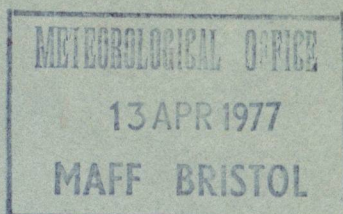


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MONTHLY RAINFALL TOTALS REPRESENTING THE EAST MIDLANDS FOR THE YEARS 1726 TO 1975

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SUMMARY

The problems of producing a homogeneous record of monthly rainfall totals for a limited geographical region, extending from the earliest years of observations up to the present time, are discussed with reference to an area in the East Midlands centred at Pode Hole, near Spalding. Estimates are made of the standard of reliability to be expected from the early data, and monthly totals are given for each of the years 1726 to 1975.

1. INTRODUCTION

This paper sets out to extend the time base of observations suitable for use in the study of regional rainfall. It is intended to be one of several following the same pattern, each of which suggests monthly rainfall totals for a particular region of the British Isles for as long a period of years as the data will support. The East Midlands is the region first considered because four stations in this region, namely Southwick (Oundle), Lyndon, South Kyme and Pode Hole, provide actual observations for all except two of the years 1726 until now. The figures are the best which can be offered at present without embodying corrections which are speculative at this stage, or which depend much on data from stations at a considerable distance. If improvements in statistical method make it clear from observations at distant stations or otherwise that revision is necessary, then the present values can readily be adjusted to include the new evidence.

2. THE 10 YEAR BOOKS AND OTHER SOURCES OF EARLY RAINFALL RECORDS

Ever since G. J. Symons began to collect rainfall records in the 1860s the '10 year books', now kept by the Meteorological Office, have formed the most comprehensive source of information on monthly rainfall in the British Isles. However, as they comprise about 16 000 separate records of which some 6000 are still continuing and total perhaps 250 000 station-years of observations, it is

not always easy to find an individual record when wanted or to estimate the coverage in space and time for a particular area. Hence our first step in seeking to extend recent records back into past centuries was to go through the early volumes of the 10 year books, and to catalogue all records with data for years before 1820. There are about 260 of these for stations in Great Britain, and Table I lists all those for which at least 10 years' annual totals are given or which are important for other reasons. This attempt to provide comprehensive and easy reference to the earliest rainfall records seems to be the first of its kind since one was published by G. J. Symons in 1866 and Table I points to much the most important part of the instrumental evidence on British rainfall in the 1700s which will ever be known. It is included firstly to draw attention to the gaps which exist in the records for particular regions, and secondly to invite any reader who knows of other considerable records for the same period to inform either one of the authors or the Meteorological Office. For the years after 1820 the problem changes from one of finding records of any kind to that of making the best possible use of records known to exist.

Most of the records in the 10 year books before 1820 were known to G. J. Symons and, indeed, appear to have been copied by him, or on his behalf, from the original sources. These are manuscript copies, in copperplate handwriting, on paper of the type used in ledgers. The entries, which include both monthly and annual totals, have been checked for internal consistency. The entries made in Symons's time have been added to at intervals ever since, but there is rarely anything to show the date of any addition or correction, or the name of the person who made it. There is some duplication, since sometimes the same record has been copied twice, by different people working from different source documents, and occasionally it is doubtful which version is to be preferred. Most entries contain some references back to the original sources, and brief notes, also dating back to Symons, on the exposures and construction of the rain-gauges. However, comparisons between these notes and the source documents, in the *Philosophical Transactions of the Royal Society* (1740) for example, show that the figures have been copied with more care than the descriptive notes. The user who works from the 10 year books alone, without reference to the original sources, is liable to lose information recorded in the sources which has never found its way into the Meteorological Office archives.

3. ERRORS IN RAINFALL MEASUREMENTS WHICH MAY BE FOUND IN ANCIENT RECORDS

Table I contains, for each station listed, a comparison between the annual rainfall as reported, averaged over all the years given before 1820, and the estimated 1916-50 average rainfall for the same position, based on the best official maps. It is clear that about half the pre-1820 averages fall below the modern estimates by amounts which cannot possibly be due to climatic change but must be due to defects in the construction or exposures of the ancient instruments. It is therefore useful at this stage to consider the probable nature of these errors.

An extensive bibliography on the measurement of rainfall has been given by Kurtyka (1953). A modern hydrometeorologist inspecting a rainfall station should look for any of nearly 20 sources of error each of which is known to have occurred at least once and which may make the catch as recorded either larger or smaller than it should be. However, most are irrelevant in the present context because of the impossibility of checking the presence of minor faults in

ancient instruments which have long since disappeared. Nevertheless some broad generalizations are justified and useful.

(i) The early observers were mostly scientists, doctors, parsons and country gentlemen who took their scientific activities seriously and who appear to have had the time to treat rain-gauging as a matter of considerable importance. There are no good reasons for believing that they were more prone to making clerical or measuring errors than are the best modern observers. Their letters, preserved for example in the Library of the Royal Society, provide ample evidence of the care they gave to overcoming the instrumental problems of which they knew.

(ii) Of faults leading to an excessive catch, the most important are obvious matters, such as a gauge with a broad brim from which raindrops slide or bounce into the funnel, or a tree overhanging the gauge and dripping into it. It is reasonable to suppose that observers of the calibre of the early pioneers in rain-gauging would not overlook such faults for long.

(iii) Faults leading to a deficiency of catch are the most numerous, and while some are obvious and were avoided from very early years, others are not obvious, or may develop gradually over the years. The modern attitude towards rainfall measurement did not exist in the early 1700s and it is worth while considering the guidance which a prospective observer in those days would have obtained from his predecessors.

The first observer whose records are known is Richard Townley (1694) who gives a graphic description of his rain-gauge. It consisted of a funnel 12 inches in diameter raised above the roof of his country house in Lancashire, with a pipe leading down from it 27 feet vertically before turning in through a window into a container. William Derham (1697) used something similar, since he refers the reader to Townley's article for a description of his apparatus, while Dr James Jurin (1722), although he does not say so at the time, in fact refers to the Royal Society rain-gauge which was on a flat leaded roof. Jurin, as Secretary to the Royal Society, issued an invitation to collaborators to make weather observations according to a common pattern which inspired the pre-1800 observations used here, and most other observers of the early 18th century. He describes the recommended apparatus in detail, and the account of the rain-gauge, translated from his Latin by Miss V. Craddock, is worth quoting:

'Sixth and last, was measured the depth of rainfall, (or snow melted to water) which had fallen since the time before, both in London inches and their decimal parts. Thus I estimated easily that with the help of funnels two or three feet across, water flowing down the funnels could be caught in a container and a cylindrical measure with a scale in inches and decimals. The funnel was so sited that, from wherever the wind blew, no part of the rain might be intercepted either by an intervening building or any other shelter anywhere. Thus there would be a bottle containing water properly closed in from all sides, lest it should disperse into the air, with one narrow opening left to collect the water from above, through the funnel. The diameter of the cylindrical measure should be allotted smaller than that of the funnel by ten parts; thus it is that water is an inch high in the measure to the height of $1/100$ inch in the funnel, and thus the fall on the rest of the earth can be calculated, and similarly for the tenth part of inches.'

This, then, is the advice that prospective rainfall observers would have received in the 1720s if they had consulted the main scientific journal of the

TABLE I—IMPORTANT RAINFALL RECORDS FOR YEARS BEFORE 1820

(taken from the Meteorological Office 10 year books in July 1974)

| Ref. | Name and Author | Period | Est. inches* | Obs. |
|------|--|-------------------------|-----------------|-------|
| Y2 | Tottenham, London (Luke Howard) | 1797–1810 | 25.30 | 24.36 |
| Y3 | Somerset House, London (Royal Society) | 1787–1809 1812–1819 | 23.70 | 16.22 |
| Y6 | Temple Bar, London (William Bent) | 1795–1808 | 23.65 | 18.62 |
| Y7 | Crane Court, London (Royal Society) | 1725–1735 | 23.60 | 21.73 |
| Y8 | Lambeth, London (Symons's MS) | 1765–1782 | 23.40 | 24.90 |
| Y9 | South Lambeth, London | 1782–1791 | 23.74 | 22.94 |
| Y12 | Camden Town, nr London (James Joyce) | 1802–1808 | 25.00 | 30.73 |
| Y13 | Highgate Hill, London (James Joyce) | 1809–1815 | 26.50 | 32.79 |
| Y18 | Falkham } Kent (John Hooker) | 1729–1734 | (3) | 21.57 |
| | North Fleet } | | | |
| Y18a | Tonbridge, Kent (John Hooker) | 1735–1764 | 28.80 | 26.91 |
| Y23 | Selborne, Hants (Gilbert White) | 1780–1792 | 38.00 | 36.41 |
| Y31 | Southwick, nr Oundle (George Lynn) | 1726–1739 | 23.80 | 22.83 |
| Y45 | Longleat, Wilts. (Jeremiah Cruse) | 1789–1799 | 35.50 | 24.75 |
| Y47 | Upminster, Essex (Dr W. Derham) | 1697–1716 | 22.00 | 19.90 |
| Y48 | Norwich, Norfolk (W. Anderson) | 1750–1762 | 26.80 | 25.41 |
| Y49 | Plymouth, Devon (Dr J. Huxham) | 1725–1752 | 39.00 | 30.32 |
| Y59 | Stroud, Gloucester (Dr Hughes) | 1771–1773 1775–1813 | 34.00 | 30.90 |
| Y60 | Radcliffe Observatory, Oxford | 1795–1804 1815–1819 | 25.10 | 21.15 |
| Y64 | Lyndon, Rutland (Thomas Barker) | 1737–1798 1800 | 24.56 | 22.97 |
| Y65 | Ferriby, Hull (Editor, Monthly Mag.) | 1800–1812 | 25.00 | 27.53 |
| Y71 | Chatsworth, Derbys. (Lord George Cavendish) | 1761–1813 | 34.00 | 30.90 |
| Y73 | Derby (Mr Swanwick) | 1809–1819 | 28.00 | 25.06 |
| Y77 | Liverpool Docks (Mr Hutchinson) | 1775–1792 | 33.50 | 34.36 |
| Y78 | Liverpool, Walton (Mr J. Holt) | 1792–1804 | 35.00 | 33.15 |
| Y80 | Manchester (Thomas Hanson) | 1807–1813 1816–1819 | (4) | 35.09 |
| Y81 | Manchester (Dr Dalton) | 1794–1819 | (5) | 32.63 |
| Y87 | Townley, nr Burnley, Lancs. (R. Townley) | 1677–1703 with gaps | 47.50 | 41.87 |
| Y88 | Lancaster (Dr Campbell) | 1784–1796 | 39.50 | 44.29 |
| Y91 | Kendal (J. Gough) (6) | 1788–1799 | 57.50 | 59.77 |
| Y96 | Barrowby, Leeds (George Lloyd) | 1772–1781 | 27.90 | 27.14 |
| Y118 | Carlisle, Abbey St (Dr J. Carlyle) | 1757–1783 | 32.30 | 24.33 |
| Y120 | Carlisle, Shaddongate (Mr Pitt) | 1801–1819 | 32.30 | 29.52 |
| Y126 | Wigton, Aikbank (Rev. J. Golding) | 1790–1810 | 34.00 | 34.64 |
| Y131 | Dumfries (Dr Copland) | 1775–1783 1790, 1793 | 43.00 | 38.06 |
| Y133 | Branxholm, Roxburgh | 1773–1783 | 34.50 | 32.07 |
| Y136 | London | 1798–1809 | 23.78 | 22.86 |
| Y147 | South Kyme, Lincs. (Rev. H. S. Neucatre) | 1800–1819 | 23.62 | 25.34 |
| Y151 | Welbeck Abbey, Notts. (Duke of Portland's estates) | 1807–1819 | 23.20 | 25.48 |
| Y157 | Kendal (a brother of J. Dalton) (6) | 1798–1809 | 57.50 | 49.67 |
| Y186 | Lancaster, Ellet (Ford) | 1798–1817 | 49.00 | 38.14 |
| Y194 | Kendal (Harrison and Gough) (6) | 1810–1819 | 57.50 | 50.19 |

Notes

- (1) The estimates are based on the fullest information for 1916–50.
 (2) The Obs. column gives the average of annual totals observed and reported for all years before 1819.
 (3) Falkham 1728–30 26.70. North Fleet 1731–33 23.00.
 (4) 1807–11 35.50. (5) 1794–1803 34.00. (6) Sites unknown—taken as modern town of Kendal.
 1812–19 35.00. 1803–1819 34.50.

* Non-metric units are used throughout this paper to maintain uniformity with those units used with historical references and quotations.

times. Following Jurin's advice, they would have had rain-gauges which were not sheltered in any direction by obstacles, and which preserved the catch from evaporation, but the funnel might have been so flat that raindrops were scoured out by the wind, and there was then no suggestion that the elevation of the funnel above the ground surface could have had any effect on the catch. Dr Heberden (1767) was the first to demonstrate, by placing similar rain-gauges on the square tower of Westminster Abbey and at his house in Westminster, the general principle that 'the higher the rim of the collecting funnel above the ground surface, the smaller the catch'. This has often been confirmed since, for example, by comparative measurements at Oxford and Paris but the processes involved were not understood till the time of Symons (1881) and Mill (1901). Mill's work in particular shows that the loss of catch with an elevated gauge depends mainly on eddies produced by the horizontal component of the wind, with the result that the loss of catch tends to be greater in the winter months when the winds are on average stronger. Painter (1975) compared measurements from ground level to 45 cm. Nash (1918) analysed the monthly totals from 1871 to 1910 of rainfall measured at Greenwich with gauges at ground level, and 10, 22, 38 and 50 feet above and showed that the average catch of the 38 foot gauge varied from 87 per cent of the ground-level value in August to only 71 per cent in March. Two points should be made to conclude this discussion:

(i) with a sharp-rimmed gauge, reasonably well exposed, it is almost impossible to catch too much rain, so that the general rule can be 'when in doubt, accept the larger reading' and

(ii) when an old record was set up by a gentleman with scientific interests, under what seemed to him to be satisfactory conditions, any changes which took place with time were liable to have produced a gradual diminution of catch. These changes may have included the growth of trees near the gauge, leaks, the slow blockage of the pipe leading to the receiving vessel, or the internal surface becoming porous. Such changes may not have been noticed unless the observer compared his records with a neighbour, but then, if he was not too old to take action, he may have put things right.

4. STATIONS IN THE EAST MIDLANDS

Coming from the general to the particular, the stations considered in this paper are listed in Table II. The names underlined provide nearly all the data in the homogeneous series produced here; on 12 and 13 May 1976, one of us (J. M. Craddock) visited these sites in search of further evidence. The findings form the basis of paragraph 10. Pode Hole was chosen as key-site, because it has a very good continuing record which started as early as 1829, and is about equidistant from South Kyme and Boston in one direction, and Southwick and Lyndon in the other. Although the distances to the supporting stations ranging from 18 to 22 miles are not negligible, they are across flat country, and are a good deal less than the distances which have to be considered when data for other parts of the country are homogenized, or which must be accepted when a user of such data treats the record for a key-site as referring to his own area.

5. ESTIMATING THE CONVERSION FACTORS TO BE APPLIED TO EARLY DATA

The method of homogenization consists in using the monthly totals given in an early record to estimate totals for the same months at Pode Hole by multiplying

TABLE II—STATIONS USED IN ESTIMATING RAINFALL TOTALS TO REPRESENT THE EAST MIDLANDS FOR THE YEARS 1726 TO 1975

| Station | Nat. Grid. Ref. | Altitude | Observer | Period | Distance from Pode Hole | 1916–50 estimate |
|-----------------------|--------------------|----------|-------------------------|----------------|-------------------------------|---------------------|
| <u>Pode Hole</u> | 214219 | 22' | Various | 1829–1975 | 0 | 23·65 in |
| <u>Southwick</u> | | | | | | |
| <u>(Oundle)</u> | 920020 | 110' | George Lynn | 1726–1740 | 22 miles | 23·80 in |
| <u>Lyndon</u> | | | Thomas | 1737–1798, | | |
| <u>(Rutland)</u> | 044907 | 300' | Barker | 1800 | 22 miles | 24·56 in |
| <u>South Kyme</u> | | | Rev. H. S. | 1800–1868 | | |
| <u>(nr Sleaford)</u> | 170498 | 11' | Neucatere | except 1826 | 18 miles | 23·62 in |
| <u>Boston,</u> | | | | 1824–1869 | | |
| <u>Grand Sluice</u> | 440327 | 40' | W. Veall <i>et alii</i> | 1865–1970 + | 16 miles | 24·30 in |
| <u>Empingham</u> | 950086 | 175' | W. Fancourt | 1836–1861 | 18 miles | 24·20 in |
| <u>Witham-on-the-</u> | | | General A. C. | | | |
| <u>Hill</u> | 165050 | 170' | Johnson | 1831–1869 | 11 miles | 23·40 in |
| <u>Wellingborough</u> | 894675 | 187' | Various | 1860–1975 | 38 miles | 24·50 in |

by a conversion factor which is itself the product of an exposure factor and a distance factor. The exposure factor converts the observed totals into estimates for a standard rain-gauge well sited at the same place with rim 1 ft above ground. These are based on the consideration of the sites given below. The distance factors convert the estimates for the 1 ft level gauges at different places into estimates for Pode Hole, by taking account of the ratio of the annual catches in the 1916–50 period, as estimated from the latest official maps and given in Table II. These factors and their products are given in Table III.

TABLE III—CONVERSION FACTORS USED FOR THE HOMOGENEOUS PODE HOLE SERIES FOR 1726 TO 1975

| Years used | Station | Exposure factor | Distance factor | Product |
|------------|----------------|-----------------|-----------------|---------|
| 1726–1736 | Southwick | 1·030 | 0·994 | 1·024 |
| 1737–1798 | Lyndon | 1·080 | 0·963 | 1·040 |
| 1799 | West Bridgford | — | — | 1·000 |
| 1800–1825 | South Kyme | 1·030 | 1·000 | 1·030 |
| 1826 | Witham | 1·000 | 1·011 | 1·011 |
| 1827, 1828 | South Kyme | 1·030 | 1·000 | 1·030 |
| 1829–1975 | Pode Hole | — | — | 1·000 |

6. THE INDIVIDUAL RECORDS

The records for West Bridgford and Witham, each used to estimate for only one year, do not warrant individual discussion, but those for Southwick, Lyndon and South Kyme are more important. The records at Southwick and Lyndon provide the best evidence which still exists for British rainfall regimes before 1800, and deserve further study which may, of course, modify the present conclusions.

(i) Southwick Hall, Oundle has been a gentleman's residence since the Middle Ages, and when the rainfall measurements were made by George Lynn the elder (1740), from 1726 to 1740, the main structure was much the same as it is today. The house is surrounded by lawns, gardens and trees, with the church and village of Southwick at no great distance, and the probability is that these

also have only changed in detail during the last 250 years. George Lynn, in a letter to Dr Jurin, describes the situation of his thermometer and barometer in considerable detail, but says nothing whatever about the exposure of his rain-gauge, an omission which suggests that he considered it too obvious a matter to deserve mention. A modern hydrometeorologist looking for a site for a rain-gauge would indeed have an obvious first choice, namely, the middle of the lawn to the west of the house, in clear view from the windows of the main drawing room (improved by George Lynn). He might also feel that this site, although the best available, is somewhat overshadowed. It lies between the manor house and the church, and there are and probably always have been big isolated trees (although not the same ones) and woods around. Any other site likely to be chosen would be more sheltered, and of course George Lynn had to make his choice without the experience available to modern observers. The impression left by a visit to the site is that an upward revision of the figures by three per cent to allow for exposure is unlikely to be excessive.

(ii) As regards the even more important Lyndon record, Thomas Barker (1771) describes his rain-gauge as follows:

'I have, on the other side, sent, as you desired, the height of my rain measurer above the ground, which, if you think proper, may be added to my former letter. Mr Edward Lawrence, who observed the rain at Stamford part of the time I have done here, generally found more water in his measurer which stood on the ground, than I did in mine; but I cannot depend on his observations, because I have been told the servants at the house used to play him tricks, and pour into his cistern more water than fell in, to which a thing on the ground is very liable . . . My rain cistern has all along stood on the top of a wall, where another meets it at right angles. The top of the cistern on the North side is 7 ft. 3 ins.; on the southwest side 8 ft. 6 ins.; and on the south-east side 10 ft. above the ground; it is all open southward for 25 yards, the north side is an orchard, but no tree hangs over it.'

The immediate response to this account is that a rain-gauge exposed in this way would catch less than one on the ground without any assistance from the pranks of mischievous servants. However, arriving at the right correction is less easy, since none of the experimenters seem to have considered a rain-gauge situated above the junction of two walls. The terrain at Lyndon is more similar to that at Stratfield Turgis than it is to the moors at Rotherham, or the urban terrain around Greenwich, and an exposure factor of 1.080 (which gives a product with the distance factor of 1.040), seems as good as any which can be suggested.

(iii) Information about the record at South Kyme can be pieced together from notes in the 10 year books, where the rainfall totals were copied by G. J. Symons, and an extensive extract from the observation book. During the 1930s a Flt Lt Lowe, stationed at Cranfield, lent the book to the Meteorological Office, stating his intention of depositing it in 'the local museum'. This book contained the observations of pressure, temperature and rainfall made by the Reverend H. S. Neucatre, vicar of Kyme Manor, from his appointment in 1826 until the summer of 1869, but it also contains similar observations for the years 1800 to 1825, which Neucatre must have copied from an at present unknown source. The site of the rain-gauge is stated to be 'near the old tower'. The book was returned to Flt Lt Lowe, and has not been seen since. A visit to South Kyme showed that the old tower is not the remains of a previous church, but a most

impressive relic from a former castle, standing in open parkland not far from the church and manor house, which was built of stone from the castle. A water-colour of the old tower in the Museum of Local Antiquities at Lincoln shows that the surroundings of the old tower when the picture was painted (between 1850 and 1870) were the same as they are now, and it is hard to see how a rain-gauge could be sited near the old tower and avoid overexposure, without placing it in the actual shelter of the tower. Here again, an upward revision of the observations of three per cent to allow for exposure seems reasonable.

(iv) As regards Podge Hole itself, the facts are summarized in the official records as in Table IV.

These changes in gauge height etc. should not result in serious inaccuracies, and it appears, too, that some of them may be matters of description rather than fact, since it seems that for many years a Glaisher gauge, with rim 2 ft 6 in above the ground surface, was surrounded by a low hedge of 1 ft 3 in height. These observations have therefore been accepted as correct.

TABLE IV—INFORMATION ABOUT PODE HOLE

| <i>Spalding (Pode Hole) NGR TF(53)214219 12 ft a.s.l. Gauge No. 32-154720</i> <i>Brief history of rain-gauging</i> | | | | | | |
|---|---|----------------|---------------|-------------|--------------|---|
| Year | Observer/Authority | Gauge dia. | Height of rim | Site a.s.l. | Inform-ation | Notes |
| 1829 | A. Harrison | | 0' 00" | 19' ? | 10 yr | |
| 1869 | A. Harrison | | 0' 00" | 19' | 10 yr | |
| 1870 | A. Harrison | 12" | 0' 00" | 20' ? | BR | |
| 1872 | A. Harrison | 12" | 0' 03" | 20' | BR | |
| 1890 | A. Harrison | 12" | 0' 03" | 20' | BR | |
| 1891 | W. Grigg | 12" | 1' 00" | 20' | BR | |
| 1905 | W. Grigg | 12" | 1' 00" | 20' | BR | 1905 may have been Rly Stn record (10 yr) |
| 1906 | W. Grigg | N & Z Glaisher | 1' 00" | 20' | 10 yr | |
| 1910 | W. Grigg | N & Z Glaisher | 1' 00" | 20' | 10 yr | 1906-10 data rec'd 23.5.1912 |
| 1911 | H. Bain | 8" | 1' 03" | 13' | BR | |
| 1938 | H. Bain | 8" | 1' 03" | 13' | BR | |
| 1939 | Deeping Fen Drainage Trust | 8" | 1' 03" | 12' | BR | |
| 1946 | Deeping Fen Drainage Trust | 8" | 1' 03" | 12' | BR | |
| 1947 | South Holland Drainage Board | 8" | 1' 03" | 12' | BR | |
| 1958 | South Holland Drainage Board | 8" | 1' 03" | 12' | BR | 10 yr gives gauge as Glaisher 1951-60 |
| 1961 | Deeping Fen, Spalding and Pinchbeck Internal Drainage Board | 8" Glaisher | 1' 03" | 12' | 10 yr | |
| 1965 | Deeping Fen, Spalding and Pinchbeck Internal Drainage Board | 8" Glaisher | 1' 03" | 12' | 10 yr | |

(1962) (Two 5" gauges installed—Pode Hole 2 and 3) 10 yr

N & Z=Negretti and Zambra BR =British Rainfall 10 yr = 10 year book

7. DISCUSSION AND CONCLUSION

The annual totals which result from this homogenization are given as percentages of the 1916-50 annual average in Table V which follows, and the monthly totals

TABLE V—ESTIMATED ANNUAL RAINFALL TOTALS FOR 1726-1828 AND MEASURED TOTALS FOR 1829-1975 FOR PODE HOLE EXPRESSED AS PERCENTAGES OF THE 1916-50 AVERAGE 23.65 in (600.7 mm)

| | | | | | | | | | | | | | | | | | |
|------|-------|------|--------------------|------|-------|------|--------------------|------|-------|------|--------------------|------|-------------------|------|-------|------|-------|
| 1726 | 115.1 | 1754 | 87.3 | 1782 | 141.1 | 1810 | 123.9 | 1838 | 89.2 | 1866 | 113.1 | 1894 | 94.7 | 1922 | 111.2 | 1950 | 101.9 |
| 1727 | 108.0 | 1755 | 93.4 | 1783 | 100.2 | 1811 | 109.0 | 1839 | 133.8 | 1867 | 98.8 | 1895 | 92.5 | 1923 | 96.8 | 1951 | 116.1 |
| 1728 | 116.0 | 1756 | 110.8 | 1784 | 119.7 | 1812 | 116.3 | 1840 | 90.1 | 1868 | 104.7 | 1896 | 96.2 | 1924 | 111.9 | 1952 | 96.1 |
| 1729 | 101.8 | 1757 | 104.1 | 1785 | 88.9 | 1813 | 104.2 | 1841 | 124.5 | 1869 | 117.8 | 1897 | 99.9 | 1925 | 97.3 | 1953 | 98.3 |
| 1730 | 92.9 | 1758 | 94.9 | 1786 | 120.0 | 1814 | 114.6 | 1842 | 135.7 | 1870 | 71.3 | 1898 | 85.6 | 1926 | 99.2 | 1954 | 124.3 |
| 1731 | 76.9 | 1759 | 92.1 | 1787 | 100.2 | 1815 | 105.9 | 1843 | 124.5 | 1871 | 107.9 | 1899 | 88.2 | 1927 | 124.7 | 1955 | 86.8 |
| 1732 | 88.3 | 1760 | 80.4 | 1788 | 75.6 | 1816 | 165.1 ⁺ | 1844 | 93.9 | 1872 | 137.4 | 1900 | 120.5 | 1928 | 106.9 | 1956 | 97.5 |
| 1733 | 76.3 | 1761 | 94.1 | 1789 | 123.1 | 1817 | 118.6 | 1845 | 115.2 | 1873 | 83.0 | 1901 | 99.7 | 1929 | 88.4 | 1957 | 101.3 |
| 1734 | 119.1 | 1762 | 78.7 | 1790 | 95.1 | 1818 | 114.0 | 1846 | 110.3 | 1874 | 68.7 | 1902 | 95.7 | 1930 | 105.7 | 1958 | 132.7 |
| 1735 | 107.4 | 1763 | 126.4 | 1791 | 108.7 | 1819 | 108.7 | 1847 | 108.3 | 1875 | 136.4 | 1903 | 130.0 | 1931 | 109.0 | 1959 | 76.0 |
| 1736 | 105.7 | 1764 | 103.3 | 1792 | 129.3 | 1820 | 104.0 | 1848 | 145.0 | 1876 | 131.0 | 1904 | 93.9 | 1932 | 107.2 | 1960 | 126.7 |
| 1737 | 92.1 | 1765 | 87.9 | 1793 | 100.8 | 1821 | 137.2 | 1849 | 116.0 | 1877 | 102.5 | 1905 | 104.1 | 1933 | 80.8 | 1961 | 90.8 |
| 1738 | 75.5 | 1766 | 83.4 | 1794 | 116.9 | 1822 | 101.4 | 1850 | 88.5 | 1878 | 108.4 | 1906 | 110.0 | 1934 | 78.9 | 1962 | 77.5 |
| 1739 | 94.8 | 1767 | 93.7 | 1795 | 94.1 | 1823 | 93.8 | 1851 | 94.1 | 1879 | 103.1 | 1907 | 94.9 | 1935 | 100.9 | 1963 | 85.1 |
| 1740 | 76.1 | 1768 | 135.9 | 1796 | 97.1 | 1824 | 136.2 | 1852 | 131.1 | 1880 | 157.0 ⁺ | 1908 | 72.8 | 1936 | 109.1 | 1964 | 70.9 |
| 1741 | 70.3 | 1769 | 94.5 | 1797 | 122.5 | 1825 | 94.4 | 1853 | 112.5 | 1881 | 110.4 | 1909 | 101.5 | 1937 | 126.3 | 1965 | 109.8 |
| 1742 | 76.0 | 1770 | 125.6 | 1798 | 96.4 | 1826 | 75.7 | 1854 | 75.1 | 1882 | 129.0 | 1910 | 110.4 | 1938 | 83.4 | 1966 | 112.1 |
| 1743 | 70.6 | 1771 | 77.3 | 1799 | 120.3 | 1827 | 99.9 | 1855 | 93.1 | 1883 | 130.6 | 1911 | 80.3 | 1939 | 119.0 | 1967 | 86.3 |
| 1744 | 99.9 | 1772 | 126.0 | 1800 | 108.0 | 1828 | 125.1 | 1856 | 95.7 | 1884 | 70.9 | 1912 | 124.2 | 1940 | 94.6 | 1968 | 111.3 |
| 1745 | 90.3 | 1773 | 129.2 | 1801 | 107.0 | 1829 | 127.9 | 1857 | 117.8 | 1885 | 101.0 | 1913 | 89.3 | 1941 | 130.2 | 1969 | 106.1 |
| 1746 | 81.1 | 1774 | 155.0 ⁺ | 1802 | 77.5 | 1830 | 145.0 | 1858 | 74.0 | 1886 | 127.9 | 1914 | 92.1 | 1942 | 93.9 | 1970 | 87.8 |
| 1747 | 105.9 | 1775 | 139.4 | 1803 | 96.2 | 1831 | 145.1 | 1859 | 106.8 | 1887 | 64.0 ⁺ | 1915 | 108.8 | 1943 | 79.3 | 1971 | 84.7 |
| 1748 | 75.7 | 1776 | 122.4 | 1804 | 114.7 | 1832 | 122.1 | 1860 | 128.4 | 1889 | 90.9 | 1916 | 117.9 | 1944 | 101.0 | 1972 | 77.0 |
| 1749 | 70.1 | 1777 | 103.8 | 1805 | 107.4 | 1833 | 105.5 | 1861 | 108.9 | 1889 | 112.1 | 1917 | 84.3 | 1945 | 85.3 | 1973 | 85.5 |
| 1750 | 72.2 | 1778 | 115.5 | 1806 | 107.6 | 1834 | 76.5 | 1862 | 105.3 | 1890 | 85.3 | 1918 | 111.9 | 1946 | 115.0 | 1974 | 84.1 |
| 1751 | 119.5 | 1779 | 96.2 | 1807 | 86.1 | 1835 | 102.3 | 1863 | 96.7 | 1891 | 106.3 | 1919 | 112.0 | 1947 | 79.8 | 1975 | 83.5 |
| 1752 | 93.0 | 1780 | 88.4 | 1808 | 113.8 | 1836 | 112.7 | 1864 | 74.6 | 1892 | 96.2 | 1920 | 101.8 | 1948 | 97.9 | | |
| 1753 | 97.6 | 1781 | 91.5 | 1809 | 108.5 | 1837 | 101.1 | 1865 | 123.2 | 1893 | 76.7 | 1921 | 53.5 ¹ | 1949 | 84.8 | | |

from 1726 to 1828 are in Table VI (the monthly totals for 1829 to the present are the published figures for Pode Hole). These figures are offered as the best advice now available on the rainfall regimes of the East Midlands during the last 250 years. It would be difficult at present to suggest better data for relation to agricultural statistics in Lincolnshire, for example, but their suitability for use with data for places further afield is less clear. The question of the manner

TABLE VI—MONTHLY AND ANNUAL RAINFALL TOTALS AND DECADAL AVERAGES FOR PODE HOLE 1726–1828 (ESTIMATED) AND 1829–1975 (MEASURED)

| | J | F | M | A | M | J | Jy | A | S | O | N | D | Year | Dec. |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|
| 1726 | 430 | 103 | 154 | 101 | 41 | 409 | 378 | 29 | 528 | 151 | 142 | 255 | 2721 | |
| 1727 | 322 | 204 | 142 | 129 | 438 | 330 | 202 | 30 | 213 | 156 | 41 | 288 | 2555 | |
| 1728 | 471 | 95 | 335 | 202 | 147 | 289 | 329 | 98 | 88 | 286 | 156 | 249 | 2745 | |
| 1729 | 16 | 49 | 134 | 113 | 159 | 85 | 231 | 250 | 545 | 225 | 428 | 172 | 2407 | |
| 1730 | 41 | 154 | 266 | 82 | 256 | 348 | 205 | 87 | 164 | 307 | 205 | 82 | 2197 | |
| 1731 | 82 | 102 | 15 | 215 | 31 | 348 | 174 | 164 | 154 | 143 | 154 | 236 | 1818 | |
| 1732 | 92 | 123 | 143 | 123 | 348 | 61 | 184 | 174 | 72 | 379 | 123 | 266 | 2088 | |
| 1733 | 102 | 143 | 225 | 102 | 2 | 205 | 225 | 369 | 143 | 61 | 51 | 174 | 1802 | |
| 1734 | 51 | 266 | 184 | 61 | 522 | 133 | 184 | 410 | 174 | 287 | 92 | 451 | 2815 | |
| 1735 | 215 | 72 | 225 | 174 | 154 | 246 | 236 | 328 | 328 | 174 | 174 | 215 | 2541 | |
| 1736 | 236 | 297 | 215 | 61 | 82 | 143 | 614 | 174 | 143 | 266 | 61 | 205 | 2497 | |
| 1737 | 63 | 173 | 184 | 71 | 104 | 75 | 32 | 655 | 361 | 210 | 59 | 190 | 2177 | |
| 1738 | 186 | 59 | 124 | 128 | 225 | 252 | 64 | 148 | 219 | 171 | 72 | 137 | 1785 | |
| 1739 | 253 | 260 | 84 | 269 | 193 | 160 | 204 | 244 | 198 | 54 | 162 | 160 | 2241 | |
| 1740 | 26 | 6 | 66 | 90 | 108 | 149 | 382 | 291 | 168 | 109 | 155 | 251 | 1801 | 2157 |
| 1741 | 113 | 64 | 59 | 28 | 46 | 142 | 90 | 170 | 513 | 152 | 204 | 51 | 1632 | |
| 1742 | 149 | 89 | 5 | 199 | 161 | 149 | 327 | 17 | 185 | 249 | 252 | 17 | 1799 | |
| 1743 | 43 | 37 | 124 | 130 | 90 | 40 | 544 | 116 | 1 | 321 | 75 | 149 | 1670 | |
| 1744 | 125 | 98 | 149 | 287 | 131 | 362 | 85 | 100 | 343 | 327 | 236 | 122 | 2365 | |
| 1745 | 86 | 59 | 264 | 178 | 119 | 359 | 75 | 409 | 94 | 152 | 215 | 128 | 2138 | |
| 1746 | 183 | 178 | 196 | 79 | 57 | 302 | 150 | 48 | 170 | 236 | 186 | 133 | 1918 | |
| 1747 | 297 | 126 | 129 | 106 | 294 | 162 | 234 | 7 | 200 | 60 | 512 | 378 | 2505 | |
| 1748 | 98 | 38 | 203 | 142 | 123 | 316 | 362 | 135 | 57 | 110 | 45 | 161 | 1790 | |
| 1749 | 258 | 106 | 194 | 57 | 115 | 316 | 109 | 79 | 64 | 113 | 72 | 174 | 1657 | |
| 1750 | 115 | 93 | 106 | 244 | 103 | 215 | 157 | 67 | 104 | 92 | 220 | 190 | 1706 | 1918 |
| 1751 | 322 | 96 | 213 | 320 | 276 | 192 | 519 | 164 | 271 | 189 | 139 | 122 | 2823 | |
| 1752 | 262 | 144 | 125 | 86 | 222 | 320 | 383 | 138 | 50 | 31 | 113 | 326 | 2202 | |
| 1753 | 176 | 191 | 122 | 146 | 102 | 105 | 269 | 352 | 74 | 152 | 219 | 401 | 2309 | |
| 1754 | 96 | 93 | 130 | 151 | 146 | 300 | 400 | 110 | 11 | 194 | 204 | 231 | 2066 | |
| 1755 | 106 | 86 | 173 | 204 | 145 | 188 | 165 | 235 | 265 | 170 | 327 | 147 | 2211 | |
| 1756 | 210 | 72 | 142 | 406 | 131 | 309 | 333 | 443 | 216 | 159 | 101 | 98 | 2620 | |
| 1757 | 223 | 61 | 199 | 217 | 142 | 38 | 312 | 630 | 54 | 203 | 156 | 227 | 2462 | |
| 1758 | 194 | 214 | 186 | 96 | 132 | 225 | 522 | 178 | 152 | 107 | 95 | 145 | 2246 | |
| 1759 | 92 | 40 | 194 | 315 | 285 | 309 | 97 | 388 | 88 | 156 | 102 | 112 | 2178 | |
| 1760 | 110 | 194 | 47 | 41 | 93 | 257 | 94 | 171 | 242 | 263 | 223 | 167 | 1900 | 2302 |
| 1761 | 20 | 153 | 55 | 51 | 211 | 363 | 59 | 375 | 244 | 384 | 150 | 160 | 2225 | |
| 1762 | 180 | 101 | 159 | 61 | 77 | 79 | 116 | 376 | 159 | 432 | 96 | 24 | 1860 | |
| 1763 | 62 | 300 | 96 | 72 | 239 | 253 | 589 | 305 | 344 | 167 | 197 | 366 | 2990 | |
| 1764 | 414 | 118 | 86 | 158 | 114 | 227 | 480 | 184 | 86 | 141 | 184 | 250 | 2442 | |
| 1765 | 149 | 129 | 288 | 219 | 43 | 82 | 60 | 291 | 73 | 503 | 133 | 109 | 2079 | |
| 1766 | 17 | 218 | 81 | 204 | 342 | 237 | 245 | 43 | 112 | 86 | 202 | 186 | 1972 | |
| 1767 | 320 | 208 | 109 | 88 | 220 | 225 | 383 | 158 | 72 | 293 | 97 | 42 | 2215 | |
| 1768 | 294 | 318 | 41 | 210 | 168 | 470 | 250 | 179 | 315 | 324 | 420 | 224 | 3213 | |
| 1769 | 125 | 162 | 72 | 87 | 151 | 496 | 207 | 245 | 268 | 125 | 128 | 167 | 2233 | |
| 1770 | 88 | 77 | 201 | 198 | 161 | 288 | 186 | 236 | 127 | 324 | 813 | 271 | 2970 | 2420 |

All totals and averages are expressed in hundredths of an inch. 1 inch=25·4 mm.

TABLE VI—continued

| | J | F | M | A | M | J | Jy | A | S | O | N | D | Year | Dec. |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|
| 1771 | 147 | 97 | 95 | 101 | 69 | 165 | 108 | 222 | 121 | 423 | 82 | 201 | 1831 | |
| 1772 | 223 | 362 | 244 | 92 | 194 | 405 | 93 | 175 | 469 | 340 | 256 | 128 | 2981 | |
| 1773 | 118 | 152 | 58 | 62 | 711 | 249 | 112 | 352 | 292 | 272 | 375 | 302 | 3055 | |
| 1774 | 344 | 203 | 284 | 158 | 327 | 258 | 336 | 407 | 832 | 121 | 159 | 237 | 3666 | |
| 1775 | 205 | 262 | 180 | 108 | 94 | 93 | 424 | 495 | 590 | 362 | 371 | 113 | 3297 | |
| 1776 | 261 | 332 | 158 | 93 | 170 | 259 | 192 | 541 | 255 | 214 | 293 | 128 | 2896 | |
| 1777 | 112 | 251 | 131 | 165 | 206 | 309 | 333 | 134 | 53 | 417 | 164 | 179 | 2454 | |
| 1778 | 206 | 99 | 125 | 108 | 137 | 282 | 426 | 41 | 173 | 441 | 400 | 294 | 2732 | |
| 1779 | 22 | 233 | 14 | 197 | 132 | 251 | 420 | 157 | 128 | 184 | 213 | 326 | 2277 | |
| 1780 | 105 | 163 | 123 | 284 | 125 | 200 | 163 | 45 | 357 | 320 | 152 | 55 | 2092 | 2728 |
| | | | | | | | | | | | | | | |
| 1781 | 235 | 173 | 17 | 202 | 101 | 308 | 175 | 114 | 417 | 8 | 329 | 177 | 2166 | |
| 1782 | 242 | 67 | 200 | 638 | 595 | 135 | 281 | 323 | 536 | 156 | 111 | 54 | 3338 | |
| 1783 | 188 | 240 | 167 | 58 | 439 | 315 | 277 | 114 | 150 | 69 | 185 | 166 | 2368 | |
| 1784 | 196 | 128 | 114 | 181 | 301 | 396 | 528 | 292 | 181 | 23 | 248 | 242 | 2830 | |
| 1785 | 155 | 38 | 22 | 19 | 70 | 163 | 341 | 448 | 344 | 172 | 118 | 212 | 2102 | |
| 1786 | 361 | 70 | 86 | 130 | 248 | 164 | 187 | 274 | 295 | 495 | 306 | 223 | 2839 | |
| 1787 | 43 | 89 | 185 | 179 | 163 | 187 | 330 | 205 | 128 | 388 | 152 | 321 | 2370 | |
| 1788 | 101 | 278 | 111 | 61 | 158 | 63 | 186 | 289 | 253 | 147 | 47 | 93 | 1787 | |
| 1789 | 270 | 192 | 120 | 105 | 175 | 463 | 443 | 34 | 295 | 513 | 125 | 177 | 2912 | |
| 1790 | 194 | 25 | 27 | 71 | 303 | 248 | 234 | 180 | 163 | 103 | 327 | 375 | 2250 | 2496 |
| | | | | | | | | | | | | | | |
| 1791 | 251 | 132 | 84 | 201 | 119 | 96 | 419 | 303 | 62 | 345 | 440 | 120 | 2572 | |
| 1792 | 218 | 74 | 114 | 420 | 173 | 420 | 382 | 297 | 414 | 183 | 79 | 283 | 3057 | |
| 1793 | 199 | 111 | 288 | 312 | 47 | 44 | 81 | 271 | 400 | 132 | 357 | 140 | 2382 | |
| 1794 | 44 | 146 | 173 | 207 | 108 | 74 | 437 | 300 | 371 | 367 | 412 | 127 | 2766 | |
| 1795 | 171 | 208 | 218 | 163 | 42 | 291 | 175 | 144 | 6 | 472 | 192 | 144 | 2226 | |
| 1796 | 203 | 171 | 40 | 68 | 295 | 97 | 587 | 116 | 197 | 137 | 213 | 174 | 2298 | |
| 1797 | 137 | 8 | 95 | 300 | 263 | 439 | 319 | 252 | 498 | 119 | 168 | 298 | 2896 | |
| 1798 | 107 | 160 | 55 | 137 | 197 | 99 | 306 | 202 | 292 | 315 | 265 | 146 | 2281 | |
| 1799 | 169 | 285 | 130 | 292 | 175 | 76 | 259 | 506 | 490 | 221 | 162 | 80 | 2845 | |
| 1800 | 368 | 49 | 44 | 384 | 145 | 102 | 58 | 146 | 323 | 162 | 508 | 265 | 2554 | 2588 |
| | | | | | | | | | | | | | | |
| 1801 | 203 | 65 | 149 | 60 | 202 | 97 | 373 | 193 | 174 | 158 | 503 | 355 | 2532 | |
| 1802 | 38 | 213 | 65 | 117 | 127 | 204 | 305 | 75 | 100 | 228 | 172 | 190 | 1834 | |
| 1803 | 244 | 113 | 56 | 239 | 369 | 158 | 64 | 69 | 151 | 75 | 310 | 428 | 2276 | |
| 1804 | 270 | 228 | 219 | 200 | 141 | 70 | 359 | 300 | 44 | 265 | 528 | 89 | 2713 | |
| 1805 | 223 | 176 | 138 | 215 | 119 | 344 | 246 | 408 | 170 | 162 | 130 | 208 | 2539 | |
| 1806 | 295 | 96 | 145 | 64 | 149 | 65 | 510 | 217 | 203 | 89 | 351 | 361 | 2545 | |
| 1807 | 96 | 127 | 80 | 43 | 264 | 181 | 90 | 138 | 173 | 125 | 399 | 320 | 2036 | |
| 1808 | 146 | 138 | 51 | 268 | 203 | 150 | 356 | 249 | 346 | 417 | 277 | 89 | 2690 | |
| 1809 | 507 | 203 | 72 | 379 | 131 | 94 | 261 | 239 | 207 | 44 | 227 | 204 | 2568 | |
| 1810 | 28 | 137 | 279 | 93 | 147 | 85 | 357 | 321 | 64 | 307 | 612 | 501 | 2931 | 2466 |
| | | | | | | | | | | | | | | |
| 1811 | 137 | 161 | 90 | 146 | 243 | 203 | 373 | 267 | 193 | 266 | 250 | 249 | 2576 | |
| 1812 | 202 | 331 | 262 | 162 | 216 | 259 | 356 | 192 | 48 | 365 | 270 | 90 | 2753 | |
| 1813 | 59 | 259 | 78 | 216 | 261 | 286 | 357 | 64 | 168 | 511 | 130 | 75 | 2464 | |
| 1814 | 380 | 65 | 224 | 152 | 149 | 265 | 135 | 271 | 152 | 267 | 291 | 358 | 2709 | |
| 1815 | 141 | 150 | 272 | 236 | 130 | 206 | 165 | 254 | 187 | 302 | 167 | 295 | 2505 | |
| 1816 | 242 | 226 | 244 | 212 | 260 | 506 | 476 | 385 | 418 | 359 | 276 | 301 | 3905 | |
| 1817 | 399 | 173 | 178 | 90 | 352 | 273 | 291 | 270 | 67 | 150 | 169 | 393 | 2805 | |
| 1818 | 208 | 277 | 374 | 399 | 267 | 98 | 44 | 33 | 348 | 202 | 300 | 147 | 2697 | |
| 1819 | 236 | 271 | 141 | 268 | 262 | 176 | 161 | 69 | 280 | 188 | 249 | 269 | 2570 | |
| 1820 | 179 | 135 | 69 | 153 | 272 | 291 | 356 | 182 | 249 | 216 | 161 | 195 | 2458 | 2744 |

TABLE VI—continued

| | J | F | M | A | M | J | Jy | [A | S | O | N | D | Year | Dec. |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|
| 1821 | 284 | 64 | 242 | 169 | 207 | 254 | 302 | 253 | 258 | 272 | 473 | 467 | 3245 | |
| 1822 | 61 | 75 | 131 | 276 | 165 | 137 | 322 | 162 | 164 | 384 | 398 | 125 | 2400 | |
| 1823 | 228 | 262 | 125 | 171 | 131 | 205 | 265 | 229 | 188 | 296 | 202 | 228 | 2220 | |
| 1824 | 65 | 228 | 219 | 213 | 375 | 370 | 183 | 250 | 373 | 267 | 355 | 323 | 3221 | |
| 1825 | 119 | 90 | 65 | 174 | 337 | 94 | 34 | 260 | 243 | 262 | 296 | 260 | 2234 | |
| 1826 | 26 | 164 | 137 | 113 | 71 | 47 | 162 | 101 | 524 | 152 | 182 | 113 | 1792 | |
| 1827 | 149 | 131 | 220 | 111 | 114 | 108 | 182 | 113 | 303 | 470 | 170 | 289 | 2360 | |
| 1828 | 393 | 108 | 117 | 218 | 176 | 427 | 588 | 322 | 201 | 99 | 109 | 199 | 2957 | |
| 1829 | 221 | 213 | 28 | 487 | 20 | 412 | 378 | 437 | 345 | 162 | 210 | 112 | 3025 | |
| 1830 | 325 | 460 | 44 | 275 | 470 | 463 | 320 | 213 | 279 | 63 | 187 | 130 | 3429 | 2688 |
| | | | | | | | | | | | | | | |
| 1831 | 200 | 300 | 162 | 230 | 125 | 310 | 499 | 410 | 425 | 290 | 250 | 240 | 3432 | |
| 1832 | 125 | 10 | 280 | 250 | 310 | 310 | 230 | 425 | 37 | 310 | 350 | 250 | 2887 | |
| 1833 | 126 | 515 | 206 | 300 | 82 | 312 | 30 | 350 | 120 | 210 | 75 | 170 | 2496 | |
| 1834 | 225 | 50 | 50 | 100 | 50 | 90 | 625 | 210 | 125 | 100 | 125 | 60 | 1810 | |
| 1835 | 200 | 175 | 250 | 150 | 220 | 160 | 140 | 120 | 340 | 425 | 180 | 60 | 2420 | |
| 1836 | 125 | 260 | 325 | 200 | 15 | 270 | 125 | 130 | 230 | 275 | 400 | 310 | 2665 | |
| 1837 | 360 | 175 | 50 | 170 | 125 | 175 | 210 | 220 | 225 | 220 | 210 | 250 | 2390 | |
| 1838 | 180 | 175 | 110 | 140 | 170 | 325 | 210 | 200 | 210 | 150 | 140 | 100 | 2110 | |
| 1839 | 150 | 140 | 370 | 100 | 80 | 500 | 450 | 300 | 225 | 240 | 420 | 190 | 3165 | |
| 1840 | 200 | 100 | 75 | 75 | 225 | 150 | 330 | 225 | 180 | 190 | 290 | 90 | 2130 | 2550 |
| | | | | | | | | | | | | | | |
| 1841 | 375 | 150 | 120 | 120 | 150 | 300 | 300 | 375 | 280 | 300 | 300 | 175 | 2945 | |
| 1842 | 480 | 150 | 160 | 60 | 275 | 360 | 230 | 290 | 565 | 90 | 450 | 100 | 3210 | |
| 1843 | 170 | 250 | 125 | 230 | 560 | 180 | 300 | 450 | 25 | 410 | 220 | 25 | 2945 | |
| 1844 | 150 | 230 | 200 | 25 | 25 | 150 | 370 | 250 | 200 | 250 | 320 | 50 | 2220 | |
| 1845 | 175 | 75 | 350 | 150 | 270 | 225 | 240 | 480 | 175 | 140 | 120 | 325 | 2725 | |
| 1846 | 240 | 30 | 40 | 475 | 140 | 60 | 175 | 290 | 310 | 475 | 150 | 225 | 2610 | |
| 1847 | 140 | 120 | 72 | 75 | 500 | 250 | 50 | 340 | 160 | 380 | 125 | 350 | 2562 | |
| 1848 | 140 | 325 | 330 | 275 | 50 | 400 | 290 | 380 | 450 | 550 | 60 | 180 | 3430 | |
| 1849 | 175 | 120 | 75 | 250 | 287 | 237 | 350 | 87 | 387 | 300 | 100 | 375 | 2743 | |
| 1850 | 163 | 87 | 50 | 137 | 137 | 63 | 475 | 163 | 237 | 237 | 169 | 175 | 2093 | 2748 |
| | | | | | | | | | | | | | | |
| 1851 | 187 | 50 | 300 | 150 | 50 | 225 | 525 | 187 | 125 | 213 | 150 | 63 | 2225 | |
| 1852 | 313 | 63 | 63 | 37 | 87 | 363 | 225 | 537 | 437 | 275 | 525 | 175 | 3100 | |
| 1853 | 175 | 300 | 163 | 150 | 100 | 300 | 337 | 275 | 137 | 363 | 225 | 137 | 2662 | |
| 1854 | 265 | 50 | 63 | 75 | 150 | 125 | 163 | 137 | 150 | 187 | 213 | 200 | 1778 | |
| 1855 | 100 | 225 | 100 | 25 | 213 | 137 | 513 | 113 | 25 | 425 | 225 | 100 | 2201 | |
| 1856 | 300 | 125 | 37 | 125 | 163 | 125 | 113 | 487 | 150 | 300 | 175 | 163 | 2263 | |
| 1857 | 413 | 37 | 175 | 225 | 75 | 137 | 187 | 600 | 287 | 413 | 213 | 25 | 2787 | |
| 1858 | 25 | 63 | 113 | 150 | 137 | 75 | 213 | 250 | 137 | 325 | 113 | 150 | 1751 | |
| 1859 | 75 | 125 | 113 | 250 | 200 | 200 | 175 | 287 | 325 | 375 | 176 | 225 | 2526 | |
| 1860 | 265 | 113 | 187 | 75 | 337 | 537 | 125 | 400 | 300 | 187 | 287 | 225 | 3038 | 2433 |
| | | | | | | | | | | | | | | |
| 1861 | 100 | 200 | 200 | 87 | 150 | 563 | 450 | 25 | 187 | 137 | 313 | 163 | 2575 | |
| 1862 | 163 | 63 | 363 | 163 | 237 | 225 | 237 | 213 | 363 | 200 | 113 | 150 | 2490 | |
| 1863 | 225 | 37 | 100 | 87 | 187 | 387 | 63 | 313 | 265 | 250 | 300 | 75 | 2289 | |
| 1864 | 75 | 175 | 263 | 113 | 175 | 163 | 63 | 87 | 175 | 137 | 213 | 125 | 1764 | |
| 1865 | 263 | 213 | 163 | 63 | 225 | 237 | 363 | 487 | 37 | 575 | 187 | 100 | 2913 | |
| 1866 | 163 | 237 | 113 | 137 | 137 | 400 | 300 | 337 | 363 | 175 | 163 | 150 | 2675 | |
| 1867 | 400 | 125 | 175 | 175 | 350 | 87 | 175 | 225 | 137 | 200 | 63 | 225 | 2337 | |
| 1868 | 213 | 137 | 163 | 175 | 50 | 50 | 37 | 375 | 225 | 287 | 113 | 650 | 2475 | |
| 1869 | 213 | 237 | 287 | 287 | 463 | 163 | 50 | 175 | 287 | 75 | 175 | 375 | 2787 | |
| 1870 | 137 | 175 | 113 | 75 | 75 | 137 | 87 | 125 | 50 | 287 | 125 | 300 | 1686 | 2399 |

TABLE VI—continued

| | J | F | M | A | M | J | Jy | A | S | O | N | D | Year | Dec. |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|
| 1871 | 113 | 163 | 113 | 275 | 87 | 350 | 413 | 225 | 475 | 113 | 125 | 100 | 2552 | |
| 1872 | 275 | 175 | 213 | 300 | 175 | 275 | 350 | 300 | 150 | 400 | 350 | 287 | 3250 | |
| 1873 | 150 | 137 | 125 | 63 | 225 | 263 | 275 | 225 | 175 | 163 | 125 | 37 | 1963 | |
| 1874 | 100 | 175 | 63 | 75 | 100 | 63 | 106 | 150 | 237 | 206 | 163 | 187 | 1625 | |
| 1875 | 213 | 150 | 50 | 87 | 125 | 400 | 900 | 113 | 225 | 387 | 450 | 125 | 3225 | |
| 1876 | 250 | 213 | 200 | 637 | 75 | 250 | 100 | 137 | 450 | 113 | 237 | 437 | 3099 | |
| 1877 | 287 | 150 | 137 | 337 | 200 | 87 | 263 | 300 | 175 | 125 | 213 | 150 | 2424 | |
| 1878 | 150 | 113 | 63 | 150 | 375 | 150 | 37 | 675 | 113 | 187 | 400 | 150 | 2563 | |
| 1879 | 125 | 187 | 50 | 225 | 313 | 300 | 387 | 263 | 300 | 75 | 113 | 100 | 2438 | |
| 1880 | 25 | 175 | 87 | 250 | 150 | 550 | 675 | 263 | 587 | 575 | 163 | 213 | 3713 | 2685 |
| | | | | | | | | | | | | | | |
| 1881 | 75 | 300 | 163 | 100 | 50 | 175 | 300 | 500 | 187 | 300 | 225 | 237 | 2612 | |
| 1882 | 150 | 75 | 187 | 250 | 187 | 263 | 275 | 313 | 263 | 500 | 250 | 337 | 3050 | |
| 1883 | 175 | 287 | 125 | 187 | 225 | 263 | 475 | 75 | 625 | 213 | 325 | 113 | 3088 | |
| 1884 | 150 | 75 | 87 | 125 | 113 | 63 | 275 | 113 | 225 | 137 | 113 | 200 | 1676 | |
| 1885 | 125 | 175 | 63 | 137 | 213 | 225 | 25 | 225 | 313 | 463 | 350 | 75 | 2389 | |
| 1886 | 275 | 13 | 250 | 137 | 413 | 125 | 400 | 250 | 75 | 425 | 275 | 387 | 3025 | |
| 1887 | 225 | 87 | 63 | 125 | 175 | 63 | 100 | 87 | 175 | 163 | 163 | 87 | 1513 | |
| 1888 | 69 | 206 | 200 | 225 | 75 | 200 | 450 | 200 | 113 | 13 | 237 | 163 | 2151 | |
| 1889 | 150 | 150 | 200 | 263 | 550 | 37 | 275 | 275 | 225 | 300 | 63 | 163 | 2651 | |
| 1890 | 187 | 113 | 267 | 87 | 225 | 225 | 225 | 163 | 25 | 87 | 363 | 50 | 2017 | 2417 |
| | | | | | | | | | | | | | | |
| 1891 | 150 | 0 | 125 | 125 | 263 | 137 | 250 | 350 | 113 | 463 | 250 | 287 | 2513 | |
| 1892 | 125 | 225 | 113 | 113 | 213 | 237 | 237 | 200 | 225 | 400 | 100 | 87 | 2275 | |
| 1893 | 175 | 225 | 37 | 13 | 100 | 125 | 300 | 100 | 125 | 213 | 250 | 150 | 1813 | |
| 1894 | 163 | 137 | 50 | 125 | 150 | 225 | 400 | 163 | 125 | 263 | 275 | 163 | 2239 | |
| 1895 | 263 | 63 | 200 | 175 | 75 | 213 | 250 | 200 | 63 | 237 | 300 | 150 | 2189 | |
| 1896 | 100 | 75 | 200 | 87 | 75 | 200 | 113 | 137 | 475 | 363 | 125 | 325 | 2275 | |
| 1897 | 137 | 313 | 213 | 137 | 87 | 225 | 213 | 350 | 313 | 125 | 125 | 125 | 2363 | |
| 1898 | 100 | 50 | 150 | 225 | 275 | 113 | 87 | 337 | 37 | 275 | 200 | 175 | 2024 | |
| 1899 | 237 | 125 | 50 | 200 | 250 | 87 | 150 | 150 | 300 | 213 | 137 | 187 | 2086 | |
| 1900 | 337 | 525 | 63 | 100 | 175 | 225 | 87 | 487 | 37 | 213 | 213 | 387 | 2849 | 2263 |
| | | | | | | | | | | | | | | |
| 1901 | 100 | 125 | 150 | 175 | 100 | 125 | 475 | 200 | 100 | 175 | 175 | 437 | 2337 | |
| 1902 | 87 | 150 | 125 | 150 | 313 | 313 | 137 | 287 | 175 | 200 | 163 | 163 | 2263 | |
| 1903 | 187 | 75 | 275 | 200 | 275 | 150 | 250 | 450 | 312 | 625 | 175 | 100 | 3074 | |
| 1904 | 200 | 275 | 225 | 83 | 263 | 50 | 237 | 325 | 200 | 87 | 100 | 175 | 2220 | |
| 1905 | 125 | 75 | 187 | 200 | 87 | 375 | 275 | 313 | 275 | 137 | 313 | 100 | 2462 | |
| 1906 | 313 | 200 | 225 | 75 | 163 | 263 | 75 | 275 | 125 | 375 | 313 | 200 | 2602 | |
| 1907 | 100 | 125 | 125 | 200 | 275 | 150 | 174 | 269 | 77 | 283 | 208 | 259 | 2245 | |
| 1908 | 59 | 104 | 196 | 214 | 131 | 114 | 229 | 195 | 172 | 100 | 82 | 126 | 1722 | |
| 1909 | 55 | 18 | 305 | 114 | 105 | 345 | 338 | 189 | 180 | 339 | 42 | 370 | 2400 | |
| 1910 | 166 | 238 | 72 | 222 | 280 | 107 | 250 | 304 | 122 | 142 | 212 | 497 | 2612 | 2394 |
| | | | | | | | | | | | | | | |
| 1911 | 124 | 77 | 148 | 88 | 51 | 210 | 24 | 140 | 170 | 202 | 237 | 421 | 1898 | |
| 1912 | 280 | 115 | 198 | 16 | 223 | 302 | 498 | 555 | 108 | 175 | 219 | 249 | 2938 | |
| 1913 | 240 | 57 | 291 | 209 | 182 | 156 | 82 | 153 | 152 | 300 | 238 | 51 | 2111 | |
| 1914 | 145 | 82 | 258 | 99 | 120 | 302 | 125 | 153 | 62 | 194 | 219 | 419 | 2178 | |
| 1915 | 202 | 207 | 144 | 51 | 175 | 77 | 492 | 345 | 87 | 128 | 260 | 406 | 2574 | |
| 1916 | 86 | 354 | 397 | 91 | 191 | 256 | 200 | 342 | 135 | 169 | 294 | 274 | 2789 | |
| 1917 | 215 | 71 | 112 | 137 | 113 | 179 | 120 | 429 | 105 | 322 | 105 | 86 | 1994 | |
| 1918 | 224 | 125 | 60 | 167 | 301 | 55 | 296 | 277 | 453 | 184 | 259 | 245 | 2646 | |
| 1919 | 312 | 258 | 304 | 239 | 51 | 104 | 287 | 243 | 168 | 145 | 204 | 334 | 2649 | |
| 1920 | 176 | 78 | 223 | 373 | 198 | 237 | 314 | 107 | 231 | 176 | 69 | 226 | 2408 | 2415 |

TABLE VI—continued

| | J | F | M | A | M | J | Jy | A | S | O | N | D | Year | Dec. |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|
| 1921 | 185 | 53 | 73 | 113 | 116 | 45 | 44 | 197 | 67 | 132 | 115 | 126 | 1266 | |
| 1922 | 275 | 264 | 183 | 257 | 114 | 84 | 547 | 196 | 199 | 134 | 117 | 261 | 2631 | |
| 1923 | 142 | 328 | 193 | 116 | 113 | 57 | 215 | 213 | 211 | 266 | 159 | 276 | 2289 | |
| 1924 | 222 | 93 | 60 | 152 | 374 | 204 | 295 | 198 | 190 | 465 | 234 | 210 | 2647 | |
| 1925 | 104 | 195 | 118 | 182 | 311 | 12 | 177 | 244 | 270 | 261 | 209 | 217 | 2300 | |
| 1926 | 315 | 154 | 36 | 209 | 259 | 288 | 132 | 89 | 249 | 220 | 315 | 81 | 2347 | |
| 1927 | 161 | 211 | 229 | 171 | 110 | 342 | 221 | 296 | 412 | 217 | 304 | 275 | 2949 | |
| 1928 | 285 | 106 | 175 | 103 | 151 | 408 | 224 | 206 | 47 | 341 | 261 | 222 | 2529 | |
| 1929 | 166 | 97 | 19 | 90 | 106 | 122 | 194 | 138 | 81 | 259 | 391 | 427 | 2090 | |
| 1930 | 213 | 62 | 164 | 233 | 265 | 54 | 295 | 233 | 389 | 104 | 284 | 205 | 2501 | 2355 |
| | | | | | | | | | | | | | | |
| 1931 | 217 | 269 | 40 | 227 | 236 | 157 | 408 | 263 | 406 | 71 | 199 | 84 | 2577 | |
| 1932 | 81 | 88 | 174 | 264 | 377 | 57 | 409 | 284 | 320 | 279 | 139 | 63 | 2535 | |
| 1933 | 125 | 233 | 226 | 114 | 143 | 162 | 70 | 56 | 243 | 281 | 194 | 63 | 1910 | |
| 1934 | 134 | 76 | 141 | 206 | 54 | 104 | 191 | 204 | 117 | 93 | 206 | 341 | 1867 | |
| 1935 | 216 | 171 | 47 | 255 | 59 | 244 | 60 | 158 | 264 | 250 | 400 | 263 | 2387 | |
| 1936 | 303 | 222 | 96 | 204 | 151 | 355 | 507 | 84 | 150 | 144 | 210 | 155 | 2581 | |
| 1937 | 320 | 291 | 315 | 260 | 475 | 154 | 330 | 41 | 159 | 217 | 157 | 267 | 2986 | |
| 1938 | 236 | 130 | 27 | 17 | 210 | 99 | 215 | 132 | 189 | 154 | 161 | 403 | 1973 | |
| 1939 | 458 | 64 | 181 | 230 | 78 | 169 | 314 | 249 | 135 | 425 | 300 | 211 | 2814 | |
| 1940 | 207 | 251 | 165 | 101 | 90 | 79 | 361 | 49 | 62 | 266 | 457 | 150 | 2238 | 2387 |
| | | | | | | | | | | | | | | |
| 1941 | 378 | 252 | 358 | 93 | 294 | 73 | 563 | 394 | 94 | 218 | 307 | 55 | 3079 | |
| 1942 | 238 | 143 | 135 | 75 | 252 | 93 | 223 | 252 | 148 | 228 | 285 | 150 | 2222 | |
| 1943 | 383 | 28 | 57 | 107 | 205 | 229 | 99 | 237 | 193 | 108 | 155 | 74 | 1875 | |
| 1944 | 164 | 181 | 19 | 183 | 99 | 275 | 224 | 270 | 380 | 226 | 254 | 113 | 2388 | |
| 1945 | 220 | 164 | 58 | 84 | 149 | 246 | 173 | 321 | 140 | 199 | 63 | 200 | 2017 | |
| 1946 | 110 | 246 | 107 | 116 | 156 | 223 | 214 | 354 | 219 | 242 | 514 | 218 | 2719 | |
| 1947 | 186 | 183 | 423 | 192 | 47 | 230 | 208 | 5 | 118 | 21 | 88 | 187 | 1888 | |
| 1948 | 375 | 91 | 49 | 115 | 267 | 304 | 106 | 228 | 214 | 220 | 144 | 203 | 2316 | |
| 1949 | 126 | 69 | 85 | 198 | 224 | 52 | 237 | 117 | 130 | 371 | 266 | 131 | 2006 | |
| 1950 | 85 | 302 | 62 | 218 | 285 | 172 | 268 | 240 | 217 | 67 | 370 | 123 | 2409 | 2292 |
| | | | | | | | | | | | | | | |
| 1951 | 250 | 309 | 335 | 223 | 317 | 74 | 123 | 365 | 124 | 102 | 398 | 127 | 2747 | |
| 1952 | 163 | 44 | 277 | 142 | 307 | 95 | 25 | 265 | 261 | 256 | 249 | 190 | 2274 | |
| 1953 | 100 | 188 | 87 | 165 | 271 | 343 | 196 | 356 | 110 | 219 | 213 | 77 | 2325 | |
| 1954 | 169 | 229 | 166 | 27 | 386 | 278 | 261 | 334 | 224 | 235 | 417 | 215 | 2941 | |
| 1955 | 244 | 304 | 199 | 105 | 302 | 232 | 34 | 88 | 99 | 150 | 136 | 160 | 2053 | |
| 1956 | 489 | 105 | 87 | 133 | 107 | 245 | 229 | 379 | 147 | 108 | 91 | 187 | 2307 | |
| 1957 | 110 | 265 | 195 | 29 | 157 | 218 | 264 | 242 | 390 | 106 | 194 | 224 | 2395 | |
| 1958 | 243 | 331 | 171 | 87 | 240 | 379 | 373 | 427 | 206 | 265 | 145 | 272 | 3139 | |
| 1959 | 294 | 17 | 266 | 127 | 71 | 58 | 227 | 95 | 34 | 103 | 162 | 344 | 1798 | |
| 1960 | 366 | 265 | 140 | 46 | 78 | 109 | 273 | 294 | 268 | 458 | 349 | 351 | 2997 | 2498 |
| | | | | | | | | | | | | | | |
| 1961 | 253 | 129 | 35 | 277 | 62 | 86 | 194 | 179 | 198 | 228 | 205 | 301 | 2147 | |
| 1962 | 126 | 54 | 124 | 232 | 116 | 12 | 156 | 282 | 274 | 81 | 238 | 138 | 1833 | |
| 1963 | 113 | 75 | 267 | 196 | 122 | 158 | 162 | 341 | 131 | 81 | 320 | 48 | 2014 | |
| 1964 | 79 | 102 | 296 | 192 | 60 | 268 | 88 | 176 | 75 | 96 | 111 | 134 | 1677 | |
| 1965 | 204 | 77 | 210 | 164 | 119 | 155 | 284 | 205 | 451 | 24 | 298 | 405 | 2596 | |
| 1966 | 117 | 298 | 39 | 314 | 177 | 326 | 198 | 311 | 185 | 269 | 197 | 219 | 2650 | |
| 1967 | 66 | 126 | 86 | 219 | 391 | 142 | 123 | 107 | 135 | 303 | 199 | 145 | 2042 | |
| 1968 | 146 | 75 | 67 | 255 | 194 | 221 | 428 | 325 | 346 | 197 | 247 | 131 | 2632 | |
| 1969 | 287 | 183 | 256 | 132 | 470 | 172 | 242 | 157 | 26 | 30 | 299 | 255 | 2509 | |
| 1970 | 213 | 176 | 134 | 277 | 27 | 101 | 160 | 211 | 86 | 73 | 479 | 140 | 2077 | 2218 |
| | | | | | | | | | | | | | | |
| 1971 | 268 | 32 | 167 | 143 | 202 | 198 | 114 | 297 | 80 | 146 | 217 | 140 | 2004 | |
| 1972 | 192 | 111 | 248 | 129 | 157 | 123 | 147 | 50 | 182 | 28 | 234 | 220 | 1821 | |
| 1973 | 60 | 66 | 61 | 156 | 384 | 352 | 298 | 53 | 233 | 143 | 72 | 143 | 2021 | |
| 1974 | 150 | 159 | 98 | 29 | 67 | 222 | 213 | 343 | 218 | 362 | 274 | 91 | 2226 | |
| 1975 | 202 | 76 | 354 | 286 | 235 | 45 | 195 | 84 | 179 | 59 | 132 | 129 | 1976 | |

in which the value of rainfall evidence decreases with distance, both annually and seasonally, is still under investigation. There are other homogeneous series published or in course of preparation, including series from Kew (Wales-Smith 1971)*, Manchester (Manley 1971)* and other places in Great Britain and also several from adjacent continental countries. Comparisons may suggest revision of a series which seems to be getting unreasonably out of line with the rest, or which is at variance with other evidence on the prevailing rainfall regimes; several years may elapse before climatologists can be assured that the homogenized records are as near the truth as the nature of the evidence will allow.

When evaluating and using a carefully constructed 'key-site' assemblage of monthly rainfall estimates made from recorded or intelligently adjusted totals at other places the following points should be borne in mind:

(i) The distribution of severe thunderstorms over a given area in a summer month can easily result in totals differing by as much as 2 inches at places only a few miles apart. Similarly, the distribution of intense rainfall in a major, synoptic-scale rainfall event lasting, say, two or three days can easily result in a 20 per cent difference between annual totals at two places with fairly low average annual rainfalls and only some 50 miles or even less apart.

(ii) At the worst an estimated monthly total for a 'key-site' is a good estimate of the rainfall not far from the site even if not at the site itself. At best the estimate is a close approximation to the true total fall at the site. Summer-month estimates are generally less reliable than those for other seasons. In the authors' view, the figures, with all their uncertainties, present a fairer view of the rainfall regimes of the East Midlands than has been available hitherto, and the references given enable any reader to judge the evidence for himself.

REFERENCES

- | | | |
|--------------------|------|---|
| BARKER, T. | 1771 | <i>Philos Trans</i> , 61 , p. 227. |
| DERHAM, W. | 1697 | <i>Philos Trans</i> , 20 , pp. 47-48. |
| HEBERDEN, W. | 1767 | <i>Philos Trans</i> , 59 , pp. 359-362. |
| JURIN, J. | 1722 | <i>Philos Trans</i> , 32 , pp. 422-427. |
| KURTYKA, J. C. | 1953 | Precipitation measurements study. Urbana, Illinois, State Water Survey Division. Report of Investigation No. 20. |
| LYNN, G. | 1740 | <i>Philos Trans</i> , 41 , pp. 686-696. |
| MANLEY, G. | 1971 | Manchester rainfall since 1765. <i>Manchester Memoirs</i> , 114 . |
| MILL, H. R. | 1901 | The development of rainfall measurement in the last forty years. <i>Brit Rainf 1900</i> , pp. 23-45. |
| NASH, W. C. | 1918 | The diminution of rainfall with elevation. <i>Brit Rainf 1918</i> , Pt I, pp. 34-39. |
| PAINTER, H. E. | 1975 | Preliminary results from a gravimetric rain-gauge. <i>Met Mag</i> , 104 , pp. 69-78. |
| SYMONS, G. J. | 1866 | An outline of rainfall investigations from A.D. 1677 to A.D. 1865. <i>Report of the British Association for 1865</i> . |
| | 1881 | On the rainfall observations made upon York Minster by Professor John Phillips. <i>Brit Rainf 1880</i> , pp. 41-45. |
| TOWNLEY, R. | 1694 | <i>Philos Trans</i> , 18 , p. 51. |
| WALES-SMITH, B. G. | 1971 | Monthly and annual totals of rainfall representative of Kew, Surrey from 1697 to 1970. <i>Met Mag</i> , 100 , pp. 345-362. |

* Both recently revised by the respective authors.

AGROMETEOROLOGICAL USE OF THE SYNOPTIC DATA BANK IN PLANT DISEASE WARNING SERVICES

By R. J. ADAMS and JUDITH M. SEAGER

SUMMARY

The agricultural section of the Meteorological Office has for some years offered a plant disease data service to the Ministry of Agriculture, Fisheries and Food. Information has been provided on the occurrence of weather conditions conducive to the spread of various plant diseases. In the past this service has been based on the manual extraction of meteorological data from incoming weather reports. An account is given of the conversion of these schemes to automatic extraction from the synoptic data bank of the Meteorological Office COSMOS computer. The form of the disease criteria and the advantages gained from a computerized scheme are described.

INTRODUCTION

The rate at which biological processes take place is affected by the weather and this applies not only to the growth and development of a particular plant but also to the diseases affecting it. Diseases which affect agricultural and horticultural crops can cause a reduction in yield which may be considerable in certain years. This means a financial loss both to the individual farmer and to the country as a whole. Sprays can be applied to combat some of the diseases, but applications need to be kept to a minimum because of their high cost, possible mechanical damage to the crop and long-term environmental effects.

Work has been carried out in the past by plant pathologists of the Ministry of Agriculture, Fisheries and Food (MAFF) and agricultural meteorologists to identify weather conditions which are favourable for the development and spread of certain crop diseases. In some cases it has been possible to define criteria for potential infection periods in terms of meteorological variables, quantities which are observed as routine. Other factors will affect the development of disease and these include the growth stage of the crop, existing disease levels and carry-over from previous years.

Plant pathologists, given information about potential infection periods together with a knowledge of these other factors, can advise on the need for spraying and the best timing to achieve optimum effect. It is usually necessary for the spray to be applied within a few days of the occurrence of an infection period, thus the information has to be passed to the plant pathologists with the minimum of delay. Schemes have been in operation (some for several years) whereby weather data for the past 24 hours have been examined, infection periods identified and plant pathologists informed by telephone, telex or letter. The number and efficiency of warning schemes which could be operated using traditional 'manual' methods were limited, thus an automated method was initiated to extend and improve the service. Computer programs have been written (the first became operational in 1975) which extract the required data from the synoptic data bank of the computer at Meteorological Office Headquarters. The data are automatically processed to check whether certain criteria have been satisfied. Finally a paper tape containing the required information is produced. This allows telex transmission of the data to MAFF Headquarters and thence to regional plant pathologists.

DISEASES FOR WHICH INFECTION PERIODS HAVE BEEN DEFINED

Apple scab

Apple scab is a fungal disease which causes lesions on the leaves and developing fruit which can become misshapen if heavily infected. The fungus overwinters on fallen leaves and infects the apple trees in the spring when the buds are bursting. The impact of raindrops causes spores to be released from the fallen leaves and then a period of leaf wetness allows the spores to infect the new growth on the tree. The length of the period of leaf wetness required for infection depends on the average temperature throughout the period. A 'Mills period' (Mills and La Plante, 1954) was defined, based on leaf wetness which is not an observed meteorological quantity. Following the development of an instrument for continuously recording the wetness of a polystyrene element (Hirst, 1957), it was found that hours of surface wetness correspond very nearly to hours when the relative humidity is not less than 90 per cent (Hearn, 1961). Although it is recorded, relative humidity is not reported hourly to Bracknell by observing stations. Since dry-bulb and dew-point temperatures are reported rounded to the nearest whole degree Celsius, calculations of relative humidity from these temperatures cannot be precise. A difference between reported dry-bulb and dew-point temperatures of 0°C or 1°C corresponds in most cases to a relative humidity of 90 per cent or more, but occasionally relative humidities in the range 88–90 per cent will be included and some greater than 90 per cent will be missed. Thus the depression of the dew-point may be used as an indicator of leaf wetness and it has been possible to redefine the criteria using only readily available meteorological data from hourly observations. 'Smith periods' have been defined as follows (Preece and Smith, 1961):

A possible infection period starts when precipitation is reported, and continues as long as there is precipitation, or a dew-point depression of 1°C or less is reported. Breaks in these conditions of one hour are allowed.* A 'Smith period' occurs when this period satisfies the temperature/time condition as for the 'Mills period'.

In practice this requires that the relative humidity criteria are satisfied for at least nine hours. A 'near miss' condition can also occur, defined as a period which is either one hour too short, or 0.5°C too cool to satisfy the temperature/time criteria.

Barley mildew

Barley mildew is a disease which, if unchecked, can spread very rapidly. It is a fungal disease in which the mildew affects the leaves, reducing their photosynthetic efficiency, producing a loss in grain yield which can be very severe, with annual losses estimated to be about £30–£40 million. These losses can be reduced dramatically by the timely application of suitable sprays.

Spores of barley mildew tend to be released under dry conditions and their spread assisted by strong winds. Two sets of criteria have been defined and are in current use. Polley and Smith (1973) suggested that the following conditions are favourable for spore release:

- daily maximum temperature above 15.6°C
- daily sunshine more than 5 hours
- daily rainfall less than 1 mm
- wind speed at 00, 06, 12 or 18 GMT greater than 15 knots.

The number of these conditions occurring determines the 'Polley count' for the day. A high-risk day is a day on which one of the following is satisfied:

a Polley count of 4

the 2nd consecutive day with a count of 3

the 3rd consecutive day with a count of 2 provided that at least one of these days had a count of 3.

An alternative method of identifying high-risk days is by means of the 'Smith index', I , defined as:

$$I = 3T + \frac{1}{2}W + H$$

where T = maximum temperature ($^{\circ}\text{C}$), W = wind speed at 1200 GMT (knots) and H = hours of sunshine for the day in question (Polley and Smith, 1973). A high-risk day is one on which this index exceeds 64.

Plant pathologists can advise on the best time to spray from a knowledge of high-risk periods, current levels of mildew in the crop and growth stage of the crop.

METHODS OF DERIVING PLANT DISEASE DATA

The criteria outlined in the previous sections were all designed (or subsequently modified) to incorporate data which are reported to the Meteorological Office Headquarters primarily for use in synoptic forecasts in the Central Forecasting Office. These data are automatically stored in the synoptic data bank of the Meteorological Office COSMOS computer complex to be immediately available for forecasting programs.

The barley mildew warning scheme was the first of the agrometeorological services to be automated, the new system being introduced in 1975. In previous years during the period 15 April–31 July relevant data were extracted by hand from copies of the teleprinter messages received from the collecting centres; 35 stations in England and Wales were used and these had to be identified from among all those reporting, as had the individual figures specifying the required elements in the messages. All the data required to calculate the Smith index and Polley count were then tabulated and passed to the Telecommunications Branch for manual punching and transmission to the appropriate recipients. An analyst familiar with meteorological codes and the day-to-day running of the scheme could expect to produce this final table within two to three hours of the last observation. The analyst also had to compute the Smith indices and Polley counts for stations in the south-east region, and inform plant pathologists by telephone if they reached critical values. For other regions, the meteorologists at MAFF Bristol, Cambridge and Harrogate were responsible for these calculations and the information service.

The computer program followed essentially the same series of operations as those involved in the manual operation, but in addition indices and counts for all stations were evaluated and included in the final table. The main problems in programming arose from the different ways in which the same meteorological information is reported by different classes of observing stations. For example, some stations report maximum temperature and a 12 hour rainfall total at 2100 GMT; others report at 0900 GMT on the following day, with a 24 hour rainfall figure. Some stations report sunshine hours in precisely defined positions within the message while others include this information within one of a varying

number of '9-groups'. The program thus has to identify the appropriate group of figures if present and recognize that it refers to sunshine hours and not, for example, to optical phenomena such as rainbows or haloes. A small section of the program deals with the computation of daily rainfall totals involving trace amounts, which are stored as -0.1 mm in the synoptic data bank. The program also has to cope with occasions of missing and, to some extent, misreported data. For example, the absence of sunshine hours from the calculation of the Smith index would give an erroneous result, but the failure to include an observation of a 1200 GMT wind would not matter in the calculation of a Polley count if (and only if) a report at one of the other observing times exceeded 15 knots.

The program produces a table of meteorological data, indices and counts in a computer printout format. To eliminate the need for manual punching of the table by telecommunications staff a further section was written to provide a simultaneous output of the table on paper tape, in the particular form required for teleprinter transmission. This message is then passed by telex to MAFF Headquarters for insertion in their telecommunications network for transmission to the regional meteorologists and plant pathologists. The total computing time to extract and process the data and to prepare the tape for transmission is of the order of eight seconds (Central Processing Unit time). The scheme now covers over 50 stations, including for the first time some in Scotland. The program is run daily throughout the year, but results are communicated to plant pathologists only during the part of the year when mildew is likely (mid April to end of July). However, the meteorological data are of relevance to agriculturists throughout the year so distribution to the regional meteorologists is continued. Because of this more general application, a section to extract daily minimum temperatures has been included in the program.

An automated 'apple scab' service was introduced in 1976. For several years before its introduction a manual scheme had been in operation in which infection periods were identified from hourly observations plotted on charts. Ten stations in the southern half of England were used. The Plant Pathology Laboratory at Harpenden was notified by telephone of infection periods as they occurred and these were confirmed by post. Plant pathologists at the Reading Regional Office of MAFF were informed by telephone of infection periods in their region.

The new scheme has enabled the number of observing stations used to be increased to 29. The distribution to the recipients has been improved, following the same method as that used in the barley mildew service. The computer program developed for the scheme uses several of the techniques in the barley mildew program. The principal difference lies in the cumulative aspect of the apple scab criteria in that the treatment of each observation depends on previous observations. The program is run each day throughout the critical time of year (1 March to 15 June). Data for each of the previous 24 hours are extracted, rainfall and relative humidity criteria examined and, when a high humidity period has ended, the time/temperature criteria are checked against a mathematical representation of the Mills time/temperature criteria. At the end of each day's run details of any continuing high humidity periods need to be stored for use on the following day.

INCLUSION OF OTHER DISEASES

Schemes for two further diseases were introduced in 1976 and are on a trial basis. *Rhynchosporium* of barley and *septoria* of wheat are diseases for which experimental criteria have been suggested. Information on infection periods using these criteria is useful to plant pathologists currently conducting trials and may allow the criteria to be confirmed so that new routine services can be introduced. The criteria at present used for *rhynchosporium* require the same hourly data as those for apple scab. For *septoria*, rainfall totals are also needed and these are provided in the data output by the barley mildew program.

CONCLUSION

The automatic warning schemes have several advantages over the old methods. The repetitive process of data extraction is accomplished in seconds and the man-hours spent on the task are considerably reduced. Difficulties arising over backlogs of work after weekends and public holidays have been removed, and the load upon the limited staff of regional meteorologists has been reduced. The greater speed of the computerized scheme makes possible the incorporation of more observing stations thus giving a better service over the country. The resulting data are distributed earlier and to a greater number of interested recipients. Finally, the basic agrometeorological programs for extracting information from the synoptic data bank may apply to any agrometeorological situation where relationships with current meteorological data have been developed. Thus a continually improving service can be offered to the agricultural community.

The agrometeorological programs provide data on meteorological conditions consistent with the spread of plant diseases only if other conditions are satisfied in the field. The plant pathologists have to apply their own expertise and knowledge to the information which the Meteorological Office provides and to find appropriate ways of speedily conveying their warnings and advice to the farming and horticultural community.

ACKNOWLEDGEMENTS

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REFERENCES

- | | | |
|--------------------------------------|------|---|
| HEARN, J. M. | 1961 | The duration of surface wetness. <i>Met Mag</i> , 90 , pp. 174-178. |
| HIRST, J. M. | 1957 | A simplified surface wetness recorder. <i>Plant Pathology</i> , 6 , pp. 57-61. |
| MILLS, L. D. and LA PLANTE, A. A. | 1954 | Diseases and insects in the orchard. <i>Cornell Ext Bull</i> No. 711, pp. 20-27. |
| POLLEY, R. W. and SMITH, L. P. | 1973 | Barley mildew forecasting. <i>Proc 7th British Insecticide and Fungicide Conf</i> , pp. 373-378. |
| PREECE, T. F. and SMITH, L. P. | 1961 | Apple scab infection weather in England and Wales, 1956-60. <i>Plant Pathology</i> , 10 , pp. 43-51. |

RAINFALL CRITERIA FOR URBAN DRAINAGE DESIGN

By J. F. KEERS

SUMMARY

An appraisal is made of those aspects of rainfall which are important for the economic design of urban storm water drainage systems. These include the mean rainfall intensity for specified durations, the average frequency of occurrence and regional variability of heavy local falls, the relationships between rainfall intensity and time (storm profiles) and between rainfall at a point and over an area. Also discussed are other aspects of rainfall which may be important as input to models of more advanced design including statistics describing the movement of extreme rainstorms, for example once-in-two-year storms, across the catchment.

INTRODUCTION

Urban drainage is concerned with the disposal of storm water, the removal of all waste water and the control of flood waters. Storm water, often referred to as surface water, is defined as the run-off of rainfall from both natural and artificial surfaces such as roads, roofs, etc. In many urban areas storm water and domestic sewage are discharged into the same pipe system, referred to as a combined system. There are also many examples of partially combined systems in the United Kingdom. In general, however, new sewerage schemes use separate systems for storm water and domestic sewage and then only the storm water sewers present a design problem because of the great variability of storm rainfall. In the United Kingdom the design of urban drainage schemes is commonly based on rainfall events (design rainfalls) with a frequency of between once a year and once in ten years but which may be up to once in 100 years in special circumstances.

The designer of storm water sewers is concerned with two types of rainfall: average rainfalls over long periods and heavy rainfalls of short duration, usually less than two hours. The former are required for estimating annual pumping costs, and the latter for determining the size of sewers, pumps, etc. The good daily rain-gauge network in the United Kingdom, approximately 3000 stations in the year 1900 and 7000 stations today, has enabled meteorologists to determine for any location or catchment area (i) monthly, seasonal and annual rainfall averages, and (ii) the geographical variation of daily or longer-period rainfall totals with any specified frequency of occurrence.

The network of continuously recording rain-gauges is much less dense than the daily rain-gauge network and until recently the best statistics of short-duration rainfall, i.e. less than a few hours, were those derived by Bilham (1936) and modified by Holland (1964). Bilham used 10 years of data (1925 to 1934) from only 12 recording rain-gauge stations widely distributed throughout England and Wales to derive a formula for estimating an average frequency of intense short-duration rainfall (up to two hours duration). Holland (1964) modified Bilham's formula for rainfalls with intensity above 32 mm/h. Holland (1967) also investigated plots of rainfall intensity against time, hereinafter referred to as storm profiles, and the relationship between point and areal rainfall for areas up to 20 km² in size using data from a close network, with an inter-gauge spacing of approximately 1 kilometre, of recording rain-gauges near Cardington in Bedfordshire.

In the mid 1960s the Road Research Laboratory (RRL)—now the Transport

and Road Research Laboratory (TRRL)—developed a computer package based on *Road Note* No. 35 (1963) for assisting with the design of drainage systems, including sewer systems. The RRL method used the results of Bilham and Holland for determining design rainfalls. Neither Bilham nor Holland considered the geographical variation of frequencies of short-duration rainfall. Moreover, neither author overcame the restrictions imposed by the shortage of long-period records from recording rain-gauges or the problem of the great variability in time of extreme rainfall in a two-hour storm.

In order to overcome the limitations of the results of Bilham and Holland, an intensive investigation of rainfalls of all durations has been made using all available rainfall records, reports of thunder, observations of precipitable water, etc., for stations in the British Isles. This work was carried out under the direction of A. F. Jenkinson of the Meteorological Office during the years 1971 to 1974 and culminated in the publication of the *Flood Studies Report* (Vol. 2—Meteorological Studies) in March 1975. Vol. 2 of the *Report* quantifies the significant geographical variation in the rainfalls of any specified return period and duration up to one month. Also the availability of relatively long-period rainfall records from a selection of stations means that estimates of the rainfall of longer return periods derived using the *Flood Studies Report* are more reliable than previous methods of estimation. The *Flood Studies Report* also enables the storm profile to be specified for design purposes and this will be discussed in a later section.

MEAN RAINFALL INTENSITY FOR DESIGN PURPOSES

One of the most common storm sewer design methods is known as the Rational or Lloyd-Davies (1906) Method. This method relates the peak flow in the sewer, Q , to the size of drainage area, A , a surface impermeability factor, p , and the mean rainfall intensity, \bar{R} (the latter for a specified duration and average frequency of occurrence) as follows:

$$Q = C_1 A p \bar{R}, \quad \dots \quad (1)$$

where the constant C_1 depends on the units employed.

For a particular urban catchment the drainage area may be taken as constant and if the impermeability factor is also fixed, i.e. its variability is neglected, Equation (1) reduces to

$$Q = C_2 \bar{R}, \quad \dots \quad (2)$$

where C_2 is a known constant.

Before the Road Research Laboratory introduced their computer package for drainage design in the mid 1960s it was common practice to use an equation of type (1) or (2), and even today *Road Note* No. 35 (1963) (1976 revision in the press) recommends that such an equation should be used when the largest sewer does not exceed 2 ft (≈ 0.6 m) in diameter, since the simplifications involved are not significant in terms of selected pipe diameter. From Equation (2) the fundamental importance of the mean rainfall intensity over short durations is obvious and many researchers have devised equations for determining the rainfall in the United Kingdom for a range of durations and return periods (Bilham, 1936; Maclean, 1945; Holland, 1964). However, the *Flood Studies Report* (1975) undoubtedly presents the most reliable method so far devised for determining the design rainfall for any location in the United Kingdom; an example of the

sort of rainfall data which can be derived is given in Table I. In Table I an event with an average frequency of occurrence of once-in- N -years is referred to as an event with a return period of N years.

TABLE I—RATES OF RAINFALL AT BALA IN NORTH WALES FOR SPECIFIED DURATIONS AND RETURN PERIODS

| Duration (minutes) | Return period (years) | | | | | | |
|-----------------------|-----------------------|------|------|------|------|------|------|
| | 1 | 2 | 5 | 10 | 20 | 50 | 100 |
| | <i>mm/h</i> | | | | | | |
| 2 | 50 | 61 | 78 | 89 | 102 | 120 | 136 |
| 5 | 38 | 47 | 61 | 71 | 81 | 96 | 109 |
| 10 | 29 | 35 | 47 | 54 | 63 | 75 | 87 |
| 15 | 24 | 29 | 39 | 45 | 53 | 64 | 74 |
| 30 | 17 | 21 | 27 | 32 | 38 | 46 | 54 |
| 60 | 11.8 | 14 | 19 | 22 | 26 | 32 | 37 |
| 90 | 9.5 | 11.4 | 15 | 17 | 21 | 25 | 30 |
| 120 | 8.2 | 9.7 | 12.4 | 15 | 17 | 21 | 25 |
| (hours) | | | | | | | |
| 4 | 5.6 | 6.6 | 8.2 | 10.3 | 11.3 | 13.8 | 16.0 |
| 6 | 4.5 | 5.3 | 6.4 | 7.5 | 8.7 | 10.6 | 12.2 |
| 12 | 3.1 | 3.6 | 4.2 | 4.9 | 5.6 | 6.7 | 7.6 |

TIME OF CONCENTRATION

It has been common practice to design a storm sewer by assuming that the N -year peak flow in the sewer is directly attributed to the N -year rainfall. The mean rainfall of any specified return period decreases markedly with increasing duration and so it is very important to specify the optimum duration of rainfall for design. When Equation (1) or (2) is used the optimum duration is the time taken for the maximum flow in a sewer to reach the design point* from the remotest part of the drainage area. This duration is called the time of concentration and is made up of the time of entry, i.e. the time for rain water to run over roof and road surfaces etc. before reaching the sewer, plus the time of flow through the sewers to the point at which the discharge is to be calculated. In general the larger the drainage area the longer the time of concentration, but other contributory factors include the size and gradient (slope) of the sewers and the type of land and its use. The time for rain water to run off an unpaved surface, such as school playing fields, is greater than the time required to run off a steeply sloping roof and through a short length of drain before arriving at a sewer. Formulae for computing the time of peak run-off and time of flow in the sewers were developed more than 50 years ago but as with rainfall the variability with time presents problems. Typically the time of concentration varies between a few minutes for a small residential estate to a few hours for a medium-sized town.

STORM PROFILES

Storm rainfall rarely falls at a uniform rate. The profile of rainfall intensity versus time, as in Figure 1, is commonly referred to as a storm profile. For drainage design purposes the storm profile is important because for a specified duration and total rainfall the storm with the greatest peak intensity, i.e. the sharpest profile, will often result in the greatest peak flow in the sewer. Also the

* Design point: point of outfall of all upstream sewers for the particular piece of pipe being designed.

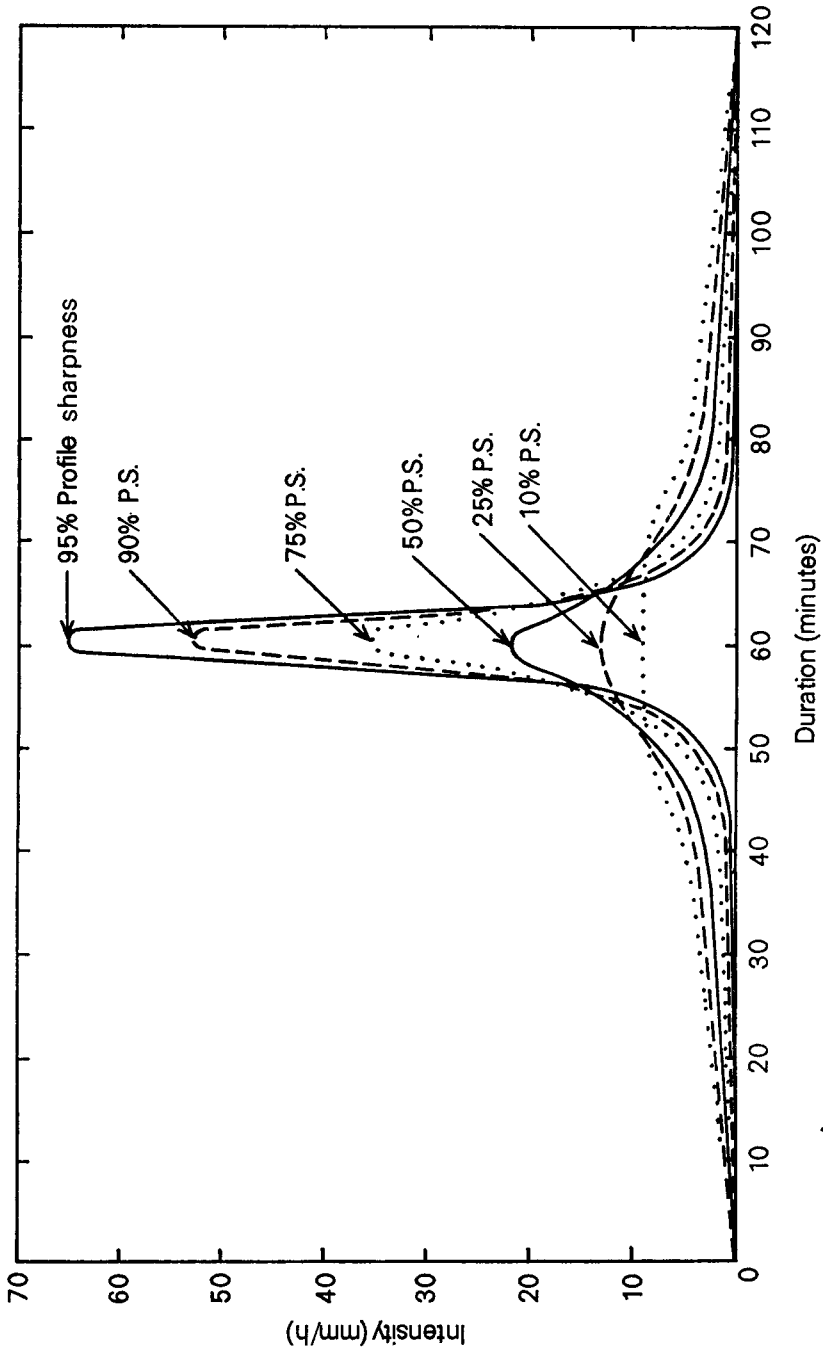


FIGURE 1—RANGE OF STORM PROFILES
(return period of one year)

variation of flow with time, i.e. the hydrograph, can only be investigated if the rainfall input is also allowed to vary in time as occurs in nature.

For a given storm duration and total rainfall there is an infinite variety of storm profiles. The variation is caused by the different rainfall types; for example, very sharp storm profiles of short duration (less than two hours) are usually associated with convective storm rainfall and flatter profiles with more continuous and less intense rainfall processes such as warm-front rain. The speed of movement of the rainfall system across the point or area and the local development and decay of rainfall intensity contribute to the shape of the storm profile. The research carried out in the Meteorological Office on the subject of storm profiles (*Flood Studies Report* (1975)) included a percentile analysis of profile sharpness. The results of this analysis apply to design storm profiles of any specified duration. The technique used by the Flood Studies research team ensures that all the storm profiles derived for design purposes are symmetrical about the mid point of the specified storm duration. A 90 per cent profile is one which is not exceeded in terms of sharpness of the storm profile shape on 90 per cent of occasions, where a numerical measure of sharpness is given by the ratio of maximum rainfall rate to mean rate over the whole duration of the storm. The 50 per cent profile is the median profile. Figure 1 shows some storm profiles at a given location for a fixed duration and return period. Figure 2 presents a range of 50 per cent profiles for the same location, and illustrates the fact that the shape of the profile is a function of the duration.

A design engineer is faced with some difficult problems if he wishes to use the results referring to the various shapes of the storm profile, for example how sharp should the storm profile be and what storm duration should be used. In practice an engineer generally opts for a simplified design technique. For example the RRL *Road Note* No. 35 (1963) storm sewer design technique uses the same storm profile for all locations, and although the rainfall changes with return period the shape and duration of the profile does not change. However, this approach assumes that variation of storm profile sharpness and storm duration are not important, which may not always be true.

A weakness of the storm profiles described in *Road Note* No. 35 (1963) is that the total rainfall in the two-hour period is varied according to the return period required, but no consideration is given to the probability of such a sharp storm profile occurring. Also there may be occasions when the optimum storm duration may be greater or less than two hours. These storm profiles simplify rainfall input since their construction assumes that one storm profile of specified return period is adequate for all pipe systems with a time of concentration of approximately two hours or less. This assumption stems from the N -year 10 minute rainfall being 'nested' in the N -year 15 minute rainfall and this in turn being nested in the N -year 30 minute rainfall, and so on up to 120 minutes.

The *Flood Studies Report* (1975) permits a design storm profile to be constructed to any predetermined specification and if the specification is not certain a variety of design storms can be constructed, all for a given return period. The best storm for a particular design purpose can then be determined by experiment.

The Meteorological Office and the Transport and Road Research Laboratory carried out a series of experiments with differently shaped storm profiles and concluded that there is a relationship between storm duration and the sharpness of the storm profile. In effect if the required once-in- N -year rainfall is distributed in time according to the median summer storm profile (50 per cent) then

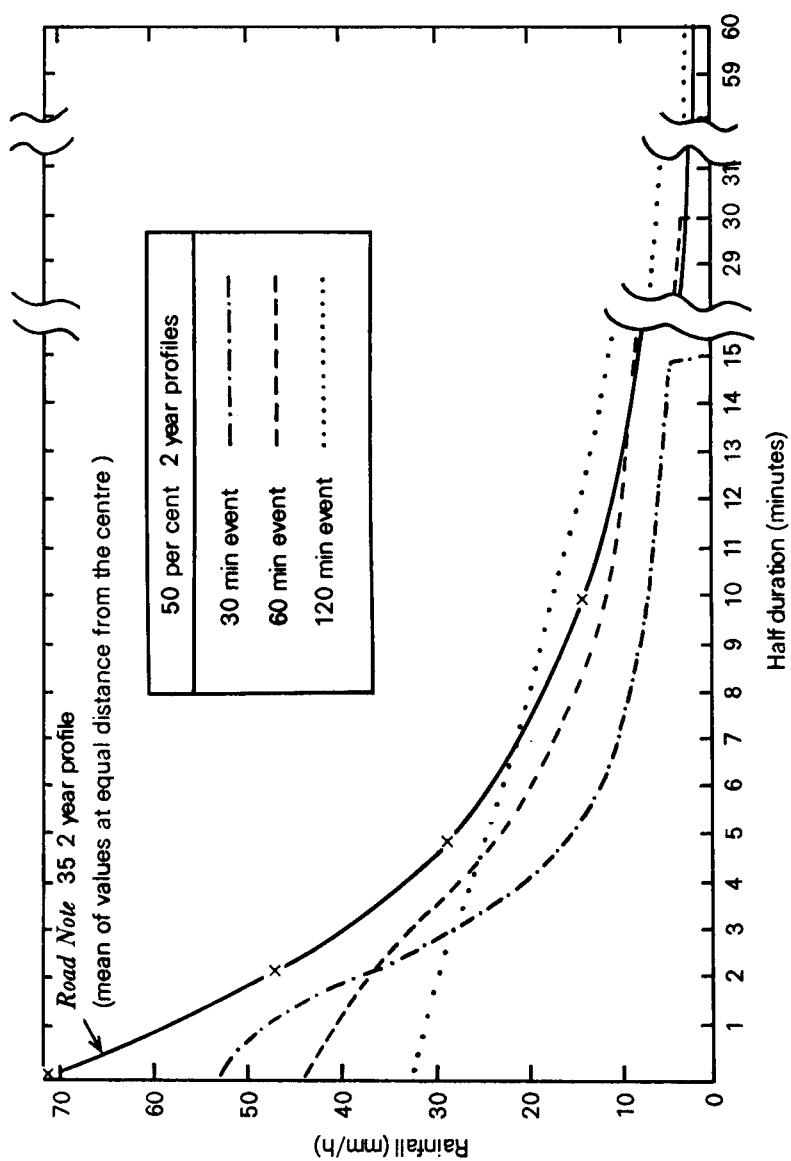


FIGURE 2—COMPARISON OF STORM PROFILES
(return period of two years)

the optimum (resulting in greatest peak flow) storm duration is between two and three times the time of concentration; for example the 60 minute storm should be used for a drainage scheme with time of concentration 20 to 30 minutes but the pipes lying far upstream should be designed using a shorter-duration storm or mean rainfall intensities applied by using the Rational Method. Figure 3 illustrates the application of this technique to a large urban surface water sewer system. The Institute of Hydrology (*Flood Studies Report*, Vol. 1 (1975)) also recommends a particular shape of storm profile (75 per cent winter profile) for river catchment studies with the storm duration determined from catchment characteristics and the total depth of rainfall determined by the specified return period.

Point to area rainfall relationships

The depth-duration frequency relationships for extreme rainfalls (twice-a-year and over) discussed earlier in this paper all refer to point rainfalls, i.e. to rainfall at a specific location, since they all derive from rain-gauge measurements. Invariably the design engineer requires information on areal rainfall rather than on point rainfall where typically the area may be an electricity generating station, an urban area, or a large river catchment.

Consider a particular river catchment with several rain-gauges suitably located to obtain a good estimate of the mean catchment rainfall. Some rainfall events will give little or no rain at a particular rain-gauge location even though the mean catchment rainfall is very large. Other rainfall occasions may result in an extremely high rainfall at the same rain-gauge location when the mean catchment rainfall is relatively low. However, for extreme rainfall events, for example once-a-year or rarer events, the N -year point rainfalls meaned over all rain-gauge locations will always be greater than or equal to the N -year catchment rainfall. This is because extreme rainfall events often affect only a limited part of a catchment and during the course of a year there are enough extreme rainfall events affecting different parts of the catchment to result in each point location's experiencing at least one rainfall that is greater than the greatest single rainfall event averaged over the whole catchment. This simplified explanation may not apply to a catchment with very varied rainfall characteristics, however, because in this case the N -year mean catchment rainfall may be greater than the N -year rainfall for some point locations in the generally drier part of the catchment; the practical application of the areal reduction factor (ARF) takes this into consideration.

The factor to be applied to the mean of the N -year point rainfalls to reduce it to the N -year catchment rainfall is commonly called an areal reduction factor (ARF). The spatial variability of rainfall is such that the ARF approaches unity as the size of area decreases. Also the spatial scale of storm rainfall generally increases with increasing duration, therefore for design storms the ARF approaches unity as the rainfall duration increases. Table II presents the relationship between the ARF, size of area and rainfall duration, as given in the *Flood Studies Report* (1975).

Every rainfall event affects an area rather than a point and the area-depth relationship is different in every case. The values of ARF in Table II present a statistical relationship between N -year point rainfalls and N -year areal rainfall events, where the geographical differences are accounted for by the differences in point rainfall values. Thus depth-duration-frequency statistics for areal rain-

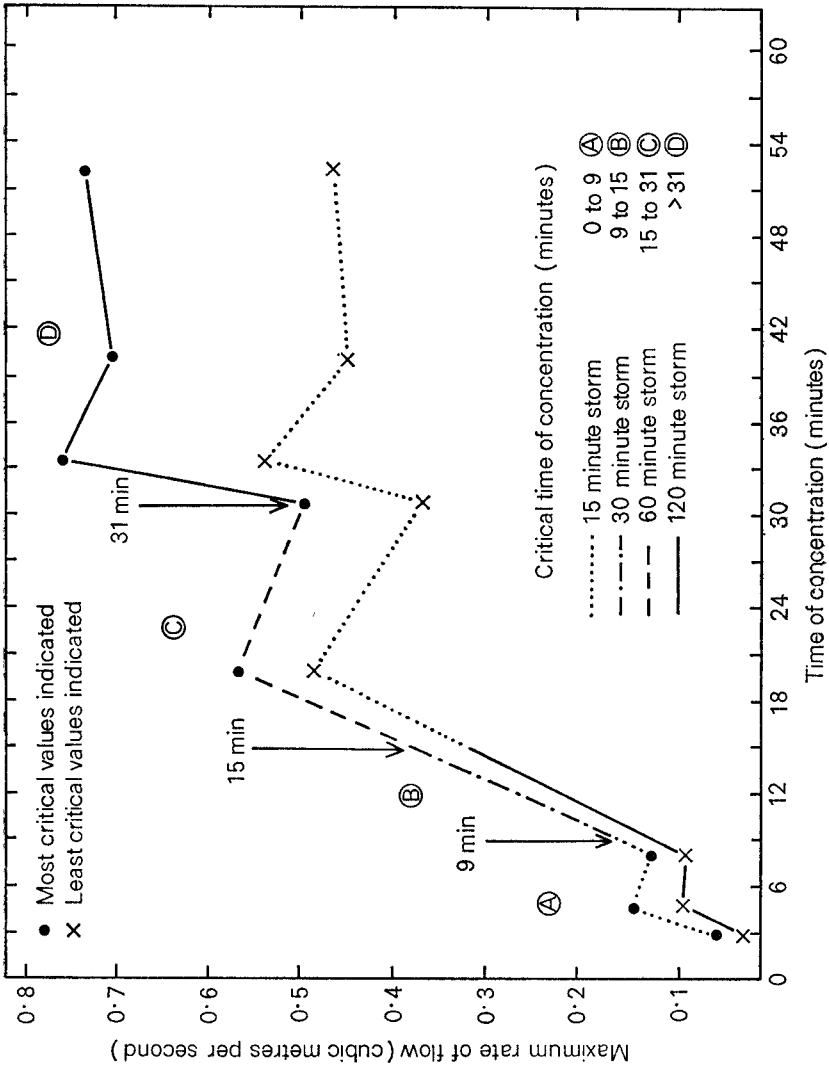


FIGURE 3—VARIATION OF FLOW RATES WITH TIME OF CONCENTRATION AND DURATION OF STORM EVENT

fall can be derived from the comprehensive statistics of point rainfall. An alternative approach using only areal rainfall factors to investigate areal rainfall statistics is not justified in view of the relatively limited data on extreme areal rainfall events compared with point rainfall measurements in many parts of the United Kingdom. Also the spatial variability of rainfall is such that in many instances areal rainfall cannot be adequately measured from the existing network of rain-gauges.

TABLE II—AREA REDUCTION FACTOR

| Duration (minutes) | Area (km ²) | | | | | | |
|-----------------------|-------------------------|------|------|------|------|------|------|
| | 1 | 5 | 10 | 30 | 100 | 300 | 1000 |
| 5 | 0.90 | 0.82 | 0.76 | 0.65 | 0.51 | 0.38 | 0.28 |
| 10 | 0.93 | 0.87 | 0.83 | 0.73 | 0.59 | 0.47 | 0.32 |
| 15 | 0.94 | 0.89 | 0.85 | 0.77 | 0.64 | 0.53 | 0.39 |
| 30 | 0.95 | 0.91 | 0.89 | 0.82 | 0.72 | 0.62 | 0.51 |
| 60 | 0.96 | 0.93 | 0.91 | 0.86 | 0.79 | 0.71 | 0.62 |
| (hours) | | | | | | | |
| 2 | 0.97 | 0.95 | 0.93 | 0.90 | 0.84 | 0.79 | 0.73 |
| 3 | 0.97 | 0.96 | 0.94 | 0.91 | 0.87 | 0.83 | 0.78 |
| 6 | 0.98 | 0.97 | 0.96 | 0.93 | 0.90 | 0.87 | 0.83 |
| 24 | 0.99 | 0.98 | 0.97 | 0.96 | 0.94 | 0.92 | 0.89 |

STORM MOVEMENT AND OTHER RAINFALL FACTORS

The models used for designing urban storm water sewer systems in the United Kingdom do not specifically take account of the dynamic effects associated with storms moving across the drainage catchment. The effect of storm movement is to complicate the sequence, and therefore the magnitude, of the peak flows in the various branches of the sewer system. The peak flows may be significantly increased if the storm rainfall movement is of comparable speed and direction to the flow in the sewer system. Speed of storm rainfall movement often exceeds 10 m/s, which reduces the possibility of movement significantly affecting the peak flow in the sewer, since the latter is generally less than 3 m/s. However, if there are preferred directions of storm rainfall movement then this may be important for some drainage purposes. Other rainfall factors such as shape and orientation of the rainfall area are relatively unimportant factors for urban drainage design criteria.

Many towns and cities in the United Kingdom have large recreational areas, and many have flood plains adjoining rivers and streams, wherein antecedent rainfall may be important for drainage design purposes through its effect on soil moisture and hence on rainfall run-off characteristics. The latter is a subject which is now being investigated at several establishments including the Institute of Hydrology, Bristol University and Imperial College, using statistical-empirical models, analytical models and physical models. Given a design rainfall, the surface run-off must be determined and then the actual flows in the sewer must be estimated. The latter is a problem of hydraulics and is being studied at the Hydraulics Research Station, Wallingford.

CONCLUSION

The rainfall depth, for a specified frequency and duration (approximately the time of concentration of the sewer system) is the most important single rainfall

factor for design purposes. The location with respect to preferred areas of heavy short-duration rainfall is also important. Storm profiles represent the variation of rainfall in time and obviously this variability is significant since storm water sewers are designed to cope with peak flows rather than mean flows. The spatial variation of rainfall over a drainage area is dealt with statistically by applying an areal reduction factor.

REFERENCES

- | | | |
|---|------|---|
| BILHAM, E. G. | 1936 | Classification of heavy falls in short periods. <i>Brit Rainf</i> 1935. |
| HOLLAND, D. J. | 1964 | Rainfall intensity-frequency relationships in Britain. Hydrological Memorandum No. 33, Meteorological Office, Bracknell, Berks. |
| HOLLAND, D. J. | 1967 | The Cardington rainfall experiment. <i>Met Mag</i> , 96 , pp. 193–202. |
| Wallingford, Institute of Hydrology | 1975 | Hydrological Studies. <i>Flood Studies Report</i> —Vol. 1, NERC, London. |
| LLOYD-DAVIES, D. E. | 1906 | The elimination of storm water from sewerage systems. <i>Proc ICE</i> , 164 , pp. 41–67. |
| Bracknell, Meteorological Office | 1975 | Meteorological Studies. <i>Flood Studies Report</i> —Vol. 2, NERC, London. |
| MACLEAN, D. J. | 1945 | Rainstorm data. <i>Surveyor</i> , 104 , p. 34. |
| Crowthorne, Road Research Laboratory | 1963 | A guide for engineers to the design of storm sewer systems. <i>Road Note</i> No. 35, HMSO. |

REVIEWS

The weather almanac (first edition), edited by J. A. Ruffner and F. E. Blair. 225 mm × 150 mm, pp. viii + 578, Gale Research Company, Book Tower, Detroit, Michigan, 1974. Price \$17.50.

The major part of this Almanac describes the weather and climate of the United States of America. The averages and extremes of temperature and the averages of precipitation and sunshine are presented in a series of charts for the country as a whole and these are followed by sections describing the types of severe weather affecting various regions, hurricanes, tornadoes, winter storms, heat waves etc. Over one-half of the volume is devoted to detailed statistics for over 100 cities throughout the 50 States. Accompanying texts successfully highlight the principal features of the topographical situation and local climate of each city. The Almanac should appeal to the weather-conscious citizen who wishes to know the average conditions to be expected during a business journey or when on vacation. A comparatively short section entitled Round-the-World Weather contains basic temperature and rainfall statistics for some 500 locations outside the USA.

P. G. F. CATON

British weather disasters, by Ingrid Holford. 250 mm × 170 mm, pp. 127, *illus.*,

David and Charles, Brunel House, Newton Abbot, Devon, 1976. Price £4.75.

This book is an attempt to gather together non-technical descriptions of some of the disasters resulting from weather action which have occurred in Britain over the last three centuries. The criteria for the selection of the events described are not stated or even implied, since although loss of life occurred in most of the cases discussed, one or two resulted merely in damage, albeit severe, to property or structures. Of the 39 events described, 30 are from the present century and 23 occurred after 1950, but this apparent bias towards more recent events is perhaps understandable in a book intended for the popular market. Press reports have been used extensively as the basis for the descriptions of the events from recent decades and many spectacular photographs of devastation accompany the text.

The earliest case described is one of lightning damage to the church at Widecombe-in-the-Moor, Devon, on 21 October 1638, and the latest one of local flooding at Surbiton in July 1973. Other notable rainfall flooding events described include the two events in southern England in 1968, the Lynmouth catastrophe of 1952 and the Norwich flood of 1912. The storm surge floods of 1928 and 1953 are discussed, as are the effects of the 1947 snowmelt floods. Occasions of severe wind damage in urban areas include the Sheffield gales of 1962 and the central Scotland gales of 1968. In most cases, the author presents a simple description of the synoptic development prior to the event, and then describes the damage caused and the effects on the unfortunate people involved.

A few errors were noted in the book. The date of the Tay Bridge collapse is consistently given as 1897, instead of 1879, and the diagram purporting to show calculated streamlines over the Pennines at the time of the Sheffield gales of 16 February 1962 relates, in fact, to 12 February.

The scientific content of this book will satisfy neither the professional meteorologist, concerned with understanding and possibly predicting extremes of weather, nor the professional engineer, concerned with establishing a rational and economic design standard. However, the human implications of weather disasters should be borne constantly in mind by both. Unless one has been personally involved with events of the kind described, the memory of such events soon fades, and so perhaps an important function of a book such as this is to act as a reminder to meteorologists, hydrologists and structural engineers that disasters continue to occur in Britain despite improvements in their technical skills.

J. S. HOPKINS

Note. That the wrong streamline diagram for the Sheffield gale was printed in *British Weather Disasters* was to a considerable extent the fault of the Meteorological Office who supplied the wrong original drawing of the diagram from *Geophysical Memoirs* Mo. 108. This drawing had been incorrectly annotated and the mistake was not discovered until the book was ready for publication.

(Editor)

The physics of atmospheric ozone, A. Kh. Khrgian, 245 mm × 175 mm, pp. v + 262, *illus.*, (translated from Russian by Israel Program for Scientific Translations, Jerusalem), John Wiley and Sons Ltd, Baffins Lane, Chichester, Sussex, 1975. Price £13.25.

The book is a translation of a Russian original published in 1973. It sets out to give an historical review of all branches of research on ozone in the atmosphere,

with the exception of its role in the ionosphere and in polluted urban atmospheres. The translation reads easily, though at least in one place transliteration into Cyrillic script and back again has transformed Århus into Orkhus. The technical description of instruments clearly presents problems for a translator, and it is not clear whether it was during translation into Russian or back into English that 'phosphor' became 'phosphorus' (p. 48) and 'sputtering' became 'spraying'.

There is little doubt that the Russian original provided a useful background for workers entering the sphere of ozone research after the upsurge of interest which followed the assertion in 1971 that oxides of nitrogen in the exhaust of stratospheric aircraft could damage the ozone layer. There is, however, no mention of this in the text and the only extension of the Chapman oxygen-only photochemical model to find a place is the inclusion of odd hydrogen species OH and HO₃. The latest of the 436 references is dated 1970.

While the book is an historical review, it has a typically eastern lack of historical perspective. All authors are equally in the foreground of the picture. Thus one is left at the end of Chapter V with the impression that the only significant measurements of ozone in the troposphere are those of Kay in 1952-53 and Britaev in 1960-61, quite ignoring the wealth of data available from the lower portions of stratospheric ozonesonde ascents. This particular instance is due in part to the author's distrust of ozonesondes in the troposphere, which he states without justification in Chapter VIII (p. 147). Elsewhere the tendency is to accept all authors and data uncritically.

The units used in ozone research have varied over the years, depending on the starting point of the authors' interests, and the inclusion of a section on units in Chapter III is very useful. The author points out that the reduced thickness of ozone per kilometre of atmosphere (expressed in 10⁻³ cm/km) is in fact a measure of ozone (partial) density, and gives the equivalent in μg m⁻³. He then, astonishingly, says it is a volume mixing ratio of 10⁻⁸, and is abbreviated pp h m.

Notwithstanding the probable usefulness of the Russian original, this translation is now little more than a comprehensive review of ozone literature prior to 1971, and as such is of only limited use to anyone engaged in ozone studies in the late 1970s.

E. L. SIMMONS

CORRECTION

Meteorological Magazine, March 1977, p. 91. After end of 'The Meteorological Magazine 1866-1977' article, add

REFERENCES

- | | | |
|-------------------|------|------------------------------------|
| CARTER, H. E. | 1951 | <i>Brit Rainf</i> , 1949, pp. 1-2. |
| GLASSPOOLE, J. G. | 1950 | <i>Met Mag</i> , 79, pp. 180-182. |
| MILL, H. R. | 1923 | <i>Met Mag</i> , 58, pp. 97-99. |
| | 1938 | <i>Met Mag</i> , 73, pp. 165-168. |

OBITUARIES

It is with regret that we have to record the death on 9 December 1976 of Mr R. R. Webb, Assistant Scientific Officer, Port Meteorological Office, Southampton, and on 27 January 1977 of Miss J. C. Perfect, Higher Scientific Officer, Met 0 11.

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NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire, RG12 2SZ, and marked 'For Meteorological Magazine'.

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