Discussion.

The President. The PRESIDENT, in moving a vote of thanks to the Author for his valuable Paper, remarked that it was very satisfactory to find that the work so long and so well done by the late Mr. Symons was being continued and developed by the Author and those working with him. He had no personal knowledge of the subject of rainfall-observations, but he was assured by friends who dealt with questions of water-supply that accurate observations of rainfall, and the analyses of them made by observers like the Author, were of the highest value to engineers in their professional work.

The Author. The AUTHOR exhibited various lantern-slides, with a view to bring out clearly one or two of the points dealt with in the Paper. The first was a graphical representation of the facts given in the Tables on p. 295. The interesting feature, on which was based the selection of 30 years as a safe period in his researches, was that in the long continental series, while the average deviation of periods of 10 years and 20 years from the long-period mean was comparatively large, the average deviation of a period of 30 years was scarcely larger than the average deviation of a period of 40 years. In England that similarity was not quite so marked, the variation being a little greater; but in order to get any substantially better mean an average would be required of at least 50 years, and for that so few stations would be available that it would be impossible to construct maps without computing by far the greater number of the observations, thereby depriving the work of a large part of its value. In order to get accurate and trustworthy observations it was necessary to have good instruments and conscientious observers. A great deal of controversy had raged as to the best form of rain-gauge, and much of it had been settled by experiment about 30 years ago. Trials with gauges of various diameters, ranging from 1 inch to 2 feet, had shown that, if they were set perfectly level and observed with great care, exactly the same rainfall was registered by all of them; so that the size of the opening of the gauge was merely a matter of convenience. Most gauges were now made with an orifice of 5 inches, which was found to be ample. They were placed 1 foot above the ground, which was taken as standard height. The higher the gauge was raised above the ground, the smaller was the quantity of rain caught, owing, as had been clearly demonstrated, to the eddies caused by the wind about a prominent upstanding object. For that reason it was more important to have gauges placed

at a uniform height than to have them of a uniform diameter. The Author.
The Snowdon gauge had generally been adopted as the standard form for daily reading. It was designed to give effect to all the necessary precautions, and to measure falling snow fairly accurately. Snow was the great bugbear of rainfall observations; and most of the results rejected from the pages of "British Rainfall" were due to the difficulty of measuring snow in exposed situations, where there was much drifting. The next important point, after ensuring good instruments and conscientious observers, was to have those instruments and observers as widely and uniformly distributed as possible. With the other elements of climate the same necessity was not felt so much. A comparatively small number of well-distributed stations would give the average temperature or the average pressure of the atmosphere; but it required a number of stations to give the average rainfall, because rainfall was subject to many disturbing influences. The observing-power of the British Isles, which, when "British Rainfall" started in 1860, was represented by 168 observers, had grown by 1902 to 3,636 observers who sent in complete records. They were not all absolutely accurate, but they were nearly all conscientiously taken, and the result formed a magnificent basis for carrying on the work. By going back 30 years it was possible to obtain averages of a large number of stations; but for every 10 years farther back the number of stations throughout the country diminished very rapidly. Accordingly, it had been with feelings of great satisfaction that he had found the 30 years 1870–1899 to be, of all the periods of 30 years that could possibly have been taken since the beginning of observations in this country, the nearest to the long-period mean. Accordingly the result came very near what a real average of 50 years or even 70 years would show —certainly within 2 per cent. It was in Ireland and Scotland that additional observers were most required, in order to secure perfect rainfall-maps. He had said nothing about the variation of rainfall from year to year, because the subject was too large, and the labour of calculating the mean rainfall for the country, or extensive parts of the country, was too great to admit of its being undertaken systematically at present. The extremely wet year 1872 shot up as a solitary pinnacle from among comparatively dry years, and had been followed by a very wet spell, which had again been followed by an extremely dry spell, during which only a few years had reached or passed the average; and the driest year of all, 1887, had occurred in the midst of years that were not really much lower than their neighbours below the average. The year 1903,

The Author. unfortunately, for the purposes of the Paper, was not yet completed; but there was reason to believe that when completed it would give an average rainfall approximate to that of 1872, and perhaps surpassing it. That was not prophecy, because already in the greater part of the country the rainfall for the 10½ months of the year had exceeded the rainfall for the whole of any previous year for which records had been kept. When studying the distribution of rainfall over a considerable area of the earth's surface the observer was confronted by a series of new difficulties, some of which were referred to in the Paper. The British Isles occupied a position in the region of maximum rainfall of the North Temperate Zone, which made a study of their rainfall peculiarly difficult. That was perhaps an advantage, just as it had been an advantage to the science of geology that the geological structure of the British Isles was the most difficult of any part of the world. But the study of rainfall had not yet advanced so far as geology, though he hoped it was progressing. The point which he had kept before him in constructing the maps was to take notice of nothing except the actual figures of rainfall determined by observation, and the result was a series of maps which showed lines of equal actual rainfall, and not hypothetical lines. One subject of investigation was the comparison of the lines of equal rainfall with the lines of a contour-map of the British Isles, which showed how closely the areas of maximum rainfall coincided with the areas of high land. That was well known; but the question still requiring investigation was the quantitative relation between the two—between the height, slope and exposure of a given district, and the rainfall upon it. In describing the map of average rainfall over the British Isles (Fig. 1, Plate 2) he drew attention to the beautiful instance, in the south-east of England, of the Wealden district, where the configuration of the North Downs, the South Downs, and the Forest Ridge, was clearly outlined by the increase of rainfall corresponding with the height. The same thing was found in several of the other hill ranges; but in those of Shropshire it was not so well illustrated, because there were so few observers there that an extremely interesting district had been of necessity somewhat slurred over. In the district immediately to the east of Cross Fell, on the flanks of the Cheviots, there was an almost total want of rain-records; and although the rainfall was probably considerably higher there, it had been impossible to represent it, for want of data. It was quite certain that the estuary which led up to Carlisle, between the Lake District and the Southern Uplands of Scotland, was a region of comparatively

low rainfall, well under 35 inches per annum. Then there was the remarkable region of low rainfall bordering North Wales and the estuary of the Mersey; and in some parts where the Pennine rainfall extended into the great plain there was no apparent difference in the configuration of the country to account for one place being wetter than another. Those were some of the questions which required investigation before the problem could be fully worked out. In investigating the extreme years, the first point to be settled was whether those years were really typical of the wettest and driest years that could be expected. The moral to be drawn from Figs. 5 and 6, Plate 3, was that there was more likely to be a uniformly very wet year than a uniformly dry year; in other words, that an abundance of rain was more likely to occur over a considerable area than was a generally dry year over an area of equal extent. An interesting point in this connection was the extraordinary dryness of the east of England in a dry year, and its still more extraordinary relative dryness in a wet year. In fact, when the maps of maximum, minimum, and average rainfall were compared it would be found that the lines ran almost in the same positions. This showed that the same influences of configuration and prevailing wind were at work in the wettest and driest years as well as in the average year; and it also showed how prominent the geographical influences really were, and how important it was to be able to understand fully the relationship between rainfall and configuration. With regard to the ratio which the wettest and driest and average years bore to each other in different parts of the United Kingdom, the average for the whole of England and Wales in the wettest year was very nearly 50 per cent. higher than the mean, but the average in the driest year was scarcely more than 25 per cent. lower than the mean; while in Scotland and Ireland, with more insular climates, the range was still more restricted. This again showed that an extreme year was likely, over a wide area, to exceed more in wetness than in dryness.

The Author.

Sir ALEXANDER R. BINNIE, Vice-President, did not know a subject which could more properly be brought before the Institution than the subject of rainfall; and when it was considered that rivers and lakes were all derived from rainfall, it would be seen that the subject was one which certainly merited considerable attention. The first thing that struck an ordinary observer of rainfall was that, among all the phenomena of Nature, it was perhaps one of the most variable. But on inquiring into that variability, the observer was at once brought face to face with the

Sir Alexander Binnie.

Sir Alexander Binnie.

question: "Variability from what?" Careful investigations in all parts of the world had led to the rough conclusion that if a rainfall-record was kept for a certain number of years, something would ultimately be arrived at which was called an average or a mean rainfall. The first point to which the Author had directed his attention was the number of years of observation necessary in order to obtain an average result, which would not be altered, although the records were continued for a greater number of years. The Author had arrived at the conclusion that 30 years' observation would afford that information. His own determination of 30 or 35 years, communicated to the Institution in 1892, and the Author's determination of 30 years, were clearly dependent upon the periods into which the total record was divided. The Author divided it into 10-year periods; he himself had divided it into 5-year periods, and he still believed that the true mean was somewhere between 30 and 35 years. He could give no reason, nor did the Author profess to give any, for that particular period, which lay somewhere in the neighbourhood of 33 years. Some hard-working and conscientious continental observers were not only coming gradually to the conclusion that 33 or 34 years was the proper period, but were trying to give a reason for their belief. The fact was fairly definite; ther eason for it was at present somewhat obscure. A mean rainfall having been derived, the next step was to determine within what probabilities that figure could be depended upon. The monumental work placed before the Institution that evening, arising out of the lifelong labours of the late Mr. Symons, F.R.S., was a concise answer to that question. The Author said it might be anticipated that for the British Isles the wettest year would exceed the average by 43 per cent., and the driest fall below it by 29 per cent. In his own Paper of 1892 he had given the figures as 45 per cent. and 24 per cent., respectively. If the matter was to be of any use to engineers as professional men, they must know a little more about the subject, and study it a little more deeply. To take his own case, in 1868 and 1869 he had been called upon to design and lay out waterworks of considerable magnitude in India, and had been faced by the fact that there were only three long records to go upon, very widely separated, namely, Calcutta, Madras, and Bombay; with a somewhat shorter record in the neighbourhood of Nagpur, where he was working.[1] He had begun

[1] "Nagpur Waterworks; with Observations on the Rainfall, the Flow from the Ground, and Evaporation at Nagpur; and on the Fluctuation of Rainfall in India and in other places." Minutes of Proceedings Inst. C.E., vol. xxxix. p. 54.

to compare those records, because he had had actually no records in the districts where the works were to be constructed. He had first attempted to find out within what limits he could depend upon the record in the exceptional circumstances of a tropical climate, where the rainfall was due mainly to the north-east and south-west monsoons; and he had at once been struck with the fact that the deviations from the mean were similar in kind, and almost identical in amount, with those with which he had been accustomed to deal under his old master, the late Mr. Bateman, F.R.S., Past-President of the Institution, in London. Out of that had arisen the idea that in order to study rainfall in its variations it was necessary to ignore—at all events to a large extent—the amount of the rainfall. The actual amount in any particular station, as the Author had lucidly shown, was a purely local circumstance. For instance, the average rainfall of Baku, on the Caspian, was about 10 inches; of Moulmein, 189 inches: how were these to be compared? Except that they had these mean rainfalls, one small and one large, there were no means of comparing them. When considering rainfall-records, he had been taught by Mr. Symons to reduce them to a percentage of the mean fall; and if that was done, instead of a confused mass of figures of inches of rainfall, varying with every climate and every position in which a rain-gauge could be set up, a lucid statement of the case was obtained. In his Papers of 1874 [1] and 1892 [2] he had shown what they meant. Considering, for instance, the fall of the maximum year, irrespective of the amount of rain that fell, England, Ireland, and Scotland he made out to be 45 per cent. above the average. For other countries he found the percentage above the average to be:—Norway, Denmark, Holland and Belgium 48 per cent.; France 61 per cent., Italy 59 per cent., Switzerland 47 per cent., Germany 39 per cent., Bavaria and Austria 44 per cent., Russia 66 per cent., India 62 per cent., Africa 66 per cent., Australia 56 per cent., and North America and Canada 41 per cent. The average excess of the maximum year shown by what might be called typical observations throughout the world was 51 per cent. above the mean, as compared with 45 per cent. in the British Isles. When the records—whether for the United Kingdom or for more distant countries—had been analyzed, there was, as the Author pointed out, still a difference of 2 per cent. At present that 2 per cent. might be put down to errors

Sir Alexander Binnie.

[1] Minutes of Proceedings Inst. C.E., vol. xxxix. p. 54.
[2] *Ibid*, vol. cix. p. 89.

Sir Alexander Binnie.

of judgment or to errors of calculation; but he was content to let it rest as a difference, because in studying so abstruse a subject it was necessary to guard against anything like prepossession. It must not be assumed that it was an error at all, because it haunted investigators in many investigations. As he had shown in his Paper of 1892, it traversed every kind of calculation made about rainfall, and therefore he was not prepared to say that it was an error due either to observation or to judgment: it was a thing to be held in suspense until more was known about the whole subject. The difference between the average of 45 per cent. in the British Isles, and of 51 per cent. throughout the world, was small; and the minimum years were in still better accord. In the British Isles 24 per cent. below the average, 39 per cent. in Scandinavia and Holland, 41 per cent. in France, 45 per cent. in Italy, 45 per cent. in Switzerland, 39 per cent. in Germany, 44 per cent. in Bavaria and Austria, 47 per cent. in Russia, 48 per cent. in India, 47 per cent. in Australia, and 32 per cent. in North America. When figures all over the world were found coinciding in that remarkable manner, the mind was led inevitably to the conclusion that, apart from quantity—and these figures were quite irrespective of the actual quantity of rain that fell—there was some force at work in Nature of which nothing was known, but which kept the deviation of rainfall from the mean within certain clearly marked limits. Again, taking the stations which he had dealt with in his 1892 Paper, in different countries, and grouping them according to the amount of their mean annual rainfall, it was found that the average excess of the falls in the maximum years over the mean falls was: for the group of stations having mean rainfalls of 50 inches and upwards, 53 per cent.; 40–49 inches, 46 per cent.; 30–39 inches, 50 per cent.; 25–29 inches, 47 per cent.; 20–24 inches, 49 per cent.; the average being 49 per cent., against his own 45 per cent. and the Author's 43 per cent. for the British Isles. With such imperfect materials there could be no better approximation to a standard. Analyzing the average defect of the falls in minimum years in the same manner, the results were: for the group of stations having mean rainfalls of 50 inches and upwards, 39 per cent.; 40–49 inches, 38 per cent.; 30–39 inches, 40 per cent.; 25–29 inches, 40 per cent.; 20–24 inches, 39 per cent.; the average being 40 per cent. The study of so great a question, affecting engineers working in all parts of the known world, was of the utmost importance; and he believed that if they would devote attention to the matter, scientific advance would be materially assisted by regarding rain-

fall not as a local circumstance, not as a matter of a few inches more or less, but as a great natural phenomenon; and by endeavouring to arrive at some measure of the limits of deviation of the forces at work. With that clearly in view, it would be possible to begin to speculate on causes with advantage, but it was necessary at present—and, as far as he could see, it would be for some time to come—to devote study to a careful and systematic determination of the facts of the actual distribution of rainfall throughout the world. Sir Alexander Binnie.

Dr. W. N. SHAW congratulated the Author upon the magnificent collection of accurate data which formed the basis of the Paper. He did not know that there could be any more fitting memorial to the late Mr. Symons, to whom every one was so much indebted for knowledge of rainfall, than the maps, which exhibited practically a résumé of the results obtained during the long period of Mr. Symons's charge of the British Rainfall Organization. The year 1899 seemed to be particularly well chosen as the year of determination of the period to which the Author gave his attention, because not only was it practically co-terminous with the rainfall-data collected by Mr. Symons, but it happened to come at the end of the Nineteenth Century, and it was only fair to the Nineteenth Century to acknowledge that it had the credit of settling the average or mean rainfall for the British Isles. The Author spoke of a mean for 70 years in words which seemed to indicate that he considered that period would in some sense furnish a true mean, as distinguished from some other less accurate mean. He did not know quite whether the Author considered that, the longer the period, the nearer to truth must the mean be. It might be so, but he did not think the proposition could be accepted without some consideration. It was, of course, a fact that 70 years corresponded with two complete Brückner cycles; and if that was why 70 years was chosen, then perhaps there might be some reason in selecting a particular period as giving a true mean in a scientific sense; but he had not discovered, either in the Paper itself or in the appended Tables, anything that conspicuously supported a variation in rainfall which was periodic in 35 years, and periodic in such a way as to make the mean for the 35 years a scientific mean in the sense in which other means were not. It was quite possible that a closer approximation to the true mean was not obtained by extending the period of observation, if the true mean was regarded as that obtained by going from zero to infinity. There was another point which Dr. Shaw.

Dr. Shaw. should limit the extent to which the mere calculation of the mean over a length of years should be carried, and that was the degree of accuracy of the instruments of measurement. In using a foot-rule, repeating measurements would not increase the degree of accuracy beyond that of the foot-rule used. The instrument for measuring rainfall was an exposed rain-gauge, and perhaps the Author could say what was the real degree of accuracy of such an instrument. In some countries, particularly where there was a good deal of precipitation in the form of snow, rain-gauges were specially guarded in order that the measure of precipitation during wind might be approximately accurate; a rain-gauge which was exposed to the wind, and not guarded, might give a measurement of rainfall some 10 per cent. or more below the actual amount of rain measured in a guarded gauge; consequently, he presumed that without special guards the rainfall instruments did not reach an accuracy of 1 per cent. In England he believed guarded gauges were not used. Dr. Buchan had suggested that, in order to eliminate the effects of the wind, a rain-gauge should be put in a hole, so that its rim did not come above the surface of the ground; also, that there should be netting over the top of the gauge. He was not certain that, even in Scotland, gauges were guarded in that particular way; and in England he had seen no gauges specially guarded to protect the rainfall from the influence of the wind. At Rothamsted, where very careful measurements of rain had been made for 25 years, there were three gauges, a 5-inch, an 8-inch, and what was called a "one-thousandth-of-an-acre" gauge; those three gauges gave different measurements. The one-thousandth-of-an-acre gauge gave the most, the 5-inch gauge the next, and the 8-inch gauge the least. The difference between the 5-inch gauge and the one-thousandth-of-an-acre gauge was about 1 inch in 27 inches in ordinary years. The least difference in the 5-year averages was a difference of 2 per cent. in the wettest group of years: it was 4 per cent. in the period of greatest difference. The situation was extremely open, and he could not imagine an exposure of gauges for comparison under more favourable conditions; consequently, he gathered that, under the best circumstances, different gauges might differ to the extent of 2 to 4 per cent. It was unnecessary to refer the differences to any want of judgment or any want of accuracy in the manufacture of the gauges: he was afraid they must be attributed to the weather. Therefore it seemed to him that when rainfall-averages were obtained to an accuracy of

2 to 3 per cent., that was about as much as could be expected with the present instruments. It was unnecessary to go farther; and he congratulated the Author on putting on a truly experimental basis averages which agreed with the averages of 70 years within 2 per cent., and represented, with all the accuracy possible, the rainfall of the British Isles. For some reason, probably habit, a year was always taken as the time-unit of rainfall. He did not think that it really represented, either for practical or for scientific purposes, the most satisfactory unit that could be chosen. For practical purposes, of course, the summer rainfall was in many ways of very different value from the winter rainfall; but in the Institution of Civil Engineers he would not presume to suggest in what way the measurements should be altered, in order to give a more effective representation of rainfall for engineering purposes. The figures in the Tables appended to the Paper were a little distracting. In the comparison of the various averages for different parts of the country, they showed considerable irregularities. It was quite possible that if the irregularities due to summer thunder-storms were eliminated from the information, the arrangement would appear much more regular. Dr. Shaw.

Mr. GEORGE F. DEACON considered the Paper to be an excellent compilation of statistics, but thought its title showed that its scope was too broad to be of much utility to engineers. He trusted that the Author would at some future time, and possibly also in his reply, help the engineer with information relating to such details as, for example, the disposition of rain-gauges, and the estimation of mean rainfall upon those limited areas with which the hydraulic engineer was concerned. The Author said a good deal about the disposition of rain-gauges over the whole area of England, Scotland and Ireland, but it was desirable to know something about smaller areas, because on those smaller areas it was found that the deviations from the mean were much larger than the Author had stated them to be for the British Isles as a whole. He had taken a number of standard gauges quite at random, and he found that in No. 1 the deviation of the driest year below the mean was 41·2 per cent.; in No. 2, 40·2 per cent.; in No. 3, 39 per cent.; in No. 4, 39·5 per cent.; in No. 5, 36·4 per cent.; and in No. 6, 35·5 per cent.; as compared with 23 per cent. shown upon the Author's table at p. 24 to be the mean for the British Islands. The reasons for this were perfectly well-known; but the effect of reducing a rainfall-area in increasing the deviation from the mean had not been reduced to any law. It had Mr. Deacon.

Mr. Deacon. frequently been stated without any reference to actual areas, that the minimum year was about 33 per cent. less than the mean; but the Author showed that for England it was 26 per cent., and for the whole of the British Isles 23 per cent.; while for small areas it was certainly a great deal higher than 33 per cent., and that was a most important element in coming to proper conclusions with respect to the ultimate yield of reservoirs. As a rule, in relation to reservoirs, the average was taken of the three driest years; and for a long time it had been stated that the minimum yield of three dry years was 80 per cent. of the mean. Now it was found that it was sometimes a great deal less. The error in the first instance had arisen from the application of general averages and general minima to detailed averages and detailed minima. Another matter on which the Author might give information was the position of gauges at a particular water-shed. Most engineers had formed their own conclusions, and many had, no doubt, read what Mr. Symons and other meteorologists had written on the subject; but there still remained a great deal of information which had not been fully published, and which only those could appreciate who went into mountain districts, and had occasion to fix gauges in such places and observe their results over long periods. They often felt astonished by what at first appeared to be the incongruity of those results. He hoped the subject would be brought before the Institution again at some future date.

Mr. Archibald. Mr. E. Douglas Archibald congratulated the Author on his Paper, and hoped it would be followed by one dealing more particularly with the aspects of the question which were mainly interesting to engineers; for instance, the rate of fall at certain times, the question of evaporation, and the way in which water drained off certain watersheds. In the discussion on a previous Paper, by Sir Alexander Binnie, a suggestion had been made that sometimes the arithmetical mean was not the best mean to take; and he thought that if an attempt were made to apply the geometrical mean, the causes of some of the discrepancies which existed might be discovered. For instance, with regard to the smaller number of years of high rainfall as compared with those of low rainfall, it was quite conceivable that in some years a wet current blew over the country which did not blow in other years, its place being taken by another current which was correspondingly dry. Consequently, if x were taken to represent the actual true mean, and in one year it was supposed that by the action of this wet current it was doubled to $2x$, and that in another year it was halved to $\frac{1}{2}x$

Mr. Archibald.

by the absence of the wet current and the presence of a dry one, the arithmetical mean between those two would not give the result desired, while the geometrical mean would. Consequently, it seemed possible that the application of the geometrical mean might be of advantage. With regard to the 30-year period, he wished the Author had gone a step farther and taken 35 years. Sir Alexander Binnie had shown in his Paper that 35 years gave a better result than 30, 40, or 50 years, because the variations from the mean were less for 35 years than they were for succeeding years. In the case of nine stations on the Continent, the variation was distinctly less; for the 35 years it was 0·94, for 40 years 1·16, for 45 years 1·35, and so on; so that the 35-year period, even without any reference to theory, appeared to be the best eliminant. But in addition there was the fact that Brückner had already shown that, in all parts of the world, the 35-year period held, in rainfall, in barometric pressure, and in other meteorological variants. The 35-year period also embraced approximately three sun-spot periods. Consequently it not only eliminated the Brückner variation, but also three sun-spot periods. Although just lately the 30 years had been a little nearer the mean, this was simply due to a temporary variation in the length of the Brückner period; the long rainfalls recorded at Padua, Klagenfurt and Milan, all showed the 35-year period. Dr. Julius Hann had traced it in those records, and it certainly ought to be generally adopted as the best period. In Table I. it would be an advantage if the Author would shift the columns back. The mean for any period of years ought to be placed opposite the middle date of that period; but in Table I., taking the Boston records as an example, opposite 1839 was placed the mean of the preceding 10 years, namely, −1. If that −1 were shifted back 5 years it would be in its right place. In the next column the 3·3 ought to be shifted back 10 years, and in the next column the −0·7 ought to be shifted back 15 years, and so on. If that were done, each of those figures would correspond with the period which it represented. With regard to total rainfall, he thought it would surprise many people to hear that the actual average annual rainfall given by the Author for England, namely 39·24 inches, was almost exactly the same as the average for the whole of India, which was 39·55 inches. It was usually believed that tropical countries had much heavier rainfall than England, but it appeared that the difference was really very small; and this result upset the conclusion come to by Mr. H. F. Blanford some years ago, that not many places outside the tropics had as large a rainfall as India. The variations from the mean in

Mr. Archibald. India were also very similar to the variations in the British Isles. The maximum found by the Author was 53 per cent. above the average and the minimum was 30 per cent. below. In India the maximum was 48 per cent. above and the minimum 28 per cent. below the average. Another curious result of the Author's investigation was that in Figs. 5 and 6, Plate 3, it would be found that the year 1874 was the minimum year for eight places in the east of England, but a maximum year for six places in the north-west of Scotland; while 1898 was the minimum year for ten places in the east of England and also the maximum for four places in the north-west of Scotland. Therefore it was possible that one portion of the country might have its minimum year while the other part was having its maximum.

Mr. Hawksley. Mr. CHARLES HAWKSLEY, Past-President, pointed out that, in determining the length of period to be taken, it was desirable to include an equal number of wet cycles and dry cycles; though when records extended over so long a period as 40 years, the inclusion of one more wet cycle than dry cycle or one more dry cycle than wet cycle was not of much consequence, because the difference was divided over so large a number of years. With regard to the variation in the records in small areas, he had noticed that in areas so small as 5,000 or 10,000 acres, in which a considerable number of rain-gauges had been placed in different positions on both sides of a valley, and at various altitudes, the several gauges gave very different results. Therefore in determining the rainfall over even a small area it was desirable to have at least three or four gauges. Otherwise it might happen that a gauge was placed in a situation which caused it to give a result differing very considerably from the average rainfall over the whole area.

Mr. Cooper Mr. C. H. COOPER regarded the subject from the point of view of flooding—a matter which had come very much under his notice during the year 1903. On 30th May he had passed over the River Wandle at 3.30 P.M., when it was practically empty; but 2 hours later it was running in full flood. At that moment a large part of the valley had had no rain whatever, whereas at other stations the fall had been very heavy. At Beddington Mr. Bayard registered no less than $2\frac{1}{2}$ inches per hour. A little distance away considerably more rain had fallen, but owing to the absence of self-registering rain-gauges, there was no record of this fall except that 3·67 inches fell in 24 hours. It would be very useful if self-registering rain-gauges could be established more generally throughout the country. It was almost impossible to make, from the present returns, a satisfactory estimate of what quantity of water would have to be dealt with in any drainage-

area; whereas, if self-registering rain-gauges were established, that information would be available.[1] Mr. Cooper.

Mr. W. B. TRIPP remarked that in the seventies he had been much struck with the succession of wet and dry periods he had observed in South Africa, and he had tried to work out the variations of average annual rainfall over the globe; but he had soon discovered that the records needed for the solution of the problem were neither numerous enough nor sufficiently long-continued. The best-recorded portion of the world was the British Isles, and after that Europe. Italy had the oldest and the longest records. He had divided the hemispheres of the globe into quadrants, and as far as possible had taken the averages in the different quadrants. He had found that, in the quadrant which included the British Isles and Europe, the cycle was 33 years, as far as could be judged by choosing the records of stations distributed as evenly as possible, in the same manner as the Author had worked. The records did not go back far enough in a previous period. The two culminations of the wet years occurred in 1838 or 1839, and in 1872, a difference of about 33 years. The middle of the dry period in the fifties occurred in 1854, which was a very dry year, and the minimum year after 1872 was 1887, which again was an interval of 33 years. As the Author remarked, the most difficult thing was to find a large tract of country over which the average rainfall was at all similar. Even in the diagrams, as had been pointed out by Mr. Archibald, the east of England might be dry while the north-west of Scotland was wet, or vice versa. By taking records over a large area and averaging them, the most persistent wet periods were brought out; and it was thus that he had obtained the two dates 1838–1839 and 1872. The seventies were marked by wet years in South Africa as well as in many other parts of the globe. The most remarkable wet year he had been able to discover was 1872. At a vast number of stations in Europe, extending from Upsala in Sweden, down to the South of Europe near Gibraltar, that year was very wet; indeed, he had been unable to find any other year so consistently wet. It therefore appeared to him that 1872 would be a very suitable year from which to reckon cycles, regarding it as being the culmination of a wet cycle. Probably 1872 was wet farther south than Europe, because in that year Stanley was on his way home after finding Livingstone, and had to struggle with tremendous floods on the Mr. Tripp.

[1] Mr. Cooper handed in Tables showing the average annual rainfall at Wimbledon for the years 1854–1899, and the average monthly rainfall for 1888–1903; also a list of excessive falls in a single month since 1853. These documents are filed in the Library of the Institution.—SEC. INST. C.E.

Mr. Tripp. Congo; while over the whole of the Cape Colony that year was more consistently wet than any year that preceded it, so far as the records went. There would, of course, be many serious gaps for which no records existed; but as far as the records went, 1872 seemed to be the most remarkable of wet years.

Dr. Scott. Dr. ROBERT H. SCOTT said that his friend Professor Mascart, the head of the French Meteorological Service, had remarked to him that meteorology meant money. Mr. Deacon had expressed regret that particular areas were not more closely planted with rain-gauges, so that more accurate records might be obtained; but was Mr. Deacon prepared to pay for the instruments? If he was prepared to put down a few thousand pounds, his demand could be met. In the same way Mr. Cooper had talked about self-recording rain-gauges. It was difficult to get gentlemen living in the country to pay 5*s.* for an ordinary rain-gauge; and it would be still more difficult to get them to pay for a self-recording rain-gauge. People who cried for self-recording rain-gauges were simply children crying for the moon. It was merely a question of money; and there was no use calling on the Author to do it, unless money was given him for the purpose. He had thorough confidence in the way in which the Author was working at the subject, and he would suggest that members of the Institution should not ask for what was impossible.

Mr. Hopkinson. Mr. JOHN HOPKINSON observed that he had worked at the subject in rather a different way from the Author. It seemed to him that two questions arose, namely, had the Author taken a sufficient number of stations, and was the length of time sufficient in order to get the mean rainfall? He thought the 138 gauges which the Author had taken for England would be utterly inadequate for giving any idea of the mean rainfall, were they not admirably selected for that purpose. From the results of his own investigation he could say that they were well selected and did give a good result. With regard to the 30-year period, in the abstract he thought it was not long enough; but the Author had selected an excellent period for showing the mean, namely, the 30 years ending with 1899. He would confine his remarks entirely to England, for which some years ago he had computed the mean rainfall for various periods ending with 1890. He had found that for the 10 years 1881–1890 he could get for each county in England one gauge for every 100 square miles, which gave 502 stations. He had selected stations as equably distributed as he could, where there was a possibility of selection. In some counties there was no such possibility, as he had only just been able to get the proper number to represent the area of the county. The mean rainfall for those

Mr. Hopkinson.

10 years, 1881–1890 was 31·76 inches. In dividing the area he had considered each riding of Yorkshire as a separate county, giving the proper proportion of stations to each riding instead of taking Yorkshire as a whole. These 10 years were utterly inadequate for giving correct results and he had taken the 25 years 1866–1890, with 102 stations out of the 502, and had calculated the rainfall for the 25 years, and also the rainfall at the same stations for the 10 years 1881–1890, and by proportion it had been found that the corrected mean for the 25 years was 33·45 inches. For the 40 years 1861–1900 he could find only 50 stations with a continuous record, so distributed as to give the proper proportion for each of four divisions of the English counties—northern, midland, south-eastern, and south-western. For the whole of England there was one gauge to every 1,000 square miles, selected as equably distributed as possible; for the northern counties 18 gauges, for the midland, 11; for the south-eastern, 10, and for the south-western, 11. For these 40 years, the mean rainfall at the 50 stations was 31·54 inches, and for the 25 years 1866–1890 at the same stations 32·55 inches, and by proportion that gave for the whole of the 502 stations as nearly as possible, supposing they had been continued throughout the 40 years, a rainfall of 32·41 inches. Carrying the calculation back to the year 1841, out of the 502 stations he had been able to find only 15 with a continuous record for 60 years, giving a mean rainfall of 33·87 inches, and, by proportion for the 60 years ending 1900, 32·28 inches. Only a few records went back beyond the 60 years, and he had not access to the details; but the Author had; and therefore he had taken the Author's percentage, and found that the correct mean for the 70 years would be as nearly as possible 32¼ inches. In this way a result was obtained midway between the result given by the stations and the result given by the map; but the 33 inches which the Author gave for the mean annual rainfall of England had to be reduced for the 70 years by a small amount, which brought the mean for the 70 years 1830–1899 to 32·60 inches. That, he thought, was as near an agreement as could be expected to be arrived at by totally different methods, an entirely different selection of stations, and a slightly different period, 1830–1899, against 1831–1900. He mentioned that fact in order to show how well the Author had selected his stations and his period. There were several other questions of great interest. He had worked out the following results with regard to certain periods of the wettest and driest years. He had taken the years ending in 5 and ending in 0, and had found that for the 60 years 1841–1900 the driest 5 years gave 7 per cent. below the mean, the driest 10

Mr. Hopkinson. years 5 per cent., the driest 20 years 3 per cent., the driest 30 years 1·5 per cent., and the driest 40 years 0·5 per cent., below the mean. The wettest 5 years gave 12·5 per cent. above the mean, the wettest 10 years 9 per cent., the wettest 20 years 6 per cent., the wettest 30 years 3 per cent., and the wettest 40 years 1 per cent., above the mean. The 40 years 1861–1900 gave the nearest result to that of the whole 60 years, namely, 0·56 per cent. above the mean. The 40 years 1851–1890 gave practically the same divergence below the mean, namely, 0·63 per cent. The foregoing figures applied to the whole of England, worked out for the 502 stations, and showed the decided advantage of a 40-year period over a 30-year period. With regard to the county of Hertford, in which Mr. Hopkinson had been making observations and compiling returns of the rainfall for nearly 30 years, the Author had taken two stations in Hertfordshire, one at Gorhambury, St. Albans, representing the catchment-basin of the Colne, the other at Much Hadham, in the catchment-basin of the Lea. It happened that the station which represented the catchment-basin of the Colne had a rainfall 0·5 inch above the mean for the Colne Valley, and that the station which represented the catchment-basin of the Lea had a rainfall 1 inch above the mean for the Lea Valley, in this case above the mean of fifteen stations in this area for 20 years: which he thought was a sufficient number of stations and a sufficient length of time to show the relation which the rainfall at any one station bore to the average rainfall in the watershed of the Lea. The result was, so far as he could tell from the small scale of the map, that the Author appeared to have drawn his 25-inch line a little too far to the north; the basin of the Lea should be brought within the area under 25 inches, instead of being placed, as it appeared to be, in the area above 25 inches. It was only a small point, but it showed that it would not do to rely upon a single station in such an area, if that station happened to be one having a rainfall departing rather largely from the mean of the whole of the gauges in the area. With regard to composite records, that was, records made up from gauges within a short distance of each other, he wished to give some figures obtained from Nash Mills and Apsley Mills. At these stations the gauges were within $\frac{1}{2}$ mile of each other; they were between the two mills in the same valley, and had very nearly the same elevation. It would seem to be impossible that the record of one gauge over a series of years could differ much from the record of the other gauge. Yet, what was found? The Apsley Mills record commenced with the year 1890; the Nash Mills record ended with the year 1898, so that they ran side by side for

9 years. For the first 6 years of the period the difference between the two gauges was only 0·05 inch (Nash Mills 26·40, Apsley Mills 26·45). There was also but little difference in the number of wet days, the average being 165 at Nash Mills, and 162 at Apsley Mills. But for the next 3 years, 1896–1898, the Nash Mills gauge gave nearly 3 inches less rain per annum than the Apsley Mills gauge, and an average of 11½ wet days less. Supposing the Nash Mills gauge had been discontinued in the year 1895, it would have been said that it was perfectly justifiable to continue the records with those of the new Apsley Mills gauge, the mean difference in 6 years of 0·05 inch being inappreciable. But if the Apsley Mills gauge had only been commenced in the year 1896, it would have been said that the records could not be treated as continuous, as there was a difference of nearly 3 inches. One gauge must be wrong, and the question was, which? He had compared the rainfall with that in the surrounding area, and had found that the Nash Mills gauge showed a decided defect in those 3 years from the relation which it had showed up to that time. He had pointed this out to Sir John Evans, in the last year of the three, and Sir John had told him, that the Nash Mills gauge was to be given up, admitting that it had become unreliable. He did not wish to throw doubt upon the accuracy of the whole of the valuable series—Nash Mills was one of the classical series of rainfall-records of over 60 years' duration —he merely wished to point out what he thought was important, namely, that the rainfall given by the Nash Mills gauge for the three years 1896, 1897, and 1898, must be neglected altogether as unreliable, and the record be considered as terminating with the year 1895. If that were done, it did not matter where the record of the two gauges was broken, between 1890 and 1895. Mr. Hopkinson.

The PRESIDENT asked whether there had been any change in the surrounding conditions. The President.

Mr. HOPKINSON was not aware of any. In the year 1890 the Nash Mills gauge burst from frost; but it was repaired and he could not say what was the reason of the difference. In that connection he might mention an experience he had had with regard to a gauge at Watford. A return had been supplied to him which he had been unable to accept for publication in his rainfall-report for the Hertfordshire National History Society, as it showed too great a discrepancy from the records of other gauges in the neighbourhood. He had suggested that the observer did not read the gauge daily, but he had been informed that that was not so, and that the Mr. Hopkinson.

Mr. Hopkinson. record was correctly taken. Ultimately it had been discovered that the gauge leaked.

Sir Guilford Molesworth. Sir GUILFORD MOLESWORTH, K.C.I.E., Vice-President, remarked that, as India had been referred to, he might say that the question of rainfall in that country had occupied a good deal of his attention. Attempts had been made to obtain formulas for the discharge of Indian rivers, which had perhaps the largest discharge in the world, especially the Ganges and the Brahmaputra; but all endeavours made to obtain anything like formulas, such as those of Dickens, Ryves, Burge and others, were of little avail. They might be applicable to very small areas, but they were utterly useless for general purposes. As might be imagined, the problem was one of great difficulty, because the rainfall varied between about 2½ inches per annum, in Karachi and in the parts about the Rann of Kutch, and 600 inches to 800 inches in Cherra Punji. The Meteorological Department actually had a record of upwards of 1,000 inches. Without throwing doubt on the record of the department, the director had informed him that that fall occurred before the Meteorological Department took over the station. Yet, 30 miles from Cherra Punji the rainfall averaged about 70 inches. Air saturated with moisture travelled over the low, hot country and met an obstacle rising suddenly from nearly sea-level to a height of, perhaps, 5,000 to 6,000 feet. The moisture was discharged like water squeezed from a sponge, and 30 miles behind the hills the rainfall was a mere nothing. Formulas for discharge were generally based upon the area of the catchment ground, etc. He had with great difficulty crossed the Gugger on an elephant in the rains when the river was nearly ½ mile wide; but that river never reached the sea; it wandered through hot districts and was lost altogether. Therefore, for practical purposes, it was almost impossible in India to deduce from statistics of rainfall any general formula to serve as a reliable guide to the engineer.

Mr. Marriott. Mr. WILLIAM MARRIOTT had been more than ever impressed during the discussion with the value of the work carried on for so many years by the late Mr. Symons. The immense amount of statistical information gathered together by Mr. Symons was now being discussed by the Author, who brought to bear upon the subject geographical knowledge, and was able to discuss the data in a way that would render his work extremely valuable. Some remarks had been made as to why a longer period and more stations had not been taken, but it should not be forgotten that in the earlier years the stations had not existed; rain-gauges had been neither

plentiful nor used under the most favourable conditions. He had known rain-gauges placed under trees where they would by no means get the proper amount of rainfall. At the Royal Observatory, Greenwich, rainfalls were quoted from about 1815. The Greenwich authorities, like the Indian authorities, did not acknowledge reliable data farther back than 1840 or 1841. Before that date the rain-gauge was on a wall over a library, about 22 feet above the ground. When Mr. Glaisher wanted to get a long series of observations for about 30 years before the period covered by the Author's work, he had had to discover the difference between the gauge started in 1840 and the earlier gauge 22 feet above the ground, and to apply a correction to the earlier records, so as to adjust them to the equivalent reading of the gauge near the ground. That want of uniformity was one of the great difficulties Mr. Symons had had to contend with in the early days. If all the rain-gauges of which the Author had exhibited diagrams were properly placed, and did not leak, they would give practically the same results. But gauges might also be affected by change of surroundings. Like Dr. Scott, he was in the habit of inspecting rain-gauges at the stations of the Royal Meteorological Society, and he had sometimes found that in course of years there had been a change; trees had grown, buildings had been erected, and other things had occurred, which had interfered with the exposure of the gauges. At Rousdon Observatory in Devon, the late Sir Cuthbert Peek had a fine equipment about 1885. It was then a new place where trees and shrubs had been planted, and these grew apace, so that in the course of a few years the exposure there became very confined and the instrument had to be shifted into a more open place. It was the same with the gauge in his own garden; a few years ago there were no houses round about, but the London builder had now erected some, and the trees planted in neighbouring gardens had grown up, and he had therefore had a second gauge placed in another part of the garden. In the first year the two gauges had agreed every day except two, which happened to be snowy days; but in the next year there had been a falling off in the old gauge; and since then there had been a considerable falling off, showing that the trees had interfered greatly with the exposure. The differences observed in the records of gauges placed in different positions on the same watershed, which had been alluded to by Mr. Hawksley, was due to the influence of the wind. A very interesting case was that of the rainfall at Seathwaite. At Seathwaite and Sty Head was found practically the heaviest rainfall in the British Isles.

Mr. Marriott.

Mr. Marriott. Seathwaite was at the end of Borrowdale about 8 or 9 miles south of Keswick, about a mile from the Sty Head pass, which rose to about 1,200 feet and then went down into Wastdale on the other side. To the south was Scawfell. The general direction of the wind was from south to west, and as it came from the Irish Sea along the low ground by Wastdale, it was forced up rapidly in a confined space to a great height; there was consequently great reduction in temperature, and the moisture which the air contained was deposited as rain. Measuring the velocity of the wind by means of the anemometer at Fleetwood, he had found that the greater the velocity of wind in a gale the heavier was the rainfall at Seathwaite, which reached even 6 inches of rain in 24 hours. Again, on those days when it was so wet at Seathwaite, the dry-bulb thermometer showed the air at Seathwaite to be comparatively drier than at other places. The air, being driven up, had parted with its moisture and come down on the other side of the hills drier and consequently warmer. In 1883 the Meteorological Office published "Rainfall Tables of the British Isles" for 15 years, compiled by Mr. Symons, and in 1897 for another 10 years, 1881–1890. He had gone through the summary for the latter 10 years with a view to find out something about the question of rainfall and altitude. As indicated by the maps, the rainfall was much less in the east than in the extreme west, and he had divided the country into two parts, east and west; the former including all that part of the country where the rivers flowed eastward, and the latter including districts where the flow was westward. Then he had sorted out the means under the heights of the stations above sea-level, and had found that there was a gradual increase in the rainfall with the elevation; but on the west side it was considerably more than it was on the east side, showing that the air came from the west charged with moisture, struck the high ground, parted with its moisture, and came down on the east side with less to precipitate. Such facts as those, if considered by engineers in connection with rainfall over certain watersheds, would be of great assistance.

Mr. Inwards. Mr. R. INWARDS called attention to one little point which had not been touched upon. Engineers required not only rainfall-data, but, generally speaking, information as to the rainfall minus the evaporation; and where they had to examine watersheds it seemed not too much to expect that they should use not only rain-gauges but some form of percolation-gauge, which would not differ much from a filter. The records could be taken monthly and deducted from the records of the rain-gauges.

Mr. HOPKINSON added, with regard to Seathwaite, that the average rainfall there for the 30 years 1870–1899 was about 130 inches, and for the previous 10 years about 150 inches. It was curious that there should be such a difference at Seathwaite, while over the whole of the rest of England there was practically no difference between the rainfalls of these two periods. Mr. Hopkinson.

Mr. DOUGLAS ARCHIBALD said he happened to know Cherra Punji well, and the highest rainfall that had ever occurred there in one day was 40 inches, on the 12th June, 1876. The actual annual average was about 500 inches. Mr. Archibald.

The AUTHOR, in reply, remarked that it had gratified him extremely to find how closely the discussion had been kept to the substance of the Paper. He desired to repeat once more that the Paper was based on the work of his predecessors, Mr. Symons and Mr. Wallis, and all that he had done was to put together, in a way that their busy lives had not permitted them to do, some of the results which could be deduced from their collection of data. It was extremely difficult to know what should be left out, and, of course, it was only possible to include a mere fraction of the vast wealth of interest in the statistics. He looked forward, as a remote ambition, to publishing a volume of "British Rainfall," possibly larger than the annual volumes, dealing with the whole series of years from the commencement of that record, and perhaps going farther back, giving the average results and the extreme results, and discussing all the data with a comprehensiveness that would be impossible in any Paper read before a society. Sir Alexander Binnie had shown how interestingly the new discussion of the data bore out the conclusions at which he had formerly arrived, and called attention to several relations with which the Paper did not deal, as the first part of the subject had been compressed in order to give more space to the distribu-on, whic h, the Author imagined, would prove more interesting to the Institution. One of the points that Sir Alexander Binnie had made was that the average percentage excess of the wettest year over the mean in different countries of Europe and other continents was, on the whole, higher than that in the United Kingdom. There was one possible explanation which might account for that fact, at least in part, namely, that on the Continent, and he thought in the United States also, the custom was to expose the rain-gauge at a considerably greater height above ground than was usual in the British Isles. The result was to give a somewhat lower mean rainfall, because a gauge raised above the ground caught less rain than one close to the surface. On the other hand, The Author

The Author. during very heavy falls of rain, the amount caught in calm weather in a gauge raised 20 feet or more above the ground was practically indistinguishable from that in a gauge at the ground-level. Consequently, very heavy rainfall was apt to exceed the mean much more in the case of a high gauge than in that of a gauge 1 foot above the ground. The question of high gauges was one of the most difficult to deal with, because there was no general correction that could be applied. Sometimes gauges which differed in elevation by 6 to 10 feet read practically identically; in other places gauges similarly exposed exhibited a serious discrepancy. That was one of the reasons which had induced Mr. Symons so emphatically to insist upon uniformity in the height above ground of rain-gauges used for comparative purposes. With regard to the remarks made by Dr. Shaw about the size of rain-gauges affecting the amount of catch, he had looked up the observations made at Camden Square for 23 years with an 8-inch rain-gauge, which was read daily, a 5-inch gauge which was read weekly, and an 8-inch gauge which was read monthly. They were read at those intervals in order that one might control the other. Taking the average of the 5-inch weekly gauge as 100, it was found that the 8-inch daily gauge for 23 years averaged 100·2, and the 8-inch monthly gauge for the same period averaged 99·9; so that the mean of the two was almost identical with the average of the weekly gauge. It would be quite impossible to get three independent readings to agree more closely. Not content with that, he had gone through the volume of "British Rainfall" for 1902 and had taken out the results of twenty-seven stations where there was a 5-inch gauge and also an 8-inch gauge at the same level. He had left out of account a few stations on the summits of some of the Yorkshire moors, because their results were so extremely discordant with the rest that there was obviously some local condition which entirely destroyed their value for the purpose of this comparison. These discordant gauges were all together, clustered on about 20 square miles, and the other twenty-seven gauges were scattered over the length and breadth of the British Isles. The result was that the 8-inch gauge sometimes read a little higher than the 5-inch, and sometimes a little lower. But in the whole twenty-seven one deviation cancelled the other, and the mean of them all came out so as to give for the 8-inch gauge an excess of 0·06 inch for an average rainfall of about 27 inches. That showed that there was really no uniform difference to be found between the 5-inch and the 8-inch gauges. When dealing

with larger gauges, like the $\frac{1}{1000}$-acre gauge at Rothamsted, the influence of condensation at night had to be taken into account. A heavy deposit of dew was formed on a large exposed metal surface (a smaller surface being prevented, by the warmth of the earth in which it is embedded, from becoming so cold), and all the dew formed on the collecting surface of the large gauge was collected and measured as rain. The fact that the $\frac{1}{1000}$-acre gauge at Rothamsted gave a much larger number of rainy days than the small gauges seemed to prove that it must be due to that form of precipitation, and not to rainfall. It was, however, essential to include that form of precipitation in the records of rainfall. He had selected 70 years as the period for comparing the various 30-year intervals into which it could be divided because he could not get a longer period: it was not because it had any occult relationship to cycles or anything else, but simply because it was the longest period he could get which was common to a considerable number of stations. If he could have obtained 90 years, so as to have had three consecutive periods of 30 years, he would have preferred it. The reason why 30 years had been adopted was a strictly practical one; it was to give the greatest possible number of long records that could be obtained, with the least amount of computation in order to make up the quantities. Some computation had been necessary, and had been applied when required. He would like at some future time to test strictly a 35-year periodicity. He did not doubt that it was a very important period, and might be found to have a bearing on practical questions, if it were possible to find a way to isolating the cycle from the various disturbing causes with which it was bound up. He sympathized with what Mr. Deacon had said about the Paper not being so helpful to engineers as they would like it to be; but that was because engineers were so detailed in their work. They worked with definite problems; and although those problems were often vast from the point of view of the ordinary workman who built a house, or dug a ditch, they were very small compared with the great processes of Nature; and it was necessary, in dealing with such circumscribed problems, to make a great many more detailed observations than were required for discussing the general distribution over the country as a whole. Those detailed observations had, as a rule, to be made at the time they were required; because, he was sorry to say, no human being had yet had sufficient foresight to take observations in places where they might be wanted 50 years later. Fortunately, many engineers were fully awake to the importance

The Author.

The Author. of obtaining records some considerable time before they were required; and year by year the possibility of determining accurately the rainfall of small areas was being increased. Since the time Mr. Symons commenced his work the possibility of making such determinations correctly had been very largely increased. The same remark held good with regard to the relation of the extreme years to the average, and with regard to the driest year or driest three years. These questions had to be generalized when dealing with a large area of country, and they had to be treated in detail when dealing with small areas. The placing of gauges was a matter of great importance, and he had no doubt that many of the rain-gauges which had been used on the high exposed moorlands of the country gave results which were much too low, because of the action of the wind on the gauge; and the utmost care must be taken in selecting a site not to have the gauge standing on a sky-line where there was a sweep of air from whatever quarter the wind might blow. Every gathering-ground had features peculiar to itself, so that the problem must be treated separately in each case, and not generalized upon. In the future it might be possible to generalize to some effect, but a great deal of additional information was first required. Mr. Archibald had referred in a very proper way to the objections to the use of the arithmetical mean, and the Author had often been struck by the difficulty of using arithmetical means for divergencies from the average. But that again involved a practical question. Very often the data dealt with were not sufficiently accurate to justify the application of the most exhaustive or the most satisfactory method that might be applied if the data were perfect; and it was his belief that it was quite unnecessary to require more accuracy in the treatment of figures than was required in the observations from which those figures were obtained. Mr. Archibald wished that 35 years had been taken. The Author wished he had had the 35 years to take for the general average, but it would have involved computing so many of the records for stations, supplying so many missing years in a theoretical way, that the result would have been very largely deprived of its practical value. The suggestion to shift the columns of figures in Table I, so that the mean for 10 years should occur opposite the middle of the 10 years instead of the last year, was a point where the ordinary reader had to be taken into account. It would perhaps be confusing to the ordinary reader to find the mean of 10 years opposite the fifth year instead of the tenth. But the matter might safely be left to the Secretary of the

Institution in editing the Paper. He had no objection whatever to its being done if it was likely to make the Table more useful. When Mr. Archibald compared the rainfall of England and India, he of course meant the British Isles and India; in questions of geographical distribution it was necessary to be explicit in nomenclature. With regard to Mr. Cooper's observations about wet days, that, of course, seriously complicated the treatment of individual years, because one wet day with 3 inches or 4 inches of rain might shift the totals of two years, especially if it occurred on the 31st December, and was counted by some people in one year and by others in the next. He heartily agreed with Mr. Cooper as to the importance of introducing more recording-gauges, and he regretfully agreed with Dr. Scott as to the impossibility of so doing under the present circumstances. Fortunately recording-gauges were becoming cheaper and more accurate, and he hoped that soon they would be much more largely used. Mr. Hopkinson had made certain statements that required to be set right. To begin with, he had misunderstood the method by which the maps were constructed. There were 138 selected stations given in full in the Paper, which were stations used to get an arithmetical average to compare with the averages calculated from areal measurements made on the maps; but the maps were drawn from more than 1,000 stations, as was described in the Paper. Of these 380 had perfect 30-year records, and about 700 had values computed from periods for the most part exceeding 20 years in length. He would never have attempted to draw the isohyetal lines across so large and important a county as Hertfordshire from two stations: he had used fifteen stations in that county. The lines were, in his opinion, correctly drawn, and he would be ready at any time to support their accuracy. He believed that the greater part of the basin of the Lea had an average rainfall greater than 25 inches. He gave Mr. Hopkinson full credit for being an excellent rainfall-observer and for having done much to promote the establishment and maintain the accuracy of rainfall stations in Hertfordshire; but rainfall only shared with many other branches of science a portion of Mr. Hopkinson's spare time, and although, after careful study of the matter, the Author was obliged to disagree with the methods adopted by Mr. Hopkinson in estimating the rainfall of counties, he wished to assure that gentleman that he was not oblivious to the good work done by him in Hertfordshire. He desired in conclusion to thank those who had taken part in the discussion, and the President for directing the discussion so ably, and he trusted that the records he

The Author.

The Author. had brought together might prove in some way useful to engineers, even though they did not give all the information that might be desired.

The President. The PRESIDENT remarked, with regard to the determination of averages, that to those who were accustomed to deal with curved surfaces and with irregular forms, it was quite clear that no geometrical mean was to be trusted, and that the only true way, which the Author had fully appreciated, and indicated in the Paper, and which he desired to adopt if he could, was to determine accurately the surface formed by contact with the heads of all the ordinates representing rainfalls, and to obtain the average ordinate by measurement of the volume. But in default of a multitude of observations it was quite clear that could not be done. He felt sure the members were agreed that the Author had made admirable use of the material at his command, and they owed him a great debt for thus analyzing and arranging the valuable data accumulated by the late Mr. Symons.

Correspondence.

Professor Abbe. Professor CLEVELAND ABBE, of the United States Weather Bureau, observed that it certainly was a pleasure to read a memoir in the English language dealing with the distribution of rainfall for a specific, fundamental period of time. He believed that the Paper was the first memoir in which this important feature had been introduced by an English or an American writer. The interval 1870–99, chosen by the Author for his rainfall-maps, was certainly the best that could have been selected, since the accurate work of recent years was the safest foundation for study. The care shown in selecting fundamental stations, as detailed on pp. 289–300, greatly heightened confidence in the results, so that the memoir became one of the best in any language. It would have been more in accordance with the practice of the best climatologists if the Author had used the probable error, as defined by Gauss, in preference to the mean of the departures, as his index to the reliability of any given series. The study of the numerous gauges maintained by Hellmann in the experimental rainfall-field of the Meteorological Institute at Berlin showed that, owing to slight variations in the local winds at the mouths of the gauges, the differences in their catches had a range of 12 per cent.; although