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RAIN INTENSITY - AMOUNT - FREQUENCY RELATIONSHIPS IN IRELAND

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DUBLIN

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Abstract: Autographic rain records for the 20 year period 1950-69 of a number of stations have been analysed with a view to determining intensity - amount - frequency relationships. The annual variation of intense rainfalls is also discussed.

1. Introduction

Information on the frequency of heavy rainfalls in short periods is of interest to engineers, architects and others, usually in connection with the design of drainage systems. In most cases it would be uneconomic to construct a system capable of coping with the most extreme rainfall possible, even if the magnitude of this were known. Instead it is usual to design the system so that it will be capable of accommodating a rainfall not likely to be exceeded, on the average, more than once in a certain period (say y years). The longer the period y, the heavier is the rainfall for which allowance must be made. The rainfall measure of interest in this connection is the average intensity (I mm/min) over a specified period (say t mins) rather than the instantaneous intensity. The interval t is a characteristic of the drainage system and, generally speaking, increases with the area to be drained.

Thus, in general terms the question requiring to be answered is 'What is the rain intensity I (mm/min) averaged over an interval t (mins) which is likely to be equalled or exceeded once in the period y (years)'? (Intensity - duration - frequency relationship)

Information on the relationship between I, t and y for a particular location may be obtained by considering records of heavy rainfalls for that location. Continuous rain records are available for a number of locations in Ireland. However a complication arises in the way the subject has to be treated because of the manner in which these records have been tabulated. In considering heavy rainfalls, it has been the practice to tabulate the minimum time in which certain fixed amounts of rain fell, rather than the maximum amount which fell in fixed time intervals. This means that the relationship must be developed in intensity - amount - frequency form, rather than in the more convenient intensity - duration - frequency form. Another difficulty is that the data available refer to rainfall at a point, whereas the quantity of interest in the design of drainage systems is the average rainfall over the area in question. The relationship between point and areal rainfall is outside the scope of this paper.

An intensity - amount - frequency relationship was derived by Bilham (1935), using data from a number of stations in England and Wales for the 10-year period 1925-34. Holland (1961) extended and slightly amended Bilham's treatment to cover more recent data. In Ireland, Dillon (1954) studied rainfall records for University College Cork for the period 1914-48 and derived a relationship valid for areas having the same general rainfall characteristics as Cork. However, no study of rain intensity - amount - frequency relationships for Ireland as a whole has been attempted prior to this study.

2. Description of data used

Data, tabulated from rain recorder records for the 20-year period 1950-69 were available for six stations: Claremorris, Clones, Dublin Airport, Mullingar, Shannon Airport and Valentia Observatory. Data for shorter periods were available for a number of other stations. The locations of all stations referred to in the text are shown in Fig. 1. The rain recorders were of the Dines tilting syphon type and the tabulation was done by the staff at the stations themselves.

The method of tabulation was as follows: For each day, the minimum time in which 10 mm of precipitation fell was noted. The rainfall was not necessarily continuous, but if there were breaks, the period of the break or breaks was reckoned as part of the duration. Thus two discrete periods of rain, the second of which ended 100 minutes after the first commenced and each giving 5 mm of rainfall, would be tabulated as a fall of 10 mm in 100 min. The same was done for amounts of 15 mm, 20 mm and 25 mm.

The manner in which the data had been tabulated had some disadvantages. Users of this type of information usually wish to know how much rain will fall in a certain time rather than how long it will take a certain quantity of rain to fall. Also the range of rainfall amount (10 mm to 25 mm) was rather limited. However most of the falls of practical interest in this connection lie within that range.

3. Method of analysis

For each station, the data for the 30 days with the shortest durations of 10 mm rainfall amounts in the 20-year period 1950-69 were extracted, arranged in ascending order of duration and allocated ranks of from 1 up to 30. The average rain intensity in mm/min for each occurrence was obtained by dividing the amount (10 mm) by the duration. The frequency of attainment of each intensity (i.e. the frequency with which that intensity was equalled or exceeded) was taken to be equal to the rank of that intensity divided by the length of the period of record (20 years). Thus, for example, the intensity of the most intense fall was attained with a frequency of once in 20 years, the intensity of the second fall was attained once in 10 years etc. Frequency of attainment was then plotted against average intensity on semi-log paper (with frequency of attainment on the log scale) and a curve was drawn through the set of points. This curve gave a relationship between frequency of attainment and intensity averaged over an amount of 10 mm. Curves for amounts of 15 mm, 20 mm and 25 mm were similarly prepared.

Thus for each of the six stations, a set of curves was prepared giving the relationship between average rain intensity, total rain amount and frequency of attainment. From these curves it was possible to read off the intensities averaged over various fixed amounts which were attained with various frequencies. Some of the results are shown in Table 1.

Table 1. Average rain intensities in mm/min corresponding to the stated frequencies of attainment and total rainfall amounts.

	Once in 20 years			
	10 mm	15 mm	20 mm	25 mm
Mullingar	1.73	1.24	1.02	0.82
Clones	2.32	1.58	1.15	0.82
Shannon Airport	1.77	1.17	0.76	0.48
Dublin Airport	1.67	1.35	1.05	0.78
Claremorris	1.29	0.83	0.69	0.61
Valentia Observatory	1.00	0.70	0.49	0.32

	Once in 5 Years			
	10 mm	15 mm	20 mm	25 mm
Mullingar	0.56	0.19	0.111	0.086
Clones	0.68	0.29	0.129	0.083
Shannon Airport	0.65	0.25	0.137	0.104
Dublin Airport	0.84	0.56	0.298	0.104
Claremorris	0.42	0.19	0.112	0.077
Valentia Observatory	0.57	0.31	0.182	0.125

Table 1. (Contd.)

	Once per year			
	10 mm	15 mm	20 mm	25 mm
Mullingar	0.180	0.087	0.058	0.042
Clones	0.163	0.088	0.055	0.033
Shannon Airport	0.192	0.101	0.049	0.036
Dublin Airport	0.168	0.096	0.067	0.046
Claremorris	0.174	0.100	0.062	0.044
Valentia Observatory	0.192	0.130	0.103	0.074

Thus, for example, a rainfall amount of 15 mm falling at an average rate of 0.83 mm/min (i.e. 15 mm in 18 mins) occurred once in 20 years at Claremorris.

4. Discussion of results

An examination of Table 1 shows that there is considerable variation in the results from station to station. At the frequency of once in 20 years, Valentia Observatory has lower intensities than any of the other stations for all the tabulated amounts. At this frequency Claremorris and Shannon Airport also have rather low intensities for certain totals, while the highest intensities are given by Clones. At the frequency of once in 5 years, Dublin Airport stands out, having very high intensities for 10 mm, 15 mm and 20 mm totals. At the frequency of once per year, Valentia Observatory again differs from the other stations, having comparatively high intensities, especially under the 20 mm and 25 mm headings.

The question arises as to whether there are genuine differences between the regimes of intense rain of the various stations or whether the variations observed are merely random ones which would not be reproduced in an independent 20-year sample of data. In order to throw some light on this question, an attempt was made to interpret the variations in the results on intense rainfalls in terms of other meteorological factors. The most obvious factor would be some measure of the continentality or oceanicity of the stations since it is known that extremely heavy rainfall in mid-latitudes is generally characteristic of continental rather than oceanic areas. Commonly used measures of continentality incorporate the annual temperature range together with the latitude of the area in question (cf Landsberg 1958, Conrad and Pollak 1950). Since the group of stations under consideration differ very little in latitude, it was decided to take simply the annual temperature range (i.e. the difference between the mean temperature of the warmest and coldest months) as the measure of continentality.

Table 2 gives the annual temperature range, together with the average annual rainfall for the six stations.

Table 2. Temperature range, warmest month - coldest month and average annual rainfall, based on 1931-60 averages

	Temperature Range	Annual Rainfall
Mullingar	10.9°C	950 mm
Clones	10.6	935
Shannon Airport	10.5	930
Dublin Airport	10.4	758
Claremorris	10.2	1135
Valentia Observatory	8.6	1398

It can be seen that Valentia Observatory has a much lower temperature range than any of the other stations and is indeed highly oceanic. As has been mentioned above, the intensity - amount - frequency results for Valentia also differ markedly from those for the other stations, giving lower intensities for the rarest events and higher intensities for events with frequencies of the order of once per year. Claremorris, which has the second lowest temperature range, exhibits some of the same features, though much less markedly. The intensity - amount - frequency results for the other stations appear to be unrelated to their temperature ranges, which in any case are virtually equal.

Considering these results, it was concluded that Valentia Observatory belonged to a different category of rainfall climate from the other five stations and should be treated separately. However, in order to check that the differences between the Valentia results and those of the other stations were not due to chance, it was decided to analyse the records of two other highly oceanic stations, Roche's Point (annual temperature range 9.1°C) and Belmullet (8.9°C). The periods of record were 15 years and 14 years and 4 months respectively. In Table 3, the three stations are compared. Because of the shortness of the records, it was necessary to extrapolate slightly the curves for Roche's Point and Belmullet in order to obtain the 'once in 20 years' figures. It may be seen that these two stations agree well with Valentia, particularly in giving low intensities at the 'once in 20 years' frequency.

Table 3. Average rain intensities in mm/min corresponding to the stated frequencies of attainment and total rainfall amounts for three southern and western coastal stations.

		Once in 20 years		
	10 mm	15 mm	20 mm	25 mm
Valentia Observatory	1.00	0.70	0.49	0.32
Roche's Point	0.90	0.55	0.45	0.37
Belmullet	0.75	0.57	0.42	0.28
		Once in 5 years		
	10 mm	15 mm	20 mm	25 mm
Valentia Observatory	0.57	0.31	0.182	0.125
Roche's Point	0.57	0.30	0.230	0.162
Belmullet	0.46	0.33	0.236	0.140
		Once per year		
	10 mm	15 mm	20 mm	25 mm
Valentia Observatory	0.192	0.130	0.103	0.074
Roche's Point	0.154	0.106	0.082	0.060
Belmullet	0.166	0.108	0.064	0.040

There appears to be little connection between the intensity - amount - frequency relationship and average annual rainfall. The results for Roche's Point (annual rainfall 910 mm) closely resemble those for Valentia Observatory (1398 mm) but are totally different from those for Clones (935 mm). The high frequency of 25 mm and 20 mm totals at relatively modest intensities at Valentia may, however, be connected with its high annual rainfall. Considering the five stations with high annual temperature ranges, it was concluded that, with the possible exceptions of Claremorris and Dublin Airport, they were climatically similar with respect to intense rainfalls. It was therefore decided to average their results in order to obtain a set of curves which would be valid for the whole of Ireland apart from southern and western coastal areas. The method of averaging was to calculate the mean of the five actual rain intensities corresponding to each frequency of attainment for each total amount, plot these mean points and draw the curves through them by eye. The results are shown in Fig. 2 and in Table 4. In Fig. 3, the same results are presented in depth - duration - frequency form, a form more suitable for direct application.

Table 4. Relationship between rain intensity in mm/min, averaged over various rainfall amounts, and frequency of attainment, based on data for the five stations Claremorris, Clones, Dublin Airport, Mullingar and Shannon Airport for the period 1950-69

	Rainfall amount			
Frequency of attainment	10 mm	15 mm	20 mm	25 mm
Once in 20 years	1.79	1.27	0.93	0.65
Once in 10 years	1.14	0.66	0.41	0.25
Once in 5 years	0.62	0.27	0.157	0.106
Once in 2 years	0.30	0.136	0.082	0.059
Once per year	0.174	0.091	0.058	0.040

Averaging the results has the advantage that it tends to eliminate random variations. As has been pointed out by Bilham (1935), these may be very large in the case of extreme rainfalls. It is therefore probable that the set of curves derived for a particular station contains features, due to chance, which would not be reproduced in an independent sample of data. By averaging the curves for a number of climatically similar stations, it was hoped to reduce or eliminate such features. The disadvantage of averaging is that genuine variations in the rainfall climate from station to station may be supressed. However, for the five stations in question, the variations appear to be random rather than systematic. Two possible exceptions to this are Claremorris, which appears to have certain features in common with Valentia Observatory, and Dublin Airport, which has a tendency to resemble the English group of stations discussed by Bilham and Holland.

5. Area of applicability of intensity - amount - frequency relationship

The intensity - amount - frequency curves given in Fig. 2 should be valid near sea level for most inland areas of Ireland. They may not be applicable in mountainous areas, since all the stations used in the derivation are fairly low-lying. For southern and western coastal areas, the Valentia Observatory curves may be more appropriate. These are shown in Fig. 4.

Along the east coast and particularly in the Dublin area, the curves of Fig. 2 should be used with caution. In the frequency range once in 10 years to once in 3 years approximately, Dublin Airport, which may be taken as representative of the east coast, gives higher intensities than the other stations and approaches the values given by Holland (1961) for English and Welsh conditions. This ties in with the fact that it is in the area the climate of which most closely resembles that of England. It would seem advisable therefore, to use the curves for Dublin Airport itself rather than the averaged curves when dealing with areas along the east coast. The Dublin Airport curves are shown in Fig. 5.

It is not considered that extrapolation of the curves beyond the range of the observations could be done with much confidence, especially since there is no theoretical basis for it. For a number of reasons, the data are not suitable for the application of extreme-value statistics. Nevertheless, Holland has argued that the intensity - amount - frequency curves, plotted on semi-log paper, should tend towards straight lines with increasing intensity. This in fact appears to be the case with the curves of Fig. 2. However if these lines were extrapolated, they would give much higher intensities than Holland's curves at frequencies of the order of once per 100 years. This would mean that rain intensities occurring with frequencies of this order would be greater in Ireland than in England, a conclusion which appears questionable. It would therefore appear that extrapolation is not justified.

6. Comparison with the results of other investigations

Bilham (1935), using data for English and Welsh stations for the period 1925-34, derived an intensity - amount - frequency formula which may be expressed

$$N = (4.47/(R + 2.54))^{3.55} . 100 R/I$$

Where N = number of occurrences per century

I = average intensity in mm/min

R = amount in mm.

This formula gives higher intensities than the curves in Fig 2 over most of the range of frequencies. In the case of the 25 mm and 20 mm curves however, it gives somewhat lower intensities for frequencies greater than about once per year. These results confirm what has generally been held, i.e. that very heavy rainfalls are generally more frequent in England than in Ireland but that Ireland has a higher frequency of the larger totals at less extreme intensities. Holland (1961) pointed out that Bilham's formula tends to give too high intensities at very low frequencies, especially for the smaller totals. He produced a set of curves which agree rather well with the formula at the higher frequencies but which give considerably lower intensities for the very rare events. Holland's curves agree rather well with those in Fig. 2 at the highest and lowest frequencies of the range covered. At intermediate frequencies, they give higher intensities, the divergence being greatest at a frequency of about once in 5 years. In Table 5, the intensities for this frequency are compared. The figures for Dublin Airport are also given since this is the Irish station which most closely approaches Holland's results. It should be noted that it is at this frequency also that the greatest divergence between Dublin Airport and the average of five stations occurs.

Table 5. Rain intensities in mm/min attained once in 5 years

	Rainfall amount			
	10 mm	15 mm	20 mm	25 mm
British stations (after Holland)	0.93	0.59	0.35	0.21
Dublin Airport	0.84	0.56	0.298	0.104
Average of 5 stations	0.62	0.27	0.157	0.106

Dillon (1954) derived a formula, based on data for University College Cork for the period 1914-48, which may be expressed:

$$N = 10600/I^2R^3$$

This formula was intended to apply only to areas with a climate similar to that of Cork and it differs considerably from the relationship shown in Fig. 2. At frequencies of the order of once per year, it gives considerably higher intensities while at a frequency of once in 20 years it gives lower intensities. The nearest station to University College Cork for which recent tabulated data are available is Roche's Point. There is considerably better agreement in this case as might be expected. Nevertheless, the observations still fall short of the formula at high frequencies. The biggest descrepancy is for the 10 mm amount at a frequency of once per year, where the formula gives a rate of 0.33 mm/min as against an observed value of 0.15. Dillon himself pointed out that his formula gives too high intensities for short durations and high frequencies. Furthermore, Roche's Point differs from University College Cork in being on the coast and in having a somewhat lower annual rainfall.

7. Annual variation of extreme rain intensities

In Fig. 6 the distribution by months of the 30 highest rain intensities for the five stations used in deriving Fig 2 is shown in histogram form for both 10 mm and 25 mm amounts.

The most remarkable features of Fig. 6 are the very strong annual variation and the position of the maxima and minima. Under the 10 mm heading, 87% of the 30 highest intensities occurred during the five months June to October. Virtually none of them occurred during the four months January to April. Under the 25 mm heading, the variation is somewhat less strong.

The maximum of the distribution occurs in August and September for the 10 mm total and about a month later for 25 mm. Thus the maxima occur later in the year than the maximum of either solar radiation or temperature. Many of the most intense rainfalls occur during thunderstorms associated with surface heating. The times of the maxima of the distributions, however seem to indicate that some factor other than local surface heating is involved, a factor which is probably related to the general circulation of the atmosphere. The fact that the 10 mm maximum occurs earlier than the 25 mm maximum appears to indicate that the surface heating factor is more effective for the extremely intense falls which tend to come under the 10 mm heading.

8. Conclusions

The intensity-amount-frequency relationship given in Fig 2 and Table 4 should be valid for most inland areas of Ireland. The curves for Valentia Observatory (Fig. 4) may be applied in southern and western coastal areas and those for Dublin Airport (Fig. 5) may be applied in areas along the east coast.

Over most of the range of frequencies considered, the Irish rain intensities are lower than those given for English and Welsh conditions by Bilham and Holland.

There is a marked annual variation in the occurrence of intense rainfalls with a maximum about September and a minimum about March.

References

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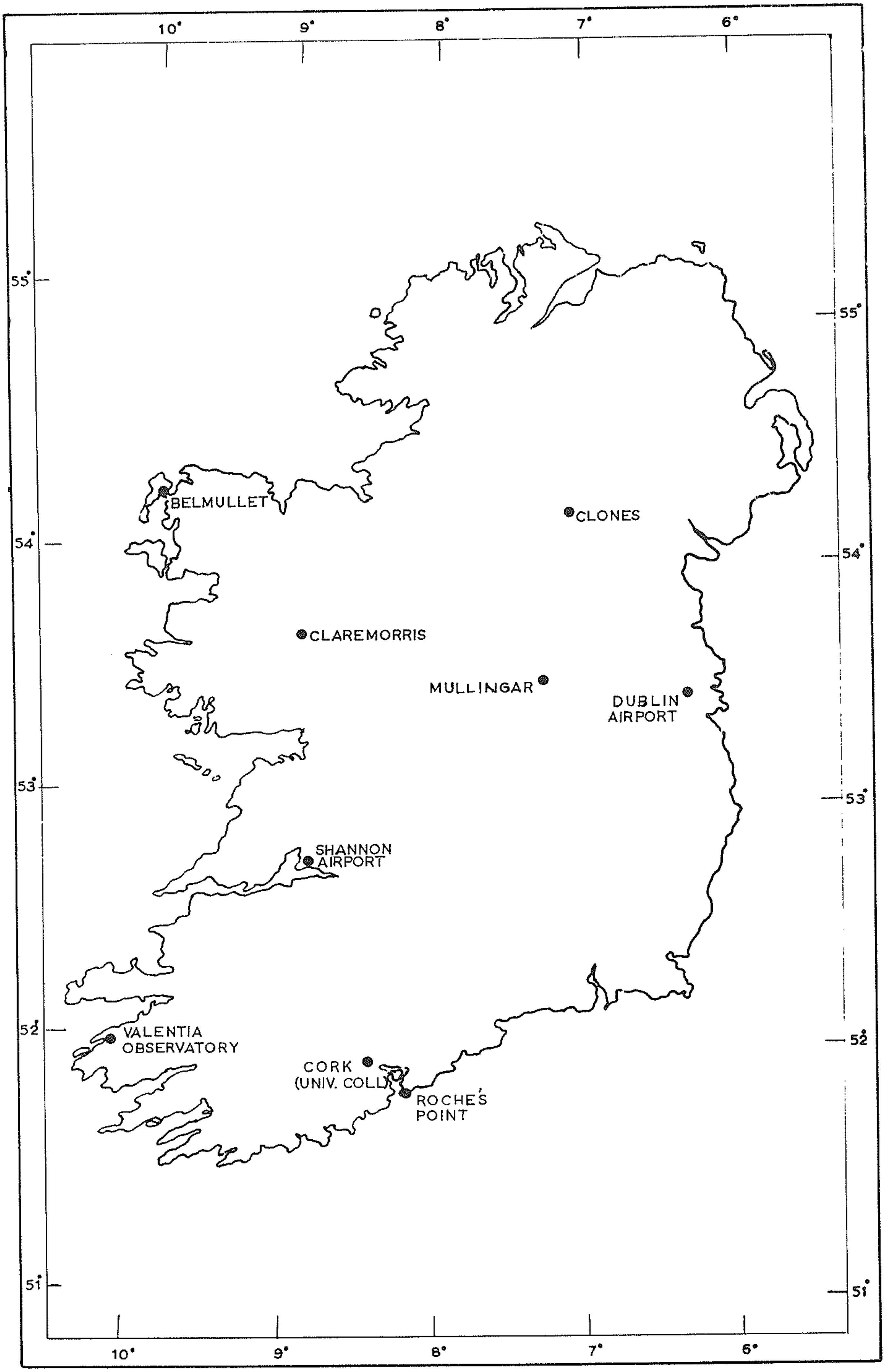

Fig. 1. Location of stations referred to in the text.

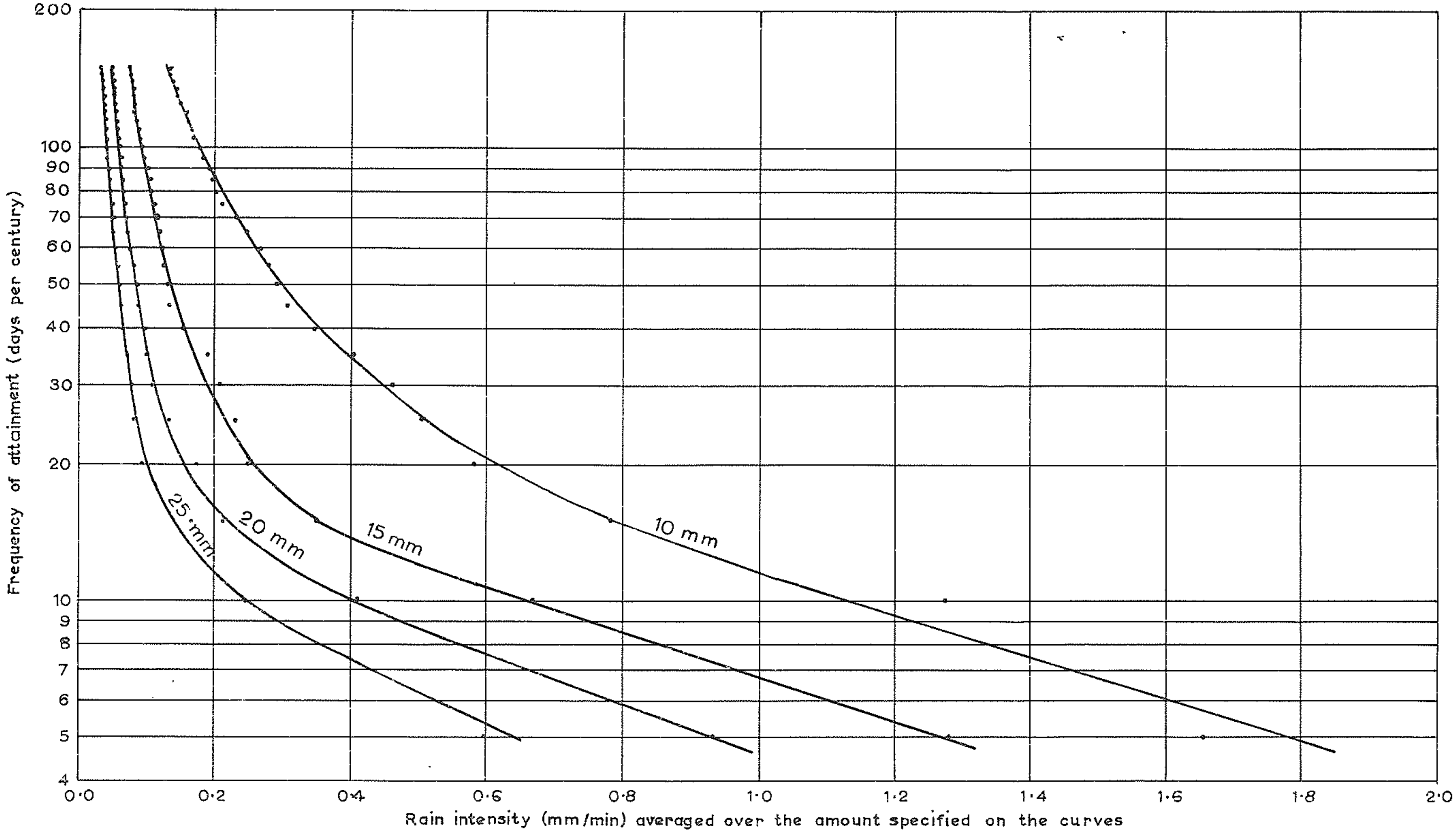

Fig. 2. Rain intensity - amount - frequency curves based on data for the 5 stations Claremorris, Clones, Dublin Airport, Mullingar and Shannon Airport for the period 1950-1969.

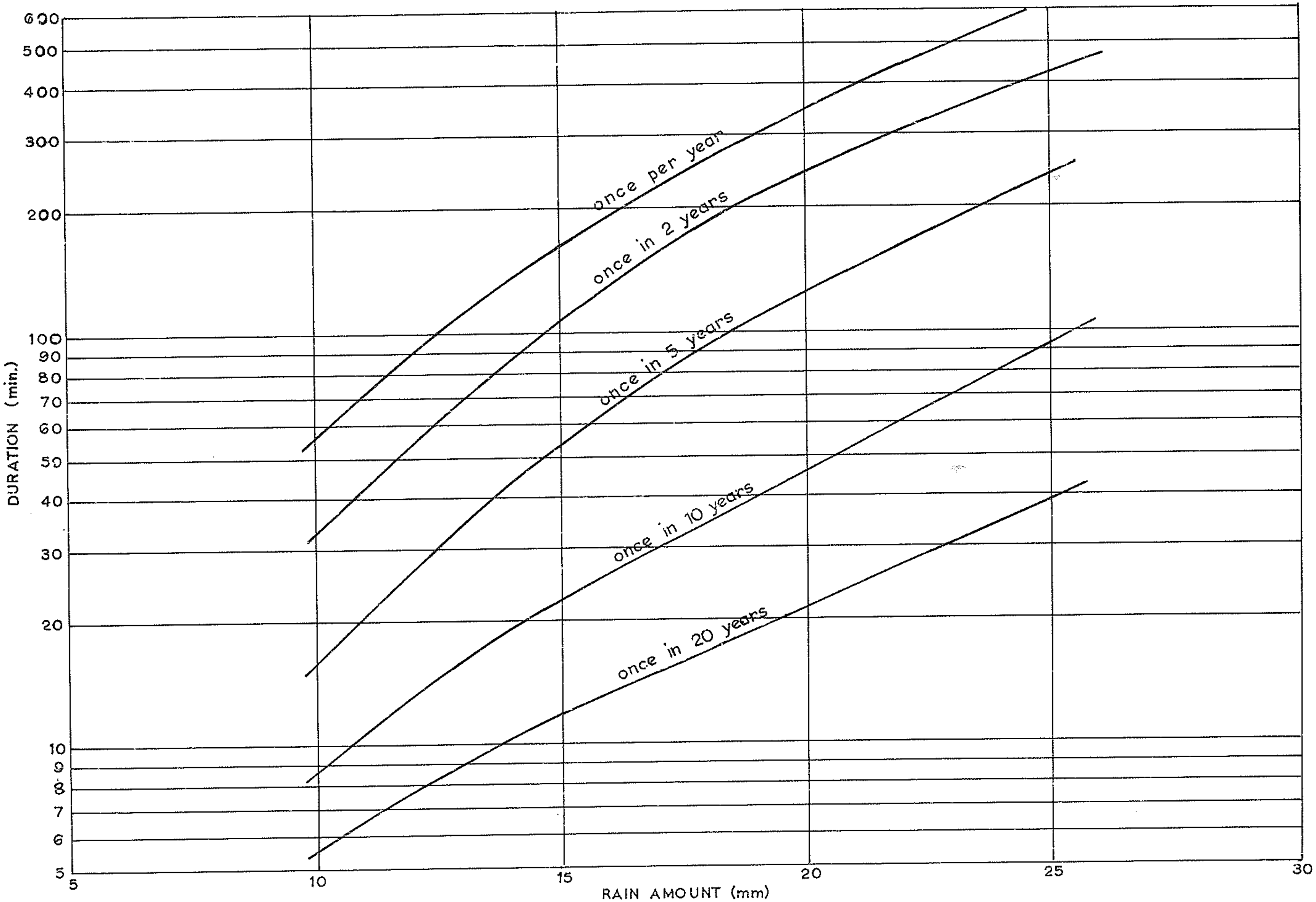

Fig. 3. Rain depth-duration-frequency curves based on data for 5 stations for the period 1950 - 69.

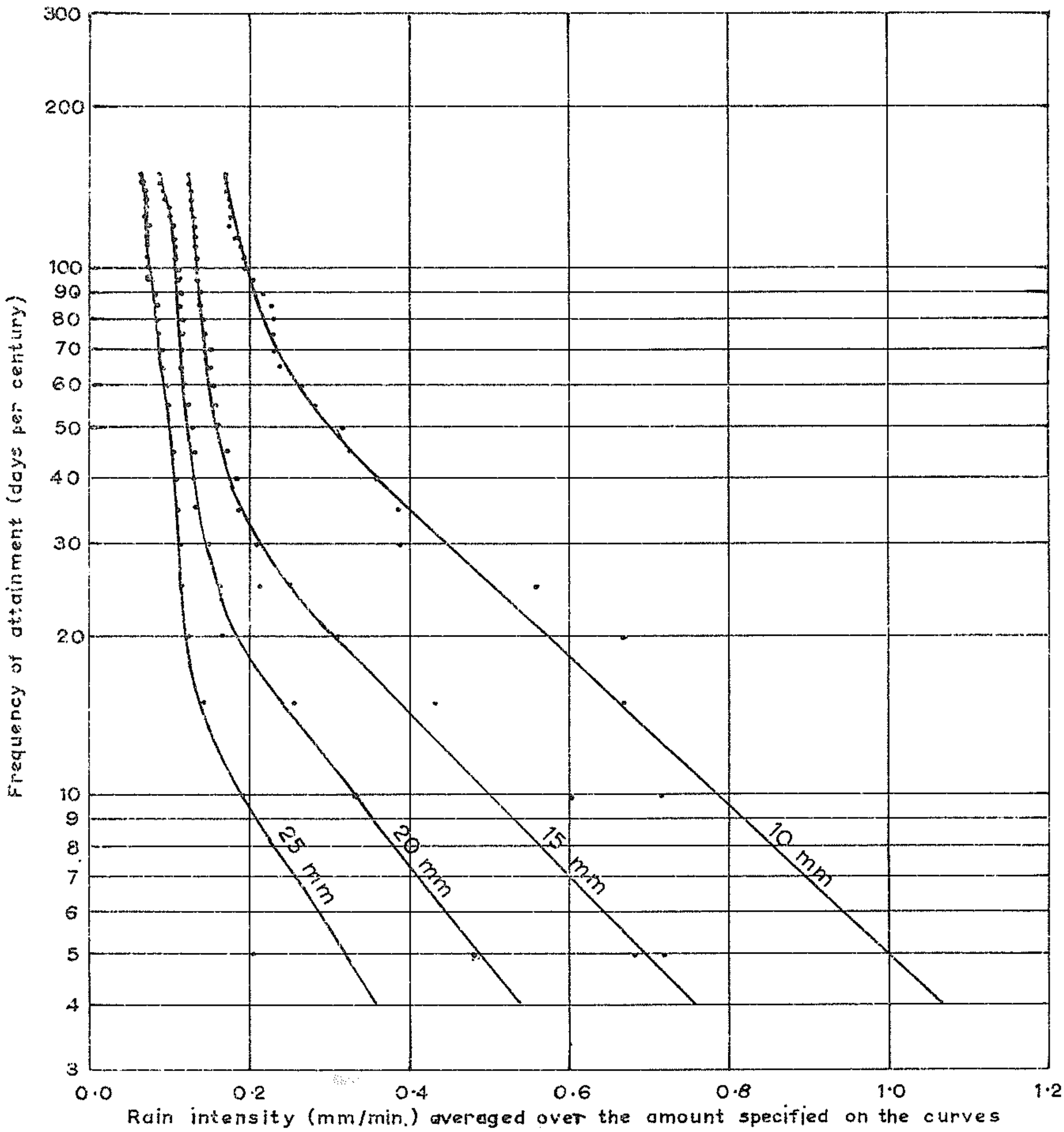

Fig. 4. Rain intensity-amount-frequency curves for Valentia Observatory based on data for the period 1950 - 1969.

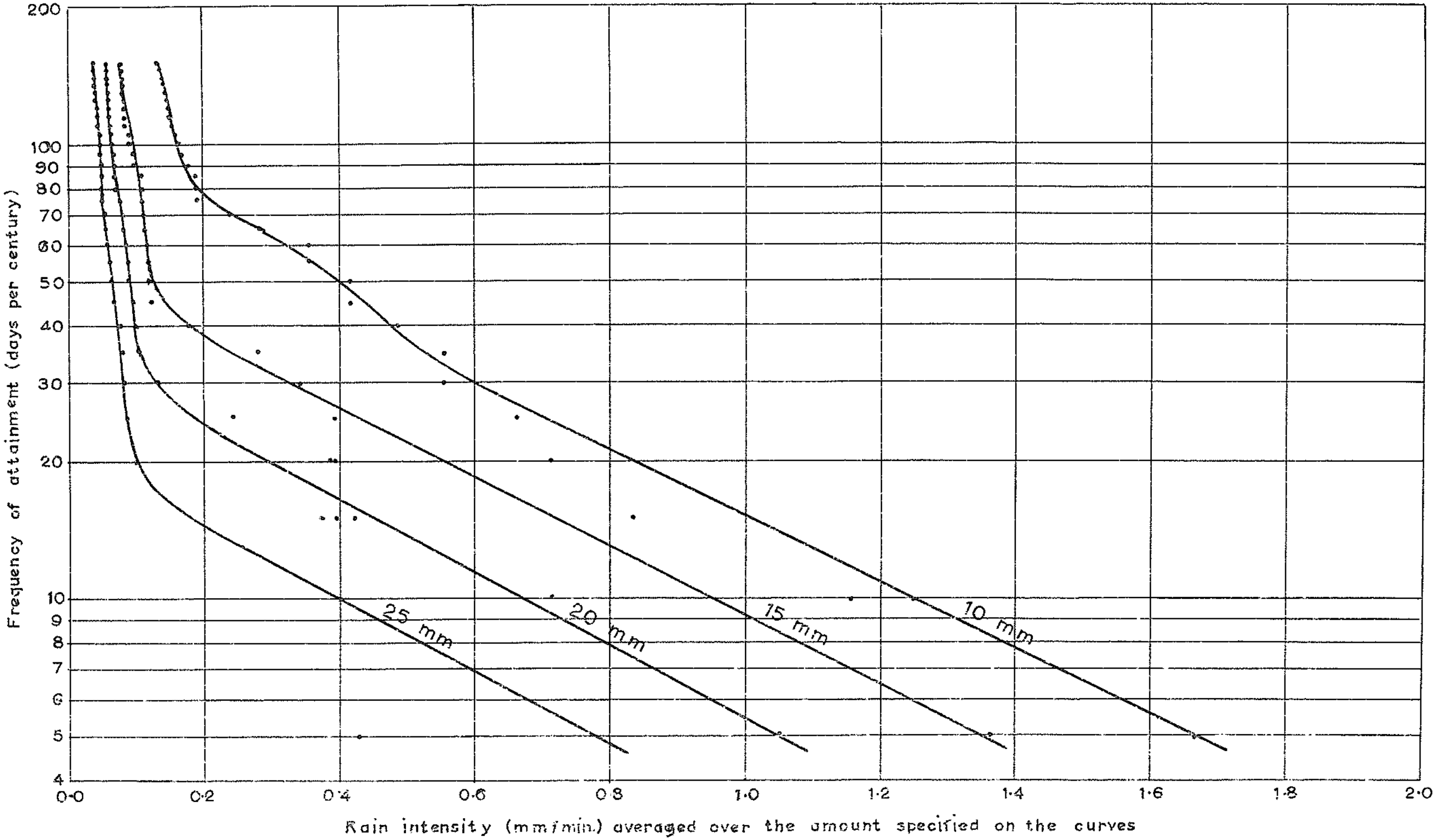

Fig. 5. Rain intensity-amount-frequency curves for Dublin Airport based on data for the period 1950 - 1969.

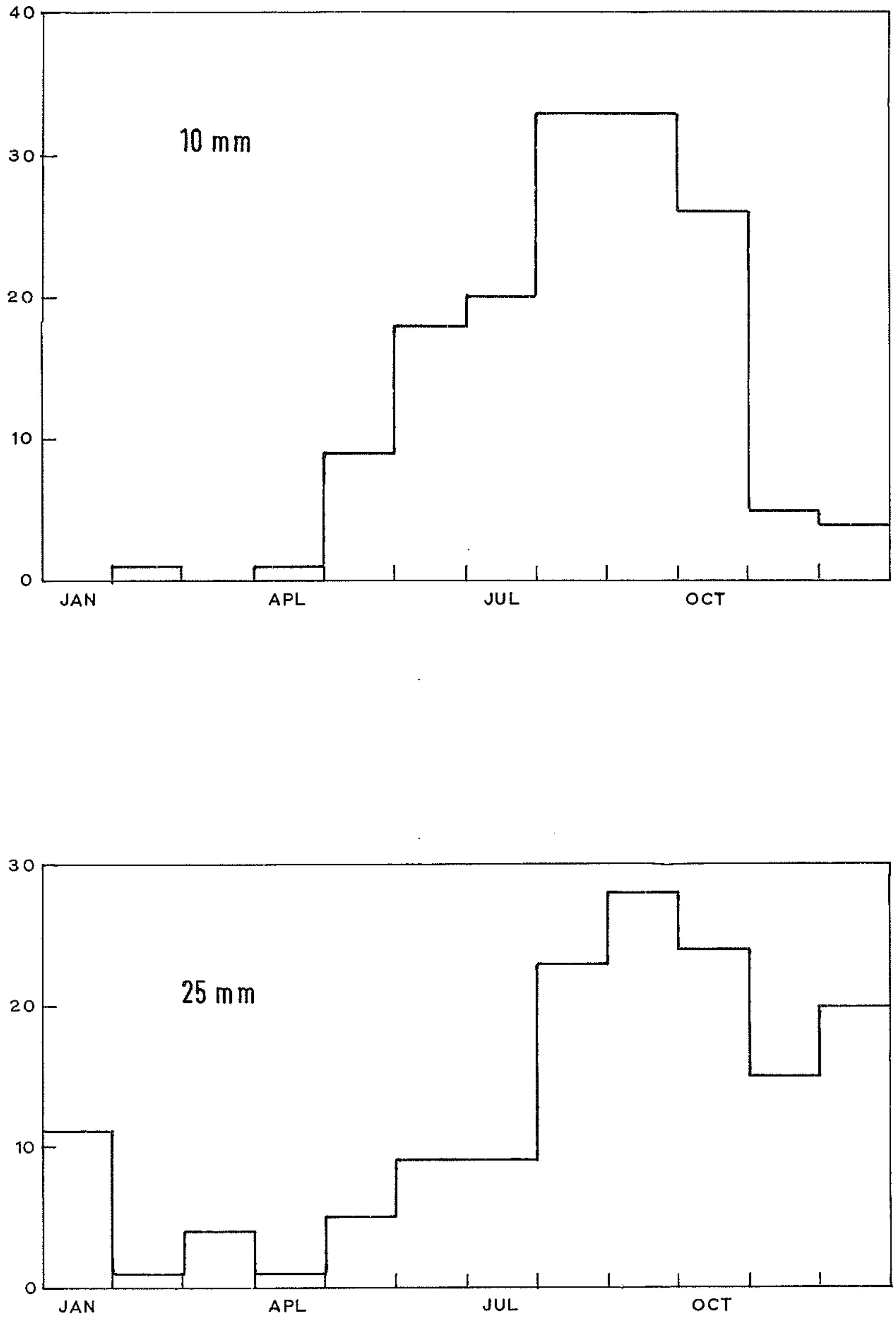

Fig. 6. Distribution by months of the 30 highest rain intensities averaged over 10 mm and 25 mm amounts, for 5 stations.