Discussion.

Sir John Coode. Sir JOHN COODE, President, asked the indulgence of the members while he referred to a personal matter. It was more than fifty years ago that he first met Mr. Harrison at the Paddington terminus, when they were both young men just out of their articles, and he had had the pleasure of his friendship ever since. It was therefore a peculiar satisfaction to him to be present on that occasion, to listen to his old friend's Paper. He need hardly say that the supply of water to the Metropolis was a matter of vital moment, especially at the present time. If any one entertained a doubt on the subject, he would refer him to a letter in *The Times* of that morning from Mr. Symons, whom he was glad to see present, and who, he hoped, would take part in the discussion. In illustration of the great importance of the water-supply to London, he might mention that the proportion of the population of the Metropolis to that of the United Kingdom was within measurable distance of one-eighth. He was quite sure that they would all unite in passing a cordial vote of thanks to Mr. Harrison for his Paper.

Mr. Harrison. Mr. J. T. HARRISON asked permission to explain the diagrams which he had, at the suggestion of the President, placed on the wall since the meeting at which the Paper was read. Fig. 1, Plate 2, was a section from Banstead to Carshalton, and by Streatham to Battersea and Chelsea. The water-level mentioned in the Paper as being 260 feet above Ordnance datum at Banstead, was marked on the section. The water issued from springs at Carshalton and Croydon between 110 and 130 feet above Ordnance datum, and flowed into the Wandle. At Streatham, the Chalk was 131 below, whilst the water stood at about 55 feet above Ordnance datum. In the neighbourhood of Tooting and Balham, the water rose in many places above the surface. Passing to Battersea and Chelsea there was a great change, the water being met with at 55 feet, and the Chalk at from 232 to 238 feet below Ordnance datum, whereas at Streatham it was 131 to 100 feet below it. There appeared, therefore, evidence of a fault or disturbance between these two points, which agreed with the east and west disturbance pointed out by Professor Prestwich.

Fig. 2, Plate 2, was a section taken on the other side of the valley of the Thames, from the Chiltern Hills to Bushey Meads, where the normal level of the water, in the famous well mentioned by Mr. Robert Stephenson about 1840, was said to be 180 feet above Ordnance datum; whereas, in the well on the Chiltern Hills, at a distance of 13 miles, it stood at a maximum of 513 feet, and a minimum of 468 feet above Ordnance datum; the maximum inclination being 22 feet in a mile, and the minimum 19 feet per mile. He had extended the section onwards through Harrow and Perivale to Brentford. It would be observed that there was a considerable elevation of London Clay at Bushey, which explained an observation he had made in the Paper as to the arrest of water passing from the Chalk by the London Clay. At Harrow water was found at 101 feet above Ordnance datum, and at Greenford, near Perivale (50 feet above Ordnance datum), it rose to the surface from a bore-hole into the Chalk, as it did also at Brentford. The Chalk dipped underground after Bushey was left, with the same inclination that it had above ground. Mr. Harrison.

Fig. 3, Plate 2, was taken in the same locality as Fig. 2, in one of the valleys that had been scooped out of the Chalk—a mere surface indentation, as it were—along which the River Gade flowed, according to observations made by Mr. Dickinson many years ago, with a regular fall of about 14½ feet per mile, or 200 feet in 14 miles, exactly similar to the adjoining railway. The cross-section extended from the "Two Waters" on the Gade, midway between Tring and Watford, to the River Ver at St. Albans; the table-land rose about 200 feet above these streams, and Mr. Dickinson found it was necessary to sink from 170 to 180 feet below the surface midway between them, in order to reach water.[1]

An important point mentioned by Mr. Dickinson was, that the

[1] Minutes of Proceedings Inst. C.E., vol. ix. p. 370. Mr. Dickinson said:—"Between Watford and Tring, on the London and North-Western Railway, there was a rise of about 200 feet, and subterranean water was found all along the valley, at an equal distance below the surface of the rails, the water-line taking very nearly the same inclination as the railway."

Minutes of Proceedings Inst. C.E., vol. xiv. p. 72. Mr. S. C. Homersham said:—"On sinking a well at Tring, water was commonly found in the chalk, standing at a level of about 450 feet above Trinity high-water mark, from whence the water-level gradually declined, in a south-easterly direction, to the level of the sea, and could be traced, issuing in large volumes, at various places along the coast."

Minutes of Proceedings Inst. C.E., vol. ix. p. 370. Mr. Dickinson said:—"Water found in the cracks and fissures of the chalk, at a moderate depth from the surface, was always in a nearly level line, taken transversely to the dip of the stratum, which corresponded very closely to the level of the water in the nearest stream. In digging wells in the high table-land, about 6 miles in width, situated between the River Pade, at Two Waters, and the River Ver, at St. Albans, and which was about 200 feet above the level of the water in those rivers, it was necessary to sink to the depth of 170 feet, or 180 feet, before water was found."

Mr. Harrison. water appeared to arrive at these two rivers by means of fissures in the Chalk, and that it stood very nearly at the same level in each; so that it percolated through the Chalk into the fissures, and was carried right and left across the dip of the stratification to the adjoining river.

Fig. 4, Plate 2, was a section taken from Stoke Common, nearly in a north and south line, through Windsor Castle. To the north of Slough the Chalk fell nearly with the same inclination as the surface, and was covered by the Lower Tertiary beds and the London Clay, with a quantity of gravel overlying both. There was a rise in the Chalk at Slough which, together with that of the clays to the southward, separated the water that came into the Slough gravel from that in the lower gravel in the Thames basin proper between Dorney and Windsor. Fig. 4 showed approximately the valley of the Thames between Slough and Windsor Castle, where the gravel was beautifully clean and full of water. Windsor Castle was marked on Professor Prestwich's map as being nearly over the line of the great east and west disturbance. At a short distance to the south of Windsor the Chalk was 300 feet below Ordnance datum, and it continued to dip for some distance, after which it rose, and cropped out again in the line of the Hog's Back, where it lay at a very steep angle; the intervening hollow space being filled with Lower Tertiary beds, the London Clay, and the superimposed Bagshot sands.

Fig. 5, Plate 2, was a section running east and west from Staines to Dorney, along the centre of what he had called the Windsor gravel-bed. Above Datchet, towards Maidenhead, there was a great depth of gravel, with the Chalk, the Lower Tertiary beds, and in some parts the London Clay, lying below it. This gravel was full of water derived from the Chalk and the Lower Tertiary beds. At Datchet, the London Clay cropped up, and the water was thrown in the gravel above it, and passed onwards until it entered the Thames, chiefly between the Colne and Hampton, where the river ran nearly at right angles to the course of the underground water.

Fig. 6, Plate 2, was a section about midway along what he had called the Slough gravel bed, from the north of Slough downwards to Isleworth. Here again, for a considerable distance from the outcrop onwards, the Chalk was covered with the Lower Tertiaries, which, with the gravel above them, were full of water; but nearly opposite to Slough they were overlaid by the London Clay beds, on to the surface of which the water passed. Thence it proceeded through the gravel to the Thames between Teddington and Isleworth, and flowing under it, supplied the enormous volume of water found in the gravel beds throughout the southern parts of London. Mr. Harrison.

Mr. G. J. SYMONS said he should perhaps best show his appreciation of the honour of being asked to open the discussion, by saying nothing about his incompetence. Those who were acquainted with his work knew that it lay almost entirely with water aboveground, whereas the Paper dealt essentially with water underground. They had had the case for deriving a supply from the Chalk put in the strongest possible way. He could not help thinking of the many speeches and papers to which they had listened in that room by the late Mr. Homersham, and how fortunate it was for the cause of chalk-water generally that the mantle of Mr. Homersham had fallen on the shoulders of such a man as Mr. Harrison. But he hoped that what he was about to say would be looked upon rather as coming from one of the general public than from an expert, since his own work had lain upon the surface. The first thing that struck him was, that the fact of there being a large quantity of water found underground did not prove that there was a great amount *available*; it might be a permanent storage, which they could run out, and there would be the end of the matter. It did not by any means follow that because they tapped a large subterranean reservoir they had found a perennial supply. With regard to the quantity of water in the Chalk, as far as he had followed the calculations, they were almost entirely based (not quite, because there was the question of the Wandle, to which he would afterwards refer) upon percolation experiments. No one appreciated more thoroughly than he did the extremely good work which was being done by Dr. Evans, Sir John Lawes, and Dr. Gilbert. He was glad to see Dr. Gilbert present, because if he said something not very polite about the experiments at Rothamsted he was in the presence of one who could correct him if he were wrong. There was a diagram in the Exhibition of the Royal Meteorological Society in the adjoining room representing the percolation gauges at Rothamsted. No one in the world had devoted so much money and care to the question of percolation as Sir John Lawes and Dr. Gilbert, but they themselves knew full well the extreme difficulty which attached to the subject. The problem, or at least an incidental question arising out of the Paper, was the supply of the metropolis, with its five millions of people, with water, and that was a tremendous thing to base simply upon experiments tried over 5 or 6 square feet of surface. The Author had Mr. Symons.

Mr. Symons. stated, and he quite agreed with him, that a great deal of substantial proof was wanted before such a gigantic project could be developed on so comparatively narrow a basis. The difficulty in connection with the experiments to which he had referred was that every engineer knew that if he dug a hole and took out the earth he could not get it all back again. They had found that out at Rothamsted. They then tried another excellent scheme; they cut down round some cubes of earth, leaving the actual soil untouched, and built walls in concrete on the four sides. Funnels were provided at the bottom so that any water percolating down might go through them and be measured. *Prima facie* it was as good a plan as he could possibly conceive for doing the work, but the difficulty which had occurred to him was this—how about the adhesion between the soil and the brickwork? They surrounded a cube of soil by brickwork. He quite understood that they could grout it in; but if the soil shrank during dry weather, surely it would separate from the four walls, and if so, when the moisture came, was it not probable that it would run down by them? It struck him that a great deal of the percolation took place, not through the cube of earth, but between it and the surrounding walls. No doubt Dr. Gilbert would express his own opinion upon that point. With respect to the question of the Wandle, he was sorry that Mr. Baldwin Latham, who had done so much in measuring water-levels in the Chalk on the Wandle and other streams in Surrey, was absent, and he was afraid there was no chance of the discussion lasting long enough for his return. He was glad, however, to see that some one competent to deal with the matter had placed a diagram of the Wandle upon the wall. With respect to the gaugings, the Author had referred to Mr. Braithwaite's Paper read before the Institution many years ago. Mr. Symons did not wish to find fault, but he had frequently noticed that the Papers read before the Institution were not accompanied by the mass of Tables which he, having a great affection for Tables, should like to see. The data given in Mr. Braithwaite's Paper were extremely limited. Those who had had anything to do with such work knew that taking two or three gaugings, or taking them once a week, gave very little idea of what the perennial flow of a stream was; and unless the diagram of the Wandle was based upon a larger number of observations than those in Mr. Braithwaite's Paper, and in Mr. Harrison's Paper, he did not personally attach any great importance to it. It had always appeared to him that the gauging of English rivers had been terribly neglected. He received three times the amount of detail with respect to the Seine, the Po, and other continental rivers, that he did with regard to the Thames. There was one point which he did not at all understand, namely, the enormous increase in the volume of water between Teddington and Kew. Mr. Harrison had alluded to the Seething Wells (the word "seething" certainly did give the idea of something bubbling up) as a sort of out-crop of subterranean water. He was not very well acquainted with the Thames, but he had thought that the Seething Wells were above Teddington, and if so, at any rate some of the water must have got into the river before reaching Teddington. Another difficulty was this. He had spent some time at Richmond, which was a good way below Teddington, and still farther below the Seething Wells, and he confessed that, although he knew nothing about gauging, the volume of the river there did not seem to him to be so enormously large. They had heard a great deal about an enquiry in connection with a proposed weir across the Thames in the neighbourhood of Richmond; and there was no suggestion then that there were these hundreds of millions of gallons going past. It must be rather awkward to gauge there, because the tide came to Teddington, and he did not know how the tidal water was separated from the upland water. There was another point that had occurred to him, on which he did not desire to express any opinion, namely that if the volume of the Thames doubled between Teddington and Richmond, surely the chemical analysis ought to tell something about it. By comparing the constituents of samples taken at the two places, they ought to be able to learn something of the history of the added water. Mr. Symons.

Dr. J. H. Gilbert remarked that as Mr. Harrison had referred to the results obtained by Sir John Lawes and himself, and had founded important estimates upon them, they thought it might be of interest to provide further data than had been already published, and they had accordingly prepared the Tables now exhibited. Mr. Harrison had referred to ten years of percolation experiments; but in the Tables they had given the results of twenty years up to last autumn. The first Table showed the average annual amount of rain in inches, and the percolation in inches, through 20, 40, and 60 inches of soil, and also the complementary amount which represented evaporation. In the second Table would be found the average for each month during the twenty years. The results were given for harvest-years, from September 1st to August 31st. Not only was that method of computation of interest to them as agriculturists, but he thought it ought to be adopted by Dr. Gilbert.

Dr. Gilbert. those who studied the question of drainage from other points of view. Thus, the second Table showed that the average minimum drainage was in August; and that in September the amount began to increase. If the civil year were taken it would be found that the end of December cut the drainage in the middle of the period of greatest activity; whilst marked decline commenced with March, not April, the point of civil year division. For other purposes, therefore, as well as those of agriculture, the harvest-year was more appropriate than the civil year. But perhaps he ought to say a word as to the observations of Mr. Symons, who had called in question, more or less, the validity of the whole thing. If, as he suggested, there was material drainage between the soil and the walls, the results were of course of very little value; but Dr. Gilbert thought they might be satisfied that the soil would very soon settle sufficiently close to the wall to prevent any such abnormal action.

Taking the average of the twenty years, the minimum drainage was in August, but the details for each individual year showed that it was frequently before August, and very rarely after it; and the recommencement of the drainage was very seldom in August, though with very heavy rain they might have much drainage, and it was not often later than September. If the drainage-beds had been covered with vegetation the average minimum drainage would be earlier than August, and the recommencement would begin later than September. He might be permitted to call attention to one or two of the main results. The first ten years, with an average of about 30 inches of rain, gave 13·21, 13·94, and 12·17 inches, according to the depth of soil, viz., 20, 40, and 60 inches. With a rather less rainfall during the second ten years they had 15·54, 16·38, and 15·05 inches of drainage. That was, with a rather less rainfall there was a larger amount of drainage. There was less through the 60 inches than through the 20 inches of soil. One vitiating element in experiments of this kind obviously was that they were obliged to cut off the drainage at a particular point, so that there was no possibility of a return upwards. If, however, they compared the drainage through the 60 inches with that through the 20 inches, they would find that there was a little less through the greater depth, which was evidence that there had been a return upwards below the point at which it was cut off in the 20-inch gauge; but the fact of its being so little less, he thought, showed that the conditions were not very wide of what they might be under ordinary circumstances. Then as to the larger amount of drainage through the 40-inch gauge, it was found that the Rothamsted subsoil was exceedingly variable, and they were able to judge from the composition of the water that passed through it that the subsoil in the 40-inch gauge was probably more gravelly, and therefore there was more percolation; there was, moreover, with more drainage, less nitric acid in it. Dr. Gilbert.

The advantage of having a greater number of years, and full details, was that they were able not only to get a better average, but to study the maxima and the minima, which were of the greatest importance, especially the latter, when they came to consider what was available over a series of years. It would be seen by the first Table, that in 1873–4, with a rainfall of something under 22 inches, the drainage was only 5·74, 5·40, and 3·94 inches. In 1879-80, with a rainfall also between 21 and 22 inches, the drainage was 6·89, 7·39, and 6·50; whereas, in 1878-9, with a rainfall of 41 inches, the drainage was 24·44, 26·03, and 24·38. In 1880-1, with a rainfall of 36·7 inches, the drainage was 22·38, 22·84, and 21·26 inches. Thus, within the harvest-year they might have little more than 5 inches of drainage, or as much as from 22 to 25 or 26 inches. Such results were of great importance to study when considering what would be available under any given circumstances.

The details further showed that although the rainfall obviously had a considerable influence upon it, the amount of drainage was by no means proportional to the rainfall, but depended to a great extent upon the distribution as well. Thus, to give a very obvious example, if they had a given amount of heavy rain during the growing period, there might be no drainage at all; whilst the same quantity during the winter, when there was no vegetation, and little evaporation, might give a very large proportion of drainage. The drainage was, in fact, materially affected by the distribution of the rain, and the drainage and evaporation were, of course, complementary to one another. The Table showed that taking the difference between rainfall and percolation to represent evaporation, they had in two years only 12 inches of evaporation, and in several between 19 and 20 inches; so that there was a great difference in that respect also. According to the average of twenty years, with rather heavy soil free from vegetation, it might be said that the drain-gauges gave about 14 inches. It was difficult to estimate exactly what deduction should be made for vegetation. A large proportion of any area that they had to consider was covered with vegetation. Sir John Lawes and himself had considered that the minimum amount would average 2 inches, as in the case of downs or waste lands, where there was very little vegetation; whereas with a heavy grain-crop, or good

Dr. Gilbert. mangel crop, there might be an evaporation of 7 inches or more. Taking the average of a large area around London, partly covered with vegetation and partly bare, over a number of seasons, they thought that between 3 and 4 inches should be deducted from the 14 inches of percolation, so leaving 10 or 11 inches. Supposing the average rainfall to be about 30 inches for the twenty years, that left about 19 or 20 inches for evaporation, both by the soil and by vegetation. This agreed very fairly with the results of Dr. Evans and others. Further, in reference to the interpretation of the figures which he had given, it should be observed that the estimated rainfall of the Chalk district was about 27 inches. The rainfall over the twenty years at Rothamsted was, however, 30 inches by the large one-thousandth of an acre gauge, but only 29 inches by the 5-inch gauge. The large gauge recorded a great many small deposits which could not be measured by a small one; and there were also some other irregularities. But if they used the same kind of gauge as that by which the observations of others were mostly made, the ordinary 5-inch gauge, the result would be 29 inches, whereas the estimate for the whole district was only between 26 and 27 inches. Hence the Rothamsted results to which he had referred probably indicated a rather exaggerated amount of drainage for the whole district.

A point to which he wished particularly to call attention was, that the details—the minima as well as the averages—should be studied, if they were to form any trustworthy conclusions from such results. He admitted with Mr. Symons, that there was something artificial in that mode of estimating the drainage of a district, but he knew of no better. He had received a memorandum from Sir John Lawes, calling attention to two or three particular points. The first referred to the fact that, within a mile to the eastward of the gauges, there had undoubtedly been a river before his time, and to the westward there was the Ver, which had gone down immensely during his lifetime, and had often been dry. Then again, the wells had frequently to be lowered, and the water-supply was at any rate lessening, and whether the scheme now in question would or would not affect the waters to the north of London, it was of the greatest importance that nothing should be done to reduce them; for there could be no doubt that they would want all they could get. Sir John Lawes agreed with Mr. Harrison in thinking it extremely desirable that they should have better gaugings of the flow and discharges of the rivers in the chalk district north of London.

Dr. Gilbert.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

TABLE A.—Summary of results, 20 years.

—	Rainfall.		Drainage through soil (uncropped).			Difference,[1] approximately = evaporation.		
	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
Harvest years, Sept. 1 to Aug. 31.								
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
1870–1	26·49	27·55	9·64	9·42	5·81	17·91	18·13	21·74
1871–2	27·83	29·02	9·69	9·39	8·24	19·33	19·63	20·78
1872–3	28·99	30·66	14·35	13·67	12·03	16·31	16·99	18·63
1873–4	20·29	21·69	5·74	5·40	3·94	15·95	16·29	17·75
1874–5	27·87	31·61	12·25	12·72	10·30	19·36	18·89	21·31
1875–6	28·83	31·98	14·75	16·87	15·46	17·23	15·11	16·52
1876–7	37·73	39·28	19·63	22·07	20·20	19·65	17·21	19·08
1877–8	32·11	32·65	14·72	16·44	14·84	17·93	16·21	17·81
1878–9	40·17	41·05	24·44	26·03	24·38	16·61	15·02	16·67
1879–80	20·88	21·36	6·89	7·39	6·50	14·47	13·97	14·86
1880–1	35·85	36·77	22·38	22·84	21·26	14·39	13·93	15·51
1881–2	31·66	32·31	15·81	16·08	14·32	16·50	16·23	17·99
1882–3	33·69	34·71	20·82	21·72	19·72	13·89	12·99	14·99
1883–4	25·29	25·77	11·86	12·00	11·21	13·91	13·77	14·56
1884–5	25·90	26·78	14·82	15·14	13·98	11·96	11·64	12·80
1885–6	29·46	31·02	17·37	18·41	16·57	13·65	12·61	14·45
1886–7	22·63	23·61	10·64	12·58	11·72	12·97	11·03	11·89
1887–8	29·11	30·50	13·96	15·58	14·67	16·54	14·92	15·83
1888–9	28·79	30·09	14·64	15·82	14·33	15·45	14·27	15·76
1889–90	26·73	27·43	13·16	13·60	12·74	14·27	13·83	14·69
Averages . .	29·02	30·29	14·38	15·16	13·61	15·91	15·13	16·68

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge.

Dr. Gilbert.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

TABLE B.—Averages for each month, 20 Harvest-years.

—	Rainfall. 5-Inch Funnel Gauge.	Rainfall. $\frac{1}{1000}$th Acre Gauge.	Drainage through soil (uncropped). 20 Inches Deep.	Drainage through soil (uncropped). 40 Inches Deep.	Drainage through soil (uncropped). 60 Inches Deep.	Difference,[1] approximately = evaporation. 20 Inches Deep.	Difference,[1] approximately = evaporation. 40 Inches Deep.	Difference,[1] approximately = evaporation. 60 Inches Deep.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September . . .	2·74	2·86	0·96	0·85	0·75	1·90	2·01	2·11
October	3·07	3·20	1·78	1·74	1·50	1·42	1·46	1·70
November . . .	2·92	3·03	2·24	2·30	2·05	0·79	0·73	0·98
December . . .	2·31	2·42	1·90	2·02	1·81	0·52	0·40	0·61
January	2·34	2·51	1·96	2·25	2·06	0·55	0·26	0·45
February . . .	1·92	2·04	1·44	1·59	1·44	0·60	0·45	0·60
March	1·61	1·74	0·80	0·95	0·86	0·94	0·79	0·88
April	2·12	2·21	0·67	0·74	0·68	1·54	1·47	1·53
May	2·22	2·28	0·60	0·68	0·59	1·68	1·60	1·69
June	2·45	2·52	0·63	0·64	0·60	1·89	1·88	1·92
July	2·96	3·03	0·84	0·85	0·77	2·19	2·18	2·26
August	2·36	2·45	0·56	0·55	0·50	1·89	1·90	1·95
Total . . .	29·02	30·29	14·38	15·16	13·61	15·91	15·13	16·68

TABLE C.—General Summary, average actual results per annum.

—	Rainfall. 5-Inch Funnel Gauge.	Rainfall. $\frac{1}{1000}$th Acre Gauge.	Drainage 20 Inches Deep.	Drainage 40 Inches Deep.	Drainage 60 Inches Deep.	Difference 20 Inches Deep.	Difference 40 Inches Deep.	Difference 60 Inches Deep.
10 years, 1870–1 to 1879–80 . . .	29·12	30·68	13·21	13·94	12·17	17·47	16·74	18·51
10 years, 1880–1 to 1889–90 . . .	28·91	29·91	15·54	16·38	15·05	14·37	13·53	14·86
20 years, 1870–1 to 1889–90 . . .	29·02	30·29	14·38	15·16	13·61	15·91	15·13	16·68

TABLE D.—General Summary, average per cent. drainage and evaporation to rainfall.[1]

—	Rainfall. 5-Inch Funnel Gauge.	Rainfall. $\frac{1}{1000}$th Acre Gauge.	Drainage 20 Inches Deep.	Drainage 40 Inches Deep.	Drainage 60 Inches Deep.	Difference 20 Inches Deep.	Difference 40 Inches Deep.	Difference 60 Inches Deep.
10 years, 1870–1 to 1879–80 . . .	..	..	43·1	45·4	39·7	56·9	54·6	60·3
10 years, 1880–1 to 1889–90 . . .	..	..	52·0	54·8	50·3	48·0	45·2	49·7
20 years, 1870–1 to 1889–90 . . .	..	..	47·5	50·0	44·9	52·5	50·0	55·1

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge.

Experiments on Rainfall and Drainage at Rothamsted. Dr. Gilbert.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

—	Rainfall.		Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1870–1.								
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September . . .	2·11	2·31	0·22	0·06	0·02	2·09	2·25	2·29
October	3·87	4·13	1·07	0·45	0·18	3·06	3·68	3·95
November . . .	1·24	1·40	1·84	1·42	0·71	–0·44	–0·02	0·69
December . . .	2·53	2·65	2·10	1·95	1·07	0·55	0·70	1·58
January	1·40	1·45	0·25	1·12	0·72	1·20	0·33	0·73
February . . .	1·64	1·63	0·91	1·13	0·71	0·72	0·50	0·92
March	1·38	1·50	0·34	0·43	0·23	1·16	1·07	1·27
April	2·82	2·89	0·81	0·80	0·63	2·08	2·09	2·26
May	0·94	0·96	..	0·05	0·04	0·96	0·91	0·92
June	3·89	3·87	1·29	1·15	0·90	2·58	2·72	2·97
July	3·99	3·99	0·81	0·85	0·60	3·18	3·14	3·39
August	0·68	0·77	..	0·01	..	0·77	0·76	0·77
Total . . .	26·49	27·55	9·64	9·42	5·81	17·91	18·13	21·74
1871–2.								
September . . .	4·60	4·74	1·82	1·43	1·08	2·92	3·31	3·66
October	0·94	1·12	0·12	0·24	0·23	1·00	0·88	0·89
November . . .	0·60	0·66	0·07	0·14	0·35	0·59	0·52	0·31
December . . .	1·28	1·43	0·82	0·76	0·48	0·61	0·67	0·95
January	4·51	4·67	3·64	3·55	3·13	1·03	1·12	1·54
February . . .	1·36	1·52	0·64	0·77	0·58	0·88	0·75	0·94
March	1·84	2·12	0·92	0·82	0·83	1·20	1·30	1·29
April	1·56	1·61	0·09	0·16	0·13	1·52	1·45	1·48
May	2·88	2·90	0·77	0·75	0·63	2·13	2·15	2·27
June	3·25	3·25	0·77	0·74	0·76	2·48	2·51	2·49
July	2·73	2·72	0·01	0·01	0·01	2·71	2·71	2·71
August	2·28	2·28	0·02	0·02	0·03	2·26	2·26	2·25
Total . . .	27·83	29·02	9·69	9·39	8·24	19·33	19·63	20·78

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge. When the drainage exceeds the rainfall the difference is entered as a minus quantity.

Dr. Gilbert.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.
Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

—	Rainfall.		Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1872–3.								
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September . . .	1·28	1·37	0·01	0·02	0·01	1·36	1·35	1·36
October	4·59	4·67	3·13	2·68	2·10	1·54	1·99	2·57
November . . .	3·90	4·03	2·85	2·80	2·44	1·18	1·23	1·59
December . . .	3·97	4·16	3·38	3·40	3·04	0·78	0·76	1·12
January	3·53	3·74	2·77	2·73	2·71	0·97	1·01	1·03
February . . .	1·13	1·34	0·71	0·54	0·55	0·63	0·80	0·79
March	1·90	2·05	0·88	1·02	0·80	1·17	1·03	1·25
April	0·54	0·64	..	0·01	0·01	0·64	0·63	0·63
May	1·74	1·87	..	..	..	1·87	1·87	1·87
June	1·66	1·76	..	..	..	1·76	1·76	1·76
July	2·31	2·39	0·62	0·47	0·37	1·77	1·92	2·02
August	2·44	2·64	..	..	..	2·64	2·64	2·64
Total . . .	28·99	30·66	14·35	13·67	12·03	16·31	16·99	18·63
1873–4.								
September . . .	2·22	2·38	0·70	0·38	0·20	1·68	2·00	2·18
October	2·61	2·82	0·99	0·83	0·29	1·83	1·99	2·53
November . . .	1·82	1·99	1·08	1·11	0·86	0·91	0·88	1·13
December . . .	0·59	0·71	0·15	0·11	0·04	0·56	0·60	0·67
January	1·78	1·93	1·22	1·35	1·21	0·71	0·58	0·72
February . . .	1·62	1·73	0·85	0·84	0·73	0·88	0·89	1·00
March	0·50	0·65	0·01	0·04	0·03	0·64	0·61	0·62
April.	2·00	2·14	0·32	0·29	0·25	1·82	1·85	1·89
May	1·14	1·19	..	..	..	1·19	1·19	1·19
June	1·53	1·59	..	..	..	1·59	1·59	1·59
July	2·82	2·81	0·42	0·45	0·33	2·39	2·36	2·48
August	1·66	1·75	..	..	..	1·75	1·75	1·75
Total . . .	20·29	21·69	5·74	5·40	3·94	15·95	16·29	17·75

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge.

Dr. Gilbert.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.
Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

	Rainfall.		Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1874–5.								
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September . . .	3·48	3·62	0·63	0·25	0·21	2·99	3·37	3·41
October	3·05	3·22	1·52	1·26	1·02	1·70	1·96	2·20
November . . .	2·10	2·34	1·21	1·04	0·69	1·13	1·30	1·65
December . . .	1·61	1·80	1·16	1·34	1·04	0·64	0·46	0·76
January	3·01	3·99	2·87	3·39	2·62	1·12	0·60	1·37
February . . .	0·77	1·18	0·34	0·44	0·38	0·84	0·74	0·80
March	0·75	0·87	0·50	0·57	0·46	0·37	0·30	0·41
April	1·38	1·56	0·09	0·11	0·06	1·47	1·45	1·50
May	2·52	2·74	0·29	0·37	0·30	2·45	2·37	2·44
June	3·15	3·53	0·35	0·26	0·14	3·18	3·27	3·39
July	5·06	5·66	3·29	3·66	3·35	2·37	2·00	2·31
August	0·99	1·10	..	0·03	0·03	1·10	1·07	1·07
Total . . .	27·87	31·61	12·25	12·72	10·30	19·36	18·89	21·31
1875–6.								
September . . .	2·46	2·80	0·89	0·83	0·71	1·91	1·97	2·09
October	5·13	5·90	3·72	3·95	3·55	2·18	1·95	2·35
November . . .	3·95	4·43	3·24	3·54	3·26	1·19	0·89	1·17
December . . .	0·90	1·19	0·78	1·01	0·97	0·41	0·18	0·22
January	1·59	1·81	1·46	1·76	1·67	0·35	0·05	0·14
February . . .	2·79	3·05	1·87	2·20	1·94	1·18	0·85	1·11
March	2·42	2·90	1·28	1·74	1·58	1·62	1·16	1·32
April.	3·24	3·33	1·36	1·66	1·72	1·97	1·67	1·61
May	0·76	0·78	..	0·04	0·03	0·78	0·74	0·75
June	1·33	1·35	..	..	..	1·35	1·35	1·35
July	1·43	1·46	..	..	..	1·46	1·46	1·46
August	2·83	2·98	0·15	0·14	0·03	2·83	2·84	2·95
Total . . .	28·83	31·98	14·75	16·87	15·46	17·23	15·11	16·52

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge.

Dr. Gilbert.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

——	Rainfall.		Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	5-inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1876–7.								
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September	4·59	5·02	2·30	2·24	2·04	2·72	2·78	2·98
October	1·37	1·52	0·82	1·10	0·96	0·70	0·42	0·56
November	4·00	4·20	2·89	2·99	2·66	1·31	1·21	1·54
December	5·80	6·00	5·21	5·74	5·25	0·79	0·26	0·75
January	4·82	4·99	3·79	4·41	4·11	1·20	0·58	0·88
February	1·98	2·10	0·87	1·19	1·23	1·23	0·91	0·87
March	2·52	2·55	1·01	1·25	1·10	1·54	1·30	1·45
April.	2·68	2·76	1·33	1·61	1·49	1·43	1·15	1·27
May	2·79	2·82	0·44	0·55	0·51	2·38	2·27	2·31
June	1·39	1·44	0·03	0·09	0·10	1·41	1·35	1·34
July	3·23	3·28	0·56	0·51	0·44	2·72	2·77	2·84
August	2·56	2·60	0·38	0·39	0·31	2·22	2·21	2·29
Total . . .	37·73	39·28	19·63	22·07	20·20	19·65	17·21	19·08
1877–8.								
September	1·53	1·53	0·21	0·26	0·21	1·32	1·27	1·32
October	1·90	1·95	0·58	0·51	0·39	1·37	1·44	1·56
November	5·15	5·16	4·03	4·20	3·82	1·13	0·96	1·34
December	2·28	2·28	1·74	1·98	1·75	0·54	0·30	0·53
January	1·73	1·75	1·10	1·36	1·20	0·65	0·39	0·55
February	1·77	1·80	1·01	1·20	1·13	0·79	0·60	0·67
March	0·88	0·98	0·27	0·50	0·46	0·71	0·48	0·52
April.	4·01	4·09	2·35	2·52	2·43	1·74	1·57	1·66
May	4·89	4·97	1·48	1·85	1·50	3·49	3·12	3·47
June	2·46	2·51	0·61	0·86	0·76	1·90	1·65	1·75
July	0·64	0·65	0·01	0·03	0·06	0·64	0·62	0·59
August	4·87	4·98	1·33	1·17	1·13	3·65	3·81	3·85
Total . . .	32·11	32·65	14·72	16·44	14·84	17·93	16·21	17·81

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge.

Dr Gilbert.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.
Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

—	Rainfall.		Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1878–9.								
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September	1·41	1·46	0·07	0·12	0·11	1·39	1·34	1·35
October	2·99	2·99	1·37	1·39	1·10	1·62	1·60	1·89
November	4·73	4·55	3·77	4·07	3·66	0·78	0·48	0·89
December	1·57	1·60	1·11	1·37	1·54	0·49	0·23	0·06
January	2·46	2·85	2·47	2·65	2·47	0·38	0·20	0·38
February	3·73	3·80	4·44	4·44	4·22	−0·64	−0·64	−0·42
March	1·09	1·18	0·14	0·28	0·26	1·04	0·90	0·92
April	2·61	2·79	1·27	1·51	1·38	1·52	1·28	1·41
May	3·45	3·48	1·22	1·39	1·30	2·26	2·09	2·18
June	5·49	5·55	2·15	2·24	2·18	3·40	3·31	3·37
July	4·17	4·24	1·83	1·97	1·81	2·41	2·27	2·43
August	6·47	6·56	4·60	4·60	4·35	1·96	1·96	2·21
Total . . .	40·17	41·05	24·44	26·03	24·38	16·61	15·02	16·67
1879–80.								
September	3·07	3·13	1·11	1·00	0·92	2·02	2·13	2·21
October	0·76	0·82	0·22	0·42	0·43	0·60	0·40	0·39
November	0·71	0·81	0·20	0·12	0·10	0·61	0·69	0·71
December	0·78	0·82	0·41	0·49	0·44	0·41	0·33	0·38
January	0·55	0·55	0·48	0·61	0·46	0·07	−0·06	0·09
February	2·88	2·90	2·36	2·59	2·30	0·54	0·31	0·60
March	1·10	1·13	0·04	0·09	0·09	1·09	1·04	1·04
April	2·14	2·16	0·49	0·53	0·43	1·67	1·63	1·73
May	0·71	0·74	..	0·02	0·03	0·74	0·72	0·71
June	1·94	1·97	0·01	0·01	0·02	1·96	1·96	1·95
July	5·22	5·26	1·35	1·23	1·06	3·91	4·03	4·20
August	1·02	1·07	0·22	0·28	0·22	0·85	0·79	0·85
Total . . .	20·88	21·36	6·89	7·39	6·50	14·47	13·97	14·86

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge. When the drainage exceeds the rainfall the difference is entered as a minus quantity.

Dr. Gilbert.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

	Rainfall.			Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
——	8-Inch Funnel Gauge.	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1880–1.									
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September .	..	5·69	5·86	3·96	3·93	3·78	1·90	1·93	2·08
October . .	..	5·88	5·94	4·47	4·45	4·07	1·47	1·49	1·87
November .	..	2·87	2·92	2·25	2·39	2·14	0·67	0·53	0·78
December .	..	3·45	3·47	2·82	2·85	2·68	0·65	0·62	0·79
January . .	1·07	1·12	1·14	1·01	1·12	1·32	0·13	0·02	–0·18
February .	3·35	3·33	3·70	3·43	3·71	3·29	0·27	–0·01	0·41
March . .	1·99	2·10	2·15	1·66	1·78	1·65	0·49	0·37	0·50
April. . .	0·92	0·97	1·00	..	0·01	0·03	1·00	0·99	0·97
May . . .	1·28	1·39	1·38	..	0·01	0·04	1·38	1·37	1·34
June . . .	1·53	1·62	1·63	0·01	0·02	0·04	1·62	1·61	1·59
July . . .	1·67	1·73	1·76	..	0·01	0·01	1·76	1·75	1·75
August . .	5·47	5·70	5·82	2·77	2·56	2·21	3·05	3·26	3·61
Total . .	17·28	35·85	36·77	22·38	22·84	21·26	14·39	13·93	15·51
1881–2.									
September .	2·01	2·09	2·17	0·81	0·81	0·70	1·36	1·36	1·47
October . .	2·84	2·93	3·05	1·76	1·73	1·53	1·29	1·32	1·52
November .	3·29	3·45	3·47	2·49	2·50	2·29	0·98	0·97	1·18
December .	4·16	4·33	4·38	3·95	4·04	3·65	0·43	0·34	0·73
January . .	1·42	1·55	1·57	1·24	1·38	1·23	0·33	0·19	0·34
February .	1·88	1·99	2·02	1·15	1·13	1·01	0·87	0·89	1·01
March . .	1·38	1·48	1·57	0·45	0·58	0·49	1·12	0·99	1·08
April. . .	3·71	3·82	3·92	1·87	1·77	1·57	2·05	2·15	2·35
May . . .	1·95	2·01	2·07	0·74	0·85	0·74	1·33	1·22	1·33
June . . .	3·79	3·90	3·93	1·25	1·15	0·99	2·68	2·78	2·94
July . . .	1·95	2·05	2·09	0·10	0·12	0·10	1·99	1·97	1·99
August . .	1·97	2·06	2·07	..	0·02	0·02	2·07	2·05	2·05
Total . .	30·35	31·66	32·31	15·81	16·08	14·32	16·50	16·23	17·99

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge. When the drainage exceeds the rainfall, the difference is entered as a minus quantity.

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EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

—	Rainfall.			Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	8-Inch Funnel Gauge.	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1882–3.									
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September .	2·15	2·21	2·29	0·71	0·57	0·40	1·58	1·72	1·89
October . .	6·39	6·46	6·52	5·46	5·55	5·10	1·06	0·97	1·42
November .	3·24	3·29	3·44	2·49	2·65	2·41	0·95	0·79	1·03
December .	3·07	3·03	3·28	3·00	3·22	2·98	0·28	0·06	0·30
January . .	3·19	3·28	3·30	2·89	3·11	2·81	0·41	0·19	0·49
February .	4·18	4·28	4·34	3·76	4·01	3·70	0·58	0·33	0·64
March . .	0·75	0·76	0·89	0·02	0·06	0·09	0·87	0·83	0·80
April . .	1·40	1·43	1·48	0·28	0·26	0·22	1·20	1·22	1·26
May . . .	1·77	1·84	1·89	0·63	0·70	0·62	1·26	1·19	1·27
June . . .	2·10	2·17	2·23	0·13	0·11	0·09	2·10	2·12	2·14
July . . .	4·03	4·16	4·21	1·44	1·42	1·25	2·77	2·79	2·96
August . .	0·71	0·78	0·84	0·01	0·06	0·05	0·83	0·78	0·79
Total. .	32·98	33·69	34·71	20·82	21·72	19·72	13·89	12·99	14·99
1883–4.									
September .	3·83	3·94	3·99	1·63	1·43	1·32	2·36	2·56	2·67
October . .	2·38	2·48	2·49	1·39	1·50	1·38	1·10	0·99	1·11
November .	3·35	3·46	3·52	2·77	2·71	2·47	0·75	0·81	1·05
December .	0·92	1·07	1·16	0·79	0·97	0·95	0·37	0·19	0·21
January . .	2·51	2·55	2·56	1·87	1·81	1·65	0·69	0·75	0·91
February .	1·31	1·38	1·42	0·72	0·92	0·86	0·70	0·50	0·56
March . .	1·59	1·64	1·66	1·13	1·18	1·10	0·53	0·48	0·56
April . .	1·69	1·74	1·79	0·24	0·18	0·19	1·55	1·61	1·60
May . . .	0·58	0·61	0·64	0·04	0·09	0·11	0·60	0·55	0·53
June . . .	2·43	2·46	2·50	1·09	1·06	1·04	1·41	1·44	1·46
July . . .	2·34	2·40	2·44	0·16	0·10	0·10	2·28	2·34	2·34
August . .	1·51	1·56	1·60	0·03	0·05	0·04	1·57	1·55	1·56
Total .	24·44	25·29	25·77	11·86	12·00	11·21	13·91	13·77	14·56

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge.

Dr. Gilbert.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

—	Rainfall.			*Drainage through Soil (uncropped).*			*Difference,*[1] *approximately = evaporation.*		
	8-inch Funnel Gauge.	5-inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1884–5.									
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September .	2·05	2·11	2·18	1·29	1·26	1·11	0·89	0·92	1·07
October . .	1·60	1·64	1·70	0·52	0·47	0·41	1·18	1·23	1·29
November .	1·86	1·87	2·05	0·72	0·69	0·61	1·33	1·36	1·44
December .	2·96	3·06	3·06	3·22	3·23	3·01	–0·16	–0·17	0·05
January . .	2·88	2·94	2·99	2·59	2·60	2·43	0·40	0·39	0·56
February .	2·73	2·84	2·85	2·43	2·60	2·45	0·42	0·25	0·40
March . .	1·30	1·19	1·46	0·63	0·71	0·67	0·83	0·75	0·79
April . .	2·76	2·81	2·88	1·04	1·05	0·92	1·84	1·83	1·96
May . . .	2·73	2·82	2·88	0·91	0·98	0·87	1·97	1·90	2·01
June . . .	2·68	2·71	2·76	1·46	1·52	1·46	1·30	1·24	1·30
July . . .	0·35	0·35	0·38	0·01	0·03	0·04	0·37	0·35	0·34
August . .	1·52	1·56	1·59	..	..	..	1·59	1·59	1·59
Total . .	25·42	25·90	26·78	14·82	15·14	13·98	11·96	11·64	12·80
1885–6.									
September .	4·19	4·31	4·39	1·55	1·42	1·25	2·84	2·97	3·14
October .	4·64	4·72	4·82	3·41	3·51	3·14	1·41	1·31	1·68
November .	3·65	3·73	3·77	3·41	3·59	3·31	0·36	0·18	0·46
December .	1·19	1·21	1·33	1·00	1·04	0·91	0·33	0·29	0·42
January . .	2·96	2·80	3·44	3·58	3·91	3·92	–0·14	–0·47	–0·48
February .	0·55	0·55	0·61	0·58	0·71	0·60	0·03	–0·10	0·01
March . .	1·42	1·44	1·59	0·83	0·93	0·69	0·76	0·66	0·90
April . .	1·83	1·88	1·96	0·59	0·73	0·58	1·37	1·23	1·38
May . . .	4·08	4·16	4·24	2·12	2·29	1·93	2·12	1·95	2·31
June . . .	1·14	1·15	1·23	0·08	0·12	0·10	1·15	1·11	1·13
July . . .	2·31	2·38	2·42	0·21	0·14	0·11	2·21	2·28	2·31
August . .	1·12	1·13	1·22	0·01	0·02	0·03	1·21	1·20	1·19
Total .	29·08	29·46	31·02	17·37	18·41	16·57	13·65	12·61	14·45

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge. When the drainage exceeds the rainfall the difference is entered as a minus quantity.

Dr. Gilbert.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.
Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

—	Rainfall.			Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	8-Inch Funnel Gauge.	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1886–7.									
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September .	1·38	1·43	1·51	0·01	..	0·01	1·50	1·51	1·50
October . .	3·77	3·91	3·94	2·16	1·99	1·74	1·78	1·95	2·20
November .	2·62	2·71	2·77	2·40	2·62	2·43	0·37	0·15	0·34
December .	4·12	4·17	4·21	2·46	2·58	2·36	1·75	1·63	1·85
January . .	2·22	2·20	2·39	2·32	3·83	3·78	0·07	–1·44	–1·39
February .	0·89	0·90	0·95	0·48	0·55	0·51	0·47	0·40	0·44
March . .	1·64	1·63	1·76	0·21	0·22	0·18	1·55	1·54	1·58
April . .	1·10	1·12	1·19	0·13	0·22	0·18	1·06	0·97	1·01
May . . .	2·22	2·25	2·35	0·04	0·06	0·07	2·31	2·29	2·28
June . . .	0·67	0·68	0·71	0·43	0·50	0·45	0·28	0·21	0·26
July . . .	0·71	0·69	0·79	..	0·01	0·01	0·79	0·78	0·78
August . .	0·95	0·94	1·04	..	..	..	1·04	1·04	1·04
Total .	22·29	22·63	23·61	10·64	12·58	11·72	12·97	11·03	11·89
1887–8.									
September .	2·99	3·02	3·11	0·36	0·26	0·19	2·75	2·85	2·92
October . .	1·57	1·57	1·69	0·35	0·26	0·20	1·34	1·43	1·49
November .	3·27	3·34	3·41	2·70	2·82	2·65	0·71	0·59	0·76
December .	1·54	1·53	1·66	1·19	1·31	1·23	0·47	0·35	0·43
January . .	0·80	0·81	0·94	0·46	0·56	0·50	0·48	0·38	0·44
February .	0·97	0·88	1·03	0·27	0·43	0·45	0·76	0·60	0·58
March . .	2·97	2·98	3·13	3·16	4·05	3·99	–0·03	–0·92	–0·86
April . .	2·03	2·02	2·14	0·76	0·93	0·88	1·38	1·21	1·26
May . . .	1·21	1·23	1·28	0·07	0·09	0·09	1·21	1·19	1·19
June . . .	4·74	4·75	4·87	2·38	2·49	2·40	2·49	2·38	2·47
July . . .	3·59	3·75	3·86	0·76	0·83	0·68	3·10	3·03	3·18
August . .	3·14	3·23	3·38	1·50	1·55	1·41	1·88	1·83	1·97
Total .	28·82	29·11	30·50	13·96	15·58	14·67	16·54	14·92	15·83

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge. When the drainage exceeds the rainfall the difference is entered as a minus quantity.

Dr. Gilbert.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

—	Rainfall.			Drainage through soil (uncropped).			Difference,[1] approximately = evaporation.		
	8-Inch Funnel Gauge.	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1888–9.									
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September .	0·86	0·87	1·03	0·08	0·12	0·09	0·95	0·91	0·94
October . .	0·96	0·98	1·09	0·07	0·03	0·02	1·02	1·06	1·07
November .	4·34	4·37	4·45	3·51	3·51	3·29	0·94	0·94	1·16
December .	1·57	1·61	1·69	1·51	1·60	1·54	0·18	0·09	0·15
January . .	1·16	1·19	1·29	0·82	1·06	0·82	0·47	0·23	0·47
February .	1·82	1·80	1·95	1·53	1·74	1·61	0·42	0·21	0·34
March . .	1·77	1·80	1·89	0·83	0·85	0·82	1·06	1·04	1·07
April . .	2·36	2·39	2·47	0·35	0·42	0·35	2·12	2·05	2·12
May . . .	4·85	4·90	5·00	3·06	3·32	2·85	1·94	1·68	2·15
June . . .	1·28	1·21	1·38	0·41	0·53	0·47	0·97	0·85	0·91
July . . .	5·58	5·59	5·67	2·43	2·58	2·42	3·24	3·09	3·25
August . .	2·02	2·08	2·18	0·04	0·06	0·05	2·14	2·12	2·13
Total .	28·57	28·79	30·09	14·64	15·82	14·33	15·45	14·27	15·76
1889–90.									
September .	2·31	2·36	2·44	0·77	0·73	0·63	1·67	1·71	1·81
October . .	3·51	3·57	3·62	2·45	2·47	2·28	1·17	1·15	1·34
November .	1·12	1·14	1·21	0·93	0·98	0·91	0·28	0·23	0·30
December .	1·36	1·40	1·46	1·29	1·46	1·34	0·17	..	0·12
January . .	2·86	2·94	2·94	2·42	2·62	2·52	0·52	0·32	0·42
February .	0·74	0·75	0·82	0·48	0·60	0·54	0·34	0·22	0·28
March . .	2·71	2·75	2·78	1·71	1·83	1·69	1·07	0·95	1·09
April . .	1·23	1·22	1·31	0·01	0·06	0·06	1·30	1·25	1·25
May . . .	1·34	1·34	1·38	0·12	0·10	0·10	1·26	1·28	1·28
June . . .	2·33	2·36	2·40	0·06	0·03	0·04	2·34	2·37	2·36
July . . .	4·41	4·49	4·56	2·76	2·61	2·54	1·80	1·95	2·02
August . .	2·38	2·42	2·51	0·16	0·11	0·09	2·35	2·40	2·42
Total .	26·30	26·73	27·43	13·16	13·60	12·74	14·27	13·83	14·69

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge.

Dr. Gilbert.

NOTE BY DR. GILBERT.—These Tables, of which the first four were placed on the wall during the discussion, contain the results of the experiments on Rainfall and Drainage at Rothamsted for twenty harvest-years (September 1 to August 31), 1870–71, to 1889–90 inclusive. The rainfall is given as registered both by a 5-inch funnel-gauge, and by a specially made gauge of $\frac{1}{1000}$th of an acre area; also by an 8-inch gauge since the beginning of 1881. The drainage, or percolation results, represent the amounts of the rainfall passing through rather heavy uncropped soil, as shown by three "drain-gauges," each of $\frac{1}{1000}$th of an acre area, one with 20 inches, one with 40 inches, and one with 60 inches depth of soil, in its natural state of consolidation. Table A shows, for each of the twenty harvest-years, the total amount in inches of rainfall by each gauge, of drainage or percolation, through 20 inches, 40 inches, and 60 inches of soil, and the difference approximately representing the evaporation. The evaporation was in all cases calculated on the rainfall shown by the $\frac{1}{1000}$th of an acre gauge. Table B shows, for each of the twelve months of the harvest-year, the average rainfall, drainage, and evaporation over the twenty years. Tables C and D are general summaries of the average results for the first ten, the second ten, and the total period of twenty years. The succeeding twenty Tables give, respectively, for each of the twenty harvest-years, the rainfall, drainage, and evaporation, for each month, and the total for the year. It should be explained that the funnel portion of the $\frac{1}{1000}$th of an acre rain-gauge is constructed of wood, lined with lead, the upper edge consisting of a vertical rim of plate-glass bevelled outwards. The rain is conducted by a tube into a galvanized iron cylinder underneath, and when this is full it overflows into a second cylinder, and so on into a third and fourth, and finally into an iron tank. Each of the four cylinders holds rain corresponding to $\frac{1}{2}$ an inch of depth, and the tank an amount equal to 2 inches. Each cylinder has a gauge-tube attached, graduated to read to 0·002 inch, but which can be read to 0·001 inch. Small quantities are transferred to a smaller cylinder, with a gauge-tube graduated to 0·001 inch. The three drain-gauges were constructed by digging a deep trench along the front, gradually undermining at the depth required, and putting in plates of cast-iron, with perforated holes, to support the mass. The iron plates were kept in place by iron girders, and the ends of the plates and of the girders supported by brickwork at the back and the two sides. Trenches were then dug round the block of soil, and it was gradually enclosed by walls of brick laid in cement. Below the perforated iron bottom a zinc funnel of the same area as the block of soil was finally fixed, and the drainage water collected and measured in galvanized iron cylinders, with gauge-tubes, as in the case of the rain. These soil drain-gauges being kept without vegetation, their results are not directly applicable for estimating the amount of percolation over a drainage-area more or less covered with vegetation, and it had been suggested that they should be so covered. But this would sacrifice important results; and as the amount of evaporation is very different with different kinds of vegetation, the results with only three drain-gauges, and these with one description of soil and of varying depth, would also be inapplicable for the purpose of directly estimating the percolation of a district. In 1874 a series of eighteen drain-gauges was arranged for the investigation of the influence of various crops, but unfortunately the specially made glazed stoneware cylinders, 24 inches diameter and 60 inches deep, were found not to be watertight, and hence the attempt was abandoned. About forty years ago, however, experiments of quite another kind were made at Rothamsted for several years in succession, to determine the amount of water

Dr. Gilbert. given off by plants during their growth, those selected including various individual agricultural plants, the mixed herbage of grass-land, and also evergreen and deciduous trees. The results afforded valuable data upon which to form a judgment as to the probable amounts of evaporation due to vegetation; and the indications so obtained, together with those of direct percolation experiments with and without vegetation, constitute the only evidence of a purely experimental kind at present available, as the basis of general estimates. It is, however, obviously desirable that estimates so founded should be studied in connection with those arrived at in other ways, such as by the gaugings of rivers and of wells.

Mr. Hopkinson. Mr. JOHN HOPKINSON, of St. Albans, had devoted considerable attention to the subject of the rainfall in Hertfordshire. The annual average during the ten years 1880–1889, at eighteen stations in the county, each of which had a consecutive record for that period, was 26·74 inches. In order to ascertain the correctness of this result for the ten years, he took the average of all the gauges in Hertfordshire from which he had collected returns, the number varying from 26 to 30 during the ten years, and found it to be 26·78 inches, *i.e.*, only 0·04 inch above the mean for the eighteen stations. He thought they ought not to be content with observations for a short series of years, or even for so few as ten, but to extend them over as long a period as possible; and in order to ascertain the average rainfall for the half century 1840–1889, he had taken the averages of five continuous series of records, namely, for the first ten years of the half century the record of one gauge; the second ten years the records of two gauges; the third ten years, those of seven; the fourth, of twelve; and the fifth, of eighteen. Those eighteen records correctly represented the average for the whole county; but the difficulty was that the smaller number of gauges might be in certain localities in which they had more or less rainfall than the average. He had found by taking the ratios of the records in the previous years to those in the last ten, that from the position of the gauges they would give rather less rainfall than if all the eighteen had been in use for the half century. The annual rainfall, taking the records as they were for the fifty years, was 26·43 inches, and the deduction which should be made to get the correct amount for the half century would bring it down to 26·16. The mean rainfall for the last ten years thus appeared to have been about $\frac{1}{4}$ of an inch, or $2\frac{1}{2}$ per cent., in excess of that during the half century. It might possibly be contended that the correction he had made was too great, so he would take round numbers and say that the mean in Hertfordshire for the half century was $26\frac{1}{4}$ inches, or 2 per cent. less than the rainfall for the last ten years. Having arrived at that determination, all they had to do for the entire area was to ascertain the rainfall for the last ten years, and deduct from it 2 per cent. Accordingly he had taken the largest number of continuous records they had over the whole of the area, which he had divided into four nearly equal portions; (1) the Kennet, (2) the Thames between Wallingford and Windsor, (3) the Colne, (4) the Lea. Mr. Hopkinson.

TABLE SHOWING THE MEAN ANNUAL RAINFALL IN THE CHALK AREA OF THE THAMES BASIN WEST AND NORTH OF LONDON, 1880–89.

River Basin.		District.	Rain.	Station.	Rain.
			Inches.		Inches.
Western Area, 28·08 inches.	Kennet, 29·68 inches.	Marlborough	31·05	The Green and Mildenhall	31·05
		Hungerford	29·70	Denford Park	29·70
		Newbury	30·44	Welford Park	30·44
		Reading	27·54	Englefield	29·75
				Russell Street	25·34
	Thames, 26·47 inches.	Ock	29·13	Letcombe Regis, Wantage	29·13
		Thames above Kennet	23·87	Wallingford Castle	23·87
		Thames below Kennet	27·74	Henley-on-Thames, Greys	27·10
				Henley-on-Thames, Assenton	30·70
				Maidenhead	25·42
		Loudwater	25·15	High Wycombe	25·15
Northern Area, 27·18 inches.	Colne, 29·04 inches.	Bulbourne	29·30	Cowroast, Tring	29·60
				Berkhampstead	29·00
		Gade	28·64	Great Gaddesden	28·07
				Nash Mills, Hemel Hempstead	28·85
				Kensworth	28·32
		Ver	28·44	Rothamsted, Harpenden	28·64
				Gorhambury, St. Albans	28·36
		Colne below Ver	29·77	Watford	28·56
				Rickmansworth	30·98
	Lea, 25·32 inches.	Mimram	25·58	Welwyn	26·56
				Datchworth	24·61
		Rib	25·04	Therfield	25·55
				Throcking	24·52
		Ash	25·98	Much Hadham	25·98
		Lea below Mimram	24·68	Bayfordbury, Hertford	25·04
				Red House, Ware	24·33
		Mean of Districts	27·63	Mean of Stations	27·58

The gauges were nearly equally distributed over this area. In the Kennet district they were situated at Marlborough, Hungerford, Newbury, and Reading (two); in the Thames district between Wallingford and Windsor, at Wantage, Wallingford Castle, Henley-on-Thames (two), Maidenhead, and High Wycombe; in the Colne district at Tring, Berkhampstead, Great Gaddesden, Hemel Hempstead, Kensworth, Harpenden, St. Albans, Watford, and Rickmansworth; and in the Lea district at Welwyn, Datchworth, Therfield, Mr. Hopkinson. Throcking, Much Hadham, Hertford, and Ware. The results of those he had grouped so that they had a mean for areas of tolerably equal size. The grouping of the areas was: in the Kennet, Marlborough, Hungerford, Newbury, and Reading; in the Thames, the Ock river-basin, the Thames between the Ock and the Kennet, the Thames between the Kennet and the Loudwater, and the Loudwater river-basin; in the Colne, the Bulbourne, the Gade, the Ver, and the Colne river-basin between the Ver and the London Clay district; and in the Lea, the Mimram, the Rib, the Ash, and the Lea river-basin between the Mimram and the London Clay district. The result of those divisions was that the mean rainfall for the Kennet was found to be 29·68 inches; for the Thames, 26·47; the Colne, 29·04; and the Lea, 25·32; giving for the whole area 27·63 inches. If they wished to ascertain the rainfall for the half century they had simply to reduce these figures by 2 per cent., and the result would be 27·08, or in round numbers 27 inches; and he thought it would be found that 27 inches was as nearly as possible the mean rainfall over the whole of the chalk area to the north and west of London. Having determined that, it was required to ascertain the amount of percolation corresponding to this rainfall, and for that purpose they could take the experiments of Mr. Dickinson and Dr. Evans—the longest series that had been published—extending (to go no farther back than the half century) over forty-four years, and the result, through 3 feet of the ordinary soil which covered the Chalk, from October 1840 to September 1884, was 6·94 inches out of a rainfall of 28·18 inches. The period was sufficiently long for this to be accepted as a fair average. The mean rainfall during the decade 1880 to 1889 was 28·85 inches; deducting 2 per cent., the mean for the half century would be 28·27 inches, which was not very different from that for the forty-four years. Therefore he thought they could rely upon the 6·94 or 7 inches percolation as being tolerably correct. At Lea Bridge during twenty-two years, from 1852 to 1873, Mr. Charles Greaves determined the average percolation through 3 feet of soil, such as usually covered the Chalk within the Thames basin in Hertfordshire, to be 6·87 inches out of a rainfall of 25·84 inches. He had also the rainfall of the nearest gauges to Lea Bridge which were on the Chalk. It was rather less, and therefore the percolation, if taken on the chalk area over the twenty-two years, would have been rather less. Still, there was a percolation of under 7 inches through the ordinary soil which covered the Chalk, so that the experiments of Mr. Greaves at Lea Bridge agreed fairly well with those of Dr. John

Evans and of the late Mr. Dickinson at Nash Mills. Averaging them, it would be seen that they gave a percolation of 6·91 inches out of a rainfall of 27·01 inches, and as he had shown that to be about the average rainfall over the whole area, it might be assumed that the average percolation was a little under 7 inches. With regard to the experiments at Rothamsted, of course there was an uncertainty arising from the ground being kept hoed and free from vegetation. Growing plants absorbed a great deal of moisture, as to which Dr. Gilbert had given them a good approximation. The water which percolated into the Chalk was usually assumed to get out of the reach of evaporation when it had passed through 3 feet of soil, but he did not think they ought to consider that to be the case. Professor Ansted had expressed his opinion that there was no practical limit to the capillary action of chalk, and he had made experiments showing that water would certainly rise in it 16 feet. Von Pettenkofer had found the evaporation from an oak tree during the whole period of its summer growth to be more than 8 times the amount of rain falling on the area covered by the tree, the excess being drawn up by the roots from a great depth. A considerable portion of the land referred to was wooded, and there must be a much greater draught upon the underground water where the ground was covered by trees than where it was bare, or nearly so. They were not, therefore, justified in considering that water which percolated through 3 feet of soil was free from evaporation and absorption by vegetation. Nor could they depend for their water-supply upon the average rainfall and the average percolation for the whole of the period under consideration; the experiments of Dr. John Evans and the late Mr. Dickinson, at Nash Mills, had shown that for six years in succession they might have to rely upon $4\frac{3}{4}$ inches of percolation through 3 feet of soil, for five years upon $4\frac{1}{4}$ inches, for four years upon 4 inches, for three years upon 3 inches, which was only about one-quarter of the average which Mr. Harrison depended upon in his calculations. With regard to the available area of percolation, Mr. W. Whitaker had constructed maps bearing upon that point. He had given the proportions in sheet 46 S.E. of the old 1-inch Ordnance map, which comprised the chalk area between Hitchin and St. Albans from north to south, and Dunstable and Hertford from west to east. All but 8 square miles were marked by Mr. Harrison in his map as bare chalk. Mr. Whitaker's computation was that out of 209 square miles, bare chalk occupied about 76 square miles, chalk

Mr. Hopkinson.

E 2

Mr. Hopkinson. covered by permeable beds 39, chalk protected by mixed beds 67, and chalk protected by impermeable beds 27 square miles. In this map there were 8 square miles of Tertiary beds, chiefly the three outliers shown at the north-east corner of Mr. Harrison's map; so that out of 200 square miles shown by Mr. Harrison as bare chalk, about 67 square miles were protected by mixed beds, and 21 by impermeable beds. If they considered mixed beds as half permeable and half impermeable, at least one-quarter must be deducted from the area shown as bare chalk. If that proportion were maintained over the whole of the chalk area in the basin of the Thames to the north and west of London, a question upon which he hoped Mr. Whitaker would enlighten them, they might have to rely for a long series of years upon an average annual percolation of three-eighths of that assumed by Mr. Harrison, namely, half the percolation on three quarters of the area; for six years in succession upon one quarter; and for three years in succession upon one-sixth; and he did not think they could safely base their estimate of minimum supply from the percolation during a longer period than three years.

Mr. Lucas. Mr. JOSEPH LUCAS remarked that Mr. Hopkinson had given some Hertfordshire rainfall averages over a period from 1840 to 1884. He did not happen to catch the figures, but they would be of particular interest in connection with a series of gaugings made by the Grand Junction Canal Company of the springs at Wendover. These gaugings began in 1841, and the whole series was published in 1884 by the Meteorological Society in the form of a diagram in the report of the Committee on the Decrease in Water-Supply. He should like to ask Dr. Gilbert, whether he and Sir John Lawes kept the register of the variation of any well at Rothamsted in connection with percolation-gauges?

Dr. Gilbert. Dr. GILBERT replied that they had not done so in connection with percolation-gauges; but they had now and then to lower their wells.

Mr. Lucas. Mr. JOSEPH LUCAS said that the water in the Banstead well was no doubt sustained by the beds connected with the chalk rock, below which there were frequently bands of marl. With regard to the well-defined gathering-grounds from which springs issued, mentioned in the Paper, he had surveyed the whole range of the Chalk from Berkshire for a distance of 100 miles, considerably beyond Cambridge, and contoured the entire area to every 10 feet of elevation, during the last thirteen or fourteen years, and he found that the area of supply to the Wendover springs, of which the gaugings were well known, might be measured accurately. It so happened that the water-ridge was singularly sharply defined round that little basin; but in order to give some idea of Mr. Lucas. the extremely complex nature of those underground water-basins in the Chalk, he would mention that if a line were drawn round that contributing to the Wendover springs, taking the water-ridge as the limit of it, it would be found to measure 2·8 square miles. The whole contributing area, however, was in reality larger. The Wendover springs broke from the Totternhoe stone, which was a sandy bed of a somewhat marly character, but in the main calcareous, which lay in the Lower Chalk. The Totternhoe stone formed an inclined plane, and the water issued from the lowest point of its outcrop, namely, the bed of the valley. It presented over a considerable area an upper surface for the reception of whatever water might filter down to it from the Chalk above. The chalk lying on the top of the Totternhoe stone happened to be almost impermeable. It was known as the Grey Chalk, and might be taken as 40 feet thick, and acted generally as a retaining bed. Above it there was a bed of perhaps the whitest chalk in the whole formation, reaching another 40 feet, and lying immediately beneath the marls, which were about 3 feet thick, and which underlay the Melbourne rock. The Melbourne rock was the base of the Middle Chalk. On section No. 2, Plate 2, where the words "Chiltern Hills" occurred, was the well sunk by the late Mr. Homersham, the only one Mr. Lucas knew of which traversed the whole of the Middle Chalk. It started about 6 feet above the Chalk rock, and it went to the base of the Melbourne rock. In most places the water-line in the Chalk rose until it met the base of the Melbourne rock, or a little above it, and then it turned and fell over the other way. Frequently the water-line dropped through the White Chalk from the point where it broke through the Melbourne rock, until it came to the Grey Chalk, when there was very slow percolation, and the gradient was lower. The Grey Chalk, being slightly permeable, passed the water down to the Totternhoe stone, which acted as a pipe, conducting it laterally to the springs at its outcrop in the bed of each valley. In this case it drained an area slightly larger than that indicated by the water ridges on the map. The area so obtained in the case of the Wendover springs was 4·6 square miles, and for the forty-four years, 1841 to 1884, both inclusive, the annual mean flow might be taken from the diagram at 177 cubic feet a minute, which represented a mean percolation of almost exactly 9 inches per annum. With regard to the Wandle, he believed that the figures given in the Paper were too large. He had himself gauged that river through one winter

Mr. Lucas. at nearly every mill daily, and he was inclined to doubt whether a mean of 20,000,000 gallons a day was exceeded by the Wandle. Wherever he had been able to get a gauging which could be converted into the form of percolation on a given area, 8 or 9 inches was generally the maximum indicated by it. Therefore with regard to the Author's further question as to what became of the difference between the quantity gauged at the springs and that shown by the percolators, he thought another fallacy was involved. Fifteen or sixteen years ago when Professor Ansted was speaking in that room, and expressed his belief that the water was re-evaporated from the Chalk, everybody laughed at him. Now, however, Mr. Lucas had entirely come round to that opinion. He considered that the large quantity to be accounted for between the 8 or 9 inches which could be proved to flow from the springs, together with the 2 inches that might pass under the Tertiaries, and the amount indicated by Sir John Lawes' percolators, was evaporated. Percolation did not take place regularly, but at intervals, and in the meantime they had no record whatever of what was going on in the way of evaporation from the soil. That a very large evaporation took place could not be doubted, because on a hot day it could be seen. However, inasmuch as London actually pumped the whole of the water that came down to it under the tertiary strata, and they could tell pretty well what was being pumped, he thought it might be set down as 10,000,000 gallons a day. It might be a little more, but he did not think it would in any case much exceed 2 inches over the whole of the chalk area, above the line that might be drawn from north to south, through the east-end of London. West of that line the whole quantity pumped, about 10,000,000 gallons a day under London, would give 2 inches rainfall on the area of the Chalk. Therefore with regard to the question as to what became of the difference, it was certainly not to be looked for underground. Whether it was possible, according to any plan adopted by Sir John Lawes and Dr. Gilbert, to determine the amount re-evaporated from the Chalk he did not know, but it seemed to him a very important point. The Author had mentioned two lines of disturbance as passing through London. He considered the east and west disturbance to be exceedingly well proved, but that running north and south had not, in his opinion, the nature of a fault. The faults at Tandridge Hill and Titsey were very well marked on the ground; but there was no evidence of their crossing the outcrop of the Chalk; at least he could not find them again at the base of the tertiary strata. He did not think they ran far. With regard to the north and south disturbance, he believed

Professor Prestwich had abandoned it long ago. It seemed to him that in the low-level gravels, whose bottoms ran below the level of the rivers, a large quantity of water might be and undoubtedly was obtained, which had penetrated from the river; but he would trust no such bed to afford water which could not be seen before it went into the gravel. High-lying gravel, which was above the level of the rivers, and was dependent on its own rainfall, was not, in his opinion, capable of yielding a large supply, and, if it did, the water would always be open to all the objections that applied to that obtained from shallow wells. Mr. Lucas.

Mr. SANTO CRIMP observed that, as he had gauged the Wandle daily for three years, he was able to give some general results of his observations. The object of the Author apparently was to show that the objection of Dr. Evans quoted in the Paper, "that Mr. J. T. Harrison's scheme for obtaining water by means of tunnels in the chalk of the Thames valley merely means that all the water derived from the tunnels will either be intercepted on its way to the river or filter into the tunnels from the bed of the river," and that "the flow of the Thames below will be diminished by the same amount of water as that abstracted by means of the tunnels," was groundless. In order to prove his case Mr. Harrison had first referred to the experiments of Mr. Dickinson, and he stated that the amount of percolation through the chalk gauge was 10·65 inches; but if he remembered rightly two gauges were employed by Mr. Dickinson, one filled with chalk and one with soil, and the average amount of percolation through the latter was only 6½ inches. He thought, therefore, that if a part of the chalk had been removed from the other gauge and a layer of soil corresponding with the soil on the top of the chalk as ordinarily met with substituted, the amount of percolation through would have been much less. The Author had referred to the want of a record of gaugings from a well-defined gathering-ground, suggesting the River Wandle, and said that measurements should be made at Hackbridge. He would point out that in that case the water pumped at the Croydon waterworks would not be included, because it was distributed upon the Beddington sewage farm, and the amount not evaporated there entered the river at a lower point. The extent of the gathering-ground had been given by Mr. Harrison as 56 square miles. In order to ascertain this, it was necessary to make a hydro-geological survey, which was undertaken by Mr. Baldwin Latham, and Mr. Santo Crimp did the work for him. He was sorry that Mr. Baldwin Latham was not present Mr. Crimp.

Mr. Crimp. to give the results himself. As a matter of fact the area of Chalk drained by the Wandle was 64 square miles, and not 56 as stated in the Paper. He took the gaugings of the Wandle at Merton, and the total drainage-area above that point was 84 square miles in extent, including about 20 square miles of London Clay. It was possible, however, to estimate the amount of water due to the London Clay by making separate gaugings of Graveney Brook, which drained a well-defined area of London Clay. The average rainfall during those three years, as shown by the nine gauges scattered over the chalk-area, was 38·8 inches. At Greenwich during the same period—1879–80–81—it was 17 per cent. in excess of the average. It followed, therefore, that if the gaugings of the Wandle had been made during the three years when the rainfall was 17 per cent. less than the mean, the results would not have been the same as they were when Mr. Santo Crimp gauged the river. During those years the average volume discharged by the Wandle at Merton was at the rate of $31\frac{1}{2}$ million gallons per day, equal to a depth of $9\frac{1}{2}$ inches over the entire drainage-area. Without the water due to the Graveney and the remainder of the London Clay area, the amount was 26·82 million gallons a day, equal to a depth of 10·6 inches from the chalk drainage-area—a figure in close accordance with Mr. Dickinson's 10·65; but, as he had pointed out, the rainfall was 17 per cent. in excess during those three years, and that was a mere coincidence. During the same time, the drainage from the Graveney area amounted to a depth of 7 inches per annum. Making the necessary reductions in order to get the mean discharge of the Wandle (perhaps a somewhat difficult matter) he thought the figures would be:—the depth run off from the entire watershed would be equal to $7\frac{3}{4}$ inches; from that of the Wandle alone, $8\frac{4}{5}$ inches, equal to 23 million gallons per day as against 30 millions estimated by the Author. He believed he was right in saying that the average amount running off from the Thames watershed was equal to $7\frac{1}{3}$ inches over the entire area. That was taking the mean discharge at Teddington, together with the quantity abstracted by the water companies, at 1,000,000,000 gallons per day, and all these figures were in fair accordance with each other. It seemed to him, therefore, that by over-estimating the volume of water discharged by the Wandle and under-estimating the drainage-area, the Author had very much over-estimated the amount available for water-supply in the upper reaches of the Thames.

Mr. Lucas. Mr. JOSEPH LUCAS said he had omitted to state, with regard to

Mr. Lucas.

the area of the Wandle, that he had measured the apparent chalk area $52\frac{1}{2}$ square miles; but as to the real gathering-ground indicated by the subterranean water ridge, $54\frac{1}{4}$ square miles, there being a slight feed on the eastern side, 8 inches upon that area gave 17,250,000 gallons a day.

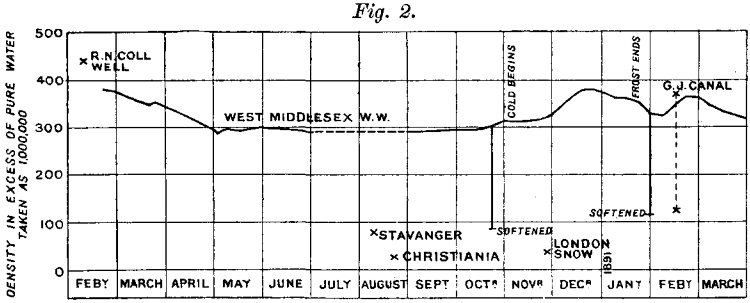
Mr. J. C. Hawkshaw.

Mr. J. C. HAWKSHAW remarked that a great deal of interesting information had been given as to the quantity of water likely to be found in the district under consideration, but there was one point that had not been touched upon. In providing for the water-supply of London, or indeed of any other town, it was necessary to consider how the withdrawal of any quantity of water from a given place would affect the supply of the neighbouring district. He thought there could be no question that the water stored in the lower beds of the Chalk and in the beds overlying and adjoining them where they dipped beneath the surface, was continuous with that stored in the upper beds of the Chalk, and he did not see how it was possible to pump any large amount from the lower storage without affecting the level of that in the upper beds, from which the population of the district would draw their supply. It was no more possible to do so than it would be to draw water from the bottom of a cistern without affecting the surface-level at the top of it or the overflow if there was any. It might be interesting to state briefly what was the effect of pumping water from the Mountain Limestone at the Severn Tunnel. The Mountain Limestone had this in common with the Chalk, that a large proportion of the water falling on its surface was conveyed to the sea by underground channels. Where the tunnel passed from beneath the Severn under the land in Monmouthshire, it mainly ran through beds of Millstone Grit and overlying Triassic Red Marls. Beneath these was the Mountain Limestone which rose to the north of the tunnel, becoming the surface-rock of a considerable district in south-east Monmouthshire. The bottom of the tunnel only touched the limestone-rock at one place, and there it cut through a fissure, from which a volume of water was discharged into the works sufficient to flood them and stop the progress for twelve months, until enough pumping power was provided to deal with it. As soon as the water was pumped out, all the wells and springs in the neighbourhood were dried. There could be no question that this was due to the pumping, because when the water was dammed back in the works it rose again to its old level in the springs and wells. It appeared to him that if any large quantity was abstracted from the Lower Chalk the same thing

Mr. J. C. Hawkshaw. would happen to a district more or less large, the area depending on the quantity of water which was pumped.

Mr. Blakesley. Mr. T. H. BLAKESLEY wished to say a few words on a question raised by the Author and touched upon by Mr. Symons. The Author had spoken of the admixture of water from the Chalk in the gravel of the London basin. There could be no doubt that the water gathered from the Thames for the supply of London contained not only a great deal of chalk-water, but also much that came from other strata. He based that view upon the fact that the water from the Chalk was invariably much heavier than that from the gravel. From a number of observations he was quite certain that the London water-supply contained a good deal which was derived from the gravel, though the bulk came

Fig. 2.



from the Chalk. Chalk-water almost invariably had a specific gravity more than 400 parts in 1,000,000 greater than that of pure water, whereas the London water very rarely reached that density. *Fig. 2* showed the quality from this point of view of the water from his cistern in West Kensington, which was supplied by the West Middlesex Waterworks. Various isolated cases were also given for comparison. It would be seen that the minimum density occurred during the summer, increase taking place about September or October. It exceeded 300 in 1,000,000 all through the winter, and it was less than 300 in 1,000,000 during the summer. He had obtained similar data throughout other years. The chalk-water of Folkestone was in the winter 429 parts in 1,000,000 heavier than pure water.[1] That from the chalk well at the Royal Naval College, Greenwich, was in February 439. The softened Canterbury water was only 101. The Grand Junction

[1] The probable error in the densities here given may be taken as 1 in 1,000,000. —T. H. B.

Canal water was 369 in February of this year, and softened to 123. The Rouen water, also from limestone, was 362 during spring. The purest water-supply he had ever met with was that of Christiania, which was only 26 parts in 1,000,000 in excess of pure water in density during summer. The result of applying the softening process was also shown in *Fig. 2*. The quality of the water had only been touched slightly upon by the Author; but, as affecting the London supply, it was a most essential matter. Some of the specimens to which Mr. Blakesley referred were remarkably soft. The Author had, he thought, very much understated the capacity of the chalk to hold water. He had given it as two gallons in a cubic foot, but Mr. Blakesley considered that three gallons would be nearer the truth. He had carefully weighed pieces of chalk, and after keeping them under water for many days, weighed them again; and so estimated the quantity that could be contained in them; he then allowed them to dry, and weighed them again. An interesting point was, that the chalk which had been as much as twenty-three days under water would return to its original weight in twenty-four hours after being taken out, showing the extraordinary power it possessed of giving up moisture to a dry atmosphere. He had no doubt that the surface of the chalk discharged a large quantity into the air in this way. Of course, it would also absorb moisture, even without rainfall, in a damp atmosphere; but he thought that an estimate of supply, based upon rainfall without considering evaporation, must necessarily be incorrect. Mr. Blakesley

Dr. JOHN EVANS remarked that the Paper appeared to him to be remarkably vague. All the Author's statements were carefully said to be "approximate," and great difficulty would be found in ascertaining in what manner he arrived at his results. With regard, for instance, to the variation in the Thames, when he found that on July 8th the increment was 49,000,000 gallons, on July 10th 131,000,000 gallons, on the 22nd 196,000,000 gallons, and in April 250,000,000 gallons, he could not imagine how by any process of reasoning these figures could be supposed to represent anything like the average increment in the volume of the Thames at the points indicated. He also found variations from 137,000,000 gallons per day in April down to 17,000,000 gallons on the 22nd of July, whereas on the 10th there had been 43,000,000 gallons. It was impossible to obtain any information from such figures as to what the average increment would be. There was another point which appeared to be of doubtful propriety, namely, the revival of views which had been exploded more than Dr. Evans.

Dr. Evans twenty years ago. For example, the Author quoted the statement of Mr. Homersham—which had been disputed in that room many times, and so far back that his memory could hardly recall it, that there were no less than 1,200 square miles of chalk sloping towards Watford. That was referred to as a statement on which reliance could be placed. In another part of the Paper it was said that the whole area north-west of London was only that 1,200 square miles, and that Watford was nearly 200 feet above Ordnance datum. He could not imagine the frame of mind in which those two statements could be placed side by side as being equally credible. Then the area of the gathering-ground of the Wandle was also quoted from Mr. Homersham as being 56 square miles. Mr. Homersham had, however, pointed out that if that were the case, in order to obtain the ordinary flow of the Wandle, 29 inches of rain must be absorbed into the ground and delivered out as the surplus quantity after all that nature required had been done. But, inasmuch as in most years 29 inches did not fall, he did not see in what manner the Author could explain the discrepancy. Another point also appeared to have been entirely lost sight of—namely, what was known as the angle of friction of water in a porous body. Statements had been made as to the height of many points of the streams above ordnance datum, but no proper allowance had been made for the difficulty that water had in passing through the Chalk. It was evident from some of the sections, as for example, that of the Gade sloping towards Watford—which by-the-way was not strictly accurate, inasmuch as the inclination was higher as they got towards the chalk-marl, and towards Tring—that the flow of the river was on an average $14\frac{1}{3}$ feet per mile. Now unless the angle of friction—that was, the elevation of water which was caused by its passage through the rock being impeded—was greater than 14 feet per mile, the river would simply disappear altogether and could not exist upon the surface. The ponds referred to in the neighbourhood of Burnham and Slough appeared to him to be simply sheets of water formed at certain points in beds of gravel above the London Clay. Then came the question as to the amount of rain which found its way into the earth in order to feed those rivers, and there he would rather not rely on any figures of his own, but would take those so carefully prepared by Sir John Lawes and Dr. Gilbert. He found from them that for twenty years the average percolation through the 16 inches of soil had been 3·89 inches in the summer months, namely, from the beginning of April to the end of September, whereas in the winter months it was 9·72 inches, making a total of 13·61 inches. But there was this peculiarity about the gauges of Sir John Lawes and Dr. Gilbert, that although evaporation was taken into account they did not in any way allow for the water taken up in the process of vegetation. The soil was kept carefully free from weeds and all growth, and the results therefore did not represent the amount which actually found its way through land in a state of cultivation, or covered with grass. It was known from experiment that a grain of wheat in growing could absorb, if it were given to it, more than the total amount of rain that fell, and he believed Sir John Lawes and Dr. Gilbert estimated that at least they must allow 2 or 3 inches of water in summer for the crops on the ground. Dr. Evans thought that 3 inches was not an over-estimate. During the months he had included in the winter half-year, from October to March, there was also generally a certain amount of absorption for purposes of vegetation. If the 3 inches in the summer were deducted there would be for the summer percolation 0·89 inch, closely corresponding with the Tables he had brought before the Institution some years ago.[1] In the winter months, deducting only the 1 inch for evaporation, there would be 8·72 inches, giving a total of 9·61 inches. It would be borne in mind that the minimum shown on Sir John Lawes' and Dr. Gilbert's Tables was only 5·81 inches, from which, again, the amount necessary for vegetation must be deducted, and that would bear out very closely his suggestion that not more than 4 or 5 inches of the rainfall were available on a chalk surface as a constant source of supply. The Rivers Pollution Commissioners in their sixth Report took as an average 6 inches, with which he did not disagree; but even then they could not rely upon that quantity being always available for the purpose of supplying water, and he thought that they must not count on more than 4 inches. The Commissioners calculated the area of land in the chalk country which might be used within 30 miles of London for the purpose of supplying water at 850 square miles. Taking the average at 4 inches (and he had known the percolation to be not so much as 3 inches) that would give 130,000,000 gallons per diem, which, he maintained, was hardly sufficient for the vast metropolis of London. But after all he did not think that the question as to the amount of rain which percolated into a porous soil like chalk was of so very much importance in the present discussion. It

Dr. Evans.

[1] Minutes of Proceedings Inst. C.E., vol. xx. p. 220, and vol. xlv. p. 208.

Dr. Evans. appeared to him that the Paper was founded on a considerable amount of assumption in various directions. He found, for instance, that two vast expanses of gravel at a low level, and saturated with water, were assumed to exist in the neighbourhoods of Datchet and Slough, together covering 90 superficial miles, and that in each of those there was said to be an underground river. He should like to ask if any one had ever seen those underground rivers or such a continuous expanse of water-bearing gravel over that large extent of country? There was no doubt a considerable spread of alluvial or diluvial beds of brick-earth and gravels at various elevations, but to believe that there was such an enormous reservoir of pure gravel as was laid down in the Paper, with subterranean rivers flowing through it, both north and south of the Thames, transcended his limited powers of imagination. No doubt there was a large delivery into the Thames out of the beds of gravel from Maidenhead down the river as far as Staines; and, indeed, he thought the Paper showed that there were no means by which the water might escape in the direction of the sea. It should be borne in mind that assuming those beds of gravel to exist, the water in them must be continuous, so that what they took from one part would be replaced by water from other places coming through the ordinary channels between the stones. The Author had shown that that water could not escape in the direction of London. Then the question arose what really became of it? Mr. J. C. Hawkshaw had pointed out that it was impossible to pump from the bottom of a cistern without affecting the surface. Even if it were filled with gravel, the interstices would hold a certain amount of water, but in pumping from the bottom the upper surface would be lowered. He believed that the opinions he had enunciated, in a lecture delivered before the Institution, some years ago,[1] were not very far from being correct. But granting that Mr. Harrison's views were just, how would any amount of pumping from the reservoirs prevent the water from the neighbourhood flowing in, and so robbing the stream precisely according to the amount taken from the tunnel? Viewing generally the history of the streams flowing through porous rocks like chalk, it must, he thought, be evident that those streams represented the excess of the rainfall over what had been absorbed by processes of nature or of art. First, it was necessary to take into consideration the evaporation, which, as was known from experi-

[1] "The Theory and Practice of Hydro-Mechanics." A Series of Lectures. Session 1884-85.

ments both on open surfaces and on moistened soils, amounted to a considerable quantity in each year; and in addition to that, in the case of chalk, it would be necessary to allow for a certain amount of moisture being brought up from the lower depth by means of capillary attraction; for though a large amount might be evaporated from the surface, there would always be more or less moisture coming up from below, keeping the ground within a certain distance of the surface slightly damp. Secondly, it was needful to take into account that large amount of water which was consumed in the process of vegetation. There could be no doubt that an enormous percentage of the weight of plants in the green state consisted of water which had been absorbed from the soil. Thirdly, there was a possibility of leakage below ground, by the water finding its way to the sea, or to some stream not immediately within the watershed. No doubt all along the southern coast there was a constant delivery of water from the Chalk into the sea, without any stream being fed by it, and the intercommunication in the pores and fissures of the Chalk, between the water flowing seawards and the sea itself, was evidenced by the well at Brighton, which rose and fell in accordance with the state of the tide. He thought it would be evident to all, that assuming that there was a leakage going on—and there was no doubt always a tendency in the water that supported those streams to be working down-hill—the subterranean waters still maintained the water in the Chalk at a certain level, so that the streams did not cease to flow. Anything that abstracted from that underground water, even supposing it was on its way to the sea, would of necessity affect the streams on the surface. They could not take away from the bottom of the cistern without lowering the level of the upper surface; they could not, by means of a cock, draw off from the bottom of an overflowing cistern without affecting the overflow. He therefore maintained, in the first place, that what water there was in those marvellous beds of gravel, and in those underground rivers, was already being delivered into the Thames by means of natural vents, and secondly that whatever they took from it, whether by tunnels or otherwise, though possibly they might by that means get a purer water than they would from the river, would be virtually so much abstracted from the Thames itself. Dr. Evans.

Mr. W. WHITAKER said the Author had spoken of the abrupt alteration in the dip of the strata between Epsom and the Hog's Back as likely to interfere with the passage of the water. Mr. Whitaker denied the abruptness of the alteration. As a matter Mr. Whitaker.

Mr. Whitaker. of fact it was very slow and gradual; it led from a dip on the east of from 3° to 5°, to what was an abrupt dip of 30° or 40° on the west; but between those extremes there was every gradation, and he was sure that the change was not enough to stop altogether, though it might to some extent retard, the passage of water; and there was a great difference between stopping and retarding. There was certainly an east and west disturbance (by which he presumed was meant a disturbance running from east to west) east of London; but he could not agree with the Author in describing it as a great one. It was a fault which had a maximum throw of 150 feet, and therefore could only result, as far as the Chalk was concerned, in throwing one part of the Upper Chalk against another part of the same stratum, and that the water would be stopped by it was very doubtful; certainly he did not think it would justify the Author's statement that the disturbance would effectually bar its passage; it might do so in one place and not in another. The Author had also made a slip in speaking of the edge of the great chalk basin; he had referred to the Lower Chalk as rising to the highest level, but that was not the case; it might rise nearly to it, but the highest levels of the chalk were hardly ever formed of the lower beds. In the Lower Chalk he included what was now known as the Middle. The Upper Chalk came on along the top of the great escarpment, and the Lower Chalk rose to a fairly high level, but not to the highest. The statement that the London Clay overlaid the Chalk was one against which he had often protested. The London Clay never touched the Chalk anywhere, and Mr. Harrison knew it as well as he did, because he had qualified the statement further on by noting other beds between. As to the 1,200 square miles alluded to by Dr. Evans, it had struck him as peculiar that a large area of Chalk from the west to the basin of the Lea should total 1,200 square miles, and that only a bit of it, which was little more than the Colne drainage, should be given by another speaker as rather more than 1,200 miles. Of course Mr. Harrison's figures were right, but Mr. Homersham's could not be. The gathering-ground of 1,200 square miles, to which Mr. Harrison referred, did not consist almost entirely of bare chalk, as shown on his maps, and on all general geological maps. On the contrary, over a great part of the tract in question, perhaps to the extent of about one half, the Chalk was irregularly covered by a set of deposits of a more or less clayey nature, which must greatly retard the access of rain to it, and lessen the quantity that soaked in. These deposits were shown on the Drift Editions

Mr. Whitaker.

of some of the Geological Survey Maps; but their mapping was not yet finished over the western part of the district. The maps to which Mr. Hopkinson had alluded, as constructed to show the areas where the Chalk was bare or capped only by permeable beds, and where it was protected from surface-action by beds of mixed or doubtful character, or by impermeable strata, could be made only from such Drift Maps. Some of these maps were exhibited and described a few years ago,[1] and it was hoped that the Geological Survey would exhibit an extended set at the National Congress of Hygiene to be held in London next August. The Author had spoken of the water crossing the London Clay barrier at Datchet. That was another mistake, but it was one for which Mr. Harrison was not in any way answerable. The statement was founded on the Geological Survey map, but even geological surveyors occasionally made mistakes. Mr. Whitaker had acknowledged the mistake in print;[2] it was simply made owing to the absence of information. As a matter of fact the River Thames entered the Tertiary barrier close to Bray, below Maidenhead, instead of at Datchet. It again touched the Chalk near Windsor and again entered it at Datchet. When he originally mapped that country, about thirty years ago, there was no evidence on the subject, and he did not like to colour Tertiaries under the gravel of the low ground above Windsor, but took the safer plan of keeping the lines well up, and so showed it as Chalk. He was a little at issue with the Author, who quoted Mr. Homersham, about the chalk water from the north of London and from the west being effectually barred from reaching the sea by a disturbance or fault running north and south across the London basin below London. He could see no trace of any such fault. There was certainly a slight disturbance up the valley of the Lea, roughly speaking. It seemed to open somewhat the fissures in the upper part of the Chalk, making the passage of the water more free than it might have been. The result was important, for it enabled the East London and New River Companies to draw a large quantity of water from wells in the Chalk in the valley of the Lea. It also affected the supply of the mills and other establishments in that district. He believed

[1] 1884. "Geological Magazine," Decade iii. vol. i., pp. 23-29, "Proceedings of the Norwich Geological Society." "Journal of the Society of Arts," vol. xxxii. pp. 847-851, and "Health Exhibition Literature," vol. viii. pp. 364-373.

[2] "The Geology of London and of Part of the Thames Valley" (Geological Survey Memoir), vol. i. pp. 176, 177 (1889).

Mr. Whitaker. that the competition had not resulted in any cessation of supply to any good well in the valley. So that the slight disturbance, instead of barring the passage of the water, seemed to have facilitated it. Professor Prestwich also had been quoted; he had, however, given up any north and south fault there. As he had stated in his book, "The Water-bearing Strata of London," it was a disturbance affecting not the Chalk, but the Tertiary beds. Mr. Whitaker thought Mr. Harrison had been a little misled on that point, having extended Professor Prestwich's statement from the Tertiary beds to the Chalk. The faults alluded to by Mr. Lucas were quite local, and might affect the supply at one house, but have nothing to do with another half a mile off, so that they would be of no moment whatever in regard to the large question of water-supply. The Author had spoken of another fault westward of Kensington as indicated by the levels of the chalk-water in artesian wells. He failed to see that the evidence bore out the conclusion, because a fault might not affect the level of the water in the wells. The difference spoken of by the Author, that the water was 30 or 40 feet lower eastward of Kensington than westward, was susceptible of explanation from the fact that the former tract was nearer the area of excessive pumping than the latter. He thought that few people realized the enormous quantity of water pumped from the Chalk in private wells in London; it was 8,000,000 or 10,000,000 gallons per day, or even more, though the exact amount was not known. Probably that was enough to account for the lowering of the water-level locally. It had been stated by many engineers and others years ago that the water-level under London had sunk enormously in consequence of the increased number of wells and the continuous pumping. Professor Prestwich in his book had spoken not merely of faults, but of disturbances generally, and the disturbances referred to by Mr. Harrison were so very gentle that there was no need to call in such a thing as a fault, which implied a fracture with disturbance, to explain them. Dr. Evans had alluded to those peculiar variations in the increment of the stream between Maidenhead and Windsor. If that increment fluctuated between 137,000,000 gallons and 17,000,000 gallons per day, he did not see how they could depend on it for a supply to London, which wanted 100,000,000 gallons or more every day. The Author had divided the large spread of gravel into two, but Mr. Whitaker did not quite understand the line of division, which was drawn a little north of Hampton. A few years ago he was at the waterworks at that place, and he had evidence

Mr. Whitaker.

that instead of there being one sheet of gravel at Hampton there were two at different levels, with a slight outcrop of London Clay between. The result was that the gravel on the south, from which the Water Companies obtained their supply, was isolated from the larger sheet on the north, and the division would be a little south of where it was placed on Mr. Harrison's map. How far that outcrop of London Clay went he could not say. In the early geological survey, they did not attempt to refine as now. The "gravel" along that part of the Thames meant simply the area which was nearly all covered with gravel; but in which there might be patches of London Clay at the surface here and there. He questioned whether the water in this gravel came from any underground source. To a large extent at least he believed it was got by filtration from the Thames, and he thought that the Water Companies' engineers were of the same opinion. He knew that Mr. Harrison had the opinion that the Bagshot Sand contributed to the water; but it could only do so to a small extent, because between it and the gravel there was a slight outcrop of London Clay all round, so that all the water flowing out of the Bagshot sand would be thrown out by springs, some of which might flow into the gravel. He could not quite understand how the water from some of those chalk districts on the north, coming apparently down the Colne, got into the higher gravel at Slough as distinct from the lower ground of Maidenhead and Windsor. It seemed to him that some of it must go against the ordinary flow of the river. He imagined that most of the water would pass through the gravel by the nearest way to the neighbouring river, and that it would go southward and not towards Slough. The most astonishing thing in the Paper, however, was the increment said to be received by the Thames between Teddington and Kew. He did not understand whether the figures had been taken over any extent of time, or whether they wanted checking; but if 400,000,000 gallons a day in a dry season got into the Thames in that neighbourhood, he could not see how the river was ever very low. He understood that the minimum flow of the Thames in the neighbourhood of Hampton was about 300,000,000 gallons a day, and if that was not enough to keep the river-bed from being dry, another 400,000,000 gallons a day would do it. An idea had occurred to him that some of the water might have filtered through the gravel from the higher part of the river where there were some bends, as would be seen from the map, and where possibly there might be some underground channels. Mr. Harrison

Mr. Whitaker. referred to the fine chalk springs at Havant, in Hampshire. He should like to know whether it was quite certain that they yielded as much as 200,000,000 gallons per day. The Portsmouth people had enlarged their works, and it might have been thought that if the water could be got so easily they need not have done so. There was undoubtedly an enormous supply there from the Chalk. The question of the water coming from the synclinal of the Hampshire chalk-basin was affected by the fact that close to Havant was an anticlinal axis, and if that had any effect, it ought to be to cut off the supply, which apparently it did not do. The anticlinal axis that he meant was a rise from under the Tertiary beds, and was visible to the eye from the railway for a long distance—the great ridge of Portsdown, in which it was possible to walk almost on the same bed of chalk up and down both sides and on the top. The springs were on the south, and there was a large chalk area further northward. There must be some communication, and it seemed as if that great disturbance were powerless at all events effectually to bar, though it might perhaps retard, the flow of water from the north, and if that were so, it might be the same in other places. Each case would have to stand on its own merits. He had to examine the cutting between Maidenhead and Twyford on the day after the Paper was read, not in connection with the water, but merely to see the character of the chalk, and he found no trace of any hole through which water could go. He did see in one place a well in the Chalk, the water in which was 20 feet or 30 feet down; that was not low for the dry season. He supposed that a wet season might have some effect in bringing the water-level in the Chalk nearly to the surface in that part. He agreed with Mr. Evans, that the water in the ponds near Burnham was held up by the London Clay, or other Tertiary beds under the gravel. Most of those mentioned by the Author in the same connection were, he imagined, filled by water from the gravel, rather than by chalk-water. He need not enter into the question of the age of the Valley Gravels of the Thames. Glacial phenomena, however, appeared to have a fascination for every one, Mr. Harrison included. He had thought that the brick-earth and the Thames gravel might have been formed during the glacial period, from wash from the sands and chalk. Mr. Whitaker considered that the brick-earth was newer than the glacial period, and was probably formed more from the London Clay than from anything else. As to the steadiness of the water through the Tertiary Sands from the well at Bushey, he did not quite understand the remark in the Paper, because the well was in chalk, and the steadiness of the water was that of chalk-water, rather than of tertiary-water. He should have been glad if some engineers would have said something on the general question at issue. On that question they were greatly indebted to the Author. He had dealt with a subject on which most people were afraid to write; he had freely expressed his opinions, and given them an opportunity of discussion. As a matter of feeling, he went with the Author to a large extent, having long thought that it would be well if London could get an underground supply from its own district. The surrounding area was so exceptional in its character, and had interests so great and varied, that it was doubtful whether London would be able wholly to supply itself from underground sources. The question was most important, and he should like to see all classes, landowners, engineers, Water Companies, and County Councillors approach it in a large spirit. Mr. Whitaker.

Mr. JAMES MANSERGH observed that Dr. Evans and Mr. Whitaker had anticipated much of what he had intended to say, and he would only make a few remarks with regard to the subjects of percolation, and of the gauging of the Thames. Dr. Gilbert had stated that the beds at Rothamsted were kept free from crop, and that in order to obtain the real percolation from the general country, some deduction, varying between 2 and 7 inches, would have to be made. It appeared to him that this was a serious drawback to the usefulness of the observations. All the work at Rothamsted was so skilfully and carefully done that he had no doubt it would be possible for Sir John Lawes and Dr. Gilbert to arrange a percolation-gauge with a growing crop upon it, so that this error might be eliminated. It would manifestly be of great advantage if such an improvement could be effected. Mr. Mansergh.

He would now say a few words on the real point of the Paper. On page 3, the Author quoted from Dr. Evans' lecture on physiography in 1885, as follows:—"Mr. J. T. Harrison's schemes for obtaining water by means of tunnels in the chalk of the Thames valley, merely means that all the water derived from the tunnels will either be intercepted on its way to the river, or filter into the tunnels from the bed of the river itself. The flow of the Thames below will be diminished by just the same amount of water as that abstracted by means of the tunnels." He then went on to say: "It cannot be doubted that apprehensions of this kind, unless they are removed or proved to be groundless, will always be sufficient to cause the overthrow in Parliament of any proposal to supply London with water from the Chalk formation. It would consequently be a useless waste of time

Mr. Mansergh. to submit a Paper on the subject to the Institution, unless the Author of it were prepared to give, as he believes, convincing proofs that no such disastrous consequences would result from the proposal." This being the real object of the Paper it was difficult to understand how the proposition could seriously be made to abstract from the ground the water which was stated to be flowing from it into the Thames between Teddington and Kew. Surely the residents on the banks of the river at Twickenham, Richmond, and the places below, would protest in the strongest terms against this reduction of volume. They would certainly consider the consequences to be "disastrous." Already they grumbled terribly at the taking of less than 100,000,000 gallons a day by the water companies; but the Author proposed to reduce the flow by a quantity sufficient "for the supply of London and its suburbs for centuries to come." This sentence would probably be considered by the general public as the most important one in the Paper. It came just after a statement as to the "increment between Teddington and Kew in August, 1887, and November, 1890," and pointed to the figures given as being the measure of the quantity available without harm to the river. It was consequently of the greatest moment that there should be no doubt whatever as to the accuracy of these figures, and he would like to ask the Author how the gaugings were made. He thought there would be great difficulty in doing it satisfactorily, on account of the complications caused by the influx of the tidal water. For the purposes of a bill which was before Parliament last session, careful observations were made at a point about half-way between Teddington and Kew bridge, in order to find the exact height of the rising and falling water every quarter of an hour throughout a whole cycle of tides. Now they showed that out of the twenty-seven tides there were—

8	when the least discharge was *not* maintained for 15 minutes.				
6	„	it *was* maintained for 15 minutes.			
5	„	„	„	„ 30	„
5	„	„	„	„ 45	„
2	„	„	„	„ 1 hour 45 minutes.	
1[1]	„	„	„	„ 2 hours 45	„

He wished to ask the Author—

1st. If it might not be fairly assumed that all the water over and above the least quantity was tidal water?

[1] The correctness of this observation was questioned.—J. M.

2nd. How he distinguished between this tidal water and the increment from the gravel? Mr. Mansergh.

3rd. Might not some of this increment (possibly a great part of it) be simply water that flowed into and out of the ground as the tides rose and fell?

He considered that a few gaugings made under these exceptionally difficult conditions were an insufficient basis upon which to build the whole fabric of this Paper.

Major LAMOROCK FLOWER wished to offer a few remarks with reference to the Banstead Well. He had occasion some years ago to make certain observations with a view of supplying that district with water, and he could state as a fact that the Banstead Well did not vary much in level, notwithstanding the condition of the springs at Carshalton. He thought that Mr. Harrison had put it too deep. Major Flower never found a greater difference of level than 3 feet between the driest and the wettest season. With regard to supplying London from underground water, he would ask whether they should not be somewhat careful of the surface from which that water was drawn. Having had charge of the Lee watershed for the last twenty years, he knew the value of looking after the surface, and also the distribution of sewage, which might, through fissures, get down to a lower level. A similar remark would apply to the gravel beds, and it was one of the objects which Water Companies had in view in opposing the disposal of sewage from the Lower Thames Valley on the beds at Molesey. Such matters, though they might appear trifles, were really worthy of consideration. Major Flower.

Mr. R. F. GRANTHAM said it would be remembered that in 1877 there was a proposal to obtain water for London from the chalk for drinking purposes and fire-extinction. In the following year his father was called upon to investigate the effects of pumping in two wells in the Chalk in Essex where 2,000,000 gallons were being pumped per day, and he found that the result between the years 1869 and 1878 was to permanently lower the level of the water 14 feet; he also found that the wells in the neighbourhood about a mile round were considerably affected. It was impossible, in the face of a fact like that, to avoid apprehending that any large abstraction of water from the Chalk must influence the outflow from it into the rivers and streams all round. So with regard to the Slough underground reservoir mentioned by Mr. Harrison. In carrying out the sewerage works at Slough they became well acquainted with the district between Slough and Datchet to the east, and between Slough and Dorney to the Mr. Grantham.

Mr. Grantham. west; and they found in the low-lying ground the existence of a considerable quantity of subsoil water as described by the Author. They had, in consequence, to lay iron pipes for the outfall sewer for 1,200 yards, and to pump night and day in order to build the tanks, which were 16 feet deep. All round the neighbourhood the subsoil water stood at about 4 feet below the surface, and on opening two holes a mile apart there was found a difference in level of the underground water from 7 feet to 8 feet, or very nearly the inclination the Author had stated. As the water-level was so near the surface, and it was flowing eastwards towards the Colne, it seemed to him that if either of the alternative culverts were laid, as proposed by Mr. Harrison, one from the Hampton Reservoir to Salt Hill, and from Salt Hill to Farnham Royal, and the other between Langley Marsh and Uxbridge—that the abstraction of water caused by them would seriously influence the quantity in the River Colne between Staines and Uxbridge. It would be remembered that two or three years ago the Grand Junction Waterworks Company proposed to lay a culvert to Dorney. The Slough sewage farm was laid out on the north side of Dorney Common, and the Eton sewage-farm was close by. They found there a sharp bed of gravel, at least 5 or 6 feet deep. The sewage pumped on to that gravel went into the soil, and never came out again. He thought it was as well to point that out, because if a culvert were laid anywhere near that place at a great depth, the water from it would not be particularly palatable.

Mr. Wentworth-Sheilds. Mr. F. WENTWORTH-SHEILDS observed that the scheme described in the Paper had been objected to on the ground that if the lower strata were tapped the higher beds would be drained of water; but he thought this would not be the case if the Author's premises were correct, namely, that the water flowed from the Upper Chalk through the porous beds next the Thames, and lipped over into the river. This would be analogous to a barrel fed from an inclined shoot, in which case the water would overflow on the barrel edge, and a portion might be intercepted immediately above it without in any way affecting either the flow down the shoot or the water-supply at the top of it. So it would be in the soil, as the upper levels would similarly remain unaltered if the water which welled over into the river were intercepted. It was for the Author's opponents to prove that he was wrong in that supposition upon which his scheme was based; and if Mr. Harrison had shown that there was really an increase of some four hundred millions of gallons in the flow at Kew, above that at Teddington, where no subsidiary stream came in to account for it, that circumstance would go far to make good his case. He presumed that Mr. Harrison's gaugings were taken at low-water; and if his data were correct, that the water would probably be collected in a long intercepting culvert with open joints, placed near and parallel to the river in the neighbourhood of Hampton. Mr. Wentworth-Sheilds.

Professor HENRY ROBINSON had no doubt that many like himself, concerned in the question of the water-supply in London, had been collecting information which would soon be brought before a public tribunal, so that their mouths were closed on the present occasion. Many criticisms had been passed on Mr. Harrison's views, and he should prefer to abstain from adding to them. There happened, however, to come within his professional experience, a few years ago, a report made by Mr. Harrison to the Local Government Board with the view of showing the large amount of water to be obtained from the Chalk by driving a tunnel, which was called the Black Pot Tunnel. From investigations which Professor Robinson had made in connection with one of the London Water Companies, and from the information given in Mr. Whitaker's geological memoirs, the Black Pot Tunnel, shown in the report as driven in the Chalk, was practically in an impervious stratum far above the Chalk, and therefore any hypothesis based upon the assumption that the tunnel could be driven at that spot, as Mr. Harrison supposed, was an entire fallacy. Professor Robinson.

Mr. W. TOPLEY did not propose to follow Mr. Whitaker and Dr. Evans in the geological details which they had laid before the meeting, and with which he agreed. He might, however, in justice to Mr. Harrison, point out that some of Mr. Whitaker's criticisms, although just and right, did not touch the real point of the Paper. It did not, for example, much matter, in considering Mr. Harrison's scheme, what his interpretation was of some of the disturbances east of London, and whether they prevented the water going to the sea or not. The real problem was whether there was water in the gravel, and whether it could be utilized for the supply of London, and on that question he agreed in part with Mr. Harrison. He was by no means sure that the quantity was as large as Mr. Harrison had stated; but it was no doubt considerable. If they tapped the water above the intakes, they would prevent it going into the Thames, or being taken by the London Water Companies, but nothing would be gained in quantity. Mr. Whitaker had made a point in stating that there was, north of Hampton, a rise of the London Clay, or something of that kind, which made a division between the two gravels, and he said that Mr. Topley.

Mr. Topley. the water was got by the Water Companies from the south side of the line of division. But the real point of the Paper was the curious statement as to the amount which got into the Thames between Kingston and Kew. That was on the north side of the disturbance, as Mr. Whitaker had admitted. If it were true, as the Author had said, that there was so large an increment between those two points, surely some of it could be utilized. It might be serious for the people at and below Richmond, but it would not affect the question as to the present state of the London Water Companies, because the water would be taken below the point at which the supply was now obtained. That, he thought, was the crucial point of the Paper, and he should have been glad if the engineers who had spoken had given more attention to it. It was curious that the Author had referred to a statement of Mr. Beardmore, that the Thames was supplemented by 60 or 80 million gallons between Kingston and Vauxhall Bridge, and he was doubtful whether that included the Wandle or not; yet, between Kingston and Kew 400 million gallons were said to flow in during the dry weather. Mr. Mansergh had dwelt upon some of the weak points with reference to that question. Mr. Topley spoke only as a geologist. Gauging the river was an engineering question, but he did not see how it could be done except at extreme low water, and in that case, how could they tell that they were not measuring what had been stored in the gravel as the tide flowed up? He thought it was quite impossible for any observations to determine the difference between the two. As it got towards high tide, the gravel on the banks absorbed the water, and as the river fell it flowed out again. With all due deference to Mr. Harrison, and the authority which he had quoted, Mr. Topley was not at present prepared to accept the deductions from these gaugings. Surely, if there was a large amount flowing out of the gravel at low water, they ought to be able to see it. A few weeks ago he was walking along the banks at Richmond at low water, and although he had not that special object in view, he thought that if any considerable quantity of fresh water had been flowing out of the gravel, he should have noticed it. If Mr. Harrison established his point, that between Kingston and Kew there was a large increment of water from the gravel, some of it could be taken without injury to the present supply. He did not know with what object the map behind him was placed on the wall, but as Mr. Baldwin Latham was prevented from taking part in the discussion, he would refer to one interesting point not shown upon it. The arrows on the map showed the direction of the line of maximum inclination of the water in the Chalk, and Mr. Baldwin Latham's observations proved that the underground flow of water did not always correspond with the surface inclination. The most important difference was in the valley running from Caterham to Croydon. Instead of the underground water running straight down the valley towards Croydon, a part of it turned to the left, and went under high ground, and so came out at Carshalton. He was glad that Mr. Harrison's Paper had been brought forward. Although it had been somewhat hardly treated, there were many points in it well worthy of consideration. Mr. Topley.

Mr. MARTIN PEIRCE agreed with the opinions expressed by Mr. Mansergh and Mr. Whitaker, that the increase between Teddington and Kew was not so large as the Author had supposed. The gaugings referred to in the Paper were made by him in 1887 for Mr. Harrison. As considerable stress had been laid upon them, he would explain fully the mode in which they were taken. He chose the straightest reach with a regular bed near the point at which a gauging was desired, and at about the middle of it stretched an accurately divided and marked stranded wire line across from bank to bank at right-angles with the shore line. He then measured the depth at each mark with a graduated staff, and from these measurements calculated the cross-sectional area, which he assumed to be the average for the distance covered by the gauging. Then, equidistant on either side of this point of cross-section, he measured and staked off on both banks, a total distance of from 50 to 300 feet, and setting small floats adrift, noted the time taken by them flowing from point to point, thus finding the average speed in feet per minute. Then speed $\times$ area $\times$ $6 \cdot 25 \times 1{,}440 =$ quantity flowing per day. In the case of the particular gaugings in question at Kew Bridge in 1887, before he commenced gauging he fixed a stake, and noted every five minutes the fall and the rise of the tide. Similar observations had since been more completely carried out by the Conservancy, at a great number of points from Teddington down the river. On the stake he found that the water fell regularly to a certain level, and then immediately began to rise, showing that the tidal influence was never absent. If a stake was fixed nearer to Teddington, the water fell for a time, and then stood steadily at a level; it was simply the land-water running down, and until the tide came up, perhaps an hour later, it would not rise from that point. That seemed to show that there was a large amount of tidal water included in the gaugings Mr. Peirce.

Mr. Peirce. below Kew Bridge. In sending in a report to Mr. Harrison he made a sketch of the stakes, showing the times and the rise and fall of the water, and the points at which he made his observations. The gaugings were taken at regular intervals on the different occasions, and in each case they were within $\frac{3}{4}$-inch of the lowest level to which the river fell, and within about five minutes of the turning of the tide.

Mr. Topley. Mr. TOPLEY hoped that some further information would be supplied with regard to the gaugings near Richmond, as that was one of the most important points, and ought to be fully explained.

Mr. Peirce. Mr. PEIRCE said he had no knowledge of the object of the gaugings, or he should have perhaps called Mr. Harrison's attention to that point. He knew nothing of it until he had heard the Paper read.

Mr. Harrison. Mr. J. T. HARRISON, in reply, desired in the first instance to thank the President for the kind reference to his name. There were in the Paper two proposals for providing London with water; one was to take it from the gravel-bed above Windsor, and the other from the gravel-bed which lay on the north side of a line drawn from Slough to Hampton. Sufficient could not be taken from the former source without injuriously affecting other interests, and the supply would therefore have to be supplemented. He should therefore direct his reply more especially to the proposal to draw the water from the Slough gravel-bed, which he believed would be ample. Attention had been called by Mr. Symons and Mr. Whitaker to the remarkably large increment in the volume of the Thames, as shown by the gaugings, between Kingston and Kew, and to the difficulty of separating the tidal from the land waters, and estimating the value of the increment for the London water-supply. Mr. Topley also had considered it "the crucial point of the Paper"; and rightly so, for if there was not a quantity of water entering the Thames from the gravel-beds below Kingston sufficient for the future supply of London, it would be useless to search for its source. Mr. Topley remarked that he did not see how the Thames below Teddington could be gauged "except at extreme low-water, and in that case how could they tell that they were not measuring what had been stored in the gravel as the tide flowed up." Mr. Mansergh, without committing himself to the expression of any decided opinion, proposed several pertinent questions, which it was most important to answer. It would be observed that neither Mr. Mansergh nor any one else had questioned the accuracy of the gaugings taken for the Author by Mr. Martin Peirce; these gaugings showed that in August, 1887, and November, 1890, after continuous dry weather in each year, the increment in the volume of water in the Thames between Kingston and Kew, at dead low water, amounted to a rate of more than 400,000,000 gallons per day. Now the first question asked by Mr. Mansergh was "If it might not be fairly assumed that all the water over and above the least quantity was tidal water?" The reply to this question would answer the two others. It might be well to mention that the gaugings taken by Mr. Peirce showed that the volume of water in the Thames at Kew was:— Mr. Harrison

	Gallons per day.
On the 10th August, 1887, at 2.40 P.M., at the rate of . .	872,780,000
" " " 3.0 " " . .	731,532,000
" 12th " " 3.0 " " . .	757,014,000
" " " 3.20 " " . .	673,951,000
" " " 3.40 " " . .	680,999,000

In each case the tide began to rise within five minutes after the last gaugings were taken, and the lowest were used in the Paper. Mr. Peirce took only one gauging in November, 1890, which was at a rate of 891,000,000 gallons per day at dead low water; if he had taken others before that period there is no doubt that the result would have been similar in character to those recorded in 1877. In reply to Mr. Mansergh's first question, it was improbable that "the water over and above the least quantity" was tidal water which had been left behind in the bed of the river, for if there had not been any land water, the bed of the river would have been left dry, as was the case in estuaries, when the tide receded, and the presence of ordinary river-water would expedite rather than retard its recession. Again, there was no large lake or pond which, having been filled with tidal water might supply the surplus through a narrow outlet towards low water. The most plausible supposition was, as had been suggested by Mr. Topley and Mr. Mansergh, that there existed above Kew a large quantity of porous gravel, into and out of which the water flowed as the tides rose and fell. With regard to this hypothesis, he would point out that the water in the land adjoining the river above Teddington weir stood at the same level as that in the river, and rose rapidly in the gravel-bed inland from the river. Under these conditions it was possible that water might enter the river above Teddington weir from the gravel, as it did above Hampton, but none could escape from the river into the gravel. The level of low water in the tidal part of the river below Teddington weir was 5·67 feet above Ordnance datum, whilst

Mr. Harrison. the water in the land at a short distance from the river stood 15 feet, and half a mile from the banks 24 feet, above Ordnance datum. At Isleworth the low-water level was 4 feet above Ordnance datum, and the water in the land adjoining was 10 feet above Ordnance datum, and rose to 96 feet above Ordnance datum in a distance of 4 miles from the river. Again, at Kew, according to information obtained for the Author by Mr. Mansergh in 1884, the low-water level was 3 feet above Ordnance datum, and the water stood 10 feet above Ordnance datum in the gravel at a short distance from the river, and rose 5 feet higher at a distance of a mile from it. The Author was informed by Mr. Bromley and Mr. Mansergh that the level of the water in the gravel at Isleworth and Kew was not affected by the tide, excepting at Kew after a succession of very high tides, when it varied a few inches. These facts showed that at low tide there was a considerable head of water in the gravel adjoining the river, equal to at least 9 feet below Teddington weir, 6 feet opposite Isleworth and 7 feet below Kew Bridge; and under these conditions some water must of necessity escape into the river from the land adjoining; but, it might be asked, "how does it happen that the water stands thus permanently in the gravel-bed at from 6 to 9 feet above low-water level in the river?" If there were no tidal action, the water in the gravel would probably be at about the same level as that in the river, and the great height at which it actually stood indicated the influence which the tides exerted on the outflow from the land. The gravel-bed thus acted like an extensive underground reservoir or regulator, in which the water pulsated almost imperceptibly as the tide rose and fell. Now supposing the outflow to be nearly normal at dead low-water, it must necessarily be checked as the tide rose, but it could not be entirely stopped until the tidal column had balanced that in the gravel-bed. Moreover this latter column was not accurately represented by the height of the water in the land adjoining the river, for the water travelled horizontally towards the river along open pebble-beds at some depth below the surface of the ground, and its level in the land adjoining the river only indicated the resultant effect of the tidal action, passing upward through the water-carrying pebble-bed, over a large extent of water-logged gravel. Again, as the tide ebbed the discharge from the gravel must increase and attain its maximum when the tidal water had all receded, after which it must gradually decrease until it again attained its normal condition towards low-water. The observations of rise and fall of the water through a

Mr. Harrison.

cycle of tides referred to by Mr. Mansergh, and kindly submitted by him to the Author, afforded some interesting and important information bearing upon this subject. The annexed diagram, *Fig. 3*, of the rise and fall of the water at Richmond between the beginning of one flood to the next (shown by the strong lines), represented the highest of the spring tides, and the lowest of the neaps in this cycle; the diagrams of the other observations at Richmond would lie within these extreme limits with very slight exceptions. These diagrams suggested the division into three periods of the time between the successive flood tides:—

(1st.) From the beginning of the flood to high water.
(2nd.) From high water to the time when the water had fallen to 9 feet below Trinity high-water mark.
(3rd.) From that time to the commencement of the succeeding flood.

(1*st.*) *Rise of the tide at Richmond.*

	Hours.
The average time of eight spring tides was	$2\frac{7}{8}$
,, ,, ,, neap ,,	$3\frac{1}{4}$

	Ft.	Ins.
The average range of eight spring tides was	10	$8\frac{1}{2}$
,, ,, ,, neap ,,	8	$9\frac{1}{4}$

(2*nd.*) *Fall of the tide to 9 feet below Trinity high-water.*

	Hours.
The average time of eight spring tides was	$6\frac{1}{4}$
,, ,, ,, neap ,,	6

	Ft.	Ins.
The average range of eight spring tides was	10	0
,, ,, ,, neap ,,	8	$1\frac{1}{2}$

(3*rd.*) *Fall from 9 feet below Trinity high-water to succeeding flood.*

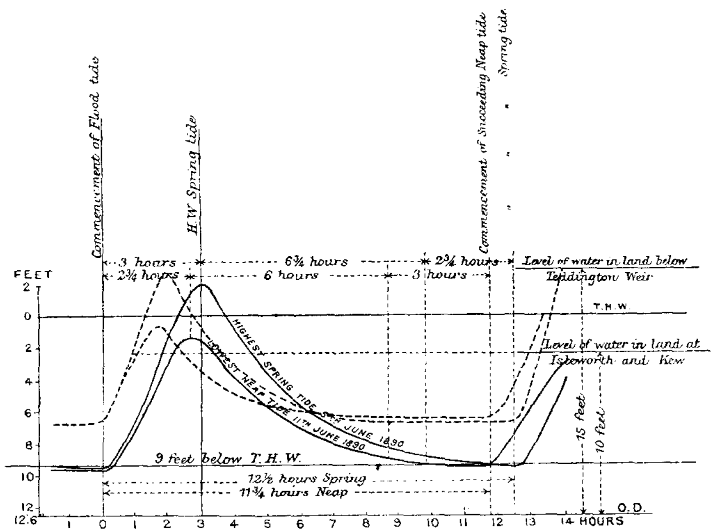
	Hours.
The average time of eight spring tides was	$3\frac{1}{8}$
,, ,, ,, neap ,,	$3\frac{1}{4}$

	Ft.	Ins.
The average fall of eight spring tides was	0	$8\frac{5}{8}$
,, ,, ,, neap ,,	0	$7\frac{5}{8}$

The level of 9 feet below Trinity high-water mark adopted for one of the divisions was quite arbitrary; it was impossible to draw a line, and say that all the water flowing down when the river was below that level was entirely fresh water, which had never before been subjected to tidal action; but it was most improbable that there should be much, if any, tidal water flowing past Richmond during the last three hours of each tide, and there must certainly be a large quantity derived from the gravel in the tidal water

Mr. Harrison. which passed down before it had fallen to the 9-foot level. The moon was in the last quarter on the 11th of August, 1887, and consequently the gaugings on the 10th and 12th of that month were taken at the dead of the neaps, when the river would rise very little above the water in the land adjoining, and for a short time only, as shown by the diagrams—which indicated that the highest spring tide did not reach the level of the water in the land at Teddington, and only rose about 4 feet 6 inches above the water in the gravel at Isleworth and Kew, and that it did not remain longer than three hours above that level. The dotted lines on the diagram (for which the Author was indebted to Mr. More,

Fig. 3.



Engineer to the Thames Conservancy) showed the rise and fall of the tide at Teddington on the 5th and 11th of June, 1890. From these it would be observed that the period of flood tide at Teddington varied from one and three-quarter hours at neaps to two hours at springs, and the period of ebb to 6 feet 3 inches below Trinity high-water, was from four and a half hours at neaps to five hours at springs; after which the water fell a few inches and continued, for about five and three-quarter hours at neaps to about five and a half hours at springs, at nearly the same level until it flowed again. This period of low water was much longer than that at Richmond—3 miles down the river. The increment in the volume of the Thames between the points explained the Mr. Harrison. difference in the diagrams; the time of high water was nearly the same at Teddington and Richmond. Unfortunately there were no similar observations at Kew; but the period of dead low water would probably be shorter than at Richmond, which accounted for the very short time that Mr. Peirce found between low water and the return of the flood. After giving the subject careful consideration the Author believed he was justified in his estimate that, after making large allowance for the check to the flow of water caused by tidal influence, the increment of the volume of the river between Kingston and Kew, at dead low water, justified the expectation that an ample supply for London could be obtained from the Slough gravel-bed. It must not be overlooked that a large quantity, which could not be gauged, entered the Thames below Kew. In answer to Mr. Topley's suggestion that "if there was a large amount flowing out of the gravel at low water, they ought to be able to see it," Mr. Harrison admitted that if the water issued from the banks of the river it could be seen, but not if it entered from the bed, which was sufficiently wide, deep, and long for an enormous quantity to flow in quite imperceptibly. W. Wheeler, a waterman at Richmond, gave the following evidence before the Rivers Pollution Commission in 1865: "The foul deposit is not so much in the bed of the river" (Thames at Richmond) "where it is covered at low water—it is more on the banks of the river. You may see the gravelly bottom where there is no filth upon it up stream." It was exceedingly probable that, wherever clean gravel was found in the bed of the Thames, there was an infiltration of water from the land adjoining; for the Thames naturally tended to deposit mud in its channel and to raise its bed. Mr. Mansergh said, "Surely the residents on the banks of the river at Twickenham, Richmond, and the places below, would protest in the strongest terms against this reduction of volume. They would certainly consider the consequences to be 'disastrous'"; but he seemed to have overlooked two matters of great importance; first, that only a small proportion of the water from the gravel entered the Thames above Richmond; and secondly, that if the water from this source were substituted for the existing London supply, the whole quantity now taken from the Thames by the Water Companies would pass on to Richmond, as it did before they drew their supply from above Hampton.

Mr. Harrison then proceeded to deal with the objections raised as to the source whence the water in the gravel-beds below Maidenhead was derived, and the alleged improbability of the Chalk

Mr. Harrison. area yielding so large a quantity as to account for the increase of the volume of river between Kingston and Kew. He considered that there was unquestionably a very large amount of water in these gravel-beds, as shown, for instance, by the numerous ponds and lakes, which had a never-failing supply, even in the driest seasons. Dr. J. Evans and Mr. Whitaker spoke of them slightingly as "simply sheets of water formed at certain points in beds of gravel above the London Clay," but these ponds could not be fed as they were if the gravel were dry, or not constantly replenished with water. It was suggested in the Paper that the two gravel-beds were supplied respectively from the gathering ground of the Chalk westward of Maidenhead, and from the Chalk area traversed on the surface by the Colne, the Lea and their tributaries; from the former by means of infiltration to fissures running east and west, along the synclinal axis of the chalk basin, and from the latter by filtration from the Chalk into the Lower Tertiary beds—which adjoining the Chalk consisted generally of flints, pebbles, and sand—and which conveyed the water to the gravel. The process in the former case was analogous to that which occurred in the Hampshire chalk basin, and resulted in the daily discharge of 200,000,000 gallons of water near Havant at a moderate height above the sea-level; the synclinal axis of the basin ran parallel to the Portsdown Hill, which formed an anticlinal axis. The process in the latter case was similar to that recorded by Mr. Baldwin Latham to which reference would presently be made. Mr. Harrison then pointed out the very different conditions under which the chalk water was collected superficially by the Thames, and by the Colne and Lea and their tributaries. The Thames tapped the Chalk at a level of 100 feet above Ordnance datum near Maidenhead, and entered that formation considerably below the 200-feet contour near Wallingford; the result of this deep tapping being that there were extensive areas to the westward and northward of the course of the Thames entirely destitute of streams. But, tracing the northern 200-feet contour (Plate 1) which followed the course of the Thames between Wallingford and Maidenhead, eastward, it would be found that, leaving the Thames, it skirted the outcrop of the Chalk to Watford and Hertford, and ran up and down the several streams for a short distance. The Bushey Meads well, which stood steadily at 180 feet above Ordnance datum, showed that these rivers and streams did not draw the water much below that level. There was consequently a large mass of Chalk, about 570 square miles in extent, which was saturated from 180 feet and upwards

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down to the level of the water in the Slough gravel-bed, about 90 feet above Ordnance datum. Under these conditions it was very probable that the Thames above Maidenhead withdrew from the Chalk a much larger quantity of water per square mile of gathering-ground than did the Colne and the Lea; but the total quantity of water per square mile, which percolated into the two areas, was probably nearly the same; and therefore the supplementary system of the Colne and Lea, whatever that might be, must carry off a larger quantity per square mile than the supplementary system of the Thames above Windsor. The conditions under which the water was withdrawn from the Chalk formation might have been very different in the past, but they were now normal, and any interference with them by artificial means must *pro tanto* disturb them. Taking, for instance, the extreme case of a proposal to supply London by pumping from a large number of wells sunk along the 200-foot contour between Rickmansworth and Hertford; this abstraction would not prevent, though it might modify, the withdrawal of water by natural processes, as at present, into the Slough gravel, but the effect of the combined natural and artificial operations would soon be to lower the water over the Colne and Lea areas, to dry up the rivers and streams, and reduce the surface to the condition so graphically described by Dr. Evans. The proposal advocated in the Paper did not in the least interfere with the natural processes by which the water was withdrawn from the Chalk. The Colne and the Lea would flow on undisturbed. It was not proposed to pump from the Chalk, as supposed by Mr. J. C. Hawkshaw, but to collect the water which had already left it by nature's process, and to utilize it for the supply of London. As to the proportion of the rainfall which percolated into the Chalk, and might be calculated upon as a source of supply, the discussion had thrown some light on the subject, although it could not be called altogether satisfactory. Dr. Evans had come to the conclusion that "not more than 4 or 5 inches of the rainfall were available on a chalk surface as a constant source of supply," and he thought that "they must not count on more than 4 inches." Mr. Hopkinson had said that "they might have to rely for six years in succession upon $4\frac{3}{4}$ inches of percolation," or even 3 inches for a shorter period. Mr. Lucas said he "considered that the large quantity to be accounted for between the 8 or 9 inches which could be proved to flow from the springs, together with the 2 inches that might pass under the Tertiaries, and the amount indicated by Sir John Lawes' percolators, was evaporated." It was not easy to understand how this quantity

Mr. Harrison. could be evaporated, but it was important to notice the accurate data by which Mr. Lucas proved that 8 or 9 inches of the rainfall flowed from springs. These data were the records of the discharge from the Wendover springs; the area of gathering-ground was 4·6 square miles, and the average yield, over a period of forty-four years, was 177 cubic feet per minute, which represented a mean percolation of 9 inches of rain per annum. The maximum yield in any one year being approximately 15 inches, and the minimum $3\frac{1}{2}$ inches, it appeared that the wells issued at an elevation of about 500 feet above Ordnance datum, and were situated within one mile of the outcrop of the stone bed of the Chalk formation. Now, considering the height at which these springs issued, the great depth of saturated Chalk below their gathering area, and the draught upon this Chalk, in common with that which supplied the Misburn stream and the Lower Tertiary beds to the level of 90 feet below Ordnance datum, it was obvious that the water yielded by these wells at Wendover was but a portion of the rain which percolated into the chalk surface of their gathering-ground. The information was valuable as a reliable record of the average discharge of a portion of the rain which had percolated into a well-defined Chalk area, and as a refutation of the opinions expressed by Dr. Evans and Mr. Hopkinson; but it could not be accepted as affording sufficient data for estimating the total average percolation of rain into the Chalk. The experiments recorded so carefully, over a period of twenty years, by Sir John Lawes and Dr. Gilbert, although on a small area, were extremely valuable and gave the following results: "According to the average of twenty years with rather heavy soil, free from vegetation, it might be said that the drain gauges gave about 14 inches." It will be observed that the experiments were made, not through Chalk, but through a "rather heavy soil"; but Sir John Lawes and Dr. Gilbert considered that an allowance should be made for vegetation, and they said, "Taking the average of a large area around London, partly covered with vegetation and partly bare, over a number of seasons, they thought that between 3 and 4 inches should be deducted from the 14 inches of percolation, so leaving 10 or 11 inches." It was not by any means proved that this deduction of 3 or 4 inches for vegetation should be made. Unquestionably vegetation was never so thriving as when the atmosphere was warm and humid, and that green crops grew most luxuriantly when their leaves were thoroughly wetted with dew in warm weather. As Jethro Tull said more than a century ago, "Dews are the richest present that the atmosphere gives to the

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earth." The dew was not measured by Sir John Lawes and Dr. Gilbert's percolation gauges. That the atmosphere supplied directly to the leaves a large quantity of the water which they absorbed appeared to be proved by the "grain of wheat" mentioned by Dr. J. Evans, which "could absorb if it were given to it more than the total amount of rain that fell," and by the oak tree referred to by Mr. Hopkinson, which evaporated during the whole period of its summer growth, "more than eight times the amount of rain falling upon the area covered by the tree." The following paragraph appeared in *The Globe* on the 23rd of March, 1891:—"At a meeting of the Royal Botanic Society it was reported that a poplar, which had been blown down in the gardens, had apparently derived nourishment, not from the soil, but from the decaying portions of itself." It was not improbable that this poplar derived its food, and the water which conveyed it, from the atmosphere for some time before it fell. In an interesting paper read on the 7th November, 1878, before the Linnean Society, "On the Absorption of Rain and Dew by the green parts of Plants," Professor Henslow said, "The conclusion I have arrived at is that, while there is no objection that I know of which cannot be met, there are ample reasons for believing that dew and rain are, under certain circumstances, absorbed and utilized to supplement the normal root-supply." Mr. Reeves, who had recently published a book entitled "Sap; does it Rise from the Roots?" went a step further, and contended that the leaves of trees took in the water which descended to the roots. Mr. Harrison was of opinion that neither the discharge from the Wendover wells, nor the percolation through Sir John Lawes' "rather heavy soil," gave the total average percolation into the Chalk formation, and that it was necessary to examine the discharge from the Wandle area, and some other area similarly circumstanced, if such could be found, in order to arrive at an accurate result. In reply to Mr. Santo Crimp's contention that the Author had under-estimated the drainage area of, and had over-estimated the volume of water discharged by, the Wandle, Mr. Harrison called attention to *Fig. 1*, which was based on the water contours marked on Mr. Lucas's map. According to this map the area was 53 square miles; Mr. Lucas estimated it at $54\frac{1}{2}$ square miles, and as the Author, following Mr. Homersham, put it at 56 square miles, he over-estimated rather than under-estimated it. Mr. Crimp had given 26·82 million gallons per day as the average volume of water, from the chalk area, which passed Merton, according to his gaugings extending over three years, 1879 to 1881 inclusive; this quantity he reduced to

Mr. Harrison. 23,000,000 gallons per day, because the rainfall was so great during that period. Accepting this as the accurate result of the gaugings, it did not appear that Mr. Crimp made any allowance for certain leakages into the Lower Tertiary beds above Merton, which were thus described by Mr. Baldwin Latham, "He started a number of gauges at different points down the river, and he ascertained that in a short distance down the Wandle at times probably not less than 10,000,000 gallons of water daily flowed out by those subterranean passages into the Woolwich and Reading beds, supplying the overflowing wells in the neighbourhood of Tooting and Wandsworth, and to a large extent supplying some of the wells under London."[1] When allowance was made for this leakage, the average daily discharge from the chalk area of the Wandle, according to Mr. Crimp's own figures, was 33,000,000 gallons per day, or 3,000,000 in excess of, instead of less, than that adopted in the Paper; 33,000,000 gallons per day from 53 square miles was equal to 15½ inches of the rainfall, or 2 inches more than was given in the Paper. Mr. Whitaker had objected, and no doubt on sufficient grounds, to the area of the Chalk above London being taken at 1,200 square miles, as measured by the maps issued by the Geological Survey Department; and stated that the Chalk was largely covered over with deposits of a more or less clayey nature, through some of which the water percolated, while it was thrown off others on to the Chalk, so that the area should be reduced by about over one-fourth, or to 900 square miles. Accepting this modification, the Colne and Lea area must be taken to be 430 square miles, instead of 570 as estimated in the Paper; and supposing it to absorb on an average 15½ inches of the annual rainfall, it would still yield 266,000,000 gallons a day, without making any allowance for the water falling on the remaining 60 square miles; this quantity, after deducting the volume carried off by the Colne and the Lea, would afford an ample supply for London. The contention of the Author was that the gaugings of the Thames at Kingston and Kew justified the suggestion made in the Paper, that a larger quantity of water entered the Thames below Teddington, from the adjoining gravel-bed, than was sufficient for the London supply; that the quantity which percolated into the gathering-grounds of the Colne and Lea with their tributaries, after making allowance for that carried off by those rivers, was abundant, and could only escape through the Lower Tertiary beds and the Slough gravel to the Thames below

[1] Minutes of Proceedings Inst. C.E., vol. xc. p. 60.

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Teddington Weir. Also that the discharge of this surplus water was so regulated, by its collection in and its passage through the Tertiary beds, as evidenced by the constant head maintained at Bushy Mead, and by its passage through the extensive gravel-bed in the Thames Valley, that it was as nearly as possible constant, and would probably remain so, even if there were no rainfall at all for several years. The Author contended also that this water might be collected for the supply of London, without interfering in any way with the condition of the rivers Colne and Lea, or of the Thames above Teddington Weir. In reply to Mr. Grantham, Mr. Harrison remarked that proper precautions would of course be taken to avoid pollution. Professor Robinson's observations, on his report to the Local Government Board in 1884, affected only the method of collecting the water, and did not touch the question of the existence of the large volume of water in the Windsor gravel-bed, or of the source whence the water was derived.

Correspondence.

Prof. Boyd Dawkins.

Prof. Boyd Dawkins pointed out that it was a fallacy to assume with the Author that the whole of the water in the Chalk was available for economic purposes, because, among other reasons, it was impossible to get at a large proportion of it, which was locked up in the capillary pores of the chalk. The practically available water was in the fissures, and they were so few in the Lower Chalk that about 250 feet of its total thickness might be looked upon as unproductive. It must also be observed that the water-partings at the surface did not always mark the lines of subterranean water-partings in the rocks. In the Croydon district, for example, in which the area of catchment of surface waters was $54\frac{1}{4}$ square miles (according to Professor Dawkins's calculation), an addition was made to the subterranean waters falling into the Wandle by the drainage of the Sanderstead district on the eastern side of the water-parting at the surface. The calculation, therefore, by the Author of the amount of percolation into the Chalk within the water-shed of the Wandle, based on the gaugings of that river, without taking into account this additional area, required modification. The Author also quoted the well at Banstead as a case in which the water-level varied between the driest and the wettest seasons no more than 5 feet. If the figure 260 feet above Ordnance datum given in the Paper was accurate, the fluctuation was considerably more than that amount, since in