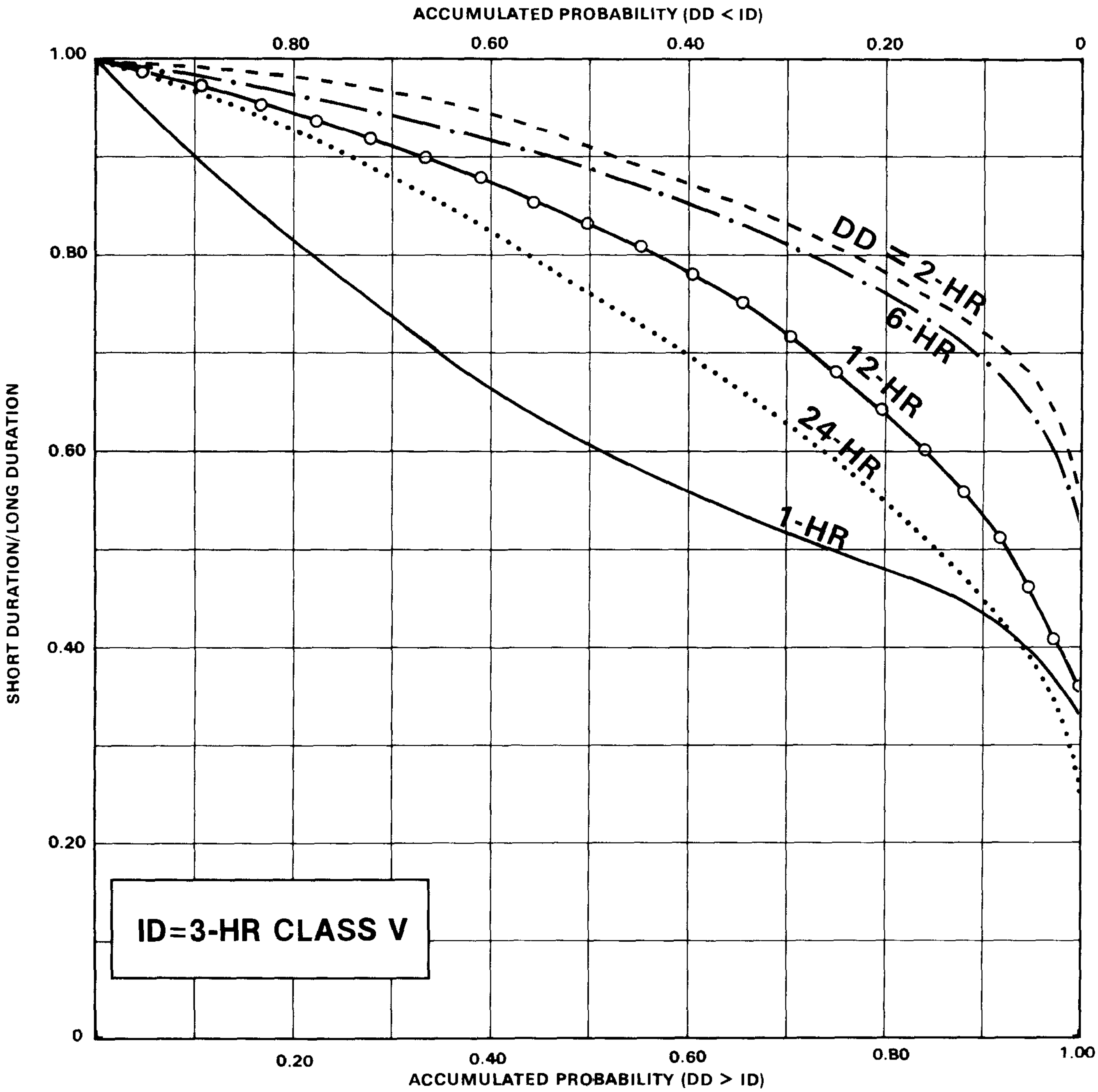

ACCUMULATED PROBABILITY (DD < ID)
0.80
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 3-HR
6-HR
12-HR
24-HR
1-HR
ID=2-HR CLASS I
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)

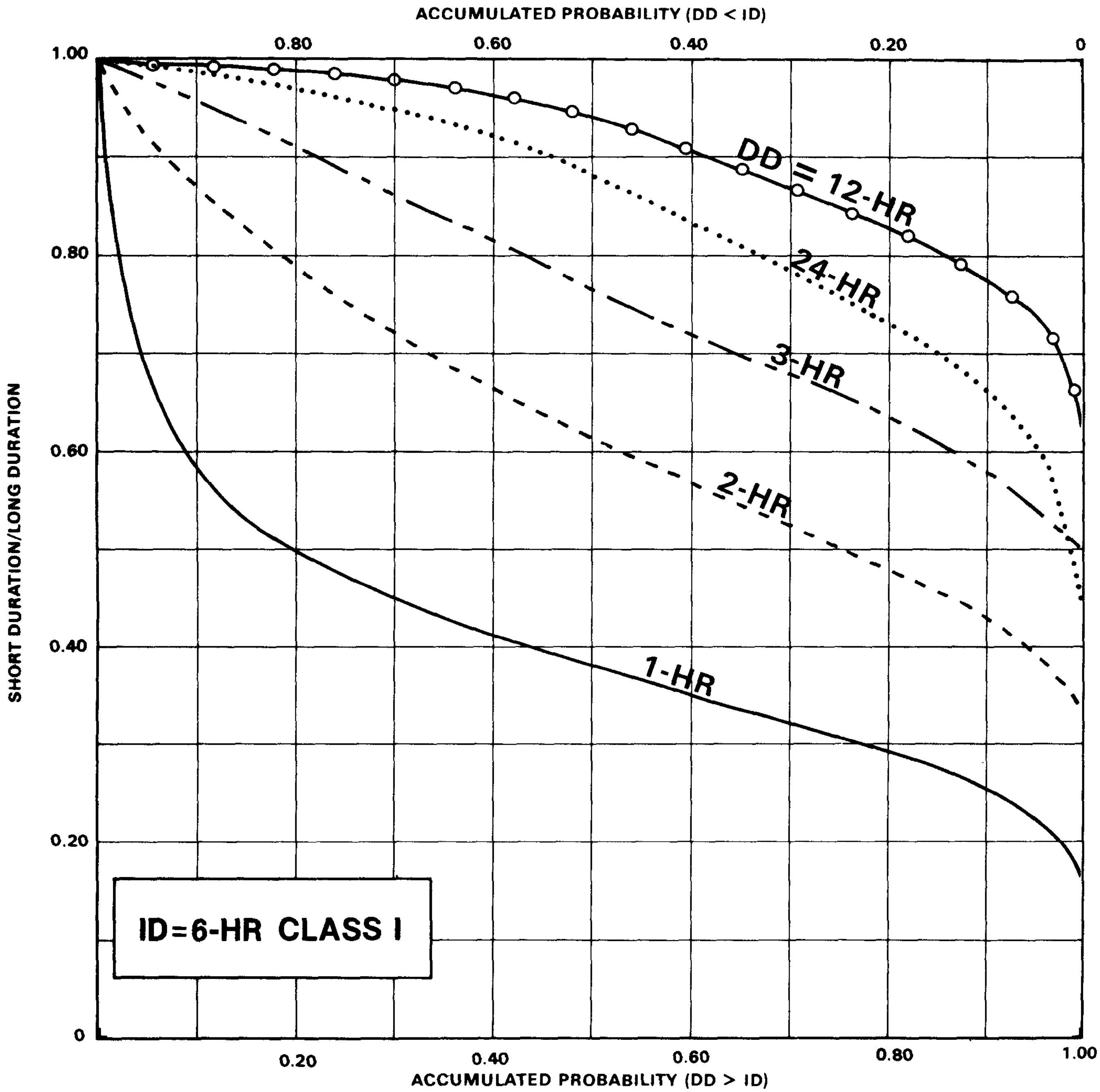

ACCUMULATED PROBABILITY (DD < ID)
0.80
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 3-HR
6-HR
12-HR
24-HR
1-HR
ID=2-HR CLASS III
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)

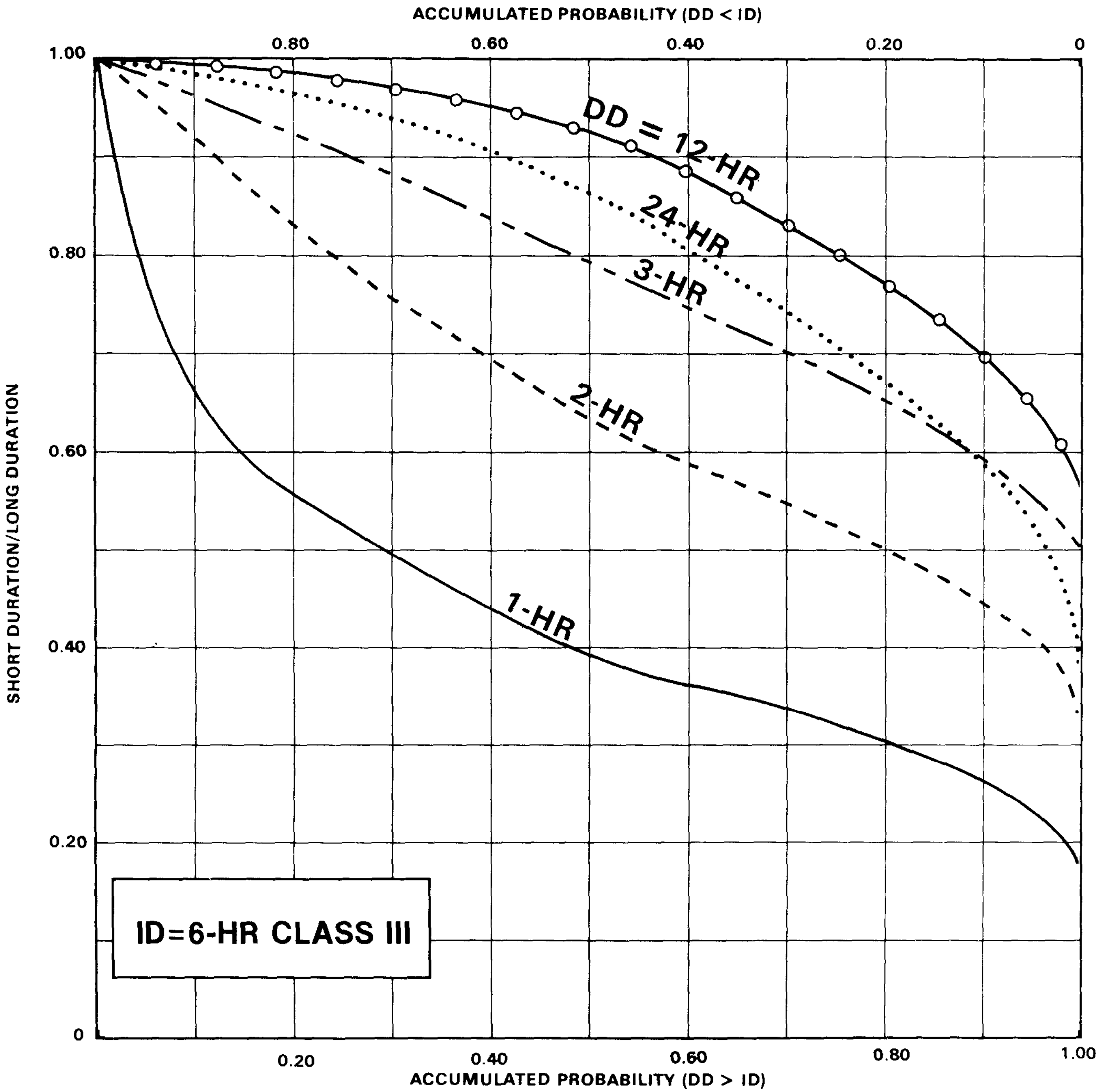

ACCUMULATED PROBABILITY (DD < ID)
0.80
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 3-HR
6-HR
12-HR
1-HR
24-HR
ID=2-HR CLASS V
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)

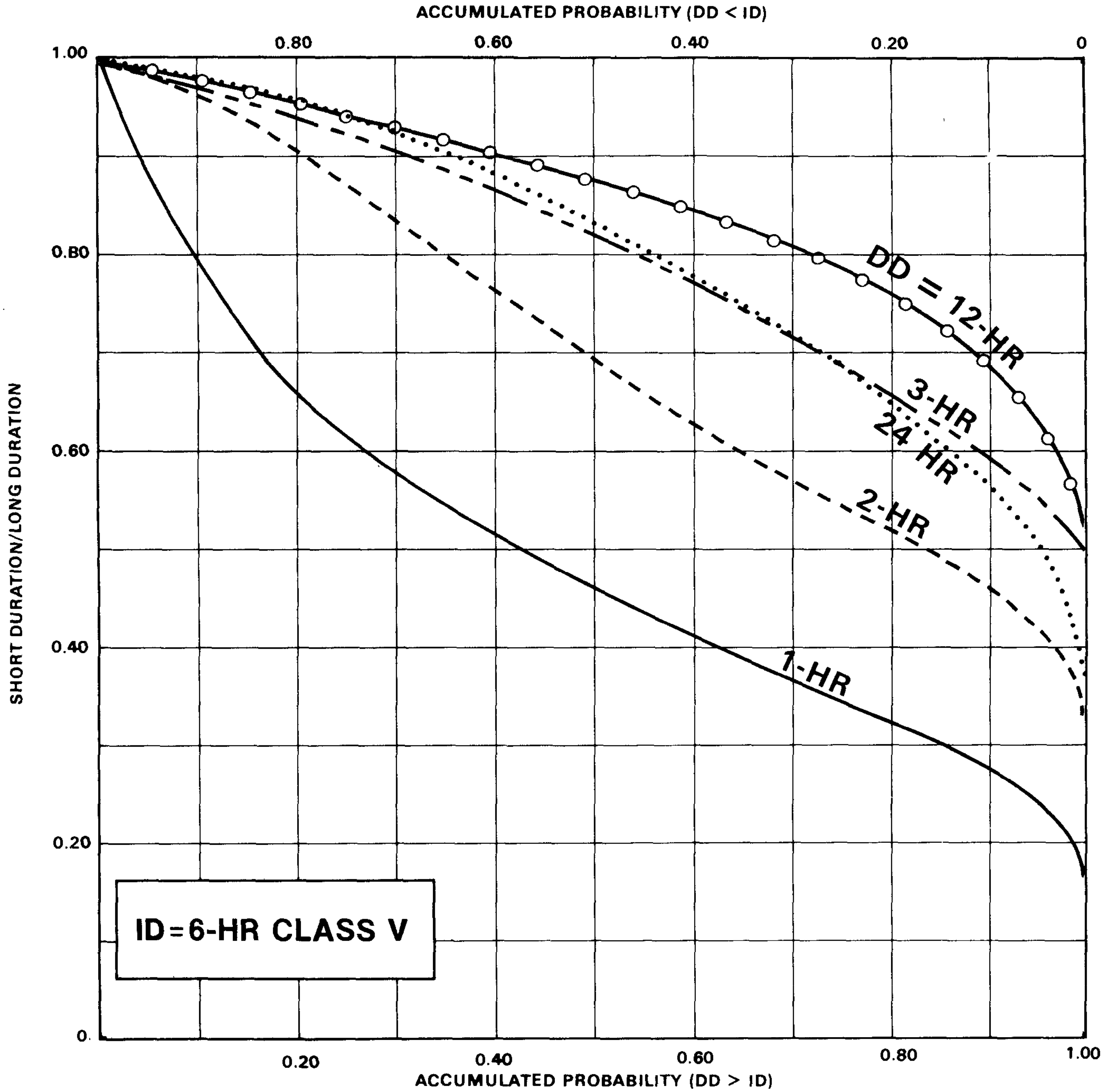

ACCUMULATED PROBABILITY (DD < ID)
0.80
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
12-HR
DD = 6-HR
2-HR
24-HR
1-HR
ID=3-HR CLASS I
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)

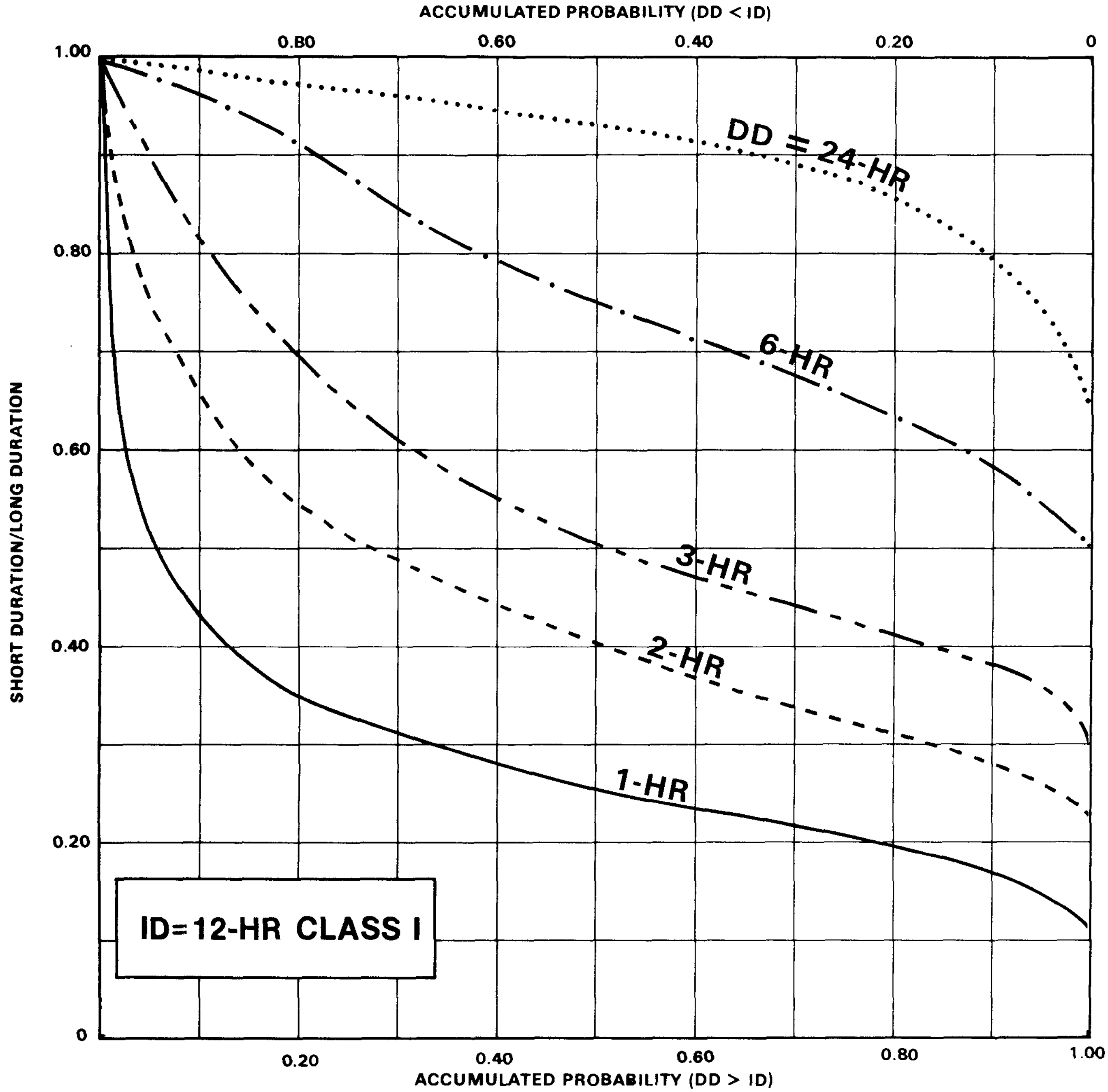

ACCUMULATED PROBABILITY (DD < ID)
0.80
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 6-HR
2-HR
12-HR
24-HR
1-HR
ID=3-HR CLASS III
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)

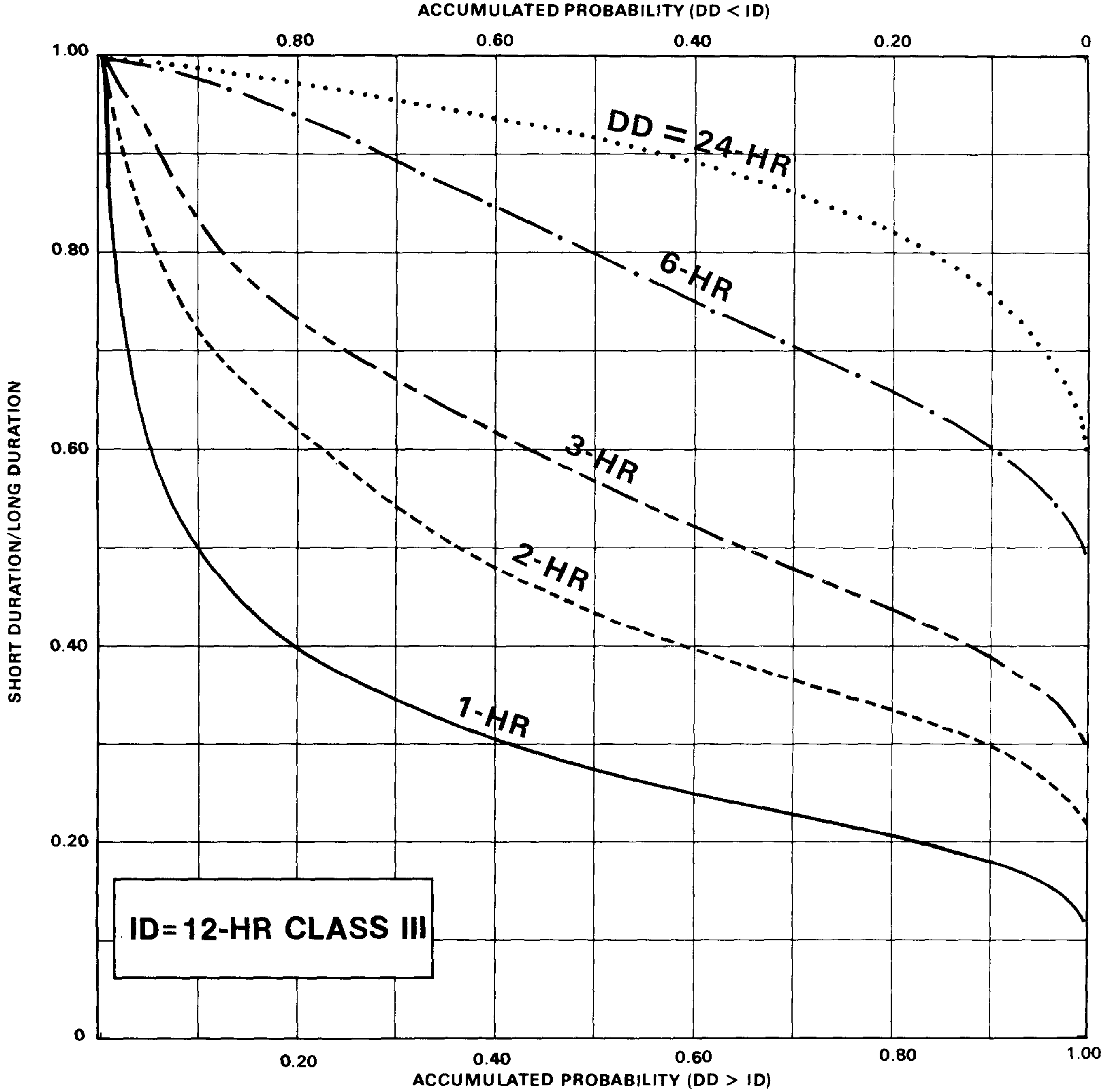

ACCUMULATED PROBABILITY (DD < ID)
0.80
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 2-HR
6-HR
12-HR
24-HR
1-HR
ID=3-HR CLASS V
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)

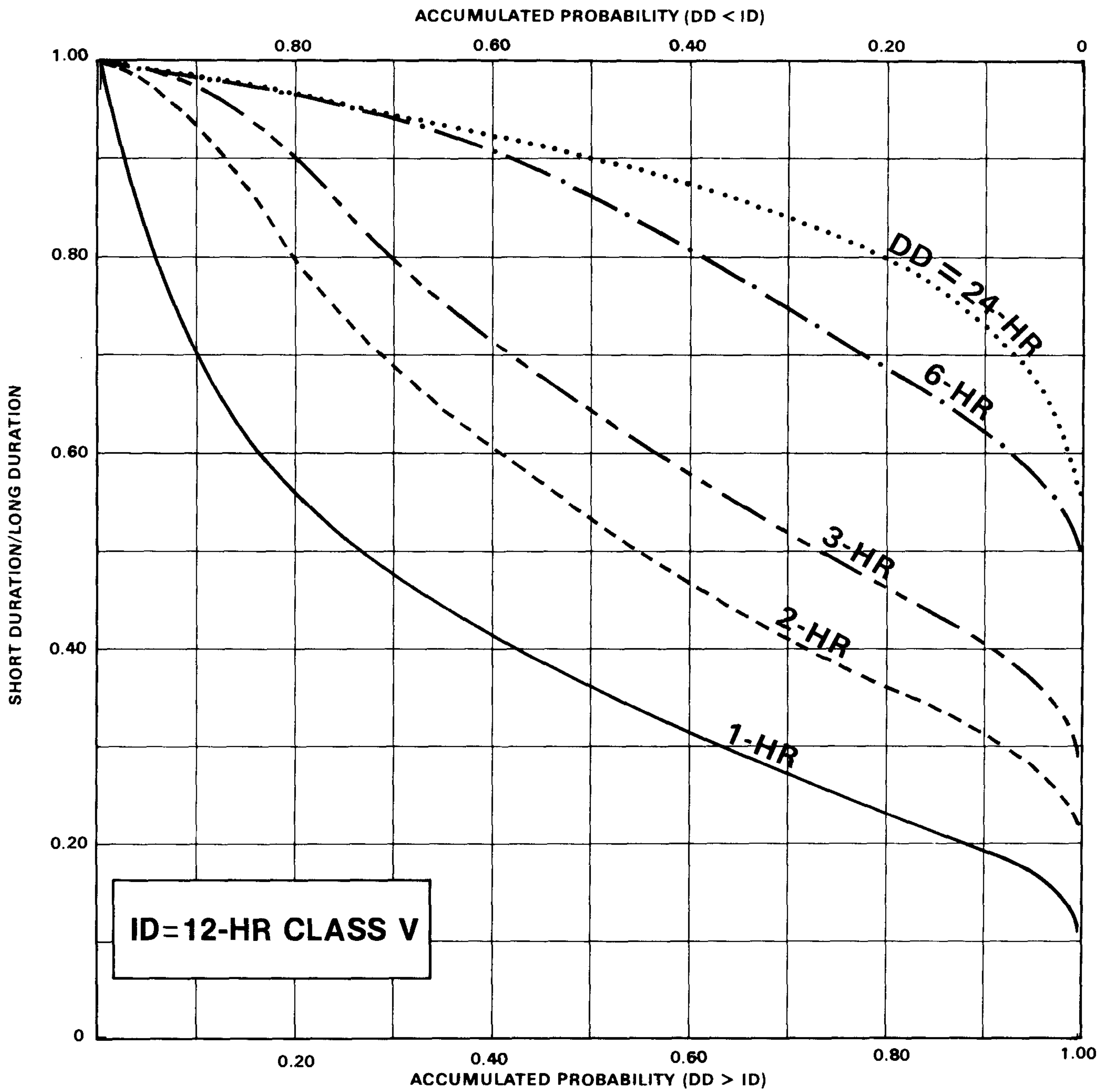

ACCUMULATED PROBABILITY (DD < ID)
0.80
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 12-HR
24-HR
3-HR
2-HR
1-HR
ID=6-HR CLASS I
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)

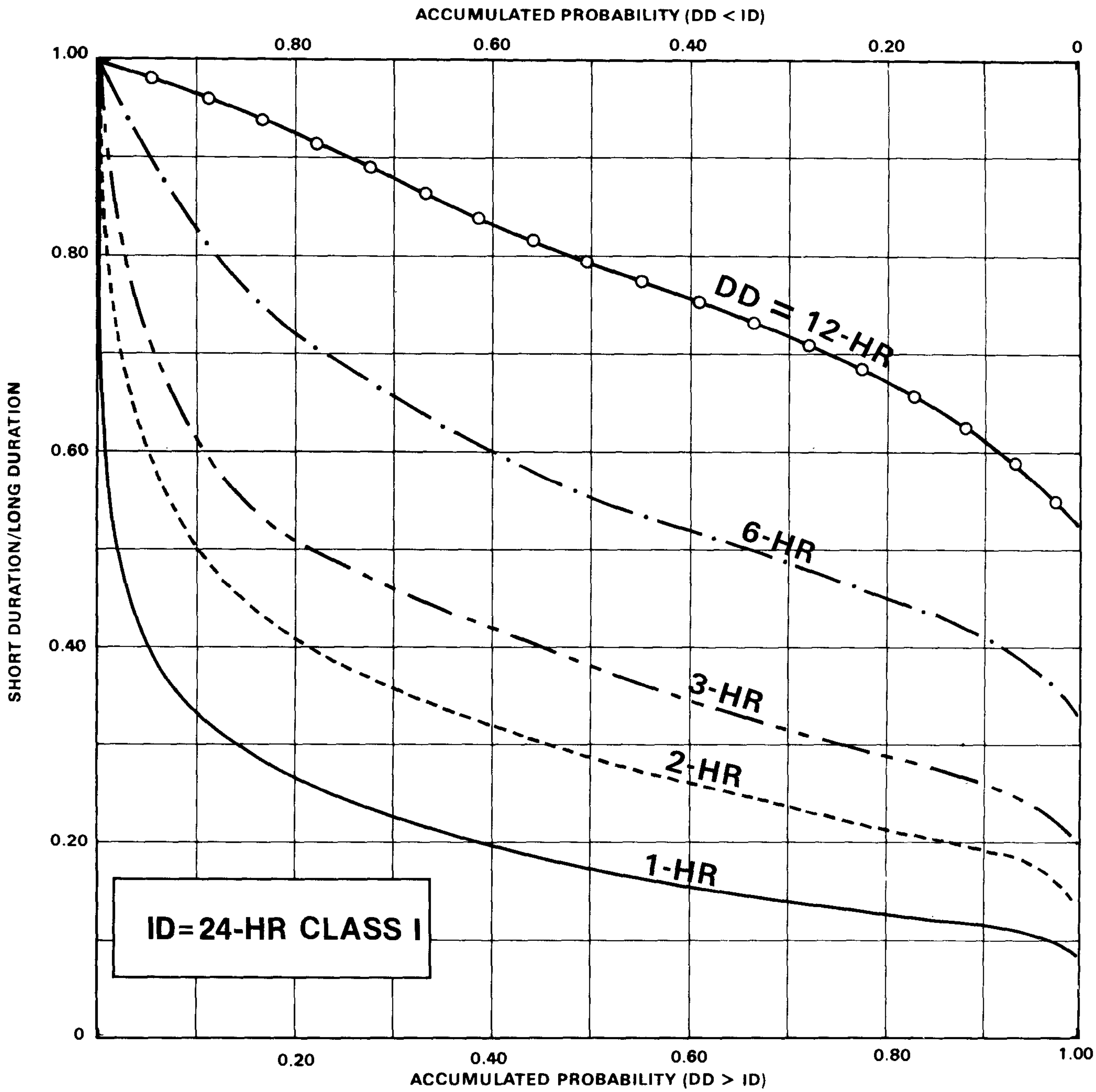

ACCUMULATED PROBABILITY (DD < ID)
0.80
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 12-HR
24-HR
3-HR
2-HR
1-HR
ID=6-HR CLASS III
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)

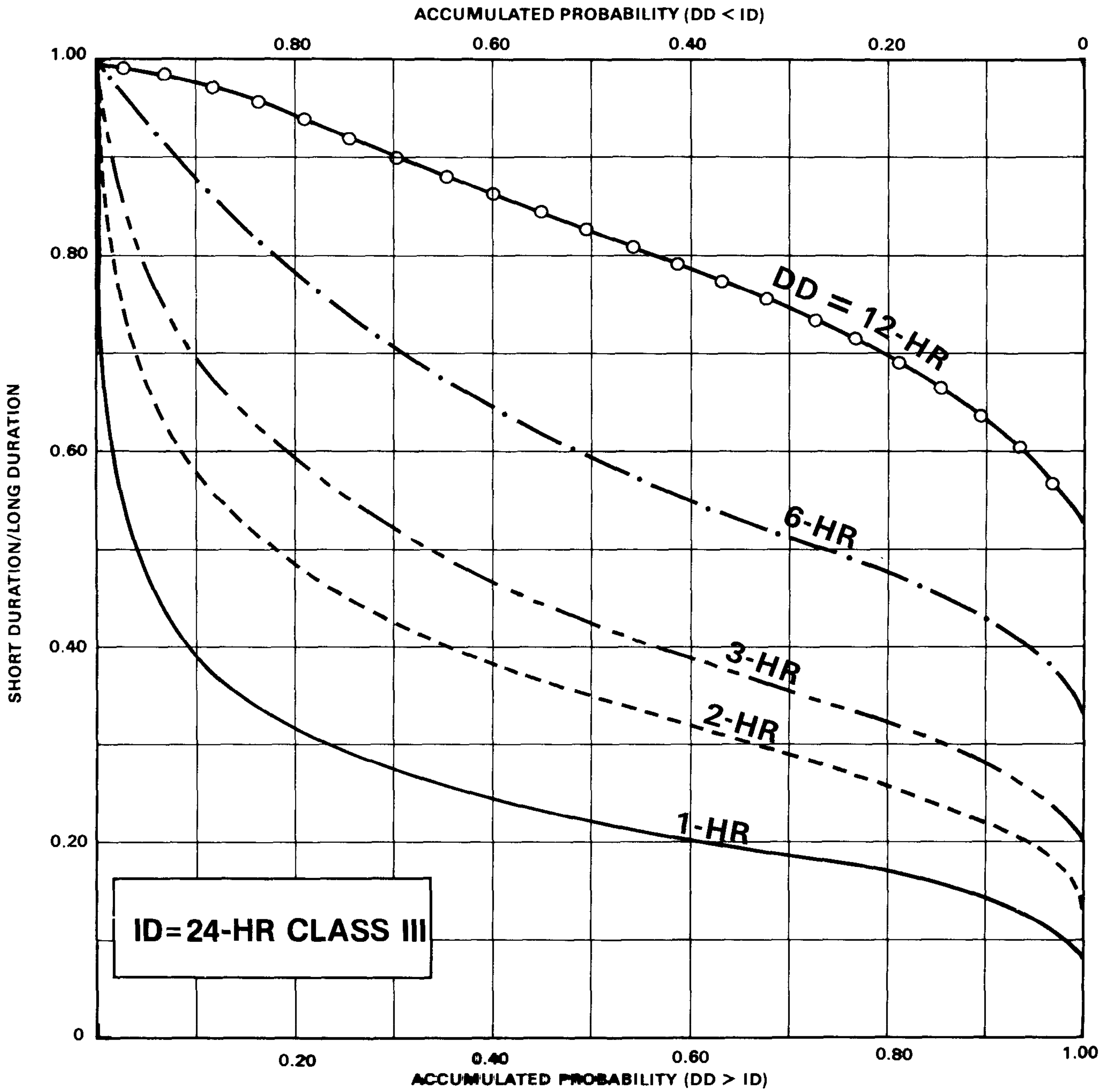

ACCUMULATED PROBABILITY (DD < ID)
0.80
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0.
SHORT DURATION/LONG DURATION
DD = 12-HR
3-HR
24 HR
2-HR
1-HR
ID=6-HR CLASS V
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)

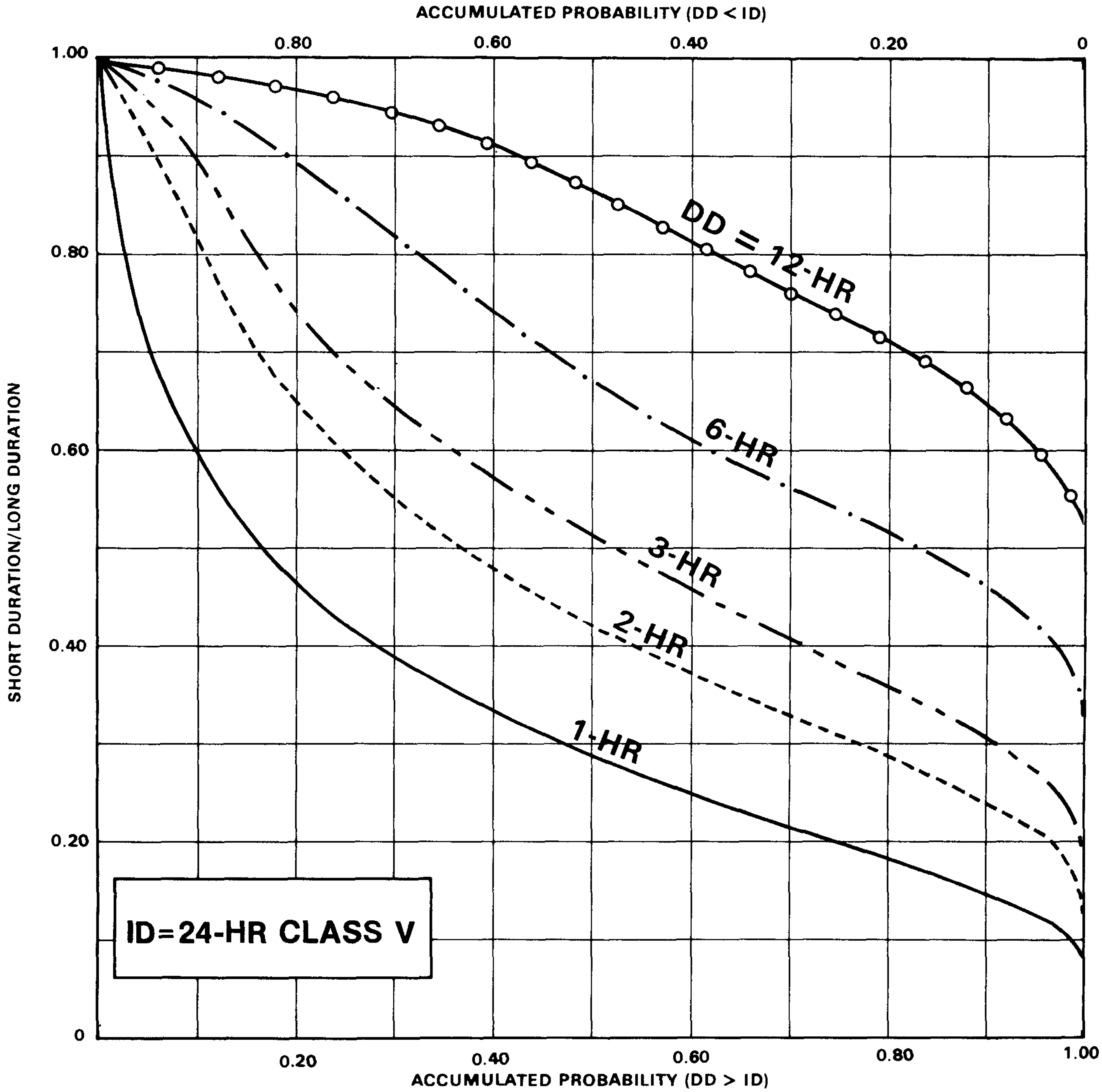

ACCUMULATED PROBABILITY (DD < ID)
0.80
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 24-HR
6-HR
3-HR
2-HR
1-HR
ID=12-HR CLASS I
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)


ACCUMULATED PROBABILITY (DD < ID)
0.80
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 24-HR
6-HR
3-HR
2-HR
1-HR
ID=12-HR CLASS III
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)


ACCUMULATED PROBABILITY (DD < ID)
0.80
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 24-HR
6-HR
3-HR
2-HR
1-HR
ID=12-HR CLASS V
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)


ACCUMULATED PROBABILITY (DD < ID)
0.80
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 12-HR
6-HR
3-HR
2-HR
1-HR
ID=24-HR CLASS I
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)


ACCUMULATED PROBABILITY (DD < ID)
0.80
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 12-HR
6-HR
3-HR
2-HR
1-HR
ID=24-HR CLASS III
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)


ACCUMULATED PROBABILITY (DD < ID)
0.80
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 12-HR
6-HR
3-HR
2-HR
1-HR
ID=24-HR CLASS V
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)

APPENDIX III. GRAPHS OF MONTHLY DISTRIBUTION OF N-HR STORMS

FIGURE III- 1
MONTHLY DISTRIBUTION (BY PERCENT) OF 1-HR STORMS - CLASS V

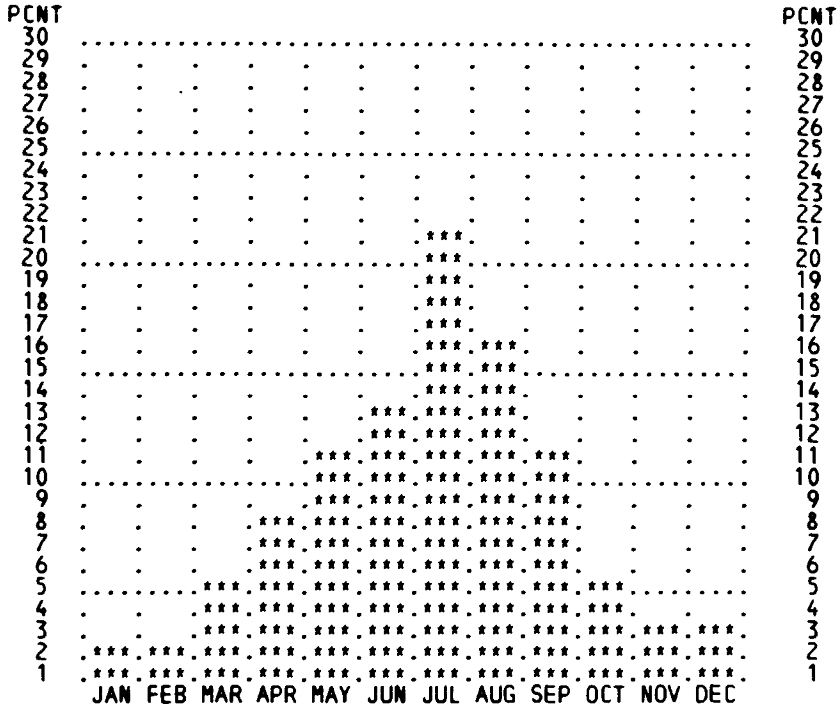


FIGURE III- 2
MONTHLY DISTRIBUTION (BY PERCENT) OF 1-HR STORMS - CLASS IV

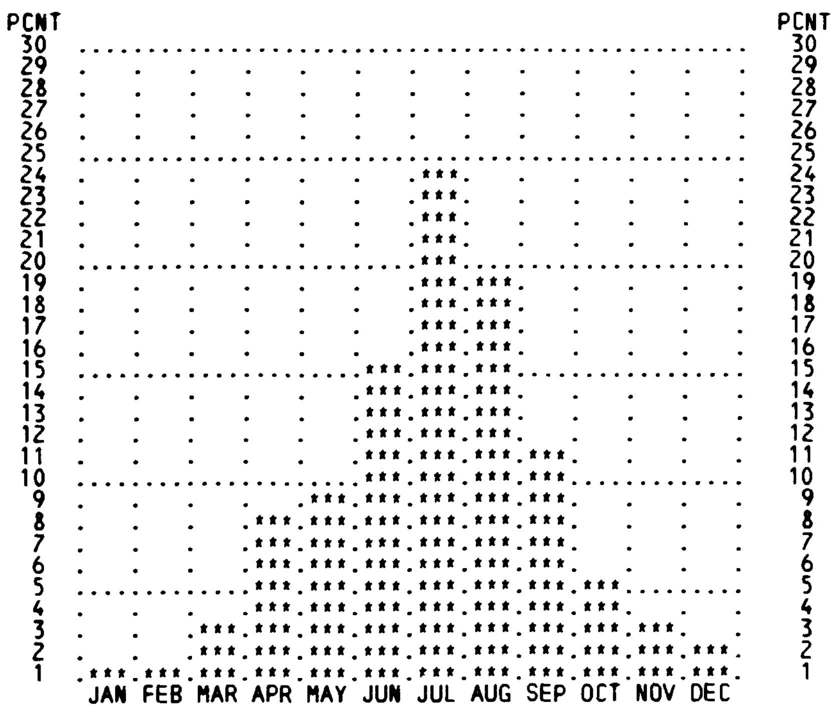


FIGURE III- 3
MONTHLY DISTRIBUTION (BY PERCENT) OF 1-HR STORMS - CLASS III

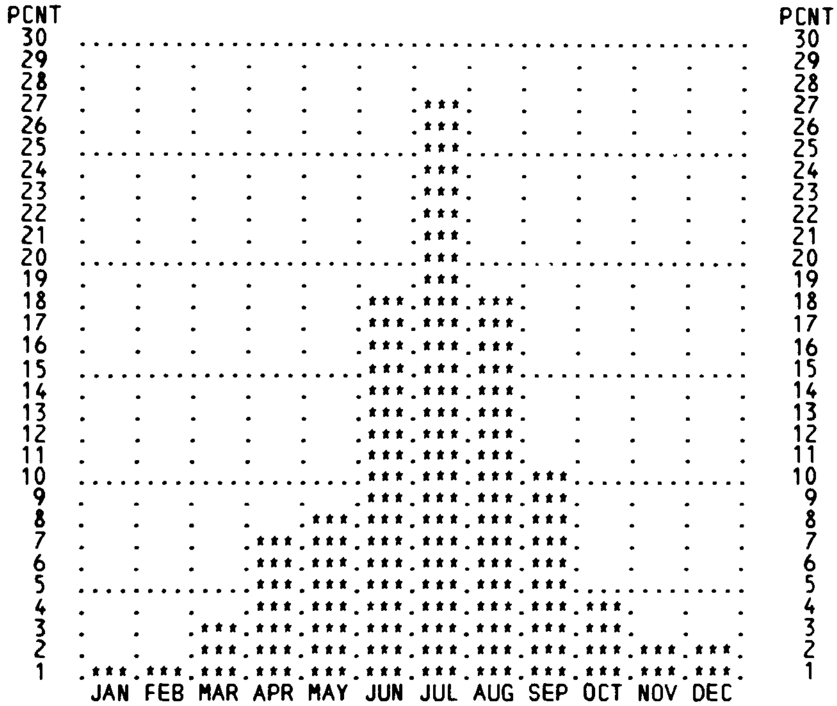


FIGURE III- 4
MONTHLY DISTRIBUTION (BY PERCENT) OF 1-HR STORMS - CLASS II

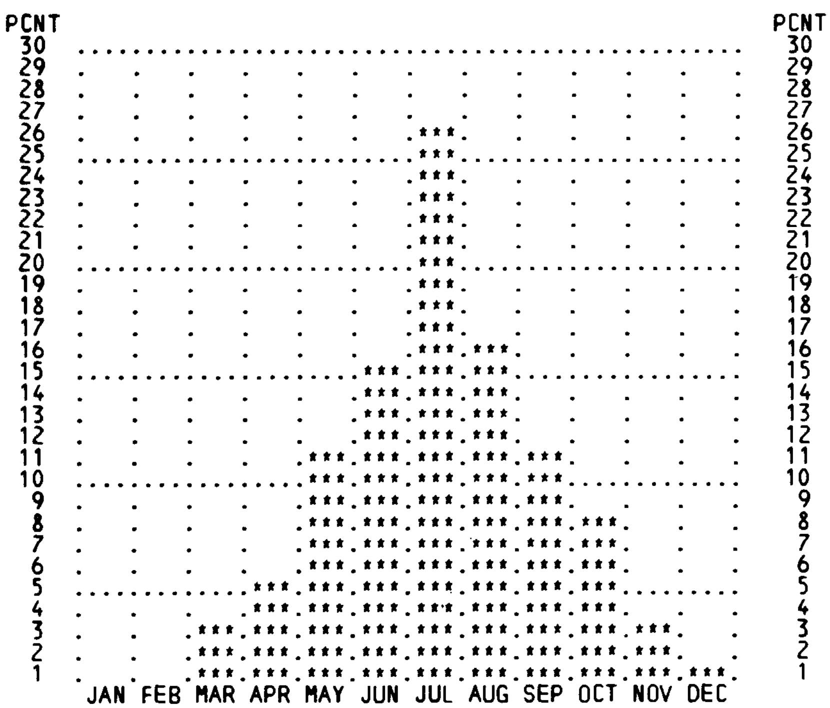


FIGURE III- 5
MONTHLY DISTRIBUTION (BY PERCENT) OF 1-HR STORMS - CLASS I

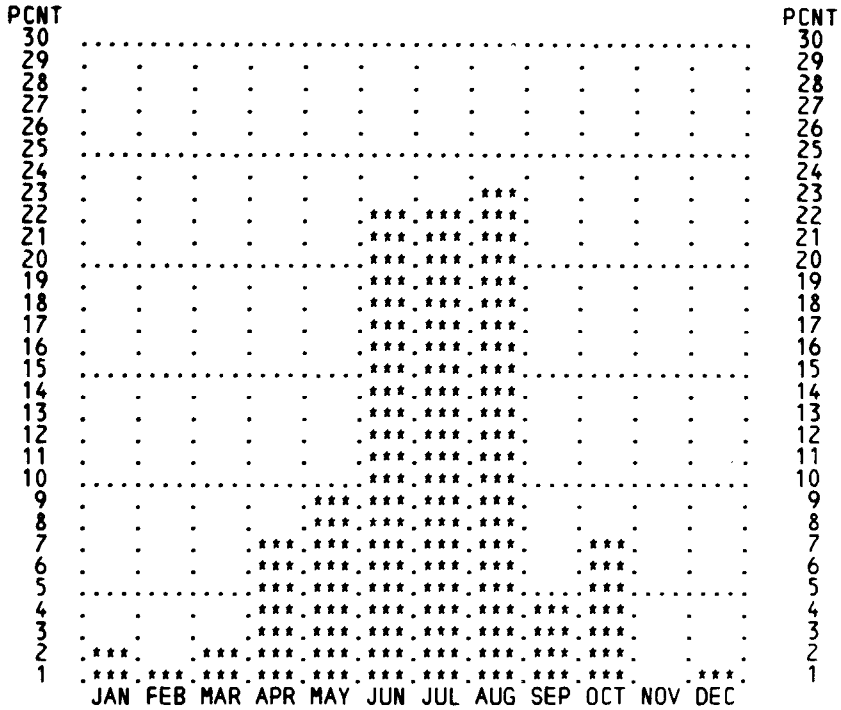


FIGURE III- 6
MONTHLY DISTRIBUTION (BY PERCENT) OF 2-HR STORMS - CLASS V

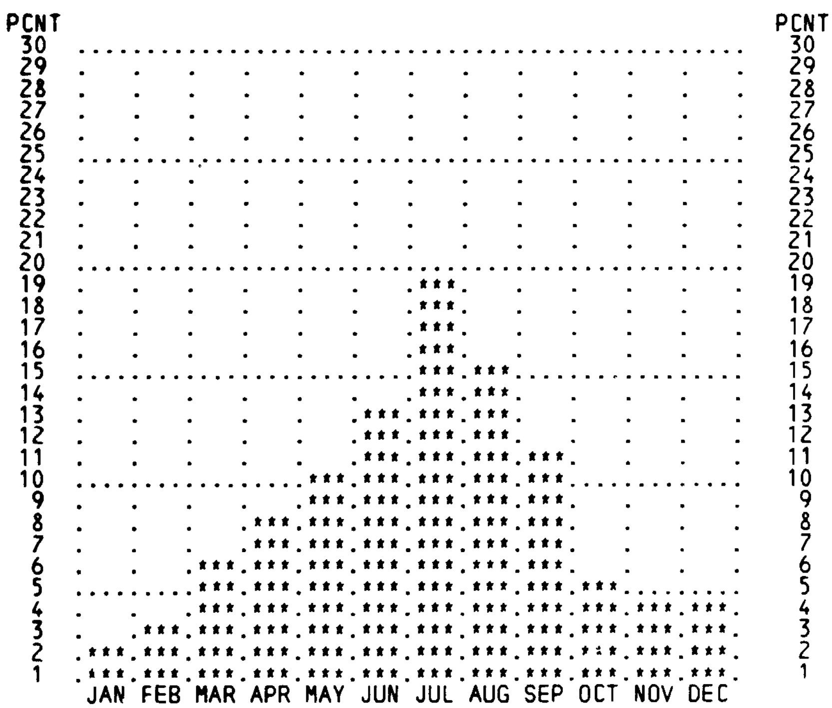


FIGURE III- 7
MONTHLY DISTRIBUTION (BY PERCENT) OF 2-HR STORMS - CLASS IV

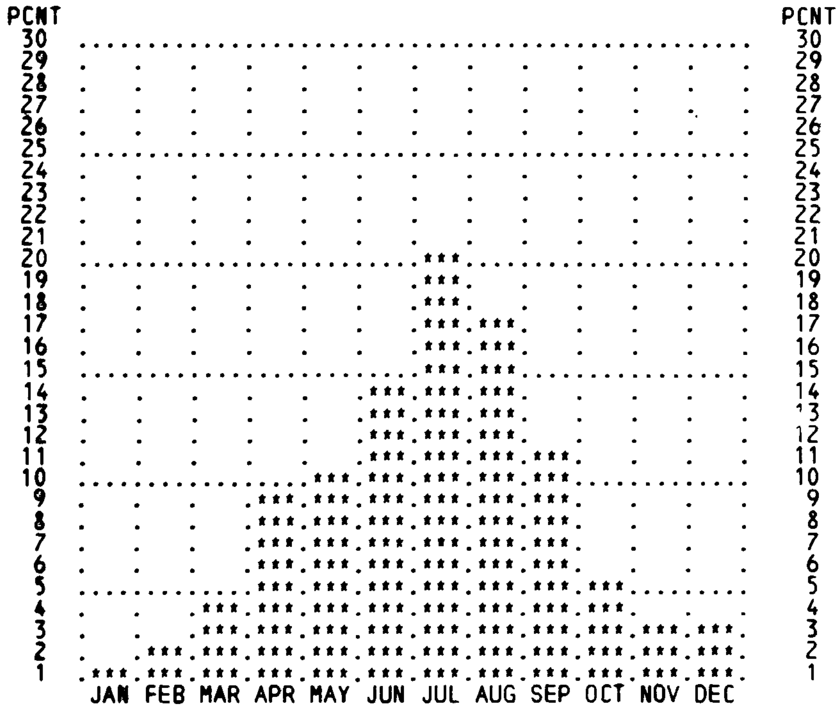


FIGURE III- 8
MONTHLY DISTRIBUTION (BY PERCENT) OF 2-HR STORMS - CLASS III

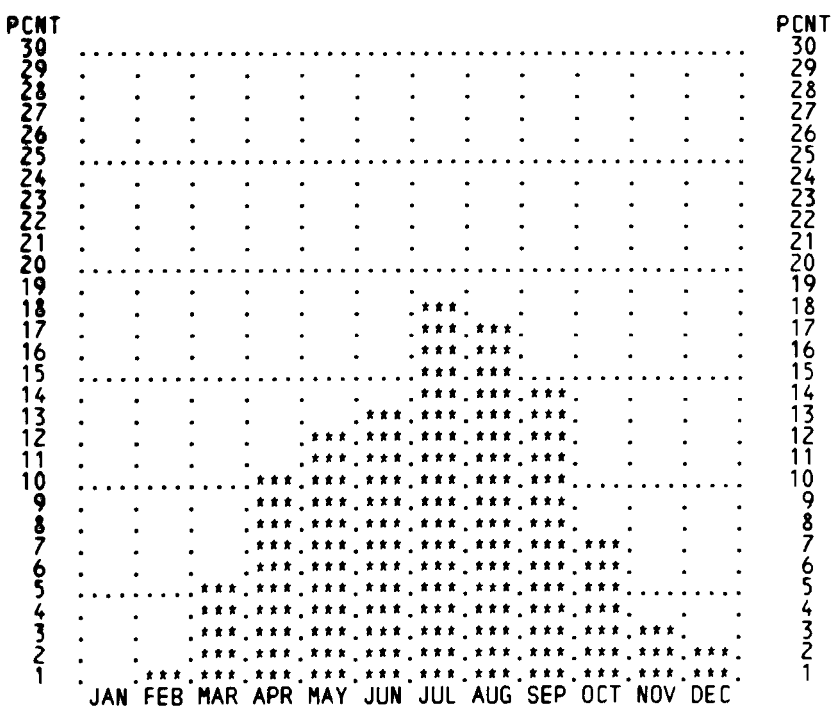


FIGURE III- 9
MONTHLY DISTRIBUTION (BY PERCENT) OF 2-HR STORMS - CLASS II

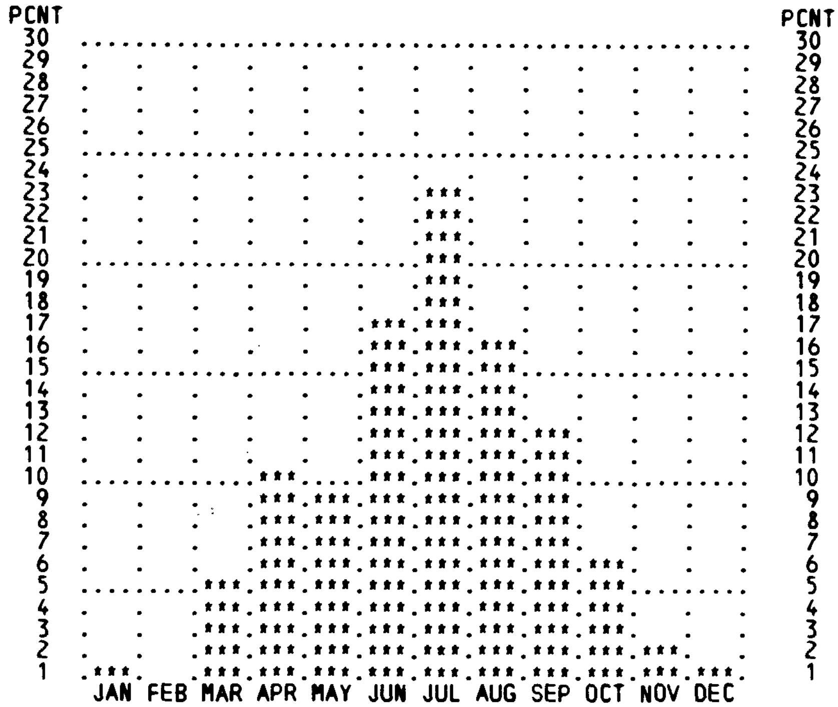


FIGURE III-10
MONTHLY DISTRIBUTION (BY PERCENT) OF 2-HR STORMS - CLASS I

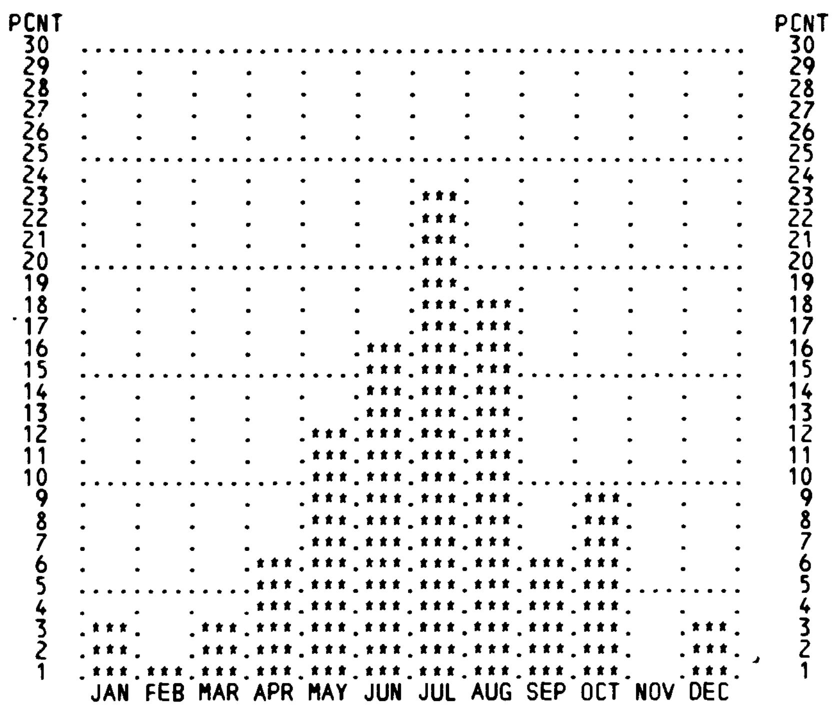


FIGURE III-11
MONTHLY DISTRIBUTION (BY PERCENT) OF 3-HR STORMS - CLASS V

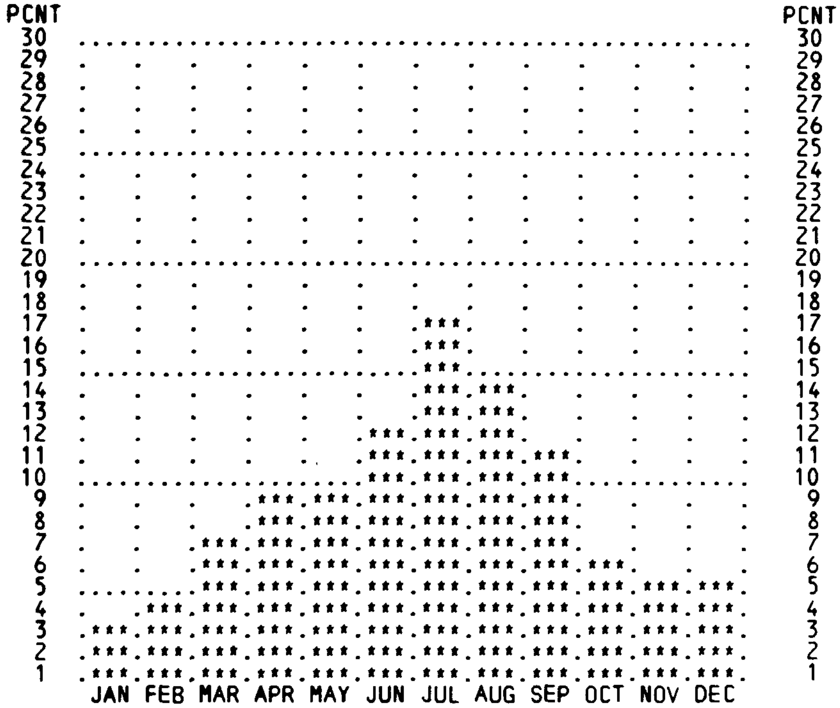


FIGURE III-12
MONTHLY DISTRIBUTION (BY PERCENT) OF 3-HR STORMS - CLASS IV

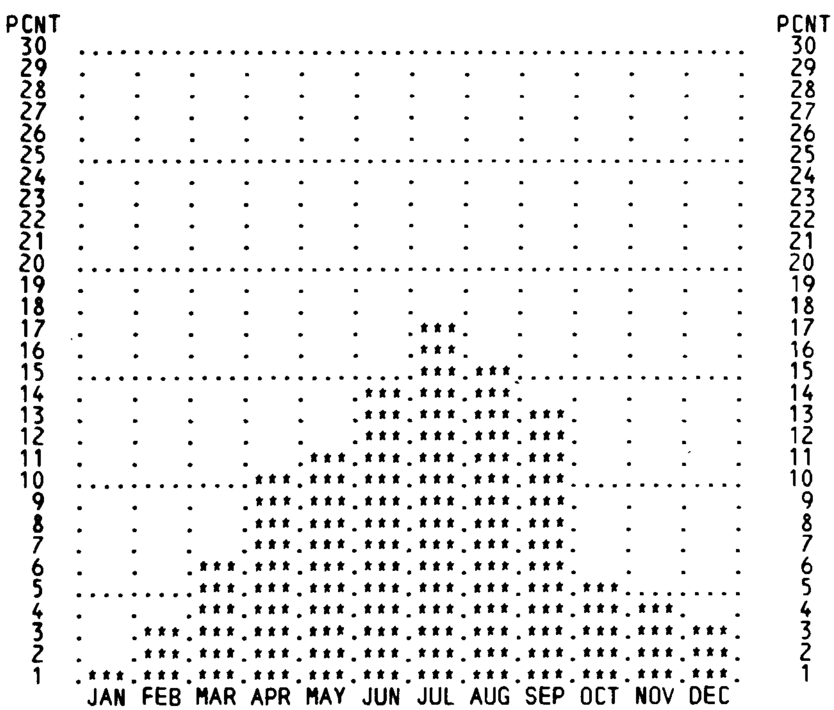


FIGURE III-13
MONTHLY DISTRIBUTION (BY PERCENT) OF 3-HR STORMS - CLASS III

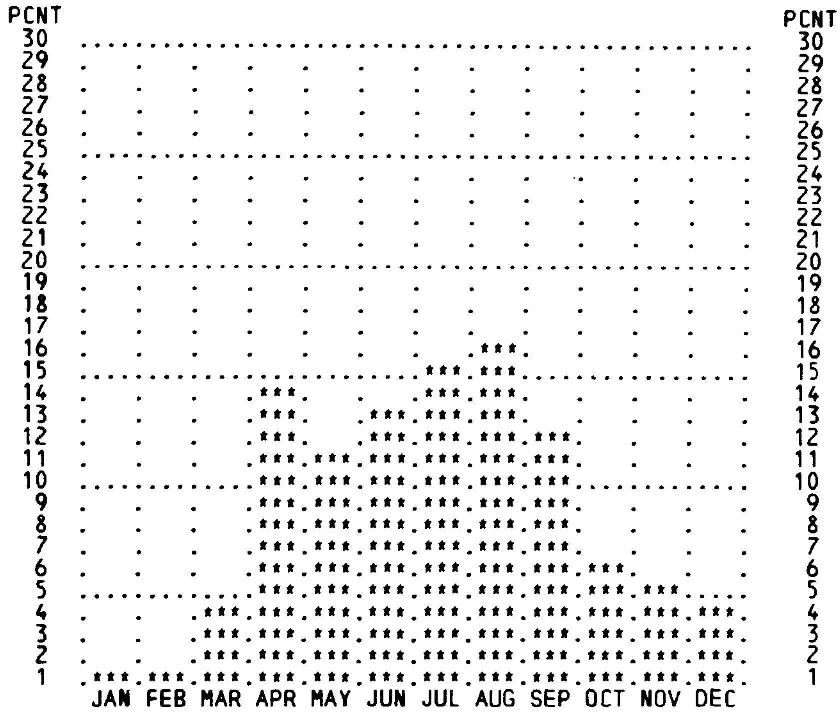


FIGURE III-14
MONTHLY DISTRIBUTION (BY PERCENT) OF 3-HR STORMS - CLASS II

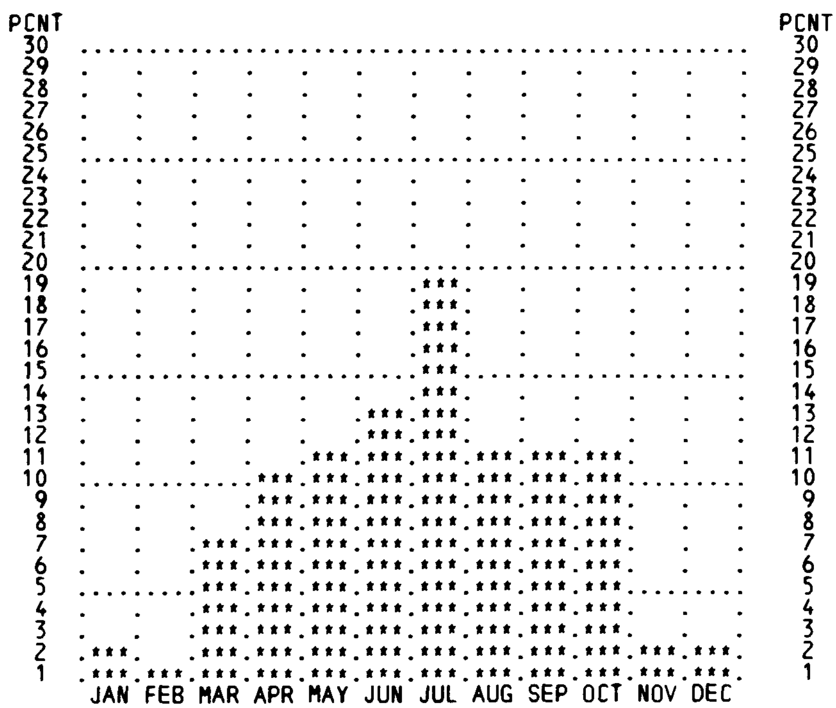


FIGURE III-15
MONTHLY DISTRIBUTION (BY PERCENT) OF 3-HR STORMS - CLASS I

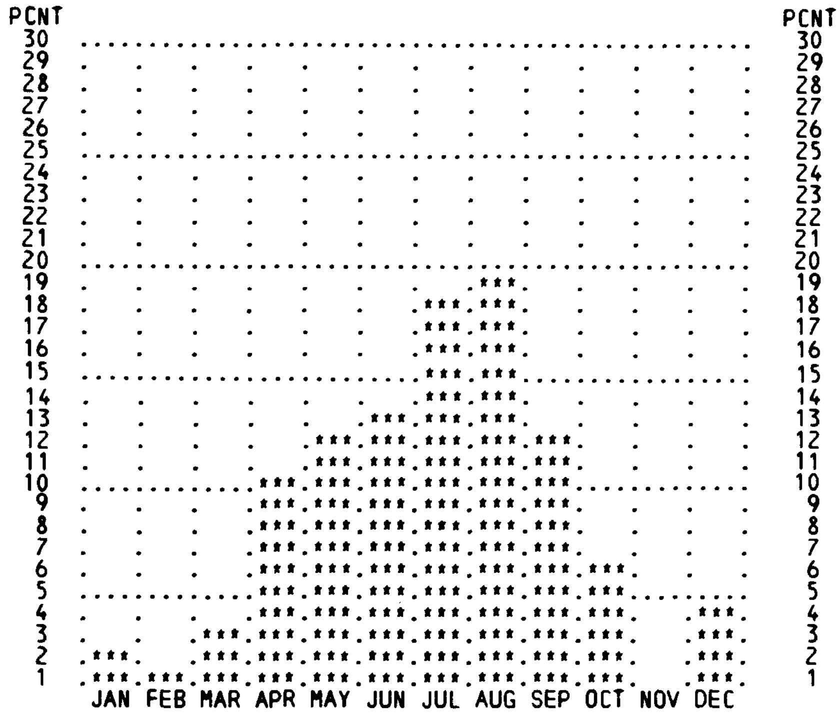


FIGURE III-16
MONTHLY DISTRIBUTION (BY PERCENT) OF 6-HR STORMS - CLASS V

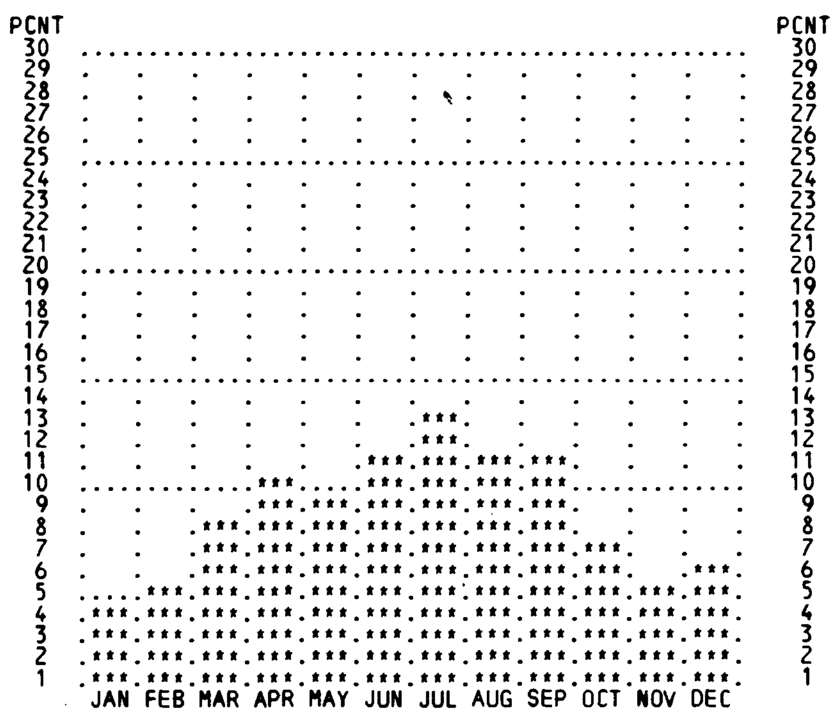


FIGURE III-17
MONTHLY DISTRIBUTION (BY PERCENT) OF 6-HR STORMS - CLASS IV

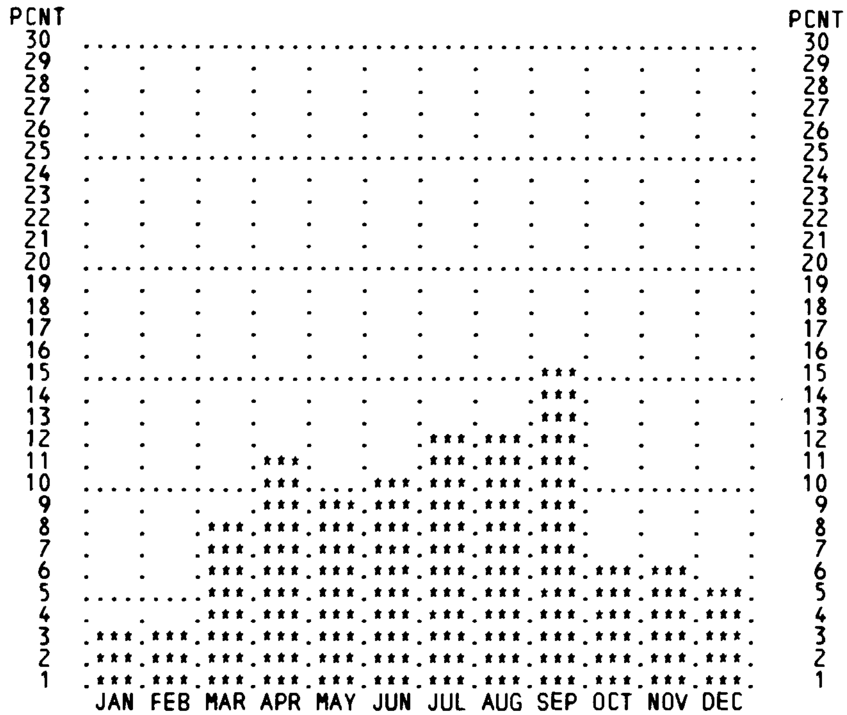


FIGURE III-18
MONTHLY DISTRIBUTION (BY PERCENT) OF 6-HR STORMS - CLASS III

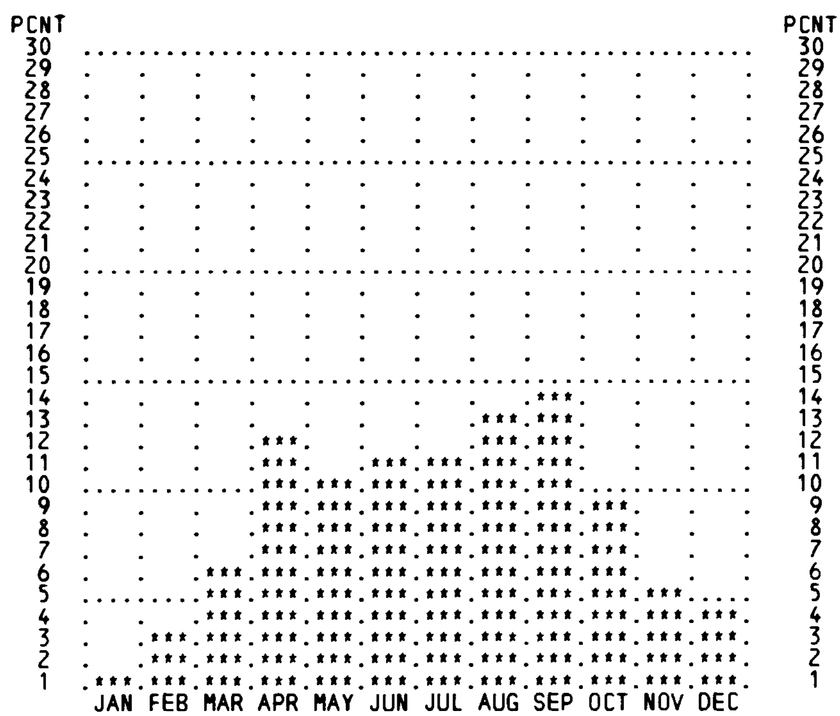


FIGURE III-19
MONTHLY DISTRIBUTION (BY PERCENT) OF 6-HR STORMS - CLASS II

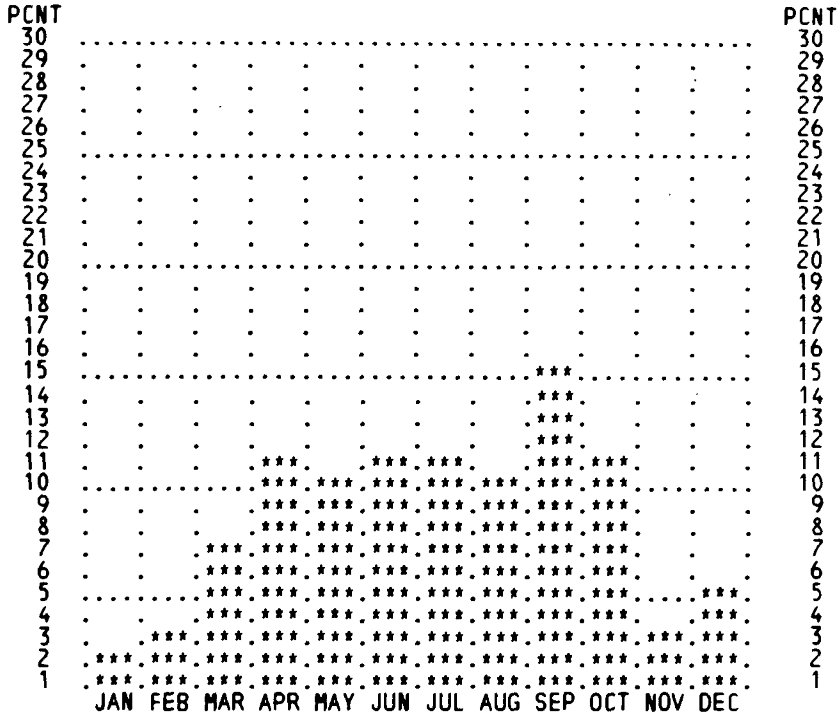


FIGURE III-20
MONTHLY DISTRIBUTION (BY PERCENT) OF 6-HR STORMS - CLASS I

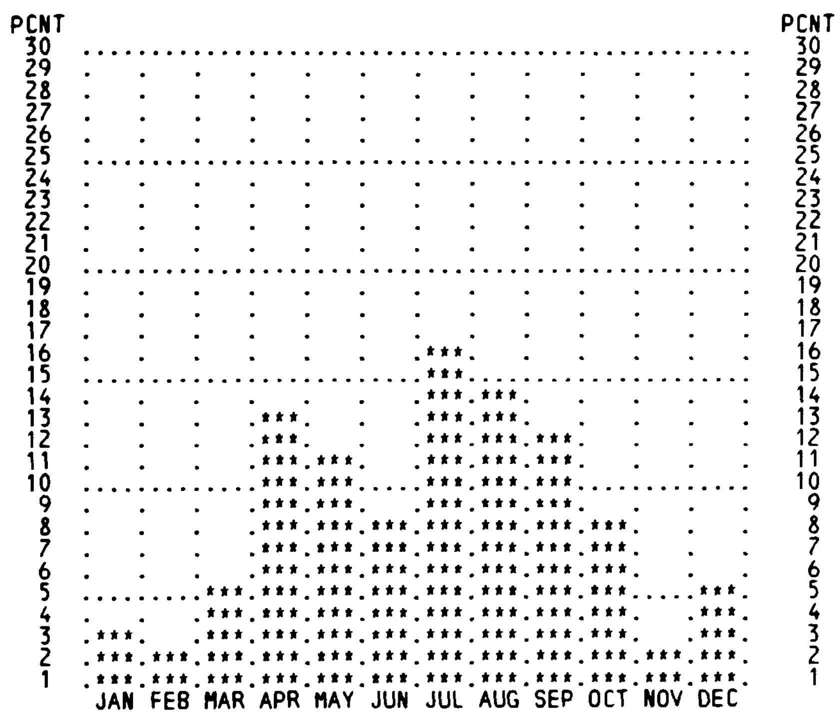


FIGURE III-21
MONTHLY DISTRIBUTION (BY PERCENT) OF 12-HR STORMS - CLASS V

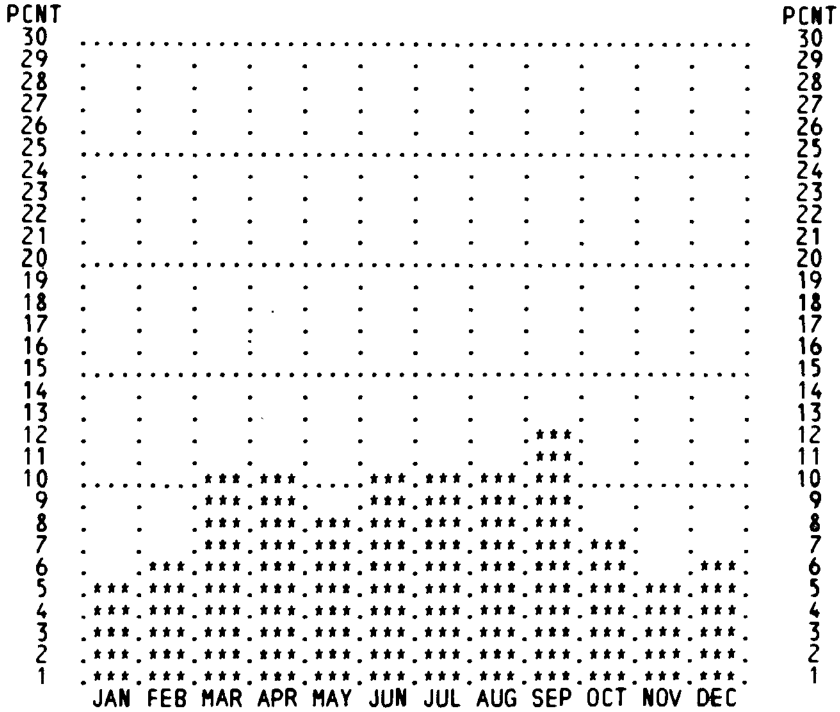


FIGURE III-22
MONTHLY DISTRIBUTION (BY PERCENT) OF 12-HR STORMS - CLASS IV

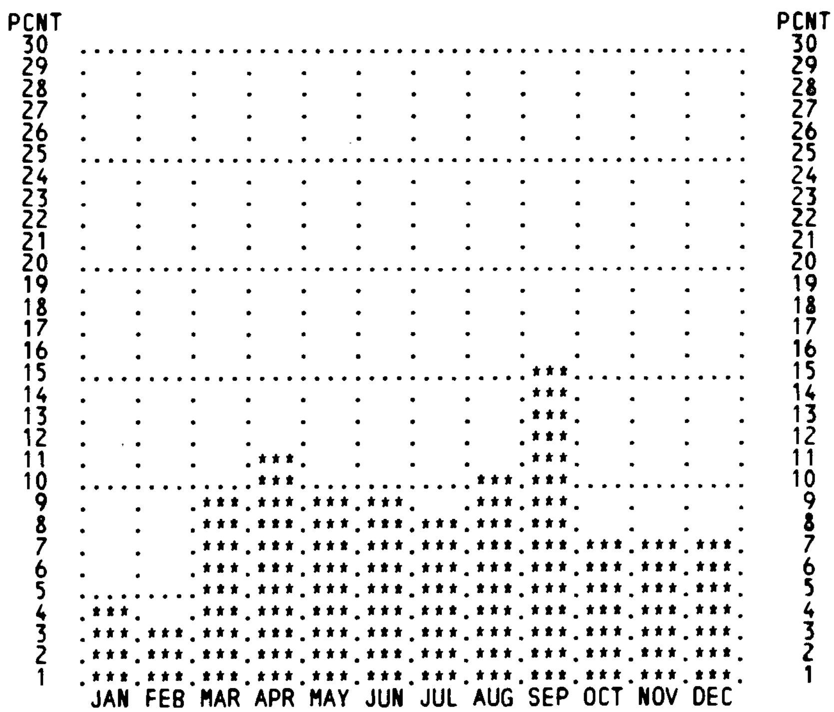


FIGURE III-23
MONTHLY DISTRIBUTION (BY PERCENT) OF 12-HR STORMS - CLASS III

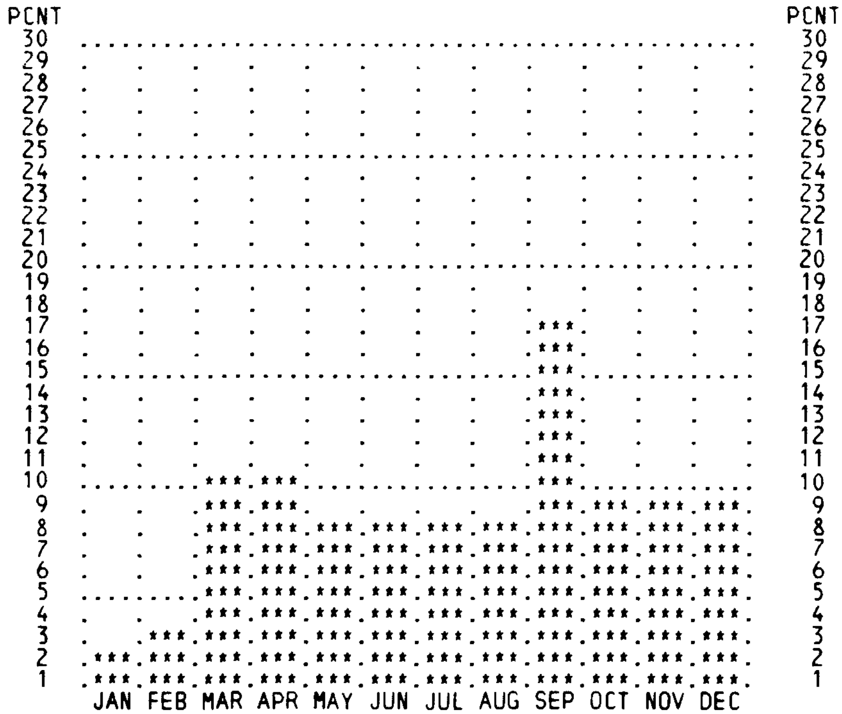


FIGURE III-24
MONTHLY DISTRIBUTION (BY PERCENT) OF 12-HR STORMS - CLASS II

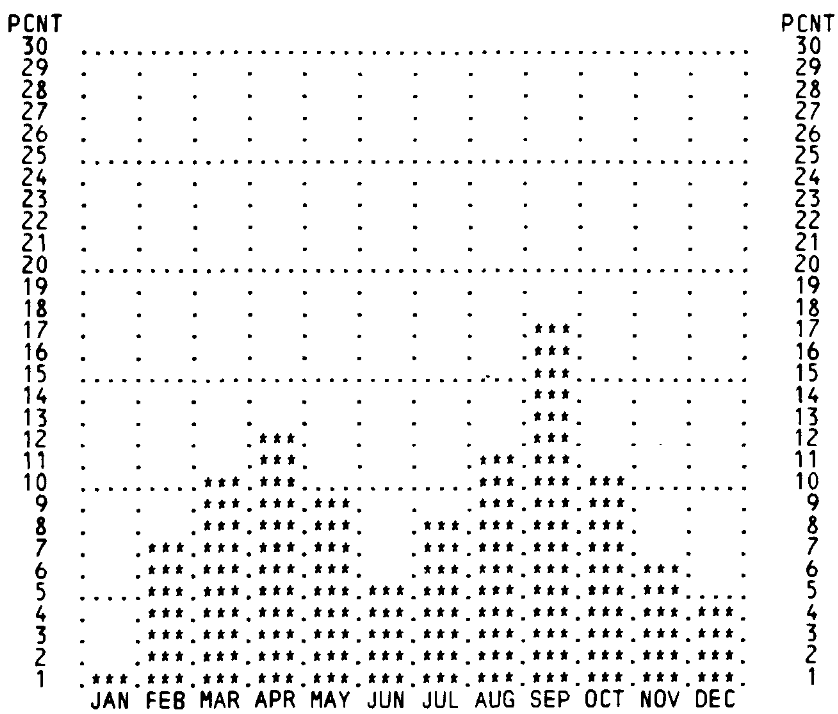


FIGURE III-25
MONTHLY DISTRIBUTION (BY PERCENT) OF 12-HR STORMS - CLASS I

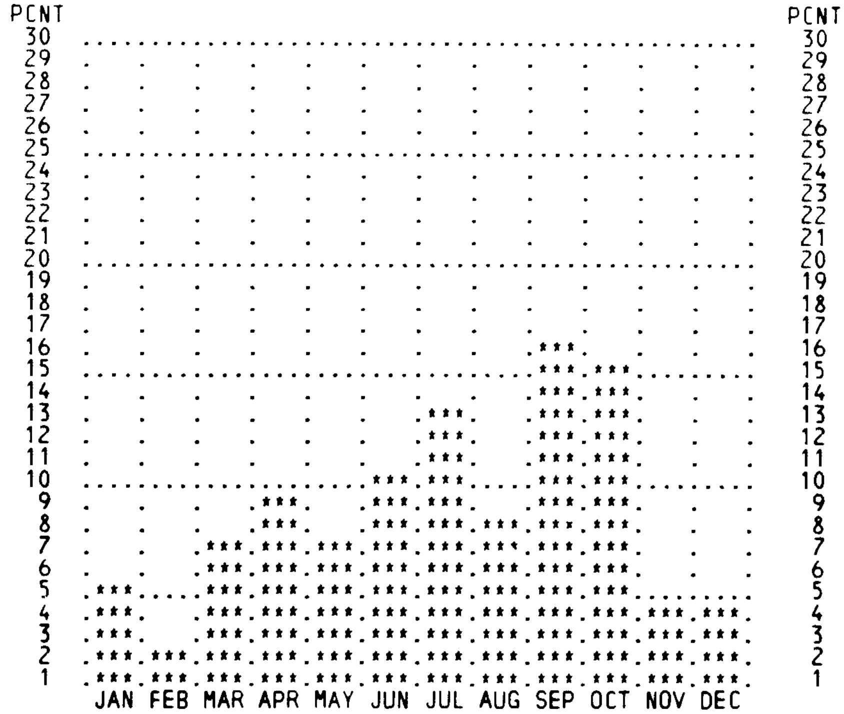


FIGURE III-26
MONTHLY DISTRIBUTION (BY PERCENT) OF 24-HR STORMS - CLASS V

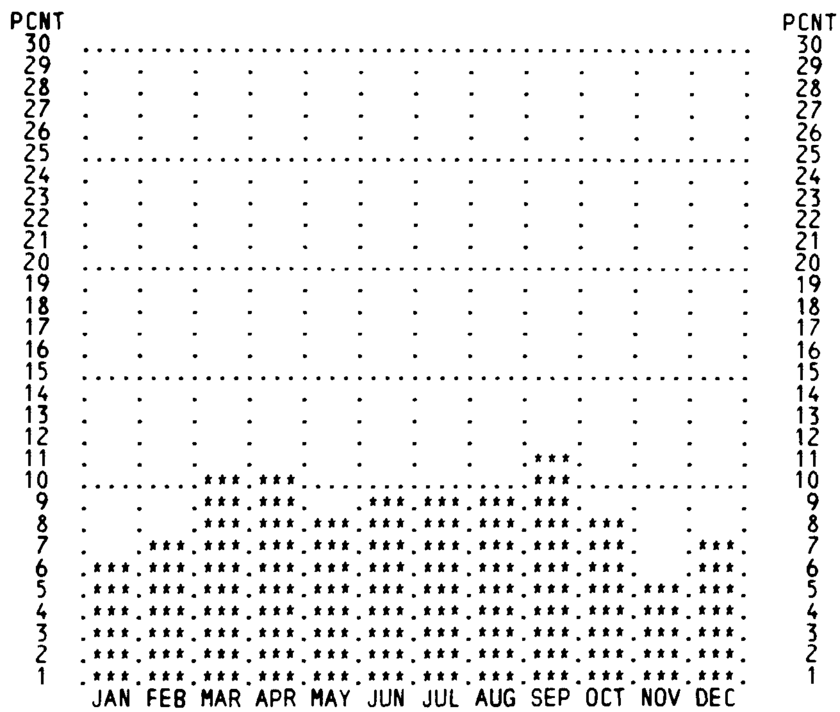


FIGURE III-27
MONTHLY DISTRIBUTION (BY PERCENT) OF 24-HR STORMS - CLASS IV

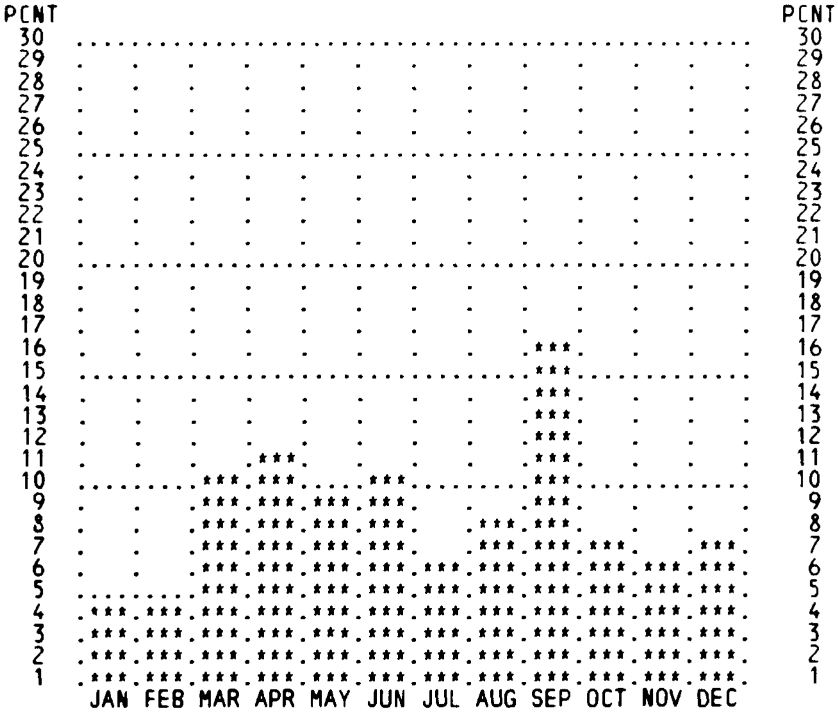


FIGURE III-28
MONTHLY DISTRIBUTION (BY PERCENT) OF 24-HR STORMS - CLASS III

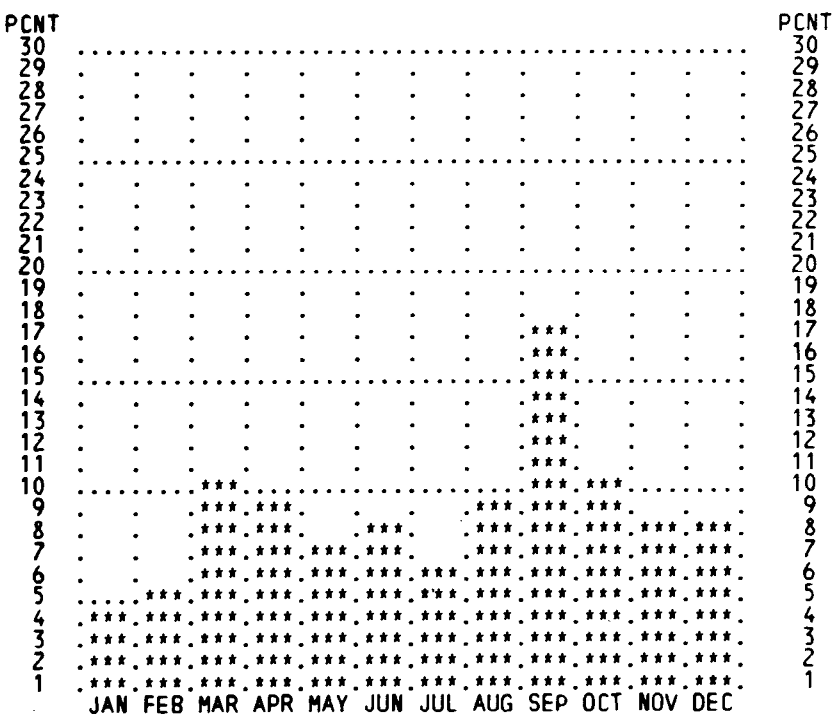


FIGURE III-29
MONTHLY DISTRIBUTION (BY PERCENT) OF 24-HR STORMS - CLASS II

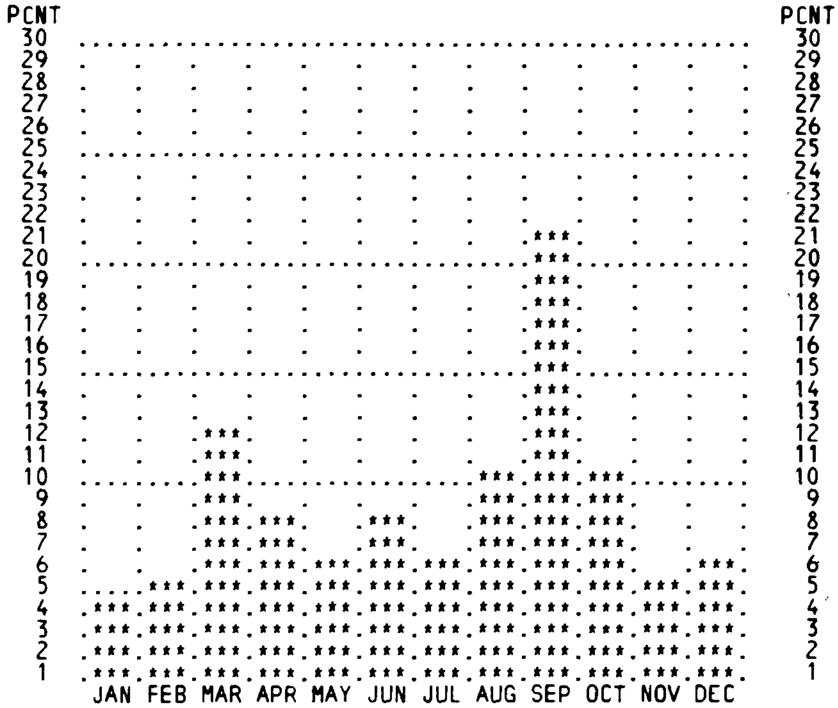
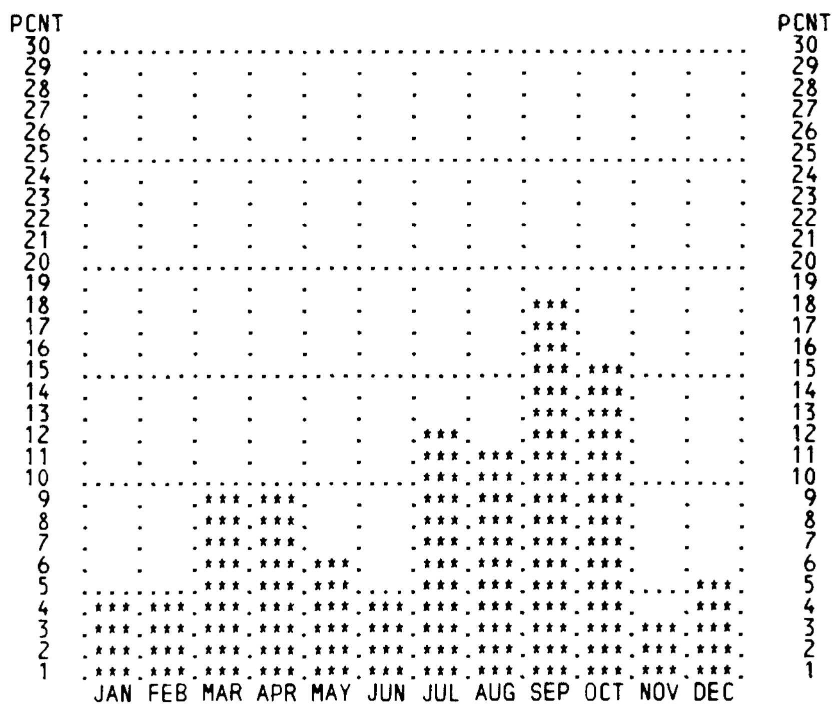


FIGURE III-30
MONTHLY DISTRIBUTION (BY PERCENT) OF 24-HR STORMS - CLASS I



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