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Interduration Precipitation Relations For Storms — Western United States

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Ralph H. Frederick
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Malcolm Baldrige, Secretary

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John V. Byrne, Administrator

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Richard E. Hallgren, Director

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INTERDURATION PRECIPITATION RELATIONS FOR STORMS--WESTERN UNITED STATES

Ralph H. Frederick, John F. Miller, Francis P. Richards
and Richard W. Schwerdt
Office of Hydrology
NOAA, National Weather Service
Silver Spring, Maryland

ABSTRACT. Annual maximum precipitation events for durations of N = 1, 2, 3, 6, 12, and 24 hours are identified. The largest precipitation amounts for durations of M = 1, 2, 3, 6, 12, and 24 hours ($M \neq N$) concurrent with the N-hr event are then selected. The events are stratified according to magnitude (quartiles) and relations between the N-hr and M-hr event are studied by forming a ratio of shorter to longer duration precipitation totals. Accumulated probabilities of this ratio are suggested as a tool to estimate precipitation increments necessary in the synthesis of precipitation mass curves. By analyzing the relative timing of the shorter duration event within the longer duration event, a characteristic time distribution can be developed.

INTRODUCTION

When hydraulic engineers or designers lack sufficient runoff and/or stream flow data to define flow frequencies for a specific project, they usually estimate such data through the use of hydrologic models that take advantage of (generally) more copious precipitation data. An often used practice is to synthesize a precipitation vs. time relationship from available precipitation-frequency values and determine a design hydrograph from it. Such a procedure requires using precipitation-frequency values for several durations in order to estimate both peak discharge and volume of water involved. A common practice fixes a frequency (return period) and combines precipitation amounts for the available durations from precipitation-frequency atlases (i.e., Hershfield 1961, Miller et al. 1973, Frederick et al. 1977). In preparation of these atlases each duration has been treated independently from all other durations, i.e., the maximum value for the 1-hr duration for each year is selected without regard for whether values for other durations in that event are annual maxima or not. But the precipitation estimates for the various durations may not be completely independent. For a given year, there is some possibility that amounts for two durations of approximately the same length (e.g., 1 hr and 2 hr, 1 hr and 3 hr, etc.) come from the same event. As the lengths of the two durations become more dissimilar, (e.g. 1 hr and 6 hr, 1 hr and 24 hr, etc.) it becomes increasingly less likely that the data samples contain amounts from the same event and are more truly independent. Where the time differences are greatest the largest events may be completely independent and each may result from a weather situation that cannot realistically be combined with the other. This likelihood varies from one station to another and from one region to another depending on both large and small scale atmospheric flow patterns and to a lesser extent on local terrain effects. The probability of the concurrence of the two events is undefined and adds uncertainty to the probability of the design storm. Indeed, if the 100-yr 1-, 2-, 3-, 6-, 12- and 24-hr precipitation values were truly independent, the probability of observing a precipitation vs. time distribution similar to that synthesized from them would be no more than 10^{-12} $[(0.01)^6]$. Further, this assumes that the placement of the various durations within the 24-hr period had been appropriately selected.

As pointed out above, it is not likely that all durations will be independent. This increases the probability that the synthesis described above may be reasonable for design purposes. But, it would be nearly impossible to quantify how probable or exactly how representative such a synthesis really was. This study makes a first attempt to provide the designer with guidance on the selection of appropriate incremental values to be used in the preparation of a precipitation vs. time curve. It also attempts to indicate a likely placement of events of various durations within the total precipitation event. This is done by examining relationships between concurrent annual maximum precipitation events for 1, 2, 3, 6, 12, and 24 hours and the largest rainfall amounts within or surrounding these annual events. The report illustrates one approach to estimating incremental precipitation values and constructing a precipitation mass curve. The procedure requires the engineer or designer to first identify a hydrologically critical storm in terms of duration and frequency. Then the critical probability for precipitation increments to be combined with the critical storm in constructing the precipitation mass curve must be selected.

DEFINITION OF TERMS

This is the second study in the NOAA Technical Report series to investigate the sequential and quantitative relation between what are defined as "storms" and "rainfalls". The terminology adopted for this study is the same as that used in the initial study that covered the Southeastern United States (Frederick 1979). The words "storm" and "rainfall" as used in the remainder of this report have specific meanings defined in this section. Until their definitions are understood, subsequent sections of this report could be confusing to the reader.

A "storm" is the largest total precipitation event at a station for N-consecutive hours (N = 1, 2, 3, 6, 12, 24) during a calendar year. The duration of this annual maximum "storm" is termed an independent duration (ID). It is independent because 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, $M \neq N$). These are 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 M-hr "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 precipitation in the last hour(s) of a "storm" or "rainfall", the hour(s) following the last hour with precipitation to the end of the period are filled with trailing zeros.

Two examples are given. At some station in some year, the largest 2-hr precipitation occurred between 6 and 8 p.m. (table 1(a)) from thunderstorms on a warm summer evening. This is the annual maximum 2-hr event for that station and that year. The depth of the 2-hr "storm" (ID) is 25.9 mm. On this day, however, some rain fell intermittently from midafternooon until nearly 8 p.m. The 6-hr "rainfall" (DD) associated with this "storm" occurred between 3 and 9 p.m. and the depth was 34.5 mm. Notice that there was no rain between 8 and 9 p.m. so the 6-hr rainfall had one trailing zero. At this same station during this same year, a severe winter extratropical cyclone (table 1(b)) brought the annual maximum 6-hr "storm". Between the hours of 8 a.m. and 2 p.m., 44.5 mm of precipitation was observed. The 6-hr independent duration "storm" for this year at this station has now been selected. The largest 2-hr precipitation during this storm (18.0 mm) fell between 11 a.m. and 1 p.m. This 2-hr event defines dependent duration "rainfall" associated with the 6-hr storm.

Table 1.--Excerpts from the hourly precipitation record for a hypothetical station in the western United States

(a) A warm summer evening				(b) A stormy winter day			
Hour ending		Precipitation (mm)		Hour ending		Precipitation (mm)	
2 p.m.		0.3		8 a.m.		0.3	
3		0.0	6-hr rainfall	9	6-hr storm	2.5	
4		0.5		10		7.6	
5		2.5		11		4.6	
6		5.6		noon		12.8	2-hr rainfall
7	2-hr storm	18.3		1 p.m.		5.2	
8		7.6		2		11.8	
9	trailing zero	0.0		3		0.5	

AREA OF STUDY AND ITS PRECIPITATION CLIMATOLOGY

In choosing areas for a study of this nature, two opposing constraints must be reconciled. The data sample must be 1) climatologically homogeneous for the elements studied, and 2) large enough to define the variations with time and in magnitude of the precipitation distributions found in nature. If an area were truly climatologically homogeneous, its climatology could be defined by studying the data from a single station with a sufficiently long record. In the United States, there are no stations with "sufficiently long" records and there are no reasonably sized areas that are climatologically homogeneous in the strict sense. Therefore, in a study of this type the requirement of climatological homogeneity may have to be relaxed to permit a data set large enough to minimize potential sampling errors.

Consideration of topographic features and a preliminary review of the precipitation climatology suggested dividing the western United States into several regions (figure 1). Initial boundaries were placed along the Cascade-Sierra Nevada crest and the Continental Divide. This separates the coastal drainages of Washington and Oregon and the east facing slopes of the Rockies from an interior region.

Further examination of the east facing slopes of the Rockies led to two modifications. First, the area was split into two regions. At the northern boundary of the South Platte River Basin, the general orientation of the mountain chain shifts from north-south to northwest-southeast. This difference in orientation suggested

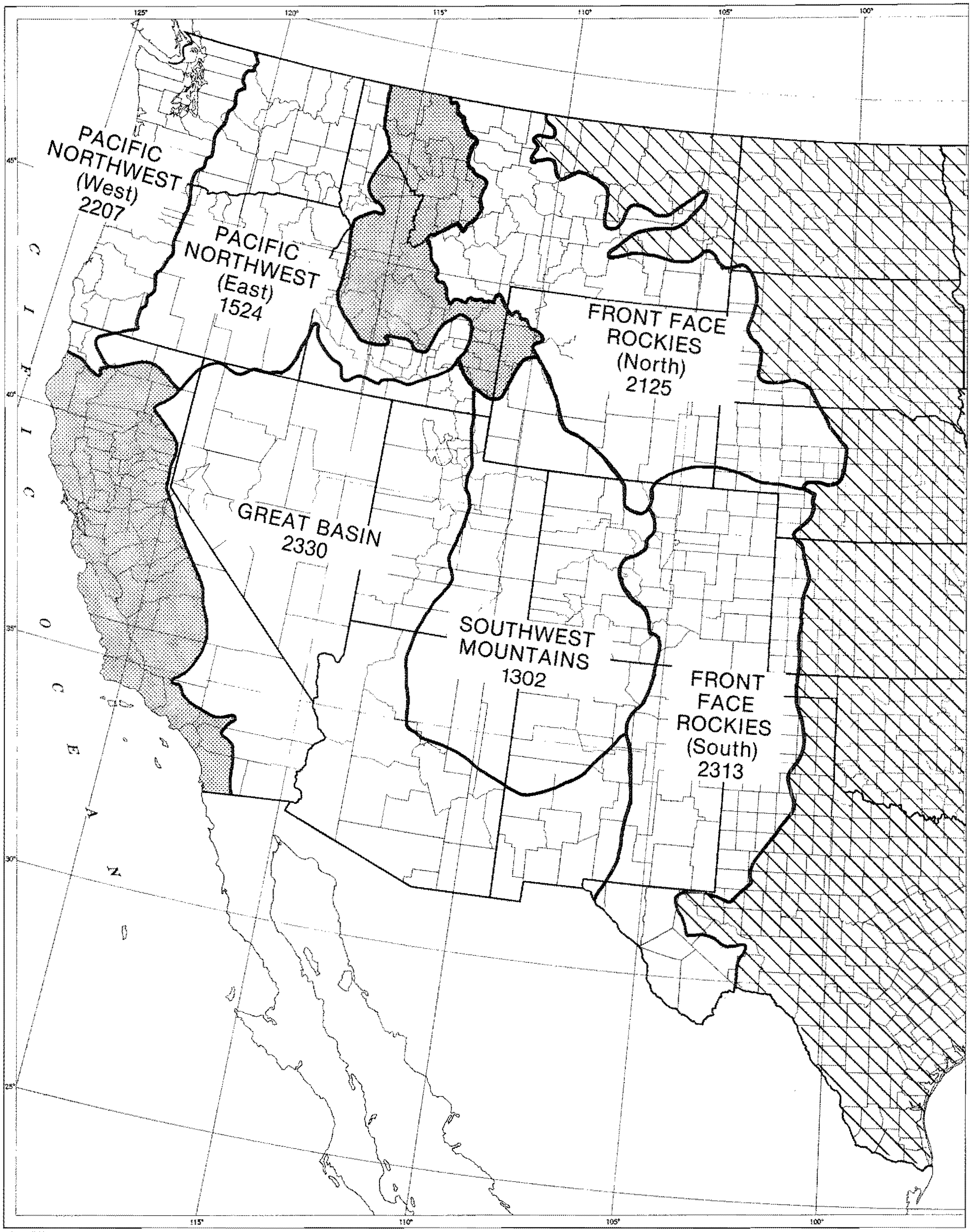

Figure 1.--Study area showing station years of data per region.

a separation into two regions. Second, for the southern portion of the east facing slopes, the Sangre de Cristo and Sacramento Mountains form a barrier to direct access of Gulf of Mexico moisture well east of the Continental Divide. Examination of storms east and west of a generalized crest line along these mountain chains suggested this would be a more appropriate boundary south of approximately 38°N than the Continental Divide. The eastern boundary of both regions was placed along a generalized 3000-ft elevation contour.

The interior region, including the Great Basin, has a varied, complex topography. The major causes of precipitation in the northern valleys are different from those of the southern deserts. East of the crest of the Cascades are the Columbia River Valley, the Palouse Valley, the Snake River Valley, and other valleys divided by many small mountain ranges but no well organized massive range. Precipitation in this region falls either from small area thunderstorms or extratropical cyclones. The moisture generally advances from the Pacific Ocean in a southwesterly air flow.

South of the Columbia Basin, the region between the Cascade-Sierra Nevada crest and the east facing slopes of the Rockies is logically separated into two major areas. The first is relatively open to moist air from the south and southwest and consists of Nevada and portions of Utah, Arizona and New Mexico. In this region, precipitation usually results from thunderstorms, or extratropical systems that are generally less well organized than those found in the Columbia Basin, or from decadent tropical cyclones. In the latter case, the system may have been so disrupted by passage over terrain features that a tropical cyclone circulation can no longer be discerned.

The last region in the study area is surrounded by multiple mountain barriers which restrict moist air flow. Weather systems that penetrate this region are normally not as well organized near the surface and frequently can only be found as organized systems aloft.

Table 2 provides a detailed description of the areas used in this study. Two sections of the western United States were not considered. The first is the Pacific Ocean drainages in California. This area will be covered in a subsequent study. The second includes the Bitterroot and Salmon River Mountains of Montana and Idaho and the Tetons in eastern Idaho and western Wyoming. In this region, no recording gages were available with sufficient data to permit a reliable analysis.

After the six geographic regions were selected to provide a reasonable climatological and topographic homogeneity, the stations were examined to see if sufficient data were available to define reliable statistics (as already mentioned one region was excluded because of a lack of sufficient recording gage data). Table 2 and figure 1 show the number of station years of data available within each region. The number of station years varied from 1302 for the Southwest Mountains to 2330 for the Great Basin. In the previous study by Frederick (1979), about 6000 station years of data were available for the southeastern United States. While the data sample for the present study is not as large, we believe it is adequate. The smaller data sample requires grouping data into quartiles rather than finer class intervals as was done in the previous study by Frederick (1979). It is obvious that precipitation is not climatologically homogeneous even in the limited subregions chosen for this study. However, the meteorological and topographic factors affecting each subregion are more uniform than for the western United States as a whole.

Table 2.--Station years of data used to define interstorm relations - by regions

Region	Station years of data State	 Years
Pacific Northwest (West)		
The Pacific Ocean drainage of Washington and Oregon west of the crest of the Cascade Mountains.	California	71
	Oregon	1264
	Washington	872
	Total	2207
Pacific Northwest (East)		
The Columbia Basin of Washington and Oregon and that portion of the Snake River drainage in Idaho below a generalized 5,000-ft contour.	California	104
	Idaho	361
	Oregon	503
	Washington	556
	Total	1524
Great Basin		
The area immediately to the south of the the Pacific Northwest (East) including Utah west of the crest of the Wasatch Mountains and a continuation of the crest southward through Arizona to the Mogollon Rim. The boundary continues eastward along the crest of the Mogollon Rim to the Escadilla Mountains, then across New Mexico along the crest of the Datil and Gallinas Mountains to the crest of the Jicarilla Mountains. The western boundary of the region is formed by the crest of the Sierra Nevada, Tehachapi Mountains, and coastal ranges of southern California.	Arizona	664
	California	414
	Idaho	40
	Nevada	490
	New Mexico	251
	Utah	471
		2330
Southwest Mountains		
The region north of a line along the crest of the Mogollon Rim, Escadilla Mountains, Datil and Gallinas Mountains in Arizona and New Mexico, east of the crest of the Wasatch and its continuation southward, west of the crest of the Sangre de Cristo Mountains and south of the Continental Divide in Wyoming.	Arizona	119
	Colorado	562
	New Mexico	371
	Utah	190
	Wyoming	60
	Total	1302
Front Face Rockies (North)		
The east facing slopes of the Rocky Mountains north of the South Platte drainage extending from the Continental Divide eastward to a eastward to a generalized 3,000-ft contour in the plains region.	Montana	988
	Nebraska	146
	South Dakota	248
	Wyoming	743
	Total	2125
Front Face Rockies (South)		
The east facing slopes of the Rocky Mountains, south of the southern boundary of the Front Face Rockies (North) from the Continental Divide or the crest of the Sangre de Cristo and Sacramento Mountains (whichever of the latter two is farther eastward) than the Continental Divide to the plains region as far as the generalized 3,000-ft contour.	Colorado	977
	Kansas	168
	Nebraska	69
	New Mexico	542
	Oklahoma	49
	Texas	456
	Wyoming	52
	Total	2313

Normal annual precipitation varies within each of the six regions. The largest values are in the Pacific Northwest (West) where amounts on the Olympic Mountains exceed 380 cm per year. The lowest values are in the Great Basin where some locations receive less than 10 cm per year. Ranges of normal annual precipitation within each region are shown in table 3 together with the ranges of some other climatological indices. Although the ranges are larger than may be desirable, they are not considered so large as to make our assumption of approximate homogeneity invalid. The exception might appear to be the Pacific Northwest (West) where the range in normal annual precipitation is over 300 cm. If a few very small areas in the Olympic and Cascade Mountains were excluded, the range would decrease to approximately 132 cm. Taking into account the trade-off between meteorological homogeneity and sample size, we do not consider this range excessive.

Table 3.--Ranges of indices used to assess climatological homogeneity; numbers in parentheses are lower and upper bounds.

Region	Normal annual precipitation⊛ (1931-60) (cm)		Days with precipitation+ (1931-60) (>1.3 cm)		Number of thunderstorms days□	
Pacific Northwest (West)	330	(50-380)	94	(14-108)	7	(3-10)
Pacific northwest (East)	82	(20-102)	75	(3- 78)	15	(10-25)
Great Basin	71	(10- 81)	19	(3- 22)	35	(8-43)
Southwest Mountains	82	(20-102)	28	(2- 30)	20	(35-55)
Front Face Rockies (North)	82	(20-102)	9	(5- 14)	25	(20-45)
Front Face Rockies (South)	82	(20-102)	8	(6- 14)	30	(30-60)

⊛Environmental Data Services (1968)
+Miller amd Frederick (1966)
□U.S. Weather Bureau (1952)

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 1951-75) for the period 1948 (in most cases mid-1948) through 1975 (1972 for the Pacific Northwest and 1974 for the northern part of the Front Face Rockies) were available on magnetic tape (Peck et al. 1977). The hourly precipitation data were scanned and the number of hours having missing precipitation data for each year was totaled. The number of hours with accumulated precipitation* was also totaled. Precipitation accumulations were handled in the following way: 1) for periods of 6 hours or less the accumulation was distributed uniformly over each of the 6 hours, and 2) for periods over 6 hours the hourly amounts (including the accumulation total) were treated as missing data.

The 6 storms (ID = 1, 2, 3, 6, 12 and 24 hr) and the associated 30 rainfalls and their times of occurrence for each station year were then listed together with the

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

number of hours missing or with accumulated data. This output was screened visually and compared with the missing and accumulated data to give reasonable assurance that the selected values were truly the maximum values for that station for that year. If it was likely that the largest storm for any of the durations for that station year occurred when the data were missing or zeroed because of long accumulations, all data for that year were eliminated from the station's series. The screened and edited data series for those stations with 15 or more years of data were then accepted for analysis.

Table 4 illustrates the number and percentage distribution of stations and station years of data by length of record for each of the 6 geographic regions studied. In the Pacific Northwest, the Great Basin, and the Southwest Mountains areas, over two-thirds of the data sample comes from stations with 20 or more years of record. This figure increases to more than 80 percent for the two Front Face Rockies regions. The total number of station years is 11,801 from 537 stations in all 6 areas.

DIVISION OF STORM SAMPLE INTO QUARTILES

To examine differences between large and small storms, the ID data sets were ranked according to magnitude and divided into quartiles. The DD values were classed using the same quartile class intervals as those applied to the ID data set for that station and duration. Therefore, the relative magnitudes of both storms and rainfalls for each station were measured against the same standard at each duration. Each station was treated independently in determining the appropriate quartile. Hereafter, the quartile with the top 25 percent of the storms will be referred to as quartile I, the next lower quartile will be referred to as quartile II, etc. In determining quartiles, a station with a record length not divisible by 4 had the remaining storms assigned to lower quartiles, i.e., a station with a 25-yr record had 6 quartile I, II and III storms and 7 quartile IV storms. The quartile assignment was strictly by rank according to magnitude. This led to the possibility that two storms of the same magnitude could be placed in adjacent quartiles. This distribution of storms was such that quartiles I (heaviest storms) and IV (lightest storms) adequately define the distribution. Because interpolation for the other two quartiles is appropriate, this report concentrates on the two bracketing quartiles.

ANALYSIS OF JOINT FREQUENCY OF STORMS AND RAINFALLS

The quartile classification of each storm vs. the quartile of each of its rainfalls was tabulated in two-way frequency distributions. (Remember that quartile class intervals for the DD values are determined from the ID data set for the station and duration.) Table 5 depicts one such distribution for the Front Face Rockies (South). For example, this table shows that 97 of the 24-hr storms of quartile II had 12-hr rainfalls in quartile III. No quartile I 12-hr rainfalls were associated with quartile IV 24-hr storms. Joint frequency tables comparable to table 5 for all 30 ID-DD combinations for all 6 areas are contained in appendix I. (See fiche Number 1 in pocket on inside rear cover.)

Table 6(a) shows the distribution of 24-hr rainfalls (DD) surrounding 1-hr storms (ID) in quartile I for the 6 areas expressed as a percent of the total number of storm occurrences. Less than 20 percent of the 24-hr rainfalls surrounding the 1-hr storms are in quartile I in the Pacific Northwest (East and West), with the proportion increasing to over 40 percent for the Front Face Rockies (South). Over

Table 4.--Distribution of stations and station years by region and length of record

			Length of record (years)														
Region			15	16	17	18	19	20	21	22	23	24	25	26	27	28	SUM
Pacific Northwest (West)	Stations	Number	4	8	1	8	10	6	8	10	23	19	7				104
		Percent	3.8	7.7	1.0	7.7	9.6	5.8	7.7	9.6	22.1	18.3	6.7				100.0
	Station years	Number	60	128	17	144	190	120	168	220	529	456	175				2207
		Percent	2.7	5.8	0.8	6.5	8.6	5.4	7.6	10.0	24.0	20.7	7.9				100.0
Pacific Northwest (East)	Stations	Number	6	3	2	9	6	5	6	15	10	10	2				74
		Percent	8.1	4.0	2.7	12.2	8.1	6.8	8.1	20.3	13.5	13.5	2.7				100.0
	Station years	Number	90	48	34	162	114	100	126	330	230	240	50				1524
		Percent	5.9	3.1	2.2	10.6	7.5	6.6	8.3	21.7	15.1	15.7	3.3				100.0
Great Basin	Stations	Number	5	3	10	10	2	6	9	5	12	12	11	8	11	2	106
		Percent	4.7	2.8	9.4	9.4	1.9	5.7	8.5	4.7	11.3	11.3	10.4	7.5	10.4	1.9	99.9
	Station years	Number	75	48	170	180	38	120	189	110	276	288	275	208	297	56	2330
		Percent	3.2	2.1	7.3	7.7	1.6	5.2	8.1	4.7	11.8	12.4	11.8	8.9	12.7	2.4	99.9
Southwest Mountains	Stations	Number	1	1	4	7	4	4	2	6	8	7	5	4	2	4	59
		Percent	1.7	1.7	6.8	11.9	6.8	6.8	3.4	10.2	13.6	11.9	8.5	6.8	3.4	6.8	100.3
	Station years	Number	15	16	68	126	76	80	42	132	184	168	125	104	54	112	1302
		Percent	1.2	1.2	5.2	9.7	5.8	6.1	3.2	10.1	14.1	12.9	9.6	8.0	4.1	8.6	99.8
Front Face Rockies (North)	Stations	Number	4	4	1	2	5	7	6	7	12	14	14	6	11		93
		Percent	4.3	4.3	1.1	3.2	5.3	7.4	6.4	7.4	12.8	14.9	14.9	6.4	11.7		100.1
	Station years	Number	60	64	17	54	95	140	126	154	276	336	350	156	297		2125
		Percent	2.8	3.0	0.8	2.5	4.5	6.6	5.9	7.2	13.0	15.8	16.5	7.3	14.0		99.9
Front Face Rockies (South)	Stations	Number	2	6	4	4	4	6	7	2	11	12	17	10	14	2	101
		Percent	2.0	5.9	4.0	4.0	4.0	5.9	6.9	2.0	10.9	11.9	16.8	9.9	13.9	2.0	100.1
	Station years	Number	30	96	68	72	76	120	147	44	253	288	425	260	378	56	2313
		Percent	1.3	4.2	2.9	3.1	3.3	5.2	6.4	1.9	10.9	12.5	18.4	11.2	16.3	2.4	100.0

Table 5.--Joint frequency distribution (number of events) of 24-hr storms (ID) and 12-hr rainfalls (DD) for Front Face Rockies (South)

Rainfall quartile	Storm quartile I	II	III	IV	SUM
I	403	106	1	0	510
II	94	305	116	1	516
III	36	97	314	107	554
IV	7	63	156	507	733
SUM	540	571	587	615	2313

the Front Face Rockies (South), the Great Basin, and Southwest Mountains regions, large short duration precipitation events are frequently associated with convective activity. The 1-hr storm is generally either an isolated event, often contributing substantially to large daily (24-hr) rainfalls or is part of a general storm containing significant shower activity. This is not as true over the more northerly regions where large rains are usually general and more continuous with less convective activity. Table 6(b) illustrates the joint frequency of quartile I 24-hr storms (ID) and the embedded 6-hr rainfalls (DD). For all regions less than 12 percent of the rainfalls are in quartile IV. All regions show at least 45 percent of the 6-hr rainfalls occur in quartile I, with values reaching more than 60 percent within the Front Face Rockies (South). The data in table 6 are derived from the tables in appendix I.

Table 6.--Quartile distribution as a percentage of the total number of events

(a) 24-hour DD when 1-hour ID value is in first quartile

Quartile	Pacific Northwest (West)	Pacific Northwest (East)	Great Basin	Southwest Mountains	Front Face Rockies (North)	Front Face Rockies (South)
I	15.3	18.3	29.4	34.0	20.4	40.9
II	9.8	13.7	26.1	23.1	22.3	29.8
III	9.6	13.7	20.7	22.4	25.7	20.2
IV	65.3	54.3	23.8	20.5	31.6	9.1

(b) 6-hour DD when 24-hour ID value is in first quartile

Quartile	Pacific Northwest (West)	Pacific Northwest (East)	Great Basin	Southwest Mountains	Front Face Rockies (North)	Front Face Rockies (South)
I	49.1	47.7	59.3	55.4	53.0	62.8
II	28.2	24.6	23.5	23.8	26.5	20.5
III	14.9	16.3	12.0	13.5	14.4	11.5
IV	7.8	11.4	5.2	7.3	6.1	5.2

As expected, smaller storms and rainfalls tend to be associated, no matter what durations are involved. Table 7 shows the simultaneous occurrence of quartile IV storms and rainfalls of all 18 tables in appendix I (next to last column, next to last row) converted to percent. The quartile IV percentage exceeds 70 for all duration combinations for all 6 areas. The largest simultaneous occurrence is 89.8 percent for the 2-hr storm and the 3-hr rainfall for the Front Face Rockies (South). All areas have at least one coincidence of at least 85 percent.

Table 7.--Percent of concurrent storms and rainfalls of quartile IV

	Pacific Northwest (West)					
ID / DD	1	2	3	6	12	24
1		82.0	83.8	85.7	84.7	85.4
2	75.4		84.0	83.7	83.2	83.0
3	75.4	82.5		81.8	79.6	81.1
6	77.0	78.9	79.7		82.5	79.6
12	79.9	77.1	78.4	79.2		79.0
24	80.2	81.4	79.9	78.0	81.3	

	Pacific Northwest (East)					
ID / DD	1	2	3	6	12	24
1		80.3	82.0	82.0	85.0	83.3
2	75.1		83.5	79.6	81.5	83.3
3	73.2	83.7		77.8	79.3	79.6
6	74.9	76.6	76.6		75.6	73.4
12	78.6	77.6	76.6	81.5		79.1
24	78.6	80.5	79.8	76.8	83.3	

	Great Basin					
ID / DD	1	2	3	6	12	24
1		82.5	79.6	79.6	77.4	76.7
2	82.5		83.8	76.8	75.5	75.5
3	79.6	83.5		81.1	75.5	75.8
6	80.0	78.0	84.8		81.4	76.9
12	81.7	79.3	79.0	86.2		82.4
24	80.3	79.2	79.0	83.0	87.7	

	Southwest Mountains					
ID / DD	1	2	3	6	12	24
1		78.0	74.6	75.7	76.9	77.2
2	79.8		83.5	73.7	76.3	75.1
3	78.3	86.7		75.7	73.4	71.7
6	79.2	79.8	83.2		79.8	74.0
12	81.5	80.1	79.5	84.1		78.3
24	82.9	80.1	78.9	80.3	83.2	

	Front Face Rockies (North)					
ID / DD	1	2	3	6	12	24
1		78.9	76.2	74.8	75.7	75.3
2	78.5		81.7	72.8	73.2	72.5
3	76.6	84.7		77.1	73.2	72.3
6	77.3	78.9	80.3		77.4	74.4
12	78.2	77.1	78.9	81.9		80.3
24	78.0	77.3	79.6	79.2	85.3	

	Front Face Rockies (South)					
ID / DD	1	2	3	6	12	24
1		79.8	77.4	72.4	73.7	72.7
2	84.4		84.6	73.5	72.2	70.9
3	83.9	89.8		79.2	74.5	72.0
6	80.8	82.1	84.9		82.1	75.6
12	82.0	79.5	80.5	87.8		82.4
24	82.1	78.0	80.3	83.7	85.5	

Table 8 shows that the relative frequency of large storms and rainfalls (quartile I) that occur simultaneously is as high as 88 percent (at ID = 2, DD = 3, Front Face Rockies (South)). However, percentages decrease rather rapidly away from the table diagonal, reaching 15.3 percent at ID = 1, DD = 24, Pacific Northwest (West). The average for the 10 values adjacent to the diagonal ranges from 79.4 percent for the Front Face Rockies (South) to 66.7 percent for the Pacific Northwest (West).

Table 7 indicates that small storms and rainfalls tend to occur at the same time regardless of the difference in time interval between the durations. In contrast, table 8 indicates large storms and rainfalls occur at the same time only when their respective durations differ by only a few hours. While there are only minor regional differences in the simultaneous occurrence of small storms and rainfalls, the regional differences are greater for the larger storms. Over the three southern regions common occurrences tend to be somewhat more frequent for durations separated by more than a few hours than they are for the more northerly regions. They can exceed 50 percent at durations separated by as much as 21 hours (ID = 3, DD = 24, Front Face Rockies (South)).

Table 8.--Percent of concurrent storms and rainfalls of quartile I

	Pacific Northwest (West)					
ID / DD	1	2	3	6	12	24
1		63.4	49.5	29.4	22.3	15.9
2	61.1		75.1	52.3	38.0	25.4
3	46.4	74.0		65.8	47.0	31.1
6	28.4	51.1	65.2		66.7	49.1
12	21.1	37.8	46.8	65.9		64.0
24	15.3	25.2	31.1	48.1	65.9	

	Pacific Northwest (East)					
ID / DD	1	2	3	6	12	24
1		72.0	62.6	39.1	26.9	19.7
2	71.4		83.4	54.0	36.9	28.3
3	62.3	84.6		64.6	46.6	34.3
6	38.9	52.3	62.3		67.7	47.7
12	26.0	33.7	42.9	66.9		62.9
24	18.3	26.6	31.7	49.7	64.6	

	Great Basin					
ID / DD	1	2	3	6	12	24
1		73.4	63.8	49.0	37.9	28.8
2	74.5		83.2	65.4	49.2	38.4
3	64.0	83.5		75.2	56.4	45.8
6	48.6	64.1	74.5		73.2	59.3
12	36.8	48.2	56.4	74.5		72.5
24	29.4	37.0	44.5	60.8	75.6	

	Southwest Mountains					
ID / DD	1	2	3	6	12	24
1		78.9	71.0	56.8	40.3	33.7
2	81.2		87.5	69.6	49.8	40.9
3	74.3	87.5		76.6	55.4	46.2
6	58.7	69.3	76.2		70.0	55.4
12	41.9	50.2	56.1	71.3		71.0
24	34.0	40.6	45.1	55.1	72.9	

	Front Face Rockies (North)					
ID / DD	1	2	3	6	12	24
1		74.1	62.3	44.1	27.7	20.4
2	74.7		82.4	59.7	38.3	28.5
3	62.8	81.8		69.6	45.3	34.6
6	44.5	58.9	70.0		68.2	53.0
12	28.7	37.4	46.2	69.2		72.7
24	20.4	27.7	34.6	52.4	73.1	

	Front Face Rockies (South)					
ID / DD	1	2	3	6	12	24
1		74.4	67.8	57.6	47.6	39.4
2	75.4		87.2	70.9	57.8	47.0
3	68.9	88.0		78.3	64.1	53.1
6	58.5	72.8	80.2		79.3	62.8
12	49.3	59.6	65.7	80.7		74.6
24	40.9	49.1	54.4	64.3	76.3	

STORM/RAINFALL RELATIONS BY RATIO

Concurrent storms and rainfalls were compared by forming a ratio of the shorter duration (either ID or DD) to the longer duration (either ID or DD) precipitation event. This was done for each ID-DD combination for quartiles I and IV. Cumulative (empirical) probability distributions of this ratio for each region were examined. As an example, figure 2 shows the accumulated probability of the 1-hr ID/24-hr DD for the Pacific Northwest (East). There is considerable difference between the cumulative probability of the ratio for the larger storms (quartile I) and the smaller storms (quartile IV). As shown by the dashed lines, quartile IV 1-hr storms are 21 percent or more of the concurrent 24-hr rainfall 80 percent of the time, while quartile I storms are 44 percent of the concurrent 24-hr rainfall 80 percent of the time (i.e., the heavier 1-hr storms make a larger contribution to the 24-hr rainfalls). This means the probability is 0.80 that the 24-hr rainfall associated with the quartile I 1-hr storm will be no more than 2.27 times that 1-hr value (1.00/0.44 = 2.27). Furthermore, the probability is only a 0.20 that the 24-hr rainfall will exceed 2.27 times the 1-hr value.

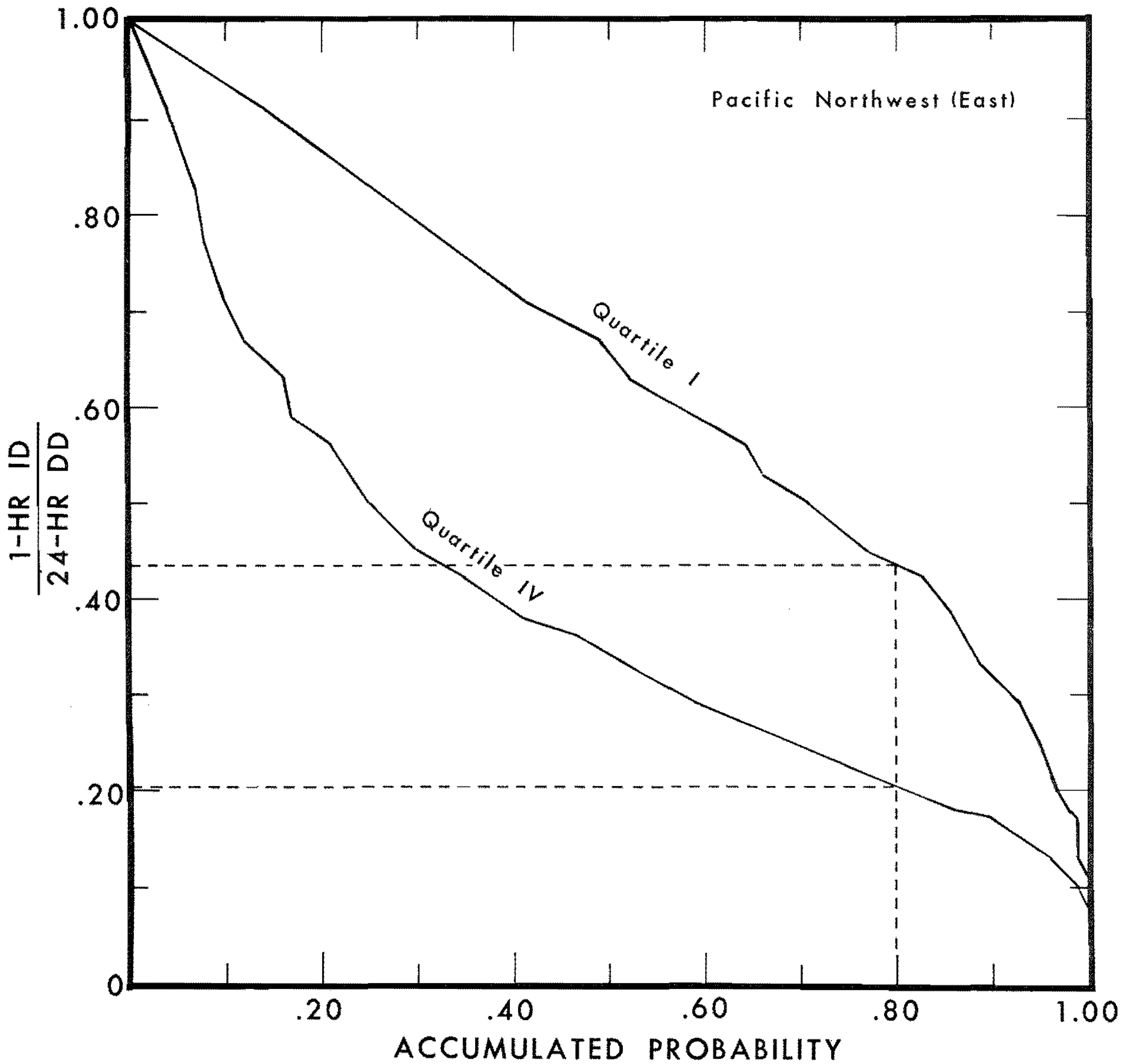

Figure 2.--Accumulated probability for ratio 1-hr ID/24-hr DD by quartiles for Pacific Northwest (East).

Accumulated probability figures for each storm duration for quartiles I and IV make up appendix II. All prescribed DD possibilities are shown for each ID. The curves in appendix II for each area have been subjectively smoothed and have been checked to insure that the accumulated probability curves for the various ID/DD ratios provide incremental rainfall amounts that smoothly decrease with time. Interpolation between the curves of quartiles I and IV to estimate quartile II and III relations is appropriate.

COMPARATIVE SEASONALITY OF STORMS

To study seasonal variations, the month of occurrence of storms for each area, duration, and quartile was tabulated. Month of occurrence was defined as the month in which the first hour of precipitation fell. The results are shown in appendix III. (See fiche Number 2 in pocket on inside rear cover.) Inspection of the 144 graphs making up the appendix indicated enough differences to preclude combining quartiles to simplify their study.

Figures 3(a)-3(f) depict the fraction of the total number of 1- and 24-hr quartile I and IV storms that occurred in each month for all six areas under consideration. For quartile I storms, except for the Pacific Northwest (West), the 1-hr storm attains a maximum in summer that is larger than that for the 24-hr storm. But, for all other areas, the 24-hr storm generally occurs more frequently than the the 1-hr storm in quartile I for all but 2 or 3 summer months. These 1-hr storms are usually the result of heavy convective precipitation associated with summer thundershowers. West of the Cascades, where thunderstorms are infrequent, cyclonic storms during the late fall and winter months produce the heaviest 24-hr precipitation as reflected in figure 3(a). The quartile IV storms generally show considerably less seasonal variation than quartile I storms. Also, the variation between the two storm durations in quartile IV is not as large as that observed in quartile I.

Figures 4(a)-4(f) each show four curves, two for quartile I and two for quartile IV. One of the two curves for each quartile represents the winter months of December, January and February, while the other represents the summer months of June, July and August. These curves depict the percentage of quartile I or IV storms for each duration that occur during the winter or summer season, e.g., of the 350 quartile IV 1-hr storms in the Pacific Northwest (West) 48 percent, or 168 storms, occurred in the winter season, and 26 percent of the 406 quartile I storms occurred in this season.

For all areas except the Pacific Northwest (West), the summer season quartile I storms show the largest percentages of any of the curves from ID = 1 through at least ID = 12 and through ID = 24 if the Pacific Northwest (East) is excluded. The winter season curves (quartiles I and IV) result in the largest percentages in the Pacific Northwest (West), although these percentages are not as large as those for quartile I in the summer season for the other five areas at ID = 1, 2, and 3. In the Pacific Northwest (West) at ID = 1, quartile I, the summer season percentage is nearly as large as that for the winter season.

The Pacific Northwest (East) appears to be a transition zone between the area west of the Cascades and the remaining four areas. Figure 4 (as well as figure 3) shows that the heavier storms (quartile I), at least at the shorter durations, have a summertime peak, indicating the influence of convection. The 24-hr quartile I storms are somewhat more likely in winter. This is due to the late fall-early winter peak in large scale cyclones that move eastward across the coast. On the other hand, the smaller quartile IV storms are more strongly influenced by these general storms, with only ID = 1 hr showing more summer than winter storms.

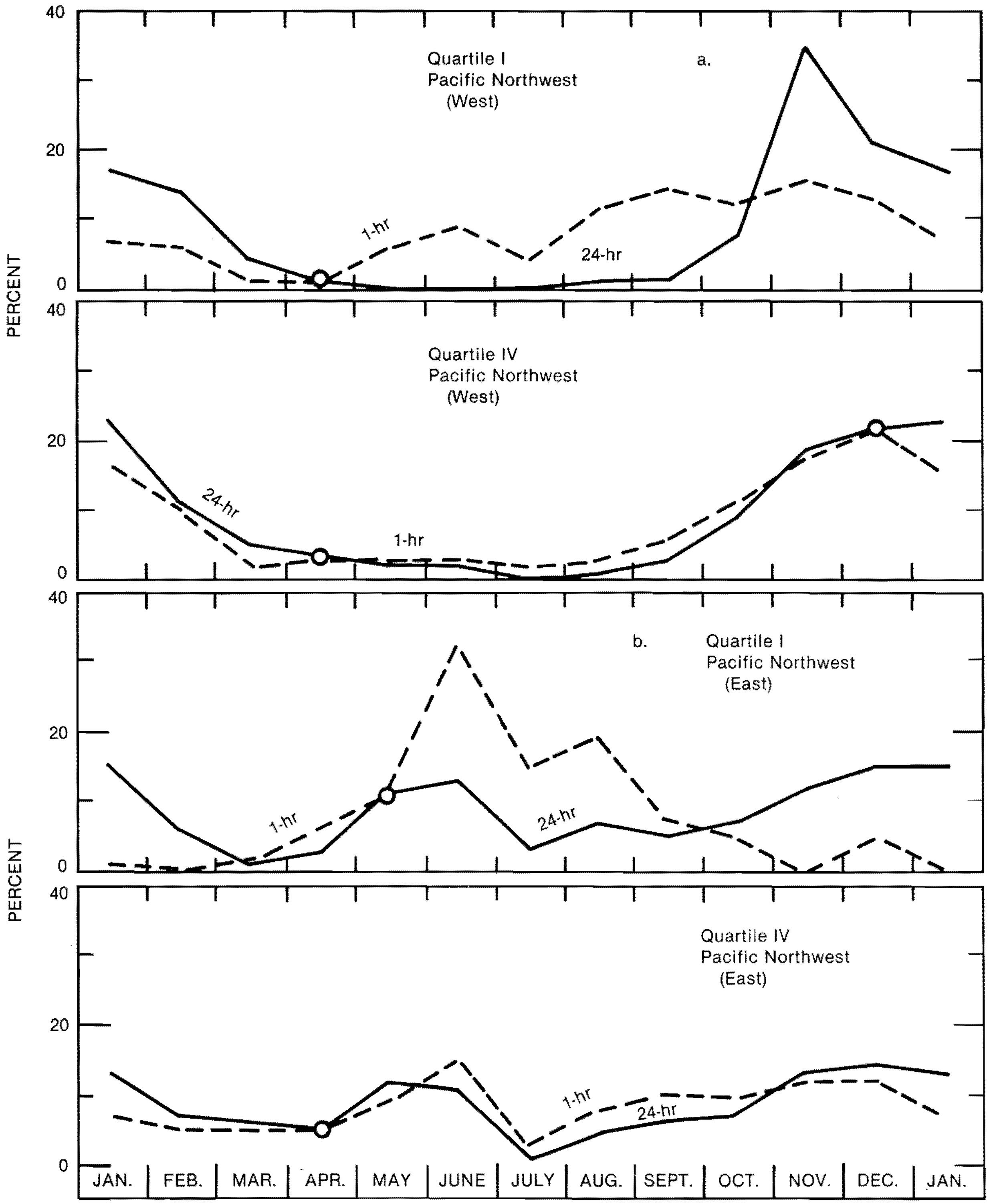

Figure 3.--Monthly distribution of annual maximum 1-hr (dashed line) and 24-hr (solid line) storms (ID) for quartiles I and IV for (a) Pacific Northwest (West), (b) Pacific Northwest (East), (c) Great Basin, (d) Southwest Mountains, (e) Front Face Rockies (North), and (f) Front Face Rockies (South).

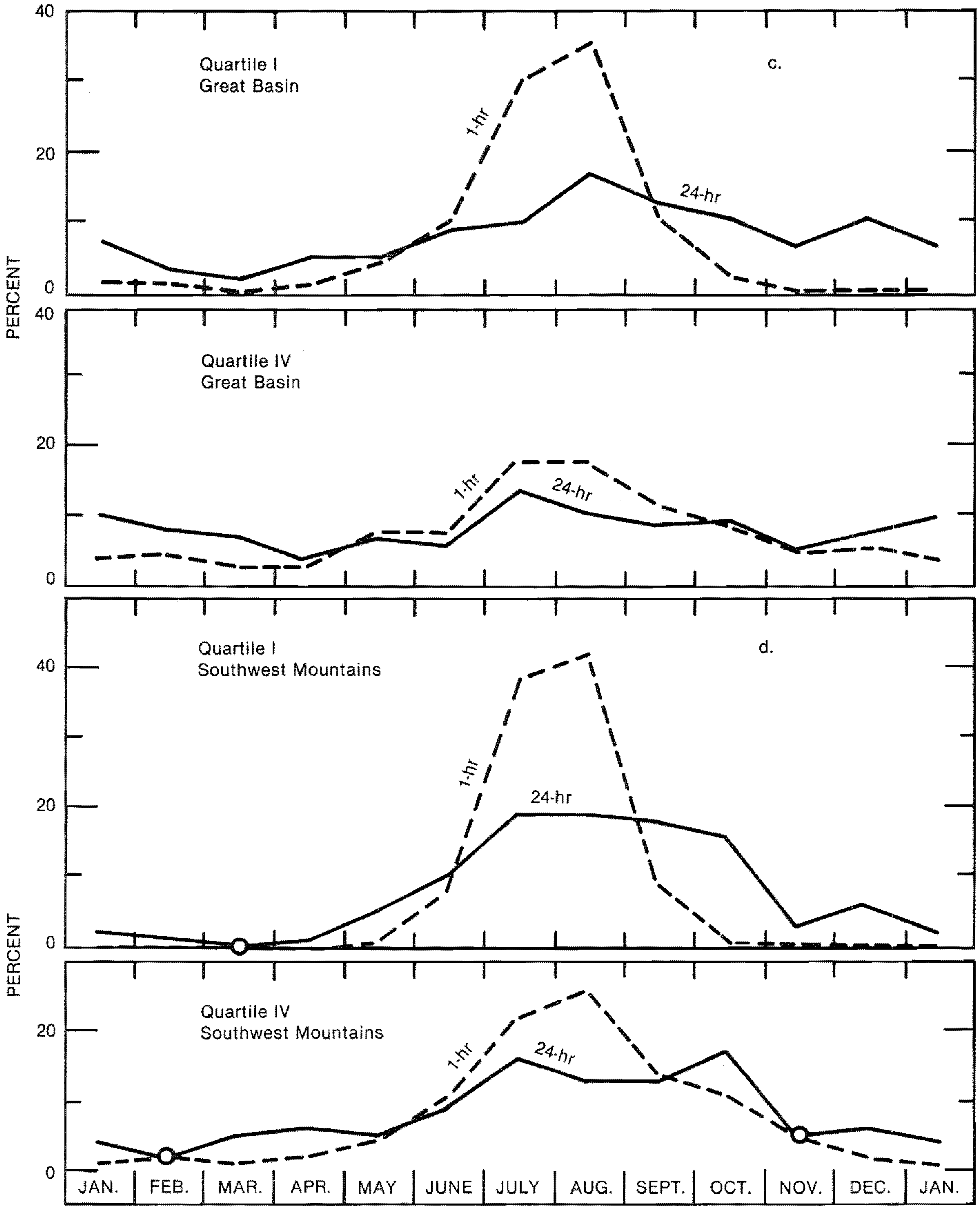

Figure 3 - continued

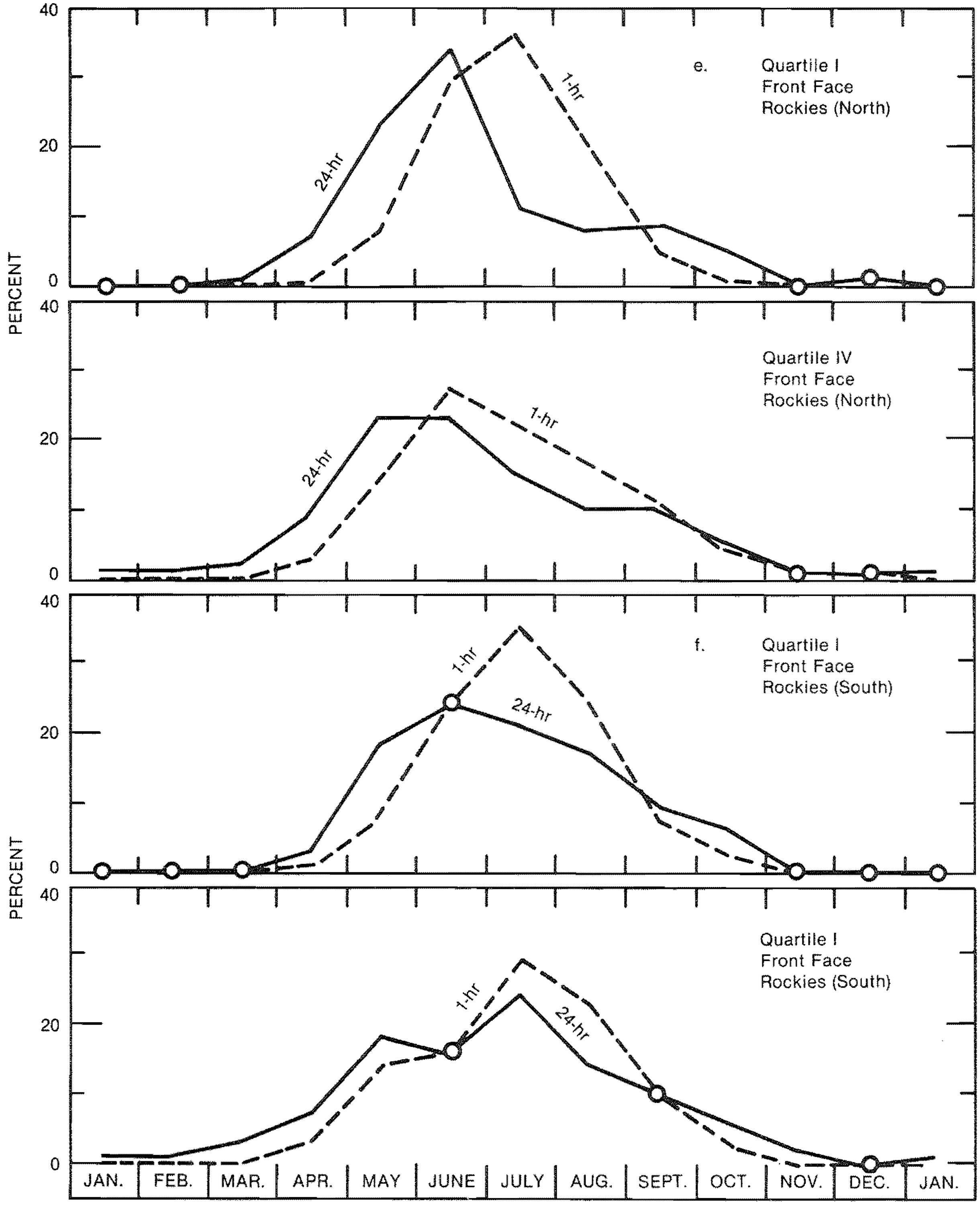

Figure 3 - Continued

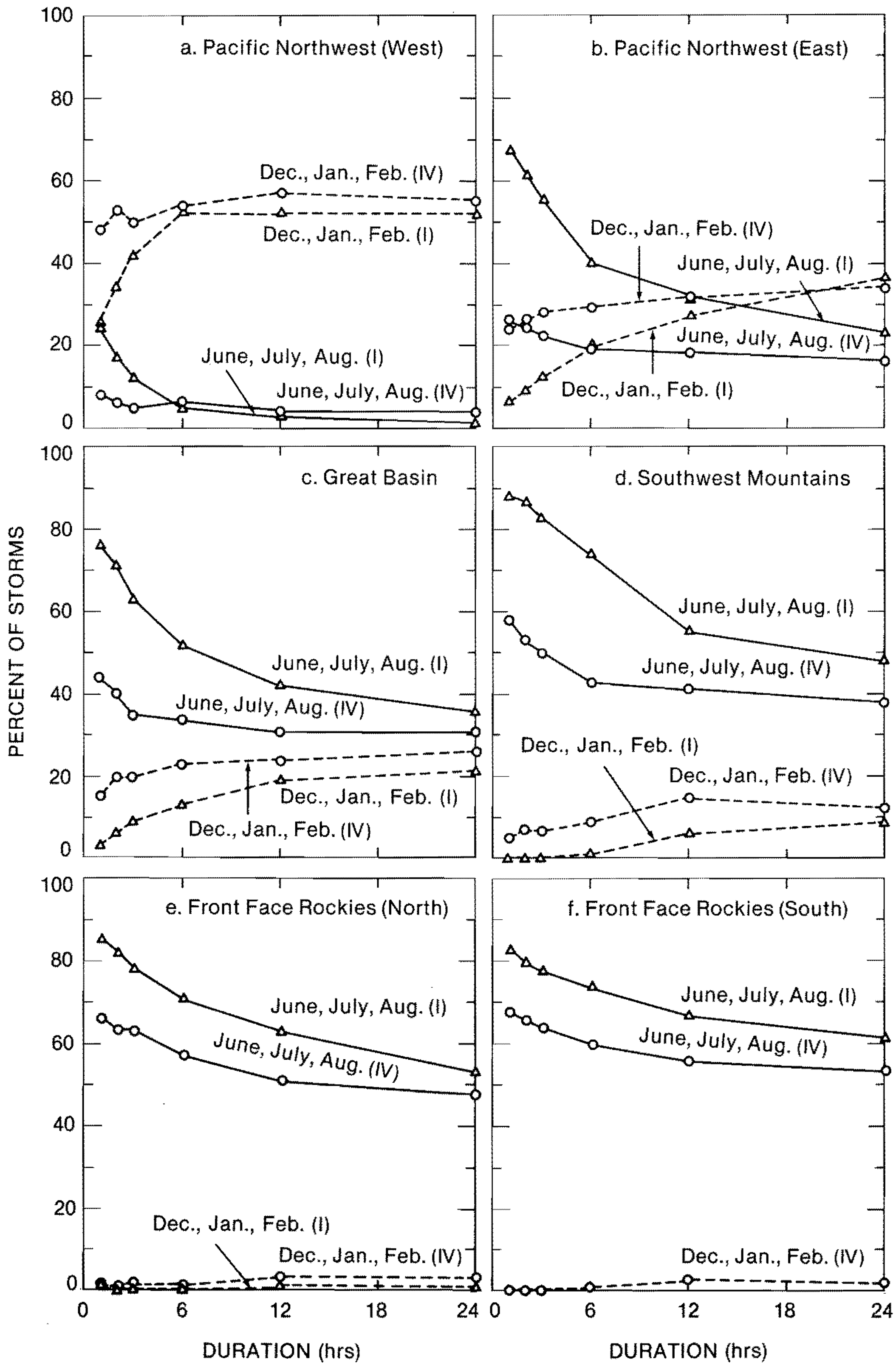

Figure 4.--Percentage of quartile I or IV storms that occur during the winter or summer season for each area.

The areas outside the Pacific Northwest (figs. 4(c)-4(f)) show similar patterns. First, the two summer season curves exceed the two winter season curves. Second, whereas the quartile I summer season curves show higher percentages than the quartile IV summer season curves, the quartile IV winter season curves exceed those for quartile I. In these four areas, summertime convective storms produce the heaviest rains of the year more often than wintertime cyclonic storms. In the Front Face Rockies (South), quartile I storms occur less than 0.5 percent during the winter season. For this area, almost all storms occur in the spring, summer, or fall with more than 60 percent of quartile I storms at all durations occurring in June, July and August.

DIFFERENCES BETWEEN STORMS AND RAINFALLS

Table 9 illustrates some differences between storms and rainfalls in quartiles I and IV for the six areas. The top part of the table addresses the question: How likely is it that a storm (or rainfall) has precipitation in each of the hours? It is more likely that all hours contain some precipitation in the Pacific Northwest (West) than the other areas and, of course, less likely as duration increases. At ID = 12 and ID = 24, quartile I storms are more likely than quartile IV storms to have precipitation in each of the hours but even then the possibility is less than one-in-four ID = 24 except in the Pacific Northwest (West) where the probability is nearly three-in-four. For all quartiles, at ID = 6, the probability exceeds seven-in-ten in the Pacific Northwest and more than two-in-five in all other areas except the Front Face Rockies (South), quartile IV. Most 24-hour rainfalls surrounding the 1-hr storm do not have precipitation in all 24 hours. The Pacific Northwest (West) shows the strongest tendency for precipitation in all 24 hours due to the fact that most annual storms/rainfalls occur in late fall-early winter as the result of widespsread precipitation associated with large scale cyclones.

What fraction of the storm or rainfall hours contain measurable precipitation? The middle part of table 9 illustrates this quantity. The Pacific Northwest (West) exceeds the other areas in hours with measurable precipitation. This again shows the storms and rainfalls west of the Cascades typically extend over periods of a day (or more), as opposed to the intermittent, convective, thunderstorm variety that contributes significantly to heavy precipitation events elsewhere. More than 98 percent of the hours in 6-hr storms and 88 percent of the hours in 24-hr storms have measurable precipitation in the Pacific Northwest (West), compared with 73 and 43 percent as the minima for the other five areas. Typically, for all areas, the 24-hr rainfalls have smaller proportions of hours with measurable precipitation than 12-hr rainfalls which in turn have smaller proportions of hours with measurable precipitation than 6-hr rainfalls.

The bottom part of table 9 investigates trailing zeros (see "Definition of Terms"). Once again, the Pacific Northwest (West) leads the other areas in the highest percentage of storms and rainfalls with no trailing zeros. In all areas except the Pacific Northwest, (both East and West) the 12-hr rainfalls associated with 1-hr storms in quartile I register the lowest percentages. Both ID = 1, DD = 6 and ID = 1, DD = 24 combinations give higher values. In the Pacific Northwest, the ID = 1, DD = 24 combination yields the lowest percentages.

Figures 5(a)-5(1) illustrate differences between 24-hr storms and rainfalls for quartiles I and IV as well as differences in precipitation climatology over the western United States. These figures show the cumulative probability that 24-hr storms or rainfalls have a certain number of hours without precipitation. Data

Table 9.--Differences between storms and rainfalls

	ID	DD	Pacific Northwest (West) Quartile I	IV	Pacific Northwest (East) Quartile I	IV	Great Basin Quartile I	IV	Southwest Mountains Quartile I	IV	Front Face Rockies (North) Quartile I	IV	Front Face Rockies (South) Quartile I	IV
Percent of	24	--	73.5	33.7	22.3	6.2	13.5	4.3	9.6	5.8	16.6	5.3	11.3	3.7
storms-rainfalls	1	24	16.3	18.0	0.9	3.0	1.3	1.3	0.3	0.9	1.6	2.1	1.1	0.5
with measurable	12	--	85.5	57.7	53.7	36.5	34.6	18.8	28.4	19.1	45.5	24.5	25.2	19.5
precipitation	1	12	39.6	47.8	5.4	14.3	3.3	7.5	1.0	7.2	3.8	9.8	2.4	4.1
in all of the	6	--	96.5	95.9	70.0	70.7	53.0	46.6	40.9	41.6	55.9	51.3	46.9	36.6
N-hours	1	6	60.0	76.5	22.3	44.8	17.2	24.5	10.6	35.4	14.6	27.4	20.2	19.5
Percent of	24	--	97.0	88.6	75.2	61.4	61.4	44.7	59.2	47.3	70.1	51.6	56.5	43.0
storm-rainfall	1	24	62.2	71.9	31.3	44.2	24.2	30.4	24.2	30.8	26.1	33.6	26.4	27.0
hours with	12	--	99.2	96.7	84.3	81.4	72.3	62.1	68.6	63.5	80.4	68.1	66.7	60.2
measurable	1	12	74.0	84.1	45.0	38.4	37.3	45.6	35.5	45.3	35.3	37.6	40.5	41.2
precipitation	6	--	99.0	98.9	88.7	90.1	82.2	79.2	76.2	77.9	82.9	80.0	80.8	73.8
	1	6	84.1	92.8	63.0	78.4	58.7	64.3	56.8	63.2	57.1	63.9	64.5	61.6
Percent of	24	--	93.5	81.3	60.9	42.4	45.3	25.2	46.5	28.6	52.6	34.1	45.1	29.1
storms-rainfalls	1	24	54.3	64.1	17.7	26.1	18.9	17.5	21.5	19.4	22.1	20.1	18.5	18.0
with no trailing	6	24	77.5	69.8	33.4	27.8	26.4	20.2	25.4	24.9	25.6	24.2	24.3	21.5
zeros	12	--	97.6	91.6	69.4	61.8	53.6	42.0	52.8	45.7	66.8	49.2	45.4	40.2
	1	12	75.1	79.2	26.3	41.9	13.1	28.6	13.2	26.3	18.2	29.7	14.6	20.0
	6	12	92.2	85.4	48.6	47.0	37.0	34.3	31.4	34.1	44.5	38.7	28.0	27.6
	6	--	98.2	97.4	80.0	79.3	62.8	61.1	53.8	56.9	66.8	63.6	58.0	50.1
	1	6	75.3	86.9	39.7	61.3	27.9	40.1	25.4	40.2	28.3	41.9	33.5	31.7

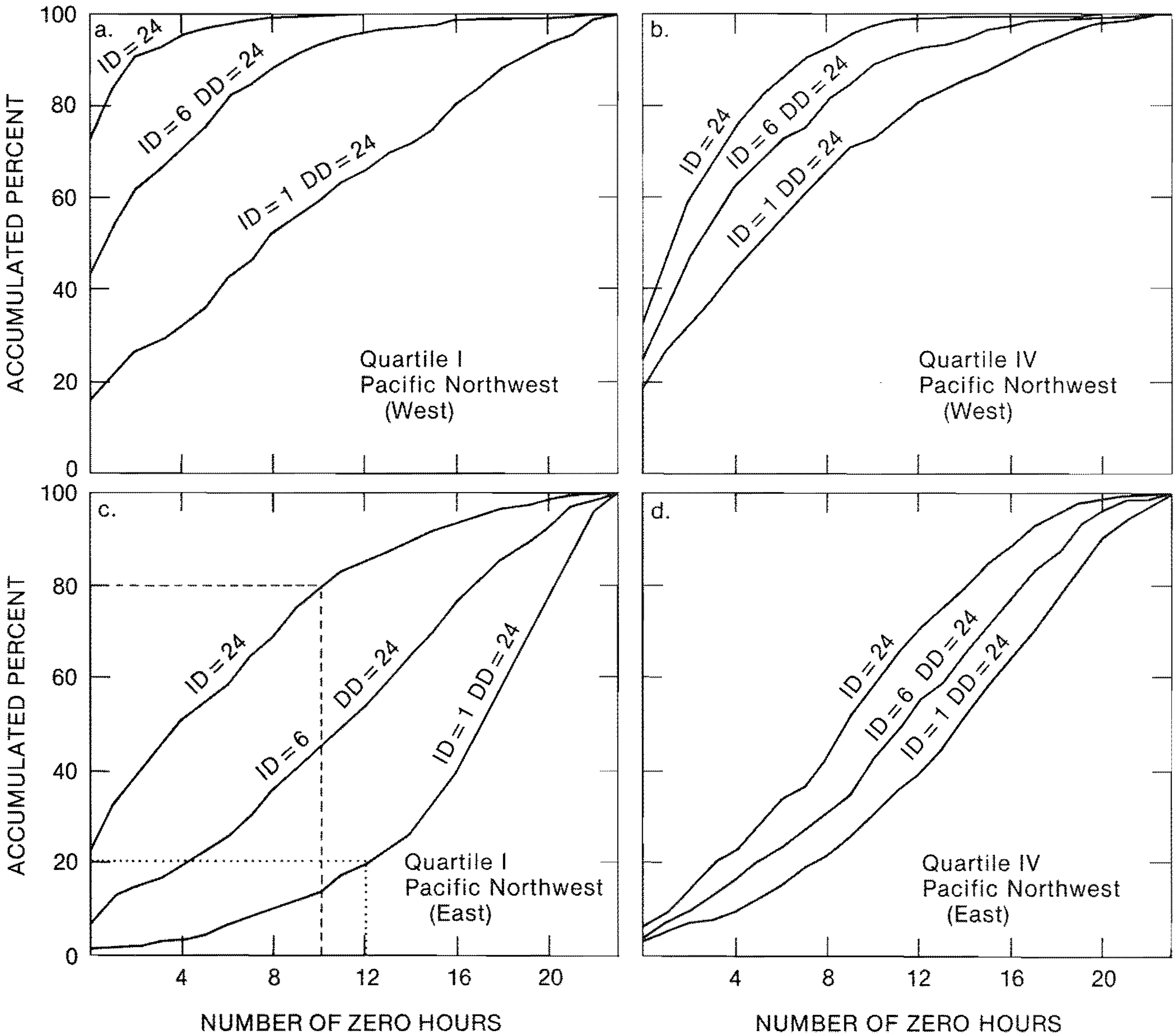

Figure 5--Accumulated percentage of 24-hr storms and rainfalls by count of hours without measurable precipitation

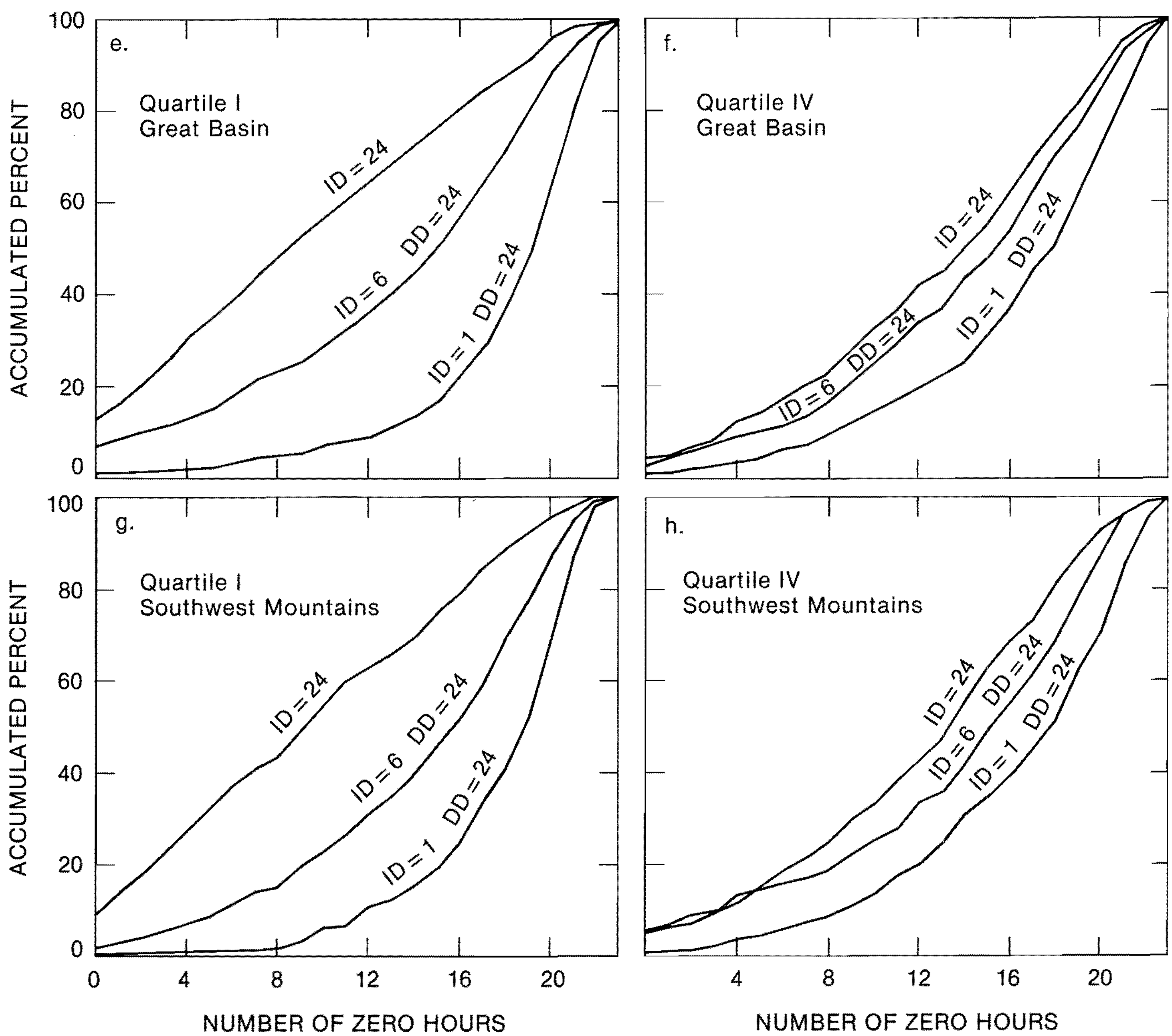

Figure 5 - continued

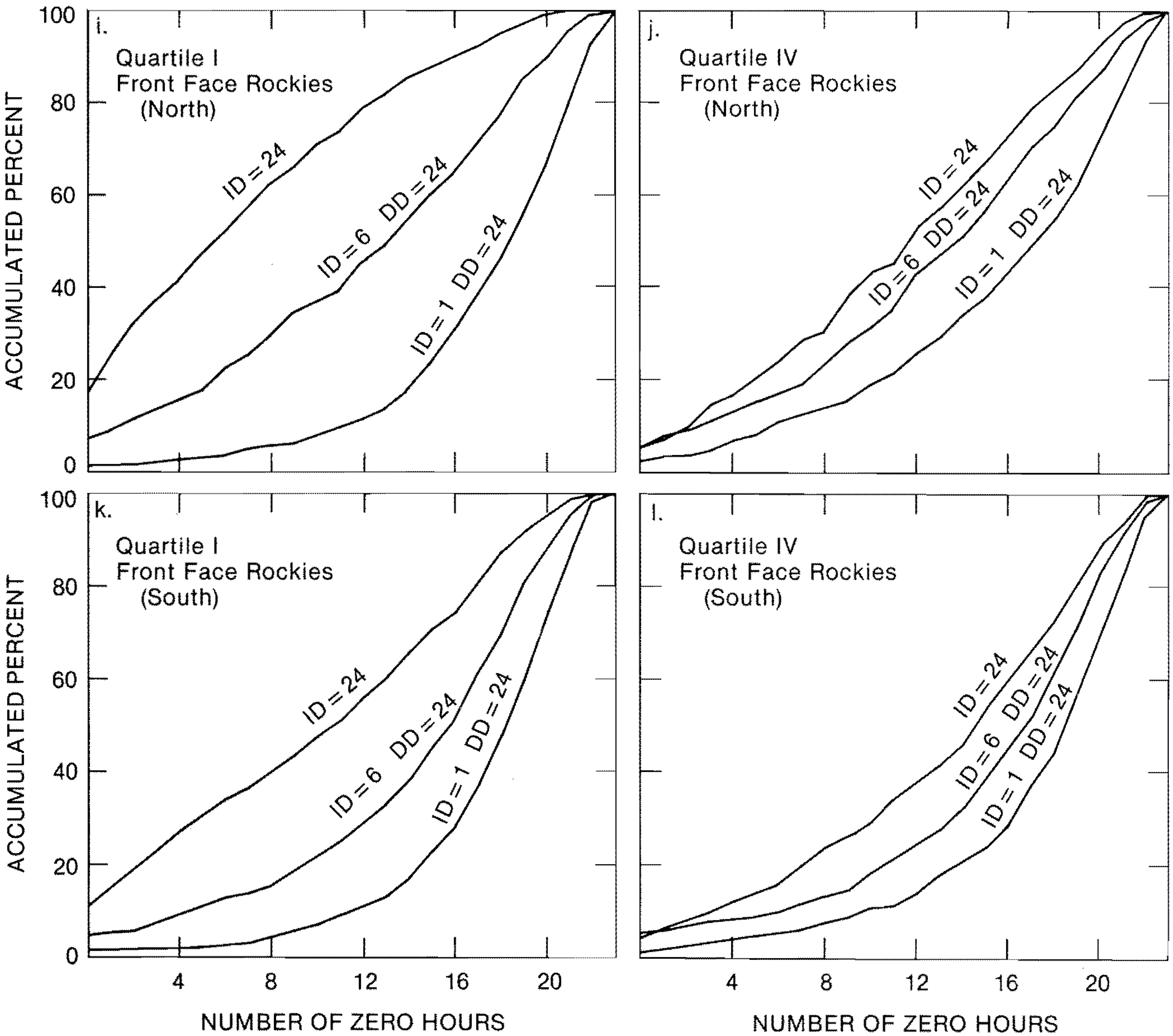

Figure 5 - continued

are extracted from the figures in the following manner: In figure 5(c), 20 percent of the 24-hr rainfalls concurrent with 1-hr storms have about 12 or fewer hours without precipitation. The figures show that the Pacific Northwest (West) has the fewest hours without precipitation for 24-hr storms and 24-hr rainfalls concurrent with 1- and 6-hr storms. The Pacific Northwest (East) has the next fewest hours followed by the Front Face Rockies (North). The three southernmost areas have the most hours without precipitation. For all six areas, the curves in quartile I are more spread apart than those in quartile IV. For 24-hr storms, the number of zero hours increases or stays the same at the same percentage as we move from quartile I to quartile IV (curves displaced to the right). In contrast, for 24-hr rainfalls concurrent with 1-hr storms, the number of zero hours decreases or remains constant in moving from quartile I to quartile IV.

TIME DISTRIBUTION OF PRECIPITATION IN STORMS AND RAINFALLS

Storms and rainfalls in this report have measurable precipitation during their first hour. Any hours without precipitation needed to complete the N-hour period would be at the end of the period (trailing zeros). In order to construct relations of precipitation vs. time, we need to establish a time sequence to accompany precipitation increments. Our approach was to tabulate, by quartiles, the time of occurrence of the beginning of the shorter duration precipitation event within the longer duration event for all ID-DD combinations. Since all storms and rainfalls do not have measurable precipitation in the final hour(s), the actual length of the precipitation for 6-, 12-, and 24-hr events was tabulated by counting the number of trailing zeros. By combining these two tabulations, we were able to analyze the time distribution in an attempt to define "typical" patterns for the six regional areas.

The first step determines the frequency distribution of the starting hour of the shorter duration within longer duration precipitation events by simple conversion to percentages of occurrences for each hour. To illustrate, of 624 quartile IV storms in the Great Basin, 72 had the maximum annual 3-hr storm begin during the third hour of the surrounding 6-hr rainfall. Thus, 72/624 = .1153 is the observed frequency for that hour as shown on the line of table 10 labeled "Observed."

In order to better explain observed frequencies, the statistical effects of trailing zeros must be isolated. For example, if the last four hours of the associated 6-hr rainfall have no precipitation (four trailing zeros), the 3-hr storm cannot begin in the third hour, but must begin in the first or second hour. Continuing this example, an expected frequency of the timing of the 3-hr storm within 6-hr rainfalls based on a uniform distribution of the 3-hr storms within the period during which precipitation actually fell is determined. The observed and expected frequencies are then compared.

Table 10 illustrates this procedure for 3-hr storms within surrounding 6-hr rainfalls of quartile IV for the Great Basin. The second column of table 10 lists the total number of rainfalls with 0 to 2, 3, 4 and 5 trailing zeros. In the first column, rainfalls with 0, 1, and 2 trailing zeros (precipitation in all hours, all but the 6th hour, and all but the 5th and 6th hours) are combined because a 3-hr storm cannot begin in the 5th or 6th rainfall hour of a 6-hr rainfall. For 1-hr storms surrounded by 6-hr rainfalls, there would be six rainfall hour columns and separate listings for trailing zero categories 0, 1 and 2. The third column of table 10 shows the fraction of rainfalls having the number of trailing zeros indicated. For this example, there are 469 rainfalls that have 0-2 trailing zeros out of 624 rainfalls. Thus, 469/624 = 0.7516. If the chance of precipitation

Table 10.--Example of time distribution analyses using 3-hr quartile IV storms surrounded by 6-hr rainfalls for the Great Basin study area

Trailing zeros	Number of rainfalls in ea. category = 624	Fraction of rainfalls =1.0000	Uniform probability Rainfall hours 1	2	3	4
0,1,2	469	0.7516	0.1879	0.1879	0.1879	0.1879
3	67	0.1074	0.0358	0.0358	0.0358	
4	60	0.0962	0.0481	0.0481		
5	28	0.0448	0.0448			
		"Expected" (E)	0.3166	0.2718	0.2237	0.1879
		"Observed" (O)	0.5593	0.1891	0.1153	0.1362
		Ratio (O/E)	1.77	0.69	0.51	0.72

starting in any given hour is assumed to be the same, a uniform distribution of 0.7516 over 4 hours would yield a probability of 0.1879 for each hour (rest of top row). Rainfalls with three trailing zeros (second row) can have precipitation in only the first 3 hours, so in this case their fraction (0.1074) is divided into three equal parts, not four. The numbers in the other two rows are developed through similar reasoning. The sum of each hour's uniform probabilities determines the figures in the "Expected" line. The bottom line shows the observed-expected (O/E) ratio. O/E ratios greater than one indicate that the observed precipitation occurred more often than would be expected if the precipitation were distributed uniformly over the hours that actually contained precipitation. In general, higher O/E ratios indicate hours when precipitation is most likely. But those O/E ratios that were large primarily because the expected probability was very small (i.e., mostly trailing zeros) were generally eliminated from consideration. The highest ratio is interpreted as signifying the most likely beginning hour for the 3-hr quartile IV storm in a 6-hr rainfall 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 first hour in the present example.

This same procedure was used for all ID-DD combinations containing 6-, 12-, 24-hr durations for quartile I and quartile IV storms. Table 11 shows, for the six study areas, the most likely beginning hour of the shorter duration DD or ID within longer duration ID or DD for quartile I. Table 12 illustrates the same type of time sequence for quartile IV. The numbers below and to the left of the diagonals in tables 11 and 12 are the most likely beginning hours for storms within longer duration rainfalls, while those above and to the right of the table diagonals are the most likely beginning hours of the rainfalls within longer duration storms. For combinations of 3 hours or less, the observed data were determined to be all that were needed to discern the most likely beginning hour; therefore normalization in the style of table 10 was not undertaken.

Tables 11 and 12 are not based solely on O/E ratios. Other factors were also used in determining the adopted time distributions. All durations (1, 2, 3, 6, 12 and 24 hours) are assumed to represent one-burst storms and rainfalls. This means that the shorter duration storms or rainfalls are nested within the longer duration storms and rainfalls. For those regions and ID-DD combinations that had two bursts in their statistics, the hour with the next highest O/E ratio was generally selected if it ensured an internally consistent single-burst storm or rainfall. For example, in the Southwest Mountains area (quartile IV) the most likely beginning hour of the 3-hr rainfall within the 24-hr storm is hour 22. But the

Table 11.--Most likely beginning hour of shorter duration storm (ID) or rainfall (DD) within longer duration rainfall or storm, quartile I

Pacific Northwest (West)

ID / DD	1	2	3	6	12	24
1		1 or 2	2	4 or 5	10	12
2	1		1 or 2	4	9 or 10	12
3	1	1		4	8 or 9	11 or 12
6	1	1	1		7	10
12	1	1	6	6		10
24	1	1	17	16	13	

Pacific Northwest (East)

ID / DD	1	2	3	6	12	24
1		1	1	1 or 2	2	1
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	

Great Basin

ID / DD	1	2	3	6	12	24
1		1	1	1 or 2	1 or 2	1 or 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	

Southwest Mountains

ID / DD	1	2	3	6	12	24
1		1	1	1 or 2	1 or 2	1
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.--Most likely beginning hour of shorter duration storm (ID) or rainfall (DD) within longer duration rainfall or storm, quartile I (continued)

Front Face Rockies (North)

ID / DD	1	2	3	6	12	24
1		1	1	1 or 2	1 or 2	1 or 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	

Front Face Rockies (South)

ID / DD	1	2	3	6	12	24
1		1	1	1 or 2	1 or 2	1 or 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	

most likely beginning hour for the 2-, 6-, and 12-hr rainfalls is hour 1. We did not select hour 22 for the 3-hr rainfall because it did not encompass the 2-hr rainfall nor would it be encompassed by the 6- and 12-hr rainfalls. We therefore chose hour 1 (the second most likely beginning hour) as the most likely beginning hour for the 3-hr rainfall within the 24-hr storm.

Each of the 6 areas in tables 11 and 12 contains at least 1 double entry, e.g., "1 or 2", "9 or 10", etc. Such entries indicate approximately equal probabilities. Thus, a synthesized storm using either hour would be acceptable.

Tables 11 and 12 are to be used as guides in constructing precipitation vs. time relations. Hourly events can all be placed as shown in the tables. Any hours not specifically assigned values, e.g., the 11th and 12th hours of a 12-hr storm can have their remaining amounts distributed linearly. That is, these 2 hours could each have one-sixth the difference between the 12-hr value and the 6-hr value. In spite of the fact that storms and, particularly, rainfalls typically contain hours without precipitation, the precipitation amounts remaining to be spread over the remaining hours are generally small. From a hydrological standpoint, it makes little difference whether the precipitation is spread evenly over some hours with no precipitation because the runoff should not be much different once the steep portion of the precipitation vs. time relation or hyetograph is fixed.

When hydrologically critical, precipitation vs. time relations using a time distribution varying (by a few hours) from those in tables 11 and 12 would not be impractical as long as the distribution remains internally consistent. Our recommended distributions are what we consider to be "most likely." They generally have a higher probability of occurrence than most other possibilities.

Table 12.--Most likely beginning hour of shorter duration storm (ID) or rainfall (DD) within longer duration rainfall or storm, quartile IV

Pacific Northwest (West)

ID / DD	1	2	3	6	12	24
1		1 or 2	2	5	10 or 11	20
2	1 or 2		1 or 2	4 or 5	10	19
3	2	1 or 2		4	9	19
6	2	2	1		7	19
12	1	2 or 3	1	1		13
24	2	3	1	1	1	

Pacific Northwest (East)

ID / DD	1	2	3	6	12	24
1		1	1 or 2	2	1 or 2	2 or 3
2	1		1	1	1	1 or 2
3	1 or 2	1		1	1	1
6	2	1	1		1	1
12	2	1	1	1		1
24	2	1	1	1	1	

Great Basin

ID / DD	1	2	3	6	12	24
1		1	1 or 2	1 or 2	1 or 2	1 or 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	

Southwest Mountains

ID / DD	1	2	3	6	12	24
1		1	1 or 2	1	1 or 2	1
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 12.--Most likely beginning hour of shorter duration storm (ID) or rainfall (DD) within longer duration rainfall or storm, quartile IV (continued)

Front Face Rockies (North)

ID / DD	1	2	3	6	12	24
1		1	1	1	1 or 2	1
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	

Front Face Rockies (South)

ID / DD	1	2	3	6	12	24
1		1	1	1	1 or 2	1
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	

Tables 11 and 12 show that for all areas except the Pacific Northwest (West), the maximum short duration precipitation is most likely at the beginning of the longer duration precipitation regardless of which is the independent and which is the dependent duration. This pattern is often the result of the many large convective precipitation events of limited duration. Large amounts of rain during the first few hours result in the longer duration annual events having trailing zeros during the last hours of the event. This is due, in part, to the definition of a storm or rainfall which must begin with measurable precipitation. Shorter duration storms and rainfalls can and do fall during the last several hours of a longer duration rainfall or storm. This is more common than ones in which shorter duration precipitation comes during the middle hours of the longer duration precipitation.

West of the Cascades, over the Pacific Northwest (West), major precipitation events are much more likely to be associated with synoptic scale cyclones rather than with convective or thunderstorm activity. In this area, when the independent duration is longer than the dependent duration, the maximum within storm rainfall tends to occur near the middle or the end portion of 6-, 12-, and 24-hr storms. When the dependent duration is longer than the independent duration, the heavier 3-, 6-, and 12-hr storms of quartile I tend to occur near the middle or end portion of the longer duration rainfalls. In quartile IV, these same duration storms occur at the beginning of the rainfalls. The 1- and 2-hr storms most frequently begin in the first hour of the longer duration rainfalls.

ESTIMATION OF RAINFALL FOR STORM PRECIPITATION VS. TIME RELATIONS

We now suggest a method to obtain rainfall increments to use when constructing precipitation vs. time relations for hydrologic purposes. First, the key duration and quartile have to be selected using appropriate factors pertaining to hydrology, cost, and safety. Incremental rainfalls are estimated from the curves in appendix II. Quartiles II and III can be interpolated from appendix II.

While the choice of which quartile, duration, or probability level for dependent rainfall is not the subject of this report, we would like to briefly discuss some considerations that may influence their choice. As mentioned in the introduction, the combination of 1-, 2-, 3-, 6-, 12-, and 24-hr precipitation estimates into a single precipitation vs. time sequence has a probability of occurrence that is greater than 10^{-12}. The exact value is nearly impossible to determine and is affected primarily by the fact that the value for each duration is not completely independent from some or all of the other durations. In this light, the terminology that the precipitation vs. time distribution synthesized from events, each with a frequency of 0.01 is a "1 percent synthetic time distribution" is also not appropriate. The combination of six specific events each with a 1 percent probability yields a joint probability considerably lower than 1 percent.

How, then, does the selection of a specific quartile and associated probability level relate to past hydrologic design practice? If the available data records were exactly 100 years long and if the observations were completely representative of the underlying population, quartile I would contain the 100-yr through the 76-yr storms (0.01-0.13 probability of occurrence). As shown in table 4, there are no data records as long as 30 years, and a typical length of record would be closer to 20 - 25 years. As shown by Hershfield (1973) the following formula gives an estimate of the probability of observing an N-yr storm at least once in an M-yr sample:

$$P_M = 1 - \left\{1 - \frac{1}{N}\right\}^M$$

Therefore, the probability that the 100-yr storm was observed in a 25-yr record is about 0.22. Similarly, the probability of observing the 50-, 25-, 10-, 5-, and 2-yr storms in a 25-yr data sample is 0.40, 0.64, 0.93, 0.996 and almost 1.00, respectively. It is quite possible that records of the length available for this study would often not contain the 100-yr storm. Quartile I storms are simply the largest 25 percent of the available data sample.

Projects that require a considerable degree of safety would probably be designed using precipitation values with low frequency of occurrence. While there could be many reasons to make other choices, the use of quartile I would be consistent with longer return periods, for instance a 100-yr storm. It must be re-emphasized that because of the small sample size, quartile I does not necessarily contain the 100-yr storm. Even if quartile I did contain the 100-yr storm, it does not necessarily produce the largest ratio. For instance, the 100-yr 24-hr storm could be 100 mm and the concurrent rainfall could be 25 mm. The 25-yr 24-hr storm for the same location could be 50 mm and also have a 1-hr rainfall of 25 mm. The 1-hr (DD)/24-hr (ID) ratio would be 0.25 for the 100-yr storm but 0.50 for the 50-yr storm. Higher probability levels yield larger ratios and larger overall precipitation totals.

For the design of low risk structures, a quartile other than quartile I might be more appropriate. Selection of an appropriate probability level will also depend on the relevant design criteria. While the simplest approach would be to select a single probability level for all durations, it is possible to let the probability level vary with duration. For instance, the design criteria might specify that the 100-yr 6-hr storm should be used for calculation of total volume, but the 1-hr value is critical for peak flow considerations. The 1-hr (DD)/6-hr (ID) ratio could be selected using the 0.99 probability level from quartile I. Because rainfalls at the longer durations are not as important to the peak flow, the 2-hr and 3-hr to 6-hr ratios could use the 0.90 probability level, while the 12-hr and 24-hr to 6-hr ratios could use the 0.80 probability level. If different probability levels are used, care must be taken to ensure that the various durations are internally consistent. That is, the 2-hr value must be at least as large as the 1-hr value, and the 3-hr value must be at least as large as the 2-hr value, etc.

EXAMPLES OF THE CONSTRUCTION OF PRECIPITATION VS. TIME RELATIONS

Pacific Northwest (West)

A proposed structure in western Oregon at 45°00'N and 123°00'W requires the use of a 100-yr 6-hr storm as the critical value for volume. An incremental precipitation vs. time curve for 24 hours must be constructed to include the 100-yr 6-hr storm. The design engineer has ascertained that he/she should use an accumulated probability of 0.50 to relate the storm to its associated rainfalls.

First, the 100-yr 6-hr value at 45° 00'N, 123°00'W is determined to be 52.6 mm from NOAA Atlas 2 (Miller et al. 1973)* as shown in table 13, column 2. Then, storm-rainfall ratios are read from the ID = 6, quartile I, figure in appendix II. The 1-, 2-, 3-, 12-, and 24-hr ratios are determined by reading up or down the 0.50 accumulated probability line on this figure. Rainfall ratios are 0.24, 0.435, 0.60, 0.69 and 0.53 at the 1-, 2-, 3-, 12-, and 24-hr durations, respectively. These ratios are tabulated in column 3, table 13. Multiplication of these ratios by 52.6

Table 13.--Construction of a precipitation vs. time relation for the 100-yr 6-hr storm at 45°00'N, 123°00'W using an accumulated rainfall probability of 0.50 (quartile I)

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Duration (hours)	ID Precip. (From NOAA Atlas 2) (mm)	DD/ID @ P = 0.5 from Appendix II	Design event Precip. (mm)	Beginning Hour DD in ID	Beginning Hour ID in DD	in 24-hr
1	22.9	0.24	12.6	5		20
2	30.0	0.435	22.9	4		19
3	36.6	0.60	31.6	4		19
6	52.6					16
12	85.3	1/0.69	76.2	--	6	10
24	118.1	1/0.53	99.2	--	16	1

*Technical Paper No. 40 (Hershfield 1961) and/or NOAA Technical Memorandum NWS HYDRO 35 (Frederick et al. 1977) is to be used in lieu of NOAA Atlas 2 over Texas, Oklahoma, Kansas, Nebraska and the Dakotas.

results in the incremental rainfall values given in column 4. Using the ID = 6 column of table 11 (Pacific Northwest (West)), the beginning hour for each rainfall increment is tabulated in column 5 for the DD in ID and column 6 for the ID in the DD. We selected the 5th hour rather than the 4th hour as the beginning hour for the 1-hr rainfall within the 6-hr storm because we felt that such timing would contribute to the production of more runoff and therefore be hydrologically more critical. The 2- and 3-hr rainfalls begin in the 4th hour of the 6-hr storm. Notice that the 6-hr storm begins at the 16th hour of the 24-hr (column 7) rainfall and the beginning of the 6th hour of the 12-hr rainfall. To accomplish this, the 6-hr storm must begin at the beginning of the 16th hour of the 24-hr rainfall while the 12-hr rainfall must begin at the beginning of the 10th hour of the 24-hr rainfall. Finally, the 1-hr rainfall occurs during the 20th hour and the 2- and 3-hr rainfalls begin at the 19th hour of the 24-hr rainfall.

The precipitation vs. time relations constructed out to 24 hours using the 0.50 accumulated probability values in table 13 is shown by the solid line in figure 6. The dashed line shows the relation obtained by using the NOAA Atlas 2 values derived from independent data samples and an identical time distribution. Rainfall for the first 9 hours and the last 3 hours is distributed linearly. Rainfalls for all five durations are lower than the corresponding durational values in NOAA Atlas 2.

Front Face Rockies (South)

The area most distant from the Pacific Northwest (West) is the Front Face Rockies (South), which experiences a very different precipitation climatology.

A project at 33°00'N and 104°00'W in southeastern New Mexico necessitates the use of a 5-yr 24-hr storm. An accumulated probability of 0.90 from quartile IV is to be used to relate the storm to its associated rainfalls.

The 5-yr 24-hr storm value from NOAA Atlas 2 at 33°00'N, 104°00'W is 69.1 mm (table 14 column 2). The storm-rainfall ratios for ID = 24, quartile IV, for the 1-, 2-, 3-, 6- and 12-hr durations are found by referring to the abscissa scale at the top of the proper figure in appendix II (accumulated probability (DD<ID))*. Reading down the 0.90 accumulated probability line the rainfall values are 0.998, 0.991, 0.982, 0.954 and 0.859 for the 12-, 6-, 3-, 2- and 1-hr ratios, respectively. The 0.90 probability means that 90 percent of the time the maximum 1-hr rainfall within a maximum annual 24-hr storm will be less than 85.9 percent of the 24-hr value, etc. As before, the rainfall ratios, incremental rainfall values, and beginning hours are tabulated in columns 3-5. All five rainfalls begin in the first hour of the 24-hr storm.

A comparison of columns 2 and 4 in table 14 indicates that the rainfall values resulting from the ratios in column 3 are higher than the corresponding five durational values from NOAA Atlas 2. This is in contrast to what we found in the

*We should note that if we were dealing with a 12-hr storm instead of a 24-hr one, the 24-hr rainfall would be determined from the bottom abscissa scale (accumulated probability (DD>ID)) but the 1-, 2-, 3- and 6-hr rainfalls would still be found by employing the top scale. The rule is: for rainfalls within storms use the top scale and for rainfalls surrounding storms use the bottom scale.

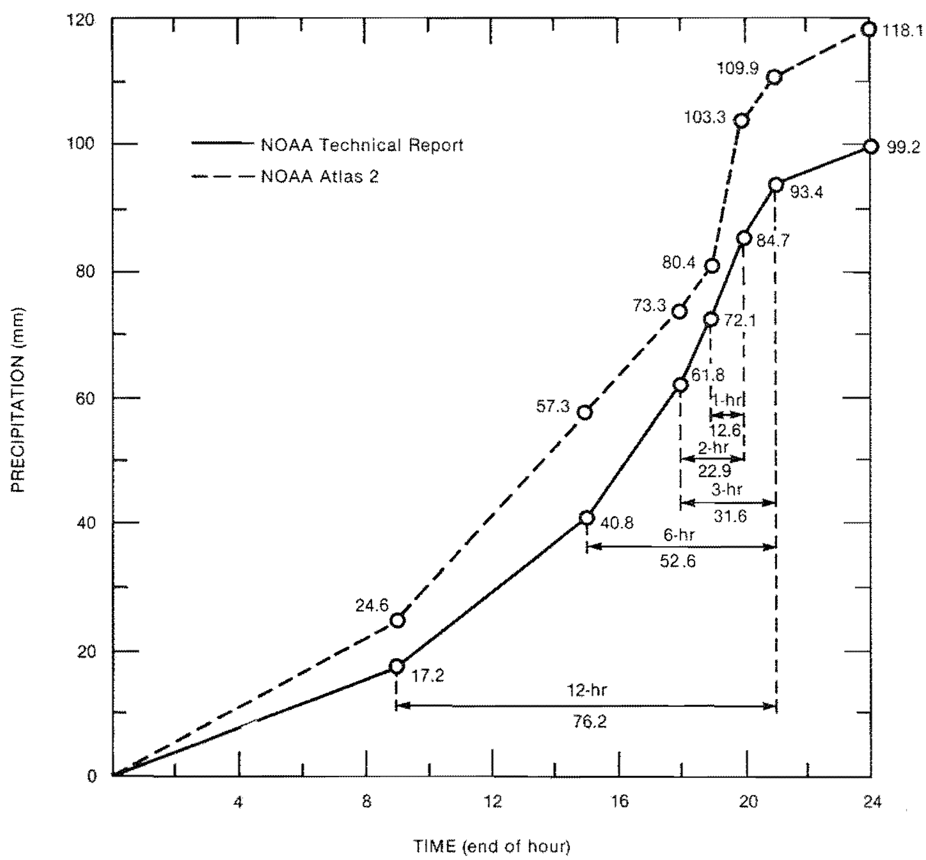

Figure 6.--Mass curves of precipitation at 45°00'N, 123°00'W.

Table 14.--Construction of a precipitation vs. time relation for the 5-yr 24-hr storm at 33°00'N, 104°00'W using an accumulated rainfall probability of 0.90 (quartile IV)

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Duration (hours)	ID precip. (from NOAA Atlas 2) (mm)	DD/ID @ P = 0.9 from Appendix II	Design event Precip. (mm)	Beginning Hour DD in ID	ID in DD	in 24-hr
1	43.2	0.859	59.4	1		1
2	47.8	0.954	65.9	1		1
3	51.2	0.982	67.9	1		1
6	56.6	0.991	68.5	1		1
12	62.2	0.998	69.0	1		1
24	69.1		69.1			

Pacific Northwest (West), quartile I, for the 100-yr 6-hr storm, where (using the 0.50 accumulated probability) the rainfalls were all lower than the NOAA Atlas 2 values. Storm-rainfall ratios and their resulting rainfalls depend on such items as the chosen accumulated probability, the selected quartile, and the closeness to which the precipitation climatology at a given point matches the overall areal precipitation climatology for a given area. Accumulated probabilities can be selected to create rainfalls that can undercut or envelop those from NOAA Atlas 2. Differences between point and areal precipitation climatology will in general be small but in some instances could be appreciable. In the Pacific Northwest (West) case, these factors combined to yield rainfall values lower than NOAA Atlas 2, while in this case the combined result gave higher values in column 4 than in column 2 (table 14).

Using the 0.90 accumulated probability values of quartile IV (table 14), we constructed another precipitation vs. time relation, shown by the solid line in figure 7. Values from NOAA Atlas 2 are joined together by the dashed line using the same time distribution. Rainfall for the last 12 hours is distributed linearly in each case.

The relations in figures 6 and 7 are quite different. In figure 6 (west of the Cascades) the precipitation is generally spread throughout the 24-hr period. In figure 7, nearly 86 percent falls in the first hour (about 63 percent using NOAA Atlas 2) with progressively decreasing amounts thereafter. Had we chosen an accumulated probability of 0.90 in the Pacific Northwest (West), the 1-, 2-, and 3-hr rainfalls would have been larger but the 12-hr and 24-hr rainfall would have been smaller. The relation would have peaked at 66.6 mm after 24 hours. Also, if an accumulated probability of 0.50 in the Front Face Rockies (South) had been selected, the five rainfalls would have all been less than in figure 7; the 1-hr rainfall would have totaled 27.6 mm or less than the 1-hr value from NOAA Atlas 2.

The use of accumulated probability levels of 0.90 in this example, 0.50 in first example, and 0.80 in the discussion of figure 2 earlier in the report are not intended to be recommendations or proposed standards for the areas under consideration. It is up to the design engineer or hydrologist to determine exact quartile levels for different design storms.

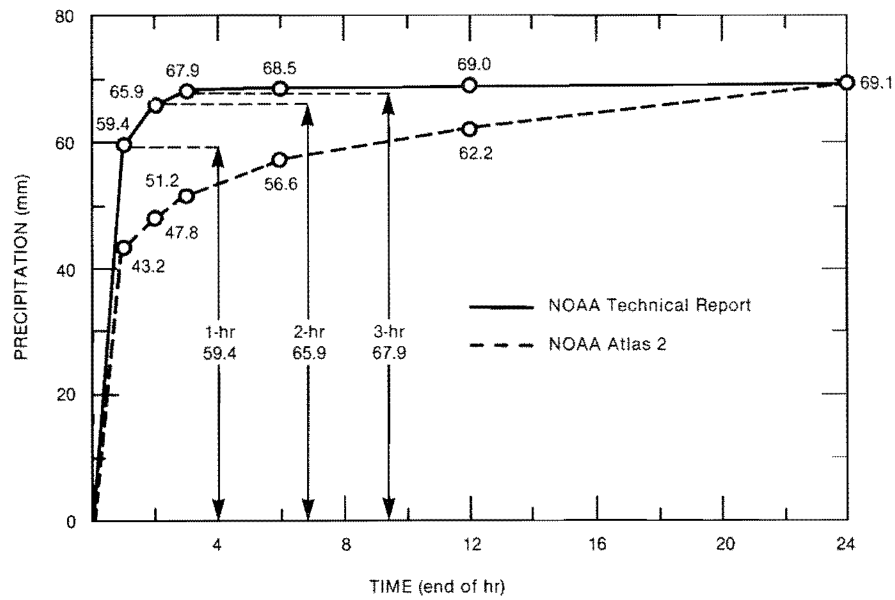

Figure 7--Mass curves of precipitation at 33°00'N, 104°00'W.

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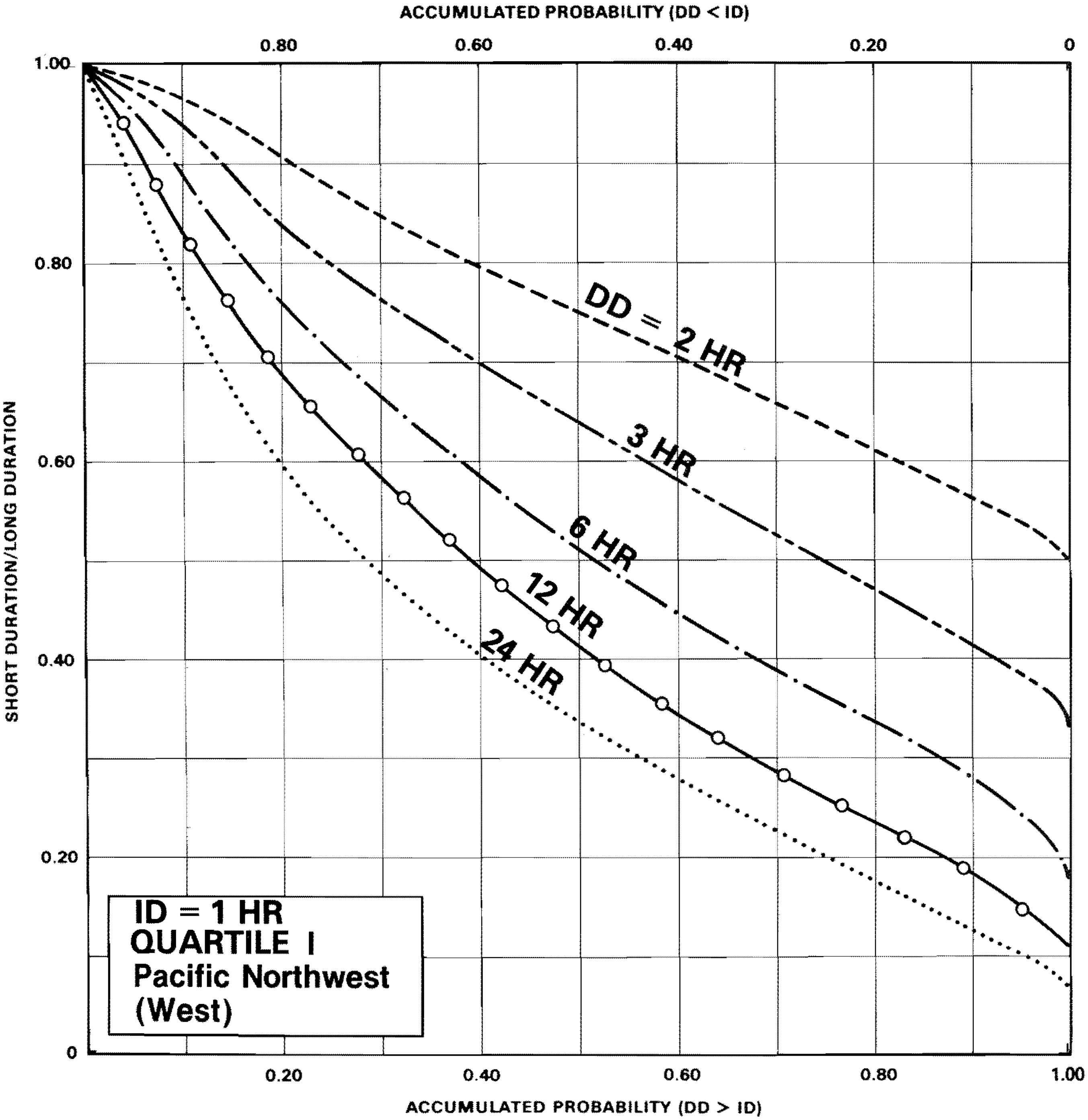
APPENDIX I. TABLES OF JOINT FREQUENCY DISTRIBUTION OF N-HR STORMS (ID) WITH M-HR RAINFALLS (DD)

(See fiche Number 1 in pocket on inside rear cover)

APPENDIX II. GRAPHS OF ACCUMULATED PROBABILITY FOR QUARILE I AND IV N-HR STORMS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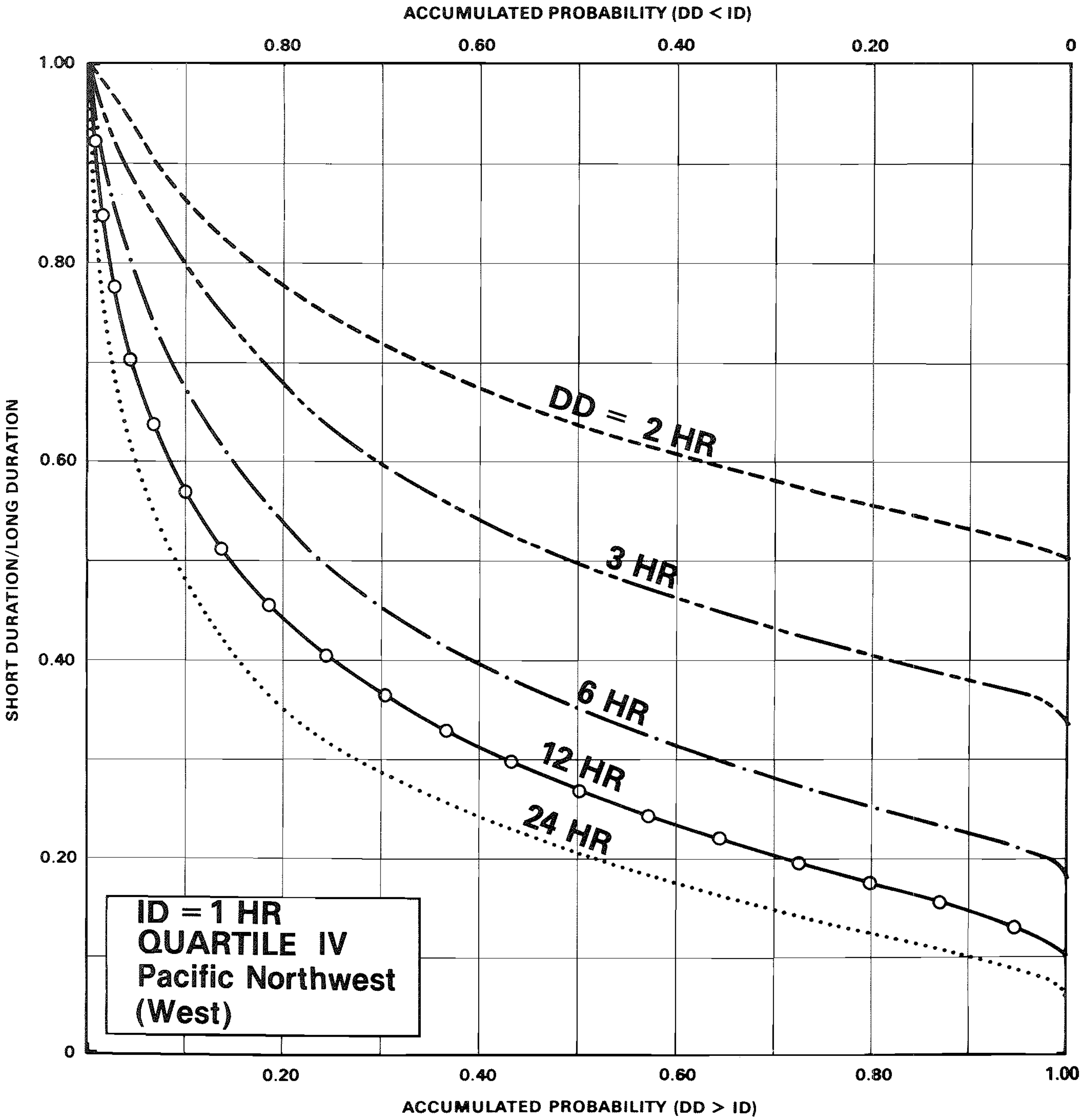
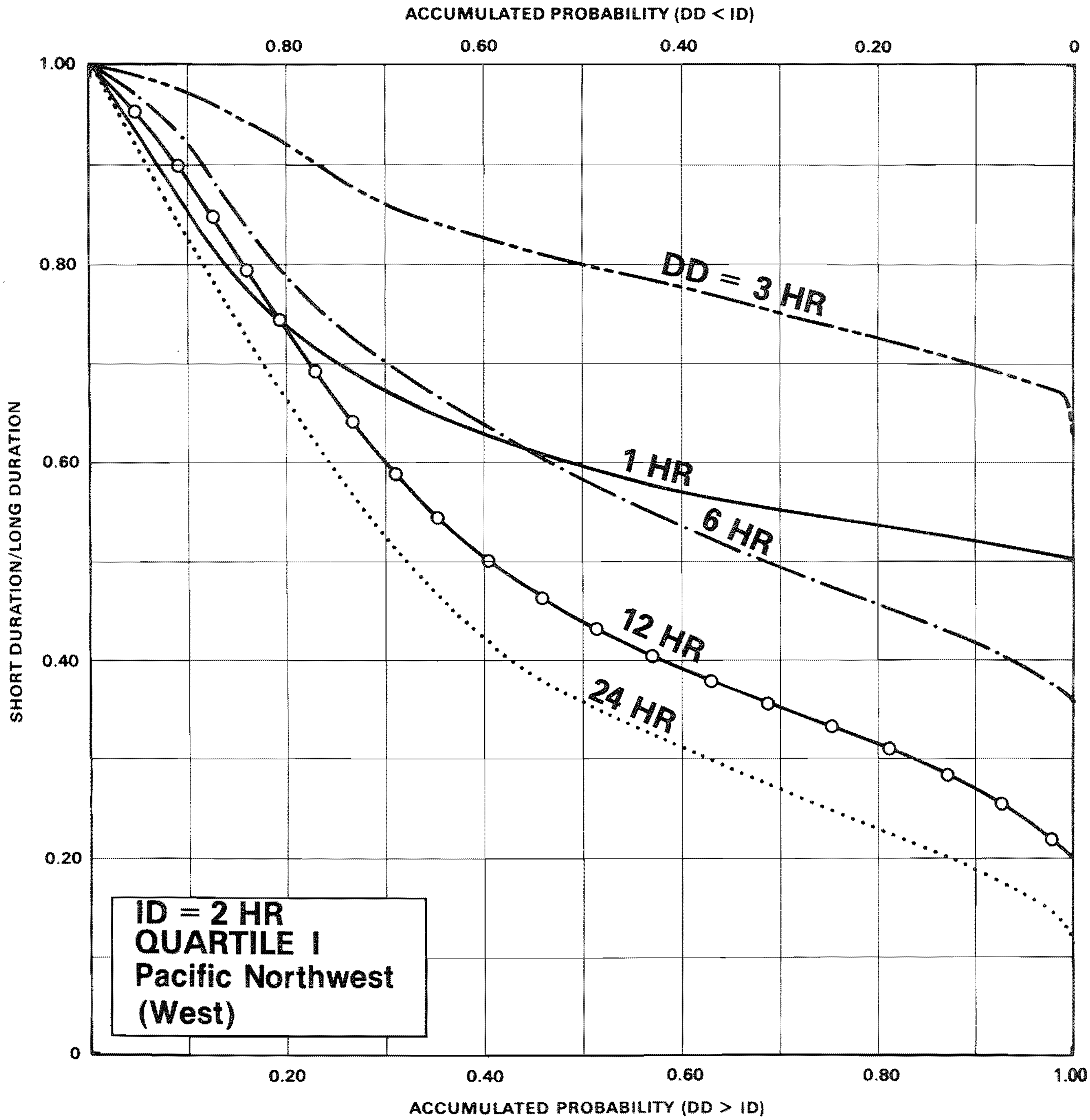
0.80
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 2 HR
3 HR
6 HR
12 HR
24 HR
ID = 1 HR
QUARTILE I
Pacific Northwest
(West)
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)



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
QUARTILE IV
Pacific Northwest
(West)
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)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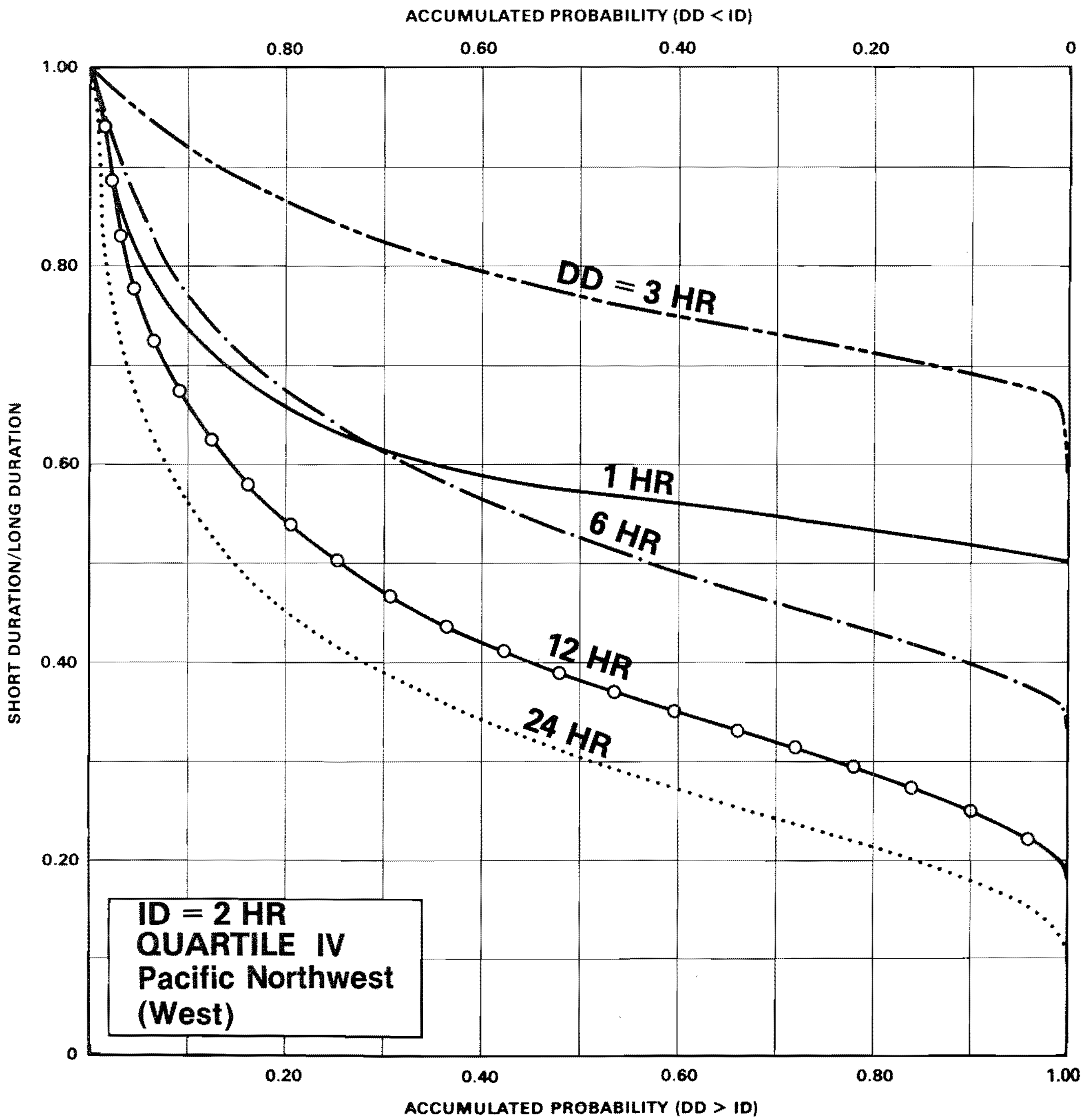
0.80
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 3 HR
1 HR
6 HR
12 HR
24 HR
ID = 2 HR
QUARTILE I
Pacific Northwest
(West)
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)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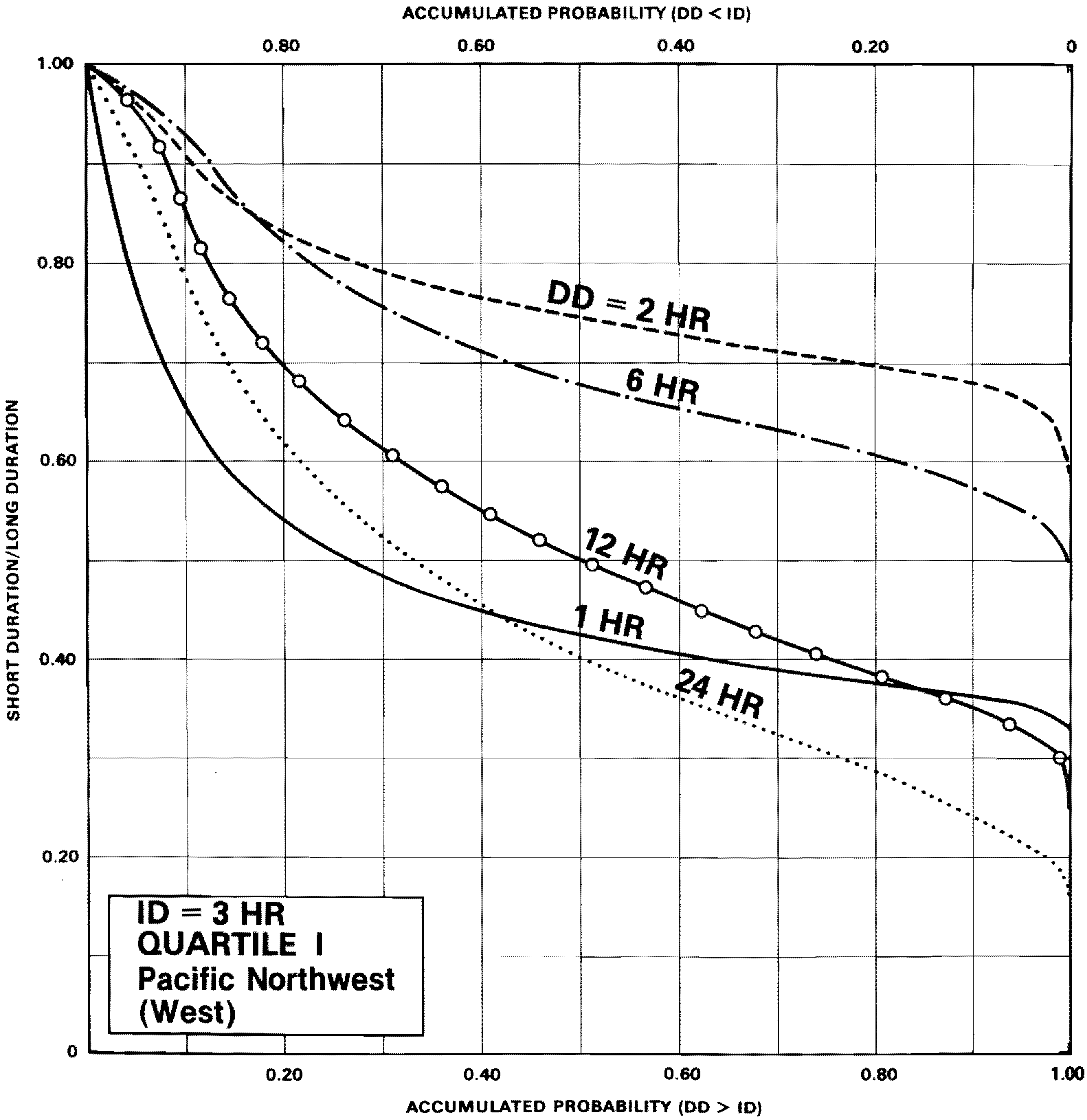
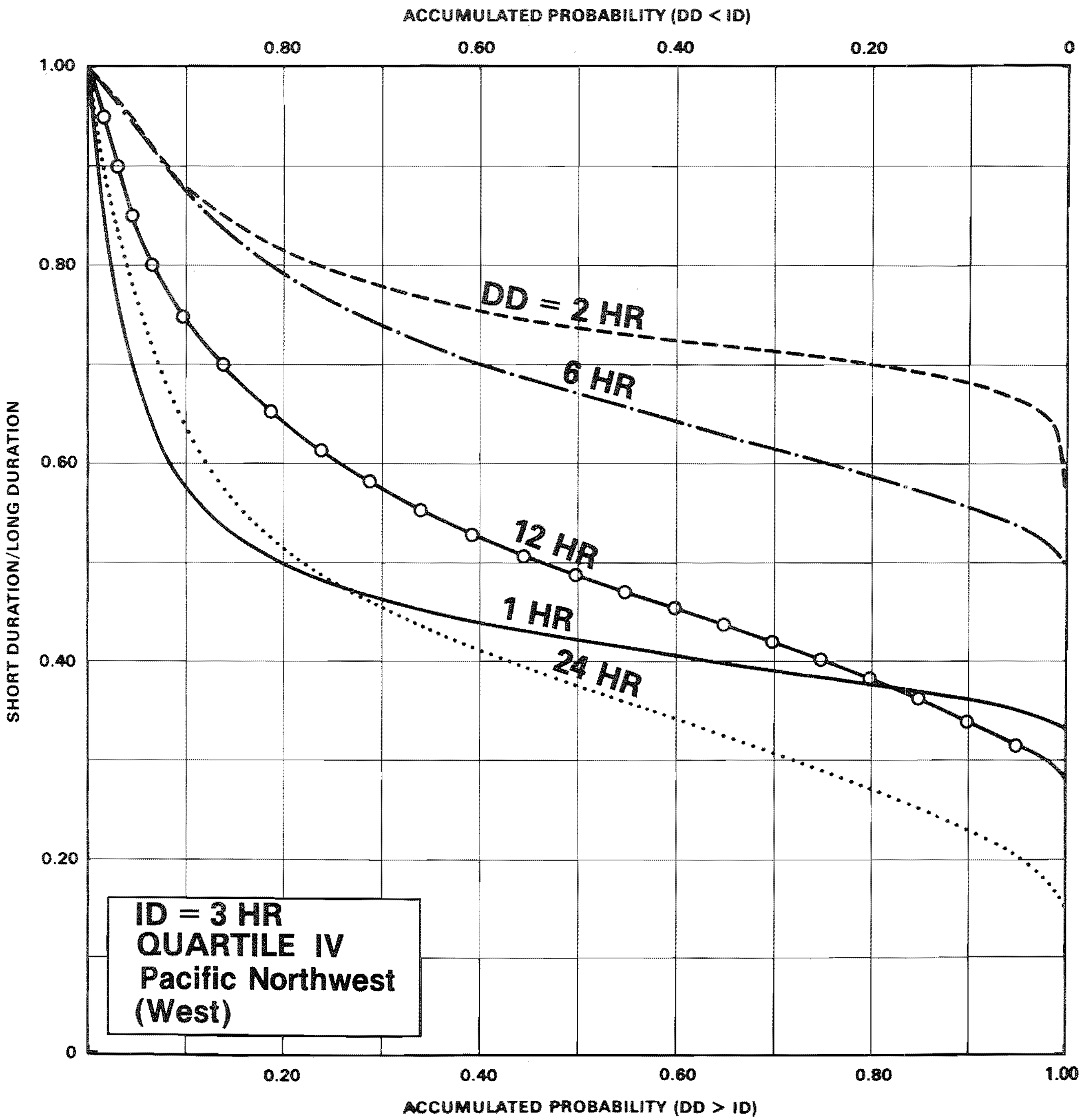
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 3 HR
1 HR
6 HR
12 HR
24 HR
ID = 2 HR
QUARTILE IV
Pacific Northwest
(West)
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)


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
1 HR
24 HR
ID = 3 HR
QUARTILE I
Pacific Northwest
(West)
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)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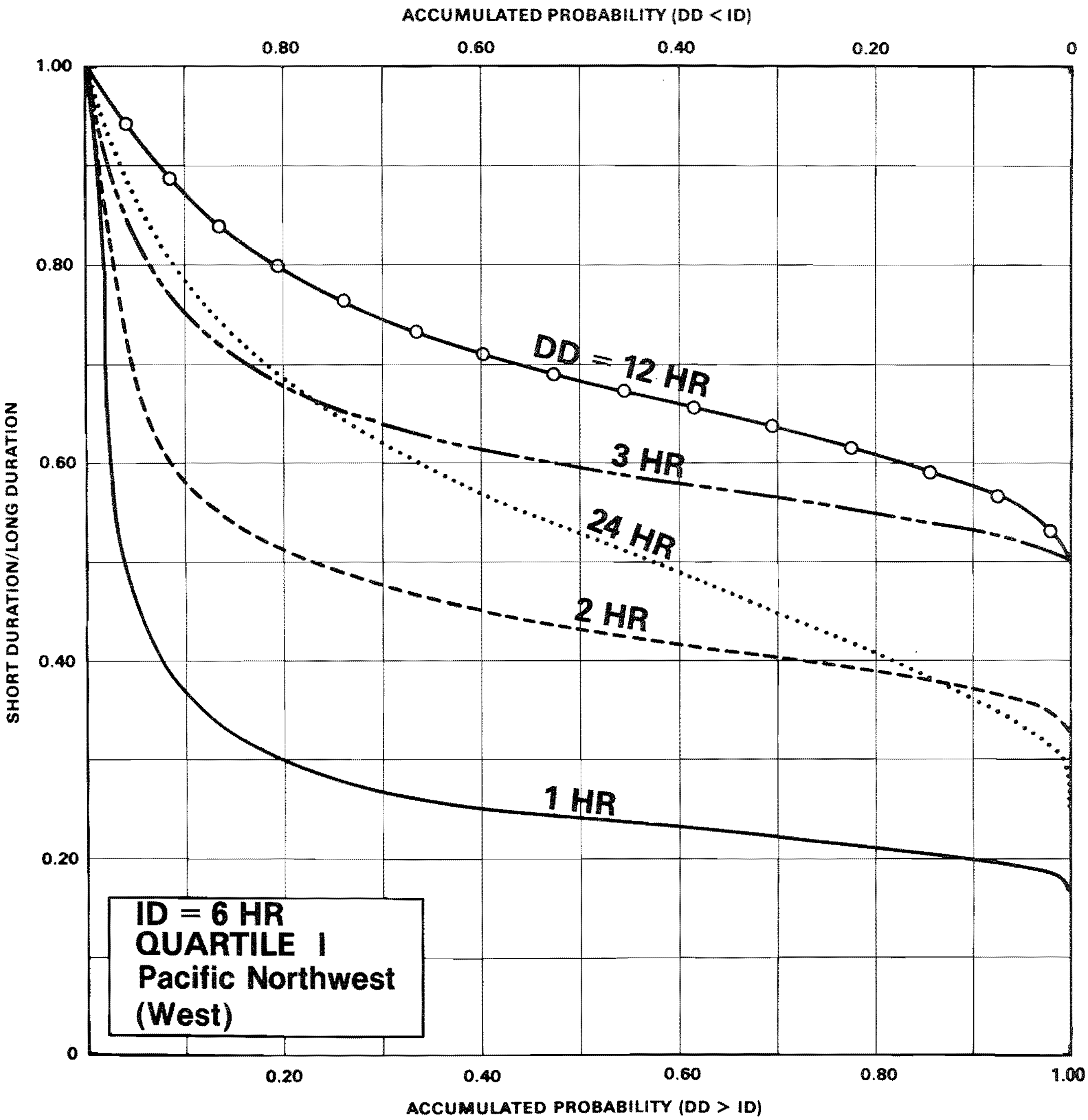
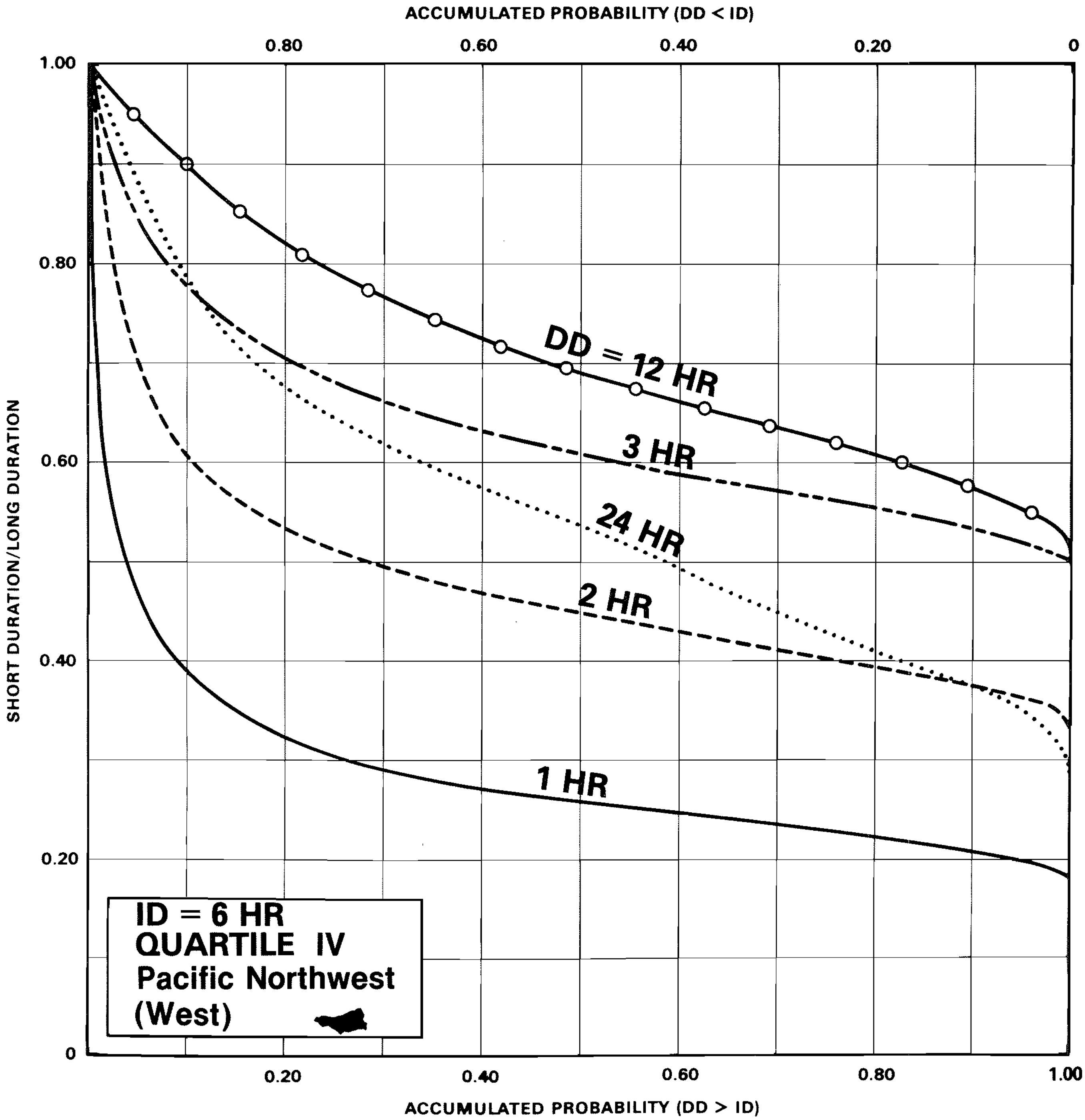
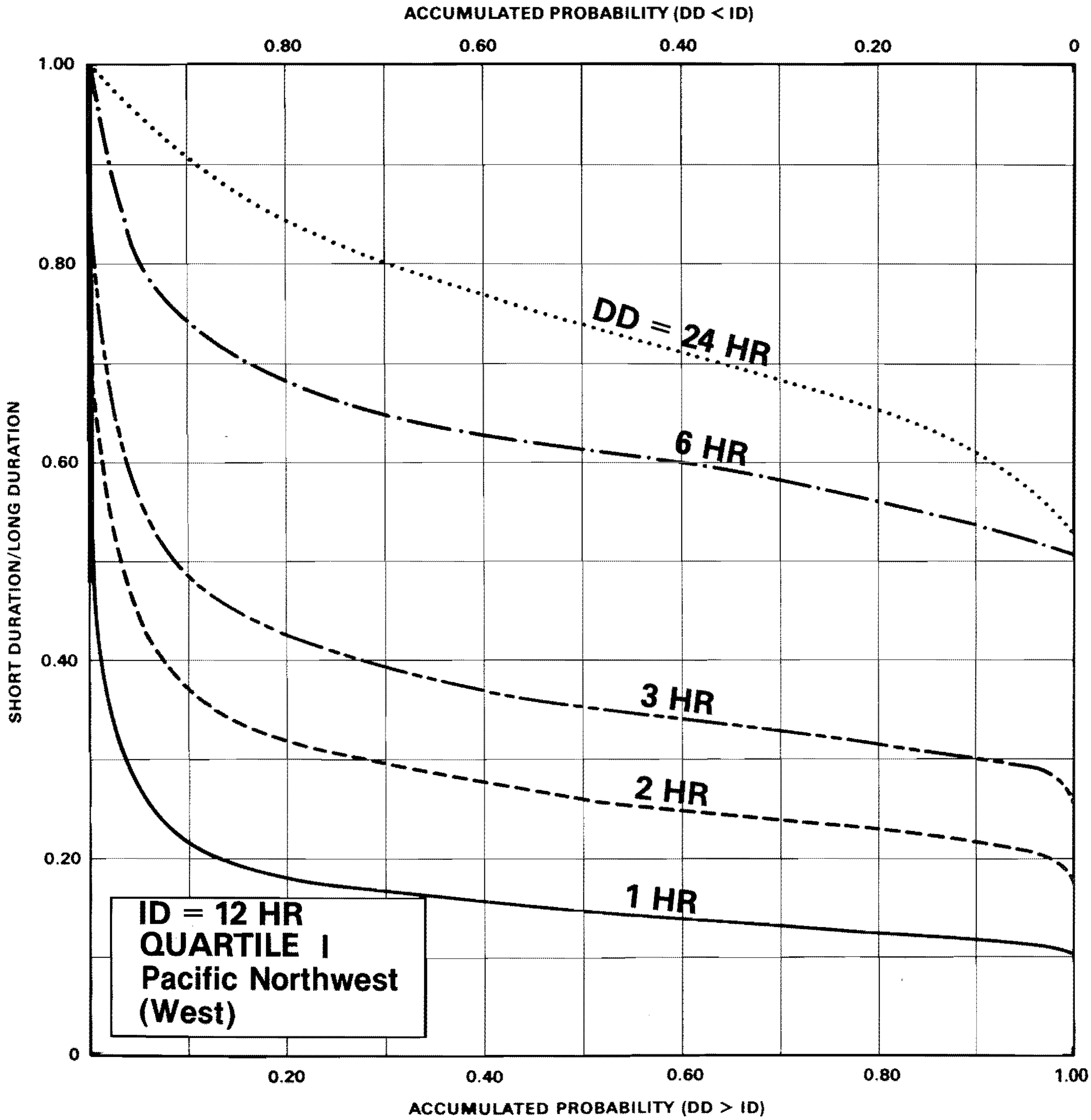
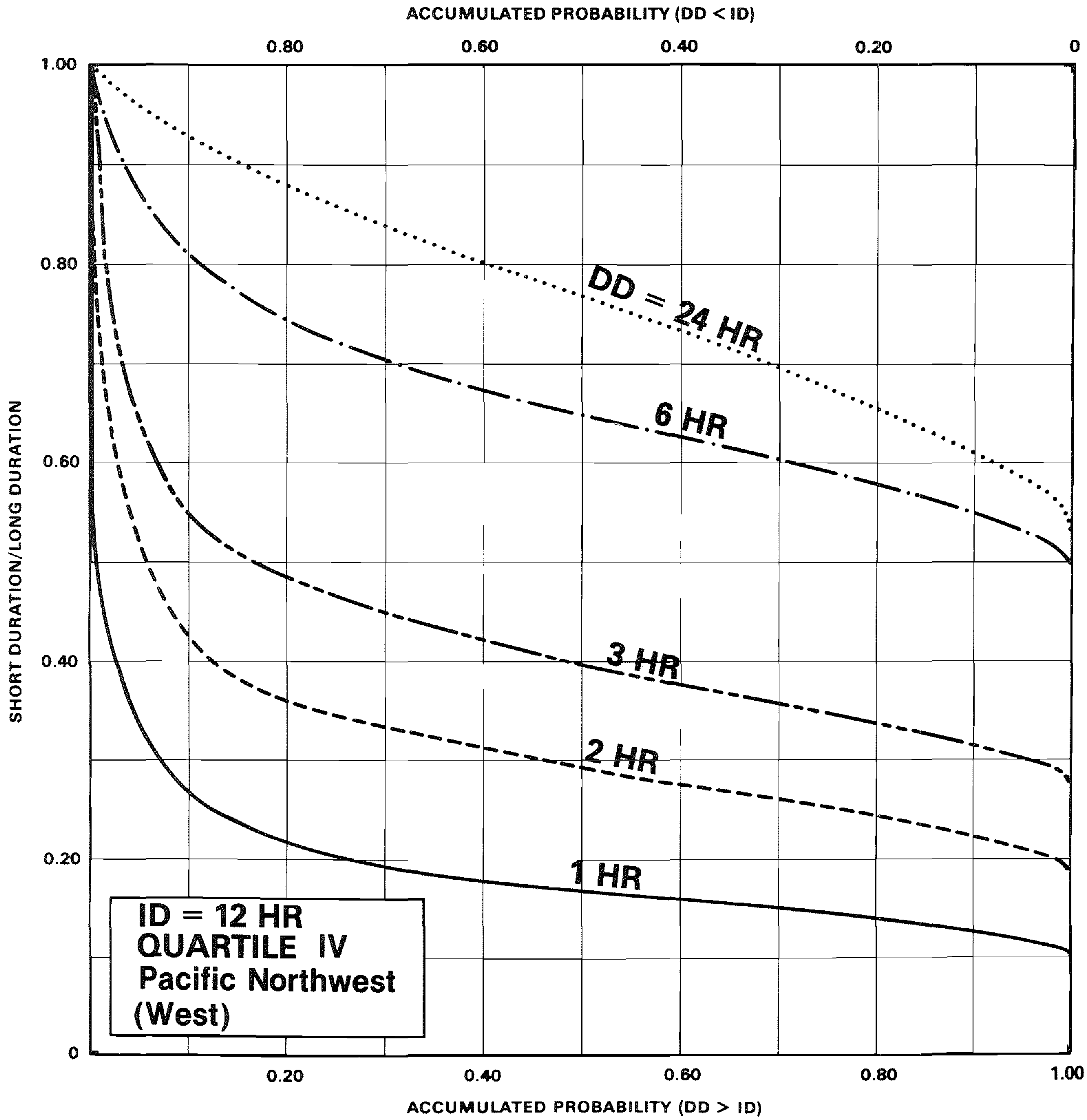
0.80
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 2 HR
6 HR
12 HR
1 HR
24 HR
ID = 3 HR
QUARTILE IV
Pacific Northwest
(West)
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)


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
QUARTILE I
Pacific Northwest
(West)
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
QUARTILE IV
Pacific Northwest
(West)
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
QUARTILE I
Pacific Northwest
(West)
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)



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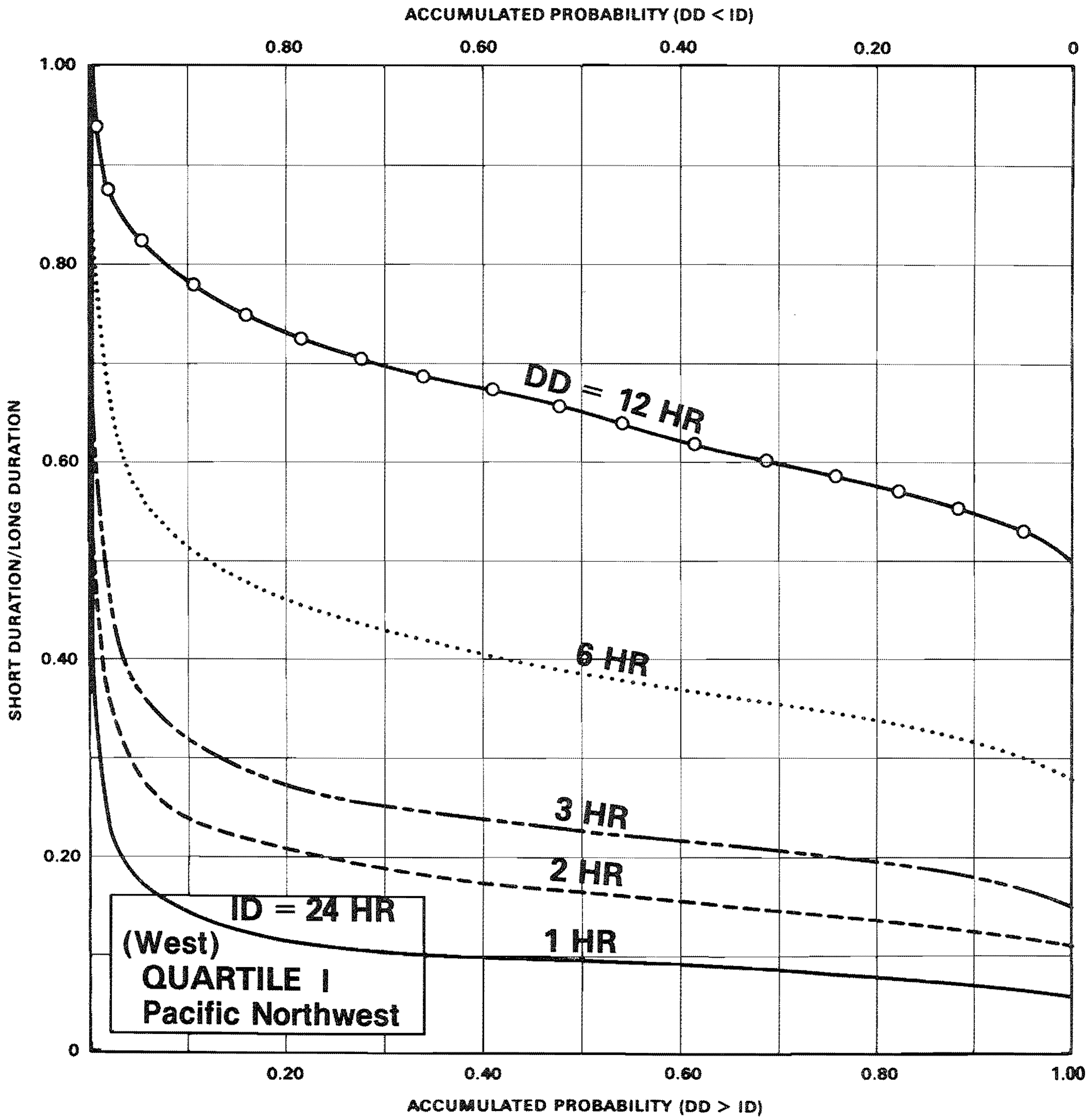
0.60
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 24 HR
6 HR
3 HR
2 HR
1 HR
ID = 12 HR
QUARTILE IV
Pacific Northwest
(West)
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)



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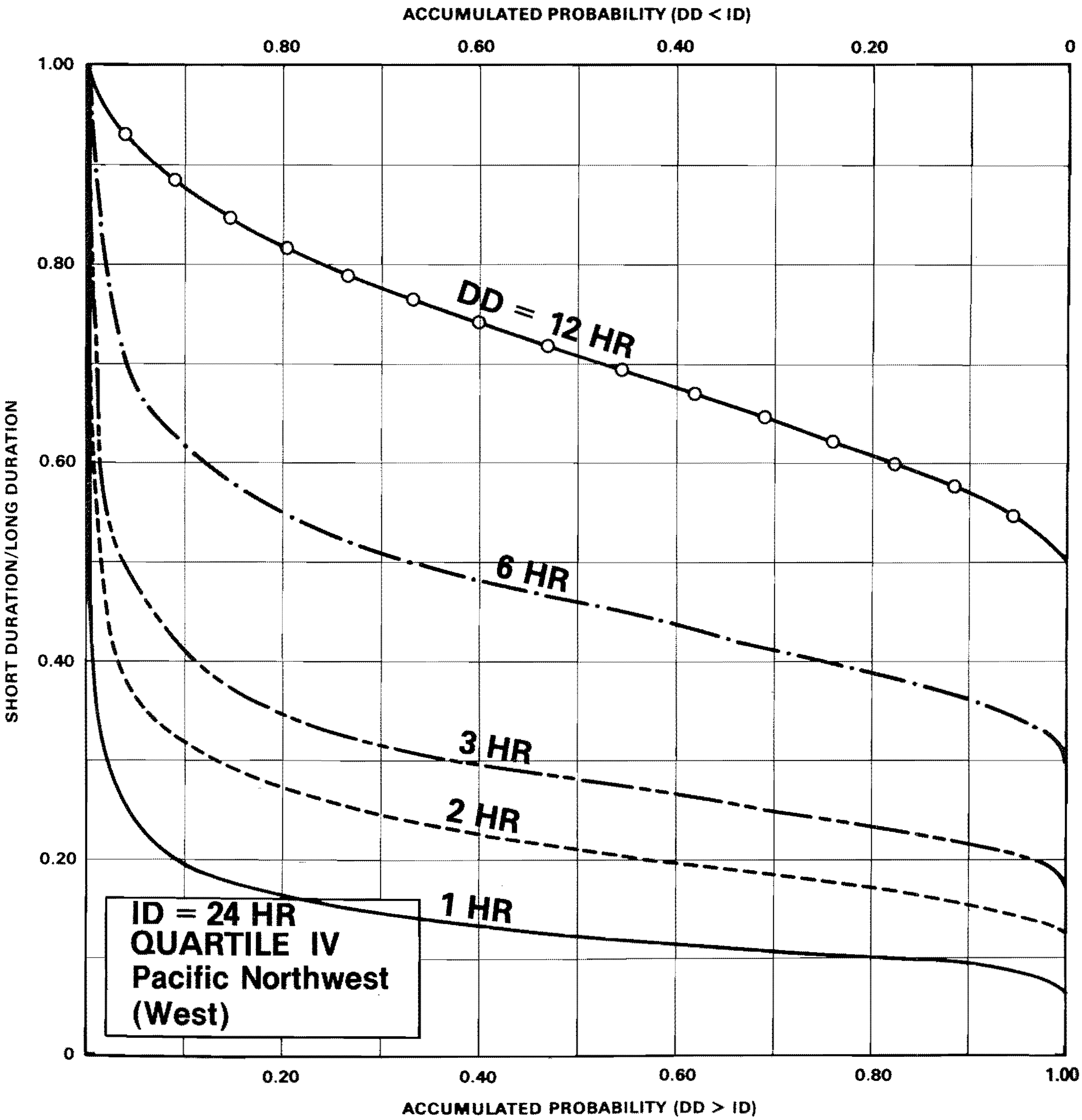
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 12 HR
6 HR
3 HR
2 HR
1 HR
ID = 24 HR
(West)
QUARTILE I
Pacific Northwest
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)



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0.40
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1.00
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0.60
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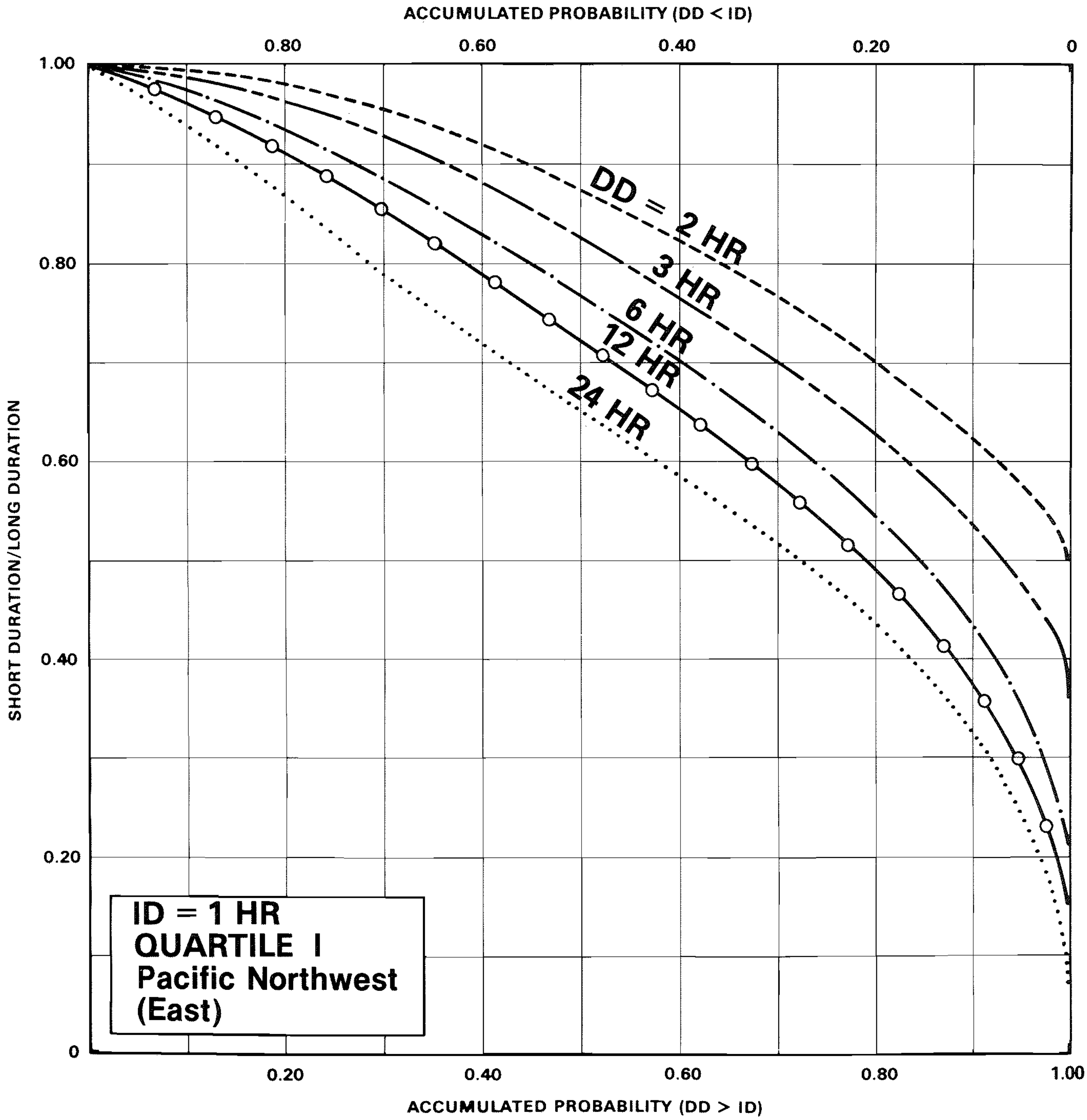
0.20
0
SHORT DURATION/LONG DURATION
DD = 12 HR
6 HR
3 HR
2 HR
1 HR
ID = 24 HR
QUARTILE IV
Pacific Northwest
(West)
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)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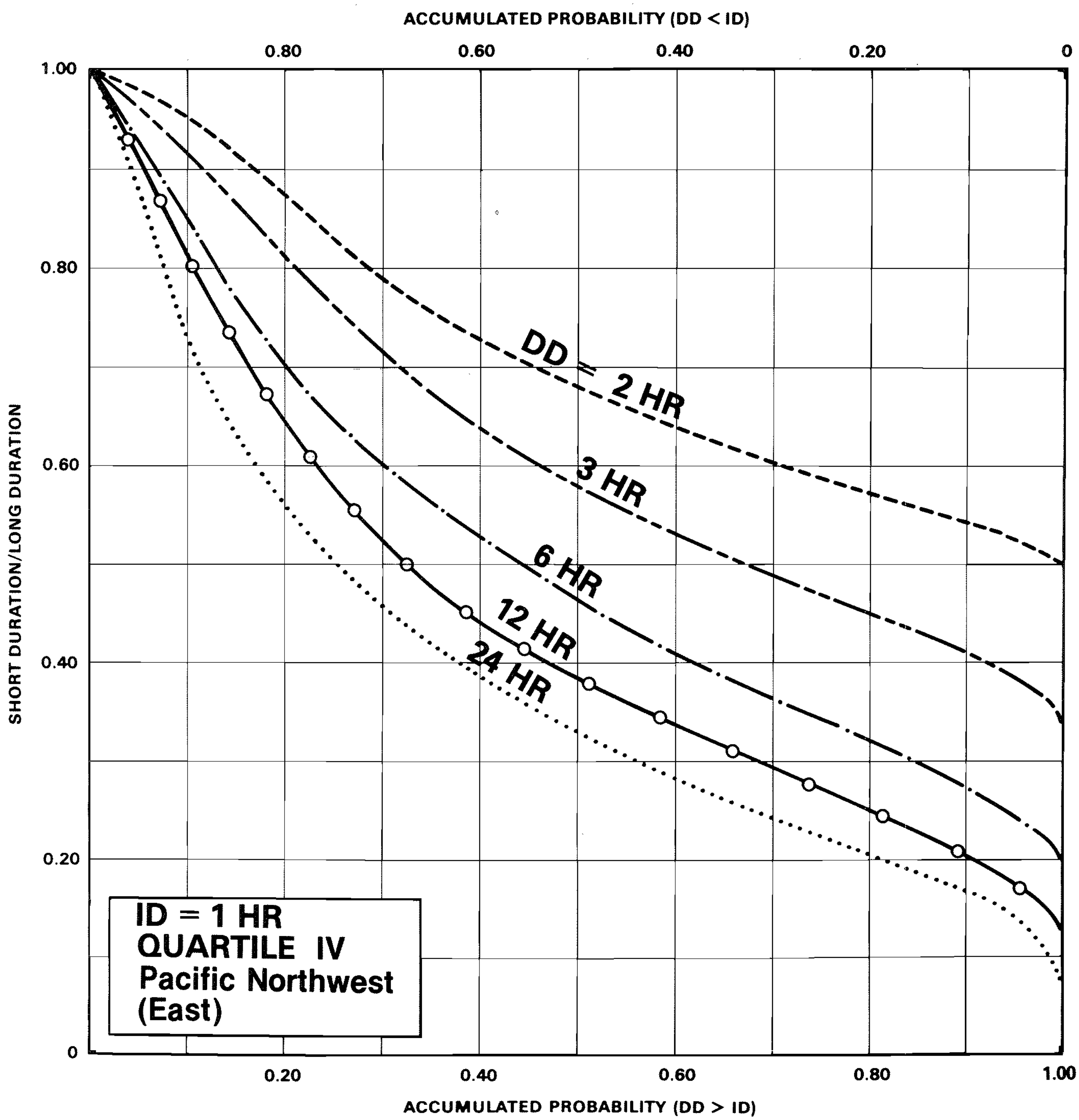
SHORT DURATION/LONG DURATION
DD = 2 HR
3 HR
6 HR
12 HR
24 HR
ID = 1 HR
QUARTILE I
Pacific Northwest
(East)
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)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SHORT DURATION/LONG DURATION
DD = 2 HR
3 HR
6 HR
12 HR
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ID = 1 HR
QUARTILE IV
Pacific Northwest
(East)
0.20
0.40
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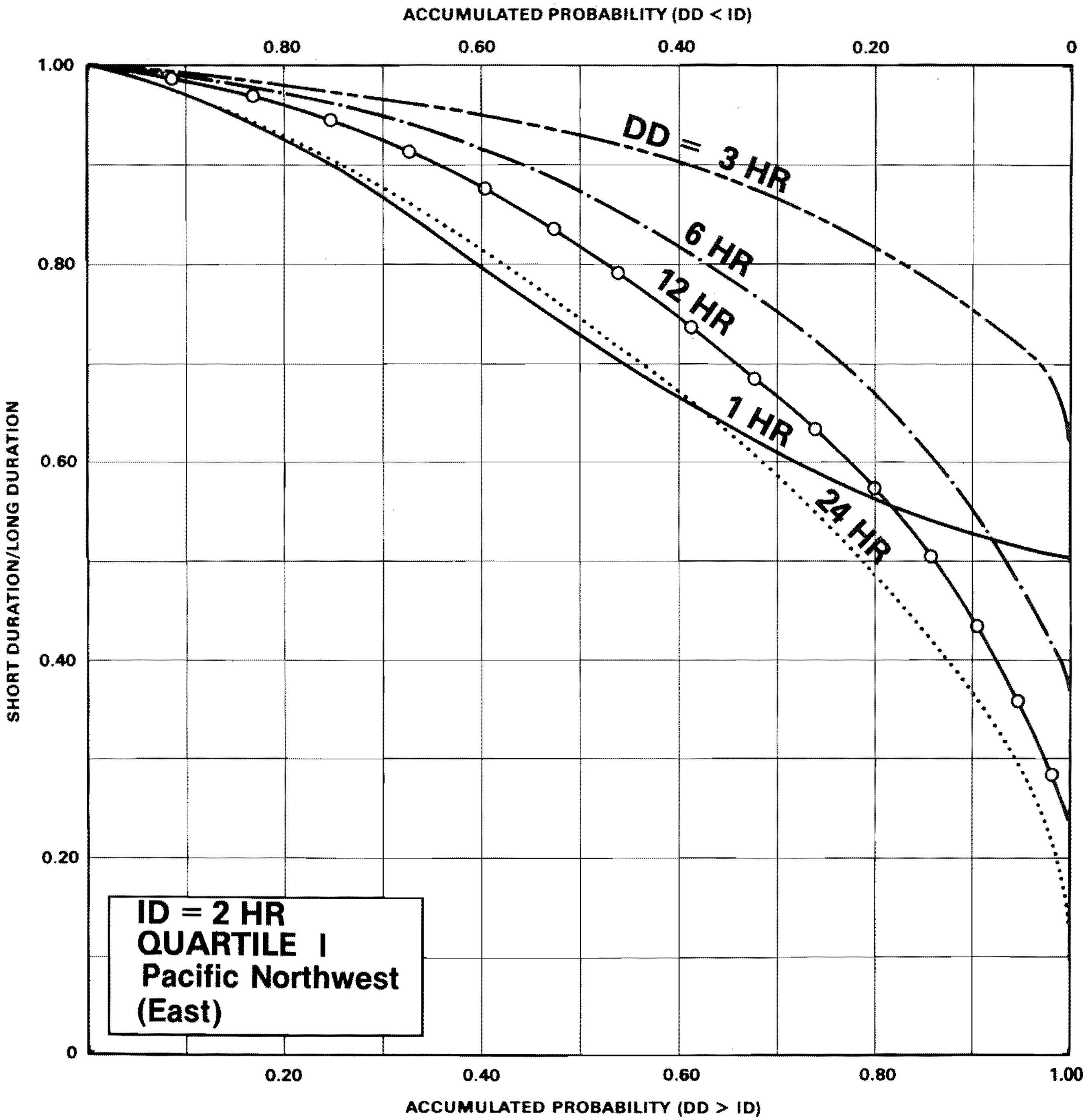
1.00
ACCUMULATED PROBABILITY (DD > ID)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SHORT DURATION/LONG DURATION
DD = 3 HR
6 HR
12 HR
1 HR
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ID = 2 HR
QUARTILE I
Pacific Northwest
(East)
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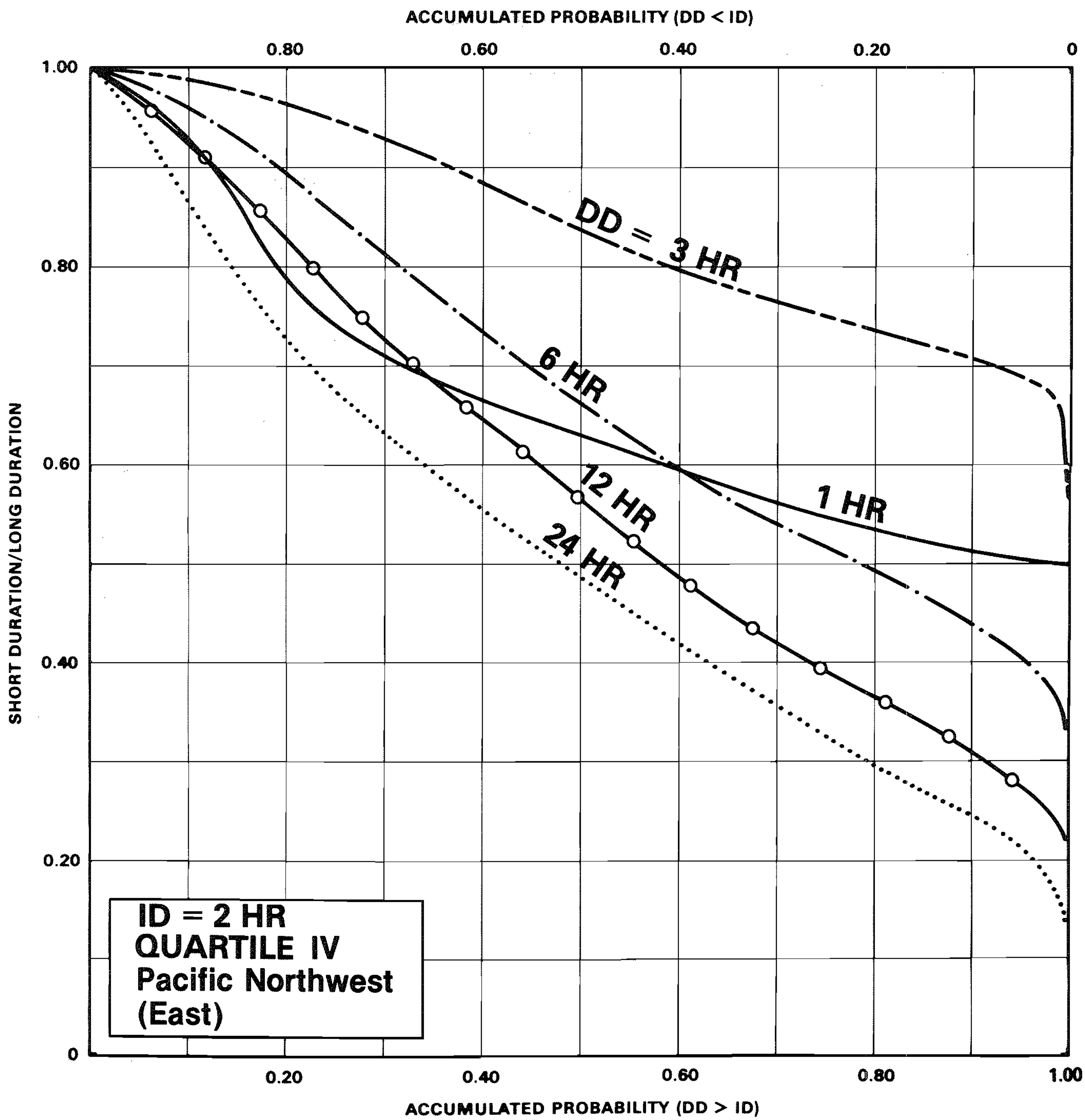
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)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SHORT DURATION/LONG DURATION
DD = 3 HR
6 HR
12 HR
1 HR
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ID = 2 HR
QUARTILE IV
Pacific Northwest
(East)
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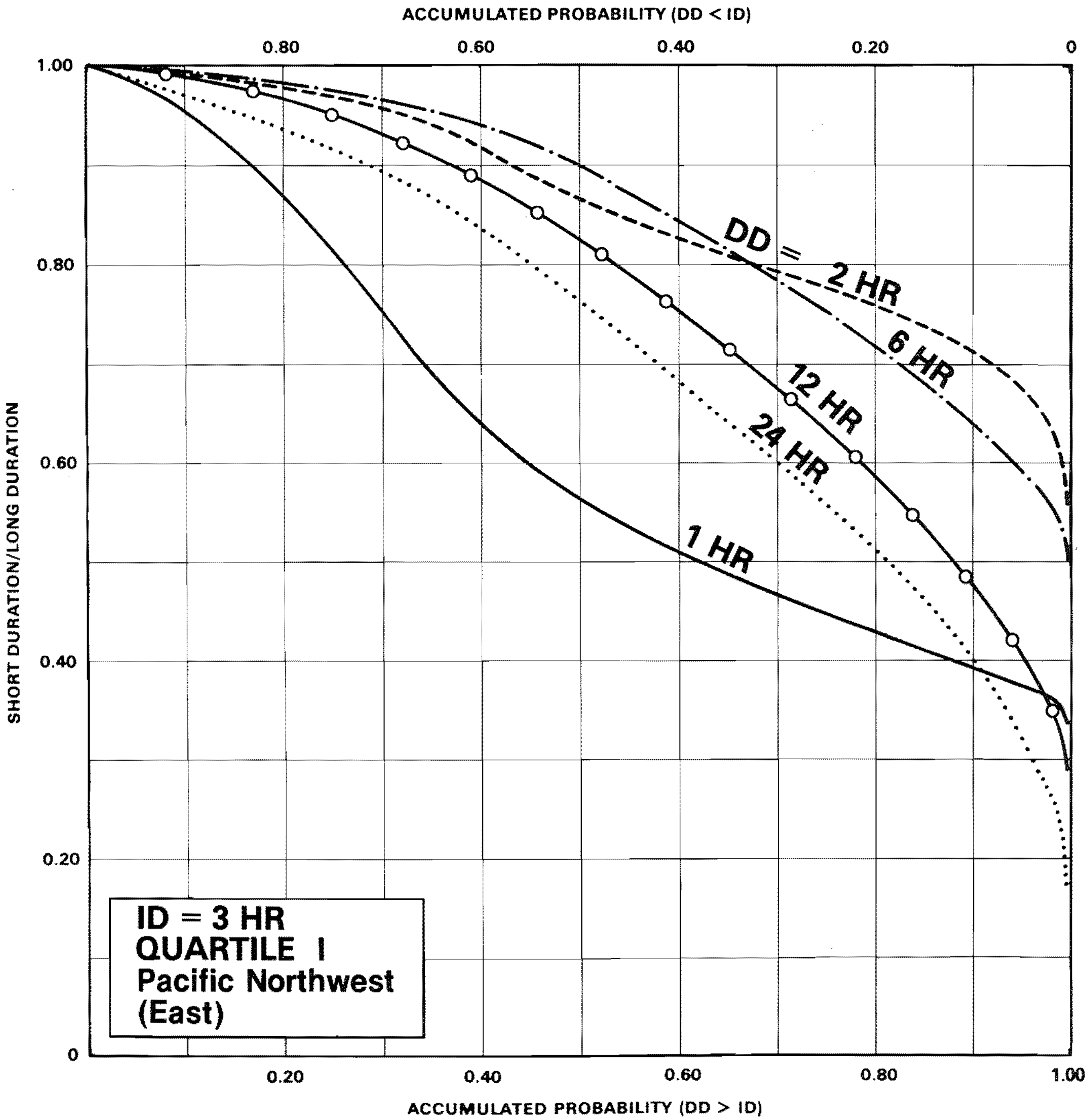
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)


ACCUMULATED PROBABILITY (DD < ID)
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SHORT DURATION/LONG DURATION
DD = 2 HR
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QUARTILE I
Pacific Northwest
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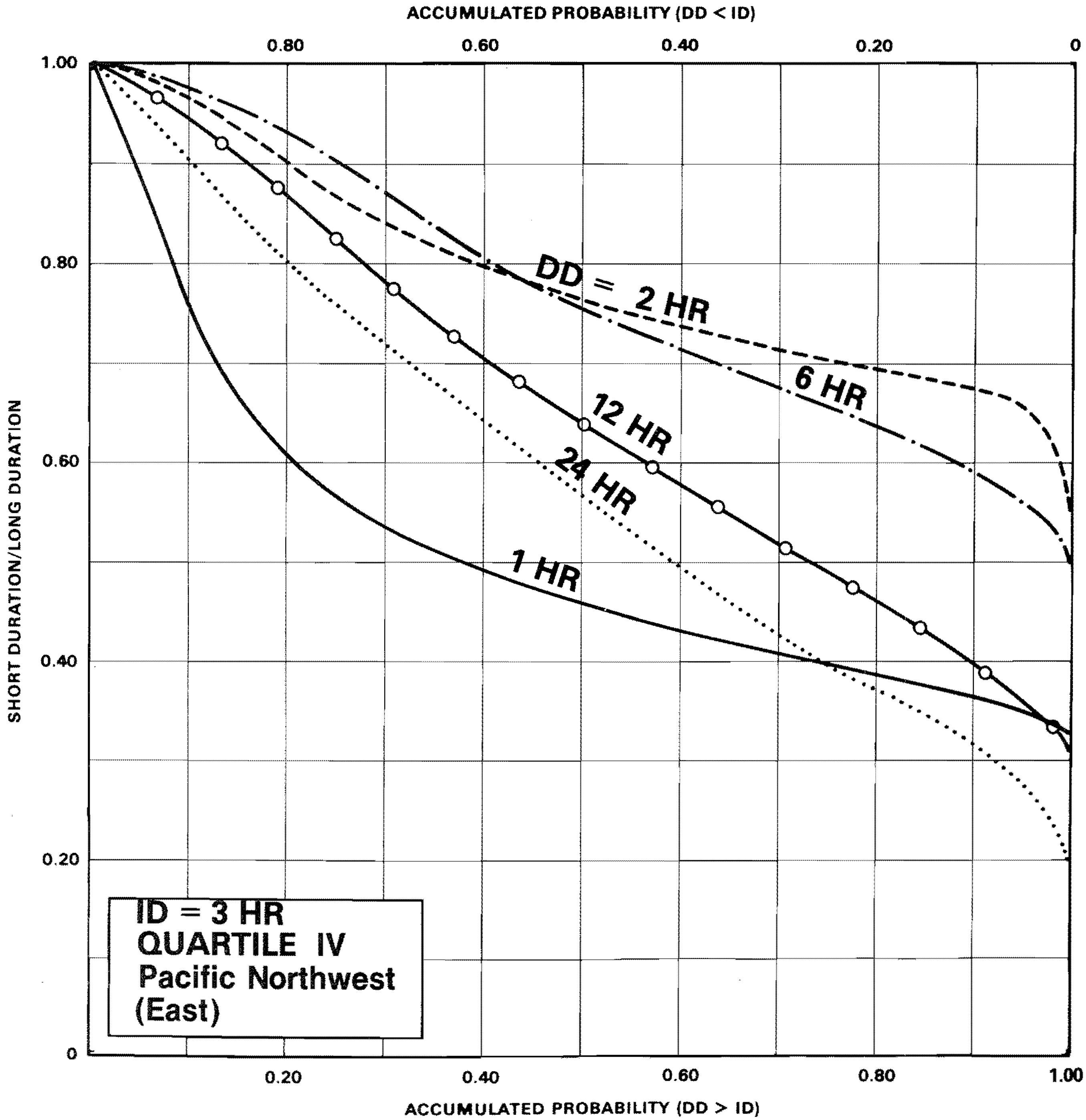
ACCUMULATED PROBABILITY (DD > ID)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SHORT DURATION/LONG DURATION
DD = 2 HR
6 HR
12 HR
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QUARTILE IV
Pacific Northwest
(East)
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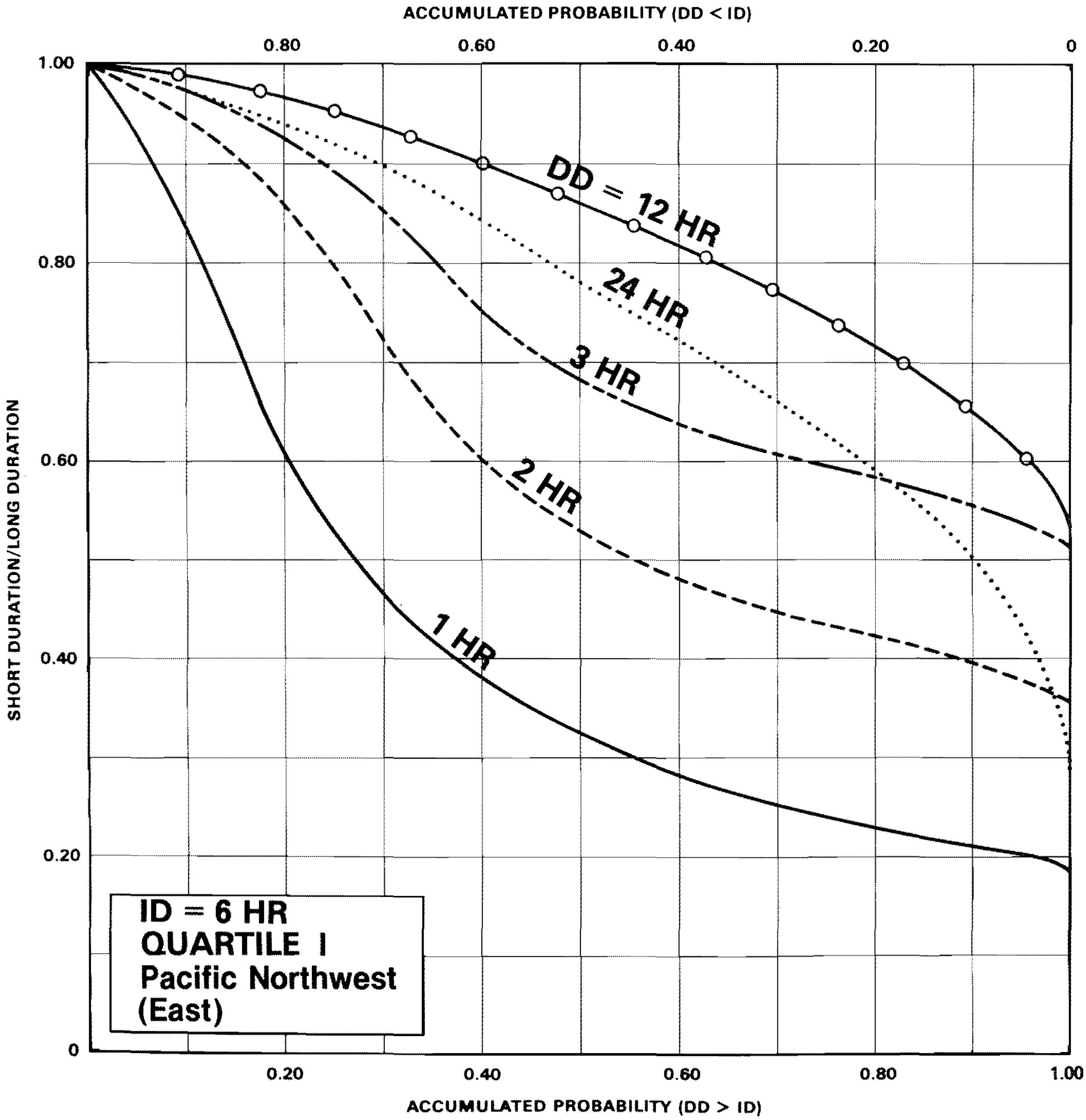
ACCUMULATED PROBABILITY (DD > ID)



ACCUMULATED PROBABILITY (DD < ID)
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SHORT DURATION/LONG DURATION
DD = 12 HR
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QUARTILE I
Pacific Northwest
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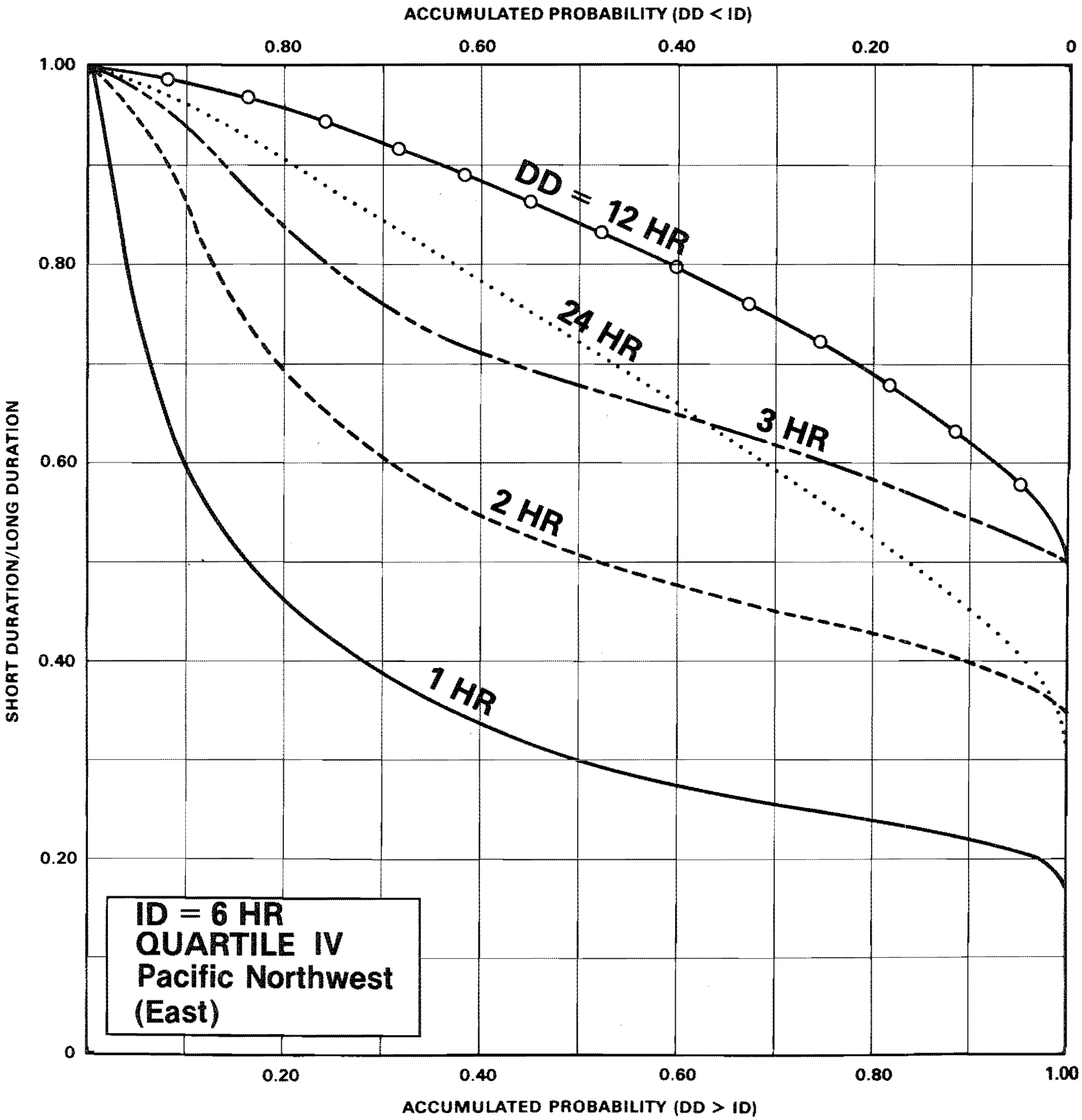
ACCUMULATED PROBABILITY (DD > ID)


ACCUMULATED PROBABILITY (DD < ID)
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SHORT DURATION/LONG DURATION
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QUARTILE IV
Pacific Northwest
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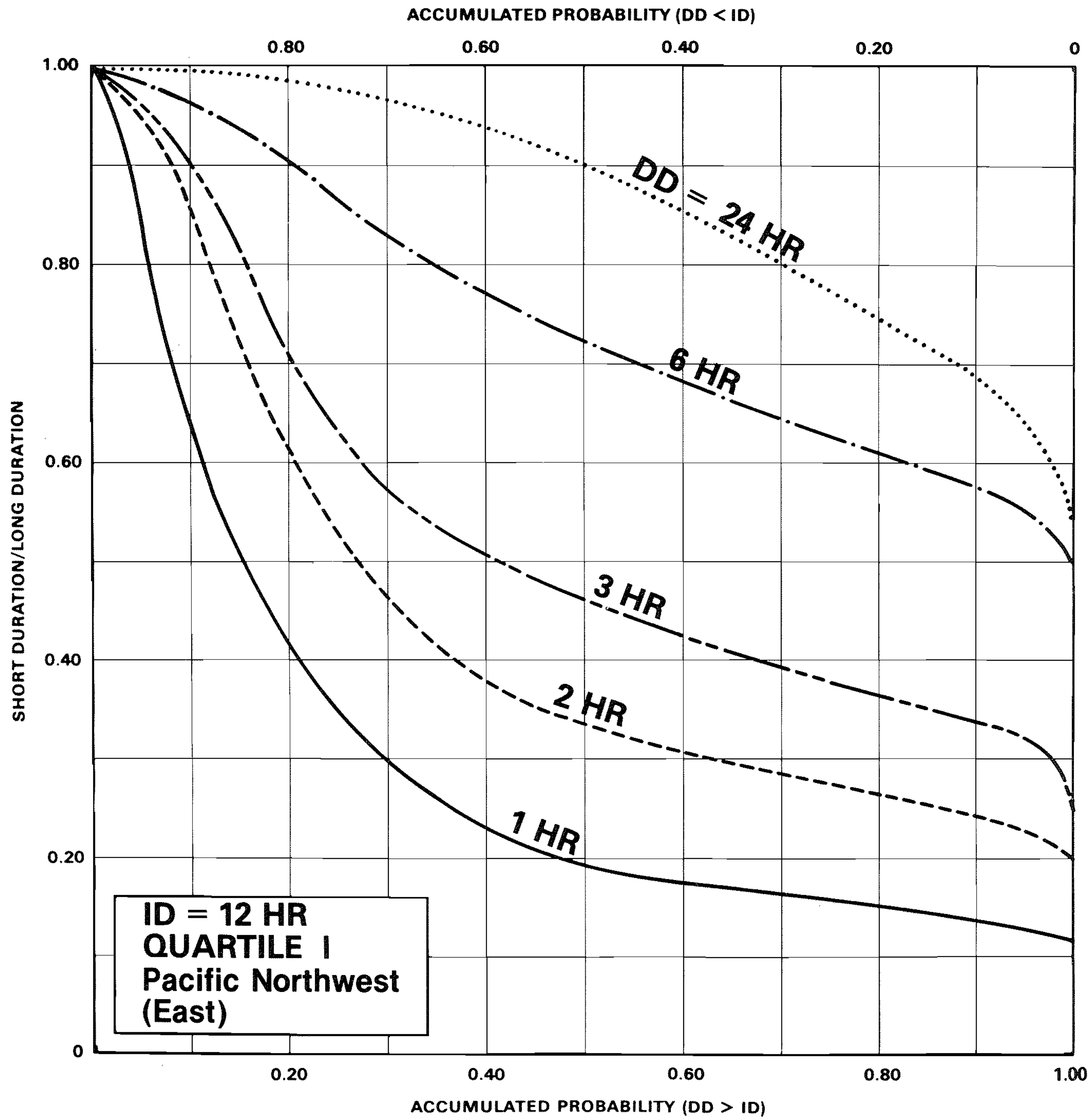
ACCUMULATED PROBABILITY (DD > ID)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Pacific Northwest
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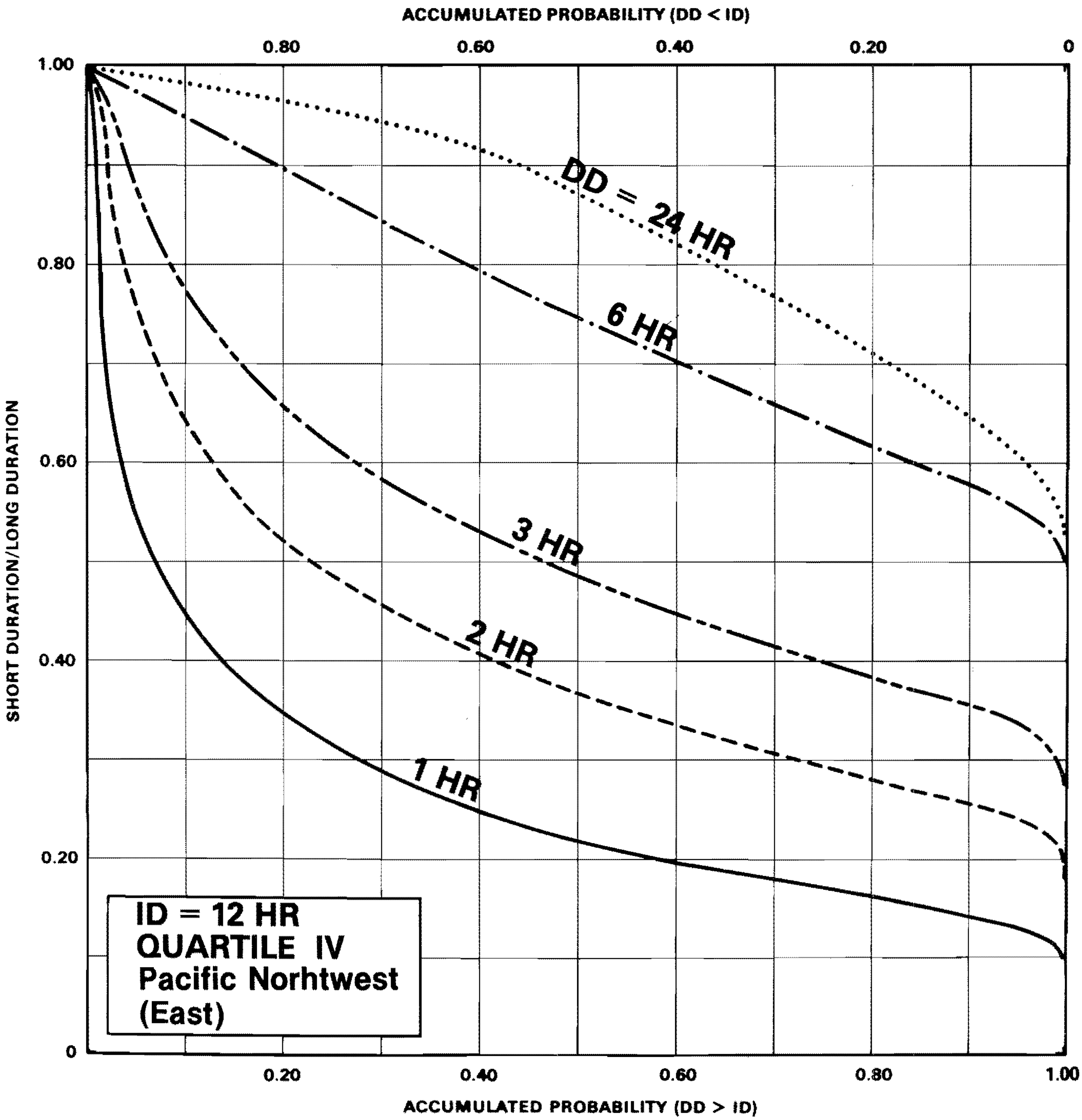
ACCUMULATED PROBABILITY (DD > ID)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SHORT DURATION/LONG DURATION
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QUARTILE IV
Pacific Norhtwest
(East)
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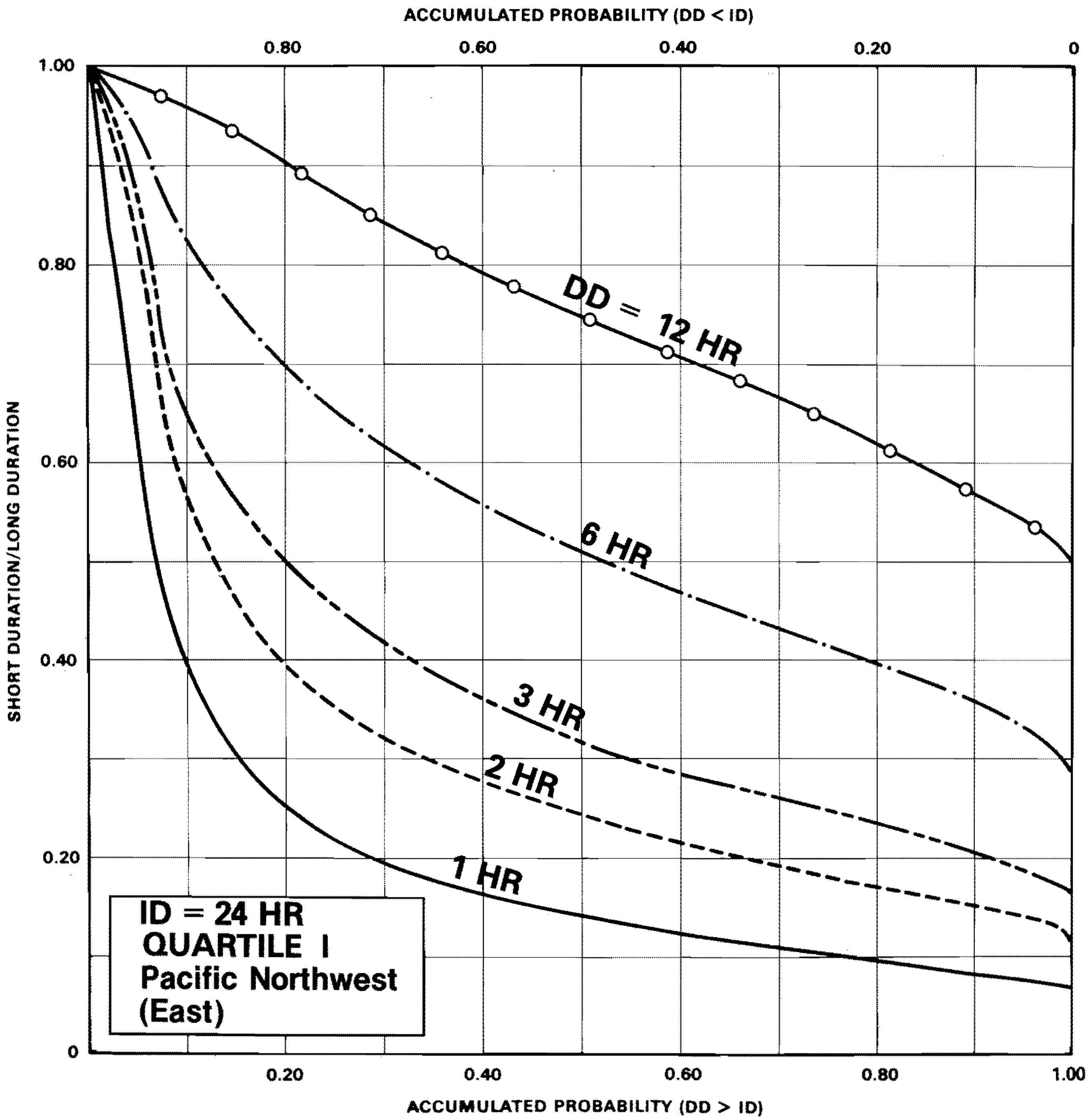
ACCUMULATED PROBABILITY (DD > ID)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SHORT DURATION/LONG DURATION
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QUARTILE I
Pacific Northwest
(East)
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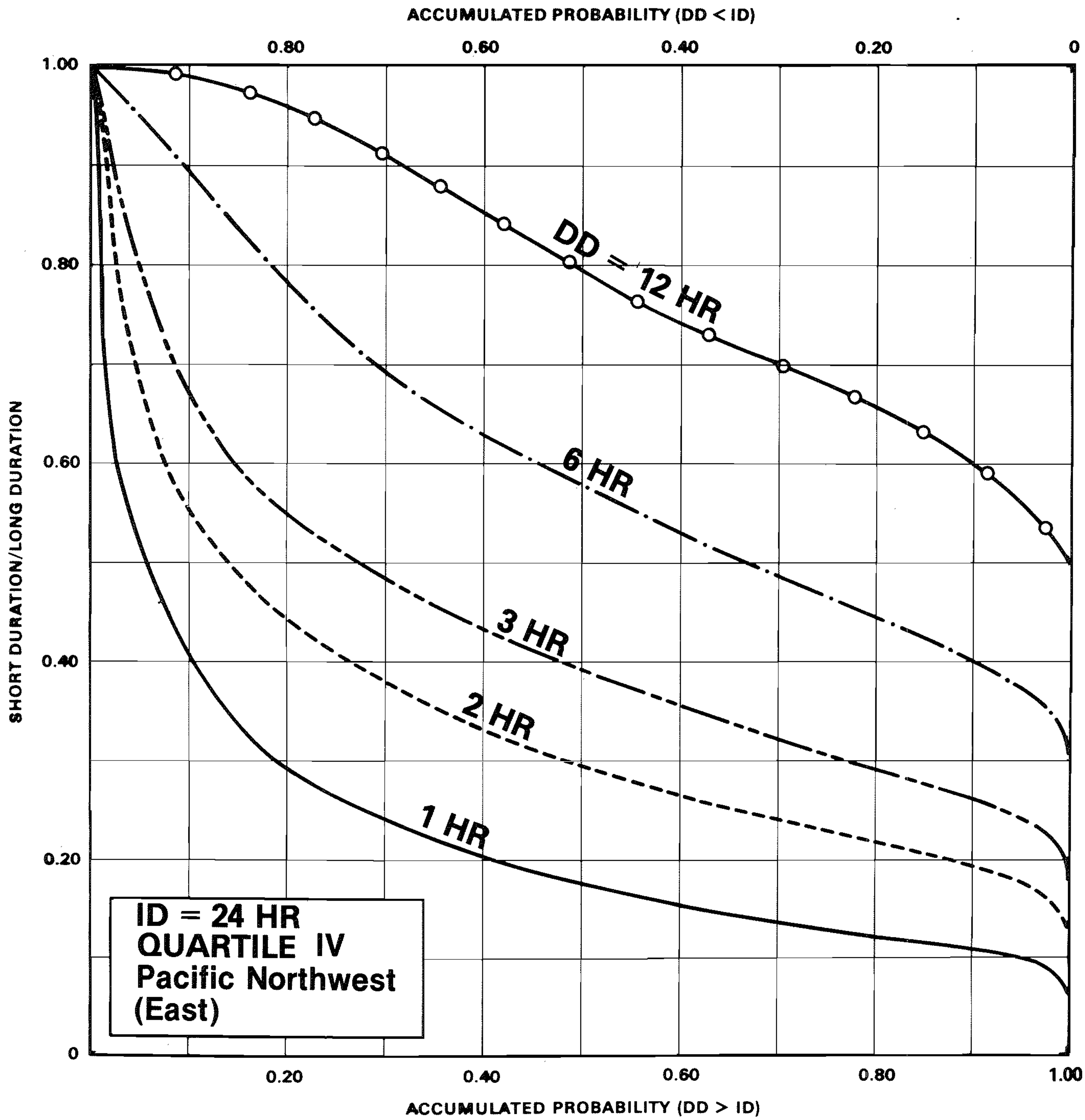
ACCUMULATED PROBABILITY (DD > ID)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SHORT DURATION/LONG DURATION
DD = 12 HR
6 HR
3 HR
2 HR
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ID = 24 HR
QUARTILE IV
Pacific Northwest
(East)
0.20
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0.80
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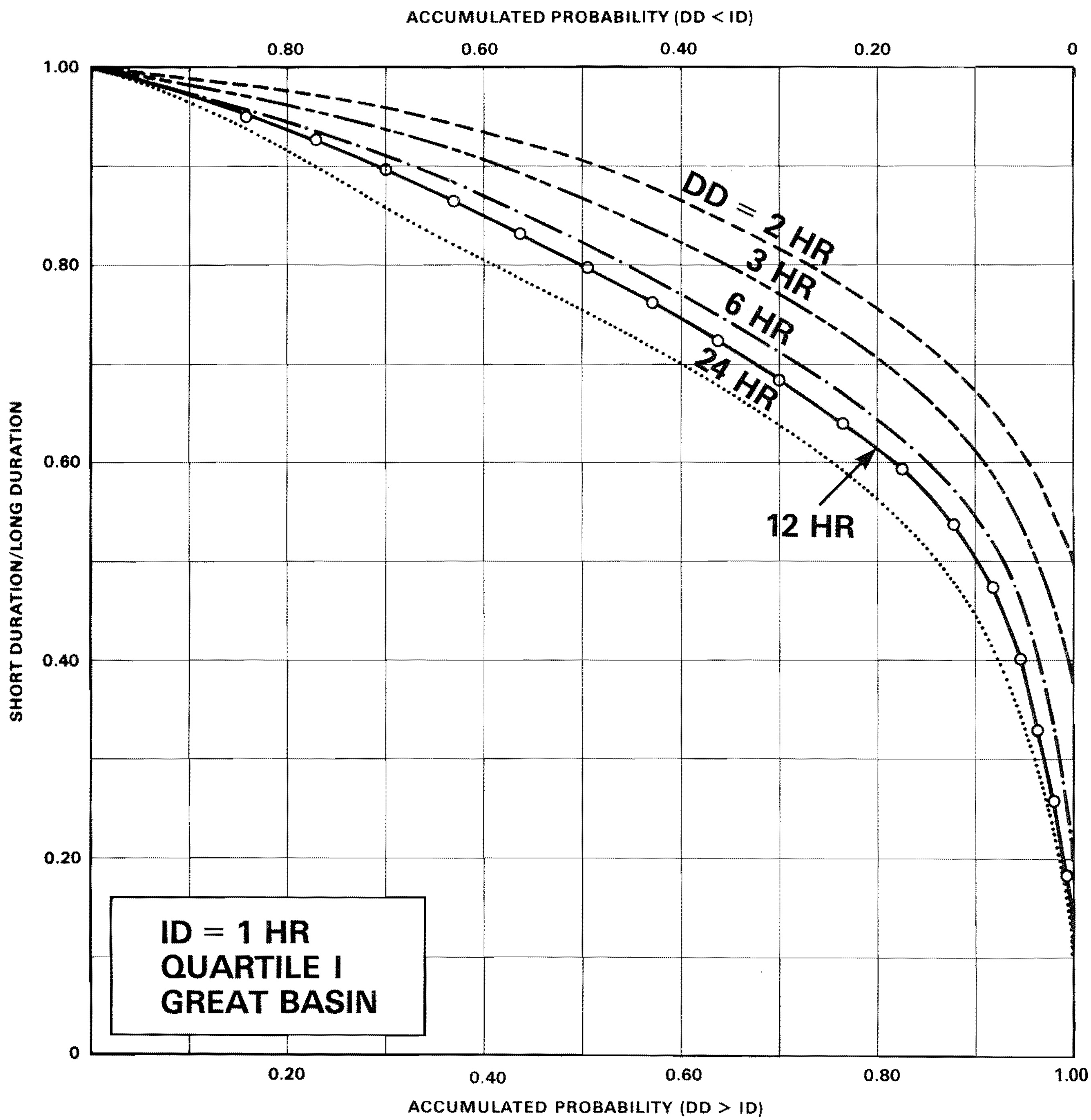
ACCUMULATED PROBABILITY (DD > ID)



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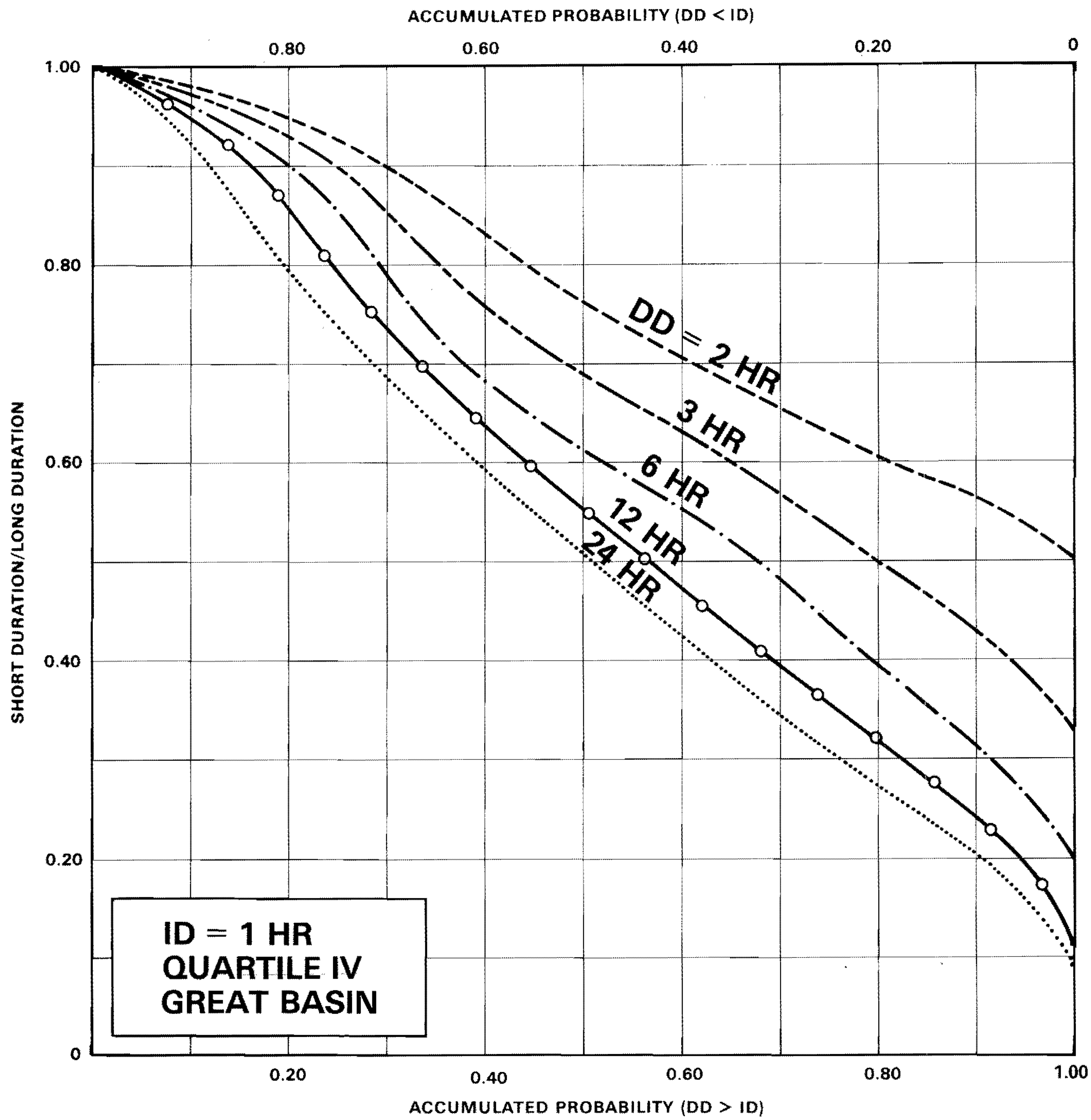
0.20
0
SHORT DURATION/LONG DURATION
DD = 2 HR
3 HR
6 HR
24 HR
12 HR
ID = 1 HR
QUARTILE I
GREAT BASIN
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)


ACCUMULATED PROBABILITY (DD < ID)
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SHORT DURATION/LONG DURATION
DD = 2 HR
3 HR
6 HR
12 HR
24 HR
ID = 1 HR
QUARTILE IV
GREAT BASIN
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0.80
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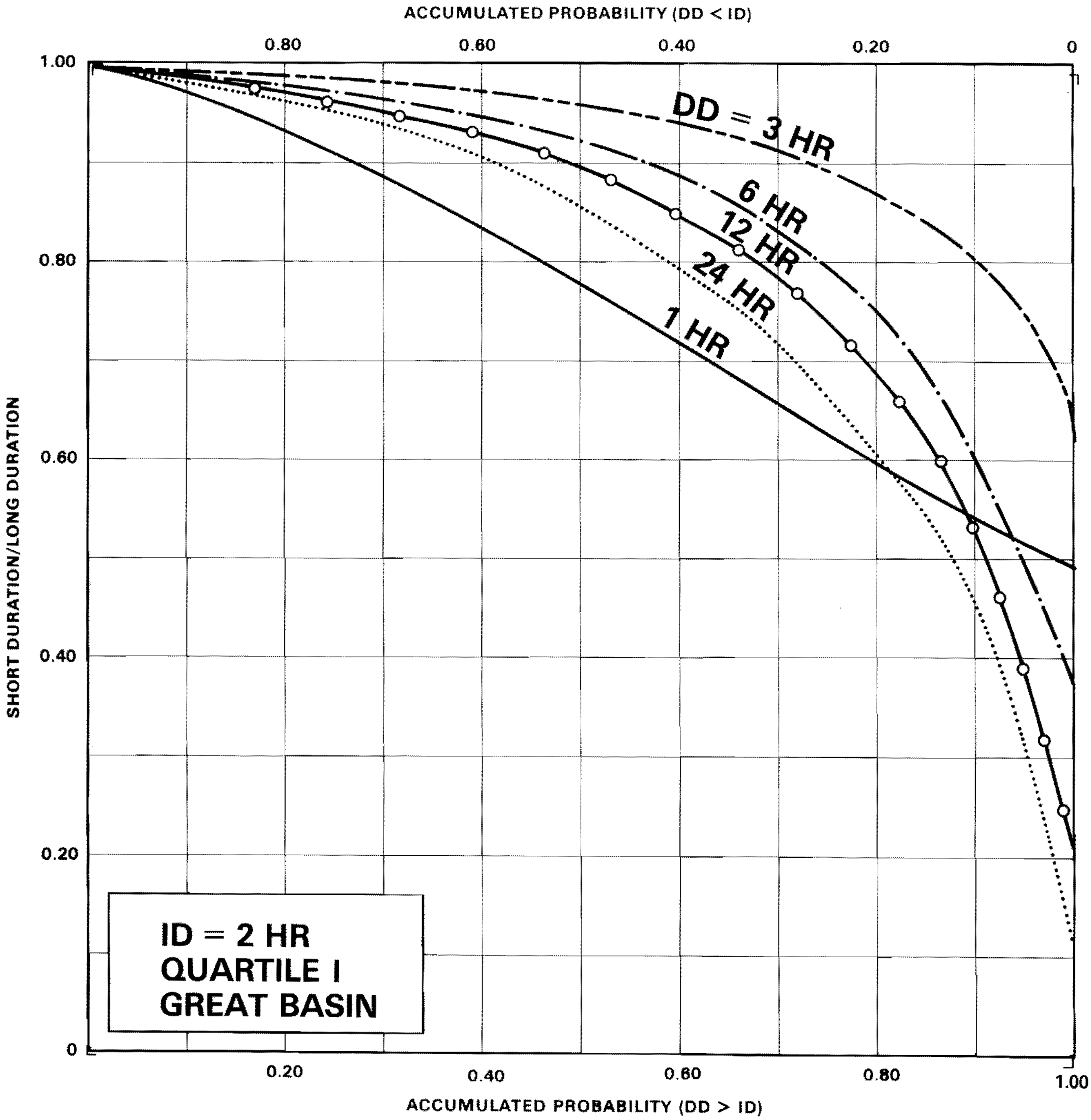
ACCUMULATED PROBABILITY (DD > ID)


ACCUMULATED PROBABILITY (DD < ID)
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SHORT DURATION/LONG DURATION
DD = 3 HR
6 HR
12 HR
24 HR
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QUARTILE I
GREAT BASIN
0.20
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0.80
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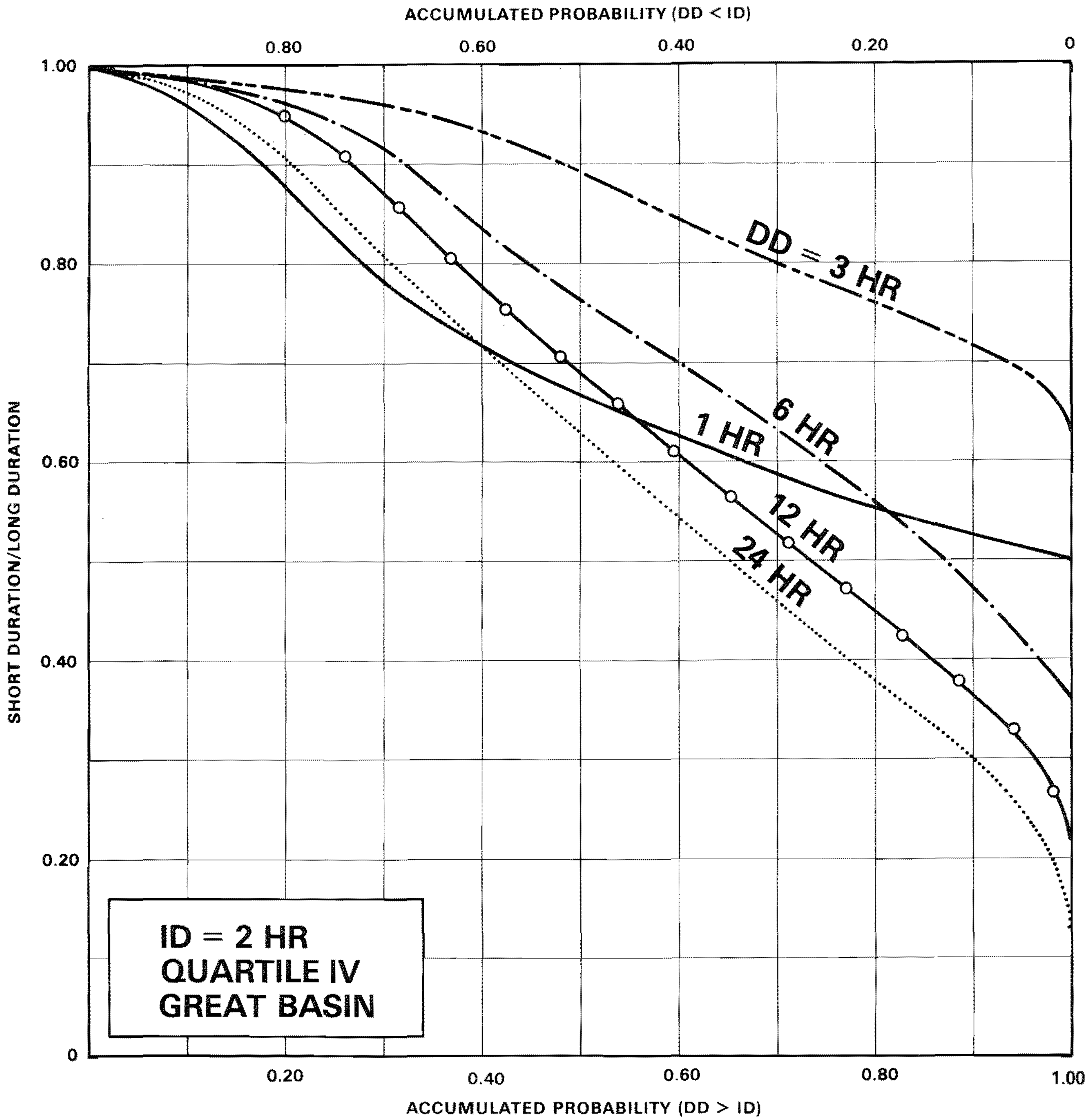
ACCUMULATED PROBABILITY (DD > ID)


ACCUMULATED PROBABILITY (DD < ID)
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SHORT DURATION/LONG DURATION
DD = 3 HR
6 HR
1 HR
12 HR
24 HR
ID = 2 HR
QUARTILE IV
GREAT BASIN
0.20
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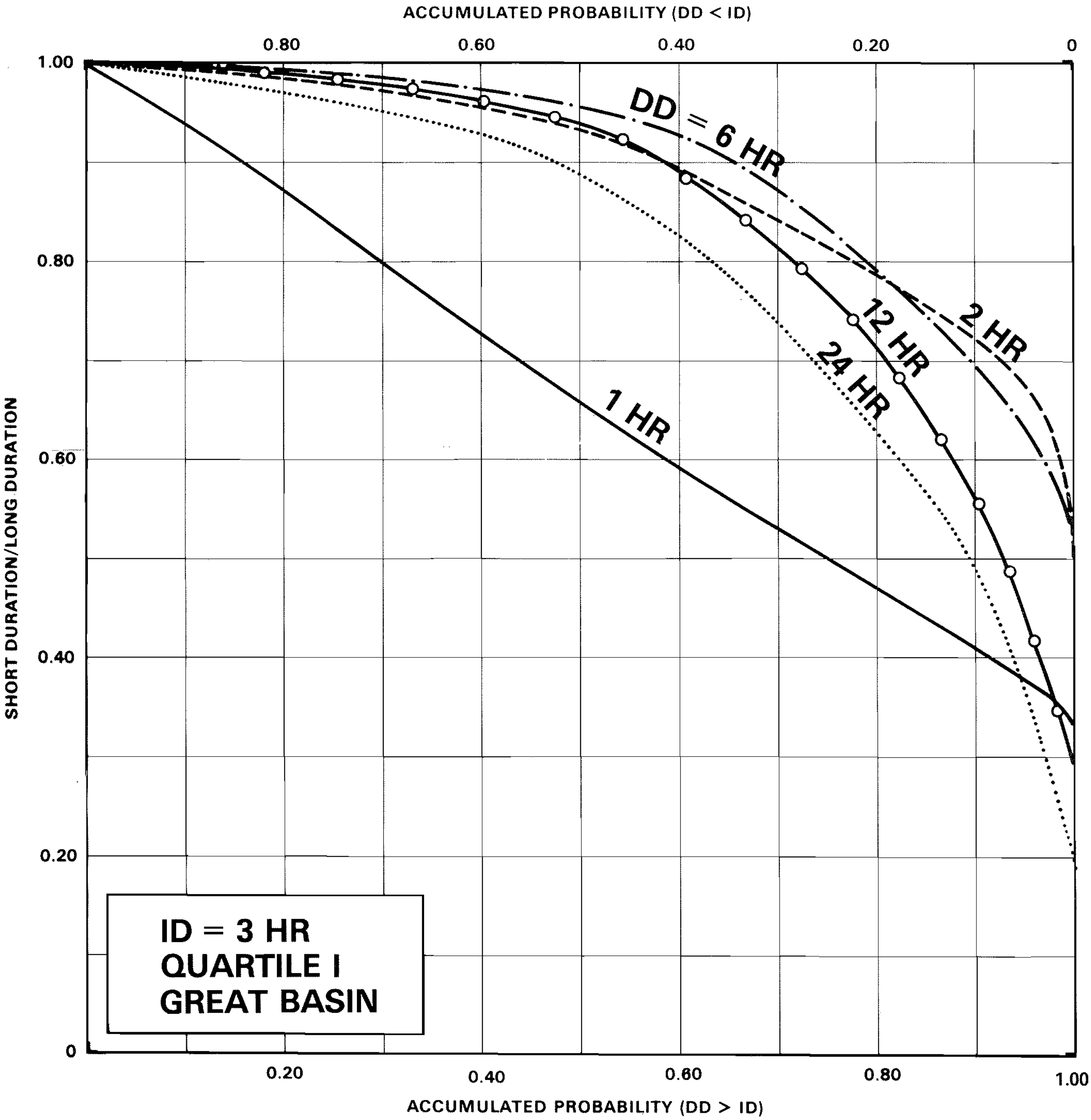
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)


ACCUMULATED PROBABILITY (DD < ID)
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SHORT DURATION/LONG DURATION
DD = 6 HR
2 HR
12 HR
24 HR
1 HR
ID = 3 HR
QUARTILE I
GREAT BASIN
0.20
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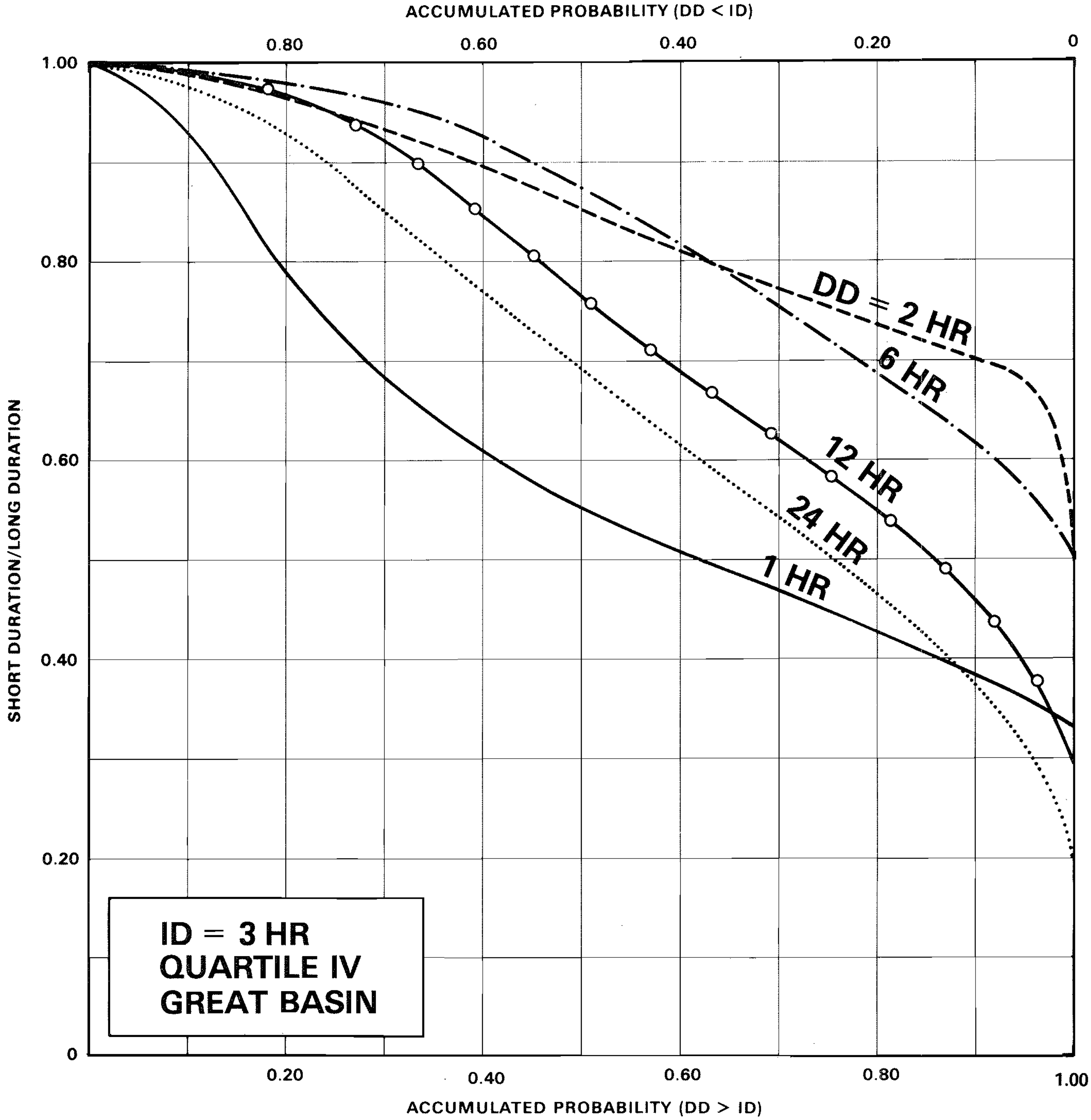
ACCUMULATED PROBABILITY (DD > ID)



ACCUMULATED PROBABILITY (DD < ID)
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SHORT DURATION/LONG DURATION
DD = 2 HR
6 HR
12 HR
24 HR
1 HR
ID = 3 HR
QUARTILE IV
GREAT BASIN
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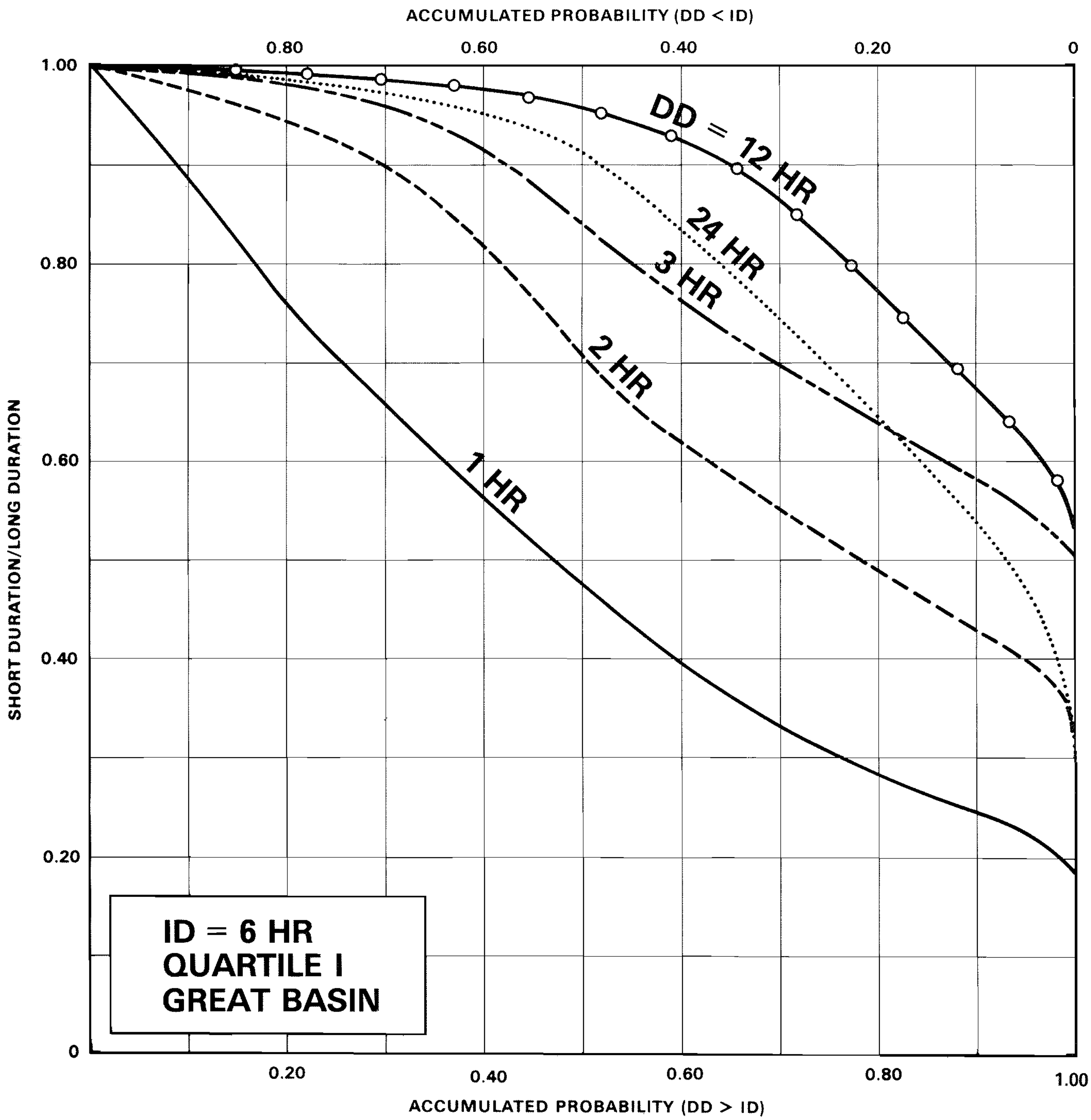
ACCUMULATED PROBABILITY (DD > ID)



ACCUMULATED PROBABILITY (DD < ID)
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SHORT DURATION/LONG DURATION
DD = 12 HR
24 HR
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QUARTILE I
GREAT BASIN
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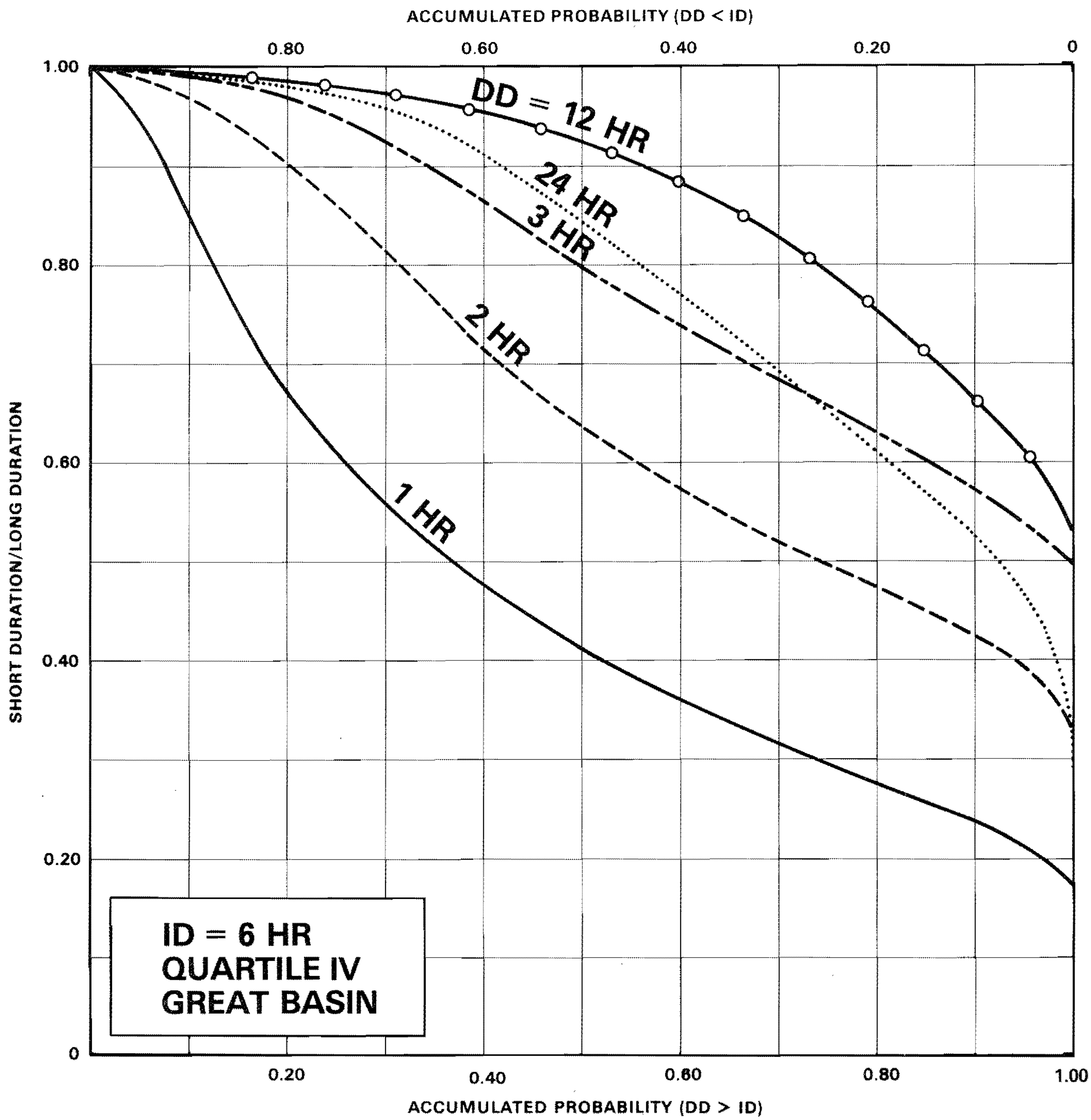
ACCUMULATED PROBABILITY (DD > ID)


ACCUMULATED PROBABILITY (DD < ID)
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SHORT DURATION/LONG DURATION
DD = 12 HR
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QUARTILE IV
GREAT BASIN
0.20
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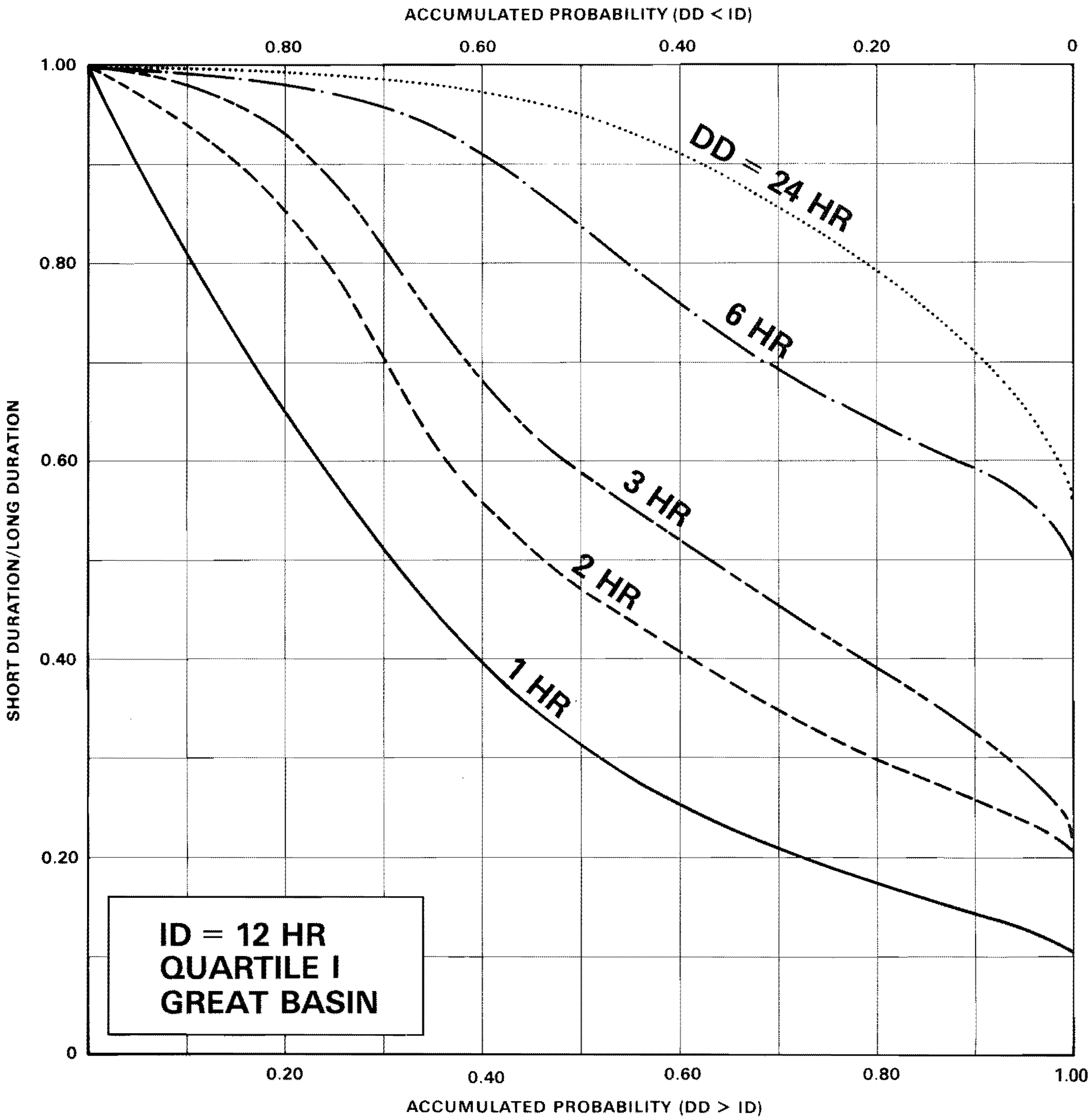
ACCUMULATED PROBABILITY (DD > ID)


ACCUMULATED PROBABILITY (DD < ID)
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SHORT DURATION/LONG DURATION
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QUARTILE I
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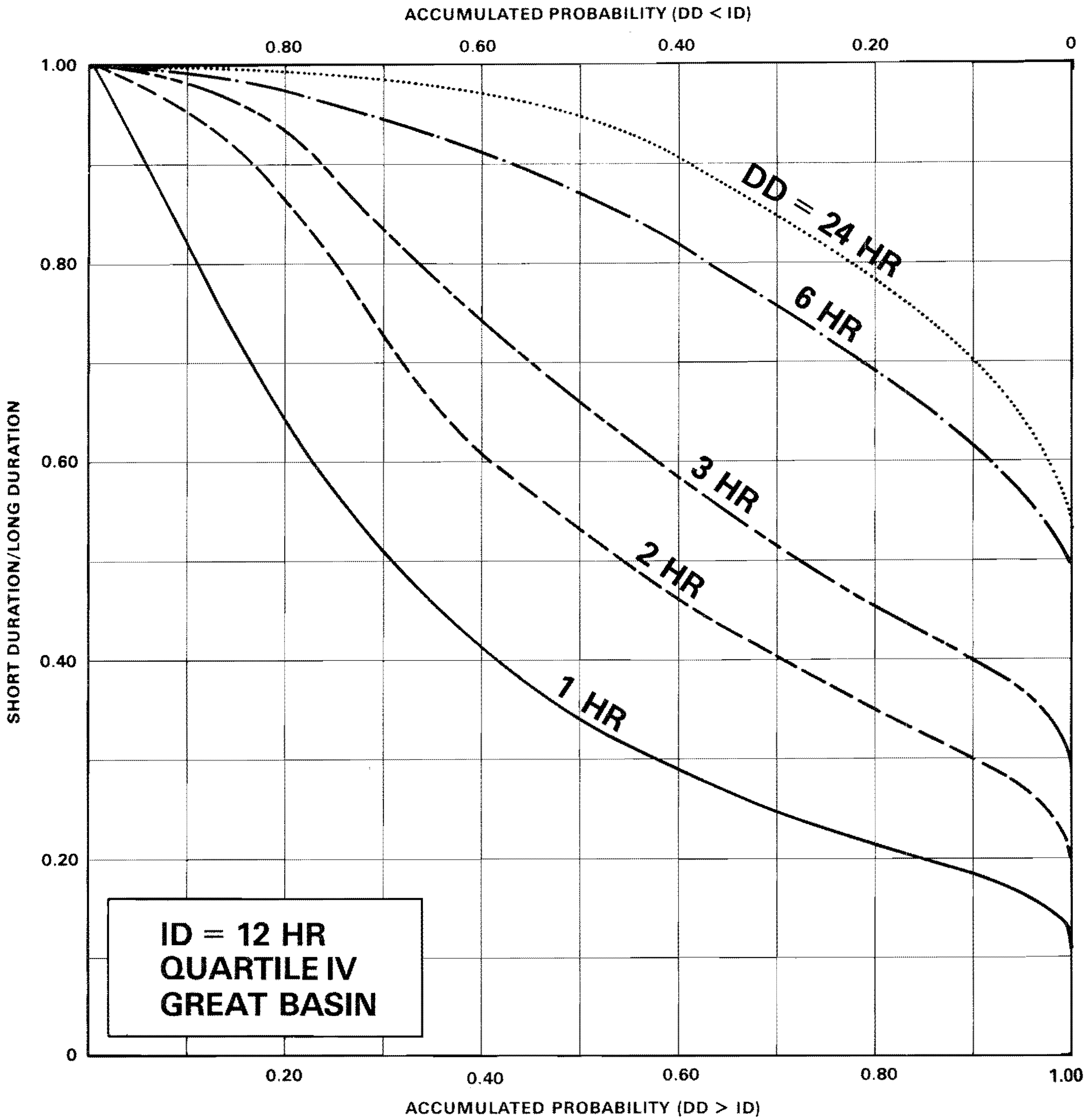

ACCUMULATED PROBABILITY (DD < ID)
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SHORT DURATION/LONG DURATION
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QUARTILE IV
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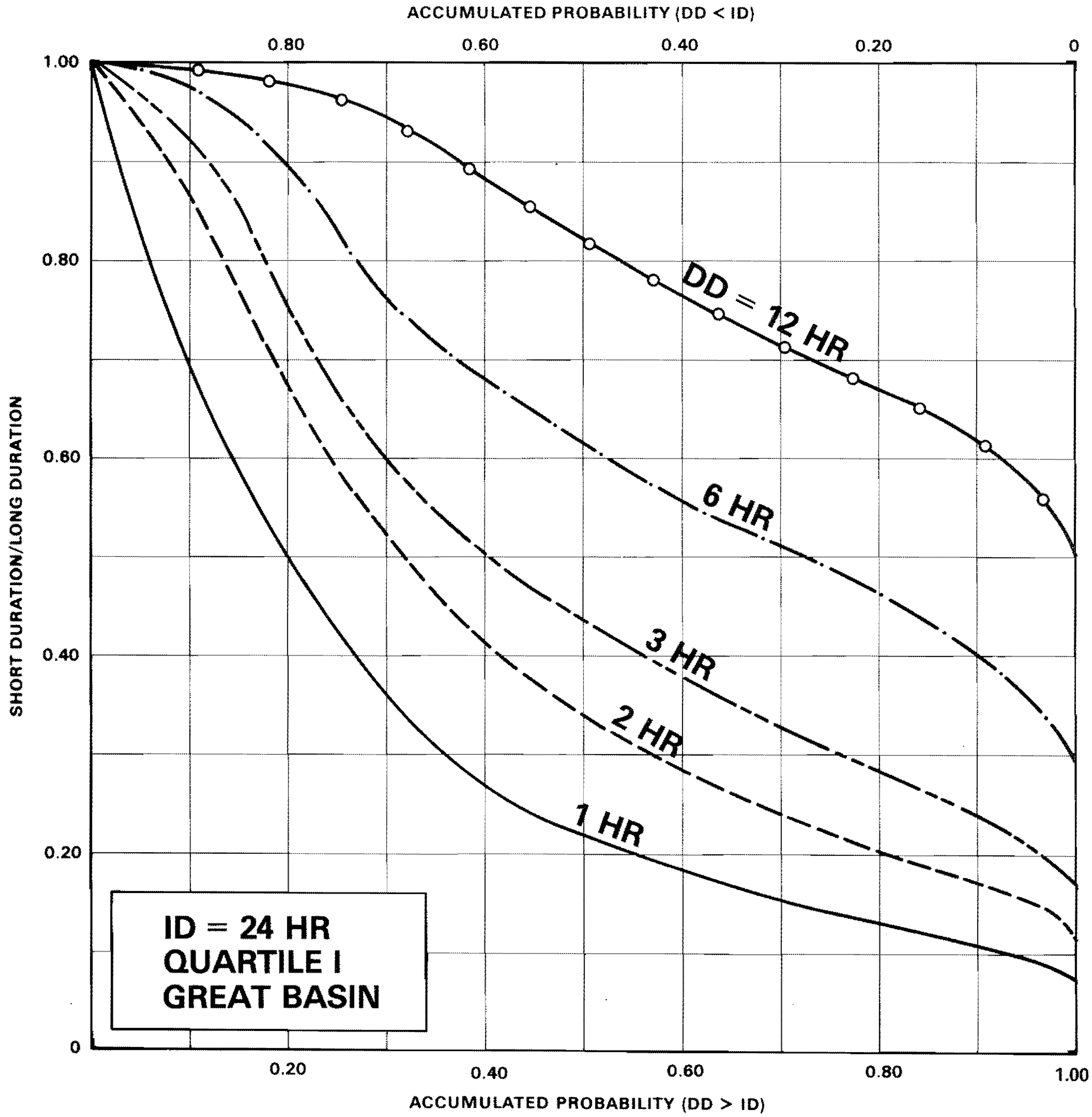
ACCUMULATED PROBABILITY (DD < ID)
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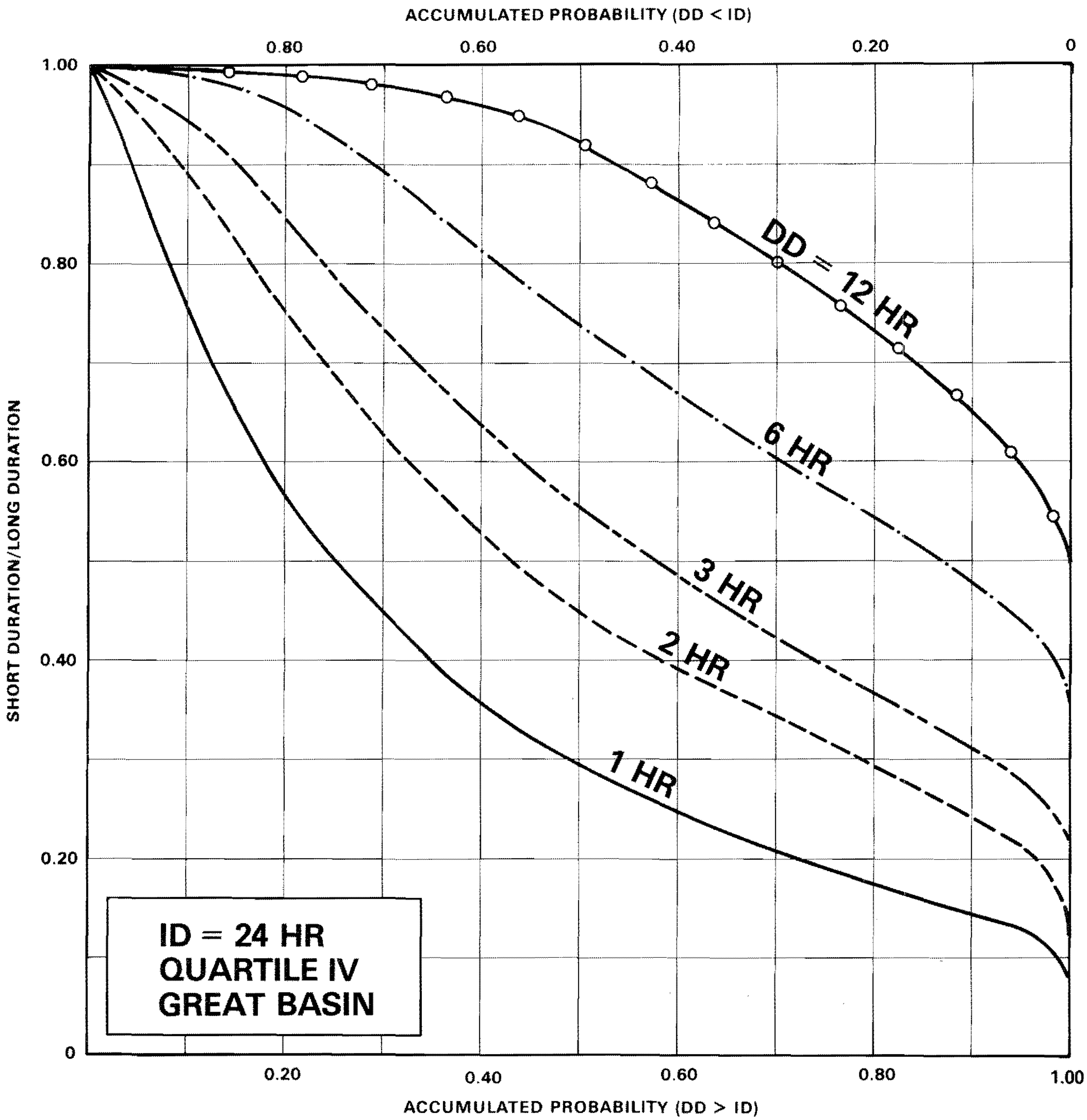
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SHORT DURATION/LONG DURATION
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QUARTILE IV
GREAT BASIN
0.20
0.40
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0.80
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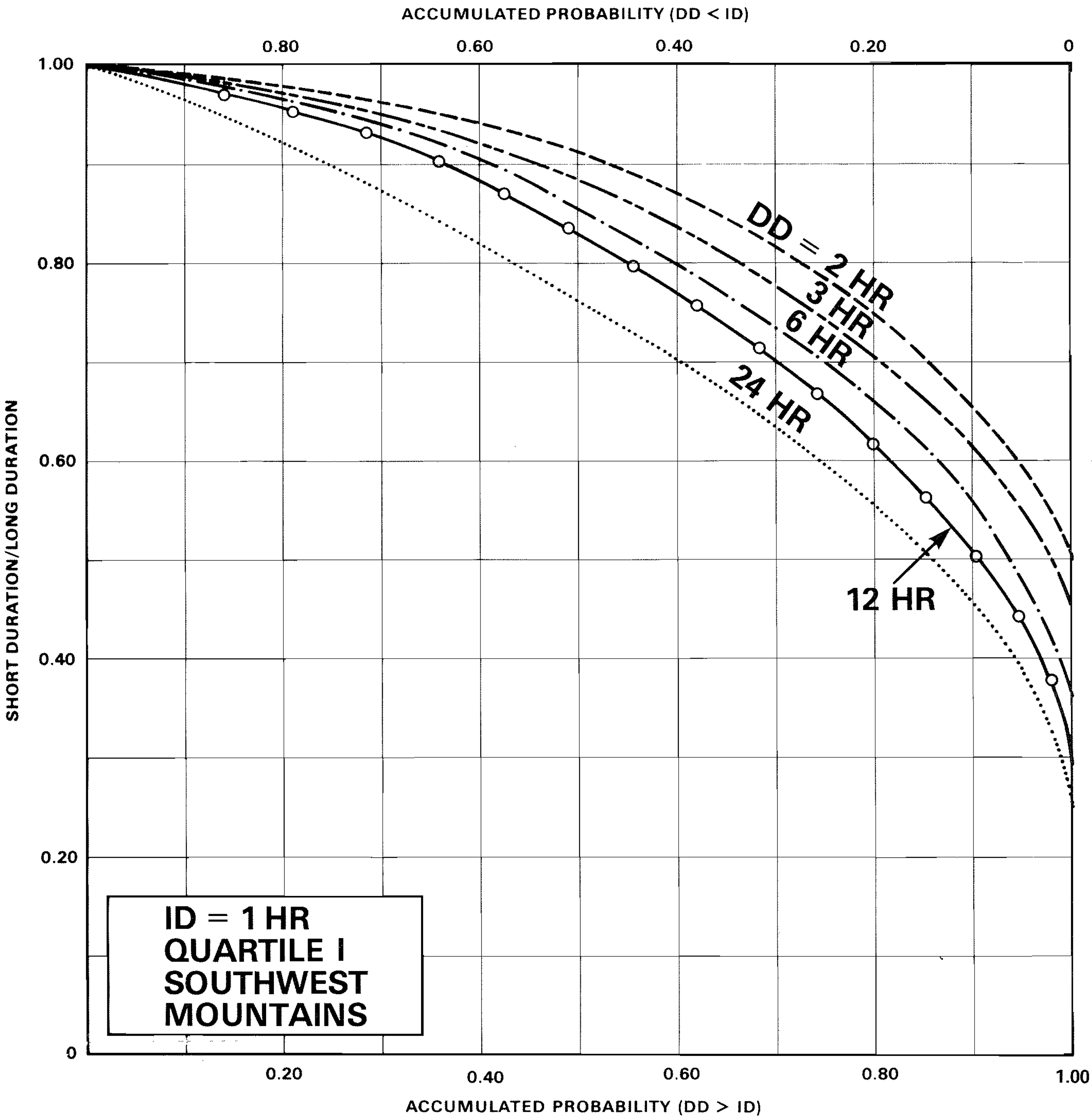
ACCUMULATED PROBABILITY (DD > ID)


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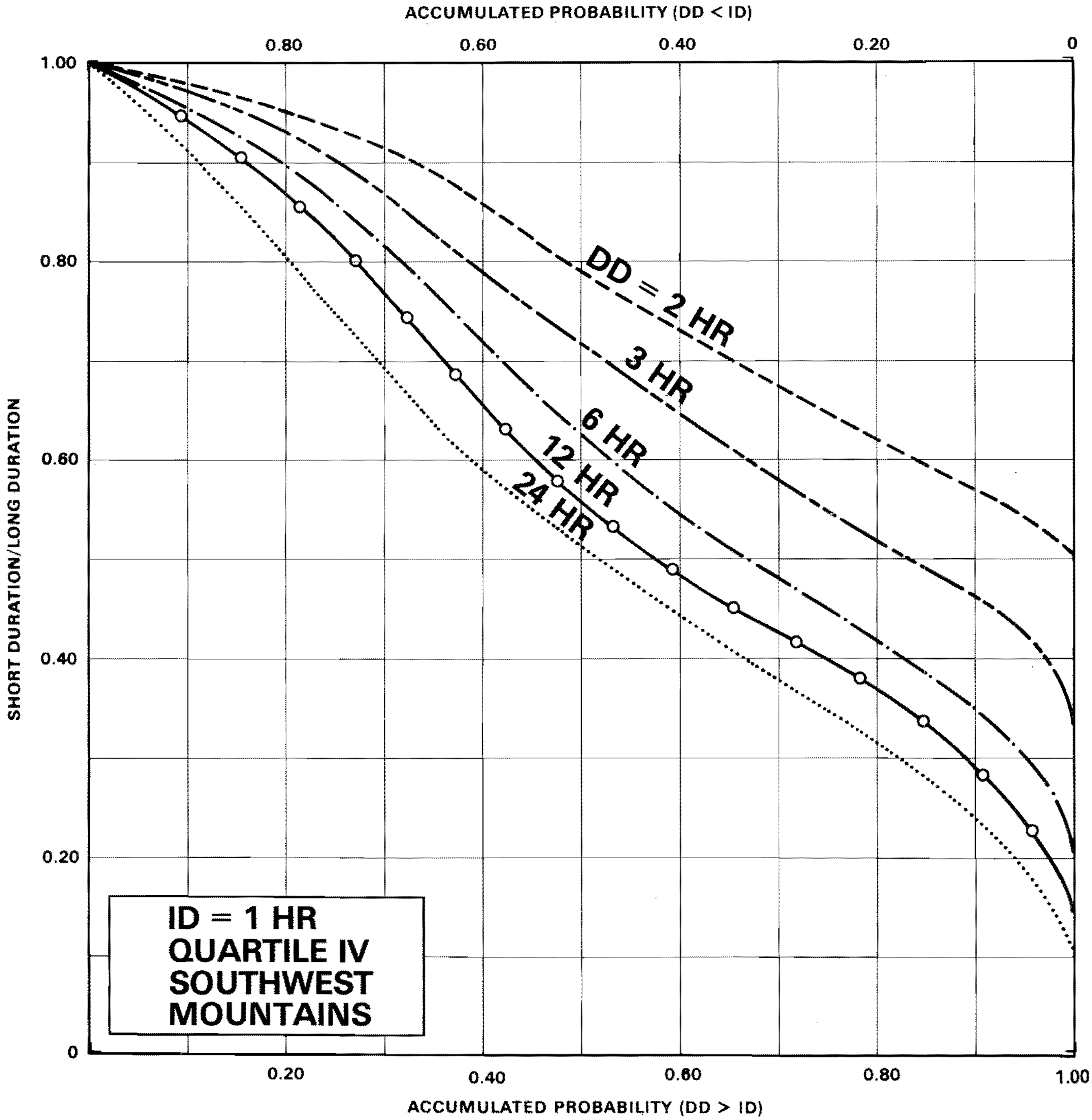
0.40
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 2 HR
3 HR
6 HR
24 HR
12 HR
ID = 1 HR
QUARTILE I
SOUTHWEST
MOUNTAINS
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)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0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD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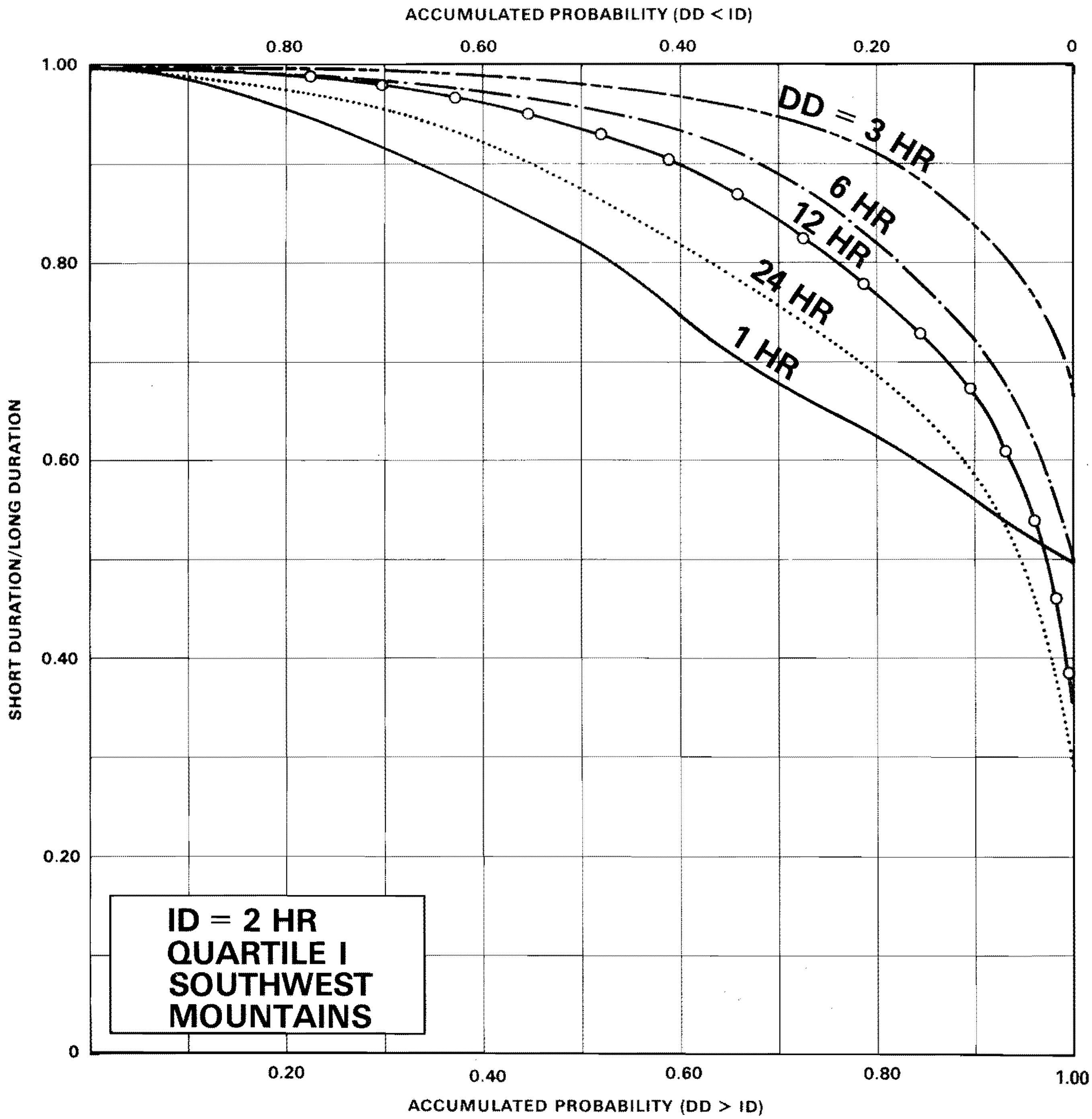
QUARTILE IV
SOUTHWEST
MOUNTAINS
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)


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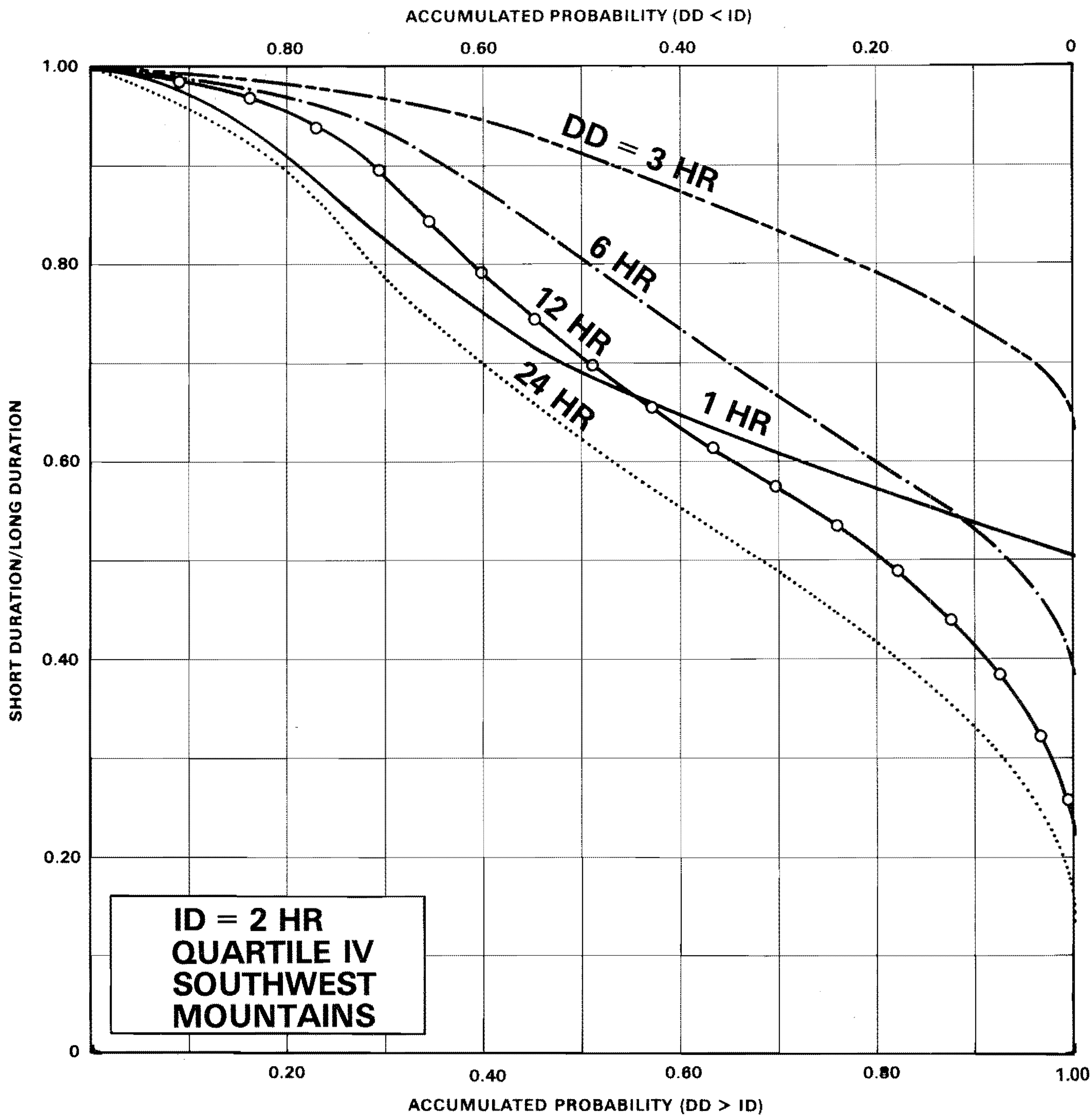
1.00
ACCUMULATED PROBABILITY (DD > ID)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0.80
0.60
0.40
0.20
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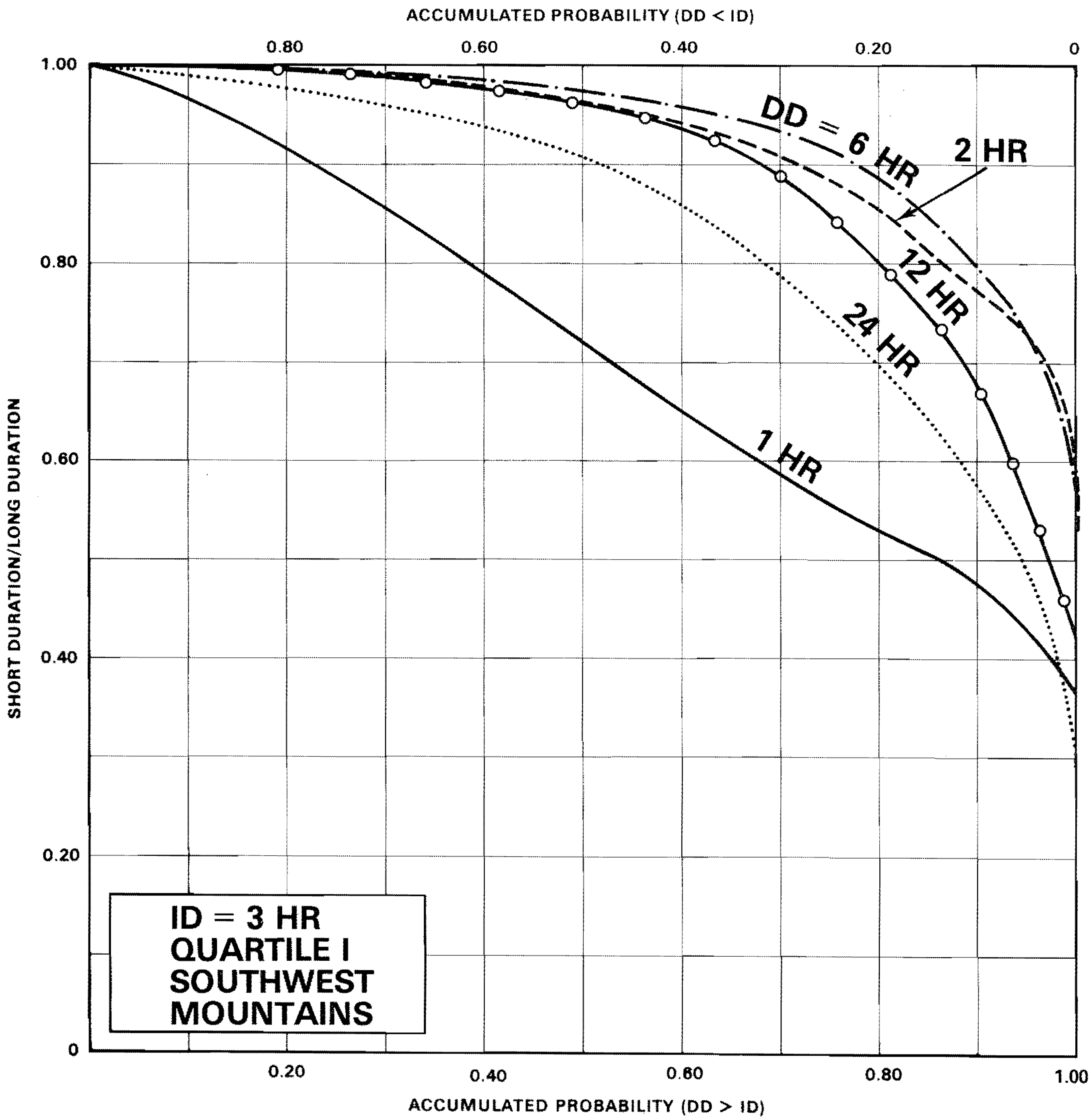
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 3 HR
6 HR
12 HR
24 HR
1 HR
ID = 2 HR
QUARTILE IV
SOUTHWEST
MOUNTAINS
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)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0.40
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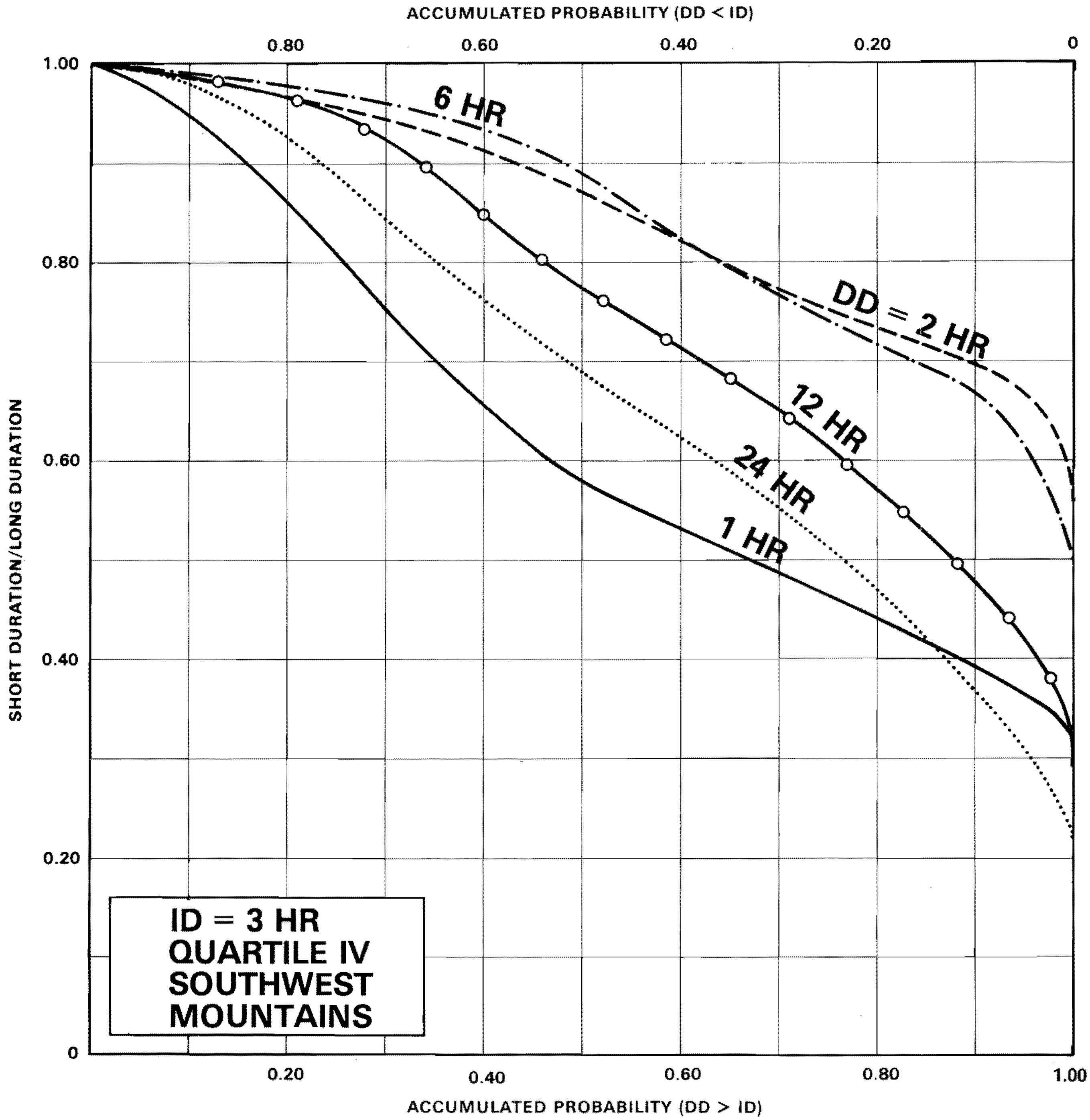
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 6 HR
2 HR
12 HR
24 HR
1 HR
ID = 3 HR
QUARTILE I
SOUTHWEST
MOUNTAINS
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)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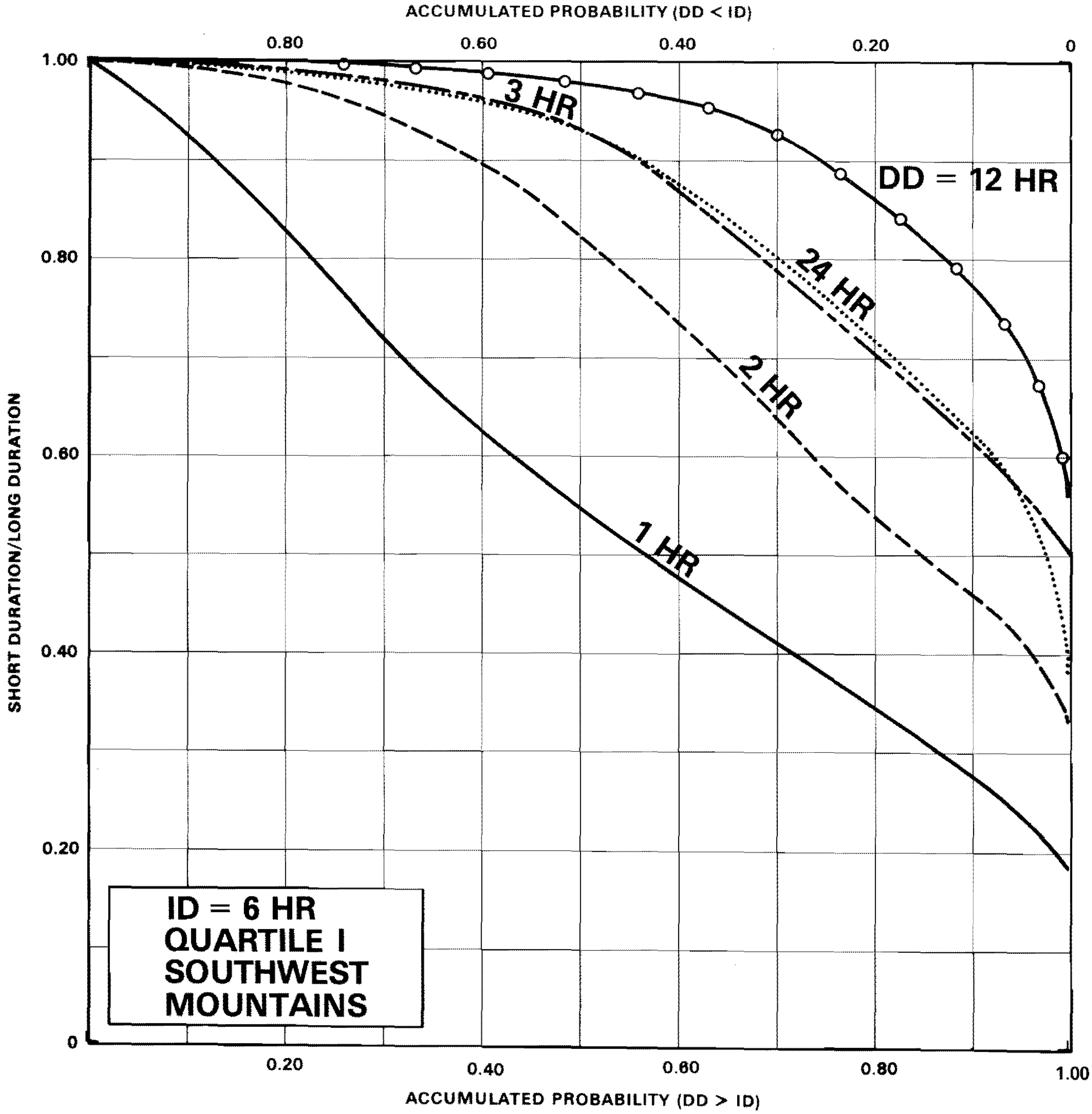
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
6 HR
DD = 2 HR
12 HR
24 HR
1 HR
ID = 3 HR
QUARTILE IV
SOUTHWEST
MOUNTAINS
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)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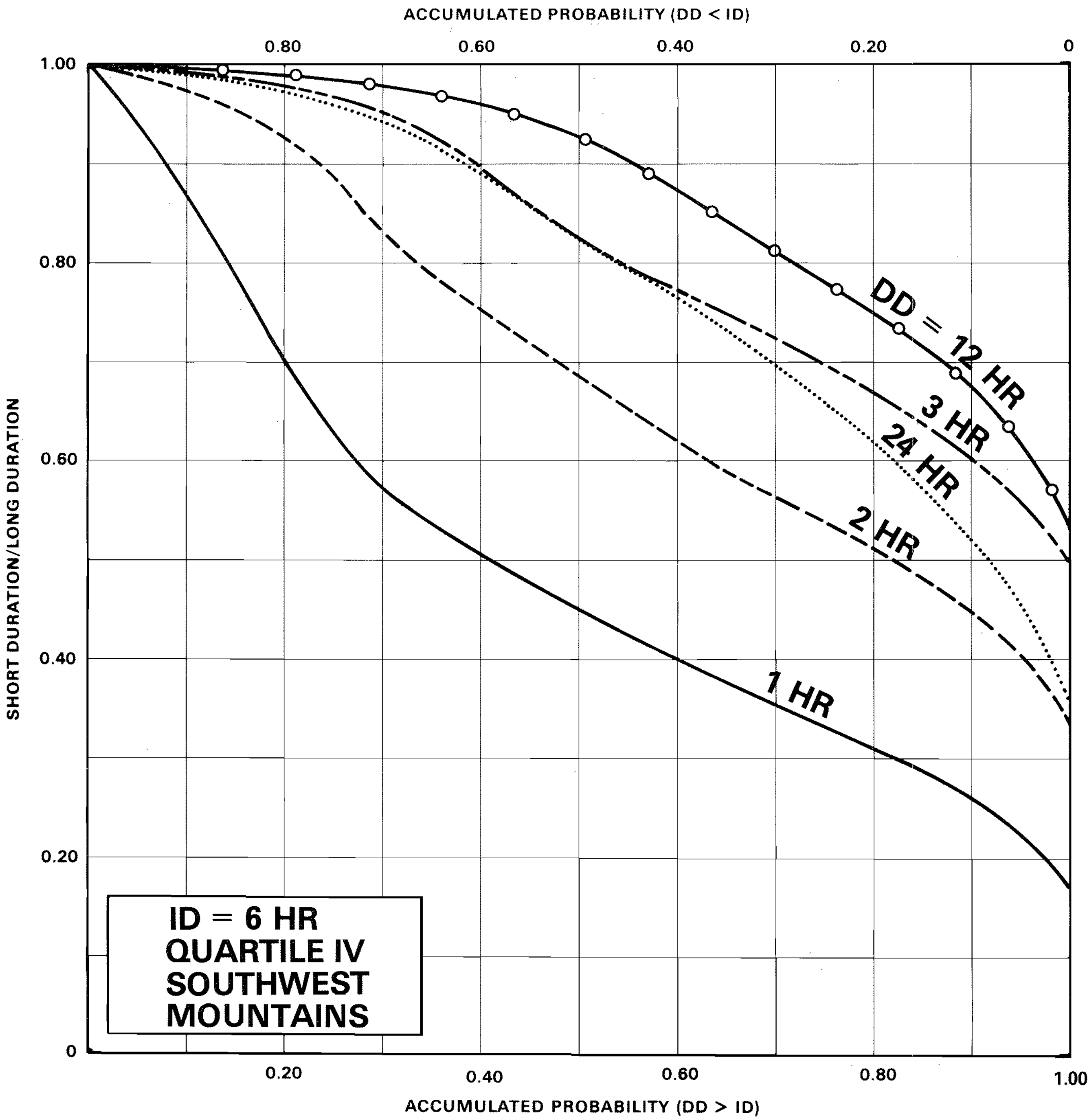
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
3 HR
DD = 12 HR
24 HR
2 HR
1 HR
ID = 6 HR
QUARTILE I
SOUTHWEST
MOUNTAINS
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)



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0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 12 HR
3 HR
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QUARTILE IV
SOUTHWEST
MOUNTAINS
0.20
0.40
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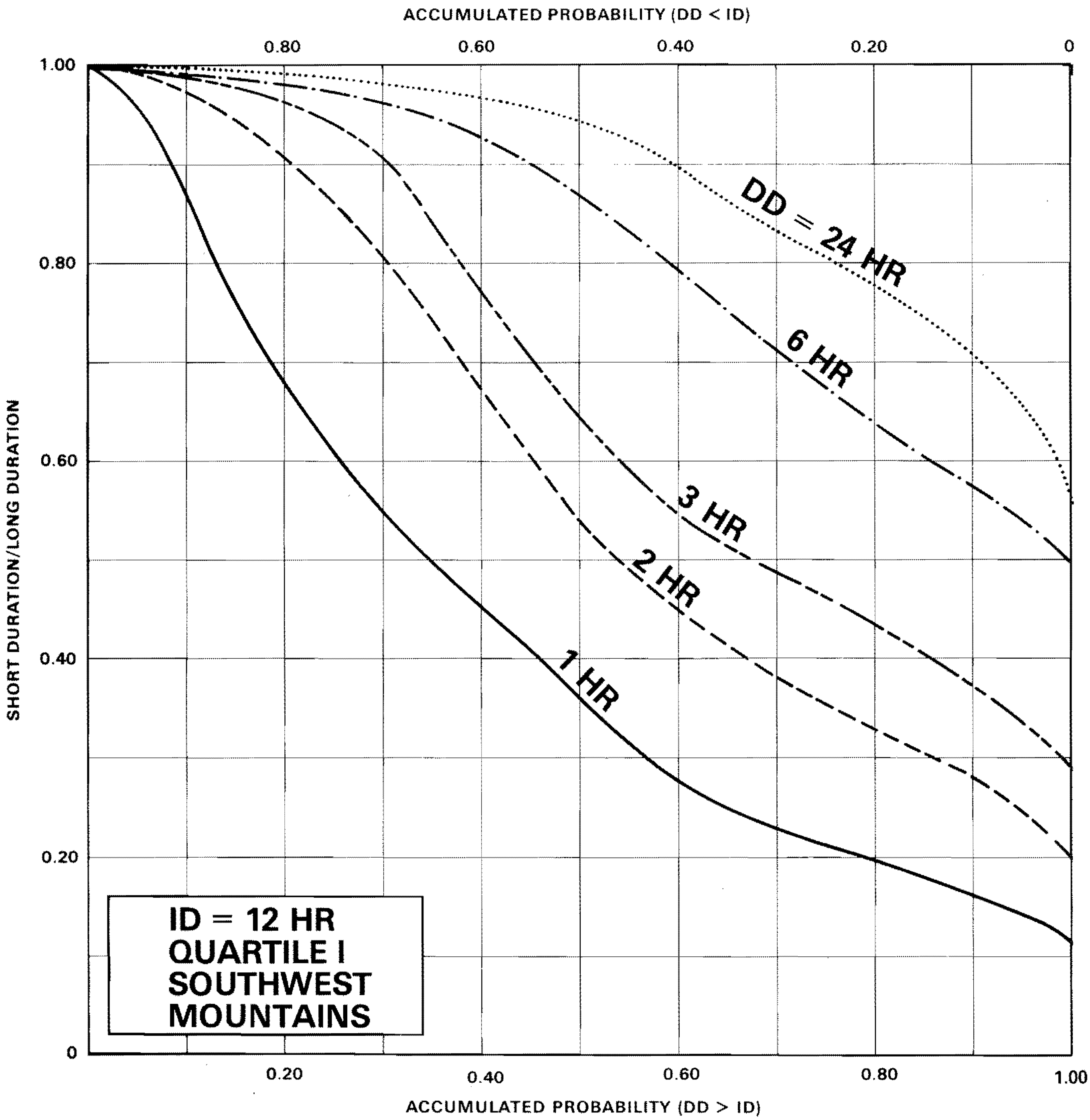
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)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SHORT DURATION/LONG DURATION
DD = 24 HR
6 HR
3 HR
2 HR
1 HR
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QUARTILE I
SOUTHWEST
MOUNTAINS
0.20
0.40
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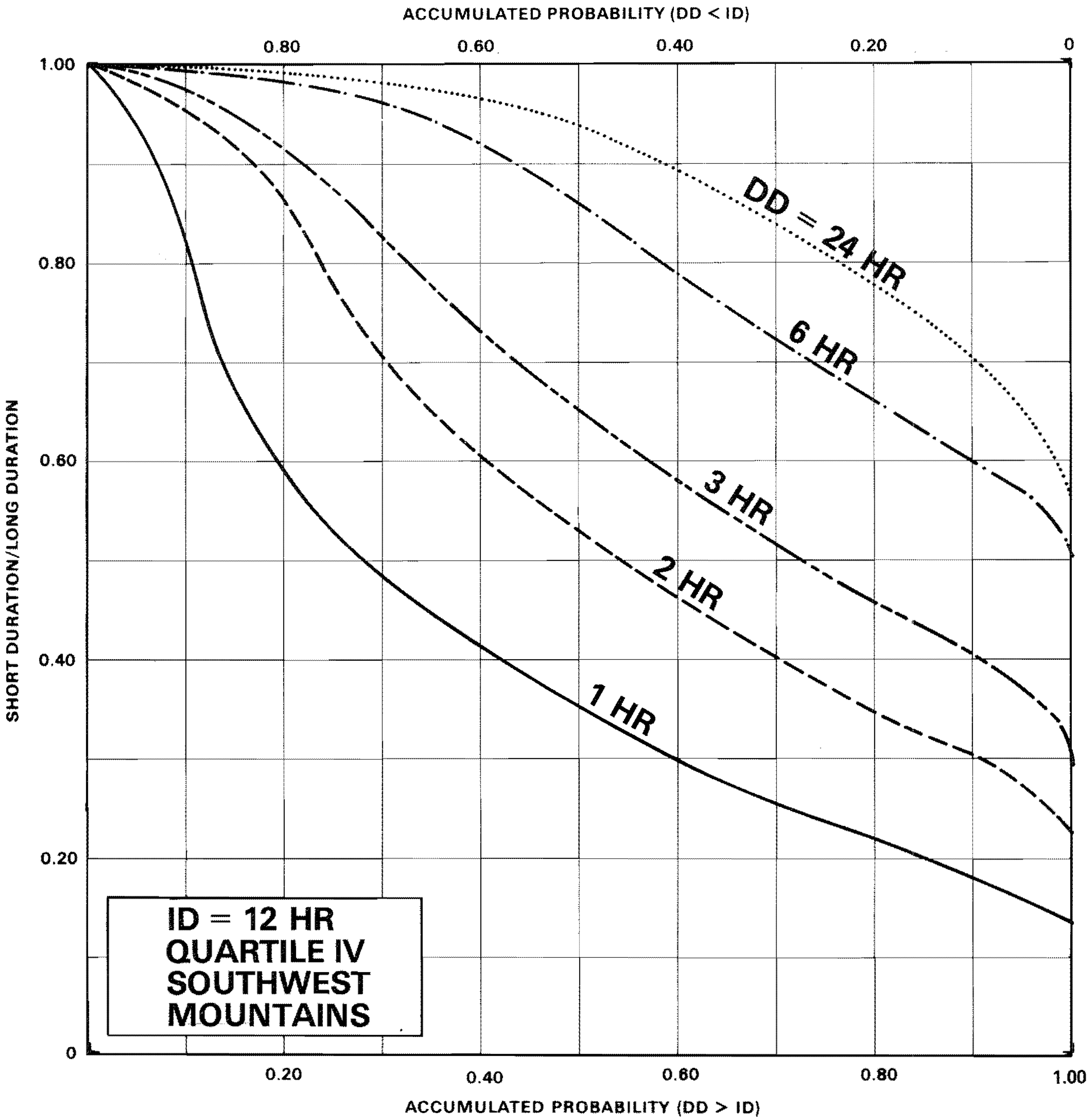
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)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SHORT DURATION/LONG DURATION
DD = 24 HR
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QUARTILE IV
SOUTHWEST
MOUNTAINS
0.20
0.40
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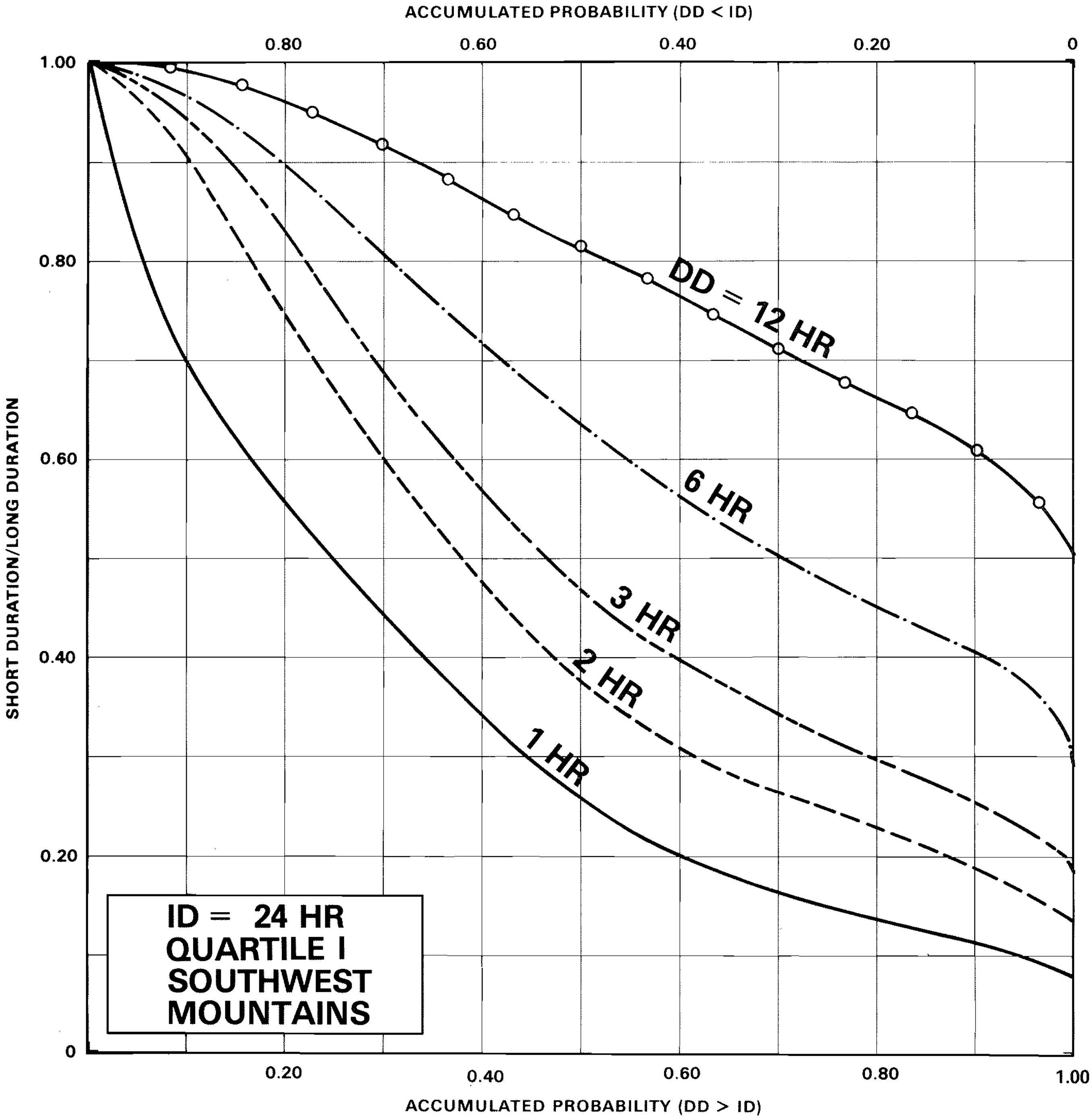
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)



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SHORT DURATION/LONG DURATION
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QUARTILE I
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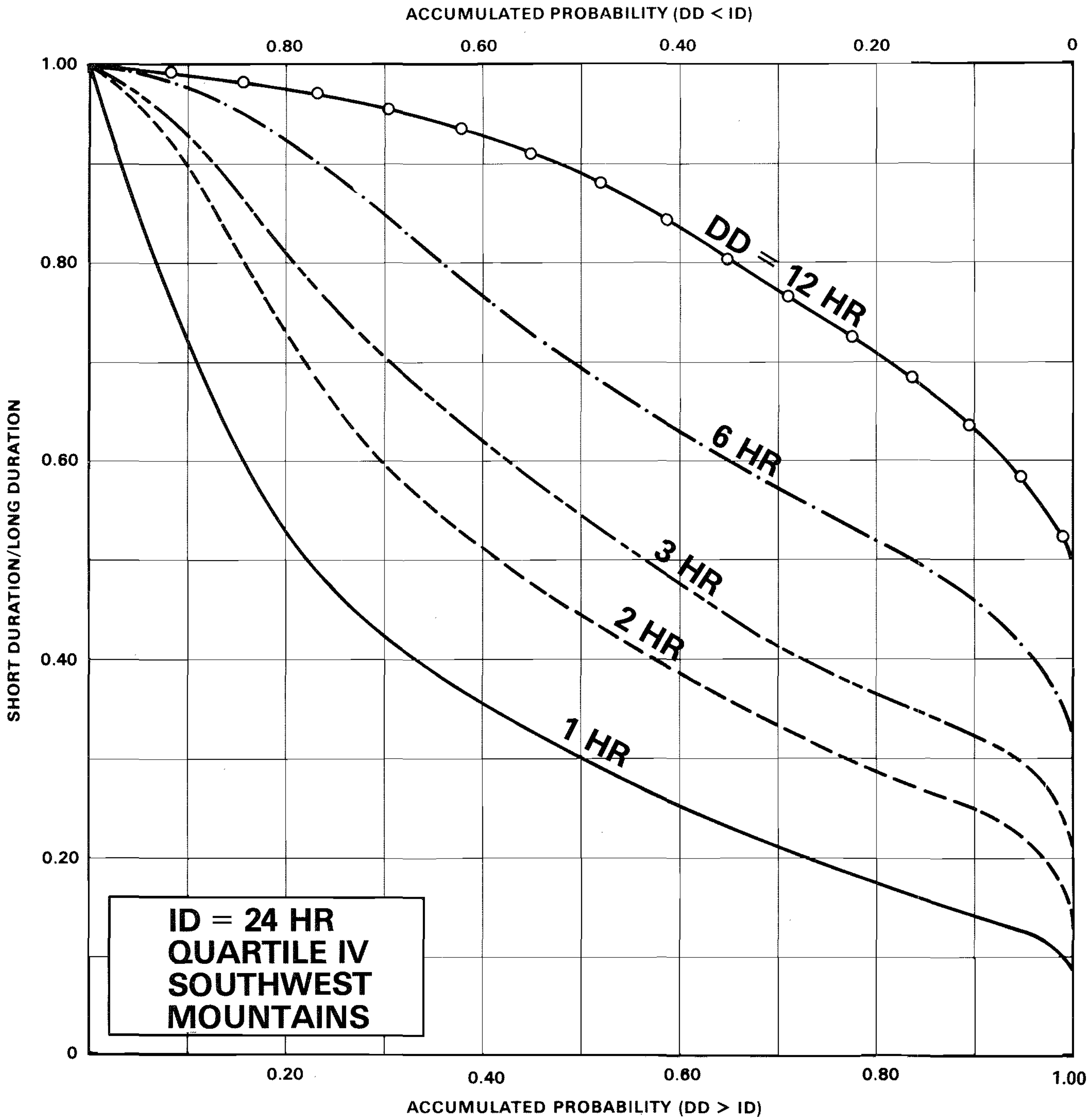
ACCUMULATED PROBABILITY (DD > ID)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SHORT DURATION/LONG DURATION
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QUARTILE IV
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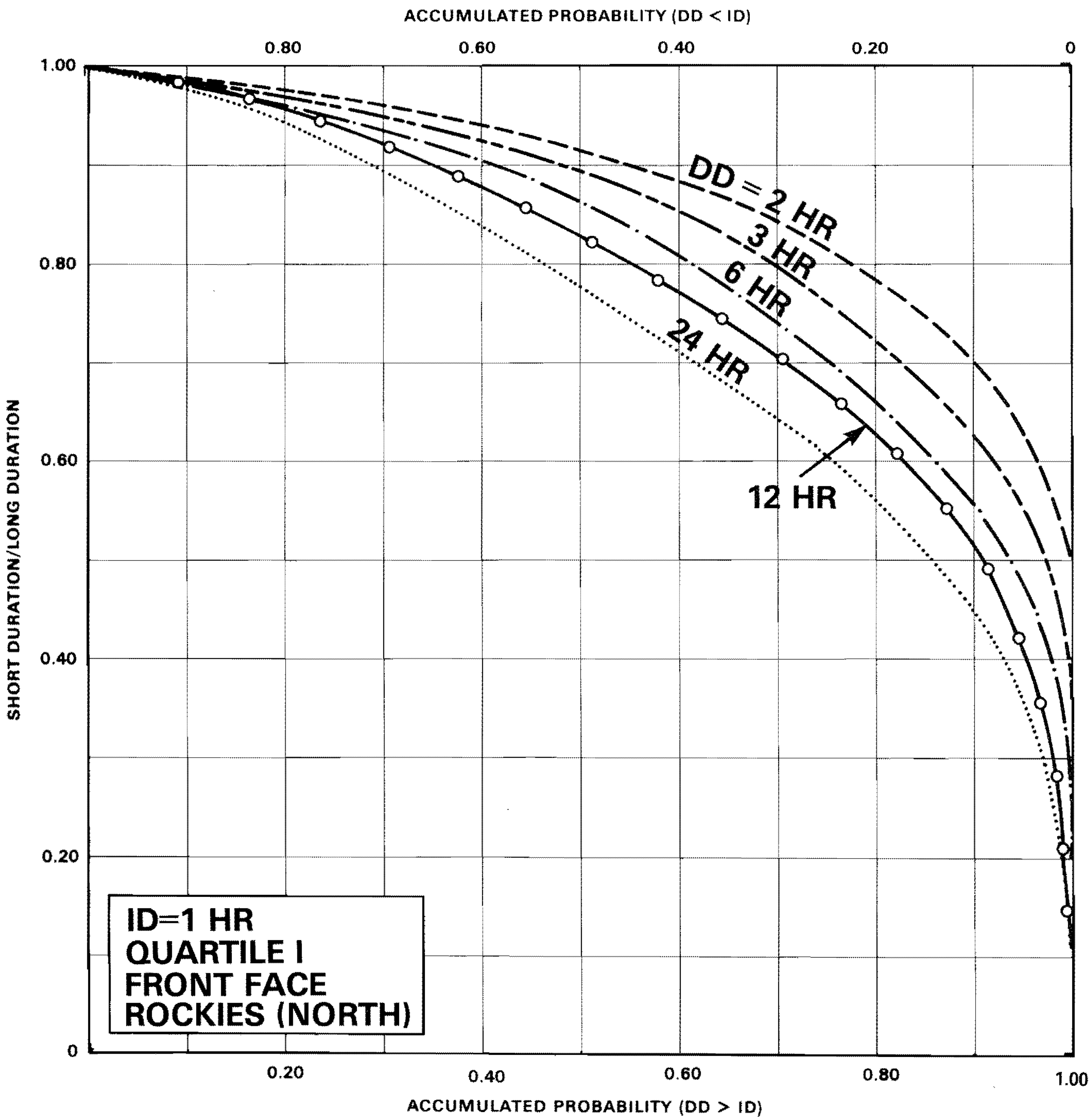
ACCUMULATED PROBABILITY (DD > ID)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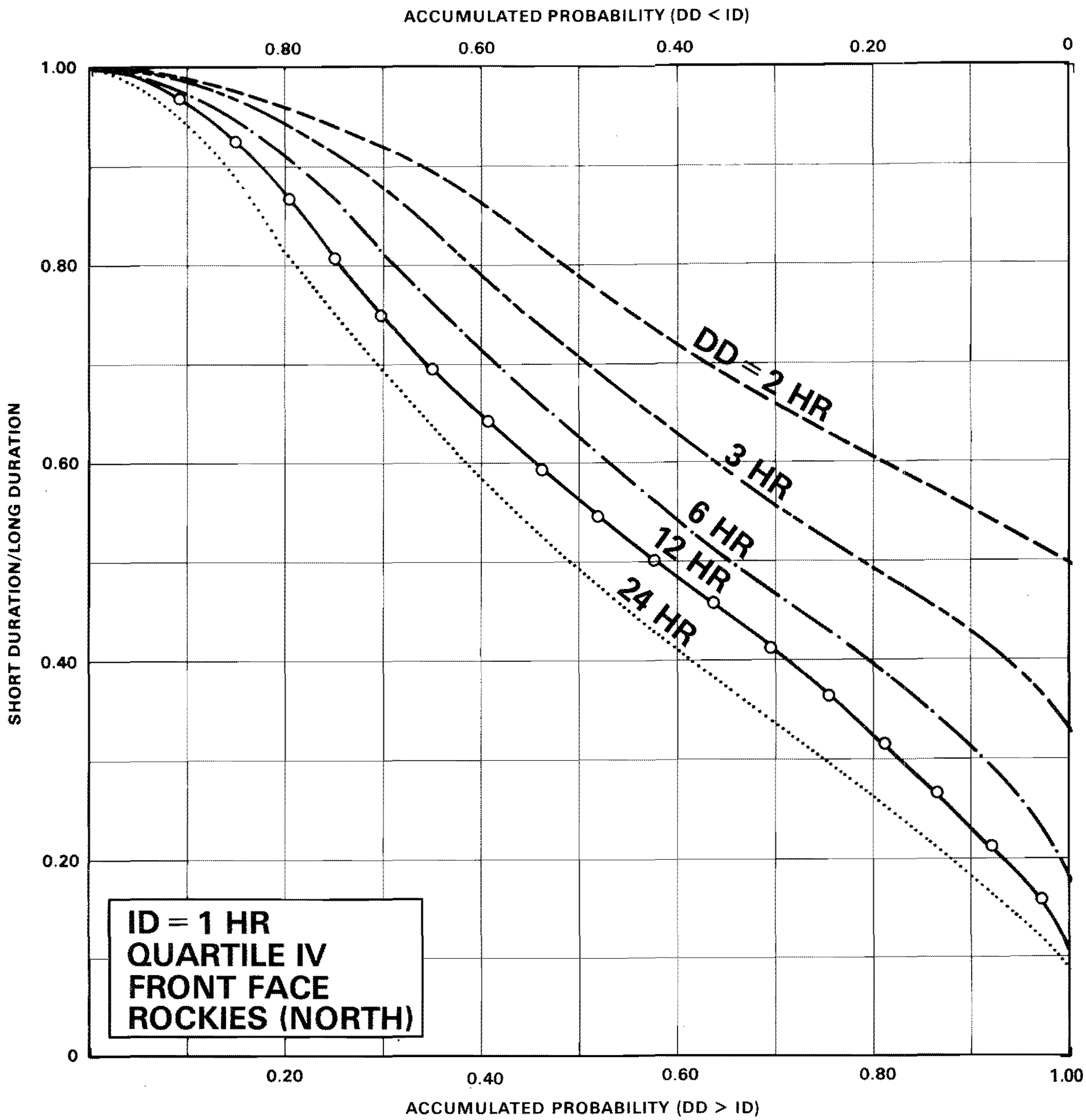
0
SHORT DURATION/LONG DURATION
DD = 2 HR
3 HR
6 HR
24 HR
12 HR
ID=1 HR
QUARTILE I
FRONT FACE
ROCKIES (NORTH)
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)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SHORT DURATION/LONG DURATION
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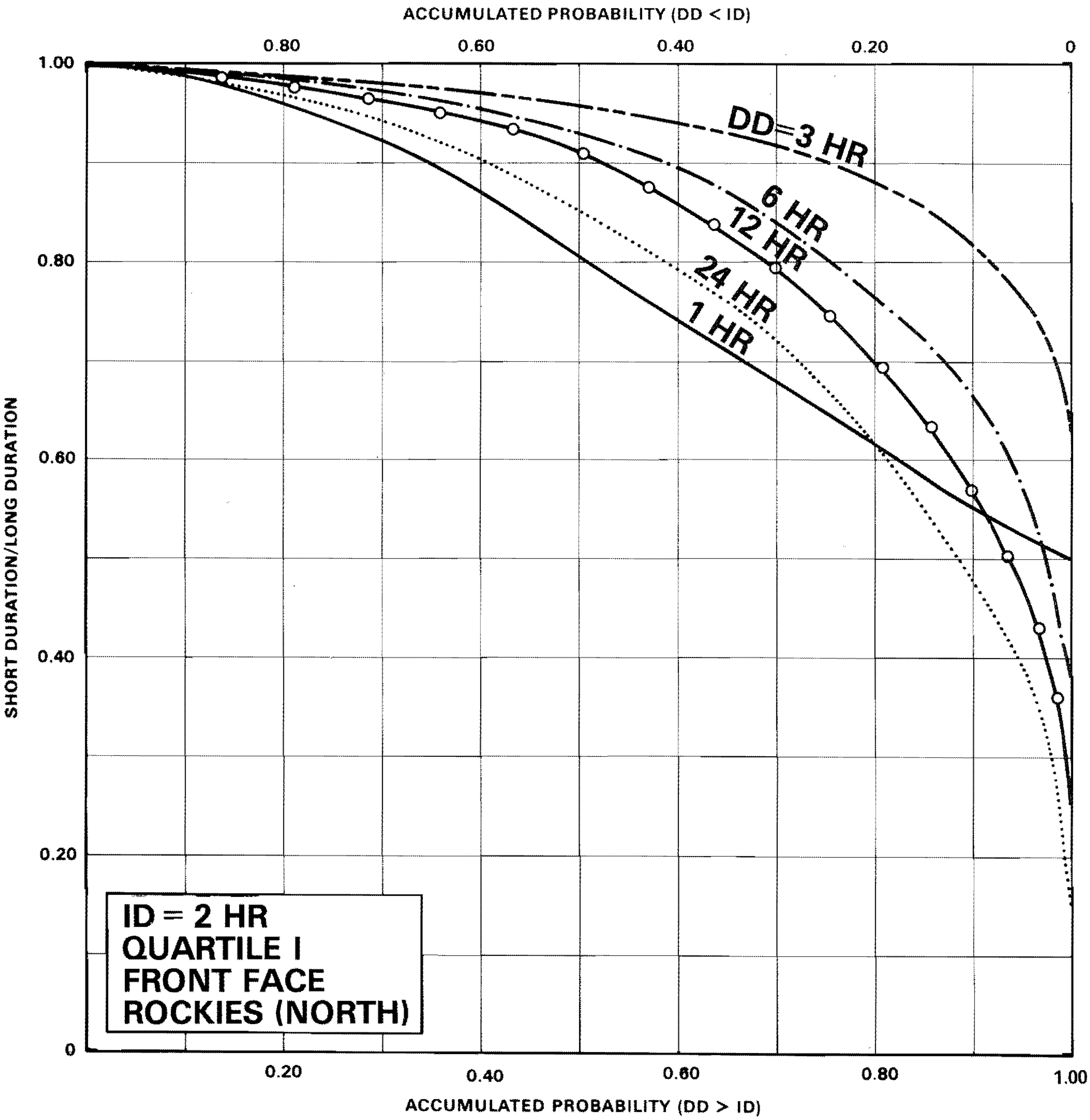
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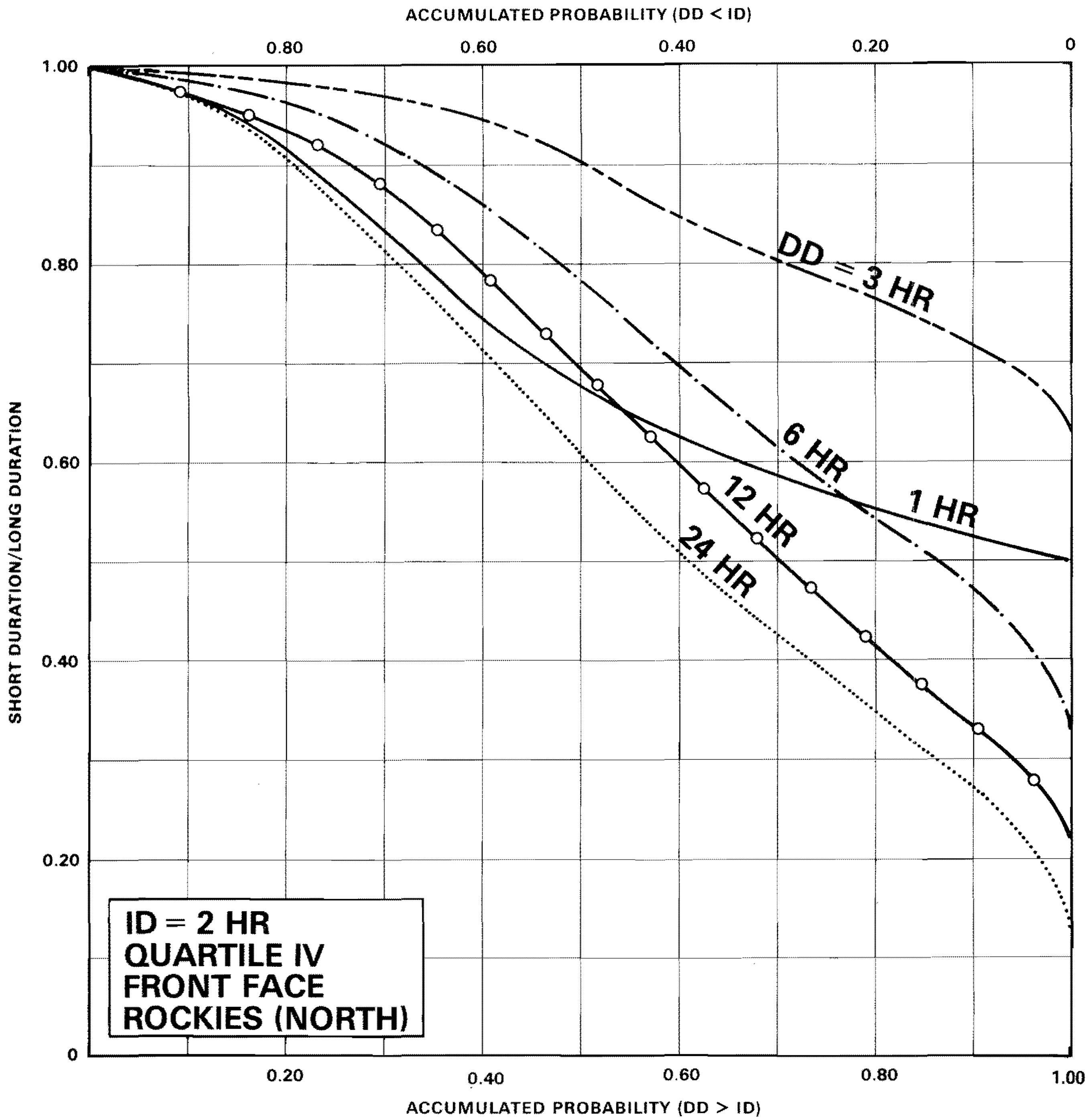
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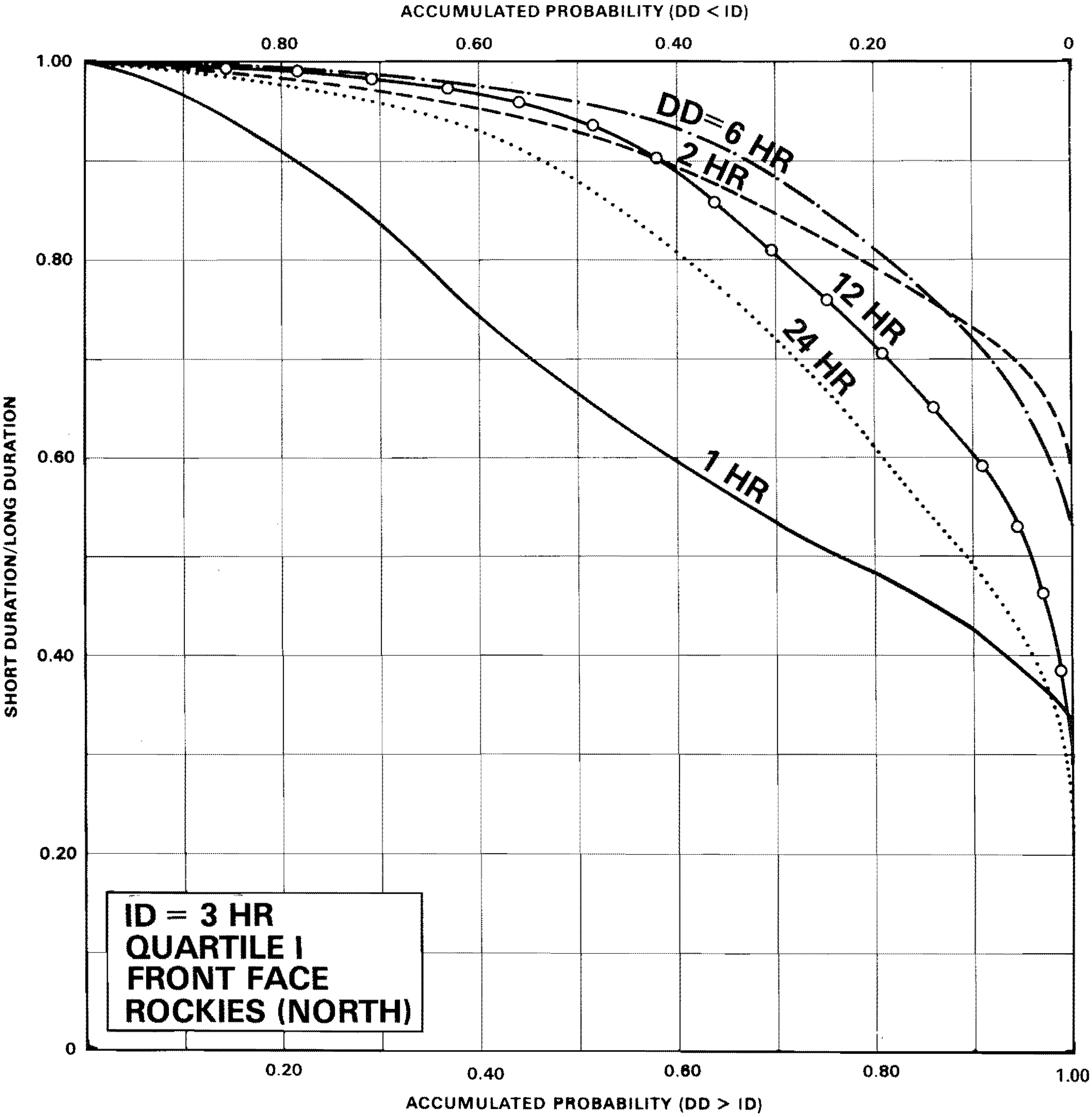
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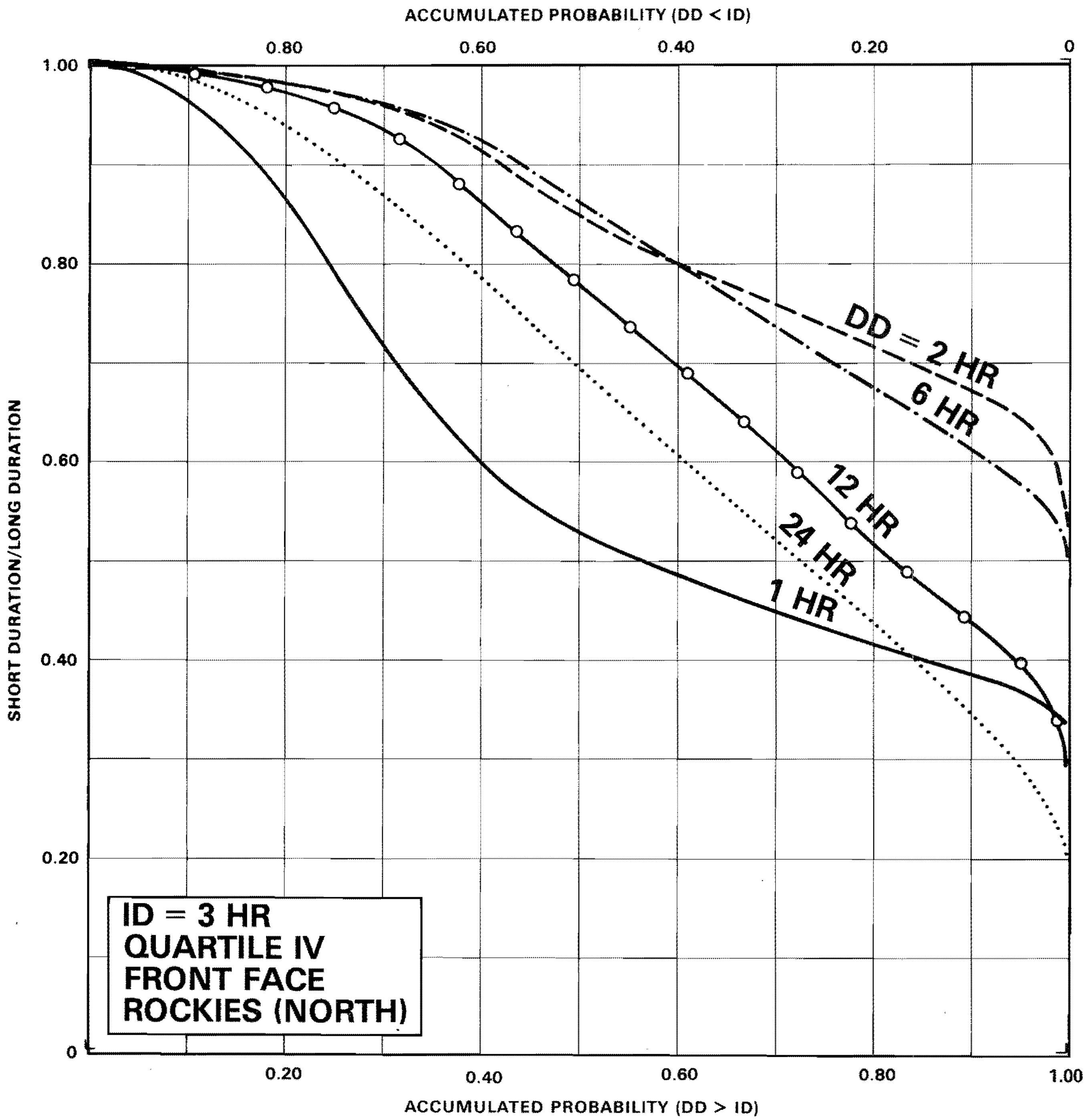
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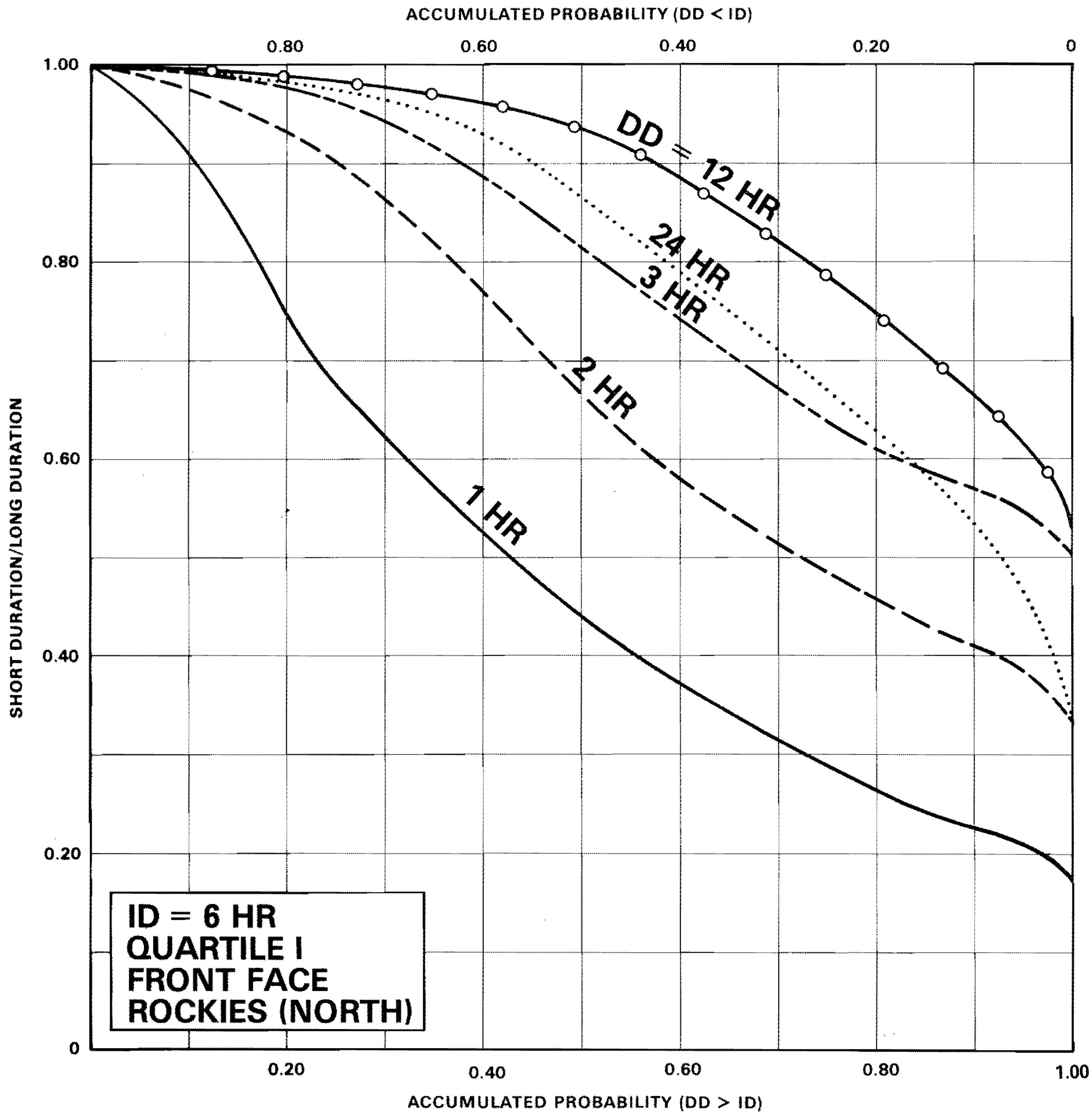
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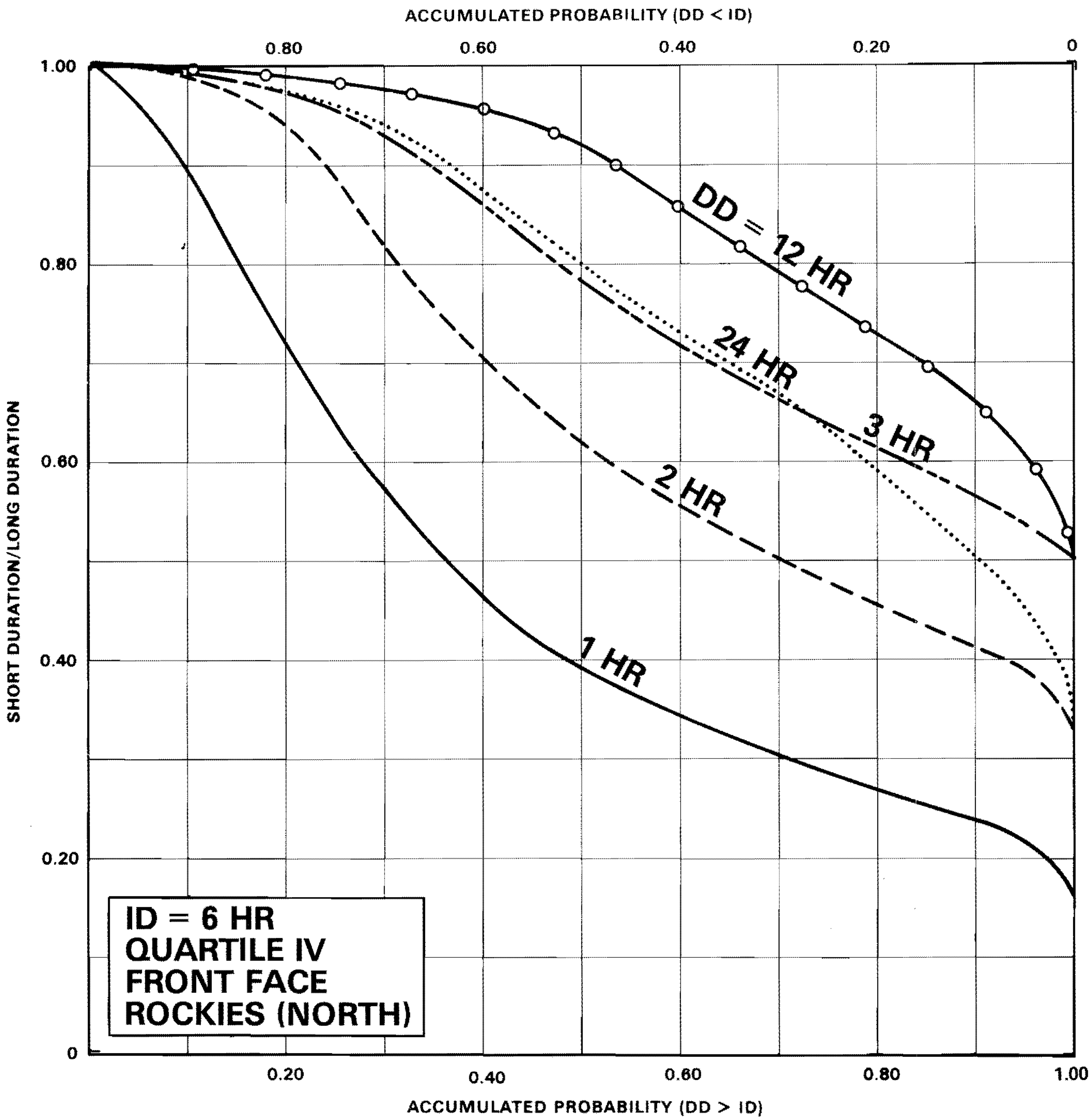

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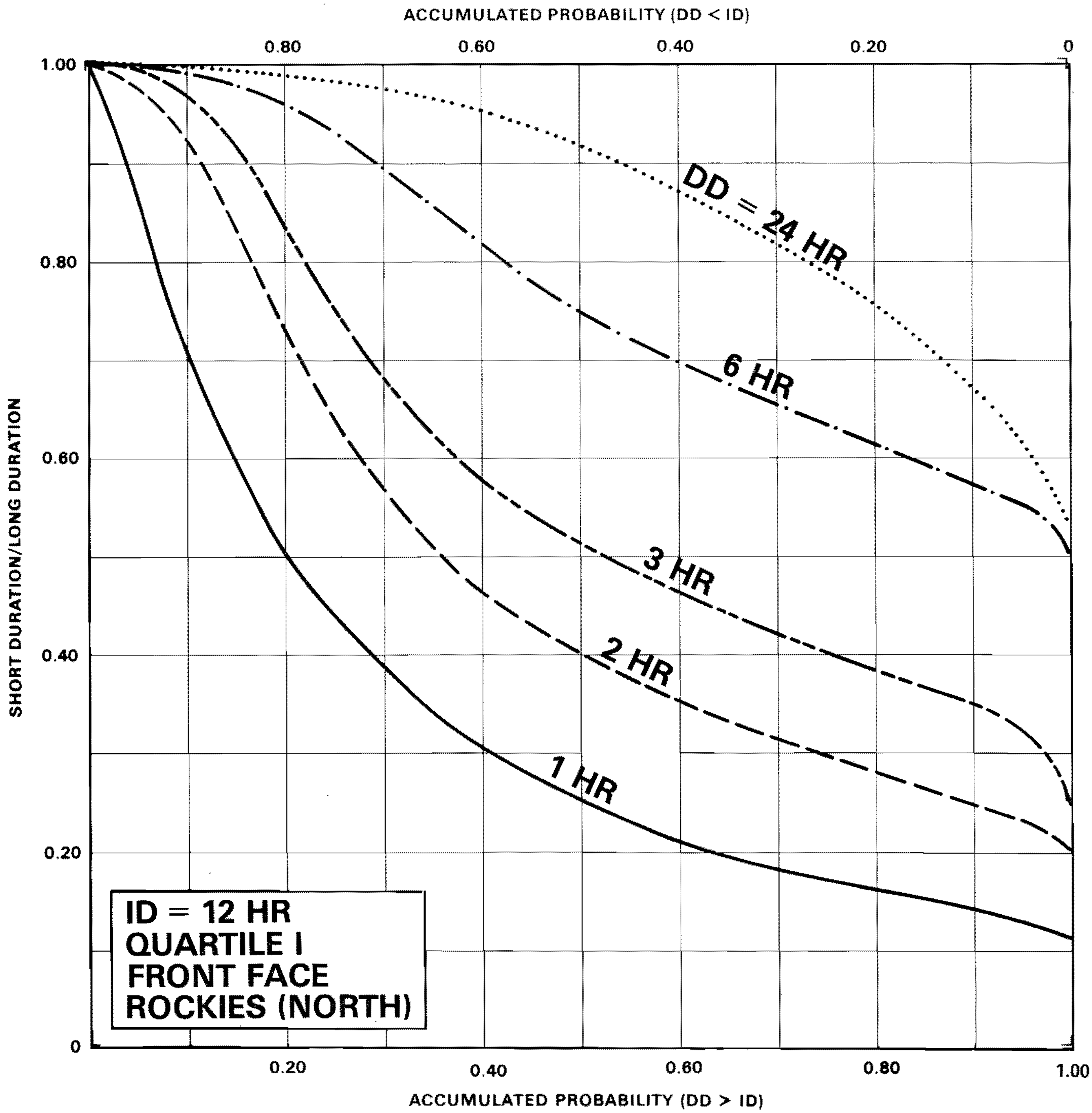
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FRONT FACE
ROCKIES (NORTH)
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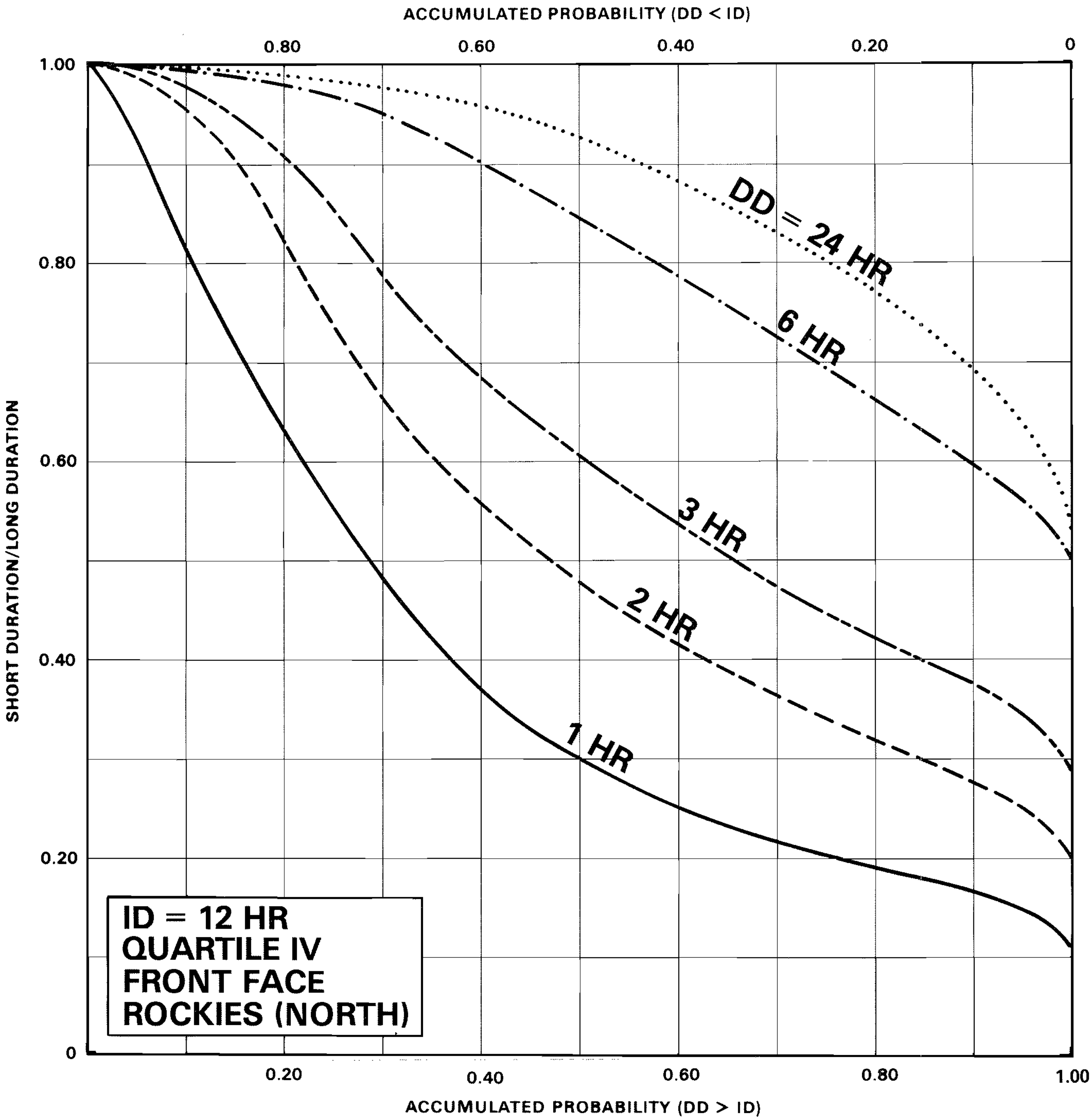
ACCUMULATED PROBABILITY (DD > ID)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0
SHORT DURATION/LONG DURATION
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6 HR
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QUARTILE IV
FRONT FACE
ROCKIES (NORTH)
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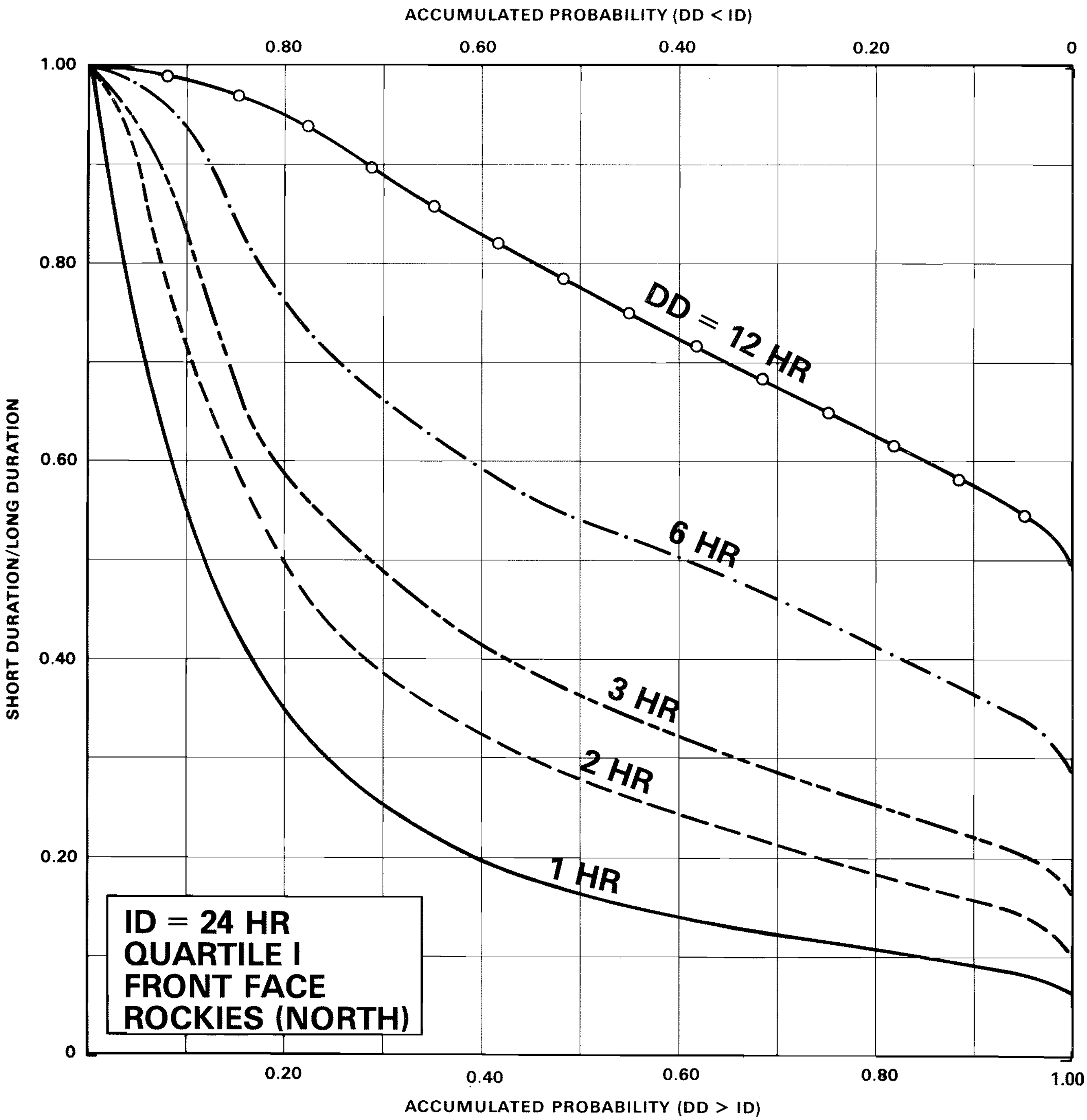
ACCUMULATED PROBABILITY (DD > ID)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QUARTILE I
FRONT FACE
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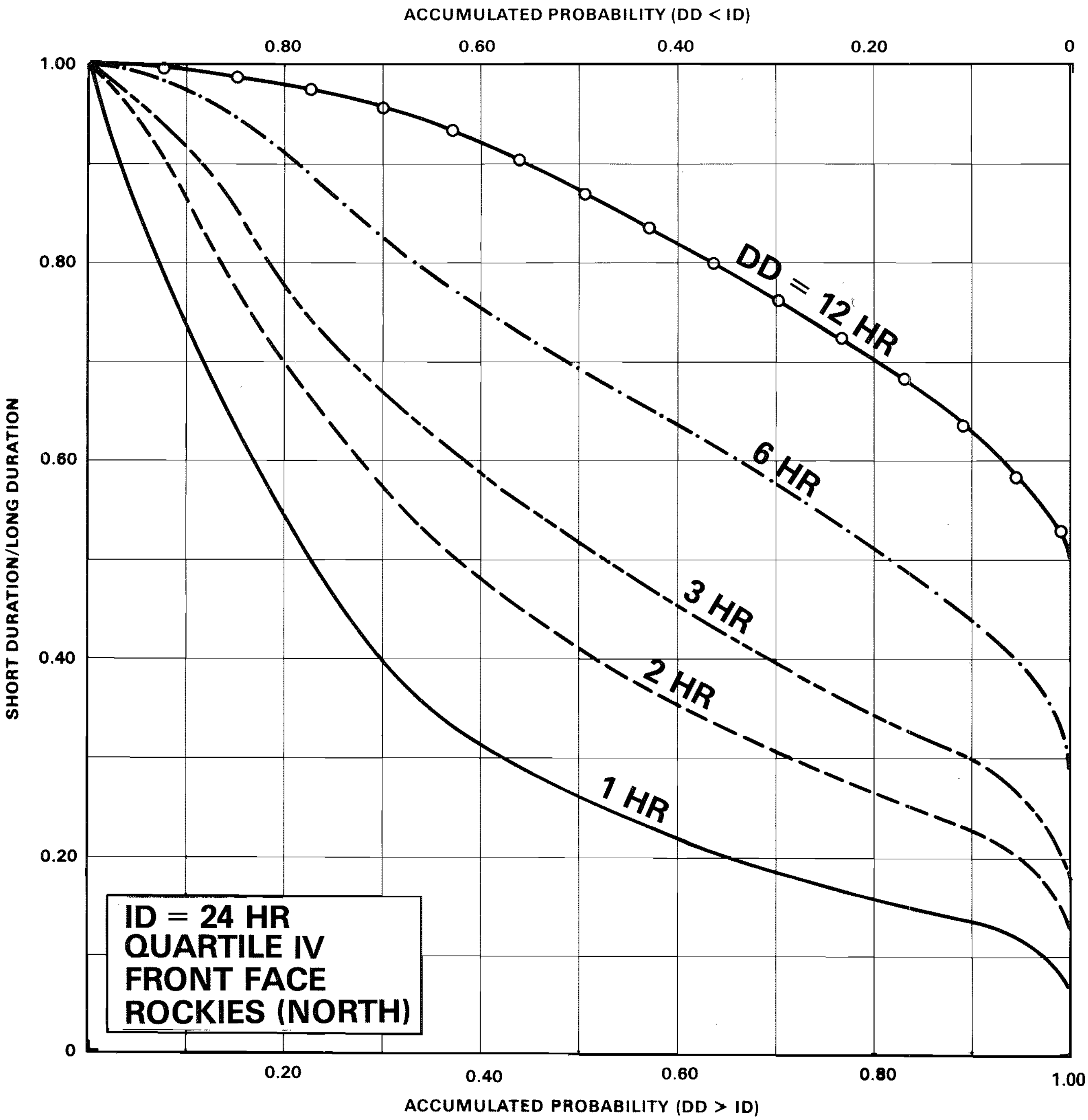
ACCUMULATED PROBABILITY (DD > ID)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SHORT DURATION/LONG DURATION
DD = 12 HR
6 HR
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QUARTILE IV
FRONT FACE
ROCKIES (NORTH)
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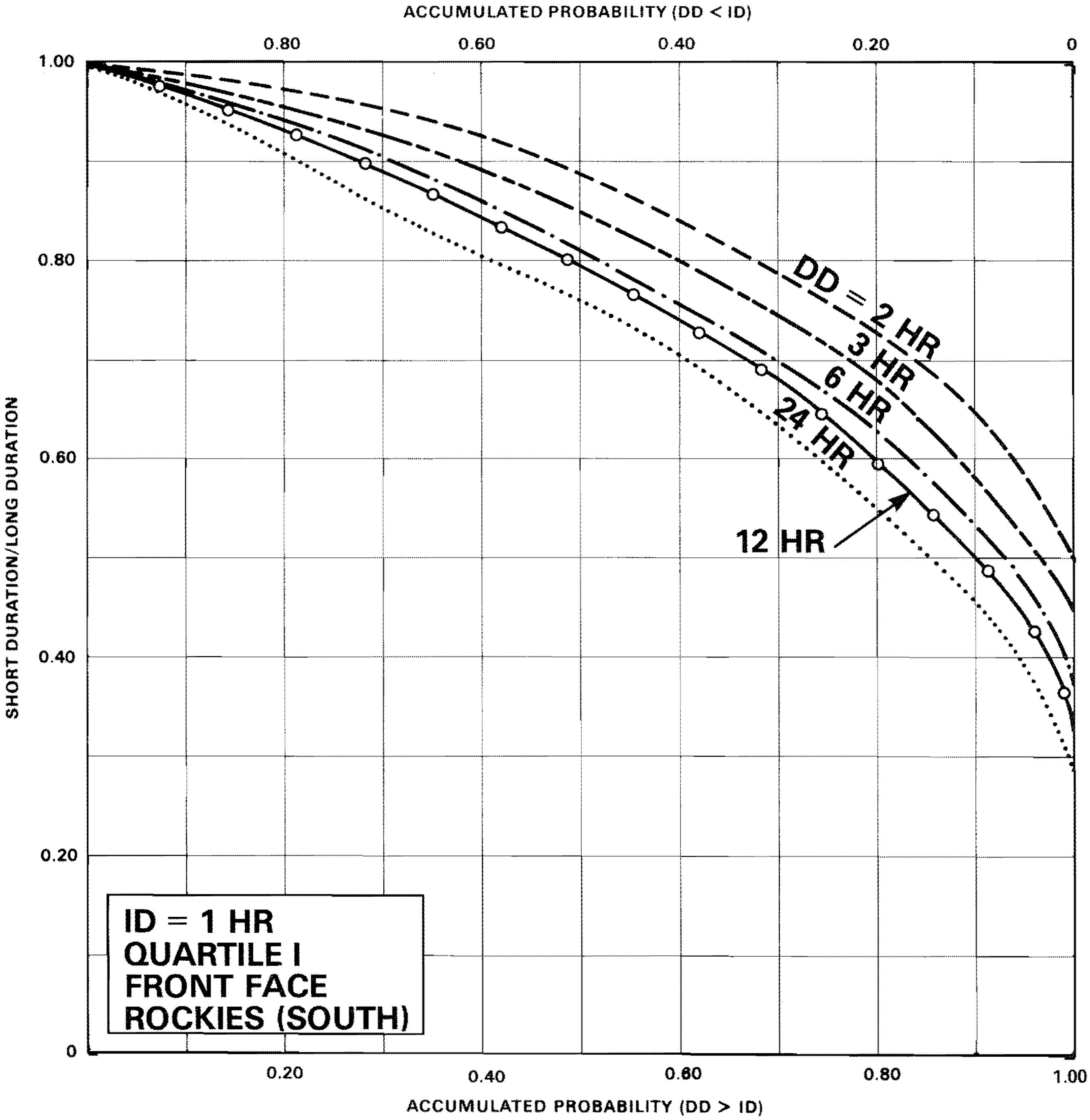
ACCUMULATED PROBABILITY (DD > ID)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0
SHORT DURATION/LONG DURATION
DD = 2 HR
3 HR
6 HR
24 HR
12 HR
ID = 1 HR
QUARTILE I
FRONT FACE
ROCKIES (SOUTH)
0.20
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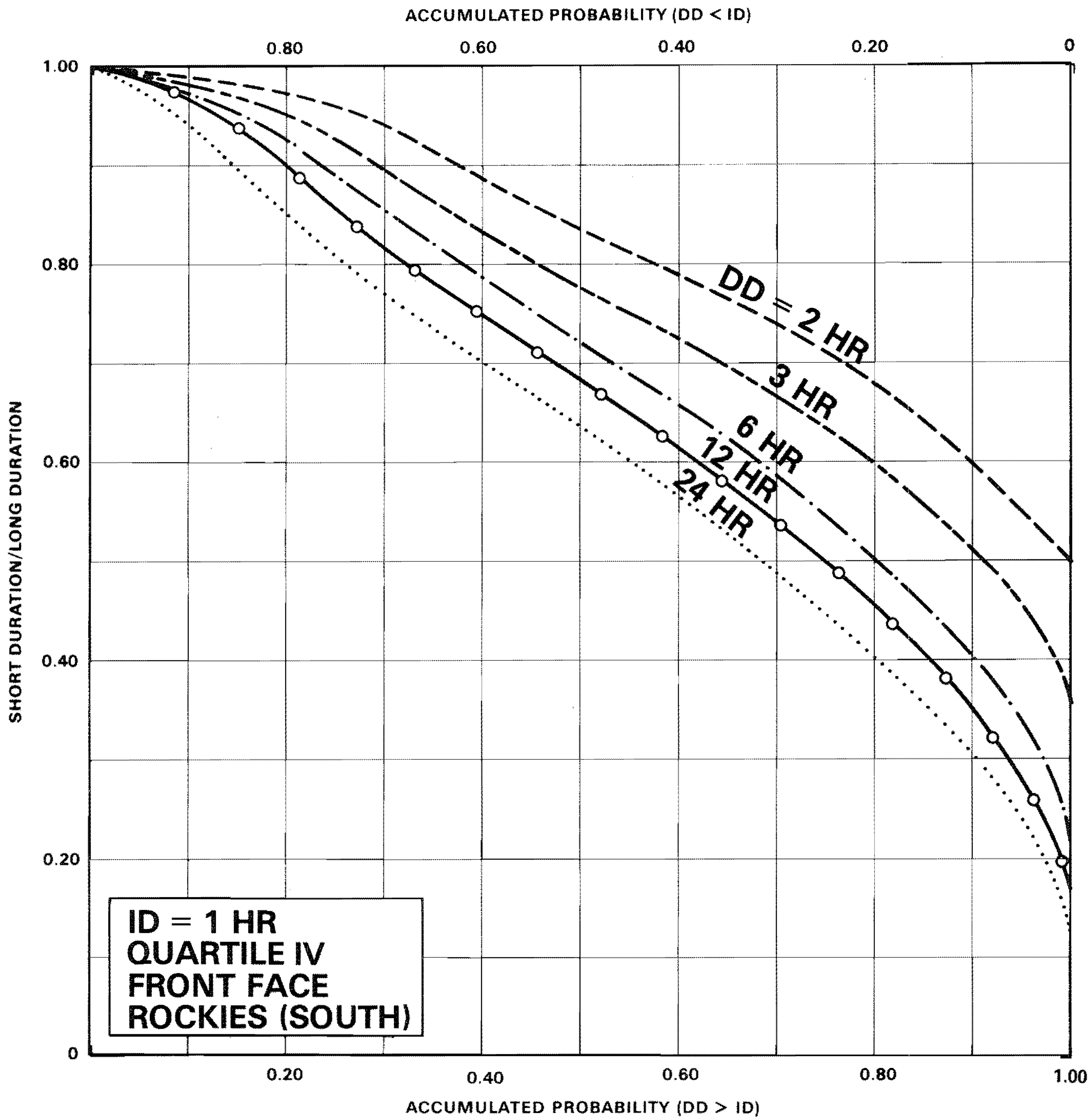
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)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QUARTILE IV
FRONT FACE
ROCKIES (SOUTH)
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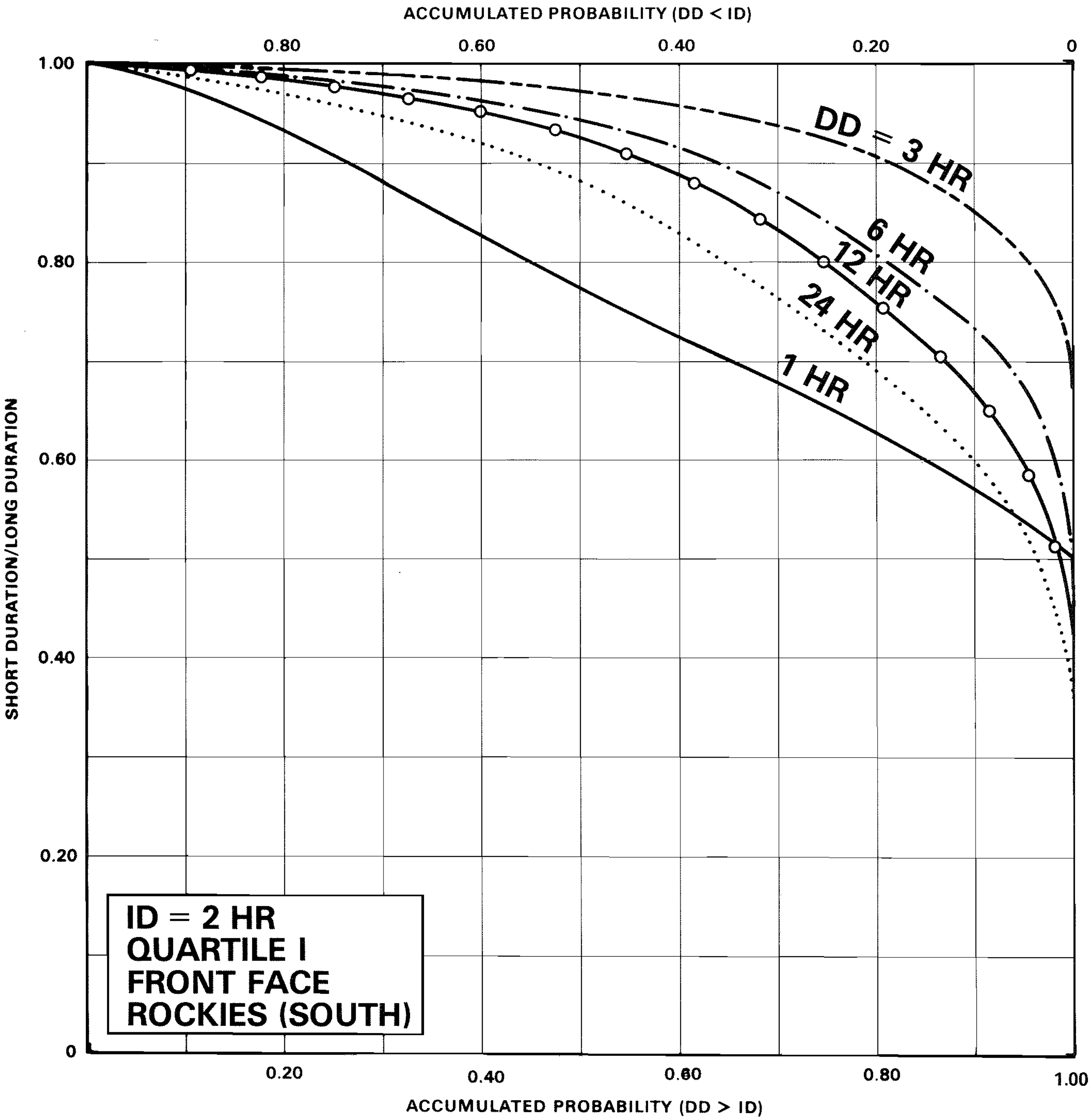
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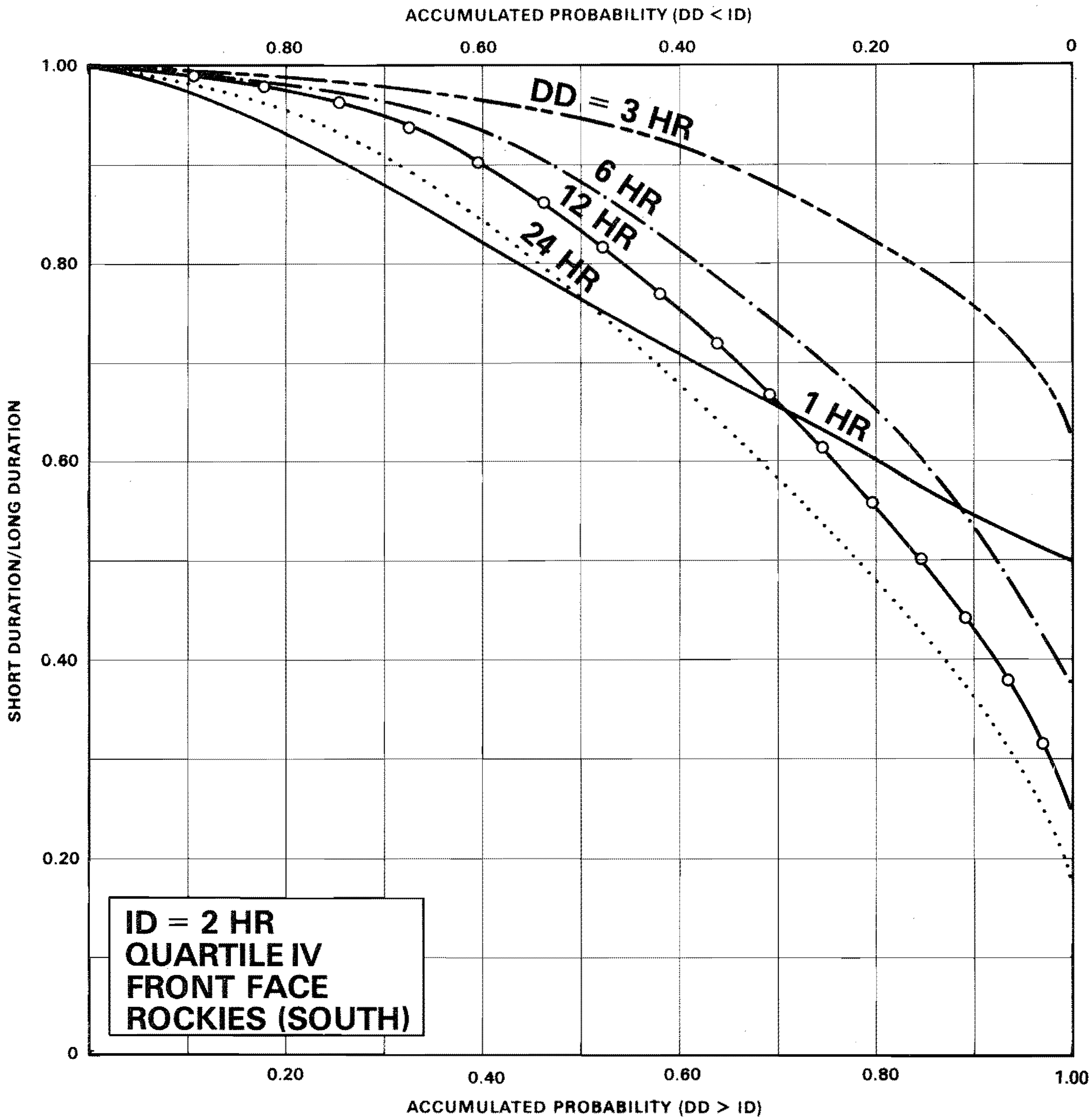

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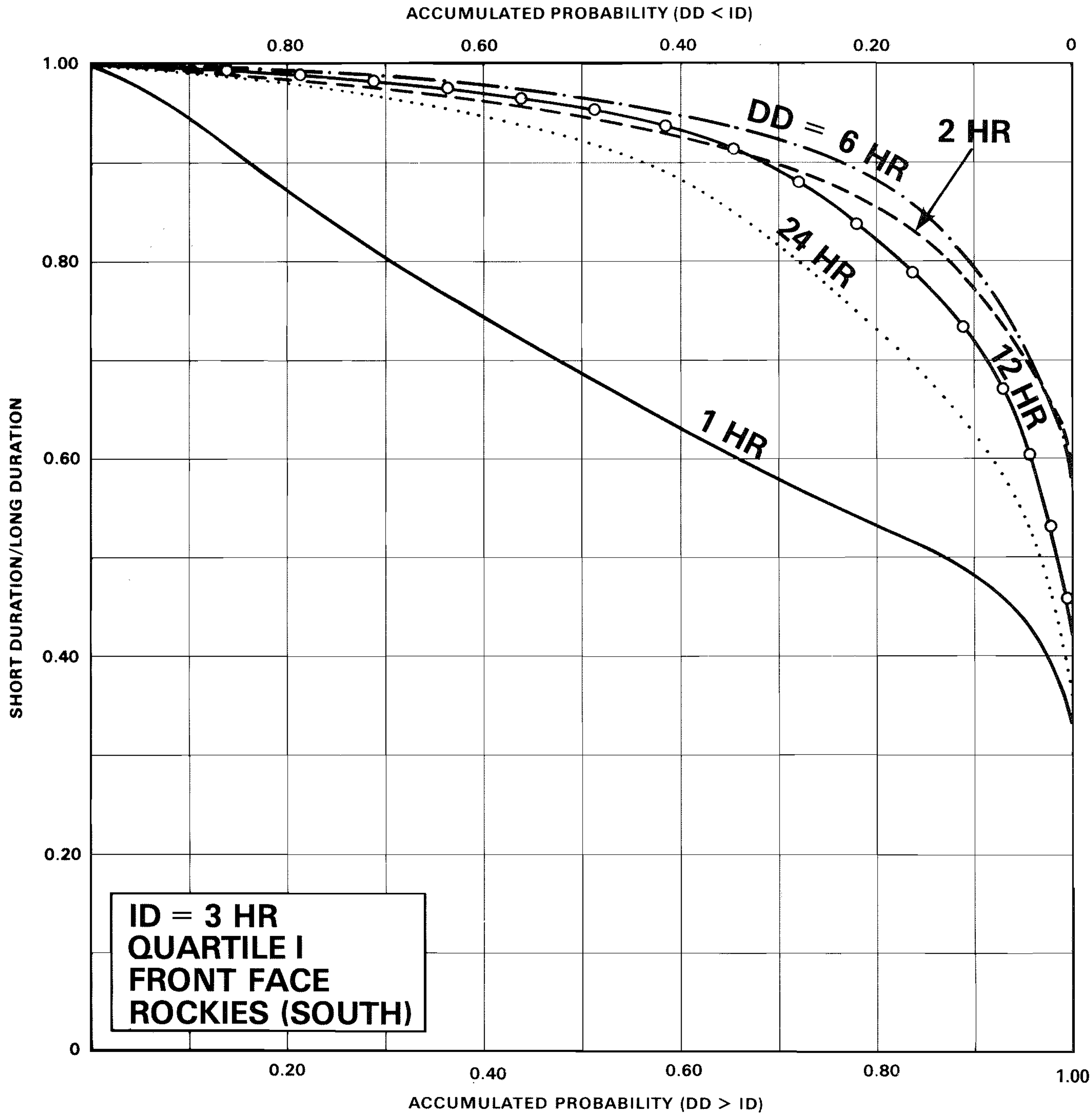
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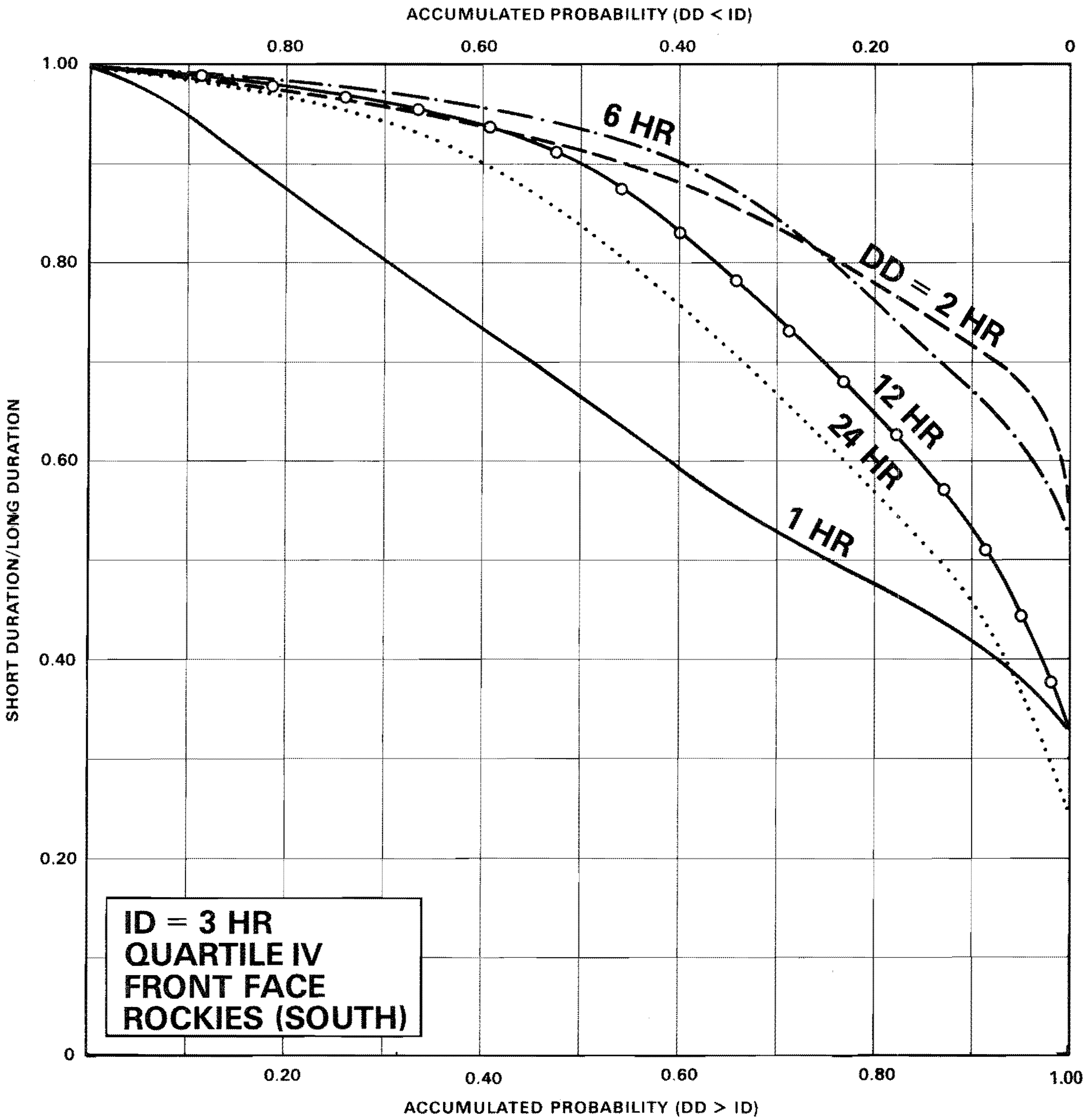
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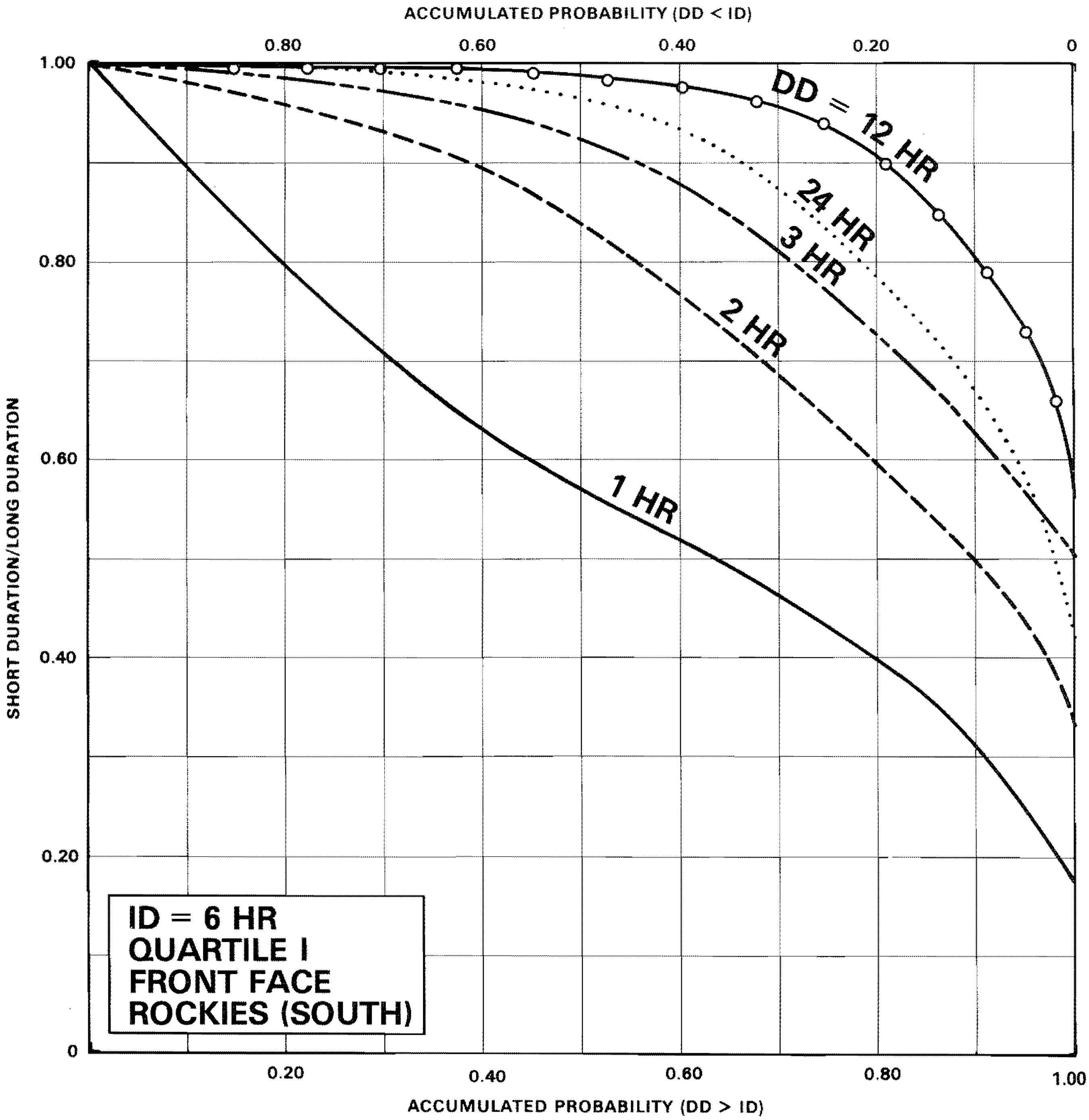

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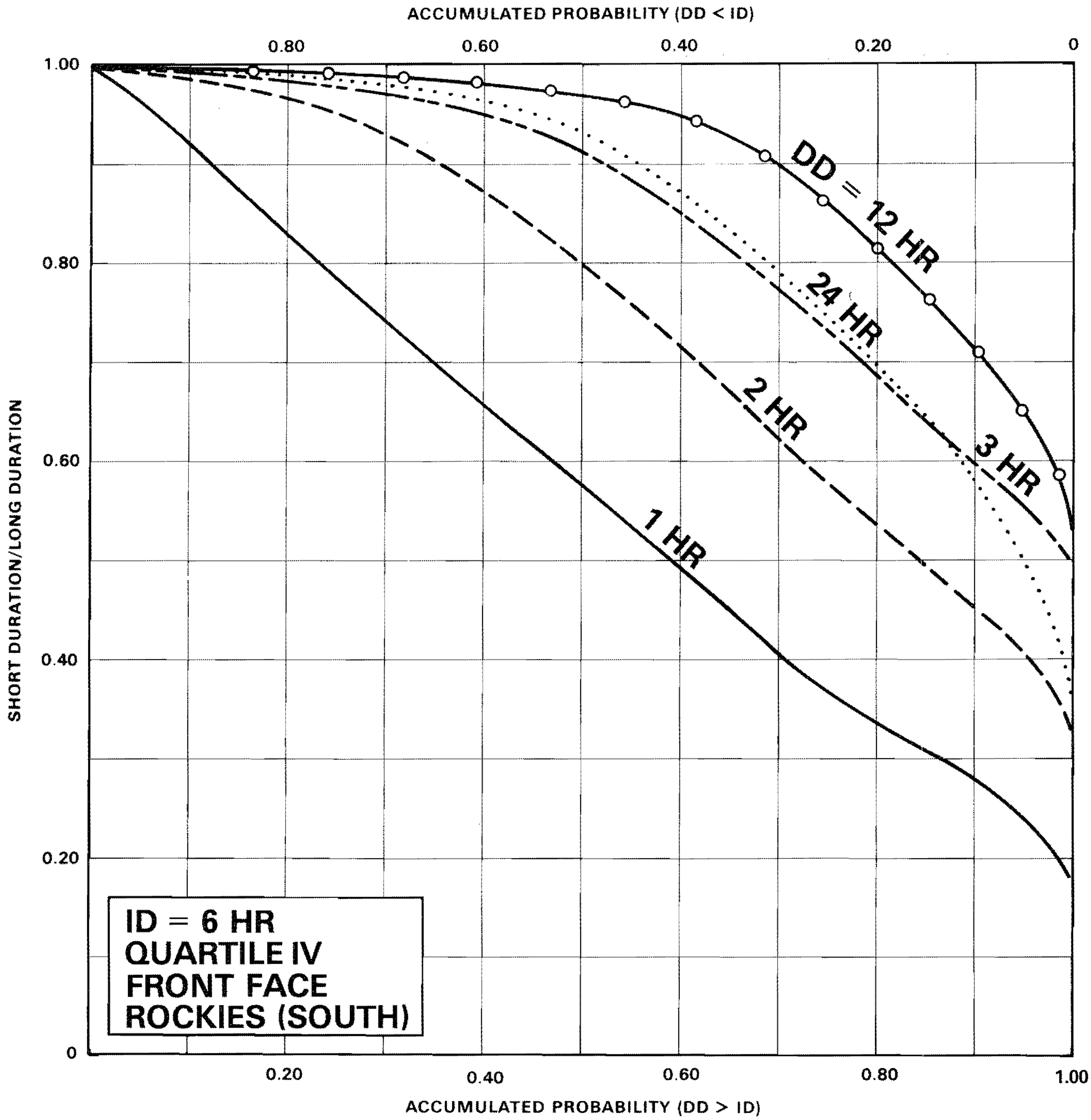

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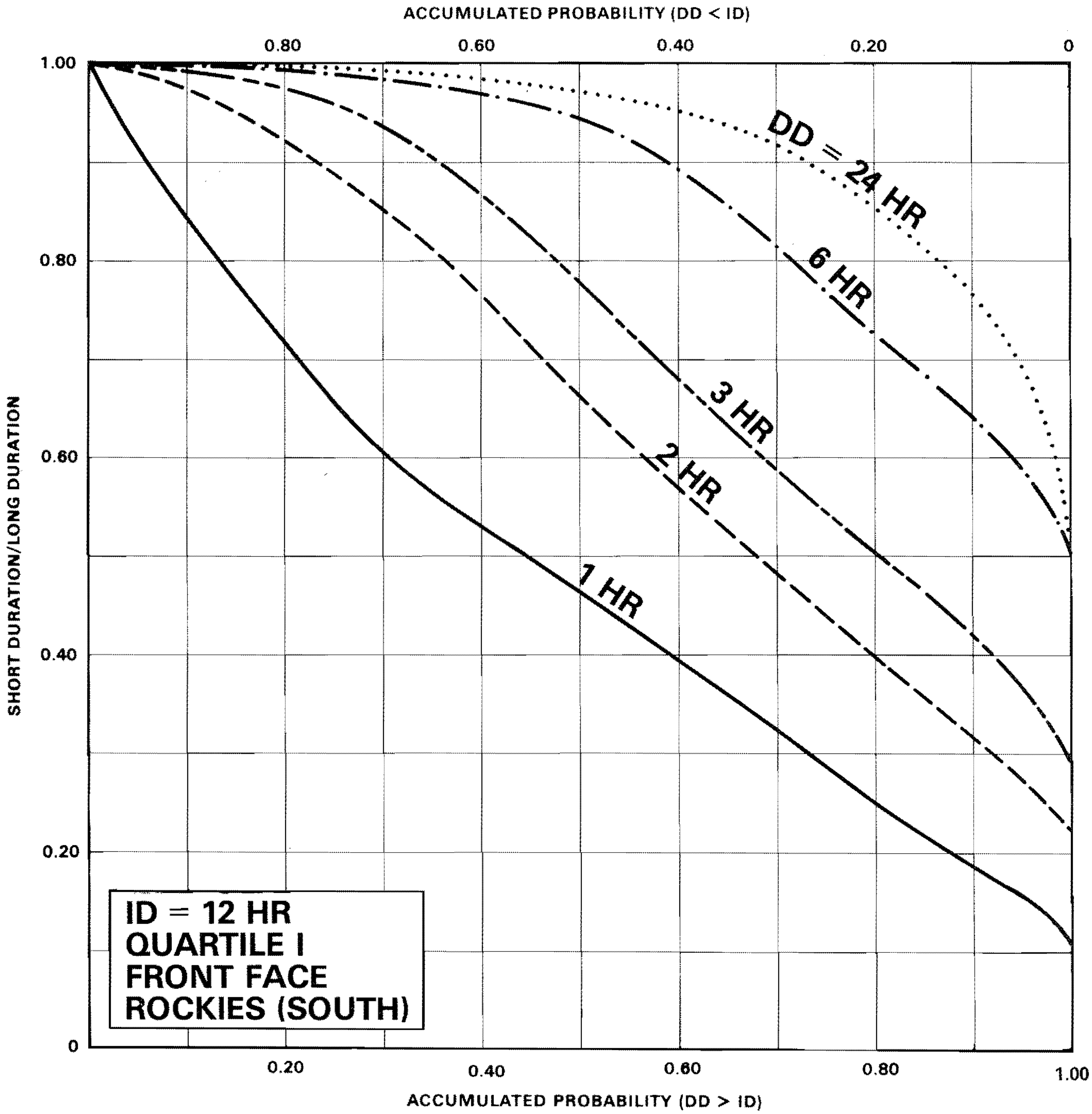

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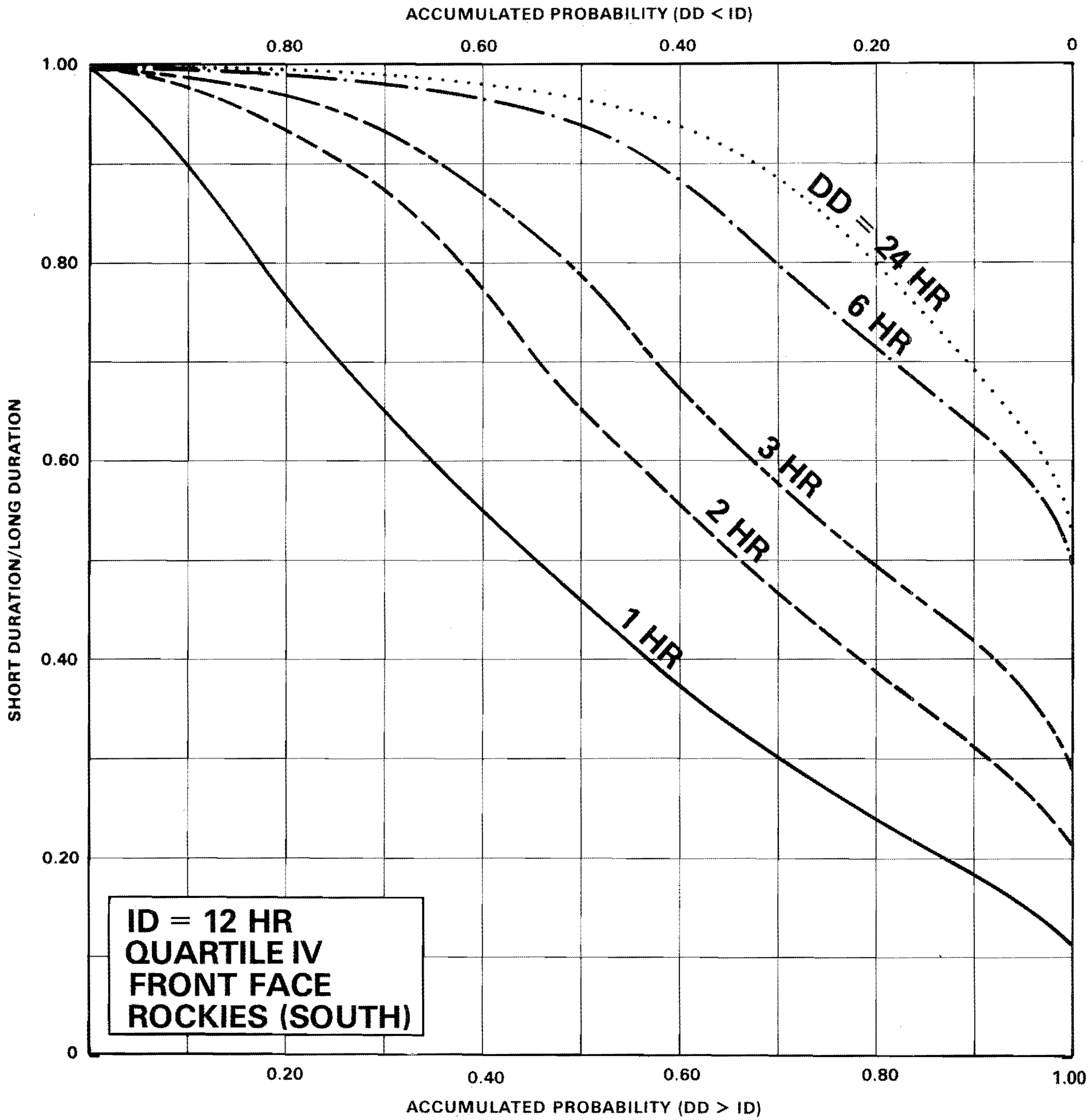

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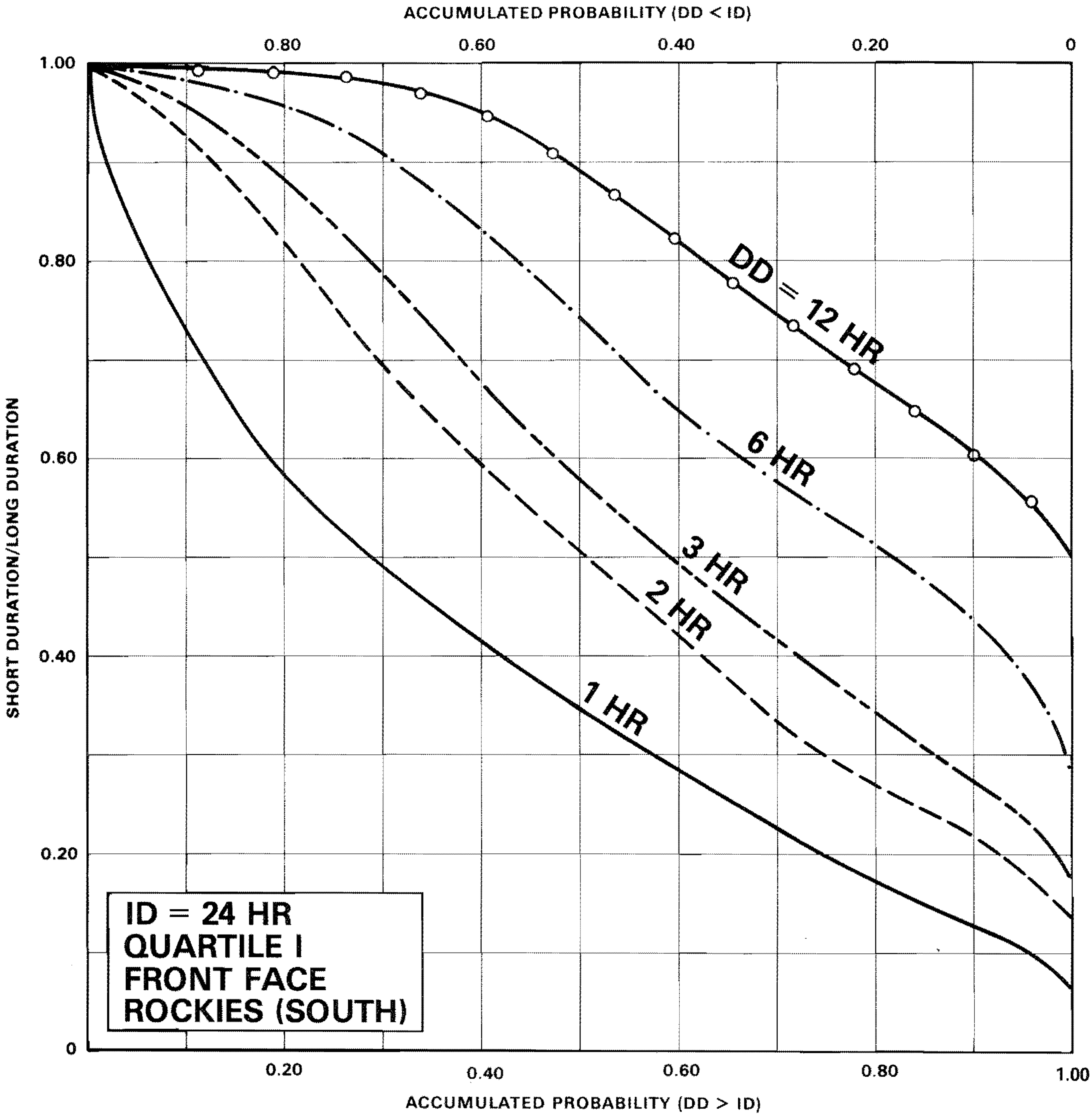
0.20
0
1.00
0.80
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 24 HR
6 HR
3 HR
2 HR
1 HR
ID = 12 HR
QUARTILE IV
FRONT FACE
ROCKIES (SOUTH)
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)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1.00
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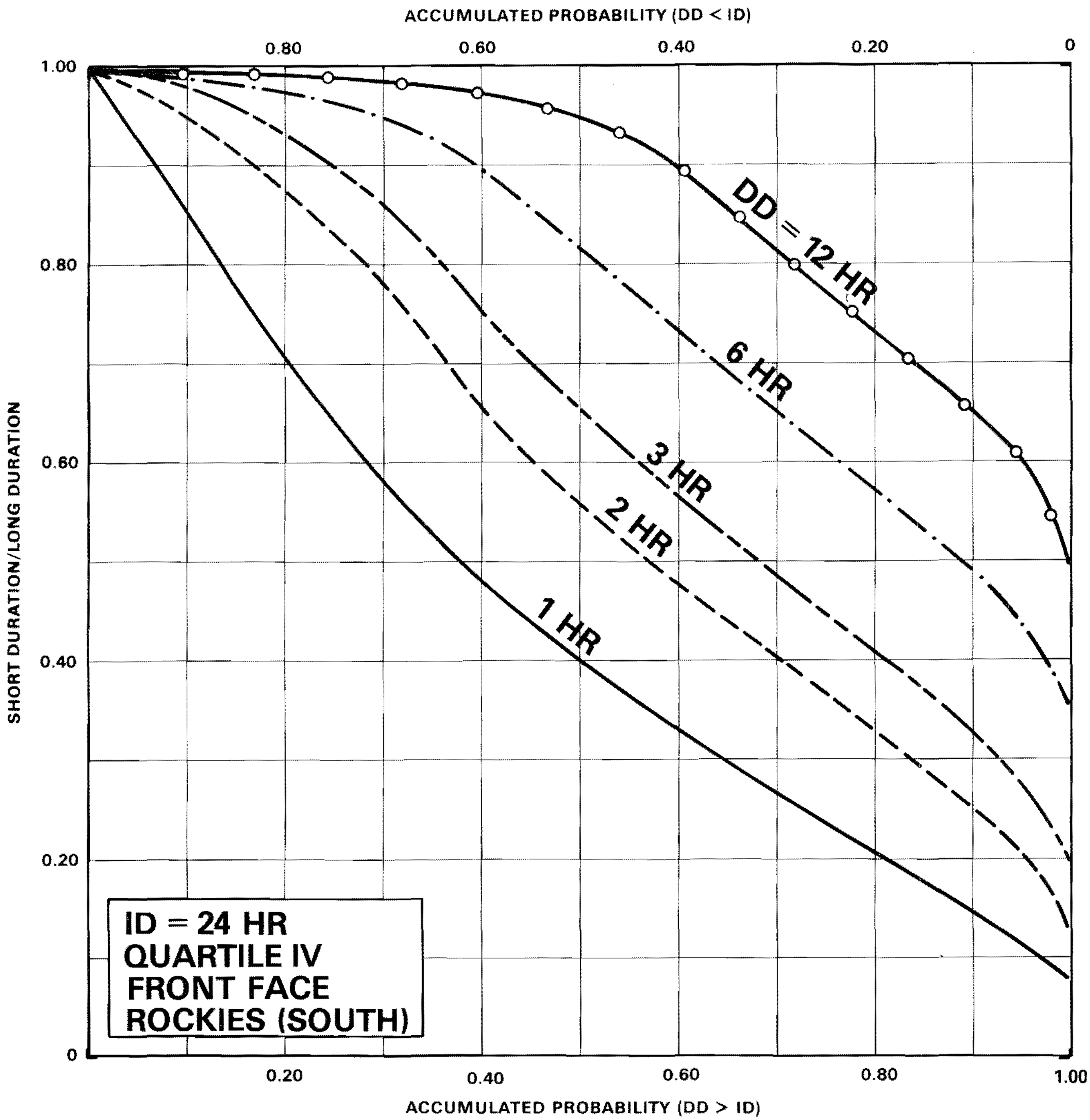
0.60
0.40
0.20
0
SHORT DURATION/LONG DURATION
DD = 12 HR
6 HR
3 HR
2 HR
1 HR
ID = 24 HR
QUARTILE I
FRONT FACE
ROCKIES (SOUTH)
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)


ACCUMULATED PROBABILITY (DD < ID)
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0.60
0.40
0.20
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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
QUARTILE IV
FRONT FACE
ROCKIES (SOUTH)
0.20
0.40
0.60
0.80
1.00
ACCUMULATED PROBABILITY (DD > ID)

APPENDIX III GRAPHS OF MONTHLY DISTRIBUTION OF N-STORMS

(See fiche Number 2 in pocket on inside rear cover)

NOAA TECHNICAL REPORTS

National Weather Service Series

The National Weather Service (NWS) observes and measures atmospheric phenomena; develops and distributes forecasts of weather conditions and warnings of adverse weather; collects and disseminates weather information to meet the needs of the public and specialized users. The NWS develops the national meteorological service system and improves procedures, techniques, and dissemination for weather and hydrologic measurements, and forecasts.

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ESSA Technical Reports

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WB 2 Weekly Synoptic Analyses, 5-, 2-, and 0.4-Mb Surfaces for 1964 (based on observations of the Meteorological Rocket Network during the IQSY). Staff, Upper Air Branch, National Meteorological Center, April 1967, 16 p, 160 charts. (AD 652 696)

WB 3 Weekly Synoptic Analyses, 5-, 2-, and 0.4-Mb Surfaces for 1965 (based on observations of the Meteorological Rocket Network during the IQSY). Staff, Upper Air Branch, National Meteorological Center, August 1967, 173 p. (AD 662 053)

WB 4 The March-May 1965 Floods in the Upper Mississippi, Missouri, and Red River of the North Basins. J. L. H. Paulhus and E. R. Nelson, Office of Hydrology, August 1967, 100 p.

WB 5 Climatological Probabilities of Precipitation for the Conterminous United States. Donald L. Jorgensen, Techniques Development Laboratory, December 1967, 60 p.

WB 6 Climatology of Atlantic Tropical Storms and Hurricanes. M. A. Alaka, Techniques Development Laboratory, May 1968, 18 p.

WB 7 Frequency and Areal Distributions of Tropical Storm Rainfall in the United States Coastal Region on the Gulf of Mexico. Hugo V. Goodyear, Office of Hydrology, July 1968, 33 p.

WB 8 Critical Fire Weather Patterns in the Conterminous United States. Mark J. Schroeder, Weather Bureau, January 1969, 31 p.

WB 9 Weekly Synoptic Analyses, 5-, 2-, and 0.4-Mb Surfaces for 1966 (based on meteorological rocketsonde and high-level rawinsonde observations). Staff, Upper Air Branch, National Meteorological Center, January 1969, 169 p.

WB 10 Hemispheric Teleconnections of Mean Circulation Anomalies at 700 Millibars. James F. O'Connor, National Meteorological Center, February 1969, 103 p.

WB 11 Monthly Mean 100-, 50-, 30-, and 10-Millibar Charts and Standard Deviation Maps, 1966-1967. Staff, Upper Air Branch, National Meteorological Center, April 1969, 124 p.

WB 12 Weekly Synoptic Analyses, 5-, 2-, and 0.4-Millibar Surfaces for 1967. Staff, Upper Air Branch, National Meteorological Center, January 1970, 169 p.

NOAA Technical Reports

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)

NWS 14 Weekly Synoptic Analyses, 5-, 2-, and 0.4-Millibar Surfaces for 1968. Staff, Upper Air Branch, National Meteorological Center, May 1971, 169 p. (COM-71-50383)

NWS 15 Some Climatological Characteristics of Hurricanes and Tropical Storms, Gulf and East Coasts of the United States. Francis P. Ho, Richard W. Schwerdt, and Hugo V. Goodyear, May 1975, 87 p. (COM-75-11088)

NWS 16 Storm Tide Frequencies on the South Carolina Coast. Vance A. Myers, June 1975, 79 p. (COM-75-11335)

NWS 17 Estimation of Hurricane Storm Surge in Apalachicola Bay, Florida. James E. Overland, June 1975. 66 p. (COM-75-11332)

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