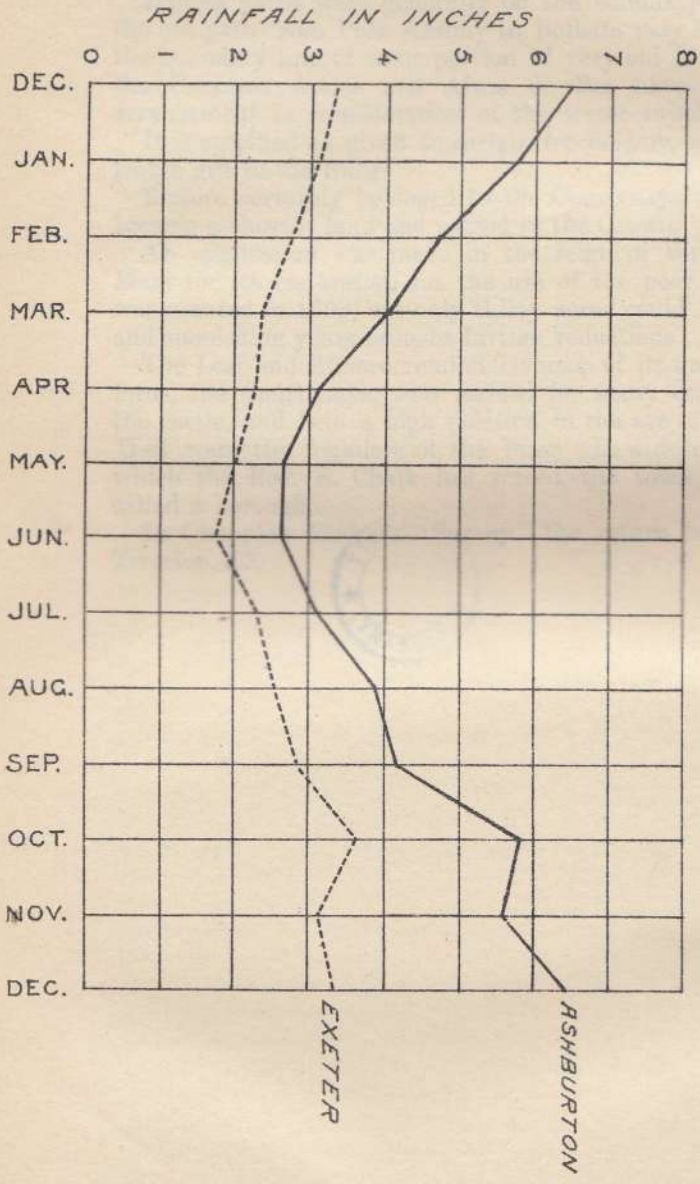


MONTHLY RAINFALL

PLATE I

RAINFALL IN DEVON.—*To face p.* 223.

RAINFALL IN DEVON,
ESPECIALLY FOR THE YEARS 1896–1905.

BY R. HANSFORD WORTH.

(Read at Axminster, 24th July, 1907.)

ALTHOUGH the true object of this paper is to discuss averages of rainfall for the period 1896–1905 inclusive, yet it is necessary to a proper understanding of such averages to consider the relation which the rainfall of that decade has borne to the fall over longer periods.

For this purpose two sets of data are available—the forty years' record at Druid, Ashburton, and the yet longer series of returns from the Devon and Exeter Institution, Exeter. These have been considered in some detail in the Climate Committee's reports read at the last and at the present meeting.

In the ten years' averages use has been made of every published record issued during the period, fifty-eight stations in Devonshire have been continuously recorded, and 137 stations show returns for some part of the time.

Certain matters not dealt with in the above-named reports of the Climate Committee are of sufficient interest to be here inserted, even at the risk of some overlap.

The monthly averages for Ashburton and Exeter for the forty years 1866–1905 should be compared; a graphical comparison is made in Plate I. At Ashburton the maximum rainfall occurs in December, with a lesser maximum in October—this is a place of true winter rain, but not out of the influence of autumnal rains. At Exeter the maximum rainfall occurs in October, with a lesser maximum in December, thus constituting it a station of true autumn rain, influenced by the winter rains. Both at Ashburton and Exeter the minimum occurs in June, but none the less absolute droughts in that month are infrequent. It appears, therefore, that on the whole Devonshire belongs to

the subtropical rainfall region, although it lies considerably north of the true northern limit of that area. But our drier stations appear slightly more removed from subtropical conditions than are the wetter stations.

Still our concession to latitude appears in the comparatively moist summers which are our usual experience, and in the extreme annual irregularity of the monthly rainfall. June is on the average the driest month, but only six times in forty years was it actually the month of least rainfall at Exeter.

In forty years at Exeter, January was the driest month in four different years; February in four years; March in six years; April was never actually the driest month of any year, but was frequently only a little removed from that position; May was the driest month in four years; June in six years; July in six years; August in two years; September in two years; October was never driest; November was the driest month in four years; and December in two years.

Thus any month in the year, except April and October, has a chance of yielding the lowest monthly rainfall, and April is frequently separated from the month of lowest fall by a few hundredths of an inch only.

When we come to the question of how much rain, or rather how little, may fall in one month, we find, at Exeter, June, 1887, with no rain whatever, and so also February, 1891, the month preceding the Blizzard. Ashburton yields, February, 1900, with no rain, and May, 1878, with only one-hundredth of an inch. On the other hand we have the extremely wet months, at Exeter, December, 1876, with 9·48 in. of rain, October, 1875, with 9·00 in.; and even June, 1879, gave 6·04 in. At Ashburton the figures are: December, 1876, 16·92 in.; October, 1903, 12.98 in.; June, 1879, 11.30 in.; the average for June being 2·64 in.

The months of greatest rainfall are not quite so surprisingly distributed over the year, but at Exeter January has been the wettest month in three years only out of forty, the figures for the whole of the months being as follows:—

January, wettest month three years out of forty; February, six years; March, two years; April, two years; May, June, and July, never in the forty years; August, one year; September, four years; October, twelve years; November, four years; December, six years.

Any month, therefore, except May, June, or July, may be the wettest of the year, but at Exeter the chances are heavily in favour of October.

There is yet another way to regard the matter, by estimating the rainfall probability of each month; that is to say, the probability that rain will fall on any one day of the month, which is ascertained by dividing the average number of rainy days in each month for, in this case, forty years, by the actual number of days in the month. This has been done for Ashburton, where it is found that in December you have two chances in three of getting a shower, and in May two chances in five—these are the extremes.

DAILY RAIN-PROBABILITY OF 0·01 INCH FALL AT ASHBURTON ON FORTY YEARS' AVERAGE.

	Rainy days.		Days in month.		Rain-probability.
January	17	÷	31	=	·55
February	14	÷	28	=	·50
March	15	÷	31	=	·48
April	14	÷	30	=	·47
May	12	÷	31	=	·39
June	13	÷	30	=	·43
July	16	÷	31	=	·52
August	15	÷	31	=	·48
September	16	÷	30	=	·53
October	19	÷	31	=	·61
November	19	÷	30	=	·63
December	20	÷	31	=	·65

It thus appears that May would impress one as the driest month, with, say, two showery days out of five, while December would seem the wettest, with thirteen wet days out of every twenty (May eight out of twenty). But for better information it would be necessary to ascertain the average number of days for each month on which, say, ·10 of an inch ($\frac{1}{10}$) of rain fell, that amount constituting something much nearer the popular conception of a rainy day than ·01 inch ($\frac{1}{100}$), which amounts to a slight shower only.

Devonshire is a county of moderately high rainfall; the average for the fifty-eight stations where records are complete for the ten years 1896–1905 has been 41·62 inches. And, with rain, Devon also has its rainy days, by which is meant days on which one-hundredth of an inch or more of rain falls, for comparison with other counties the seven years 1899–1905 have been taken, during these we have had an average of 185 rainy days for the year; during the same period Essex averaged 150, Middlesex 153, Bedfordshire

157, the East Riding of Yorkshire 171, the North Riding 176, the West Riding 187, Anglesea 185, and Cornwall 195.

Rainfall and rainy days are not so closely connected as may be thought; reverting again to the ten-year period under consideration, *Princetown* averaged 77·08 in. of rain the year, which fell on 168 days; *Exeter* averaged 29·97 in. of rain, falling on 171 days; and *Torquay* 32·45 in. with 163 rainy days. The place of greatest rainfall by no means has necessarily more wet days than drier stations—but the fall is busier while it lasts.

There is some interest in ascertaining how Devon stands with relation to the extremes of English rainfall. *The Stye* in Cumberland heads the rain-gauges of England, as *Princetown* heads the gauges of this county. For the period 1896–1905 the annual fall at the *Stye* averaged 176·59 in. against *Princetown's* 77·08, excelling the latter by nearly 100 in.

The competition for lowest place in the English returns is rather keen—*Shoeburyness*, *Huntingdon*, *Beachy Head*, *Higham*, *Foulness*, *Great Leigh*, *Moulton*, *Barking*, *Dungeness*, *Hope-u-Dinmore* all occupy the position in some one of the ten years. The average derived by taking each in its turn is 16·22 in. the year, to compare with *Exmouth* at 27·86.

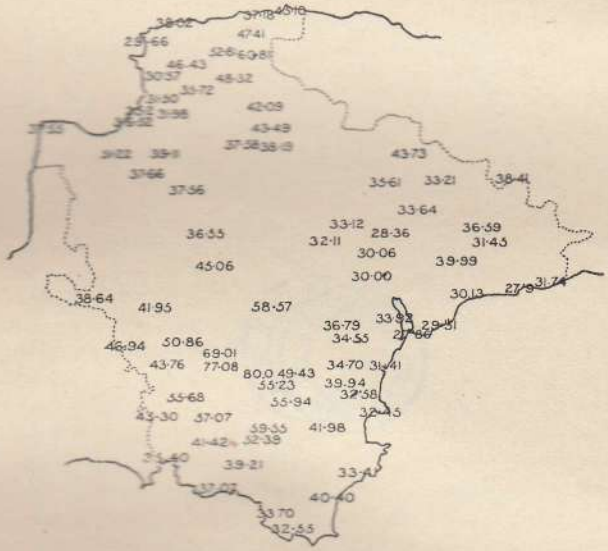
And, as a final comparison, the rainfall of *England and Wales*, 1881–1905, averaged 33·92 in.; of *Great Britain and Ireland* 39·25; and of *Devonshire* somewhat over 43 in.

Taking the decade as a whole, and judging by the long-record stations, the rainfall was about five per cent deficient, but the yearly fluctuations were considerable. The following was the average rainfall for each year of the whole fifty-eight stations which continuously recorded, with the rainfall of each year expressed as a percentage of the average fall throughout the decade.

1896, 35·85 in., 86·1 %. *1897*, 47·01 in., 112·9 %. *1898*, 37·17 in., 89·3 %. *1899*, 40·51 in., 97·3 %. *1900*, 46·22 in., 111·0 %. *1901*, 38·21 in., 91·8 %. *1902*, 37·32 in., 89.7 %. *1903*, 53·51 in., 128·6 %. *1904*, 44·90 in., 107·9 %. *1905*, 35·51 in., 85·3 %. *1896–1905*, 41·62 in., 100 %.

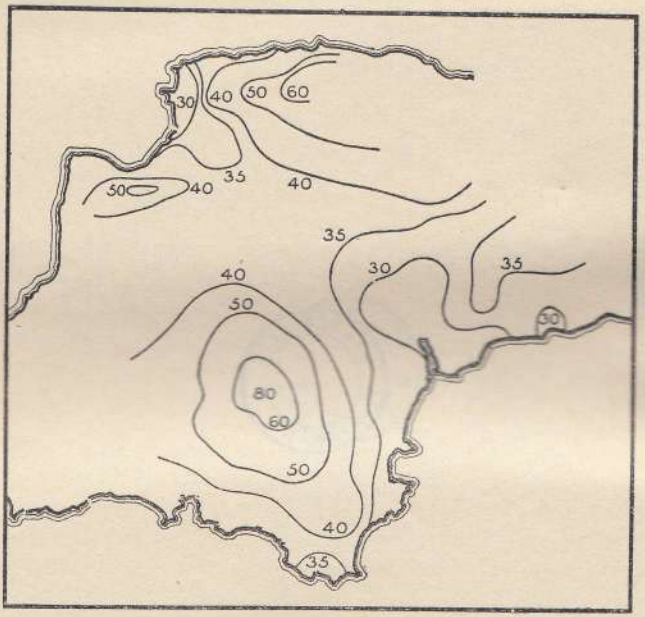
We may now consider the distribution of rainfall in Devon. For this purpose the returns from 195 gauges, between the years 1896 and 1905 inclusive, have been used. Many of these gauges were not in use the whole time, but to these corrections have been applied from the mean values of the rest. These ten years, as already stated, have con-

PLATE II.



Map showing the Mean Annual fall at certain stations for the ten years 1896–1905 inclusive.

PLATE III.



Map showing rainfall contours, based on the Mean values for the ten years 1896–1905 inclusive.

stituted a dry period, and hence any rainfall map prepared from the data in question will show less than the real expectation of rain—about five per cent less, in fact.

The map on Plate II has marked upon it the actual ten-year means at a number of stations. More should have been shown, but considerations of space prevented. At first sight it does not appear a very hopeful collection of figures from which to derive any satisfactory order.

But following indications which reward careful examination, one can in fact contour the county very satisfactorily, and the rainfall contours on Plate III have been prepared. Purposely these were drawn on a map which gave no indications of relative ground levels, in order to avoid mental bias.

None the less, it will be seen that rainfall and elevation are very closely connected. There are two large elevations on this rainfall map, each reaching above 60 in. These correspond to the highlands of *Dartmoor* and *Exmoor*. There is one lesser elevation of 50 in. in the north-west, also corresponding to high land. Across Devon, from the mouth of the *Taw* to the mouth of the *Exe*, runs a great rainfall valley, starting below 30 inches on each coast, and reaching about 37 in. in the centre of Devon. This corresponds to the terrestrial valleys of the *Taw* and the *Creedy* and *Exe*. The railway from *Exeter* to *Barnstaple* runs up the centre of this rainfall depression; it has been governed in its location by the river valleys in question.

There is a branch rainfall valley which follows the river *Culm* to *Culmstock*, and another which follows the *Torridge* toward *Holsworthy*.

The centre of *Dartmoor* towers to a height of 80 in., or rather this elevation is reached at a point south of the physical centre of the moor, the south-west winds discharging the bulk of their burden when the first height of 1500 to 1600 feet has been reached.

This close correspondence between the physical features and the rainfall is most interesting, and has not been so clearly brought out on any previous rainfall map of Devon —the reason probably being that too few stations have been utilized in their construction.

To windward (counting off-sea breezes only) the rain contours are always a little in advance of their corresponding heights above sea level, the foot-hills receiving rather more than their share in comparison with the extreme heights. And to leeward the contours for rainfall occur somewhat sooner

than they should, the rainfall decreasing more rapidly, since the first and heaviest precipitation has largely occurred on the windward slopes. But the valleys just beyond the first important hill receive the heaviest fall of all. The question of the influence of elevation on rainfall is complicated by purely local circumstances. The position of the gauge with reference to the prevailing rainy wind is one such circumstance. The influence of neighbouring high land, or of areas of low elevation, has also to be considered. Notwithstanding which, other circumstances being equal, rainfall is directly influenced by elevation, increasing with height above sea level. For the whole of Devon the averages are:—

70 inches at 1600 feet.
60 „ „ 1150 „
50 „ „ 700 „
40 „ „ 400 „
33 „ „ sea level.

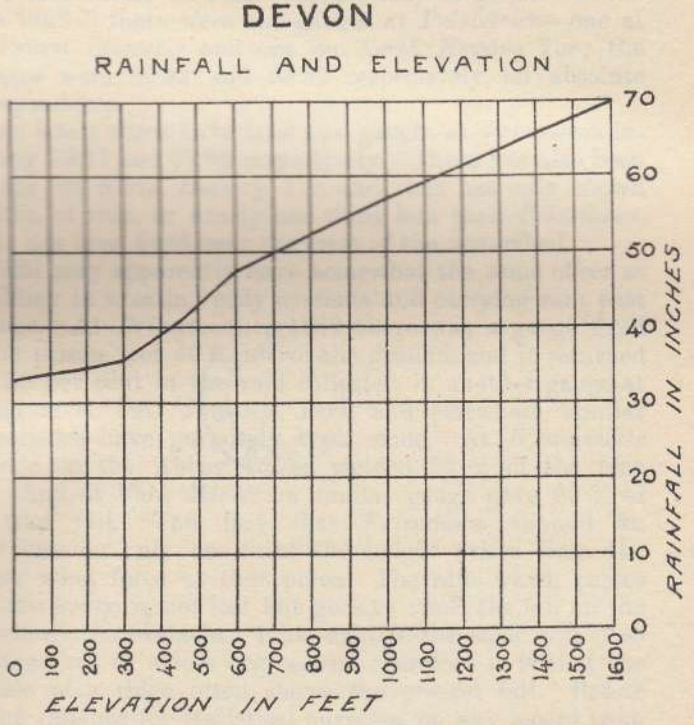
(See Plate IV.)

The increase is not very rapid from sea level to 300 ft., being from 33 in. to 35½ in.; but from 300 ft. to 400 ft. there is a rise of 4½ in., and a further rise of over 7 in. to 600 ft. From this point the increase continues at a less rate.

Thus far on averages only. The actual addition, when proper allowance is made for local variations, is more uniform. The figures just given depend on the returns from stations which are by no means uniformly distributed over the county. And many gauges in the higher levels, where there are far too few, are only read monthly or at uncertain intervals.

What really has to be considered is a variation from 28 in. at sea level to 80 in. on Dartmoor, and the true method is to divide the stations into groups, according as they fall below, at, or above, the average of other gauges at the same elevation. Then for each group a curve can be drawn expressing the influence of elevation, and these curves, although of different heights above the datum, will be found to have the same equation in each case. The rate of increase is greatest in the lower levels, and falls somewhat as the higher lands are reached. From 250 ft. to 500 ft. the increase is 15·7 %; from 500 ft. to 750 ft. it is 12 %; from 750 ft. to 1000 ft., 9·4 %; from 1000 ft. to 1250 ft., 7·2 %; and from 1250 ft. to 1500 ft. it is 5·4 %. Or,

PLATE IV.



RAINFALL IN DEVON.—*To face p.* 228.

differently stated, and starting from 250 ft. in each case, the increase is, at 500 ft., 15·7 %; 750 ft., 29·7 %; 1000 ft., 42·1 %; 1250 ft., 52·3 %; 1500 ft., 60·6 %. These corrections are best applied over limited areas only, and for comparatively slight differences in height.

The difficulty in hilly country of so placing gauges that they truly record the general fall of the neighbourhood is very considerable. A local instance may be given. In the years 1862-8 there were two gauges at *Princetown*—one at the *Prison Reservoir* and one on *North Hessary Tor;* the averages were 80·92 and 80·92 respectively, an absolute correspondence.

Now lately there have been two gauges at *Princetown* indicating 79·17 and 77·08 respectively. There has also been a gauge on *North Hessary Tor*, and that has only shown 54·12 in. of rain, or nearly one-third less than *Princetown*. But it has been fixed near the crest of the watershed.

A hill may apparently have somewhat the same effect as a building in creating eddy currents and carrying rain past a gauge. At *Princetown* in 1862 there was a gauge fixed on the prison roof 40 ft. above the ground, and it returned only 58 per cent of the rain collected in another gauge at ground level. At *Townley*, *York*, and elsewhere, similar comparisons have purposely been made. At *Westminster* a gauge on the Abbey Tower yielded 54 % of the true fall. And at *York Minster* a similar gauge gave 60 % of the true fall. The fact that *Princetown* showed an equal loss on only one-third the height arises from the greater wind force at that place. The rain which passes over the gauge is not lost but goes to swell the fall on the lee side of the obstacle. Hills exhibit the same action as buildings but in a less degree, and therefore it is that the lee side of a ridge often shows the greater fall. Before placing reliance for statistical purposes on any record from mountain country, it is necessary to know the precise position of the gauge with reference to the contour of the land and the wettest winds.

In the past ten years there have been some instances of prolonged absolute drought, but scarcely extreme examples. In 1896 there was a 26 days' drought in April and May at *Torquay*, 26 days during which no rain fell. In 1897 *there were 19 days of drought in October and November.* In 1898 20 days in June and July, 17 days in August and September. In 1899 four droughts, 15 days in February and March, 23 days in May and June, 19 days in August,

19 days in November. Yet that year *Torquay* had 34·90 in. of rain, as compared with 27·62 in the preceding year.

As to how much rain may fall in any one day. The highest fall during the ten years occurred at *Cofton Vicarage, Starcross*, on August 15, 1905, and amounted to 3·98 in. *Holne* came next, on December 29, 1897, with 3·85 in., and *Druid* (Ashburton), on the same date, 3·60. But probably 5 in. per day sometimes falls on some parts of Dartmoor.

The rate per hour, over short periods, is sometimes very great. On August 18, 1898, 0·38 in. fell at *Whitchurch* in eight minutes, or at the rate of 2·85 in. per hour.

The *Torquay* Waterworks gauge at *Chudleigh* shows a more imposing fall: there, on July 20, 1897, 2·75 in. of rain fell in one hour and ten minutes, or at the rate of 2·36 in. per hour.

Now considering that an inch of rainfall yields 100 tons of water per acre there must from this fall, lasting 70 minutes, have been 275 tons of water to run off each acre, or 61,600 gallons, sufficient to supply 30 gallons per head to a population of 2050 people for one day. Or this fall of a little over an hour, if all caught and stored from 1000 acres, would have supplied 5640 persons with 30 gallons per head for a year. Considering the elevation of the gauge, 718 ft. above sea level, the fall represented a potential energy of 1915 horse-power per acre, or very nearly 2000 horse-power, and neglecting all necessary losses in pumps and engines and in friction in pipes, that is the power that would have been necessary to spray sea water at the same rate over an acre of ground at Chudleigh.

It would have been quite possible to supply in detail the very numerous figures on which the above general statements have been based, but probably the publication of the results, without the numerical basis thereof, will serve any useful purpose to which this paper may lend itself. Very free use has been made of sources of information additional to our own climate reports, and especially of the "British Rainfall" publications.