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EXTREME RAINFALLS IN IRELAND

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Summary: The records of 330 daily rainfall stations and 12 rain recorder stations for the period 1941-70 have been analysed. Maps and tables have been prepared which enable extreme rainfall amounts with durations ranging from 15 minutes to 30 days and with return periods up to 50 years to be estimated for any location in Ireland.

Introduction

Information on the frequency of heavy rainfalls is often required by engineers, architects and others, usually in connection with design criteria for water management or drainage schemes. 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 likely to be exceeded only once in a specified number of years (the return period). The longer the return period, the greater is the magnitude of the rainfall for which allowance must be made. The duration of the rainfall which is of interest depends on the characteristics of the catchment of the system in question and, generally speaking, increases with the catchment area. In the case of the drainage of a small area, for example a car park, rainfall of a few minutes duration may be critical for the production of floods whereas, in the case of a large river, the duration of importance may be several days. Another important point is that, whereas rainfall is measured at discrete points, the quantity of interest to the engineer is the average rainfall over the area in question. The relationship between point and areal rainfall is outside the scope of this study which is concerned solely with point rainfall.

Bilham (1935) developed a relationship between the depth, duration and frequency of heavy rainfalls which has been widely applied, both in Britain and in Ireland. Bilham's relationship was based on data from 12 English and Welsh stations with average annual rainfall less than 35 inches (889 mm) for the 10 year period 1925-34. In its derivation, only falls of 1 inch (25 mm) or less were considered and its range of applicability is consequently limited. In Ireland, Dillon (1954) studied rainfall records for University College Cork for the period 1914-48 and derived a relationship valid for durations of between 10 minutes and 24 hours in areas having the same general rainfall characteristics as Cork. The frequency distribution of the annual maximum rainfall of 1-day duration has been studied by Morgan (1953) for 16 Irish stations. Logue (1971) developed intensity –amount- frequency relationships based on data from a number of stations for the period 1950-69. These results are limited to falls of between 10 mm and 25 mm and to correspondingly short durations.

The present study is based on data from 12 rain recorder stations and over 300 daily rainfall stations having records ranging from 15 to 30 years in length. The range of durations considered is from 15 minutes to 30 days. Most of the data were originally prepared in connection with a Flood Studies Programme undertaken by the British Meteorological Office and the British Institute of Hydrology in which the Irish Office of Public Works and the Meteorological Service also participated (Jenkinson et al. 1975).

Statistics of extremes

Information on the frequency of extreme values of any physical parameter such as rainfall, wind, speed temperature etc. may be obtained by considering series of historical extremes over a number of years. A series consisting of all observations exceeding a certain base value is referred to as a partial series. A series consisting of the highest value in each year is known as an annual series. The annual series suffers from the limitation that the second highest value in a particular year is not counted even though it may be higher than the maximum in other years. However, this disadvantage is outweighed by the fact that it is more suitable for theoretical statistical analysis than the partial series.

The return period associated with a particular value X, say, is the average interval in years between events which equal or exceed X. In the annual series, the return period (denoted by T) must be greater than or equal to one year. The partial series return period (denoted by T') may be less than one and is equal to the inverse of the average frequency with which X is exceeded, expressed in years $^{-1}$. A relation ship exists giving T' in terms of T. T' is always less than T but for return periods exceeding 10 years the difference is inconsequential (WMO 1970).

Consider an annual series of N values $X_1, X_2, X_3, \ldots\ldots X_N$ arranged in order of magnitude so that X_1 is the lowest annual maximum, X_2 the second lowest and so on. Then it is usual to display the series by plotting X against the "reduced variate" y where

$$y = -\ln \ln [T/(T-1)]$$

The reason for the choice of y is that, if the series follows the Type 1 or Gumbel distribution of extreme values (Gumbel 1954), the graph of X against y is a straight line. In order to plot the values it is necessary to assign a return period to each of the X's. A commonly used formula is that due to Chegodayev (1953) which gives T_m, the return period associated with the m^{th} member of the series by

$$(T_m - 1)/T_m = (m - 0.31)/(N + 0.38)$$

Annual series of heavy rainfall values do not in general fall in straight lines on the extreme value plot and hence do not fit the Gumbel distribution. However, Jenkinson (1975) has shown that an excellent summary of such a series may be made without assuming anything about the type of statistical distribution it follows. The ordered data are dived into quartiles and the mean value of X for each quartile is obtained. The highest value in the series is also noted. Thus a series consisting of, say, 30 values is summarised by 5 values and hence the handling of data from a large number of stations is greatly simplified. Jenkinson (1975) has computed the appropriate values of y for the four quartile means, assuming that each quartile lies in a straight line on the extreme value plot. The y values vary with N, the number of values in the series but over the range of N used in this study (15 to 30 approx.) the variation is small.

Following Jenkinson's notation, let the four quartile means be QM1, QM2, QM3 and QM4. Then it turns out that QM1 is approximately equal to the value 2M which occurs twice a year in the partial series, QM2 is very close to the value M10 which occurs once in 10 years in the annual series. Furthermore, the mean of QM2 and QM3 is very close to M2, the value occurring once in two years in the annual series and the mean of QM3 and QM4 is very close to M5, the value occurring once in five years in the annual series. These approximate relationships are summarised in the following table:

Quartile Mean	T'	T
QM1	½	-
QM2	1	-
½(QM2 + QM3)	-	2
½(QM3 + QM4)	-	5
QM4	-	10

Thus by a very simple calculation it is possible to obtain values of X for a number of important return periods.

From an annual series of, say, 30 years for a single station, values of X with return periods of up to 10 years may be determined reasonably accurately as described above. However, a sample of 30 values cannot be expected to give reliable estimates of X for longer return periods. Due to the random nature of the events, a 30-year sample may, for example, contain two or three values having a true return period of 30 years or, on the other hand, it may contain no such value.

In order to obtain reliable values of X for the longer return periods, it is necessary to analyse data from a number of stations having similar characteristics and located in the same climatic region and to average the results in some way. For example, consider the highest in an annual series of 30 values. Its estimated return period, obtained by putting $m = N = 30$ in Equation (2), is 44 years, but this is an unreliable estimate. Suppose however that we have 10 similar stations each with 30 years of record. Then if we take the highest value from each station and calculate the median of these ten values, the median may be with a much higher degree of confidence be allocated a return period of 44 years.

Description of data

Daily rainfall is measured using a standard raingauge of diameter 12.7 cm, with its receiving surface 0.3 m above ground level and is normally read at 0900 GMT.

330 daily rainfall stations were chosen for length and reliability of record and so as to give an even coverage of the country. Data for the period 1941-70 only were considered and most of the stations used had records of between 25 and 30 years in that period. However it was necessary to use some stations with records of between 15 and 25 years because of the lack of long-period stations in certain areas. Daily values of rainfall for all stations were punched on Hollerith cards, quality controlled and written to magnetic tape.

Continuous records of rainfall were obtained from 12 stations equipped with rain recorders of the Dines Tilting Syphon type. The records varied from 16 to 35 years in length. Values of maximum rainfall amount for various durations from 15 minutes to 24 hours were tabulated and were adjusted by reference to the raingauge readings made at the terminal hours 0600, 1200, 1800 and 2400 GMT. Owing to limitations of the equipment and to the small time scale of the records, it is difficult to estimate amounts of less than 15 minutes with sufficient accuracy and this was not attempted.

Outline of procedure adopted

Following Jenkinson (1975), the value with a return period of five years (denoted by M5) is chosen as a basic parameter in the extreme value distribution. The reason for the choice of M5 is that it may be determined fairly accurately from the annual series for one station by taking the mean of the two upper quartiles i.e. the mean of the top half of the series. It is less stable than M2, the mean of the two middle quartiles, but is preferred because it is nearer the high return period end of the distribution.

M5 is determined for all stations for durations of 60 minutes, 2 calendar days and one calendar month and maps of these quantities, denoted respectively by M5(60 min), M5(2d) and M5(CM), are drawn. In the case of M5(60 min) there are not enough stations to enable the map to be drawn directly and it is necessary to develop a relationship linking M5(60 min) with M5(2d) and thunderstorm frequencies. Extreme rainfalls with short durations are frequently associated with thunderstorms.

These three maps span most of the range of durations that are of practical interest. They also span a range of characteristic weather systems associated with heavy falls of different durations. Extreme falls with durations of 60 minutes or less are usually caused by individual thunderstorms or convective systems of small horizontal dimension which may however be embedded in larger rain-producing systems. In the one-day or two-day duration range, heavy falls are often associated with individual extratropical cyclones or frontal systems affecting large areas of the country. High monthly totals are associated with whole families of cyclones or frontal systems.

A two-day rather than a one-day duration was chosen for the second of the three maps because of the fact that the typical cyclonic rainfall with the duration of the order of one day is frequently divided into two less significant daily fall by the 0900 gauge reading.

Heavy falls with durations other than 60 minutes, two days and one month are investigated for a selection of stations, and linking relationships are developed which enable M5 for any duration from 15 minutes to 30 days to be determined. Finally, using the same selection of stations, other relationships are developed giving rainfall with return periods of up to 50 years as proportions of M5.

Preparation of maps of M5 (2d) and M5 (CM)

Daily rainfall data for 330 stations were available on magnetic tape. A computer program was written which enabled the maximum rainfall in any number of consecutive from one to 30 to be extracted for each year of record for any station. The annual maxima could also be sorted into order of magnitude and the amount and date of occurrence of each printed out. Allowance was made for maximum falls overlapping the beginning or end of the year. For example, a large eight-day commencing on 27th December, 1963 could be counted as the maximum eight-day total in 1963 provided more than half the amount fell in the five days 27th – 31st. If more than half fell in the period 1st – 3rd January, then the eight-day total would be counted as occurring in 1964.

For each of the 330 stations, the program was used to print out an ordered series of annual maximum two-day falls. In the case of some stations, the program was unable to identify the maximum fall in certain years because of missing or combined daily readings. In these cases the original records were re-examined, but for around 4% of the station years of record it was still impossible to determine the maximum fall. These station years were eliminated from the subsequent calculations.

M5(2d) was then calculated for each station by taking the geometric mean of the top half of the ordered series. The geometric mean was used because rainfall increases proportionately rather than additively, a fact which is consistent with the usual practice of expressing rainfall as a percentage of average rather than giving its difference from average. Taking the geometric mean is equivalent to using the log of rainfall amount rather than the amount itself and in fact it is found that annual series of log R lie closer to a straight line on the extreme value plot than annual series of R, especially for the longer return periods.

The value of M592d) obtained for each station was also expressed as a percentage of the annual average rainfall (AAR) at the station. Maps of M5(2d) expressed both directly and as a percentage of AAR were then plotted and drawn up (Figs. 2 and 3). The distribution of AAR is shown in Fig. 1. The maps were originally prepared on a scale of 1:625,000 and a small degree of smoothing of the plotted values was employed in drawing them. The drawing over the northern part of the country was agreed with the British Meteorological Office. This also applies to Figs. 4 and 5 (see below).

From Figs 1, 2 and 3, it may be seen that the distribution of M5(2d) resembles that of AAR in that it shows high values in mountainous areas and lower values in the plains. However, the range of variation is relatively less. The ratio of the highest to the lowest value of AAR shown on the map is approximately 4.6 whereas the corresponding ratio for M5(2d) is about 2.8. This is also illustrated by the fact that the value of M5(2d) expressed as a percentage of AAR is, generally speaking, low in mountainous areas and high in low-lying areas. The physical reason for this lessening of the orographic effect in the case of extreme as compared to average rainfall is that heavy rainfalls with durations of the order of a day are usually caused by vigorous weather systems which are capable by themselves are capable by themselves of producing strong uplift in the atmosphere and are thus less dependant on orographically produced uplift.

Another point which may be noted from Fig. 3 is that M5(2d) expressed as a percentage of AAR is generally higher near the south and east coasts than in other regions. To understand the possible reason for this, it is necessary to consider the movement of extra-tropical cyclones in the vicinity of Ireland. Most commonly, these cyclones pass to the northwest of Ireland and their associated fronts cross the country, usually giving more rain in the west and northwest than in the east and south. This is why the average annual rainfall shows a general decrease from west to east. Occasionally however, cyclones pass close to the southeast of the country and in these cases rainfall near the south and east coasts may be as heavy or even heavier than any which may be experienced with a similar frequency in the west. Thus the relatively high values of the ratio M5(2d)/AAR in the south and east are due to the relatively low values of AAR combined with the fact that the more extreme rainfalls in these areas are just as heavy as those experienced elsewhere.

It may also be noted that the lowest values in Fig. 3 occur in the midlands, indicating that the proximity to the sea may be an important factor in the occurrence of heavy rainfalls of the duration being considered.

Ordered annual series of maximum rainfall in a calendar month were extracted and printed by computer for each station, and values of M5(CM) were calculated in a similar manner as in the case of M5(2d). A map of M5(CM) expressed as a percentage of AAR was drawn up (Fig. 4).

Fig. 4 is similar to Fig. 3 in that it shows high values along the south and east coasts and low values in the midlands, but differs from it in that the pattern of the isopleths is unaffected by the presence of mountain ranges. This means that the orographic increase of rainfall with elevation is of the same relative magnitude for maximum monthly rainfall as for average annual rainfall.

The pattern of the isopleths of Fig. 4 is relatively simple and unrelated to that of AAR (Fig. 1). In fact, the correlation coefficient of log AAR with P, where P=100. M5(CM)/AAR, based on data from 52 selected stations, is –0.08 i.e. virtually zero. This suggests that it might be useful to treat P as a fundamental independent variable in the study of extreme rainfalls in longer duration range. The map of M5 (2d)/AAR (Fig.3) appears to combine some of the features of Fig 4 with the orographic pattern of Fig.1. It is possible to derive a relationship giving M5 (2d)/AAR in terms of P and AAR and thereby to prepare a map of calculated M5 (2d)/ AAR which shows most of the features of Fig.3. However, the relationship does not give M5 (2d)/AAR with sufficient accuracy to be used in practice.

<u>Preparation of map of M5(60min)</u>

Values of annual maximum one-hour rainfall were available for 12 stations with records varying from 17 to 35 years in length. These values were maxima over any 60-minute period rather than over fixed clock hours and for that reason are henceforward referred to as "60- minute" rather than "one-hour" falls.

The number of stations was too small to permit the map of M5 (60min) to be drawn directly from the station values. Instead, it was necessary to seek a relationship between M5 (60min) and other quantities, which could be easily evaluated at a large number of locations. The quantities chosen were M5 (2d) and the average number of days with thunder during the months May to September (denoted by T). Winter thunderstorms were disregarded because they are rarely associated with extreme short-duration rainfalls, most of which occur during the summer months. The distribution of T is shown in Fig.5.

The relationship actually developed was one relating M2 (60 min), M2 (2d) and T. The mean of the two middle quartiles of the annual series (M2) is more stable than M5 and, because of the small number of stations and the large random variability characteristics of extreme rainfalls, it was necessary to use the most stable parameters available. Linear regression of log M2(60min) on log M2 (2d) and T for 12 sets of values gave:

$$\text{Log M2 (60min)} = 0.373 \log \text{M2 (2d)} + 0.0169T + 0.385 \qquad (3)$$

The partial correlation coefficients of log M2 (60min) with log M2 (2d) and with T were +0.53 and +0.52 respectively. The correlations are not quite significant at the 5% level but/ because of their agreement with what would be expected on physical grounds, they were accepted.

Values of M5 (60min) were calculated and plotted at a large number of grid points on a map of Ireland. To do this, values of M5 (2d) and T were obtained from figs. 2 and 5 respectively. M2 (2d) was obtained from M5 (2d) using Table IV (see below for the derivation of this table) Equation (4) was then applied to given M2 (60min) and finally M5 (60min) was obtained, using Table IV. Isopleths of M5 (60min) were drawn on the map (fig.6).

The chief characteristics of the distribution of M5 (60min) are its relative uniformity over the country. The highest values are still between these and the values, in other areas is much smaller than in the case of M5 (2d). This partially explains why the correlation coefficients associated with equation (3) are so small

Since the true variation inM5 (60min) from station to station is small, random variations assumes a greater relative importance.

Derivation of M5 for intermediate duration's

Of the 330 daily rainfall stations, 52 were chosen for more detailed analysis. For each one of these, annual series of four-day, eight-day and sixteen-day maximum rainfalls were printed by computer and M5 values were calculated in the same manner in which M5 (2d) and M5 (CM) had previously been calculated.

It is necessary to bear in mind that these various M5 values refer to fixed numbers of calendar days beginning at 0900 GMT and not to intervals of the same duration beginning at an arbitrary time. The M5 values for two, four, and eight calendar days are denoted by M5 (2d), M5 (4d) and the M5 values for the corresponding arbitrary intervals by M5 (48h), M5 (96h) and M5 (192). By considering data for stations recording hourly rainfall, Jenkinson (1975) found the following relationships:

M5 (48h)	=	1.06 M5 (2d)	(4)
M5 (96h)	=	1.03 M5 (4d)	(5)
M5 (192h)	=	1.015 M5 (8d)	(6)

Since 48-hour, 96-hour and 192-hour rainfalls were not readily available for Irish stations, it was not possible to check that the above equations are valid for Ireland. However, in view of the similarity of climatic conditions, it is reasonable to assume that they are.

In order to derive the relationship between M5 (30d0 and M5 (CM), 30-dayM5 values were calculated for 10 selected stations and were compared with calendar month M5 values for the same stations. It was found that

M5 (30d)	=	M5 (CM)	(7)

Also by considering values of M5 (23d), M5 (25d) and M5 (27d) for the same stations, it was found that

M5 (25d)	=	M5 (CM)	(8)

The latter relationship was also found by Jenkinson (1975) to apply in Britain.

From the maps of M5 (2d), M5 (CM)/AAR and AAR (Figs. 2,4, and 1) using equations (4), (7), and (8), it is possible to derive M5 for duration's of 48 hours, 25 days, and 30 days. In order to find means of obtaining M5 for intermediate duration's, the values of M5 (4d), M5 (8d), and M5 (16d), already obtained for 52 stations, were examined in detail. Taking the case of M5 (8d) as an example, it was found that that the ratio M5 (8d)/ M5 (2d) varied from station to station and in general. Increased with AAR. However the expression K8 = [log M5 (8d) – log M5 (2d)] / [log m5 (CM) – log M5 (2d)] was found to be independent of AAR, and for practical purposes it may be regarded as a constant, subject only to random variations from station to station. An estimate of the median value of K8 was obtained from the individual values for the 52 stations by taking the mean of the two middle quartiles. The ratio M5 (8d) / M5 (2d) was then calculated for various values of M5 (CM) / M5 (2d), and M5 (192h) / M5 (2d) was obtained by applying equation (6). The same procedure was applied to obtain values of M5 (96h) / M5 (2d). Table 1 gives each of these ratio as a function of M5 (CM) / M5 (2d).

In order to derive M5 values for duration of between 15 minutes and 24 hours, annual maximum rainfalls with duration's of 15 minutes and 30 minutes and two, four, six, and 24 hours were tabulated from the records of the 12 rain-recorder stations and M5 values were calculated. The M5 values for two hours, four hours, and six hours, are denoted M5 (120min), M5 (240min), and M5 (360min) to distinguish them from clock-hour values. By means of a procedure similar to that applies to the longer duration values, the ratios M5 (15min) / M5 (2d), M5 (30min) / M5 (2d) etc. were calculated for various values of the ratio M5 (60min) / M5 (2d). The results are given in Table 11.

If M5 is required for duration falling between two of those specified in Tables 1 or 11, it may be obtained by linear interpolation on a graph of log M5 against log (duration).

Heavy rainfalls with return periods other than five years

Annual series of one-day, two-day, four-day, eight-day, and calendar month maximum rainfall were available for each of the 52 selected daily rainfall stations. In addition, annual series of 15-minute, 60 minute, four-hour and 24-hour rainfall were available for 12 rain-recorder stations. In the case of the case of each of these series, the geometric means of the four quartiles, QM1, QM2, QM3, QM4, were calculated and the highest value, H1, was noted. M5 which is equal to the geometric mean of QM3 and QM4, and M2, the geometric mean of QM2 and QM3, were also calculated.

For any particular station, the set of values thus calculated (i.e. QM1, QM2, QM3, QM4, H1, M2 and M5) may be plotted against the appropriate values of the reduced variate y on a graph of log (rainfall) versus y (cf the section on "statistics of extremes"). The curve obtained by joining the plotted points is, following Jenkinson (1975), known as a "growth curve". It is also useful to express the above set of values as proportions of M5 and in this form they are know as "growth factors".

Because of sampling errors, the growth curves for different stations vary considerably in slope and shape. However, if growth curves for a large number of stations are combined, a characteristic shape emerges. In Fig. 7 the combined curves for all selected stations for durations of one, two, four and eight calendar days and one calendar month are shown. The method of combining them was as follows. The median value of each of the "growth factors" QM1/M5, QM2/M5, Qm3/M5, and M2/M5 was obtained by taking the geometric mean of the middle quartiles of the ordered station values. The highest value in the series, H1, was treated somewhat differently. The median value of H1/M2 was obtained and multiplied by the median M2/M5. This gives a more stable value of H1/M5 than direct calculation of median H1/M5. This gives a more stable value of H2/M5 than direct calculation of median H1/M5 (Jenkinson 1975). The growth curve was then obtained by multiplying the median growth factors by median M5 and plotting the resultant values.

It may be seen from Fig.7. that, although the average slope of the growth curves decreases towards toward longer durations their general shape is similar for all durations. At the lower values of y, the curves are concave downwards but as y increases they tend towards straight lines. This is also true of the growth curves for durations of 15 mins. one hour and four hours, although these curves are less stable on account of the small number of rain recorder stations. If a straight line is drawn, joining the M2 and M5 points, the it is found that the deviations of the other points from the line do not vary systematically between curves for different durations, and it is possible to calculate mean values of the deviations. Accordingly if M5 and the difference log M5 – log M2 are known for any growth curve, then the curve is specified completely. This fact has been used in preparing Table III, which gives rainfalls of various periods as proportions of M5 for various various values of the ratio M5/ M2.

It was now necessary to find relationships between M5/M2 and one or more quantities which, could be readily evaluated at any location. It was found that the most important quantity explaining the variation of M5/M2 was the duration of the rainfall in questions. M5/M2 is high for rainfall of short duration and low for rainfall of long duration. For any given duration however, M5/M2 varies from station to station, being high where the average annual rainfall (AAR) is low and low where AAR is high. The variation with AAR is most important for short-duration rainfall: in the case of 16-day and 30-daynfalls if is relatively small. Finally for the duration s exceeding four days, M5/M2 increases with P, where P = 100.M5 (CM) /AAR is the quality mapped in Fig.4.

The log of M5/M2 corresponds roughly to the average slope of the growth curve on the extreme value plot and is a measure of the variability of the annual maximum rainfall. It is natural to expect that it should vary with the duration of the rainfall, since maximum rainfalls of different durations are associated with different types of meteorological system. Also, maximum falls of long duration usually comprise rainfall from a number of different meteorological events and thus some of the variability associated with individual events is averaged out. Therefore on would expect that M5/M2 would be lower for falls of long duration than for those of short duration, and this is in fact the case. It is also east to understand why M5/M2 should decrease with increasing AAR. In mountainous areas where AAR is relatively high, as may be seen from Figs.2, 4, and 6. However the most extreme rainfalls, with long return periods are less affected by orography. This means that, for a particular duration, the difference between the growth curve for a mountainous location and that for a low-lying location is larger at low values of y (or t) that at high values, and hence the growth curve for the mountainous (high AAR) location has the lower average slope. The increase of M5/M2 with P for long duration falls may be understood if one, considers that the magnitude of long duration falls with short return periods must be closely related to average annual rainfall since they contribute a considerable fraction of it P, on the other hand, is an indication of the degree to which the falls of longer return period deviate from the pattern of AAR.

Jenkinson (1975) found that the growth curves could be completely specified in terms of one parameter only, viz. M5. There is, of course, a positive correlation between M5 and the duration of the rainfall and, for durations of 60 minutes and upwards, M5 is also positively correlated with AAR. Thus the variation of the characteristics of the growth curve curves with M5 is consistent with their variation with duration and AAR. However, in the case of the group of stations considered here, it is clear that the primary variation is with duration and AAR and that variation with M5 is merely a consequence of this. For example, the correlation coefficient based on 52 sets of values, between a measure of the slope of the growth curves and log AAR was –0.55 for eight-day falls and –0.37 for one-day falls. The corresponding correlations between the slope and the log M5 were only –0.33 and – 0.02 respectively. Incidentally, the low values of all these correlations coefficients illustrate the large random variability of the slope of the growth curves.

In Tables IV A and IV B, the ratio M5/M2 is given as a function of duration, AAR and P. These tables were prepared as follows. The mean values over all stations of log (M5/M2); log AAR and P were obtained for each duration. The rate of chance of log (M5/M2) with log AAR was then obtained by regression, for each of the duration 15 mins. , 60 min., 240 mins. , one, four, and eight calendar days and one calendar month. This rate of change was plotted against and was found to decrease as the duration increased. Use was made of this fact to effect some smoothing of the rates of change. The amount of soothing was rather small in the case for the lowest duarations which were based on the data from the small number of rain recorder stations and were consequently somewhat unstable required to be smoothed to a greater extent. The rate of change of log (M5/M2) with log AAR for all required durations could then be read from the, smoothed curve. A similar procedure was applied to give the rates of increase of log (M5/M2) with P for of eight, 16, and 30 days. Finally, making use of the mean values and the rates of change, values of M5/M2 were calculated for various values of duration, AAR and P.(Tables IV A and IV B)

Rainfalls with very long return periods

Jenkinson (1975) has shown how extreme rainfalls events with very long return periods may be estimated by combining sets of annual maxima foe stations with similar characteristics into a single set. However this procedure is based on the assumption, that the annual maximum events are independent, an assumption which does not appear to be valid under Irish condition. Of approximately 300 stations with records covering the periods 1949-70, no less than 62 recorded their highest two-day total on 31st October/ 1st November 1968 and 92 recorded their highest monthly total in December 1959. This non-independence of extreme rainfall events at different stations is a result of the fact that those with durations of a few hours or more are usually caused by synoptic scale cyclones or families of cyclones affecting the whole country or large regions of it. Heavy falls with durations of an hour or less show a higher degree of independence since they are normally associated with showers of small horizontal extent. However, individual showers occurring on the same day are not completely independent, since their intensity is related to vertical instability in the atmosphere, which may occur on a wide scale. As an example, annual maximum 60-minute falls were examined at two typical rain-recorder stations, each with 29 years of record, situated about 70 kilometres apart. It was found that, in two of the years, the annual maximum fall had occurred on the same date at each station, In four other years, the maximum falls had occurred within three days of each other, presumably because a weather situation favourable to intense convection had persisted over the country for a few days.

It was therefore concluded that, under Irish conditions, no sound basis exixts for the extension of the growth curves to return periods greatly exceeding the length of the station records.

Conclusions

From the maps and tables which have been prepared, it is possible to estimate the magnitude of rainfalls with durations ranging from 15 minutes to 30 days, for return periods up to 50 years, at any location in the country. The maps and tables may be used as follows: M5(60min) and M5(2d) may be obtained from Figs. 6 and 2 respectively and M5(CM) from Figs. 1 and 4. Having calculated the ratios M5(60min)/M5(2d) and M5(CM)/M5(2d), M5 for various durations may be obtained, using Tables 1 and 2. If the required duration falls between two of those specified in either of these tables, M5 may be obtained by linear interpolation on a graph of log M5 against log (duration). Having found M5, the ratio M5/M2 may be obtained from Table 4 and hence values for return periods other than five years may be obtained from Table 3, expressed as proportions of M5.

Those parts of the tables which refer to falls with durations of one day or more are based on data from 52 stations with a wide range of location, elevation and exposure. The parts referring to durations less than a day are based on a data from 12 stations which are well distributed geographically but none of which is at a high elevation or has an average annual rainfall exceeding 1500 mm. The availability of rain recorder data from a larger number of stations will doubtless lead to an increase in accuracy of these parts of the tables. For the moment, they may be considered to be reasonably accurate and should lead to much better results than the use of individual station data.

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Table I. Ratio of M5 for various durations to M5(2d) as a function of M5(CM)/M5(2d)

M5(CM) / M5(2d)	Duration 48h	96h	192h	16d
2.6	1.06	1.26	1.59	2.13
2.8	1.06	1.28	1.65	2.26
3.0	1.06	1.30	1.71	2.39
3.2	1.06	1.32	1.76	2.51
3.4	1.06	1.34	1.82	2.64
3.6	1.06	1.36	1.87	2.76
3.8	1.06	1.38	1.91	2.88
4.0	1.06	1.39	1.96	3.00
4.2	1.06	1.41	2.01	3.12
4.4	1.06	1.43	2.06	3.24

Table II. Ratio of M5 for various durations to M5(2d) as a function of M5(60min)/M5(2d)

M5(60min) / M5(2d)	Duration 15min	30min	120min	240min	360min	12h	24h
0.36	0.232	0.292	0.44	0.55	0.63	0.76	0.89
0.34	0.214	0.273	0.42	0.53	0.61	0.75	0.89
0.32	0.196	0.254	0.40	0.51	0.59	0.74	0.88
0.30	0.179	0.234	0.38	0.49	0.58	0.73	0.88
0.28	0.162	0.216	0.36	0.47	0.56	0.71	0.87
0.26	0.146	0.197	0.34	0.45	0.54	0.70	0.86
0.24	0.130	0.179	0.31	0.43	0.52	0.69	0.85
0.22	0.115	0.161	0.29	0.41	0.50	0.67	0.85
0.20	0.100	0.144	0.27	0.39	0.48	0.65	0.84
0.18	0.086	0.127	0.25	0.36	0.46	0.64	0.83
0.16	0.073	0.110	0.23	0.34	0.43	0.62	0.82
0.14	0.060	0.094	0.20	0.31	0.41	0.59	0.80

Table III. Rainfalls of various return periods expressed as proportions of M5, for stated values of M5/M2

M5/M2	2M/M5	1M/M5	M2/M5	M10/M5	M20/M5	M50/M5
1,42	0,48	0,62	0,70	1,25	1,55	2,03
1,40	0,50	0,63	0,71	1,24	1,52	1,97
1,38	0,51	0,65	0,72	1,23	1,49	1,91
1,36	0,53	0,66	0,74	1,22	1,46	1,85
1,34	0,54	0,67	0,75	1,20	1,43	1,79
1,32	0,56	0,68	0,76	1,19	1,41	1,74
1,30	0,57	0,70	0,77	1,18	1,38	1,68
1,28	0,59	0,71	0,78	1,17	1,35	1,63
1,26	0,61	0,73	0,79	1,16	1,32	1,58
1,24	0,63	0,74	0,81	1,14	1,30	1,52
1,22	0,65	0,76	0,82	1,13	1,27	1,47
1,20	0,67	0,78	0,83	1,12	1,24	1,42
1,18	0,69	0,79	0,85	1,11	1,22	1,37
1,16	0,72	0,81	0,86	1,09	1,19	1,32
1,14	0,74	0,83	0,88	1,08	1,16	1,27
1,12	0,77	0,85	0,89	1,07	1,14	1,23
1,10	0,79	0,87	0,91	1,06	1,11	1,18

Table IV A. The ratio M5/M2 as a function of duration and AAR

Duration	AAR(mm)										
	700	800	900	1000	1100	1200	1400	1600	2000	2400	3000
15 mins.	1.42	1.40	1.38	1.37	1.36	1.35	1.33	1.31	1.28	1.26	1.23
30 mins.	1.41	1.39	1.37	1.36	1.35	1.33	1.32	1.30	1.27	1.25	1.23
60 mins	1.39	1.37	1.36	1.34	1.33	1.32	1.30	1.28	1.26	1.24	1.21
120 mins.	1.36	1.34	1.33	1.32	1.30	1.29	1.28	1.26	1.24	1.22	1.19
240 mins.	1.32	1.30	1.29	1.28	1.27	1.26	1.25	1.23	1.21	1.19	1.17
360 mins.	1.31	1.29	1.28	1.27	1.26	1.25	1.24	1.22	1.20	1.18	1.16
12 hrs.	1.29	1.28	1.27	1.26	1.25	1.24	1.23	1.21	1.19	1.17	1.15
24 hrs.	1.28	1.27	1.26	1.25	1.24	1.23	1.22	1.21	1.18	1.17	1.15
48 hrs.	1.27	1.25	1.25	1.24	1.23	1.22	1.21	1.19	1.18	1.16	1.14
96 hrs.	1.23	1.22	1.21	1.20	1.19	1.18	1.18	1.16	1.15	1.13	1.12

Table IV B. The Ratio M5/M2 as a function of duration, AAR and P

Duration	P(%)	AAR(mm) 700	800	900	1000	1100	1200	1400	1600	2000	2400	3000
192 hrs	16	1.17	1.16	1.15	1.15	1.14	1.13	1.13	1.11	1.10	1.09	1.08
	18	1.19	1.18	1.18	1.17	1.16	1.16	1.15	1.14	1.13	1.11	1.10
	20	1.22	1.21	1.20	1.19	1.19	1.18	1.17	1.16	1.15	1.14	1.12
	22	1.25	1.24	1.23	1.22	1.21	1.21	1.20	1.19	1.17	1.16	1.15
16 days	16	1.14	1.13	1.13	1.12	1.11	1.11	1.10	1.10	1.09	1.08	1.07
	18	1.17	1.16	1.16	1.15	1.15	1.14	1.13	1.13	1.12	1.11	1.10
	20	1.20	1.19	1.19	1.18	1.18	1.17	1.16	1.16	1.15	1.14	1.13
	22	1.23	1.22	1.22	1.21	1.20	1.20	1.19	1.18	1.18	1.17	1.15
30 days	16	1.12	1.11	1.11	1.11	1.11	1.10	1.10	1.10	1.09	1.08	1.08
	18	1.15	1.15	1.14	1.14	1.14	1.13	1.13	1.13	1.12	1.11	1.11
	20	1.18	1.18	1.17	1.17	1.17	1.16	1.16	1.15	1.15	1.14	1.14
	22	1.21	1.21	1.20	1.20	1.20	1.19	1.19	1.18	1.18	1.17	1.17

Fig. 1. Average Annual Rainfall (mm) 1931-1960. (AAR)

Fig. 2. Two - day rainfall (mm) with return period five years.
[M5(2d)]

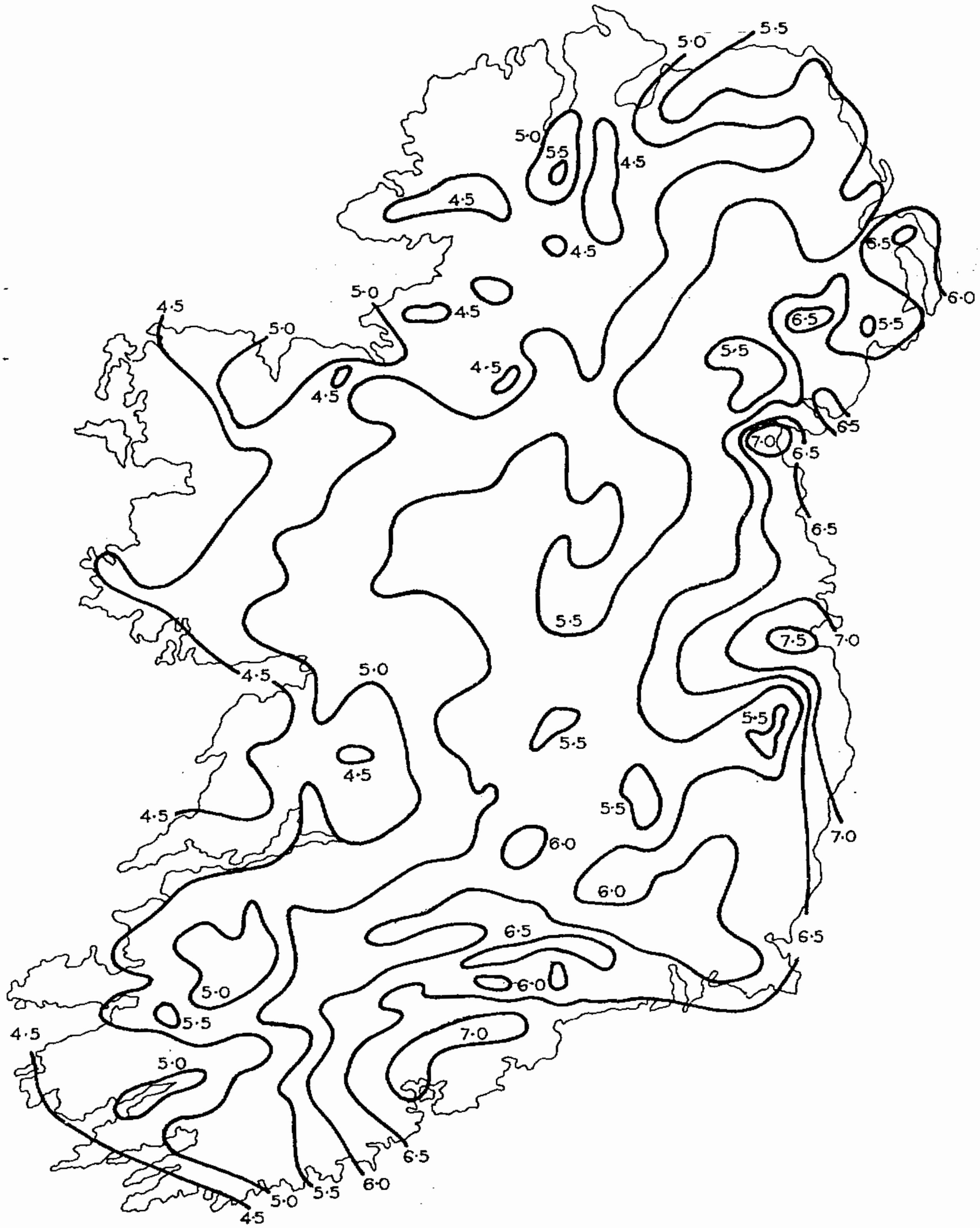

Fig. 3. Two - day rainfall with return period five years expressed as a percentage of average annual rainfall.

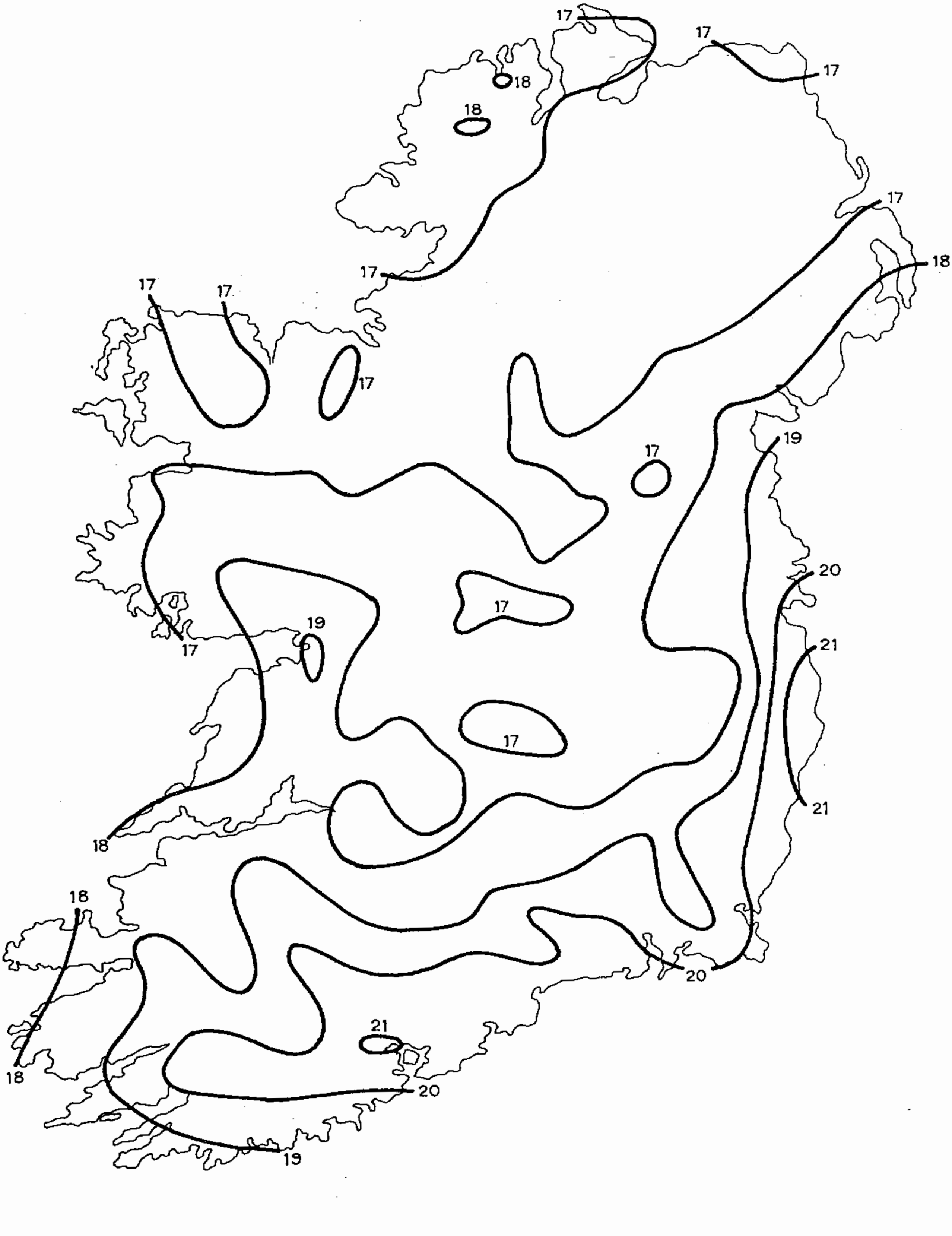

Fig. 4. Calendar month rainfall with return period five years expressed as a percentage of average annual rainfall.

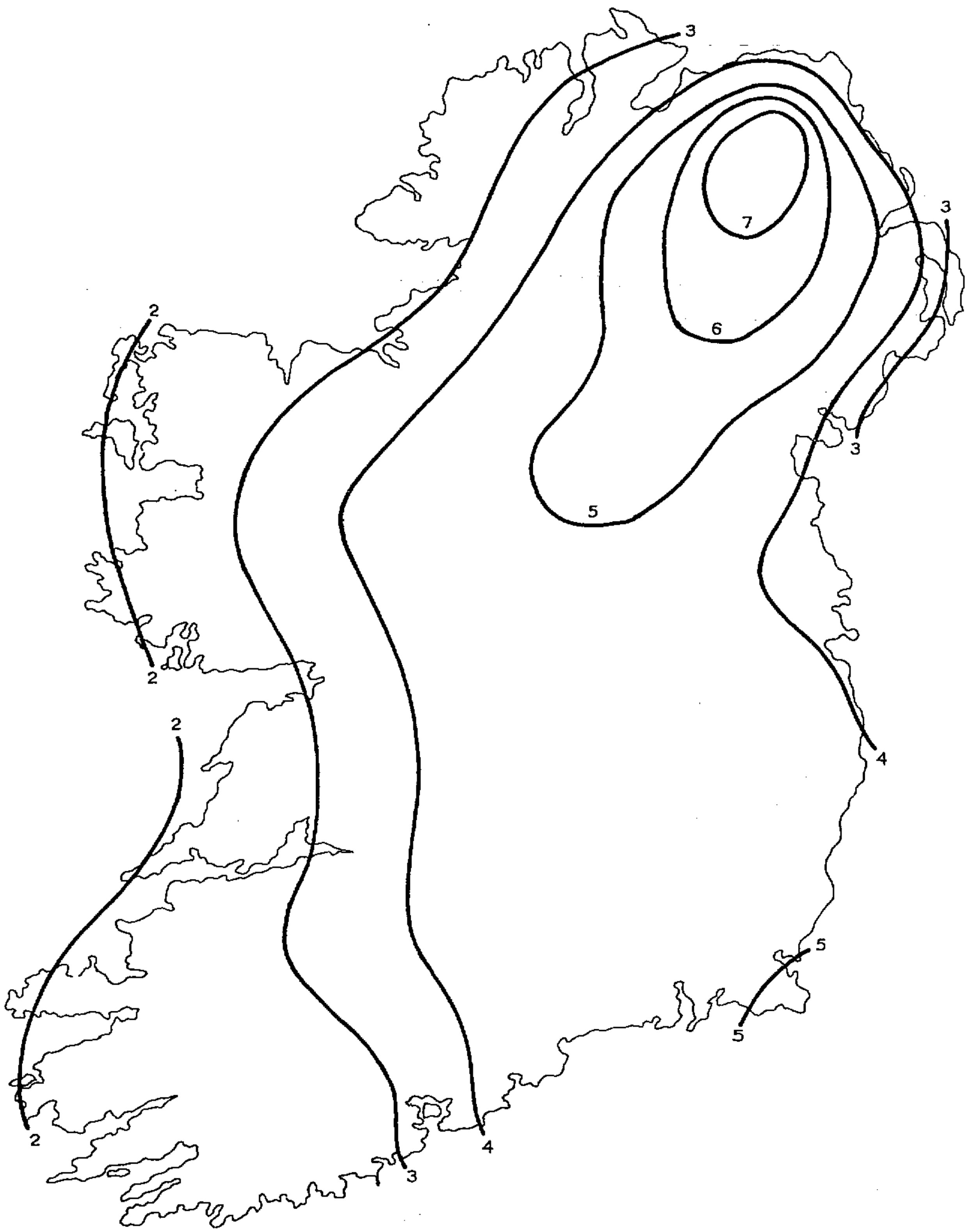

Fig. 5. Average number of days with thunder during the months May – September inclusive, 1958 -1972.

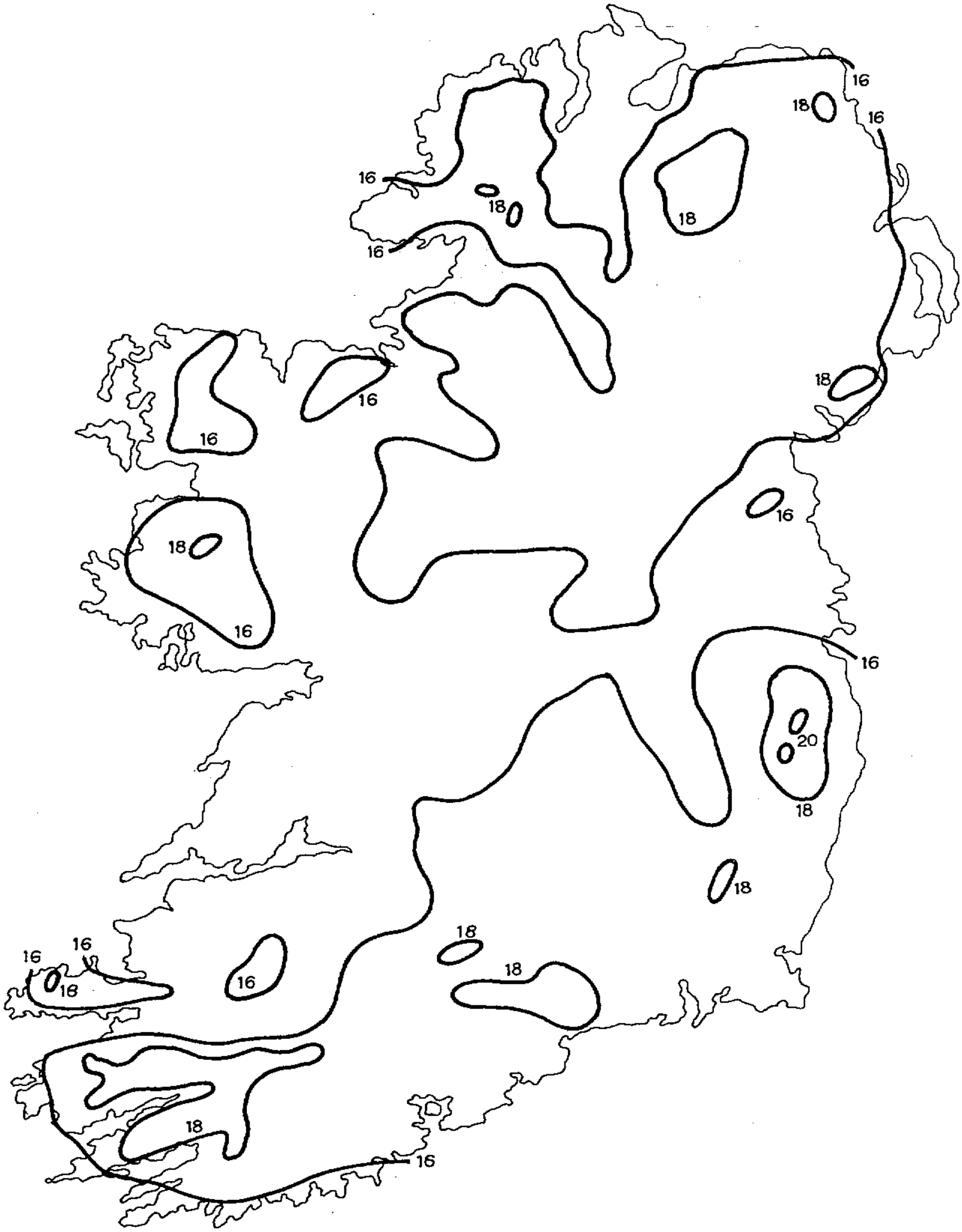

Fig. 6. Sixty minute rainfall (mm) with return period five years.
[M5 (60 min)]

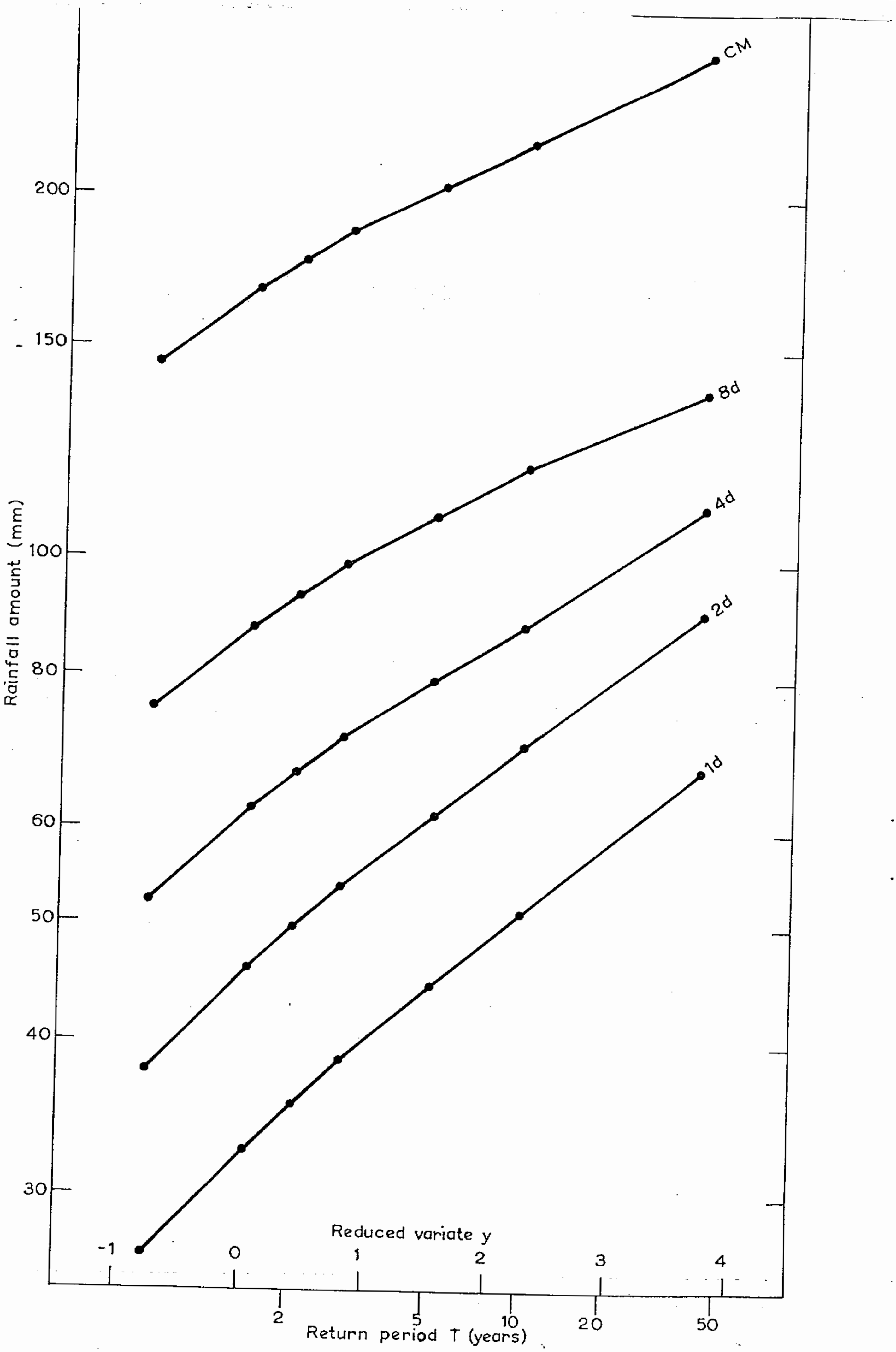

Fig. 7 Median "growth curves" for rainfall of various durations.