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POSTAL AND TELECOMMUNICATIONS DEPARTMENT

Broadcasting Engineering Division

REPORT NO.54

Prediction of Rain Attenuation at 12 GHz

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PREDICTION OF RAIN ATTENUATION AT 12 GHz

INTRODUCTION

Rain is the dominant factor in the reliability of satellite broadcasting services using the 12GHz band. At these frequencies rain is known to cause significant absorption, scattering and depolarisation of the signal. In order to estimate service reliability at any given location a complete knowledge of the spatial and temporal rainfall statistics is desirable.

ATTENUATION DUE TO RAIN

When a rain cell traverses the signal path it will absorb and scatter some of the signal causing both a change in the signal level and in propagation delay relative to the undisturbed path. The resulting attenuation depends upon factors such as the size, number, shape, orientation, density, dielectric properties and spatial distribution of the rain drops. Numerous scientific studies carried out relate to these various parameters (1), (2), (3). Their combined effect is generally expressed in the form of the attenuation co-efficient versus rain rate, and this is given by the formula:

$$A = aR^b$$

Where A = attenuation co-efficient in dB/km

a,b = constants for a particular frequency dropsize distribution and rain temperature

R = rain rate in mm/hr.

Depending on the nature of the rain there will be a spread in the values of the constants. The analysis in (2) gave for 12GHz and the temperature range -10°C to $+20^{\circ}$C the following spread in the values of the constants:

a: 1.12×10^{-2} to 3.25×10^{-2}

b: 0.942 to 1.236

The dependence of A on R for some typical values of a and b are shown in Figure 1.

The knowledge of the rain rate distribution along a path would enable an estimate of the total attenuation for the path to be made.

RAIN CHARACTERISTICS

The problem in predicting the total attenuation lies in the nature of rain. Extensive observations of the nature of rainfall rates, especially those which give rise to significant signal attenuations, show that the rain is composed of many small relatively intense showers imbedded in a larger area of light rain (1). Intense showers are also usually accompanied by gusting winds bringing about a rapid transition of the rain cell. The widths of intense rain cells range between 2 and 6km with heights extending up to 8km.

.../2.

These characteristics have been measured by radar techniques and confirmed by actual rain gauge measurements. It is obvious that relatively large and rapid fluctuations in the received signal level could be expected with heavy rainfall rates at 12GHz and large signal attenuation would be limited to relatively short periods.

An example of the extent to which rain may disrupt satellite reception at 12GHz was provided in the Australian trials using the Canadian/USA experimental satellite, Hermes, during August 1979. Heavy rain prevented reception for half an hour at Goondiwindi, Queensland, during one of these demonstrations.

EARTH-SPACE ATTENUATION STATISTICS

Ideally rainfall attenuation statistics should be based on actual reception of satellite transmissions. Up to the present time, due to the lack of a satellite signal source in the 12GHz band, this has not been possible in Australia. It was intended to use Hermes for this purpose during part of the 1980 wet season in northern Queensland, but control of the satellite was lost before any significant rain attenuation statistics could be gathered. Alternative methods, using the sun or the sky as an extra-terrestrial source could be employed to gain preliminary information on likely attenuation characteristics (4), (5), (6).

Since 1972 the Australian Telecommunications Commission has carried out an extensive research program into rain attenuation at 11 and 14GHz in the Innisfail and Darwin areas using radiometer measurements. The most recent report (6) has also included an analysis designed to correlate the total path attenuation with published rain intensity data. The analysis was based on measurements carried out at an elevation angle of 60 degrees during the 1977/78 wet season at Darwin. The Darwin results were also compared with those obtained earlier at Innisfail where fixed elevation angles of 45 and 30 degrees were used for the measurements.

Unfortunately, rainfall intensity data for Innisfail is not available from the Bureau of Meteorology hence the comparison could not embrace this data. A notable aspect of the results is the similarity of the total path attenuation versus rain intensity for the above 3 elevations. In the absence of further data this would imply that the relationship between the above two variables as established for Darwin would be equally valid for other tropical localities with like rainfall patterns. Due to the lack of measured data this assumption was extended to embrace all localities irrespective of climatic zone in which they were located.

Hence, by necessity, additional simplification was introduced in this paper by ignoring the effect of the satellite elevation angle. In the case of a service planned on minimal margin of C/N above threshold and with a low elevation angle, this simplification could introduce serious errors in the prediction of rain attenuation. At low elevation angles the signal path might traverse the entire horizontal extent of a relatively light rain shower and in the process eliminate the margin.

In this prediction, use is made of the results obtained by Telecom for various elevation angles in Darwin and Innisfail. For the conversion, the highest attenuation value for a given rain intensity was first determined followed by the correction to 12GHz. The graph of this relationship is shown in Figure 2.

POINT RAIN STATISTICS

The determination of actual rain statistics for each receiving site would require the measurement of instantaneous rain rates along the entire signal path. This approach to forecasting is obviously not practical. The rainfall pattern at ground level is not necessarily representative of the moisture level along the signal path especially in the upper regions of the rain carrying atmosphere. The only practical approach is to relate the satellite broadcasting service reliability to the point rainfall characteristics.

Rainfall rate is measured by averaging the rainfall over a finite time interval. The longer the sampling time the more likely brief heavy rainfall rates tend to be missed.

Very little information is being published by the Bureau of Meteorology on point rainfall intensity. In Bulletin No.49 the Bureau has published point rainfall intensity statistics for the various capital cities (7). These are tabulated in average rainfall durations per month exceeding specified intensities. A typical tabulation is shown in Appendix A. As can be seen the tables provide only 6 steps in rainfall rates. Close perusal of the data would tend to indicate that the sampling time interval for the measurements of rainfall rates was one minute. This, however, is not so. The results are only analysed to provide rainfall intensity levels over a six minute period.

Elsewhere in Bulletin No.49 reference is made to a sample tabulation for one calendar month, as shown in Appendix B. In this particular table the minimum sampling interval was given as 2.4 minutes. However, once again, the minimum period for the data analysis was only six minutes as shown under "Daily Maxima".

The only other published information relating to rainfall intensity is in the form of the Rainfall Intensity - Duration - Frequency diagram, an example of which is shown in Appendices C1 and C2. The diagram indicates the probability of highest rainfall intensity, recording over durations from six minutes to ten days for return periods from one to 100 years.

The return period is the average interval between rainfall occurrences whose intensity or duration exceeds the indicated values. Unfortunately the data contain only showers of relatively long duration and do not allow us to gain information on the frequency of short duration downpours. Nevertheless, a comparison of probabilities in Appendix C with the data presented in Appendix A indicates that the duration of heavy showers is, at most, a few minutes.

Due to the lack of any other readily available point rainfall intensity data at the present time, all service reliability forecasting has to be based on the type of information shown in Appendix A. In conjunction with this information it would be advantageous to know the extent of the rainfall intensity variations from the

.../4.

published average values, however, the requisite standard deviation figures could not be obtained. Cumulative distribution of rainfall intensities can be obtained directly from this tabulation, and are shown in Figure 3.

As mentioned earlier, Bulletin No. 49 contains rainfall data in relation to capital cities only. The Bureau does, however, operate a number of pluviographs and tipping bucket raingauges which are necessary to gather information on rain intensities at other locations also. The data from these stations has been collated but has not yet been published. However, it is available on request.

SUMMARY

An attempt has been made to forecast service reliability for a future satellite broadcasting system operating in the 12GHz band based on published point rainfall intensity data. The higher attenuation caused by short duration heavy downpours which, in general , are of only a few minutes duration, tend to be smoothed out by the six minute minimum period of data analysis.

The forecasts are based on radiometer data and not on 12GHz transmissions from a satellite.

Correlation between measured and published data is based on observations carried out at one single location. As yet, no investigation has been carried out which would validate the extrapolation used in the correlation to other geographical locations or time spans.

It is assumed that the forecast is independent of the elevation angle of the satellite. This hypothesis will have to be proven experimentally before its adoption can be accepted.

Forecasts for a number of locations in Australia have been prepared and are attached as Figure 4-14. For each locality the annual average and worst month probabilities have been calculated. In selecting the worst month consideration was only given to rainfall intensities of 10 mm/hr and higher since it has been found that significant total path attenuations occurred only for these rain intensity ranges. This selection method for the above locations has invariably produced consistent results at the 10 mm/hr and 20 mm/hr rainfall intensities. At higher intensity levels, however, longer average time durations were sometimes recorded in different months. In these cases the highest intensity recording irrespective of the month was employed.

It is imperative that better understanding of the effects of rain on service reliability in the 12GHz band should be gained now that the Government has made a firm undertaking to introduce satellite broadcasting services. Towards this end it would be desirable to investigate the availability of an experimental satellite service which permits an extensive monitoring and recording program to gain a better insight into rain attenuation and statistics especially in the tropical north. This would be the ideal approach and undoubtedly would be very costly.

.../5.

Even without such a program, useful information on service reliability could be derived from more detailed rainfall intensity measurements than can at present be obtained from the Bureau of Meteorology.

REFERENCES

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3. D.C. Hogg, T.S. Chu, "The role of rain in satellite communications" Proc. IEEE, Vol. 63, pp. 1308 - 1331, September 1975

4. G.F. Jenkinson, "Tropical rain attenuation at 11GHz - A Study of 18 months' measurements at Innisfail, Queensland", Aust. Telecommunications Res., Vol. 9, no. 1, pp. 45 - 53,1975

5. G.F. Jenkinson, "Tropical rain attenuation at 11GHz on earth-space paths - Radiometric measurements in Australia", Proc. IEEE, Vol. 65, pp. 480 - 481, March 1977

6. R.K. Flavin, "Earth-space path rain attenuations at 11 and 14GHz - Darwin, Australia", Aust. Telecommunications Res., Vol. 12, no. 2, pp. 9 - 17, 1978

7. C.L. Pierrehumbert, "Point rainfall intensity - frequency - duration data", Bulletin No. 49, Dept. of Science, Bureau of Meteorology, August 1974.

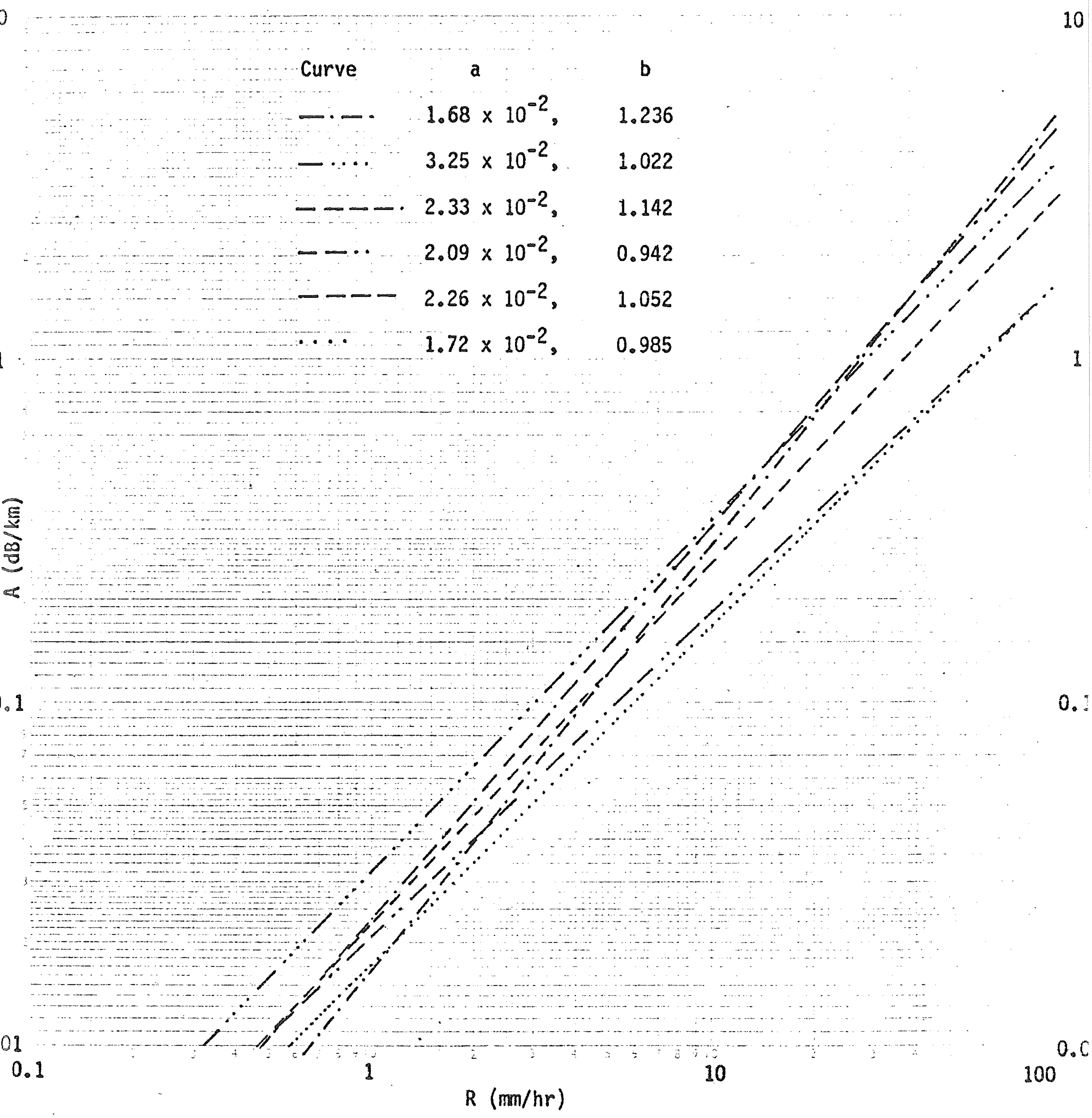


FIGURE 1. Attenuation coefficient versus rain rate as described by $A = aR^b$ for some typical values of a and b.

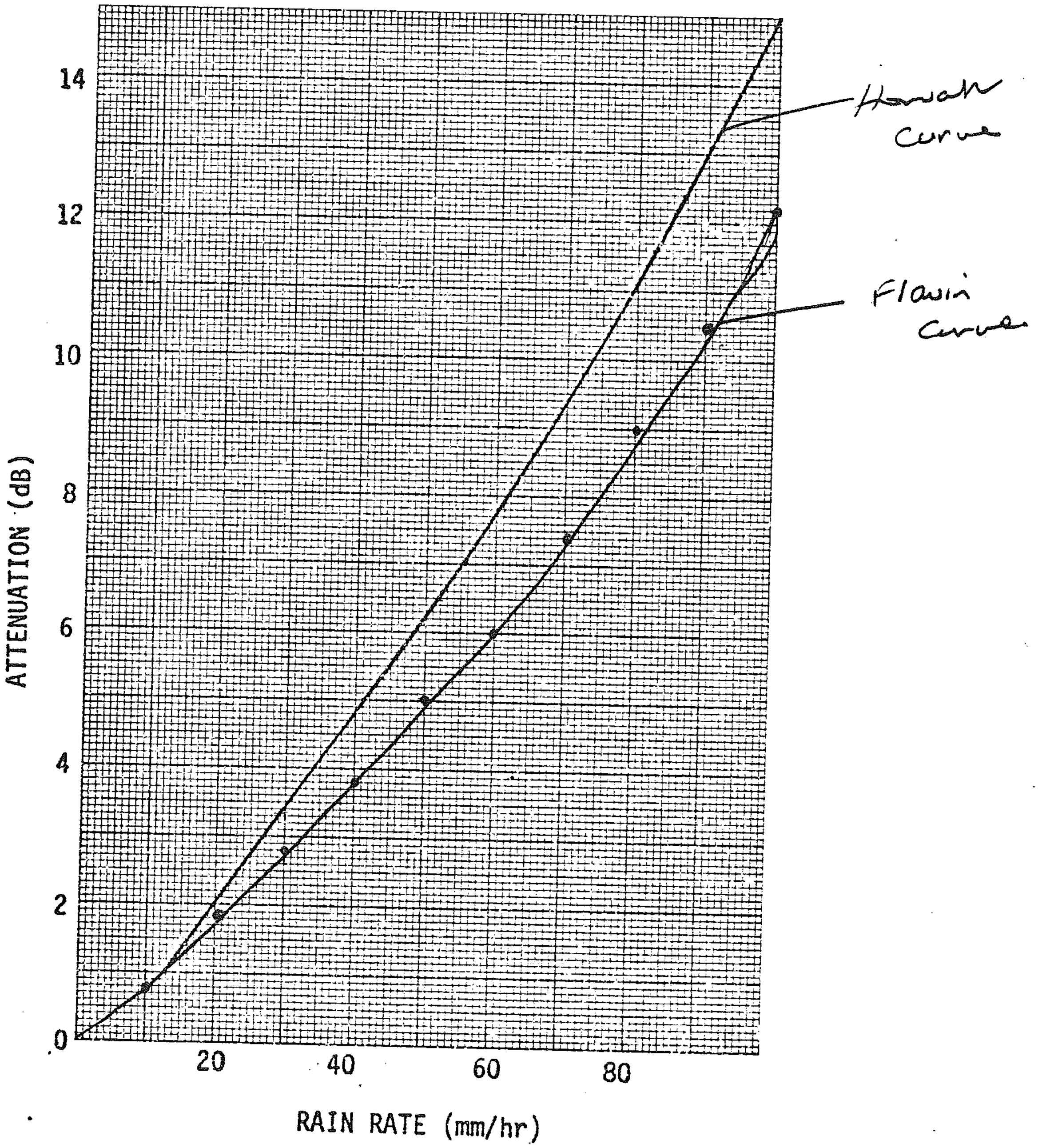


FIGURE 2. Rain attenuation versus point rain intensity at 12 GHz.

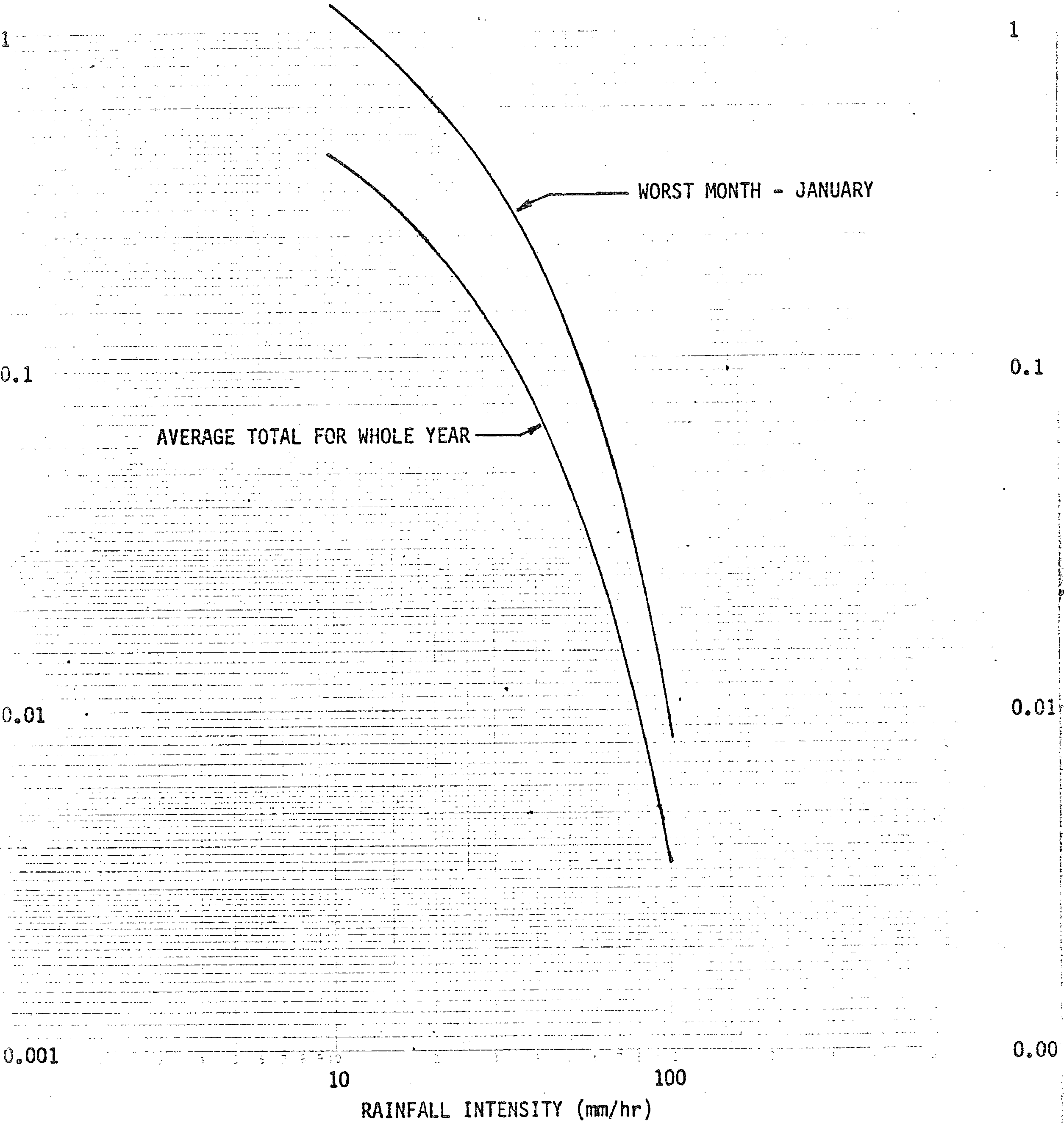


FIGURE 3. Cumulative distribution of rainfall intensities for Darwin.

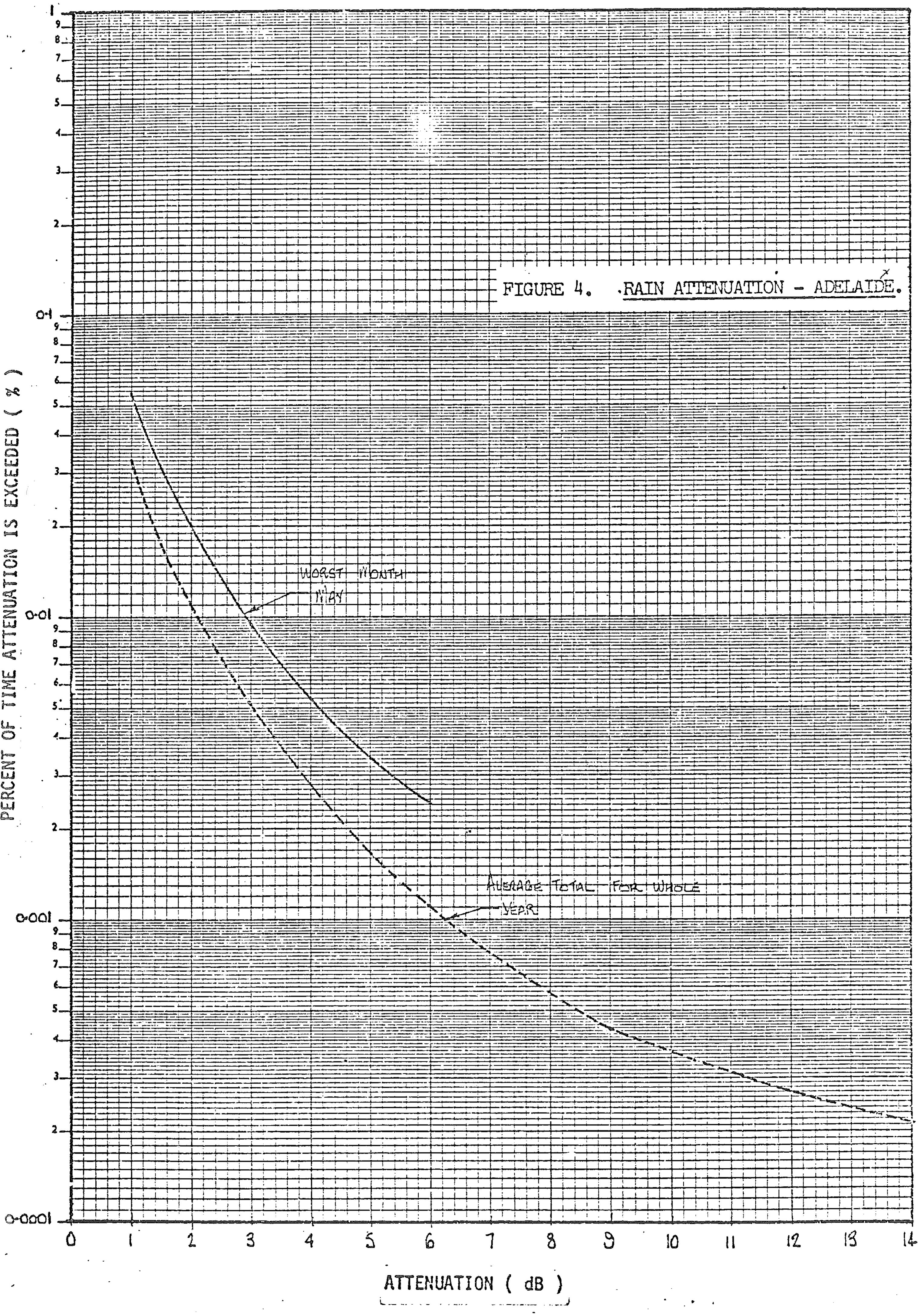


FIGURE 4. RAIN ATTENUATION - ADELAIDE.

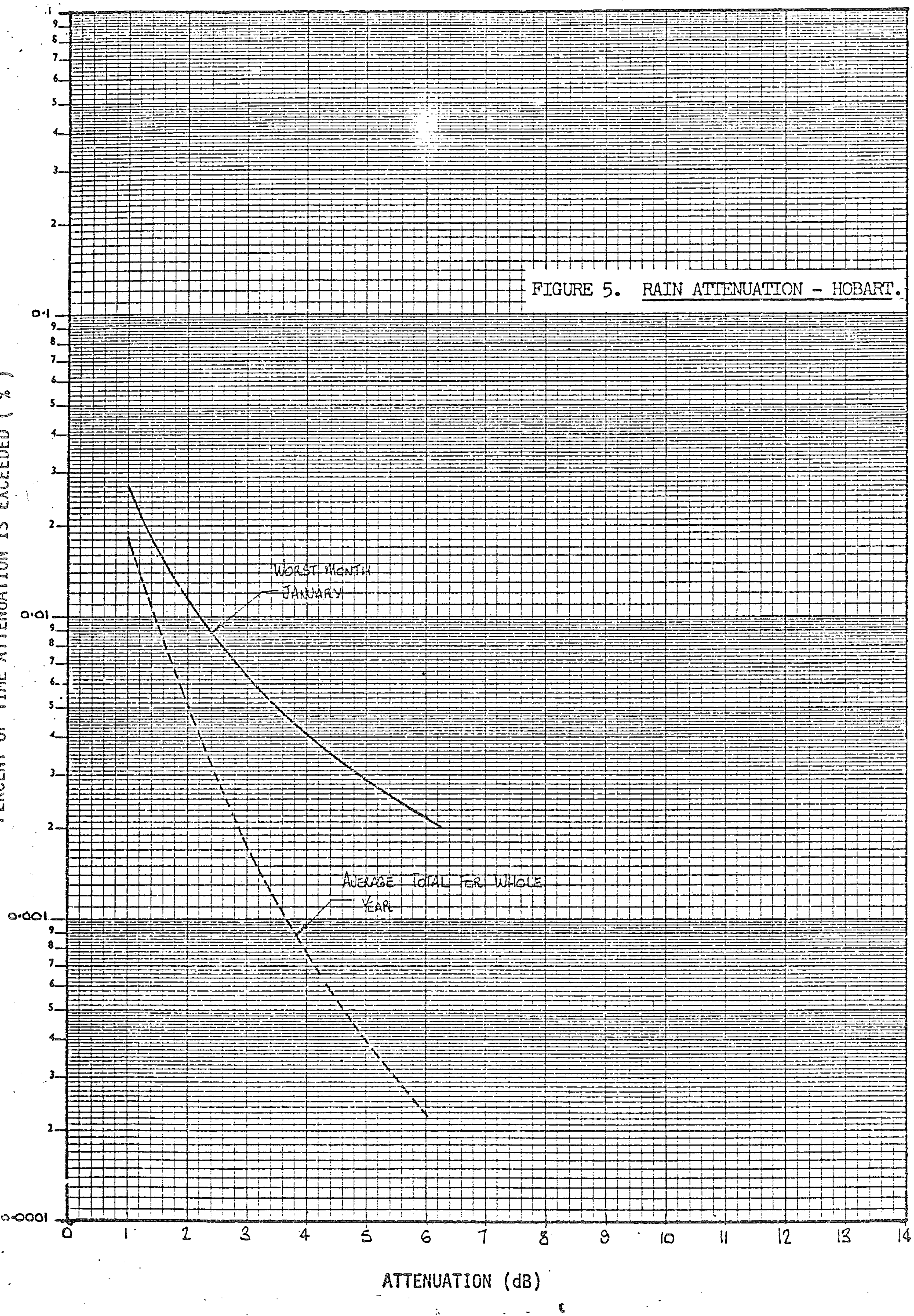


FIGURE 5. RAIN ATTENUATION - HOBART.

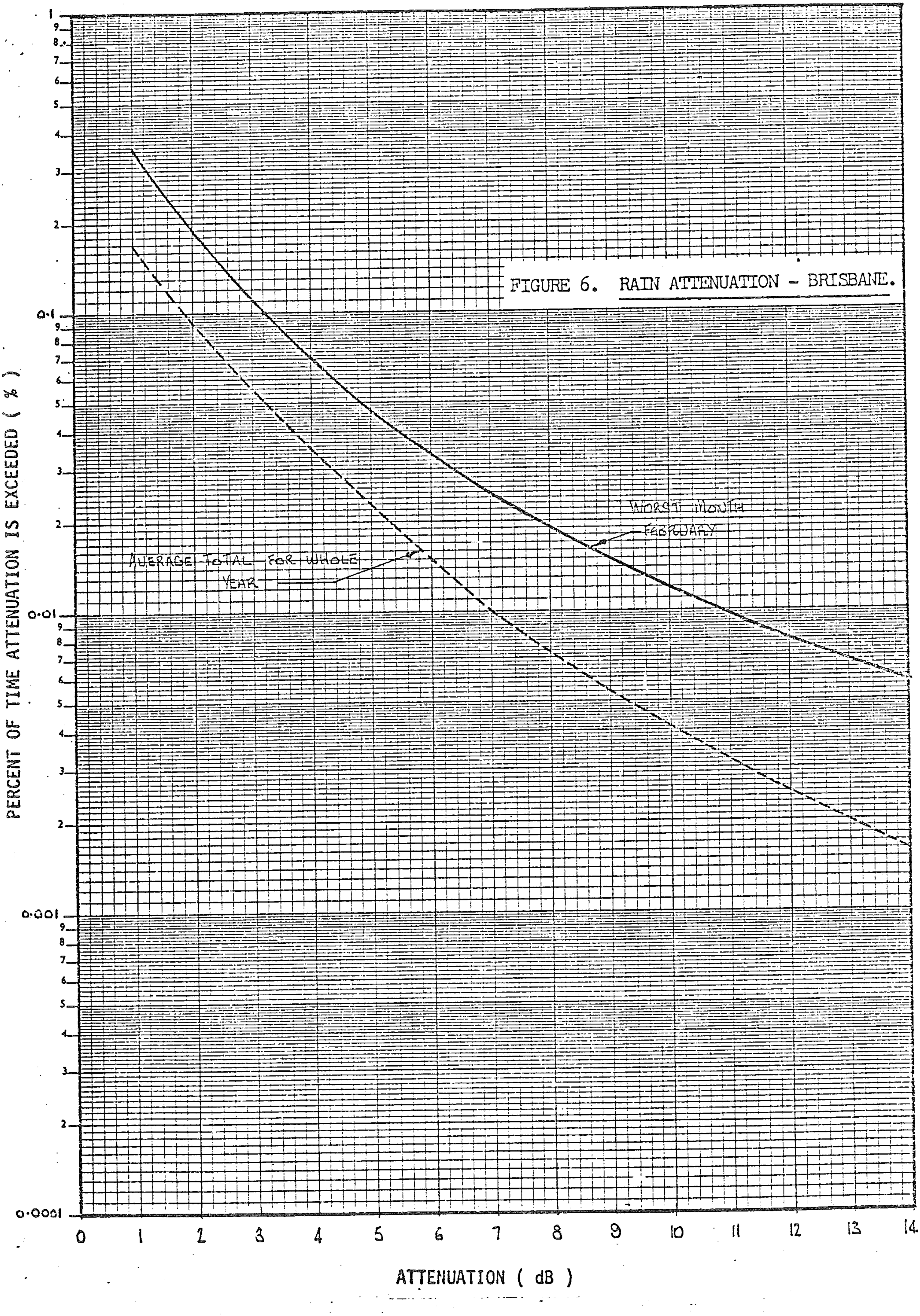


FIGURE 6. RAIN ATTENUATION - BRISBANE.

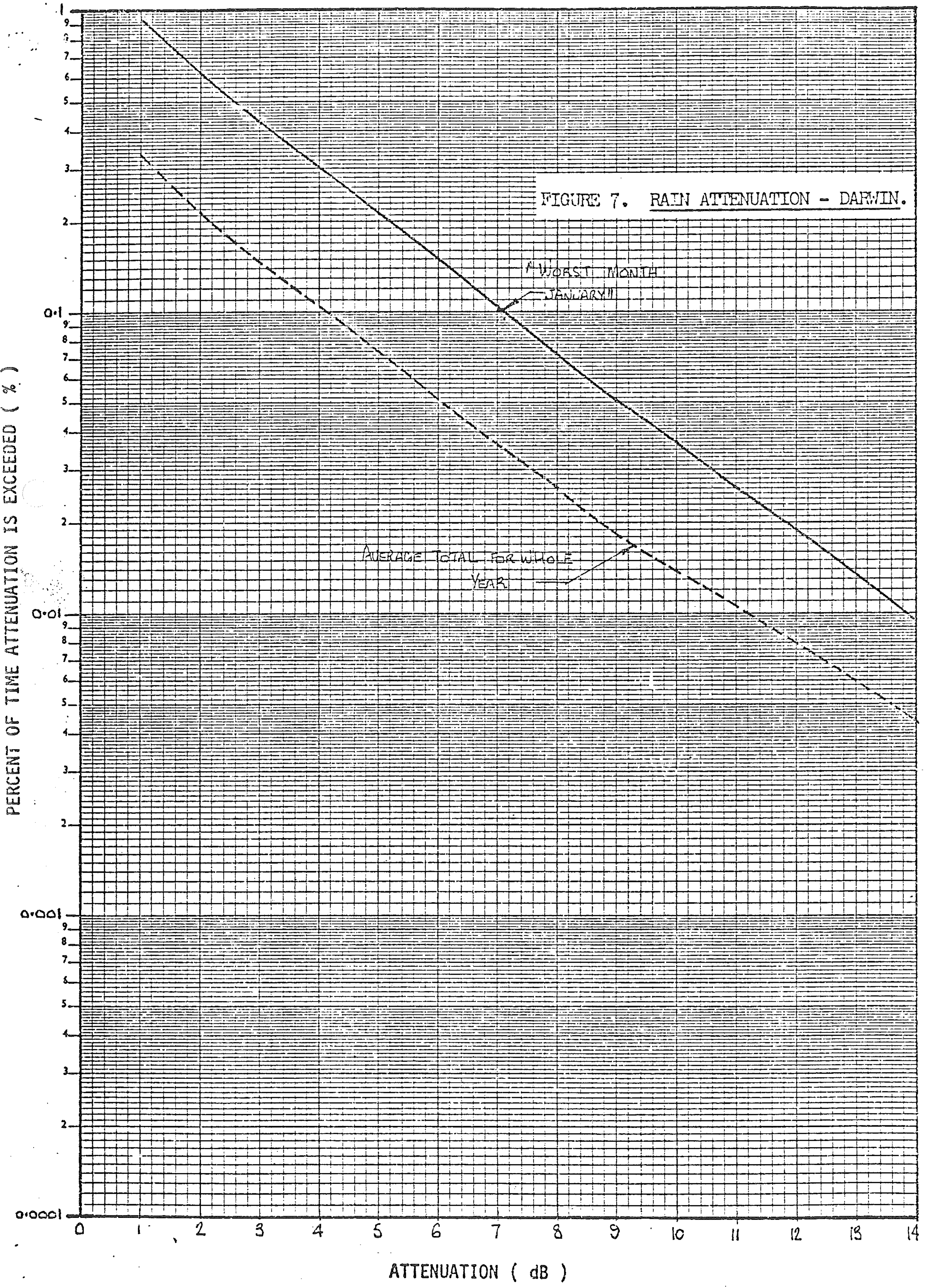


FIGURE 7. RAIN ATTENUATION - DARWIN.

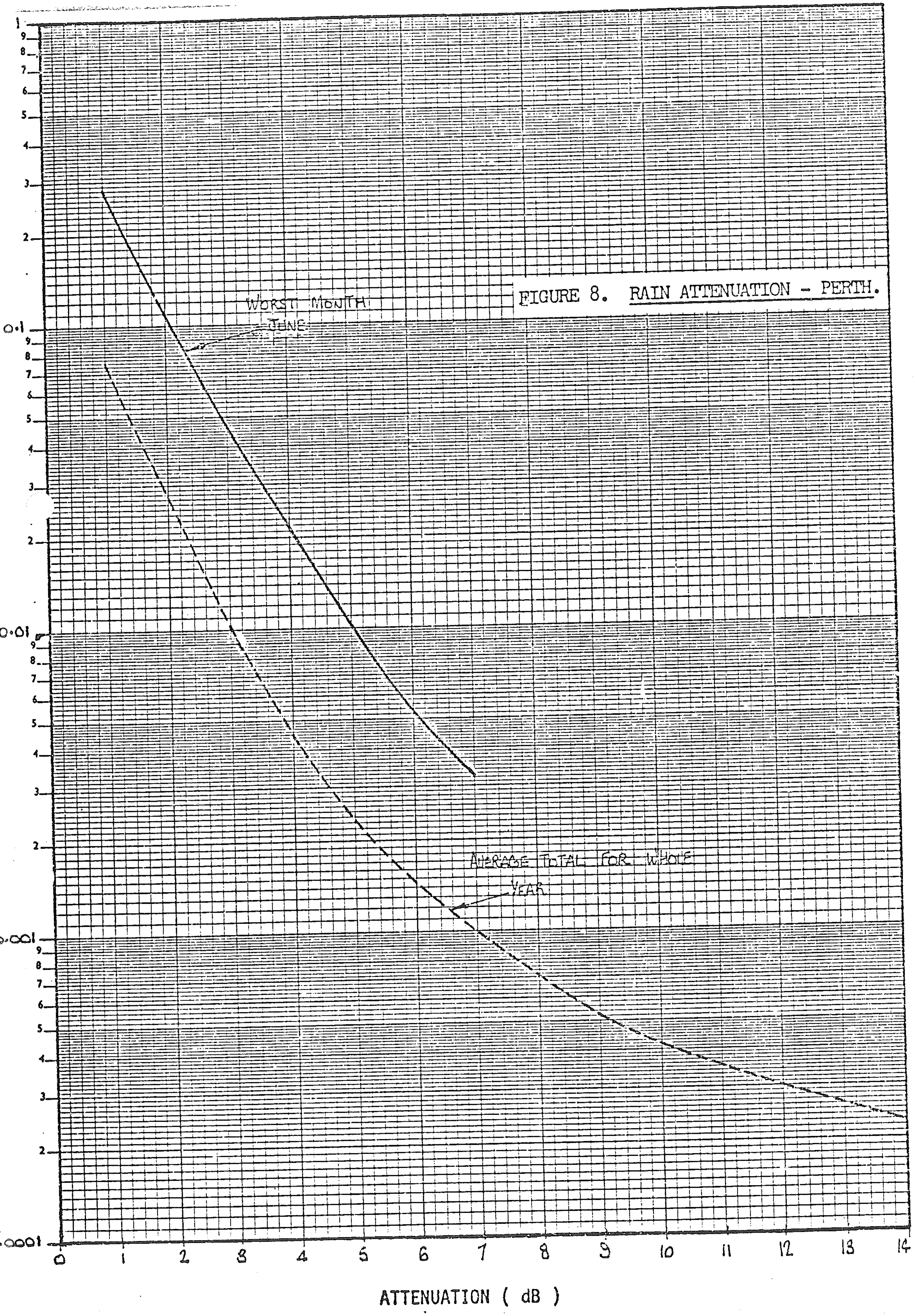


FIGURE 8. RAIN ATTENUATION - PERTH.

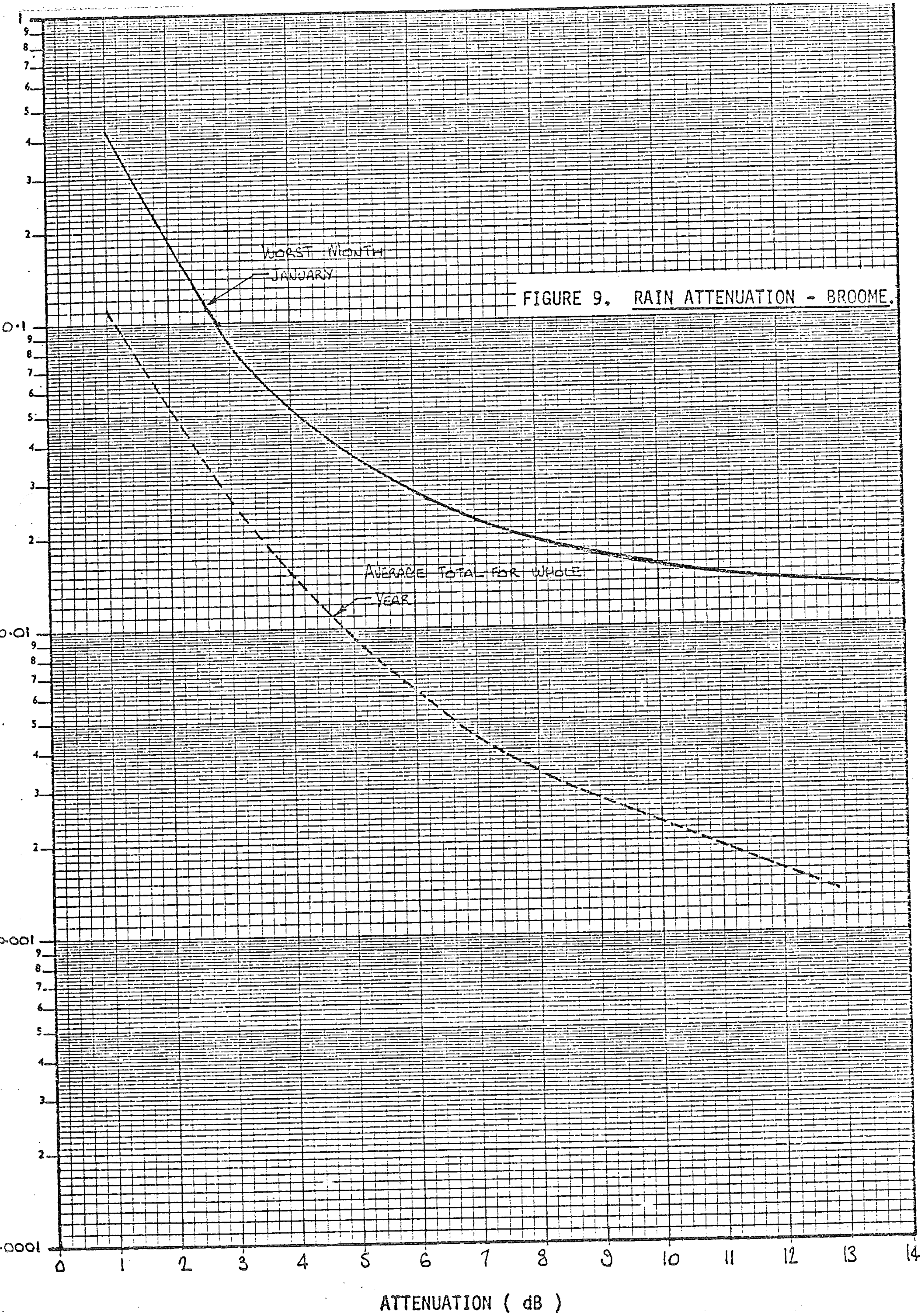


FIGURE 9. RAIN ATTENUATION - BROOME.

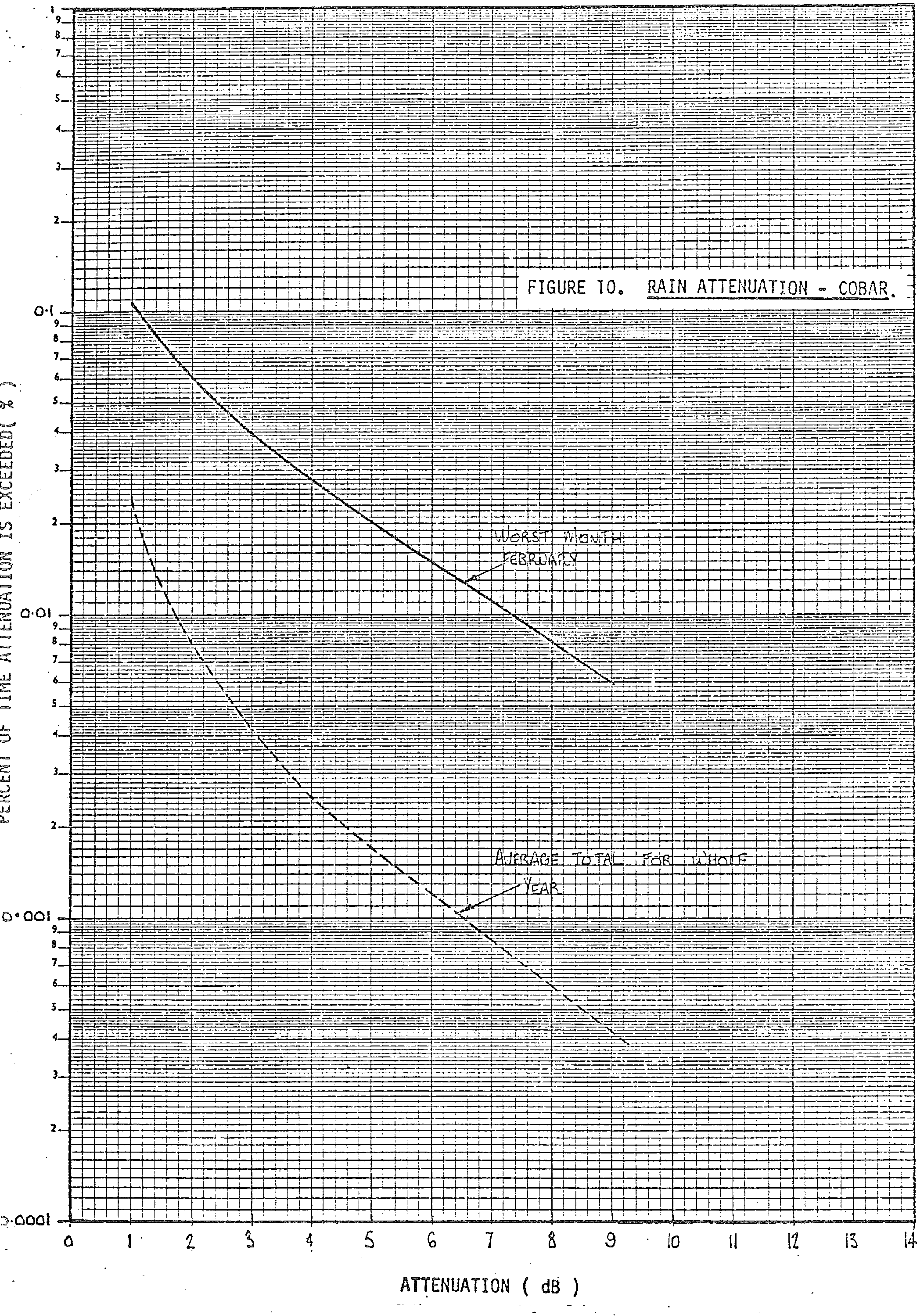


FIGURE 10. RAIN ATTENUATION - COBAR.

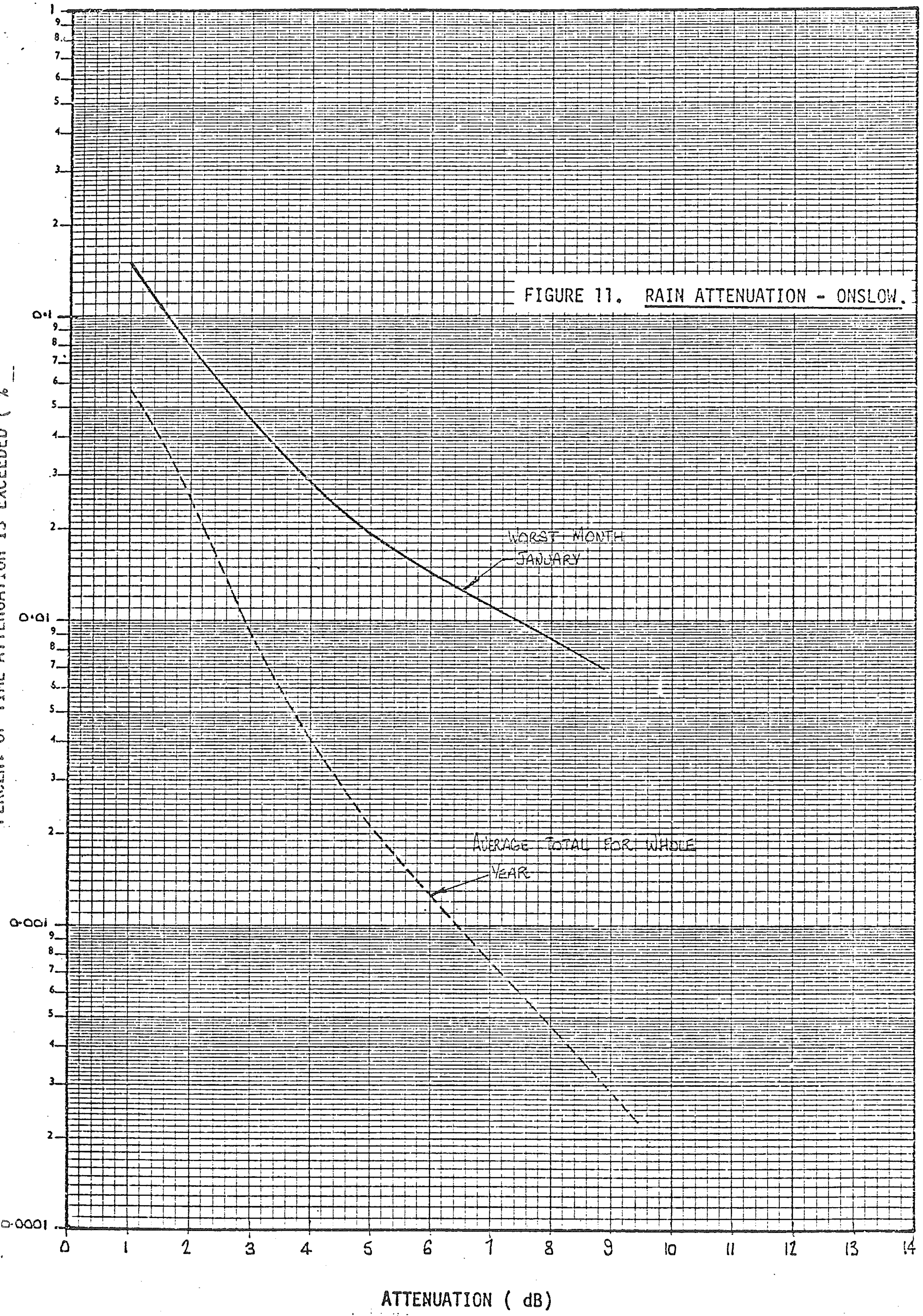


FIGURE 11. RAIN ATTENUATION - ONSLOW.

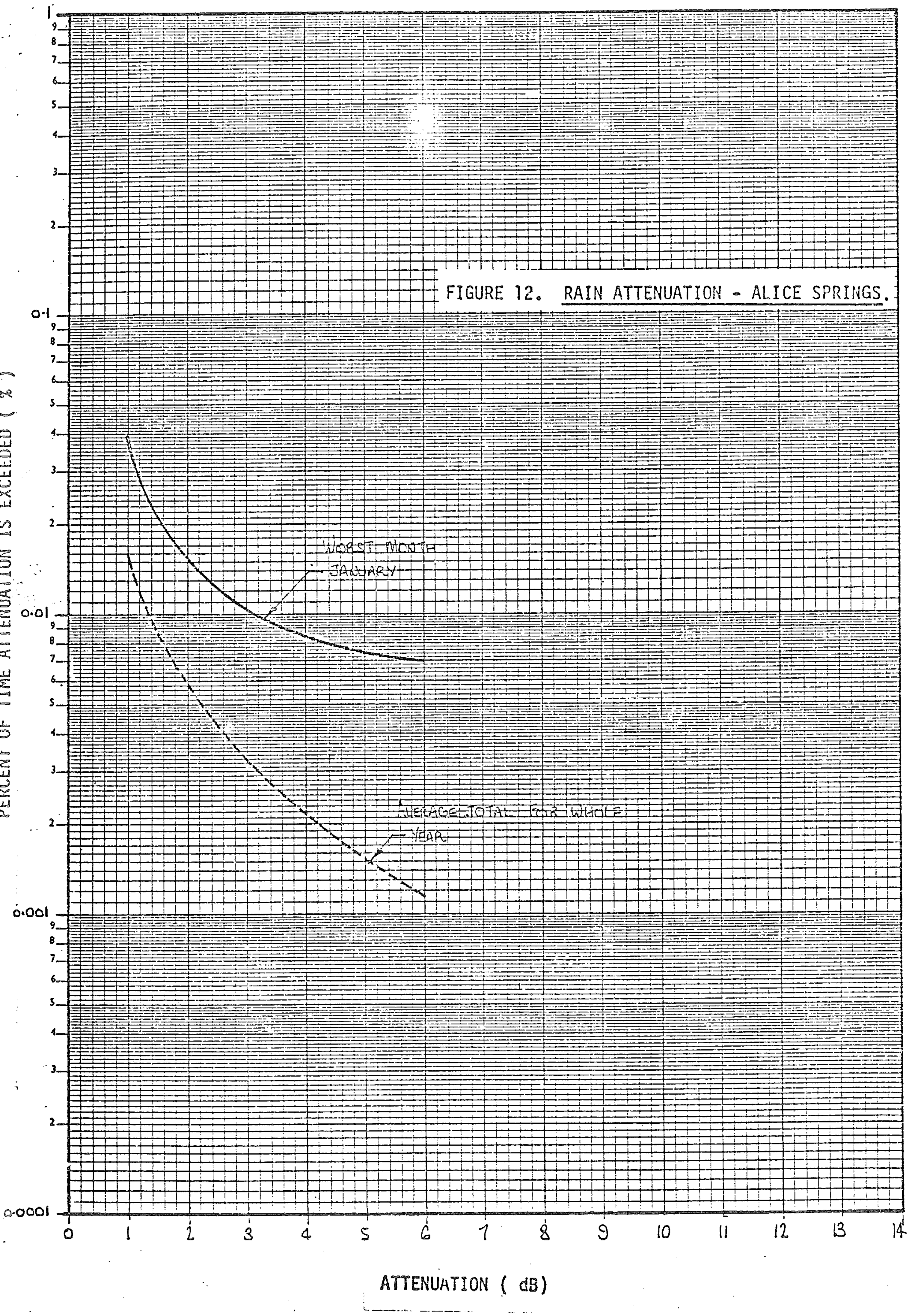


FIGURE 12. RAIN ATTENUATION - ALICE SPRINGS.

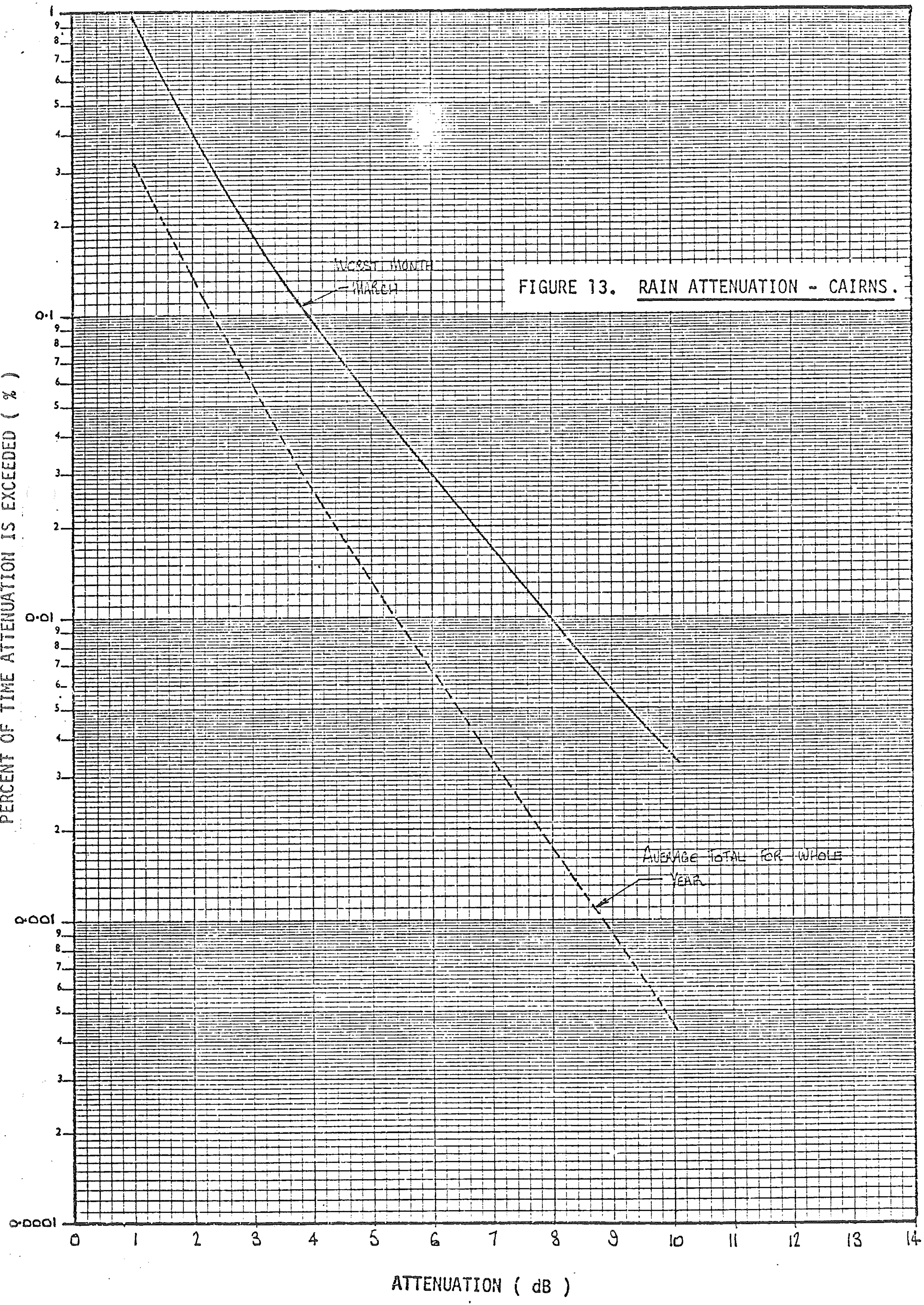
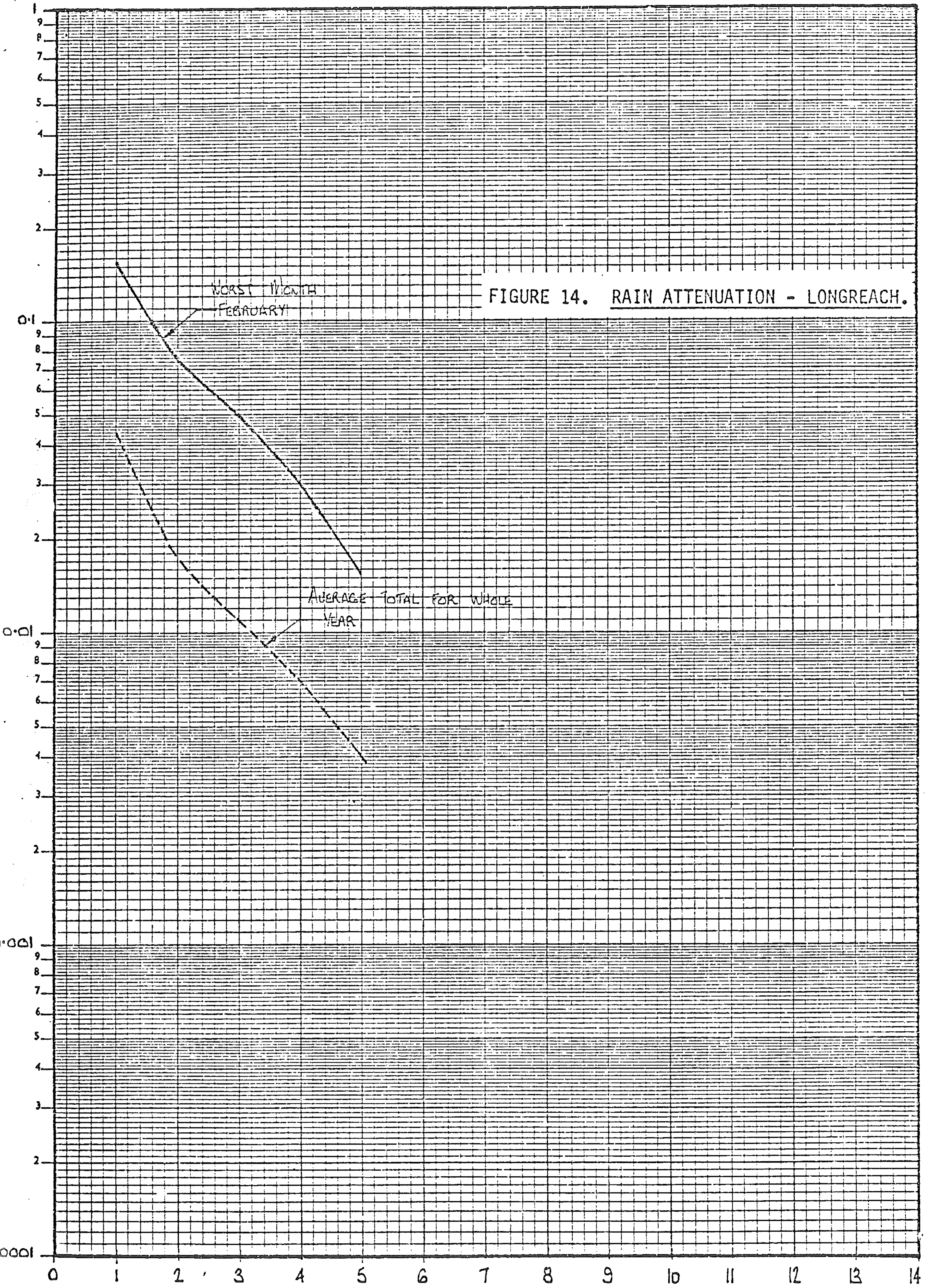


FIGURE 13. RAIN ATTENUATION - CAIRNS.

FIGURE 14. RAIN ATTENUATION - LONGREACH.



APPENDIX A

STATION 14015 DARWIN AIRPORT

PERIOD OF ANALYSIS FROM 1953 TO 1970 NUMBER OF YEARS INCLUDED 18

AVERAGE DURATION IN HOURS AND MINUTES PER MONTH OF RAINFALL EXCEEDING SPECIFIED INTENSITIES

	JAN h m	FEB h m	MAR h m	APR h m	MAY h m	JUN h m	JUL h m	AUG h m	SEP h m	OCT h m	NOV h m	DEC h m	YEAR h m
0.2 mm/HOUR OR MORE	51 46	54 23	36 20	13 31	4 58	0 12	0 15	0 10	1 08	6 17	15 07	32 47	216 55
1.0 mm/HOUR OR MORE	38 49	40 45	26 57	9 38	3 44	0 10	0 13	0 08	0 56	5 08	10 59	23 54	161 19
10.0 mm/HOUR OR MORE	8 57	8 43	5 46	2 06	0 41	0 02	0 03	** **	0 17	1 47	3 21	5 38	37 19
20.0 mm/HOUR OR MORE	4 37	4 22	3 02	1 08	0 22	** **	0 01	** **	0 09	0 59	2 07	2 59	19 45
50.0 mm/HOUR OR MORE	0 59	0 46	0 31	0 11	0 05	** **	** **	** **	0 03	0 22	0 30	0 41	4 06
100.0 mm/HOUR OR MORE	0 03	0 04	0 04	0 01	0 01	** **	** **	** **	0 01	0 02	0 01	0 04	0 19

PERCENTAGE OF TIME DURING WHICH RAINFALL EXCEEDING SPECIFIED INTENSITIES WAS RECORDED

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0.2 mm/HOUR OR MORE	6.96	8.09	4.38	1.88	0.67	0.03	0.03	0.02	0.16	0.84	2.10	4.41	2.48
1.0 mm/HOUR OR MORE	5.22	6.07	3.62	1.34	0.50	0.02	0.03	0.02	0.13	0.69	1.52	3.21	1.84
10.0 mm/HOUR OR MORE	1.20	1.30	0.77	0.29	0.05	0.00	0.01	****	0.04	0.24	0.46	0.76	0.43
20.0 mm/HOUR OR MORE	0.62	0.55	0.41	0.16	0.05	****	0.00	****	0.02	0.13	0.29	0.40	0.23
50.0 mm/HOUR OR MORE	0.13	0.11	0.07	0.03	0.01	****	****	****	0.01	0.05	0.07	0.09	0.05
100.0 mm/HOUR OR MORE	0.01	0.01	0.01	0.00	0.00	****	****	****	0.00	0.01	0.00	0.01	0.00

NOTE 0.00 AVERAGE DURATION LESS THAN 0.005 PER CENT OF MONTH

**** RAINFALL OF THIS INTENSITY HAS NOT BEEN OBSERVED

APPENDIX B

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STATION    14015    DARWIN AERODROME                BUREAU OF METEOROLOGY                                         FEB    1956
                                        RAINFALL INTENSITY ANALYSIS IN TENTHS OF MILLIMETRES

NOTE: THE MINIMUM SAMPLING INTERVAL FOR THIS MONTH IS  2.4 MINS
      RAINFALL DATA OBTAINED FROM PERIODS WHERE CHART WAS UNAVAILABLE OR WHERE TIMING WAS UNCERTAIN ARE FLAGGED BY UNDERLINE OR *

DATE                                      CLOCK HOUR ANALYSIS                                             DAILY MAXIMA
                    DATA QUALITY CODES:   NO RAIN     BLANK, CHART UNAVAILABLE  *
                                          NO RECORD     X  , UNCERTAIN TIME     -                        PERIOD IN MINUTES

      01   02   03   04   05   06   07   08   09   10   11   12   13   14   15   16   17   18   19   20   21   22   23   24   TOT    6   18   30   60  180  360  720

   1    2                                            4   10    7    1        65   26   35   31   13    4    2    1    1    1   203   15   29   42   70  136  174  199
   2        10   10   22    2    2    9   23  106   75   44   12   18    2   66  161   23         1    5   85  145  145  145  1111   29   61  102  203  435  526  796
   3   52   31   11   13   31   18   41   22        38   66   48   38   17   20   35  106   34  168   31   56   38  226   33  1173   43  129  187  228  321  577  820
   4   21   16   45   12   15   16    6                  7   21   38  .15    *    *    *    *    *    *    *    *    *    *   271   12   24   35   48   83  125  181
   5    *    *    *    *    *    *    *    *    *  112    *    *    *    *    *    *    *    *    *    *    *    *    *    *    61    1    2    3    6   18   35   55
   6    *    *    *    *    *    *    *    *    *   13                                                                          5    0    0    0    1    2    3    5
   7                                                10                                                                         10   10   10   10   10   10   10   10
   8                                                                                                                                  0    0    0    0    0    0    0
   9                                                                                                                                  0    0    0    0    0    0    0
  10                                                                                                                                  0    0    0    0    0    0    0
  11    1                        1         3                                                                       .4    1    10    3    3    4    4    5    5    5
  12         2   86    9    2   99   94   76   33   33    5                                                       14    1   454   47   77  112  157  275  374  439
  13  149    2                   1   45    2                                    45    5   14  156   56    4   25   16   73   83   676   46  113  149  159  228  344  477
  14   37   17    3    1         2   19                  *    *    *    *    *    *    *    *    *    *    *    *    *    *    *   257   19   25   32   37   58   71  142
  15    *    *    *    *    *    *    *    *    *  284    *    *    *    *    *    *    *    *    *    *    *    *    *    *   173    1    4    5   12   36   71  123
  16    *    *    *    *    *    *    *    *    *  107                                                                         40    1    1    2    5   13   27   40
  17                                                                                                                                  0    0    0    0    0    0    0
  18                                                                                                                                  0    0    0    0    0    0    0
  19              3                                                     15                                                     18   10   15   15   15   15   15   18
  20              3   20   44        24                                                                                17         108   28   49   63   64   85   91   91
  21    1   22   47   15    7   19    1    1                   13         1         12             16                          155   35   45   46   67   90  111  126
  22    2    1        10    1        18    2                                                                  2              14    50   15   18   19   20   20   32   34
  23    2   11         1                   1    1   29  162    1    1   10                   2                   1    3    3    1    9   238   49   78  106  162  193  204  217
  24                                                 *    *    *    *    *    *    *    *    *    *    *    *    *    *    *     8    0    0    0    1    2    3    6
  25    *    *    *    *    *    *    *    *    *   13        20    6    7   71  100   60   40                                  309   43   61   78  118  253  293  306
  26              1                        4                                       49    3         2    3                   4    66   21   44   49   52   54   56   61
  27             25        52    2   10                                                                                            89   21   33   45   54   78   89   89
  28           308  167   37   21    6                                                                  *    *    *    *   75   615   43  129  215  419  515  539  539
  29                                                          16   26                                 4   15    5        17    5    88   29   40   41   42   42   46   87
                                                                                              MONTH TOTAL                     6188

                                                MONTHLY MAXIMA

PERIOD           6 MINS  12 MINS  18 MINS  30 MINS   1 HOUR  2 HOURS  3 HOURS  6 HOURS 12 HOURS 24 HOURS 48 HOURS 72 HOURS
(UNRESTRICTED)

1ST FALL             49       86      129      215      419      478      515      605      865     1357     2368     2675
DATE/TIME       23 0908  03 2230  03 2230  28 0220  28 0220  28 0305  28 0406  03 0215  03 0231  03 2030  04 0637  04 1341

2ND FALL             47       86      129      187      228      290      435      577      820      695     1183    *1411
DATE/TIME       12 0234  28 0220  28 0220  03 2237  03 2256  02 2400  02 2400  03 2239  03 2314  14 0007  14 0153  15 0221

3RD FALL             46       86      129      149      203      266      321      539      539      667      709    *1000
DATE/TIME       13 0018  28 0134  28 0140  13 0037  02 1545  03 2256  03 2256  28 0548  28 0548  02 1631  28 2300  28 0548

STATION    14015    DARWIN AERODROME                                                                        FEB    1956
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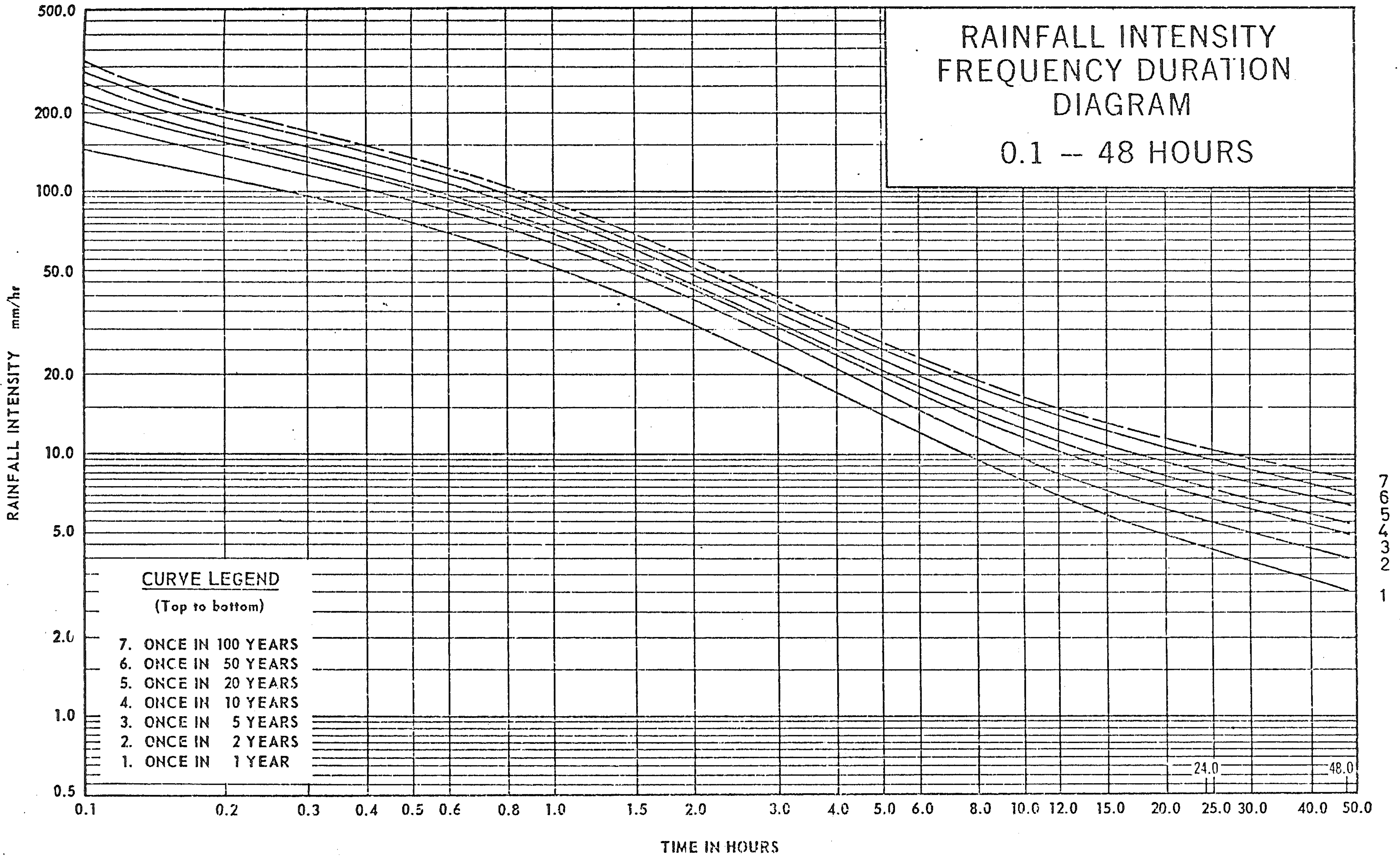
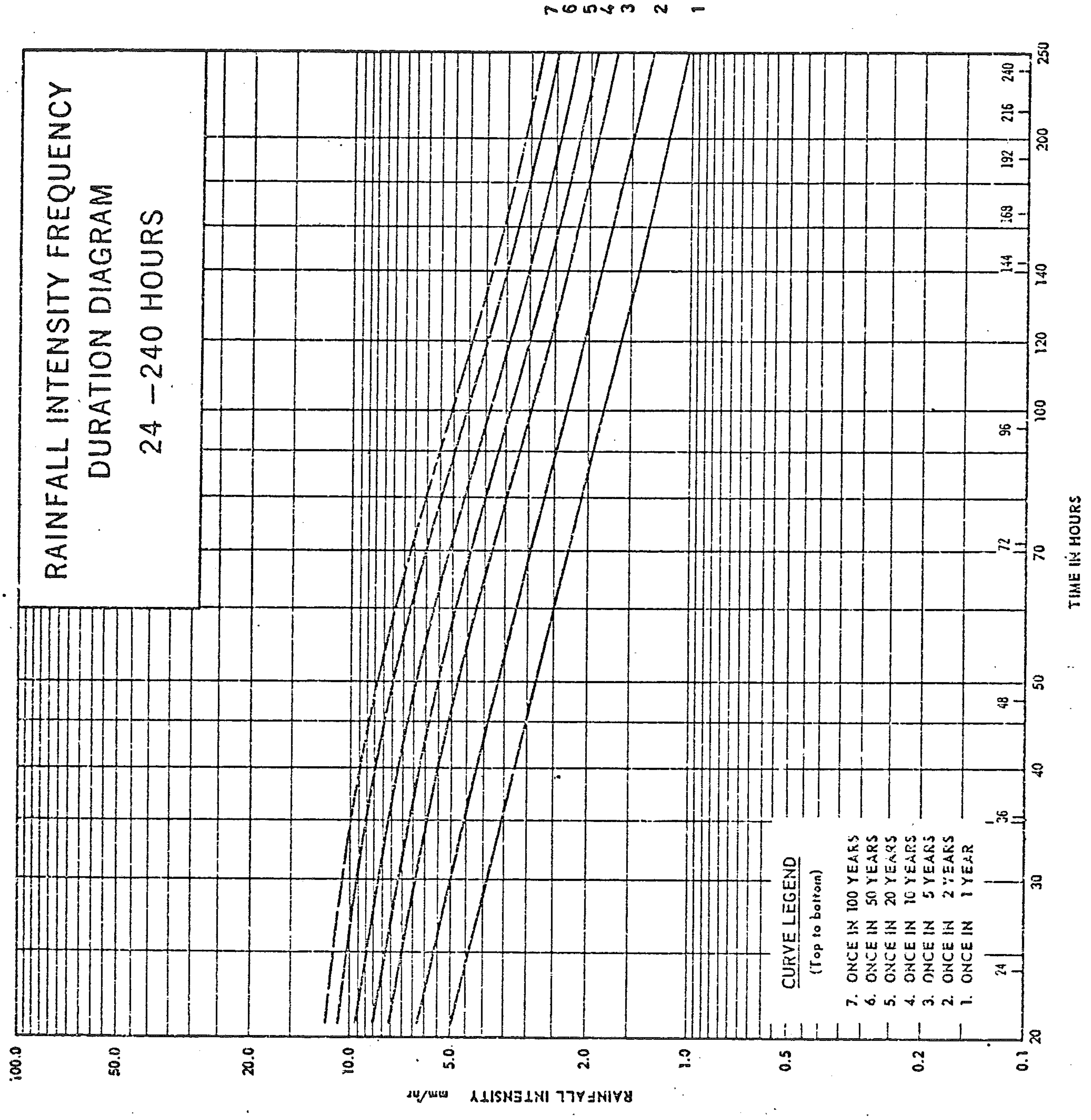


DARWIN AIRPORT – 1954–1970, 15 COMPLETE YEARS, ANNUAL

APPENDIX C2


RAINFALL INTENSITY FREQUENCY DURATION DIAGRAM 24 —240 HOURS

DARWIN AIRPORT – 1954–1970, 15 COMPLETE YEARS, ANNUAL