Discussion.

Mr. Woods. Mr. E. Woods, President, said it was a matter of great advantage that the Papers had been grouped together, dealing as they did with the same subject, and which had occupied the attention of engineers for the last thirty or forty years or more. One of the first occasions on which it had been brought prominently under his notice was the work of Mr. George Berkley, who carried out the investigations in connection with the Liverpool Waterworks, upon which Mr. Robert Stephenson reported. There were so many persons interested in the water-supply of London, and the surrounding districts, that he was sure an important discussion upon the Papers which had been read might be anticipated.

Mr. Grover. Mr. J. W. Grover said he thought the diagrams (Figs. 5, 6 and 7, pp. 12, 16 and 19) had not been sufficiently explained. In each case the lines generally represented pumping at a uniform rate. That, of course, was necessary to obtain a line which represented the actual power or force of the spring. In the case of Rickmansworth (Fig. 7), at the lower half, the line coming down showed an increase in the rate of pumping. The pumping was generally carried on at the rate of 15,000 gallons, and then it increased to over 21,000 gallons an hour. The diagram showed the value of increasing the depth and the size of the bore-hole. At Wokingham, the spring continued to fall for a number of hours: in ten hours it had fallen 42 feet, then, on ceasing to pump, it rose for many hours, but not to its original level. That showed that the water had great difficulty in reaching the bore-hole, due to the fact that it had to travel a great distance underground. The water was coming on as fast as it could, but it could not get through in consequence of the enormous pressure of the Tertiary beds overhead. The thing to be sought for in chalk wells was the presence of flints. Wherever there were flints in abundance there was water in abundance, and where there were no flints there was little water. He had often had the idea that the water itself tended to create the flint in chalk, but how far that theory was to be supported by chemists and geologists he did not know. What happened was this:—In flint beds in the Chalk there was a quantity of sand; and on pumping, that sand gradually worked out, the water dissolving the Chalk and leaving spaces between the flints, through which it could readily travel. In the case of the Leatherhead well, at the bottom there was a continuous bed of flints, hence a vast underground reservoir of water. It was

Nature's wonderful provision that there should be this subterranean volume of water, kept at a uniform temperature all the year round, ready for the requirements of man. The same remark applied to Rickmansworth, where there was also a mass of flints. He looked upon these two sources as being those from which a vast volume of water could hereafter be obtained. With reference to the well of the Colne Valley Waterworks at Bushey, it was remarkable that so few flints should have been struck. It was stated that there was a depth of over 500 feet through the Chalk where there were no flints, and that there was a great quantity of clay in the fissures. This would show that at that particular spot, there being an absence of flints and clay being present, there would not be so large a volume of water as in chalk where there were many flints and a small quantity of clay. The object of his Paper was to point out where to sink wells. There was a narrow band of something like 300 miles in extent round the Metropolis to which his remarks would apply. That was the outcrop of the Chalk, and it had been utilized enormously by the Kent Waterworks Company, who had succeeded in obtaining all the water that could reasonably be expected in the South Eastern district. It certainly did astonish him that what the Kent Waterworks Company had accomplished so successfully in that county, should not have been done on the south-west and north-west sides of London. Mr. Grover.

Mr. W. Fox said that in the Colne Valley boring, at from 300 to 350 feet below Ordnance datum, or 500 feet from the surface, the chalk, above which was blue clay, was very soft, and in that soft chalk, although there were no flints, and had been no flints for about 300 feet, the greater part of the water was obtained. It would be observed that the supply increased from 288,000 gallons a day at 70 feet above Ordnance datum, to 318,000 gallons a day at 80 feet below Ordnance datum. Then again at from 300 to 320 feet below Ordnance datum the supply increased to 635,000 gallons a day. He quite agreed with Mr. Grover, that to find water to that extent there, was contrary to anticipation; but so it was, and there was an absence of flints. Mr. Fox.

Mr. William Matthews pointed out that the Geological Survey had brought to light certain facts in the neighbourhood of Southampton which pointed conclusively to the reason why the old well failed. It was possibly not generally known that this well, although sunk to such an enormous depth, never gave more than about 130,000 gallons a day; while the Southampton authorities, sinking to a very shallow depth, got a very large supply; but there was Mr. Matthews.

Mr. Matthews. an upheaval in the Chalk, the extension of which eastward would be recognized by many people at Portsdown Hill, near Portsmouth; that upheaval extended to the neighbourhood of Southampton, and had a retarding effect upon the water in the Chalk, added to which there was a depth of about 500 feet of London Clay and Bagshot beds, the pressure of which, no doubt, acting on the Chalk, had the effect of closing up the fissures and retarding the percolation of water. This bore out what Mr. Grover had said as to the necessity, to a supply of water from the Chalk, of sinking somewhere at or near the outcrop, and not going where there was a heavy superimposed bed.

Sir Robert Rawlinson. Sir ROBERT RAWLINSON, C.B., said Mr. Grover did not seem to know what was the origin of flints in chalk. They were, however, generally connected with animal matter, round which silica had aggregated, and when some flints were cut through and polished they gave very beautiful specimens of the skeleton structure of animal life of a spongy and coralline nature. The reason why water was found where there was an abundance of flints was simply that the flints gave a loose character to the chalk which was crystallized or hardened about them, leaving cavities which the water penetrated from the surface, and widened in course of time, by these means affording facilities for the storing of water. They had, however, nothing whatever to do with being a cause of the water. He remembered that in the chalk districts about Dorchester, some of the farmers and many of the agricultural labourers believed that flints grew like potatoes, because although they might take tons of flints from the surface of their chalk-fields, they never found them any less after storms of rain. With regard to the Hinckley well, he was only astonished that it had ever been sunk. It was his fate to have had a bore-hole put down there some years ago, and the characteristics of the boring were such that he was surprised it should have been repeated, as the stratification which occupied that area, contained at intervals thin beds of gypsum and rock-salt, which were utterly unfit to produce water suitable for domestic purposes. Many persons at that moment, members of local boards and of town councils, were spending money and sinking in districts of a similar character, where it was known that for from 300 to 500 feet in depth the stratification was clay, interspersed with thin beds of gypsum and salt. They had consulted young members of the Geological Survey, and he was told that some of them had said, "Oh yes, go on; it is a very interesting experiment; you will reach the Bunter Sandstone when you get down 500 or 600 feet, and the probability is you will get

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an abundance of good water from that sandstone." The advice was, however, as fallacious as it could possibly be, as there was no fresh water in the substrata that did not come from the surface. If, therefore, there were intervening beds, extending 500 or 600 feet, impervious to wholesome water, it was very risky to attempt to get it by a bore-hole going down through such strata. He, however, knew that in several instances large sums of money had been thrown away by persistent sinking in that character of stratification. At Rugby, for instance, the authorities persistently went on sinking and boring, getting no water that could be used. At last brine was encountered some 1,300 feet below the surface, and so, having thrown all their money away, they gave over. He was afraid that that must be the end of some other borings now in progress. He was certain that water fit for domestic uses would not be found in the Hinckley boring. Taking the neighbourhood of Watford and districts of a similar character north, south and west of London, the great mass of the water to be obtained by well-sinking would probably be found within 100 feet of the surface. He had sunk a well at Worthing. At 100 feet there was an abundance of water, but he was not content with that depth, and sunk the bore-hole down 400 feet. He was, however, now satisfied that he got nothing worth the cost from that extra 300-foot bore-hole. He subsequently found that out, and then told the Worthing people that if they ever wished for more water they must sink a supplementary well at a distance from the existing well to a depth of 80 or 100 feet, and then drive headings betwixt the two wells, and they would get water in abundance without expending any more money in deep boring. There was one characteristic of the London Basin which must not be forgotten, namely, that the stratification under London and along the valley of the Thames was known to be what the geologists termed "unconformable;" and that sinking in the valley of the Thames to obtain water from the Greensand would be useless, as it was not there. Well-sinking was a very old operation, and had been carried on extensively from very remote periods. It had been even said that scientific well-boring had been carried on from time immemorial in China. In England it was comparatively new. Well-sinking, to be successful, implied some knowledge of geology, and also a hypothetical knowledge of the probable flow of underground water. With regard to geological strata, the known range of stratifications was supposed to be about 52,000 feet. That was, if all the known strata of the earth in their greatest known thickness could be placed one upon the other, the total depth would extend to about

Sir Robert Rawlinson. 52,000 feet. But he need not state that they were never found in that position in any portion of the earth's crust, as from the earliest period the processes now witnessed of deposit, denudation, re-deposit, upheaval, and depression, had apparently been going on continuously, in a mode not very different from that which was at present observed. In the enormous range of stratification to which he had referred, there were vast portions in which it would be useless to sink, and in which no geologist would sink, to find water. But what he desired to urge was that even in the essentially water-bearing strata, such as the sandstones, the limestones, the sands, and the chalk, there were dry areas and limits in depth beyond which it was useless to sink in the attempt to find water. Within his own knowledge, many thousands of pounds had been expended because persons believed that if they went deep enough they would get as much water as they required, and there had been many failures in consequence. He did not know that there were any reliable records of the deepest wells, or deepest shafts, sunk in modern times. The deepest shaft that he knew of was for a coal-mine in Lancashire, said to be 2,700 feet deep, having, however, no water at the depth. The Monkwearmouth shaft, near Sunderland, one of the first and deepest shafts for coal-sinking, was 1,800 feet in depth; he had been down it, and had seen the headings of the workings. The temperature at the bottom, all the year round, was about 81°. What the temperature was at 2,700 feet deep he did not know, but it was stated that the temperature increased 1° Fahrenheit for about every 50 feet in depth. If that law prevailed, there was a speedy limit to boring; but there was also this further limit, namely that there was no material that would bear the strain of so great a depth, say as 7,000 feet and upwards, because 1-inch square iron rod for that length would weigh about 11 tons, and he knew of no metal that would be capable of bearing the strain of friction and of concussion in boring to greater depths. But again, sinking and boring were two distinct things. In the celebrated well at Grenelle, which was a boring into the Greensand, through the strata of the Paris Basin, water came up with great force, and rose to a considerable height above the surface of the ground, and in contra-distinction to some of the surmises that had been made in one of the Papers, that superincumbent pressure retarded the flow of water, that was not found to be the case at Grenelle as the intervening strata did not prevent the water getting there, and lodging there, because there was a pressure of 1,800 feet upon the Greensand, and yet the water came up with great force, and at a

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temperature of 81°. In this country—in the Thames Valley, for instance—there had been many failures in trying to obtain water in volume from deep wells, as in the well at Meux's Brewery, in the well recently sunk at Richmond, and at some others sunk by the New River Company, and in some borings made by the Metropolitan Board lower down the Thames, water in volume was not obtainable. The strata in the London Basin, and along the valley of the Thames, below the Chalk, were unconformable by the absence of strata, to the extent of many thousand feet in depth. Some geologists had stated that the rock reached after passing through the Chalk, and through a mere trace or modicum of Greensand, was the New Red Sandstone, while others said it was the Devonian. In either case there was below London an absence of strata to an enormous extent, and therefore deep-sinking for water in the valley of the Thames, anywhere above or below London, would be to throw money away. Then there were other parts of England—in the valley of the Severn, for instance—where there was a superincumbent stratum of 400 or 500 feet of clay and marls, interspersed with the beds of gypsum and rock-salt, borings had been made and wells sunk in the hope of getting potable water, but the effort had been a failure. The third Paper dealt with a stratification of that kind; and how the promoters of the well came to venture upon that sinking, when they knew, or might have known, what the stratum would turn out, passed his comprehension. At the celebrated breweries at Burton, water was wanted that was hard, and the water that best suited the purpose was obtained by a repetition of wells sunk not more than 35 or 40 feet in depth, to avoid the thin beds of salt found at greater depths. It might be taken for granted that large communities had never been permanently supplied by wells. Ancient Rome was contented with water from wells; but during the Empire was supplied with a volume of water, according to some historians, equal to the dry-weather flow of the Thames at Teddington, namely, about 300,000,000 gallons a day, by twenty aqueducts. New York was first supplied with wells, but now enormous works were being matured to bring in larger volumes of water. Liverpool and Manchester were first supplied by wells, which, in 1846, he proposed to supplement, by bringing in pure water from the Clay-slate district of the River Dee, in North Wales, where, by a new river-conduit, he proposed to supply 60,000,000 gallons per day; but he was told his ideas were far too grand, and so the abortive works of both towns were established which had failed; and at large cost the River

Sir Robert Rawlinson. Severn was to supply Liverpool, and the Cumberland lakes Manchester, and works were now being carried out in both districts. There had been strong objections to the Metropolitan rivers supply, and proposals had been made to go to the Welsh or the Cumberland lakes. He did not, however, advocate that method for London, and for several reasons. The Thames water was to be repudiated, because it was taken from an open river, and had what was termed an excessive hardness—about 16°, but returns showed that in soft-water districts, where the water was at or below 3° or 4° of hardness, the average mortality was higher than amongst a similar population using water up to 16° or 18° of hardness. Unquestionably it was a great luxury to wash in soft water; but it was injurious to some constitutions. He found that the complaint was as old as the time of Sir John Pringle, in 1745, when the British army in the Highlands became disorganized with diarrhœa and cramps in the stomach, brought on by drinking the lake- and river-waters. It was true that the water did not affect the natives, because they were accustomed to it, but it certainly did for a time seriously affect strangers. Another objection to soft water was that being comparatively pure, it was a powerful solvent, so that, if it was taken into districts and carelessly stored and permitted to come into contact with injurious matters, it combined with them, and when supplied from cisterns of lead or drawn through pipes of that metal, there might be lead-poisoning. Water like that from the Thames with 16° of bicarbonate of lime, did not so readily combine with matters that might be injurious; it certainly did not with lead. He therefore did not approve of changing the Thames supply for a lake supply; but he did advocate the preservation and purity of the rivers Thames and Lee to the uttermost. In deep sinking for mines, like coal mines, there was generally abundance of water between 300 and 600 feet in depth, which had to be tubbed out; but below 900 or 1,000 feet the mines were mostly dry, and for the purpose of working the coal it became necessary to tap the tubbing, and lay pipes to convey water down to water the roads. That showed that in sinking in the Coal Measures, New Red Sandstone, or any similar stratification, water ought not to be expected at depths much below 600 or 700 feet.

Mr. Lucas. Mr. JOSEPH LUCAS observed that in 1885 the Local Board of Alnwick decided to bore in search of water, and when the matter was first brought under his notice the problem suggested was to find a source of spring-water which could be brought into the Local Board's existing mains without the aid of pumping. The supply for Alnwick was taken from a series of springs in the Drift which abounded on the hills in the neighbourhood, and also from Rugley burn at a point $2\frac{1}{2}$ miles south-west of Alnwick. The original notion failed, because the point at which the Local Board proposed to bore proved to be such that even if water had been struck it would not have risen to a sufficient height to serve the main. Another site, after a proper survey, was chosen, and it was estimated that the result of the boring put down at the very point of the intake would be that the water would rise above the surface. The boring was made and carried out in a series of strata which were feebly represented in the south of England. The series was totally different from any of those with which the Authors of the four Papers had to deal. It was a northern development of the lowest part of the Carboniferous rocks, which part of the Carboniferous rocks was only represented by a very thin stratum in the west of England, but became developed in Northumberland and afterwards formed the Scotch coal-field, and had an immense range across into Russia, through the Baltic, all over the east of Europe, forming the coal-fields in that district, the Carboniferous rocks of England being entirely absent. It was through those strata that this boring was carried. The series resembled the rocks in the Millstone Grit in being a succession of sandstones and shales, and thin beds of limestone which marked the disappearance of the Mountain Limestone as it was known farther south. The first spring struck rose to the expected height of 5 feet above ground.[1] That spring was struck at 60 feet, below which there was a succession of beds and a succession of springs, each spring rising to a greater height than those which had been met with before; each as it came to the surface was separately gauged, and what he called the "standage," or height to which the water rose above the ground, was specially measured on every occasion, by putting on a 2-inch pipe to the bore-pipe so as to ascertain the height at which the water came to rest. The last spring rose 32 feet above the ground. There was nothing very remarkable about the boring except that the district, as far as regarded the overflowing boring, was entirely a virgin one. The basin-shaped arrangement of rocks, usually considered essential to an artesian boring, was absent, the dip being steadily to the south-east, the beds pierced rising to their outcrop successively higher and higher up the burn. One remarkable point was the hardness of the bed Mr. Lucas.

[1] A copy of Mr. Lucas's Original Report, printed by the Alnwick Local Board, is in the Library of the Inst. C.E.

Mr. Lucas. of limestone known locally as the Hobberlaw Limestone. This limestone was entered on the 21st of October, but was not bottomed till the 31st of December, 1885. It was considered good boring to pierce 3 inches a day, and it took nine weeks to get through it. Another point to which he desired to draw attention was the possibility of treating the heads which were actually observed, and the discharges actually found, by the usual formulas. He was not an engineer, and was not in the habit of making such calculations every day; but finding that the springs continued to give an increased discharge and an increased head, he endeavoured to find out for his own satisfaction whether by working some of those formulas the results would come out at all approximately. The observed discharge in the case of the first spring was 11 gallons a minute, and by the formulas the theoretical quantity would be 11·6, which was certainly very close. In the case of the second spring the observed discharge was 11½ gallons a minute, and the theoretical quantity 12·1, which was again not very far off. The fourth spring gave an observed discharge of 17½ gallons, and the theoretical quantity was 18½. It might be familiar to engineers, but it was new to him, that formulas for the flow of water in pipes could be at all successfully or approximately applied to water rising up bore-pipes, but these results went far to prove that they could be. What the Alnwick boring proved practically was this: There were many places along the Pennine chain, which consisted of alternations of grits and shales, that were capable of being treated in exactly the same way. At many points the water would rise above the ground on the slopes of the Pennine chain, and although 80 gallons a minute might be a very small quantity for a large town, there were many small places where it would be a sufficient quantity. Having studied these things for many years, he had never found a satisfactory explanation of the fact that, when a boring was made, the supply of water was always very much greater at first than it was permanently. At Alnwick the boring gave 80 gallons a minute at first, and continued to do so for some few weeks, but after that it settled down to 60, at which it stood for a few months, and for the last five months it had been yielding 40 gallons a minute. The burn which was replaced by the boring was dry in some years, and in August 1875 was flowing at the rate of only 9 gallons per minute.

Dr. Evans. Dr. JOHN EVANS said it was rather more than two years ago that he had an opportunity of delivering a lecture before the Institution, which was the first of a course on "The Theory and

Practice of Hydro-mechanics,"[1] and he was in hopes that the seeds he had then sown would have taken root in the minds of the members and borne fruit; but he was very much disappointed, in looking at the first Paper, to find that the Author had not profited by the instruction he had then attempted to give. There were two or three points in the Paper upon which he desired to make a few remarks. He would first direct attention to a rather remarkable geological diagram (Fig. 2, p. 4) which showed a fault coinciding with the line of the river in the Chalk. It used to be a rather commonly accepted idea that most rivers owed their position to such faults; but he believed that more recent experience had shown that the faults were rather those of observation than those existing in nature. Though it was possible that in one case in fifty the line of a river might coincide with a fault, as a rule the existence of rivers ought not, by any means, to be associated with the existence of faults under ground. That, however, was a comparatively trifling matter as compared with the other details to which he wished to call attention. The Author had stated (p. 4), "It is often said that wells sunk in the Chalk have the effect of abstracting water from the rivers; this is true where the district is all chalk, but it is not true when the well is sunk through clay, and only partially true where the wells are sunk at the junction of the Chalk and the clay. For example, the water flowing along the fissures G (Fig. 3), being near the surface, breaks out at the junction of, and owing to the pressure of, the clay, at H, and flows as a river over the impervious clay, and this water when abstracted by a boring no longer reaches the river. The water, however, traversing a lower bed of flints, J, never finds its way into the river, but passes under the clay to the sea. Hence, when this water is intercepted by a boring at K, it comes to the surface at H, and is so much gained at that point." With regard to the first assumption he quite agreed with the Author. With regard to the second he confessed he could not see in what manner the water that was partially covered with clay could be distinguished from water in a purely chalk country. So far as his experience went the whole of the water that was not carried away by vegetation, or evaporation, or, in the case of districts nearer the sea-shore by springs arising along the shore, must find its way into those natural overflows, the rivers. But it was said that by sinking down deep enough in the Chalk, instead of the water being abstracted Dr. Evans.

[1] The Inst. C.E. Lectures on "The Theory and Practice of Hydro-mechanics," Session 1884–85. "Physiography." By John Evans.

Dr. Evans. from that which would find its way to the surface, it would be abstracted from some which would find its way by a mysterious channel into the sea, and which was totally disconnected from the water above. He had had some experience in the Chalk, and he had never known any instances in the Upper or the Middle Chalk in which there was not an absolutely complete junction, as it were, between the water at the top, and the water at the bottom, by means of fissures. In point of fact, it was much the same as filling a cistern with bits of stone, and saying, "If you pump from the upper surface, you take water out of the cistern, but if you pump from the bottom of the cistern, you do not affect the level of the water in it." He thought that on experiment it would be found that the water in the cistern would be lowered whether the pumping was from the top or from the bottom. And further, assuming, for a moment, that there was such a thing as an underground current of water to the sea, he was at a loss to understand how pumping from that would in any way prevent the abstraction of water from the streams; because, if the water was pumped from that channel, the channel was connected with the land above, and any water taken out by pumping would be replaced by water coming from the higher ground before it was carried on its way to the sea. But the idea of water going on its way to the sea, especially from a place like Rickmansworth, was totally devoid of any probability whatever. Mr. Grover had justly pointed out that in the beds under the heavy London Clay, the Chalk was more compact and less fissured, and there was, therefore, a difficult passage through it, and the wells which had been sunk under London did not give that very large amount of water which, at first, might have been expected to be received. But if the water could not find its way through the Chalk under the London Clay to the sea, he did not quite understand how the underground currents that were supposed to exist could have any existence, at all events at Rickmansworth. It should be borne in mind that the Thames was tidal considerably above London, and that inasmuch as water, at a high level, would naturally seek its lowest vent and its nearest vent, it would rather flow into the Thames than it would flow into the sea. But it was known further, by a series of experiments, and, indeed, by nature, that the angle of friction in the Chalk was certainly hardly less than 12 feet 6 inches to the mile, and occasionally in the Upper Chalk, in the Chalk in the neighbourhood of Dover, for instance, it was as much as 20, and even 40, feet to the mile. That was proved in this manner: If the angle of friction was less than 12 feet 6 inches to

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the mile, the rivers, the inclination of which was as a rule at that gradient, would disappear; the water would have a more ready way of finding its road to the sea, by some low-level channel underground, than it would by flowing above-ground. There was, no doubt, a certain small amount of drifting water tending downwards, in the same direction as the streams, which in all probability was delivered at the springs at a somewhat lower level than the river at the particular point at which the water was found drifting; but the supposition of the Author, that the water of the valley which flowed away underground greatly exceeded the volume of the river, appeared to him to be absolutely and utterly unfounded. The Author stated that this was readily seen by computing in any valley the volume of water flowing in the river, and comparing it with the amount of water due to the catchment area and the rainfall. All such things as the loss by vegetation and evaporation, from the surface of the ground, were there left out of the account. He agreed that it could not be expected to find the same amount of water flowing in a river in the chalk as fell on its catchment area, and he had pointed out that, as a matter of permanence, hardly more than 4 or 5 inches, even from 26 or 28 inches of rainfall, could be reckoned on. With reference to the question of the current of water underground, Mr. Grover had stated that the water came up like cream. Did that look like water flowing at a very great rate underground? He remembered the late Mr. Homersham saying that in tapping some deep wells he had tapped water which had been lying there since the Flood. The motion of those underground waters was extremely slow, and could not be taken into account. If there was leakage, any amount of pumping from the cistern in which there was that leakage would not stop it; and it should be remembered, as he had pointed out in his lecture, that in the case of a chalk country the whole of the water abstracted by pumping was so much abstracted from the streams which would otherwise flow through the country. Of course the question would arise as to the water-supply, not only of the Metropolis, but of the towns around the Metropolis, and in every case where there was chalk, and where the people had the good fortune to retain the services of an accomplished engineer like Mr. Grover, they might get an admirable supply of chalk-water for the towns and villages. That water, after being used, was returned to the rivers, and practically the rivers did not suffer. But if London were to obtain the whole of its supply from the wells sunk around London in the Chalk, taking

Dr. Evans. Mr. Grover's figures of 160,000 gallons daily as the produce of 4 inches of rain on a square mile of country, London would require, instead of that, 160,000,000 gallons; and the whole of the water of the streams on 1,000 square miles of country—an area considerably larger than a great many English counties—would be consumed for drinking-water, and for other purposes, in the Metropolis. But he was wrong in speaking of it as drinking-water. There was not the slightest necessity for any such large supply of drinking-water being brought into London. There was, for ordinary purposes, any amount of water, in the shape of Thames water. At present there was brought into London more than enough spring-water to supply all the necessities of the Metropolis; and if he were to make a suggestion to The Institution of Civil Engineers, it would be—why not try whether some system of double service could not be adopted, rather than attempt to rob the whole neighbourhood around London of its natural water-supply, and be at an enormous expense to bring pure water into the Metropolis, to flush the sewers and water the roads?

Mr. Whitaker. Mr. W. WHITAKER said that as a geologist he was occasionally troubled with some of the geology that he heard from engineers, but it was excusable if they were not quite up to the latest developments. In Mr. Grover's Paper the Chalk was said to be a mass "thinning off at the edges." Unfortunately the term "thinning off" was a technical geological term. Taking the whole formation from top to bottom, having the whole of the Chalk, as it were, in hand, it could be said whether it thinned off or did not. As a matter of fact, the Chalk in the London Basin did not thin off at the edges but thinned slightly towards the centre. Perhaps what was meant was that at the edges of the London district the upper beds of the Chalk were much planed off by denudation, which was quite another thing. Mr. Grover further stated that the Chalk was covered by London Clay. Mr. Whitaker had seen as many sections of junctions of Chalk and Tertiary beds as most people, but he had never seen, and he ventured to think he never would see, the Chalk covered by London Clay. The two formations never came together. There was always some intermediate set of beds. Probably Mr. Grover meant covered by London Clay and other Tertiary beds; but it made a difference, because some of those beds were occasionally water-bearing. He had also said that, "the London Clay attains its maximum thickness near Bagshot." It was, however, thicker near Westminster; it thickened eastward from Bagshot. The Author's remark about the risk of getting large supplies of water from chalk under dense masses

Mr. Whitaker.

of Tertiary beds was certainly correct, and engineers generally avoided sinking through great depths to chalk; at the same time there were cases of large supplies being got in Chalk beneath Tertiary beds. It was a matter on which all were now pretty well agreed, but it was necessary to enforce it, because it was occasionally disregarded. The question was, what was the reason for the stopping of the flow of water in chalk covered by Tertiary beds? It might be the pressure of the superincumbent Tertiaries; it was difficult to see any other explanation at first; and yet, if it was a question of weight, there were cases where a good deal of water was got out of chalk at considerable depths, where it was covered by a great thickness of chalk only, and the Chalk was as heavy as the clay. Possibly some other things besides mere weight ought to be considered. He was rather troubled with the particular case given by Mr. Grover, to which Dr. Evans had alluded: "Where chalk-beds are inclined across a valley, it is important to sink on the upper side of the valley." Reference was made to Fig. 2, p. 4, but that was only a particular case. Having a tolerably minute acquaintance with the areas referred to by Mr. Grover, he thought that no such section was at all likely to occur in any part of the district; he would not of course say it was impossible. Mr. Grover had a natural partiality for the Colne Valley, but Mr. Whitaker could not agree that the Colne Valley was the only possible source of supplemental supply to London north of the Thames. Westward of that valley there was a considerable area of chalk, which was perhaps less touched, as regarded water-supply, than that of the Colne Valley, and might be taken into account. There might also be other areas on the north-east. He agreed with Dr. Evans as to the question of two sources of supply in the Chalk, deep down and high up. There might be exceptional cases where that occurred, where there was in the midst of the Chalk a more or less impermeable bed; so that independent supplies might be got from higher beds and from lower beds. But those cases were rare, and did not affect the general issue.

Turning to the part of the Paper which referred to the Newbury District Waterworks, he could not agree with Mr. Grover that the hills on both sides of Newbury were Upper Chalk. The hills on one side were nearly all Tertiary beds, and there was hardly a particle of bare chalk on the southern side; even on the northern side the Chalk was very largely capped by Tertiary beds. Below Newbury there was no chalk at the surface for some distance; it was wholly covered. The area available as catchment in that part was estimated at 120 square miles: that was assuming

Mr. Whitaker. that the Chalk over that area was bare, at all events the chief part of it. A large part of it was, but there was another large part covered with a series of surface clays and loams, and it was clear that the water on those did not sink into the Chalk. It might flow partly over the edges of the clayey beds on to the Chalk; but that would still leave a considerable reduction in the available chalk area. It was a matter to be gone into with detailed geological maps showing the Drift, ordinary geological maps being almost valueless. The Author had stated that the depth of the well at Newbury was only 13 feet, but he did not say what that depth was through; he had however recorded, in the publications of the Newbury District Field Club, that it was simply peat and gravel, chalk being perhaps touched at the bottom. It was likely that in such a position any desired quantity of water could be obtained; and he thought that the communication with the river might be more direct than in the wells to which Dr. Evans had alluded, where by pumping the deep chalk-water the river at a distance might be affected. It seemed possible that, with a well sunk at no great distance, the river might to a certain extent be pumped: it would be filtered through the gravel bed. Mr. Grover thought that the water was chalk-water from its "clear blue tint and low temperature." Mr. Whitaker did not think that a blue tint was enough. He thought that, in most characteristics, the water of the River Kennet in that part would be much the same as chalk-water. It was chalk-water, only it came along the river. There was a great deal of calcareous tufa, and a large amount of decomposed shelly matter in the valley, so that the water would be highly calcareous. Not being content with his own experience of many years ago, he had asked the opinion of a colleague now in the district, whose statement he appended.[1] This quite agreed with

[1] The valley of the Kennet at Newbury does not entirely consist of the Upper Chalk with flints, which is hardly exposed at all there.

The deposits of the valley of the Kennet at Newbury consist of peat, malm and gravel to a depth of 15 feet or more. Mr. Bristow, in the Memoir on Sheet 12, mentions that a well sunk in Northbrook Street passed through 15 feet of peat with trunks of trees, and then the "malm" was met with, but does not say how thick this was, nor whether the gravel was touched, so that it would seem that the "malm" was not sunk through; this makes the valley deposits on this spot more than 15 feet.

These deposits, both on the north and south of the town, are surcharged with water, but especially to the north of the town; this water filters through from the Kennet except in those cases where wells are sunk in the valley-gravel mid-way between the Lambourn and the Kennet, where water would filter in from both.

This was probably the case in the water met with in making the foundations

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his own views. It appeared that in digging foundations there had been trouble in keeping the water down. That was in a continuous mass of gravel and peat. There was therefore plenty of water; but there might be some ground for anxiety as to the future regarding the quality. It would probably be satisfactory, but it was a case in which surface contamination was a thing to be guarded against.

With regard to the success of the Wokingham Waterworks, Mr. Grover was to be congratulated, because most of the deep wells in that district had not much water. The reason he had assigned for the wells not being successful—not excluding the fine running sand in the Tertiary beds immediately above the Chalk—might be correct, but he did not quite follow it. He thought that a powerful chalk-water spring would not be much affected by the infiltration through a few feet of sand above it. Success in such a case might be a matter of accident. Chalk-water was to a great extent found in fissures; and going down with a bore-hole a foot or so in diameter a fissure might or might not be cut; so that one boring might succeed, while four or five others failed. A much more detailed account of the beds passed through in the well had been given by Professor T. Rupert Jones.[1]

Again he had been perplexed by the statement as to the Leatherhead works, that, "A well was sunk about 500 yards east of the spring on the other side of a ridge in the Chalk, so as to obtain water chiefly from another catchment area, and from the valley of the Mole itself, which . . . . could not be its source of supply." The whole of the water there, on the one side of the river and on the other, was all in one catchment area, the basin of the Mole. Possibly Mr. Grover meant that the springs came from the left side of the Mole, whereas the well got its water from the right side. Then there was the statement that "this catchment

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for St. Mary's Church, in the London Road; extreme difficulty was experienced in keeping the water out, and constant steam-pumping, I am told, had to be resorted to for a considerable time to enable the work to proceed. The same thing occurred south of the Kennet, when building the London and County Bank and the Town Hall, both in the Market Place.

There is nothing, I think, to show that the water-supply of the waterworks well differs very much from that of the wells of the town, and the source is probably the same, viz., from the water-logged valley deposits.

The well is about ¼ mile from the River Kennet, and nearly on a level with it, so that much of the water must be river-water.

No statement is made showing that chalk was sunk into in the well.—F. J. Bennett, Geological Survey, Newbury, Berks.

[1] Geological Magazine. Decade II. vol. vii. p. 421.

Mr. Whitaker. area includes the whole basin of the Mole above Leatherhead, exceeding 100 square miles." But very little of all that had anything to do with the Chalk. By far the greater area was of beds below the Chalk. The Mole Basin was comparatively narrow in the Chalk, but south of the Chalk it spread out far and wide, the river having many branches. It was not therefore fair to put in that area exceeding 100 square miles as evidence of what could be got by the chalk-well at Leatherhead. And it was quite needless. To be able to draw on 20 square miles of chalk was more than enough for every purpose there. The Author had alluded to flints as water-bearing beds. The most remarkable case that he knew was in the Isle of Thanet. There was a continuous bed (water-bearing) some inches thick that went right through the island from north to south, and from east to west. In many cases wells were sunk to the bed, and water was obtained. That was a very remarkable case of a flint bed being a water-bearing bed; but he believed it was because it was a water-stopping bed, so that water could not easily get through it. That was an exceptional case. According to Mr. Grover's account the flint beds were continuous for a depth of 360 feet; but probably it was only meant that they were frequent. He doubted whether any flint beds in the country equalled the Isle of Thanet bed of which he had spoken. The Leatherhead Waterworks were very successful; they were made for a district that ought to have water, and he imagined that no harm was done to any one, the amount taken not being large. He was not clear whether the site was in the river-flat or a little above it. Mr. Grover was to be congratulated on the success of his works. It was not often that an engineer was able to describe four waterworks of a somewhat similar character, for all of which he had obtained as much water as was wanted, and of good quality.

With reference to the Paper by Mr. Fox on borings in the Chalk at Bushey, it appeared to him, from a geological point of view, that boring had been continued when it ought to have been stopped, and stopped when it ought to have gone on. He could not understand what object was to be attained by so deep a boring at that site, except as a question of experiment. As a matter of fact, the amount of water got out of it was not as large as was got out of the shallower, older work. The boring had gone, it was said, through the Upper Greensand into the Gault. As a geologist, however, he wanted to know what was meant by the terms "Greensand" and "Gault." In the present case the greensand was defined as a mixture of sand and clay; he doubted

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whether it was Upper Greensand. With regard to the Gault, if it was clay it was Gault, but if it was a chalky earth, drying white, it was open to doubt whether Gault had been reached.[1] At the same time the thickness of the beds pierced was very much what might be expected. Geologists would have predicted all that had been found without much trouble; but probably, as a matter of safety, they would have estimated the depth to the Gault a little greater. Nothing new had been ascertained, except that the Gault was a little nearer than had been expected. Having gone so far, and expended so much money on the well, it was a pity the boring had not been carried some 200 feet farther. Then, one of two results would have followed: either the Lower Greensand would have been reached, in which case some water would have been got out of it; or if not, it would then have been known what came next beneath the Gault in that district. If he had been a landholder in that neighbourhood, he should have been inclined to subscribe to sink the bore-hole a little deeper. He thought that water could be got there more easily than by a deep boring of that character. The extraordinary want of flints in the Chalk was rather peculiar.

With regard to the Paper by Mr. Stooke, he did not know the district alluded to in it. The Paper was an interesting example of a failure in getting good deep-seated water, and it was well that failures should be discussed, because there was a great deal to be learnt from them. He should have been glad to have more information as to the cause of the badness of the water. The Author simply stated that it came from the upper strata, without saying from which of them. He thought it was not a matter of surface-contamination, but that it was mineral matter from parts of the New Red Series, which might come in not only from above but from all round. The Author had stated that the town was going to get a supply from a well and heading in the "Water-stones" in another place; but the Water-stones were also touched in the well that failed, and he had not stated whether the other place was differently situated. Mr. Whitaker expected that it was, and that the Water-stones were not covered by higher beds of the New Red Sandstone. He hoped that the Author would explain the exact state of the case.

With reference to the last Paper, he would not find fault with

[1] From specimens, seen at the close of the meeting, it was clear that the Gault had been reached, as described, and that the Greensand was the green calcareous sandy bed that always marked the base of the Chalk Marl.—W. W.

Mr. Whitaker. the geology, which he thought was right, he having seen to it himself. He thought he might bring forward that case as an illustration of the right plan to be adopted in getting large supplies of water from such a formation as the Chalk; he meant supplies for such a town as Southampton, or a town half that size, that wanted not merely hundreds of thousands of gallons, but millions. There were several points to be considered. First of all, it was well to have the site as near as possible to the place; but that was governed by a great many other considerations. In Southampton the authorities tried it and spent £20,000 upon it, but they had now not much to show except a big stone, marking the site of a deep well, with an old boring-tool at the bottom. The fact was that at Southampton the Chalk was thickly covered with Tertiary beds, and, as Mr. Grover had said, that almost prohibited the site as one for large supplies; for a small supply it might do very well. It would be seen from Fig. 2, p. 89, that not only was the Chalk covered with Tertiary beds, but between it and the outcrop there was a roll or uprise of the beds. That roll did not favour the flow of water that way. The nearest available site to Southampton where the Chalk cropped out to the surface was selected. Another point was to get the site as low as possible. Some persons liked to get waterworks at the top of a hill. He would rather see them down in the lowest ground, because there was then less well to sink, and the pumps could be got at a lower level with greater ease. They had governed the site in the present case. It was not absolutely in the lowest ground; there was a river close by, and probably Mr. Grover would have gone close to the river, as others had proposed to do, but the authorities had avoided that. They did not wish to be told that they were taking water direct from the river; they wished to intercept it on its way to the river. That was the best thing to be done, and he thought it could be done. Then there were several minor considerations. The last, and the chief, point was to go where the water-level was lowest, paradoxical as it might appear. Of course, that meant going to a site to which the water naturally flowed, so that no one else could have a pull on the authorities from elsewhere. The site chosen, he believed, fulfilled that requirement as nearly as possible. In this case the town had consulted its own geologist and employed its own engineer to do its own work, and he thought it was a great credit to a young engineer, like Mr. Matthews, to have had the sole conduct of an important work of that character. It was creditable to the Corporation to have helped Mr. Matthews to carry out his scheme without cavil or delay. Mr. Matthews, how-

Mr. Whitaker. ever, had cleverly refuted himself in one point, the statement that the well on the Common had been finally abandoned. Since the Paper was written, the "final abandonment" had itself been abandoned, and by Mr. Matthews' own act, for he had suggested, and the suggestion was to be acted on, that a small engine worked by water-pressure should be put down the well, and what little water could be got from it, 100,000 or 150,000 gallons a day, should be pumped. That water could be used in the town for watering roads and flushing sewers, in common with other water at present so used. There was a sort of dual supply for the purpose. The reason for using this water was not because Mr. Matthews doubted the supply at Otterbourne, but because the pumping and softening of the water at Otterbourne was a matter of some cost, and instead of using that comparatively costly water for common purposes, he proposed to save 100,000 gallons at a small expense. Mr. Whitaker believed that the first outlay would be repaid in three years.

Mr. Latham. Mr. BALDWIN LATHAM said that Mr. Grover had begun his Paper by stating that 96,000,000 gallons of water were daily taken from the Thames, which was one-third of the minimum flow, in July 1885. He did not know how the Thames could materially suffer by having such a small amount of water abstracted from it by the London water companies, because at a very short distance below the points where it was abstracted the upland water entered the tidal portion of the river. By far the larger portion of the water in the Thames was tidal water, and 100,000,000 gallons a day was infinitesimal in quantity as compared with the whole tidal capacity of the river. So far as the upper part of the river was concerned, as long as there was sufficient water for navigation purposes—for lockage—nobody would suffer, and instead of one-third, even two-thirds of the upland water might be taken from the river without the slightest detriment. The period referred to was an exceptional one—it was a very hot month in a dry year. But what did this rate of abstraction amount to if continued throughout a whole year? A depth of $\frac{2}{3}$ inch off the whole upland drainage area, which was equivalent to about $\frac{1}{11}$ of the average flow of the Thames. As to Mr. Grover's statement that a well should be sunk at the line of junction between the Chalk and the overlying beds, in order to yield a large supply of water, in his experience no such general rule could be laid down. He knew of a well sunk exactly in that position, which furnished no water. It was in the valley of the Wandle, immediately below Croydon, at the Gasworks. It was sunk to a depth of 240 feet, and more than 100 feet below the

Mr. Latham. sea-level, passing through the Tertiary beds. The most singular thing about this well was that in passing through the Tertiary beds water was obtained, and when the Chalk was bored the water disappeared, the well becoming absolutely dry. After the well was sunk he was consulted by the Gas Company, and he recommended puddling up the bore-hole, which was done, and the well then yielded a small supply of water. A question arose as to what had become of the water which flowed into the bore-hole below the level of the sea, and below the level that any wells were pumped down to in the neighbourhood; it was a point which required investigation. Owing to faults in the Chalk, the whole of the water of the large area contributing to the Wandle was prevented from passing under London. In fact, none of the wells under London were really yielding chalk-water. If it were chalk-water, the analysis would show it; for if the water passed from chalk through chalk, and was taken out of chalk again, it could not deteriorate or change in quality. None of the water in the Wandle Valley, after leaving Croydon, and none of the water under London, could be said to be chalk-water. Where did it come from? It came principally out of the rivers which overflowed the outcrop of Tertiary beds. Some years ago, at Croydon, a surface-water drain was being made to bring some of the water into the Wandle, and a trench was being excavated below the bed of the stream. In looking at it, when the men had left off work at the end of the week, he found that there was a distinct current of water from the river into the trench, the water soaking away in the strata, which were the Woolwich and Reading beds. 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. The water, in filtering through the Tertiary beds, became extremely soft; the lime-salts entirely disappeared, and soda-salts took their place. It was impossible now to enter fully into the question as to how chalk, at such a low level, absorbed such large quantities of water; but there was an explanation of it, and it was no doubt connected with the temperature of the beds and the evaporation due to the temperature. There were some well-known instances, in other parts of the world, where currents of water entering into the earth were due to the same cause. As to the quantity of water, Mr. Grover had given, p. 7, an estimate which was equivalent to 4 inches in depth off the drainage area, equal to 17 cubic feet per minute for each square mile, and at p. 19 he had given another estimate, which, when worked out, gave as much as 33 cubic feet per minute as the yield of chalk per square mile. Which of these quantities was correct? The question had been raised by Mr. Grover, and already controverted by Dr. Evans, as to whether a larger quantity of water passed underground than was found in the rivers. Taking the gaugings of the River Lee for thirty-five years, commenced by Mr. Beardmore in 1850, the average quantity of water flowing off by the river was $7\frac{1}{4}$ inches in depth from the whole area. Taking the percolation experiments of Mr. Dickinson, continued by Dr. Evans during the same period, the actual amount of rain which had percolated through one of the gauges, was shown to be $6\frac{1}{2}$ inches, which was less than the quantity represented by the flow of the Lee. That was accounted for by the fact that the percolating gauges were at a low point, and that the average elevation of the River Lee was much higher, and, consequently, the rainfall on the whole valley would be greater than would be shown by the rainfall as gauged at Nash Mills; but it clearly demonstrated that, as a rule, whenever water was thrown out into a river, it represented the whole drainage of the country. Nothing could be clearer than the case of the Colne. Anyone who, like himself, had made a survey of all the streams and underground waters around London, would soon find it was impossible for any water to get out of the Colne Valley, except by passing under London. What was the state of the underground waters inLondon? Their level had been depressed so that it was now many feet below the mean level of the sea, and if there was to be a flow from the Colne Valley to the sea, as suggested by Mr. Grover, the water must, by some means, leap over the great depression caused by pumping in London. There were, no doubt, cases where the effect of a mill in heading up water, was not to intercept the whole of the water, but to cause some of it to escape laterally by the valley. That could be soon ascertained by a number of gaugings down the valley. But he did not know of any example where the whole of the water in a watershed did not ultimately find its way to the river. Wherever a well might be sunk in the river basin, and whatever water might be abstracted from it, it absolutely represented so much water abstracted from the river itself. In other words, if it were not pumped, it would be found in the river. But if it was pumped and returned again locally

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Mr. Latham. through cesspools and sewers the river did not lose the water, however much the quality might be deteriorated. In most of the examples mentioned by Mr. Grover, the water was all used locally, so that practically the river did not get robbed. With regard to Leatherhead, he thought that Mr. Grover had not given a very correct notion of the state of the underground water in the valley. The well had been sunk immediately below Leatherhead bridge. Within a short distance above the bridge there were some of the largest springs in the county, which were not even mentioned by Mr. Grover. The River Mole took its name from its burrowing underground. There were certain swallows at the foot of Box Hill, and the river at times almost entirely disappeared there, springing up again a few yards above the waterworks; and in all probability the Fetcham Mill springs, which were a little below the waterworks, formed also another tributary of the "Swallows." In an old book published over two hundred years ago, he found the following statement with regard to the Swallows: "There is a river in this county which, at a place called Swallows, sinketh into the earth and riseth again two miles off near Leatherhead, which the country people say was experimented in a goose, which was put in and came out again alive, but without feathers." There was evidently therefore a large underground passage, and it commenced immediately below Dorking, after the whole of the sewage of that town had been poured into the river, to come out again near the site of the Leatherhead Waterworks. Such was the state of things existing in that valley, where the waterworks had been constructed. At Wokingham, the well had been very successful with regard to the quantity of water. He had himself investigated the supply some years ago, as the authorities at Wellington College were considering whether they would take the water to supply that establishment. On investigation they were advised not to take the water, because it was so peculiar in its quality, containing 71 grains of solids in a gallon, of which 51·18 grains were alkaline chlorides, the largest portion being potash salts. The amount of lime in the water was only 2·35 grains per gallon, showing that it could not be chalk-water, which always contained 16 or 17 grains. With reference to the Colne Valley well, he thought that the Paper dealing with it was a very valuable one from an engineering point of view. There were some very good experiments upon the amount of water yielded by pumping at different levels. He should like to know what was the temperature of the water, and whether the deep bore had silted up. It might be taken as an invariable rule that if borings were made to any con-

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siderable depth, and there was no direct flow from them, they would silt up in a short time. It was a good guide for engineers in sinking wells to get the measurements of borings already made, and ascertain whether they had silted up. When he made the extension of the Croydon Waterworks in 1864, he sunk a well there, and bored it to a depth of 150 feet, but he found after a short time that it had silted up 50 feet. He thought that some accident had happened, and advised the authorities to re-bore it. That was done, but it silted up again, clearly indicating that the lower part of the well was not of the slightest value. As Sir Robert Rawlinson had mentioned, it might be taken as a rule that no large quantities of water would be found in going down deep; that the main flow was near the surface, and that the water gradually diminished lower down. Some years ago he had made some experiments with water passing through sand, which showed that the same law obtained in the movement of water in geological strata as in a river. Where the waters were of very great depth the movement at the bottom was slow, and at the top of the underground stream comparatively rapid; but in most strata, below the fluctuating low-water line, if sufficiently low to get the water into the adits, water would be procured more cheaply by adits than by a deeper sinking. It should be borne in mind that the more the water-level was lowered by pumping, as shown by Mr. Fox's experiments, the greater was the proportion of water got; there must always be sufficient depression created so that the head of water due to the springs should give the required volume of water. The law which governed the flow of water into wells was exactly the same as that governing the flow of water under any other circumstances. In a deep well at the Anerley Schools the water came in entirely at the bottom, and the yield of the well was exactly in proportion to the square root of the rate of depression. In the case of a well at the Windsor Waterworks, in the Chalk near the river, where the water came in at all points from the surface downwards, the quantity yielded was exactly proportional to the cube root of the square of the head. Knowing the laws governing the flow of water into a well, it was very easy, by making an experiment on any well existing in the neighbourhood of the locality where it was thought desirable to sink for water, to ascertain how much would be got by a certain degree of lowering in the well intended to be constructed. There were two statements which seemed to be at variance in the Papers by Mr. Grover and by Mr. Fox. Mr. Grover stated that the more he pumped at the wells the more water they yielded; while Mr. Fox's Paper showed the

Mr. Latham. exact opposite to be the case. The two statements, however, could be easily reconciled. The wells referred to by Mr. Grover were wells that were not really drawing water direct from the water-bearing strata, but were getting it from some distance, so that it was like water passing from a reservoir through an aperture, and by pumping the aperture might grow larger. So long therefore as there was only that one well to exhaust the source of supply, the supply might increase. But in a case like the Colne Valley, where the well itself was sunk into the reservoir, the first effect of pumping was to lower the reservoir, and after that lowering had once taken place, the water in the reservoir never got up to its former altitude, unless under some exceptional climatic conditions. Whatever tended to lower the water had exactly the same effect as that which was observed in wells at different periods of the year. It was a great mistake to suppose that all wells yielded the same quantity of water all the year round. His experiments showed that at one period of the year the drainage area might yield ten times as much as at another period. These changes, due to the influences of climate, were far greater than those which took place under any exigencies of pumping. Every estimated yield of a well, which was made to take water from the Chalk, should therefore be based upon the quantity which the well would supply at the minimum period. Those minimum periods sometimes came at different periods of the year; but they commonly fell in November. In 1885, the lowest water period was in January, but in other years there had been uniformly low water throughout the whole year; 1854 was a year of very low water, and the water was very low in January 1855. Probably 1864 considered as a low-water year was as low as 1854, if not lower, generally throughout the country. As he had elsewhere pointed out, every tenth year appeared to be a low-water period. With reference to the boring in Leicestershire, the temperature of the water pumped was said to be 52°, the well was 754 feet deep. A water-tight joint was put in, to exclude all surface-water, and in action it showed how little reliance could be placed upon such appliances for that purpose. If the water came from the great depth indicated, its temperature ought to have been 10° higher. The actual temperature indicated that it had come from a comparatively shallow depth, under 150 feet from the surface. The temperature might always guide an engineer as to the depth from which a water-supply was obtained. He had heard before of the plug mentioned in the Paper. It was put into a well at Bootle, with the avowed object of getting an independent supply of water from a deep source; but there was

Mr. Latham. no additional supply, and in consequence of the failure, the Corporation abandoned the project of taking a large supply for Liverpool from the New Red Sandstone. Mr. Whitaker had stated with reference to the Southampton well, that the geology of the district had been rightly given in the Paper. He wished to ask whether it was correct to show that the water from the Southampton Common well was kept out of the Chalk by a simple upheaval, or by a slight difference of level in the Chalk. He thought that no such upheaval could prevent the water from passing into a well. The Chalk, before it was overlaid in the London Basin, was similar to what was now seen outside, a series of hills and dales. In some cases Chalk could be reached at a much less depth than at others, and in all those cases, not one of the underground ridges or hills had interfered with the free flow of water through the Chalk. Chalk permitted the water to pass although it was not chalk-water. In sinking wells in the London Basin the great object of passing into the Chalk was to obviate the difficulties of the sand. The bore-pipes, as a rule, were always now carried through the waters in the sand. He ventured to take exception to the Author's statement that the wells at Southampton Waterworks, which he had described, were the largest sunk at one operation, and had been completed in a remarkably short time. In 1864 the well at the Croydon Waterworks was bored at one operation, the borings commencing at 7 feet 6 inches internal diameter. At Croydon a layer of about 15 feet of coarse gravel overlaid the Chalk, and the water rose, according to the season of the year within a few feet of the surface—perhaps not more than 9 feet. It appeared desirable, if possible, to shut out the surface-water; but he never believed that it could be successfully done. Indeed, it was utterly impossible to tub out the waters unless some impervious material existed between the water-bearing strata and the source of the water itself. Nevertheless in order to prevent, as far as possible, any direct contamination of the water, he sank a set of cylinders 9 feet in diameter down to the water, but he allowed no pumping to take place. He then put in a second set of smaller cylinders, 7 feet 6 inches in diameter, with the sharp cutting edge at the bottom, and after these a 6-foot cylinder was used, the lower cylinders projecting 2 feet 6 inches into the upper cylinders. For the 7-foot 6-inch cylinder the length of well was bored and misered at one operation, and when the work was finished, the space between the two cylinders was filled in with concrete, his object being to prevent what often happened in such cases—the water passing at the back of the cylinders

Mr. Latham. down to the bottom of the well. If he had pumped the well he should have had the same result as had been found by experience in connection with the well sunk in 1876 near the same spot, and which cost over £3,000, while the bored well cost but £1,100. In the one case the work was done entirely by boring in a single operation; and in the other case an enormous expense was incurred for pumping, with the great disadvantage, now clearly shown, that when the pumping from the bored well was taking place, the fluctuation of the water outside was only measured by inches, whereas, when pumping took place from the more expensive well the fluctuation in the water outside the well was measured by feet. The great cost, therefore, of a well was no criterion of its future safety and usefulness. He was sure that the Croydon bored well was only a small one compared with the wells that had been recently bored and misered out. He understood that a well had been misered out 11 feet in diameter by Messrs. Docwra at Hornsey. That well, according to Mr. Whitaker, was one of those that ought not to yield a large water-supply, but he believed it yielded 3,000,000 gallons a day. There seemed to be a fault running through London from about Hammersmith, which had a tendency to hold up the water in that neighbourhood, so that much more water was to be found in the wells there than in some other parts of London. The site of the new Southampton Waterworks appeared to be only a few hundred yards away from the river, and it was sufficiently near to abstract water directly from the stream. Looking at the sections showing the direction of the flow (Plate 1, Fig. 2), it was impossible that those could represent the lines of flow of the water, because it was evident, owing to the volume of water already in the river above the site of the well, that the water must have broken out and supplied the river long before it reached the site of the proposed waterworks. If the wells at the new Southampton Waterworks were required to yield 3,000,000 gallons a day at the minimum period, he stated, without fear of contradiction, judging from experience, that in an extremely dry time, every drop of water from something between 20 and 30 square miles of country, must be abstracted, and with the abstraction of such a large quantity, it could not be supposed but that the flow of the river must considerably decline. With regard to the well on Southampton common, the upper part of which was so much out of the perpendicular, the contractor who executed it failed; the lower part of the well was thoroughly well executed by Messrs. Docwra. He could not believe that the real cause of the non-supply of water to the well was as stated and as shown in the section. The whole of the strata about Southampton were very much disturbed and faulty, and that was the cause why the water could not pass in that direction. An inquiry was held with reference to the Metropolitan Water-Supply in 1850, and some curious evidence was then given with regard to Southampton; indeed, it appeared that the question of water-supply was a political question. There was a Whig river and a Tory river; the Whig river being the Test, and the Tory river the Itchen. According to the evidence, the well at Southampton Common was sunk as a matter of compromise. Mr. J. Hill, an architect of Southampton, pointed out in 1850, that Southampton ought to take its supply of water from near Otterbourne, where, as a matter of fact, the waterworks were now being constructed. The selection of that site was probably due to the person he had mentioned. In conclusion, he would say that all experience tended to show that water could not be taken from the ground at any spot without diminishing the flow of the rivers. As wells multiplied in a district the quantity of water in the rivers diminished; as pumping increased the water-level in wells was lowered, owing to the fact that a very much larger volume of water was taken, and therefore a much greater head was necessary to bring it into the well. There was a record that the first well sunk in the London Basin was at Norland House in 1794, and that the water overflowed. There was also a record that the well at Coutts' Bank formerly overflowed into the Thames. The water-level in these wells was now many feet below the mean river level, clearly indicating what might be expected in other places where large volumes of water were abstracted. Mr. Latham.

Mr. W. Shelford had made some observations as to the water-bearing capacity of the Chalk in the Isle of Thanet, and he had examined twelve wells scattered over the island. One well was evidently an exception, but the other eleven showed that the water stood at from 1 foot to 3 feet above the mean level of the sea, and he believed that it was the mean level of the sea which determined the level of the water in the Isle of Thanet. It was not the flints, although they occurred in horizontal layers to a remarkable extent, for while flint beds were acknowledged to be feeders to wells, when they were horizontal and extended to the coast they acted as drains to draw the water from them. There had been all along a great difference of opinion about the storage-capacity of the Chalk.[1] One authority, now dead, had stated that Mr. Shelford.

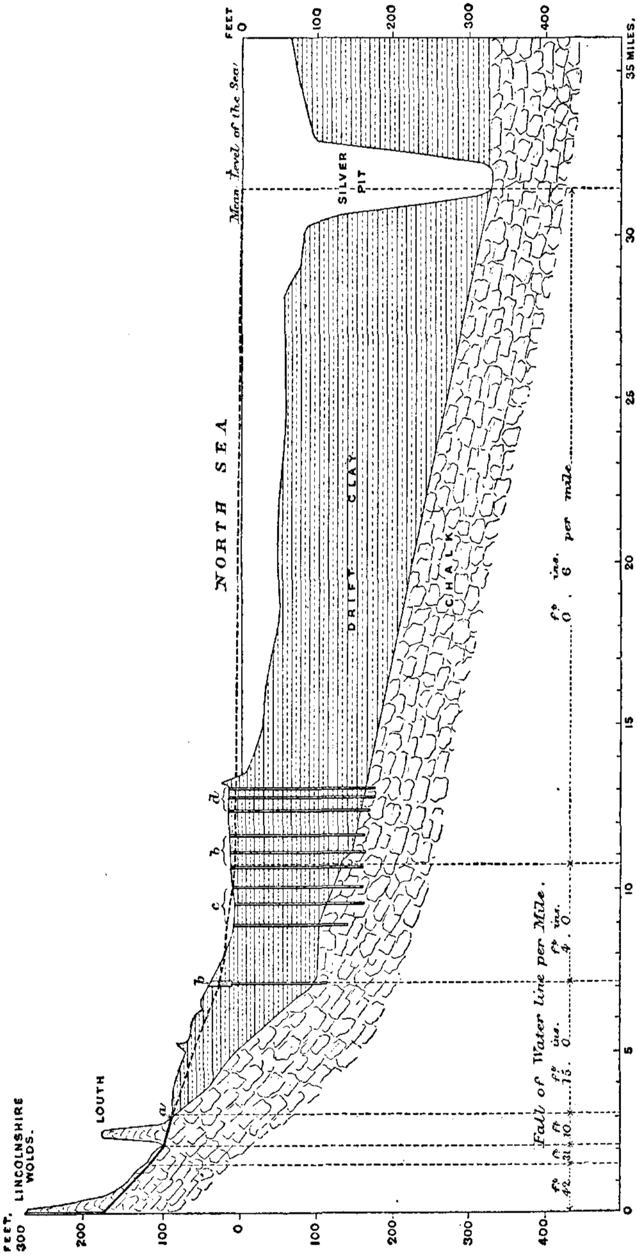
[1] Minutes of Proceedings Inst. C.E. vol. xlvii. p. 117.

Mr. Shelford. the evaporation from the Chalk occasionally exceeded the annual rainfall; and another authority had stated that the water from the Chalk now being drunk was derived from rain which fell in the time of Charles II. Mr. Grover had properly stated that the best place to find an abundance of water was at what he called the "outcrop" of the Chalk; by which he meant where the Chalk emerged from the bed of clay which overlaid it, in cases where clay occurred. Ten years ago, in a discussion upon a Paper by Mr. Lucas, he drew attention to that point as far as the district of the South Downs was concerned,[1] and it was true of all the Downs; and the Lincolnshire and the Yorkshire Wolds. Fig. 1, p. 69, was well worth the attention of Dr. Evans; it was a section along a line of railway from the Lincolnshire Wolds down to the sea, running east and west; and as he, with his partner Mr. Robinson, had supplied the town of Louth with water, and he had constructed that railway, on which several wells were sunk, he had studied the subject closely. In the Lincolnshire Wolds the water varied in level 15 feet between summer and winter; and it would be observed that it passed under the hill, through a fissure, upon which the town of Louth stood; that immediately it got beyond Louth it encountered clay, and that was the point which Mr. Grover called the "outcrop," where there were powerful springs; then it descended and was lost sight of; but on sinking wells it was found that it always rose directly the Chalk was tapped. The surface of the water had a fall from the Wolds to the sea, varying from 42 feet per mile to 4 feet per mile. The first well was an ordinary well; the next three were artesian wells; the next three were ordinary wells; and the next three were tidal wells—showing clearly that there was a connection between the sea and the wells. At spring-tides the water rose and fell about 3 feet in the tidal wells. At 20 miles out from the shore there was a remarkable depression, shown upon the Admiralty chart. This was a place called Silver Pit, 20 miles long and from 50 to 250 feet deep below the bed of the sea adjoining; and from the circumstance of the Silver Pit, occupying as it were the focus of the concave chalk formation of Eastern England, and from its extraordinary depth, which could not be accounted for by currents, he assumed that that was the point at which the chalk-water from the Wolds was discharged into the sea. In the Humber itself, further north than his section, the tidal channels were very deep, and the bottom had been proved by borings made by Messrs. Easton and Amos to have been within 20 feet of the Chalk. He

[1] Minutes of Proceedings Inst. C.E. vol. xlvii. p. 125.

Mr. Shelford.

Fig. 1.



a, Springs. *b*, Ordinary Wells. *c*, Overflowing Wells. *d*, Tidal Wells. Gradients of Water in the Wells are shown by Dotted Lines.

Mr. Shelford.—thought that the depth of the tidal channels in the Humber might be partly due to the quantity of water derived from the Wolds, which burst up through the chalk bottom. He thought so because in the Thames precisely the same thing occurred. Taking a longitudinal section of the valley of the Thames, and comparing it with a geological map, it would be found that directly the river intersected the Chalk, and as long as it travelled in the chalk district, it was much deeper than elsewhere. The question of the storage capacity of the Chalk he would again refer to. Every speaker seemed to assume that all chalk was alike; but there was a vast difference between the Chalk south of London and the Chalk in the Lincolnshire and Yorkshire Wolds. Every one knew that the soft Chalk, full of flints, in the North and South Downs was water-bearing. But in the Yorkshire Wolds, the Chalk was of different texture; it was stone, and had been used largely for masonry, for backing the dock-walls in Hull. He had made a tunnel $1\frac{1}{4}$ mile in length there, and several fissures had been encountered containing a good deal of clay, and that circumstance might account for the fact that water was not always found in chalk when it was below clay. The hill was capped with clay, and no water was found in the Chalk anywhere, except at the fissures; and when any rain fell it penetrated in a few hours through the fissures into the tunnel. Fully one-third of the very large quantity met with in the tunnel and adjacent cuttings had to be blasted. Returning to Fig. 1, p. 69, it was well to consider what became of the water which fell upon the Chalk, a point that might be disposed of under four heads—the overflow from the surface, surface-springs, evaporation, and deep springs. He had not full information about those points in that particular locality, but a few years ago he was engaged upon an investigation of the subject in the south-east of London, east of the meridian of Deptford. The area then under investigation included 70 square miles, and the annual average rainfall was 28 inches. It was proved that there was practically no overflow from the surface. The surface-springs were carefully gauged for a long time, and this showed that the average would not exceed 8 inches of rainfall, leaving 20 inches to be accounted for under the heads of evaporation and deep springs. Then arose an exceedingly important point. Dr. Evans and his predecessors at Nash Mills, Herts, had for a long time carefully recorded experiments upon the evaporation from chalk, and Mr. Shelford deduced from those experiments that 17 inches would be due to evaporation, leaving 3 inches, which would go down to the deep springs. That there were such springs, and that there was such a flow, was proved by the fact that he had gauged a large number of wells over the 70 square miles, and took the level of the water, and had found the same general fall, as in Lincolnshire, but varying from 5 to 70 feet per mile, from all points within that district down to Gravesend, where the Thames intersected the Chalk, so that there could be no doubt as to the existence of such springs. The quantity could be deduced only from the evaporation by first of all ascertaining what that was. Of course, there was plenty of room for investigation and experiment on the subject. The point, however, of most interest to engineers was not so much the amount of sub-soil water as the mode of collecting it. In the case of the Thames Valley, the water trended down the valley through the Chalk until it came to Deptford, where there was a fault which arrested it, and accounted for the large quantity of water which the Kent Waterworks Company drew from wells at that place. But such convenient faults did not often occur. At Gravesend there was no such fault, and it would not be so easy to collect the water. Hull was similarly situated to Gravesend. The waterworks there, which belonged to the Corporation, were originally built over an old spring at the "outcrop." That was soon exhausted, and the Corporation made deep borings but did not get much water. Adits were then driven, and one had just been driven 70 or 80 feet below the level of high-water in the direction of the Wolds, with the object of intercepting the fissures in the Chalk and so getting some water. That water would be got was certain, because there were fissures in the Chalk, and if one of those fissures was encountered water would flow from the Wolds as long as it lasted, and when it did not keep up to the level of high-water it would come from the Humber. There were actual cases of that kind, not only at Hull but elsewhere. For example, there was another waterworks 2 miles from the "outcrop," under the clay in Hull itself, where there was an abundant supply of water, and always would be, because a fissure had been tapped below the level of the river. In the Isle of Thanet, also, the water pumped for one of the large towns was taken partly from the sea, as shown by its containing 33 grains of chloride of sodium per gallon. He thought that, as a rule, it would be found that where a large reservoir of water was stated to exist in the Chalk, it was below the level of the sea or of some adjacent river, and that above such level there was not any store of water which could not be accounted for when sufficient data were available. Mr. Shelford.

Mr. J. H. TAUNTON did not propose to traverse any old ground, but to submit shortly one or two matters which had occurred to Mr. Taunton.

Mr. Taunton. him in connection with Mr. Grover's Paper. The Newbury shaft evidently simply arrested the water passing to the river, whilst the shaft and boring in the Valley of the Mole, at Leatherhead, and also at Rickmansworth, in the Colne Valley, were much the same in character and in office. In the case of Wokingham there was a distinct artesian boring, from which water was obtained at the rate of about 166 gallons per minute. At Leatherhead the quantity was 187 gallons per minute, and at Rickmansworth about 360 gallons. At Rickmansworth the depth was 300 feet; at Wokingham 408 feet; and at Leatherhead 200 feet. Having reference to all that had been done, and the expense incurred, he thought the result a rather poor one. In the archives of the Institution there was an interesting Paper by Mr. James Pilbrow,[1] giving an account of a boring at Bourn, in Lincolnshire, through oolitic strata, which was carried down 92 feet, with only a 4-inch tube; and yet it delivered more than the greatest of the borings made by Mr. Grover, the amount being 575,000 gallons daily, or 400 gallons per minute. In the oolites and particularly in the Inferior Oolite, thrown out by the Lias, a great deal more water was found than in other closer and more compact strata. He might refer to the Thames head springs, which gave 4,000,000 gallons a day, and to the Chalford springs, which gave between 7,000,000 and 8,000,000 gallons a day. There were also the springs which surrounded Cheltenham, like the Syreford spring, which yielded more than 1,000,000 gallons a day. He thought it would be found that the soakage through the oolite was vastly superior to the soakage through the chalk. He believed that Mr. Grover had given the soakage at 158,500 gallons per diem per square mile, which would be equivalent to 4 inches per square mile per annum. He had made a number of experiments to ascertain the soakage in oolitic districts, particularly in the Stroud Valley, and he had found that at short-water time, which was the only suitable time for the enquiry, the soakage was expressed by about 7 inches per square mile per annum. The total minimum flow from the Thames was equivalent to about 12 cubic feet per square mile per minute, which would be $2\frac{7}{10}$ inches per square mile only per annum of rain. Inasmuch, therefore, as the Thames was supplied in short-water times from springs, and very largely from chalk-water springs, when a depth of 4 inches was taken by Mr. Grover as the available rain from soakage in the Thames in drought, he certainly did not underrate it. Instead, then, of pointing to Mr. Grover's conclu-

[1] Minutes of Proceedings Inst. C.E. vol. lxxv. p. 245.

sion that the Chalk was a proper prospective supplemental source of water-supply for London, he thought it better to look to other districts which were more favourably situated. Already, according to the last report by Major-General A. de C. Scott, R.E., there were upwards of five million persons to be supplied within the range of the Metropolitan Water Act. No doubt the Chalk afforded a very suitable suburban supply to London, but if the demand went on increasing as it had done, it would be necessary to look to other districts besides the Chalk, and it must be borne in mind that the rainfall in the districts around London was small—25 inches, or less; whilst in other districts, such as the Cotswold Hills and the oolitic districts, extending from Yorkshire to the Severn, the rainfall was much larger. Mr. Taunton.

With reference to Mr. Stooke's Paper, he could not do better than quote with respect to artesian borings in Triassic strata the opinion expressed by the late Professor Phillips, who had pointed out that from the lowlands in the Valley of the Exe, through the Valley of the Severn, and that of the Trent, up through the Ouse Valley to the Tees in Yorkshire, all through Triassic strata, there was no ground of any material elevation, and therefore it would be very unsuitable for the purpose of obtaining water by means of boring. Apart from that, the Triassic formation was well known as dangerous, in its connection with gypsum and other salts. The Great Western Railway Company, at Swindon, had been seeking water for the use of that station, and possibly for the town, and had lately sunk a shaft upwards of 730 feet, and had gone into the Forest Marble, which was a bed of the Great Oolite, and had come, in the most extraordinary way, upon a brine spring. There could be no doubt about the matter, because Mr. Woodward had been sent from the Geological Survey Office, to examine the place, and his report would be found in the Journal of the Geological Society.[1] The water had been analyzed, and it was as nearly like sea-water as could be.

Mr. J. I. THORNYCROFT described a boring instrument which he thought was calculated to cheapen the making of wells. Instead of fastening the boring-tool at the end of the boring-bar, in the ordinary way, it was made to slide down the boring-bar, and as the bar was gradually lengthened other parts were added. It was always left down the well. The boring-tool slid up the bar and carried with it the spoil, being hauled up by a chain which Mr. Thornycroft.

[1] The Quarterly Journal of the Geological Society of London. vol. xlii. (1886) p. 287.

Mr. Thornycroft.

formed the means of raising the bars should they break, as the tool was made to lock in the boring-bars and very great facility was afforded, because the bars had not to be disconnected, except when the boring was sufficiently deep. The tool was made to expand and carry a cutting edge, slightly larger than the tubes, which were slipped down, and the tubes were found to slide down the better for it. He had been told that it worked exceedingly well. It was the invention of Mr. Parsons, of the Isle of Wight, and it appeared to be an excellent device.

Mr. Homersham.

Mr. S. COLLETT HOMERSHAM wished to supplement the remarks made by Sir Robert Rawlinson with reference to the deep well-boring at Richmond. It was only when that bore-hole was completed that a new light was shed on the geology of the London Basin. For many years engineers had been told that they had only to penetrate the Gault clay found below the Chalk to obtain a large supply of pure water from the water-bearing Lower Greensand, and a deep boring at Meux's Brewery was sunk with that idea. In this boring it was said by geologists that the Lower Greensand had been reached and penetrated to a depth of 64 feet, below which the Upper Devonian strata were encountered; but this bed of 64 feet of so-called Lower Greensand was acknowledged to be of a very abnormal character, and proved totally unfit for water-bearing purposes, and the bore-hole was then abandoned. When the Richmond well and bore-hole was sunk there was an insufficiency of water in the Chalk, and it was determined, in spite of the failure at Meux's Brewery, to go through the Gault in hopes of reaching the Lower Greensand below. Below the Gault a bed 87 feet in thickness was passed through, and the geologists at first were very much puzzled to know what it was. The Richmond boring was made the subject of two Papers read before the Geological Society by Professor Judd and himself,[1] and it was conclusively proved that the 87 feet of strata below the Gault belonged to the oolitic formation, which was totally without water, and that the Lower Greensand was practically non-existent. Below the Oolite, red rocks were found, which were described as Poikilitic beds, as the Authors, owing to the absence of all fossiliferous remains, were unable to determine whether they belonged to the New Red Sandstone or to the Devonian, and the members of the Geological Society were about equally divided in their opinions on the subject. But whether Old or New Red Sandstone

[1] The Quarterly Journal of the Geological Society of London. vol. xl. p. 725; and vol. xli. p. 523.

Mr. Homersham.

these beds failed to yield any large supply of water. The red rocks were penetrated to a depth of 203 feet, the bore-hole reaching a total depth of 1,442 feet, and the temperature of the water which came up from the bottom was $76\frac{3}{4}°$ Fahrenheit, thus proving that under London at least it was hopeless to go to any great depths for water. It had since been proved that the strata encountered below the Gault at Meux's Brewery, and which had been described as Lower Greensand, were not of Necomian age at all, but belonged to the same series as the rocks immediately below the Gault at Richmond, namely the Lower Oolites. Thus all hope of obtaining a supply of water from the Lower Greensand under London must definitely be abandoned. Mr. Grover had, he thought, conclusively proved that a great deal of water was to be got out of the valley in the Rickmansworth district. Mr. Grover did not pretend that the chalk-water supply was illimitable; he merely suggested that it would make an excellent supplementary supply for the largely increasing suburban districts of London. He had shown that he was able to pump enough water from his well for the purpose of supplying the inhabitants of the Uxbridge and Rickmansworth valley. On the opposite side of the valley to that in which Mr. Grover's well was situated some other bore-holes had been sunk 40 inches in diameter, and had been carried down 200 or 300 feet into the Chalk below. These borings, three in number, were full of water to the surface, in fact two were now overflowing, each yielding 266 gallons per minute at the surface. Very little expense had been gone to in testing what these borings really would yield, but a pump was lowered down one of the bore-holes which pumped 85,000 gallons an hour, and only lowered the water in the well some 18 feet. What one bore-hole would yield if the level of the water was depressed to a greater depth was left to the imagination, but it was evidently a very large quantity. Dr. Evans had stated that every drop of water pumped from the Chalk strata of the Colne Valley district had reached the Chalk by the rainfall in the district, that he was prepared to agree with; but he was not so certain as Dr. Evans that every drop of water abstracted from the Chalk was so much abstracted from the rivers and streams flowing in the neighbourhood. But even if this was so, anyone glancing at the Ordnance map of the district where Mr. Grover had sunk his well, would see that the valley was full of streams and rivers, and he would go so far as to say that even if some of the streams disappeared altogether, owing to water being extracted from the Chalk for the purposes of water-supply, it would be so much the better for the neighbour-

Mr. Homersham. hood. The whole valley was crowded with streams that were of no use except to a few mill-owners up the river, and surely it was better to abstract the water before it reached the rivers, and was fresh and pure, than afterwards, when it had been contaminated by the natural drainage from the country round about.

Mr. Spon. Mr. ERNEST SPON said that Mr. Grover had stated that the district under examination was covered by a bed of chalk about 650 feet in thickness, thinning off at the edges. It was, however, he believed, well ascertained that the Chalk, so far from thinning off at the edges, was rather thicker at the outcrop, and that it was thinner under London. Mr. Grover had also made the misleading assertion: "From this it follows that any attempt to obtain large volumes of water from the Chalk under London will never be successful; neither will the Upper nor Lower Greensands yield much water, owing to the immense pressure upon them." The fact was it was not a question of the pressure, but that the Lower Greensand was generally absent under the Chalk in London, and where it was present, or supposed to be present in one or two places, it would never yield a large supply, because it was much thinner as a stratum than the Chalk: it had a smaller outcrop and therefore a much less catchment area. Mr. Grover had further stated (p. 14): "In the Chalk, where water can always be obtained by going deep enough;" and again (p. 18), "as in other wells in the Chalk, the volume of water was greatly augmented by enlarging the bore-hole and increased sinking." It was not necessary to sink to any great distance in the Chalk in the London Basin to get a supply of water. Mr. Spon thought it was rather a matter of sinking in the Chalk until sufficient fissures yielding water were found, and this usually occurred in the first 300 feet. It was remarkable that much water was rarely encountered in the Chalk at a greater depth than 500 or 600 feet. Very little allusion has been made to the enormous number of wells in the London Basin which had nothing to do with the general, but which had everything to do with the particular, supply. The practice of most engineers in London, who had to deal with the question, was mainly concerned with wells already in existence, and not with the selection of sites. There were still plenty of places where water could be found in the London Basin if only they had the opportunity of choosing. But there were many spots where it would be extremely difficult to get a supply, or an increased supply, unless they thoroughly knew what they were about. Professor Prestwich's book was as well worth careful and intelligent study as ever, being a thoroughly sound authority upon the water-supply of the London Basin. Professor Prestwich had pointed out what Mr. Spon had confirmed by his own observations, that water in the Chalk almost invariably passed through planes called "bedding planes," and through fissures which were often very numerous in a small distance. As an instance, he had driven a heading in the Chalk where, within 150 feet, he had found no fewer than thirty-four fissures. But it was necessary to take into account the particular character of the chalk in each locality. He did not know any mineral formation that differed so much in different districts as chalk. In some places it closely approximated to dense limestone, and in others it was very soft, almost resembling the whiting sold at shops, which was levigated chalk deposited under water not more than a few feet in depth. The same reasoning or the same process, ought not to be applied to different substances, because, however much they might be alike chemically, they were totally different in mechanical structure. He had noticed with pleasure the construction of the boring-tool to which allusion had been made. It was a common practice in sinking a well, 5 feet 10 inches, or 6 feet in diameter, to put down a small well and then enlarge it. Mr. Matthews had made a central chisel to form the advance well, and had so made the side cutters that at one and the same operation he was cutting three different holes. But he had not heard anything about the failures in the former well; he suspected that they had something to do with the chains attached to the cutters. Very few failures had been mentioned, but it was always desirable to know about them. Such cutters were used in the Mather and Platt apparatus and others. The cutters broke off at the neck, and when that took place they fell to the bottom of the well, dropping on to the soft bed prepared for them by the jumping action of the tool, and the pressure of the water kept them down. When the crow was passed down, it would not grasp the broken cutter, and when an effort was made to hammer it, being made of tough iron, it resisted. In one or two instances, where proper measures had not been taken, the well had to be abandoned. He had once been consulted in connection with the Slough Waterworks, and when he arrived on the spot he found that two cutters had broken off and fallen to the bottom of the well, and by no effort, after several weeks' trial, could they be raised. He overcame the difficulty in a very short time, and got rid of them by firing a blast. One cutter was driven into the side of the well and the chalk was so loosened that it enabled the other to be picked up by the crow. Of course keep-chains could not be attached to comparatively small cutters. It was only in the Mr. Spon.

Mr. Spon. case of a large cutter, where there was a large thickness of metal, that they could be fastened in the way illustrated.

Mr. Hogg. Mr. JABEZ HOGG said he had been startled by what had fallen from Sir Robert Rawlinson, on the question of shallow wells. He understood him to say that he should be satisfied with water obtained from tolerably shallow wells. Some years ago the Privy Council (who consulted Sir Robert Rawlinson) determined to close all the shallow wells in London, to prevent any further supply of water being drawn from such sources. It was then believed shallow wells were receptacles for sewage leakages, although a good deal of the water came through the gravel, and a good deal more from a greater depth. In the neighbourhood of Russell Square there was a well that supplied water drawn from a depth of 120 or 130 feet, but it was peremptorily closed. The water was supplied all the year round at a nearly uniform temperature, and the inhabitants around partook of it. The closure of this well, and of several other wells, was looked upon at the time as a great hardship. It was supposed that all wells were contaminated, and no doubt the Government was right in ordering the closure of many of them; but the order was to close them all, whether they were deep or shallow. He could not entirely agree with Sir Robert Rawlinson that the shallow well-water to which he had alluded should be taken as a supplementary supply for London, because a good deal of the underground water might be, as Mr. Grover had said, rendered impure from cesspool leakages, and it was rather dangerous to draw a supply from such a source. Mr. Grover limited his borings to between 300 or 400 feet, that was to the Chalk, below the London clay. In sinking wells to greater depths a good supply might be missed. The prediction of Professor Prestwich that a supply of water would be obtained from the Upper and Lower Greensands had proved to be an utter fallacy. In truth by boring to greater depths below the Chalk so good a supply could not be got as from shallower sources. This fact was made apparent fifty years ago by Robert Stephenson, who incontestably proved that the Chalk Formation contained an abundant supply of pure water. He sank two wells in the Bushey Hall Meadows, and with two temporary engines pumped no less than 1,091,000 gallons per twenty-four hours. Having thus experimentally satisfied himself as to the abundance of the supply, he undertook the investigation of another doubtful point, namely, whether or not the water was drawn from independent springs in the Chalk, or from the adjacent river—the Colne. This he settled in an equally satisfactory way; he found that the water came from independent springs, and not from the river. Moreover, Stephenson proceeded up the valley from Watford to Boxmoor, Berkhampstead and Tring, and all along the line he obtained well-water, "at levels corresponding with the inclination of the valley far above those of the wells sunk at Watford." Surely such evidence must be regarded as most conclusive on this point, if it was not equally conclusive on another raised by Mr. Baldwin Latham, namely, that all the wells around London derived their water directly and solely from rivers in the vicinity of the borings. Stephenson's investigations anticipated and disposed of this statement. He emphatically stated, "In the chalk district between Watford and Tring my attention has been particularly directed to the extraordinary quantity of water existing in the Chalk below the level of the natural drainage of the country, that is, of the adjoining streams," and he added, "I have been struck with the uniformity apparent between the surface of the subterranean reservoir of water, and the natural surface of the country." ... "In the execution of a cutting at Tring, a very large quantity of water was encountered, notwithstanding the situation was on the summit of the chalk ridge forming the actual brim of the basin, where it could not be supplied with water but such as fell upon the immediate neighbourhood. Yet it yielded upwards of 1,000,000 gallons per diem, so that practically there is an almost inexhaustible supply of water to be got by the action of a very small hydrostatic pressure." Mr. Grover qualified Stephenson's statement in that particular. At p. 4 he observed, "It is often said that wells sunk in the Chalk have the effect of abstracting water from the rivers; this is true where the district is all chalk, but it is not true when the well is sunk through clay, and only partially true where the wells are sunk at the junction of the Chalk and clay." Mr. Hogg quite agreed in the opinion, that "the water of the valleys, which flows away underground, greatly exceeds the volume of the rivers," and Mr. Grover's several borings, and those of Mr. Fox, clearly proved it. Indeed, no one who considered for a moment the enormous extent of the catchment area of the chalk ranges to the north-west, and which the late Mr. Homersham put at 1,200 square miles, would entertain a doubt on the subject. Mr. Latham admitted that the temperature of the water was a fair test of the depth from whence it was drawn. Mr. Grover and Mr. Fox had taken especial care to determine this, and invariably the water of their wells maintained a uniform temperature of 52° or 53° Fahrenheit, summer and winter alike. Mr. Grover mentioned an interesting fact with reference to his having constantly encountered in the deeper borings accumula-

Mr. Hogg.

Mr. Hogg. tions of flints; hence he concluded that these beds of flints formed the more natural subterranean reservoirs of water. He was unable to offer an explanation of the fact, or of the formation of the flint beds, but the chemistry of Nature appeared to Mr. Hogg to afford a solution. The crust of the earth was made up, among a number of other mineral substances, of from 20 to 36 per cent. of silica, in the more familiar forms of sand, granite, quartz, agate, &c. Throughout the chalk strata, silica was in very intimate relation with an alkaline earth. To bring about a separation of the two a fluid was required, holding in solution a certain quantity of carbonic acid. Now, rain descending on the chalk hills absorbed from the air and from the surface soil just so much of this acid as was wanted for the purpose, and, as it percolated through the lower strata, dissolved out all the siliceous material, and left the calcareous particles to be carried away by the onward stream. The silicate, now in a hydrate amorphous state, had the appearance of a transparent gelatinous mass; moved slowly, and on meeting with an organic fragment, as a piece of sponge, it enclosed it, and this became at once an active nucleus of crystallization, which rapidly grew and continued to convert all the silica within reach into itself. That flints accumulated by rotation was seen in section; the circular rings seemed to show this; and that chalk was chiefly composed of the siliceous remains of Protozoa was known by placing a section under the microscope, when numerous fragments of diatoms, sponges, and foraminifera were presented to the view. The vast bed of the Atlantic Ocean was covered with a living gelatinous mass of siliceous matter, Globigerinæ, and which, by absorption of the carbonate of lime held in suspension in the water, formed the chalk beds of the future. There was, however, another way in which the underground formation of flints might be brought about, namely by the action of siliceous springs, situated below or in the deepest chalk recesses. Silica springs were occasionally seen in action above the surface on an extensive scale in Iceland, and, until quite lately, in New Zealand, where those remarkable pink and white terraces were the wonder of the world. These springs quickly pulverized and broke up the chalk, to rob it of its silica. In this way, perhaps, the liquid silex, meeting with little resistance, would more rapidly form flints, in vertical ramifying masses, while the finer calcareous particles, separated and held in suspension by the moving, agitated body of water, would be either carried away or brought to the surface by pumping, as occurred in Mr. Grover's experience. Of the quality of the deep well-waters, Mr. Hogg was able to speak from a personal examination of numerous specimens obtained from Bushey, Rickmansworth, Watford, Leatherhead, and other localities, and he could say they were pure and wholesome and entirely free from all organic life. As to quantity, he had already observed this was almost inexhaustible, and he agreed with Mr. Grover that from the springs of water which rose in the neighbourhood of the Colne, a supplementary supply could be had which would go far to meet the demands of the annually increasing metropolitan population. He knew of but one drawback to chalk-water, and that was that it held in solution and suspension about $17\frac{1}{2}$ grains of chalk per gallon; this could, however, be readily and very cheaply reduced to $2\frac{1}{2}$ grains, when it became a pure soft well-water, suited for all domestic purposes; and, quite unlike other soft waters, it had no deleterious action whatever on lead pipes. In regard to the rapidity with which water percolated through chalk hills, and which was chiefly determined by atmospheric pressure, if a large surface of chalk was exposed on one side to the action of the wind or the sea, or both together, then an extra pressure was brought into operation. He was much struck by what occurred in this way at Netley a few years ago, and he should like to ask Mr. Matthews, whether in his Southampton experience, anything of the kind had been noticed. The Netley well was first sunk at some 400 or 500 yards from the edge of the chalk cliff. In the following summer, when the wards of the hospital were tolerably full of invalids, a severe outbreak of diarrhœa and summer cholera took place. The cause of this could not at first be traced; but after a month or two it was discovered that the total solids per gallon in the water had greatly increased, and then it was further seen that at certain periods there was a very considerable increase of water in the well, and this was traced to the daily percolation of the sea-water at high-tides. Mr. Hogg.

Mr. J. W. Grover, in reply, exhibited some of the water referred to in his Paper. It was he said absolutely untouched, not having passed through any filter. When it was remembered that the water came up at a uniform temperature, all the year round, of 52° to 54°, and in the quantity he had described, from its vast reservoir in the flints, it would be seen that Nature was very kind and abundant. The colour of the water could only be seen in bulk, but its great brilliancy and purity were well worthy of observation. He had been astonished at finding that he was sometimes able to see in chalk-water springs every pebble and stone at a depth of 20 feet, with perfect distinctness. He had been a good deal criticised by mill-owning and geological representatives, but Mr. Grover.

Mr. Grover. he believed that as far as his engineering facts were concerned they had not been severely controverted. No doubt Dr. Evans was an excellent authority, and he had been so desirous that that gentleman should be present, that he had specially drawn his attention to the subject, in order that his views might be placed before the members of the Institution. Dr. Evans, as a large mill-owner, naturally felt desirous of keeping all the water he could in the valley, while Mr. Grover, as an engineer, having merely to consider the public requirements, took a different view of the matter. Dr. Evans had stated that rivers did not always flow along faults. It was true that they did not always do so, but at Rickmansworth the river certainly ran along a great fault in the Chalk, and powerful springs coming up in the middle, drove back the green water. Dr. Evans objected to his statement that he did not think that much water was abstracted by a well sunk at the junction between the Tertiaries and the Chalk. His reason was that the water there was divided into two parts; the lower part, the underground flow, passed away under the Tertiary beds, and the upper flowed over the London Clay in the form of rivers. All that he proposed to intercept was the lower water, which travelled as Dr. Evans had admitted at a very slow rate. That water passed beneath London, and when wells were sunk there the water came up. Of course by intercepting it at the edge of the London Clay it was prevented getting to London wells. His attention had first been drawn to the matter by finding that at the outcrop of the Chalk from the London Clay Nature had thrown up remarkable springs; and he asked himself, if Nature did that why should not the engineer help Nature, that being his legitimate function? Of course Dr. Evans was right in saying that water would be abstracted if he limited his assertion to the immediate cone of depression near the well. No doubt that occurred, but only to a very limited extent. Dr. Evans had said that "he had never known any instances in the Upper or the Middle Chalk in which there was not an absolutely complete junction, as it were, between the water at the top, and the water at the bottom, by means of fissures"; and he added that "it was much the same as filling a cistern with bits of stone, and saying, 'if you pump from the upper surface, you take water out of the cistern, but if you pump from the bottom of the cistern, you do not affect the level of the water in it.'" Any one who had sunk a chalk well and had stood over the boring-rods would comprehend that Dr. Evans's idea was a mistaken one. He had himself had a nail driven into the side of the shaft in the morning before the men began work at the water-level, and as they went on working and pumping, they would suddenly come upon beds of flints; then as they broke through them, the water in the shaft would rise perhaps 2 or 3 inches above the nail. A new vein of water had been struck, and the water gradually rose and afterwards fell again. There were two separate channels. The water passed in a vast sheet in the Woolwich and Reading beds under the London Clay. When he had used the word "sea," he of course referred to tidal water as well as the sea, including the River Thames so far as it was tidal. The water passed under the Tertiary beds into the Thames where it was tidal, and tended to produce those springs immediately below London, which supplied the district served by the Kent Waterworks Company and also the neighbourhood of Grays. Dr. Evans, in his Lecture on Physiography, had said that only 4 or 5 inches of the rainfall were available for the supply of the rivers and of the underground waters; but at the end of that Lecture would be found a series of experiments conducted during thirty years at Nash Mills, which distinctly showed that out of a rainfall of 27·84 inches in the year as much as 10·65 inches percolated into the Chalk, representing a very extensive volume of water. If there was not that supply of water passing into the Chalk, how was it that the Kent Waterworks Company, which had not more than 150 square miles of basin to pump from, within the last twenty years had been pumping 10,000,000 or 11,000,000 gallons per day, and continually supplied that amount? So much had been said in the discussion about the quantity of water to be got from the Chalk, that he felt a fuller reference would have been desirable in his reply on the subject; but he would confine his remarks to one point, namely to the Rickmansworth experiments. The facts were broadly these:—A well 300 feet deep contained water in it 293 feet deep; by pumping at a rate exceeding 500,000 gallons a day, it was found possible so far only to reduce the level of the water 13 feet, leaving still a depth of 280 feet of water in the well. It was easy to calculate, from these data, how many million gallons a day this represented. He thought the results would astonish some of his critics, especially if they also noticed on the diagrams that water came in much more rapidly as its level in the well was reduced, following of course the well-known laws of hydrostatics. Mr. Grover.

Mr. W. Fox said that Mr. Grover's statement, in regard to the theory of Dr. Evans about a cistern filled with stones, was pretty well illustrated at Bushey, where pumping from one well lowered the water 20 or 30 feet deeper than it stood in the other boring. Mr. Fox.

Mr. Fox. If Dr. Evans's theory were correct, the water-level in both boreholes would be pretty nearly alike. That was shown to a still greater extent at the old works of the Harrow Waterworks Company, where there were two or three wells in a space not larger than the theatre of the Institution, and pumping from one well did not affect the level of the water in the other. With reference to the remarks of Mr. Whitaker about the deep boring at Bushey, the Directors certainly did not want to trouble themselves to go through the Gault. If they had not found so much water at 500 feet below the surface, having gone to that depth, they would probably have been told that they had gone too far. The fact was, that the machinery being on the ground, boring 200 feet further was a matter of very little expense. The Directors were not advised that there was much probability of any water being found on the top of the Gault, but they were told that there was a possibility, and they continued boring with the laudable desire to prove the actual depth of the chalk at that point. Mr. Whitaker appeared to doubt whether they ever did get to the Gault, but he afterwards admitted it when he saw the samples. He had no doubt that if the Directors had acted on the first advice that Mr. Bateman had given, to sink a well 150 or 200 feet outside the engine-house, and from that point had driven adits, they would have obtained a much larger amount of water; but it would have cost a great deal more money. Tenders were invited for the work, but various eminent well-sinkers in and about London fought shy of the quantity of water they anticipated would have to be dealt with, and the idea was consequently abandoned, and boring was adopted instead. He thought it could hardly be said that the boring was a failure; 600,000 or 700,000 gallons a day was a fair quantity of water for an outlay of £3,000. No doubt the first well yielded more water than the second, but that was accounted for by the fact that water could be drawn to a considerably deeper level, 20 or 30 feet, and if the second boring could have been pumped from to that extent, he had no doubt as much, or nearly as much, water would have been got. The temperature in both wells was pretty nearly constant, 52° in summer and winter. With reference to the silting up of the borings, he had found, on testing, that the first boring, the shallow one, was very nearly of the same depth now as in 1876, there being only a few inches difference; but the deeper boring, sunk two years ago, had apparently silted up to the extent of about 9 feet.

Mr. Stooke. Mr. T. S. Stooke forwarded the following comments upon the discussion:—He agreed with Sir Robert Rawlinson's views upon the second bore-hole, near Hinckley, so far as regarded the fact Mr. Stooke. that it ought not to have been put down. Mr. Stooke, however, simply completed the testing of the bore-hole, after the work had been far advanced under other professional guidance. His especial object, in bringing the Paper under the consideration of the Institution, was to draw attention to the plug and pump system; and to show the doubtful policy of penetrating strata known to be of an objectionable character, in the attempt to reach good water which might be thought to underlie them, when the same good water might be reached near the surface within a few miles from the same point. Not only was the latter policy as a rule more economical, because a few miles of water-pipes involved less cost, but such a system was also more definite, and the costs could be generally more approximately estimated. He hoped the present record would be useful when similar works were contemplated by other boards. The recommendation which he made to the Local Board of Hinckley was to the effect that, by going to the outcrop of the Water-stones 3½ miles distant from Hinckley, a supply of water might be obtained with less difficulty, and at no greater cost than from the deep well, or bore-hole, however successful that well or bore-hole might have proved. A somewhat parallel case to this had come under his observation under the following circumstances: Proposals had been made for seeking a supply of water for the town of Wem, in Shropshire, by boring through the marl, when he advised the sinking of a well at the outcrop of the Bunter Sandstone at a distance of 4 miles from the town. Objection was, at first, taken to going such a distance, but ultimately a well was sunk to the depth of 70 feet, and connected by a heading to a bore-hole taken to a further depth of 20 feet, an ample supply of water was secured of only $10^{\circ}\cdot 8$ of hardness. These works had been in operation upwards of three years, and the water still rose to its old level of 32 feet under the engine-house floor, after the pumping had been suspended for twenty-four hours. Of the two bore-holes at Hinckley, that which had been previously driven ought to have been more fully tested. It must be admitted that the diameter of the second bore-hole should have been larger than 6 inches, and the extra cost of the larger hole would have been compensated for; but the testing work had to be carried forward by him in the then existing bore-hole. When the continuous pumping was carried on for periods of twelve and seven days respectively, there was no falling off in the water. The boring of the 3-inch hole from the depth of 783 feet to 800 feet was through a very soft sandstone, from which no core was obtained. On each

Mr. Stooke. occasion when pumping was resumed the water was largely charged with sand from this part of the bore-hole, but no permanent silting up of the hole took place, which proved the strata to be water-bearing. There was no doubt that the last 100 feet of the bore-hole was in the Water-stones, and that these measures were water-bearing, but probably not to any large extent. Mr. Whitaker recognized the desirability of recording such an instance as this, of seeking water from the Water-stones, or from the Bunter measures, when underlying some hundreds of feet of marl. His enquiry indicated that he had overlooked the fact that the section of the bore-hole showed the Water-stones, as existing from about 690 to 800 feet beneath the surface. In reply to Mr. Whitaker's enquiries as to the cause of the inferior quality of the water, and the strata from which the impurities came, it might be stated that the bore-hole was tubed to the depth of 476 feet, but as already mentioned that tubing fell short of the base of the Keuper marls by about 25 feet. It was also mentioned that small nodules of gypsum were traced in the cores of sandstone from the boring to the depth of 680 feet from the surface. Mr. Stooke was satisfied that the rubber plug, from being pressed so firmly against the bore-hole, by the weight above acting directly on it, prevented the passage of any water in the bore-hole itself. He had no doubt that the badness of the water arose from the percolation of the saline water through the sandstone or fissures in it, against which the plug acted, and that therefore all the upper strata containing the gypsum contributed to it. The impurity was of mineral and not of surface contamination. Analyses gave an average of about 430 grains per gallon of solid matter, consisting chiefly of sulphates of lime, and chlorides of soda and magnesia. The site at which a supply of water was being sought, referred to in the last paragraph of the Paper, was situated on the outcrop of the Water-stones, near the White Stone. Water of very good quality had been obtained, but not yet in sufficient quantity. The strata pierced by this well were of a similar character to those pierced in the lower part of the bore-hole. Mr. Latham had taken exception to the plug system adopted; but Messrs. Mather and Platt had several instances where it was in successful work. One case was at Messrs. Holden and Sons, Bradford, where an illustration of its efficiency was found. A bore-hole, 18 inches in diameter was taken to the depth of 275 feet; the natural level of the water in the bore-hole was 65 feet from the surface, and it possessed 22° of hardness. The plug was fixed at 225 feet from the surface, the water-level inside the pump-tubes was 92 feet from the

Mr. Stooke.

surface, and this water possessed only 3° of hardness. In another instance an experiment was tried to ascertain the quality of water yielded by a certain section of rock, and two plugs were fixed in a line of pipes with about 20 feet of perforated pipe between; and although there was a large supply of water above and below the plugs, no water passed either plug; it therefore proved that that particular rock did not yield water. The plug placed in the Bootle bore-hole also proved that no additional supply of water was obtainable, and he therefore considered this might be taken as evidence in favour of its action, and certainly not against it. In reply to the remarks made by Dr. Evans, a dual system of water-supply would answer where the inferior water was laid on only for street-watering and sewer-flushing; but in no case should the dual service be laid on to any houses, or the adjoining premises. Instances had come under his notice where such services had been laid, and the use of the inferior quality of water had been productive of very serious results. The time was probably not far distant when the Metropolis would look further abroad for its water-supply; when Plynlimmon, or the range of Cardiganshire hills to the south, would be found capable of meeting its increasing requirements, and thus leave the water, which might yet be obtained from the Chalk for the inhabitants of the surrounding districts. During the years 1881–2 when he was engaged in taking a supply of water from Llyn-Llyad-Rheidol, on Plynlimmon to Aberystwith, he had frequent opportunities for judging of suitable sites amongst the Welsh hills for the large storage of water. The water-supply to Aberystwith was of less than 1° of hardness, and although the town services were generally of lead, the water had never been found to act as a solvent. The satisfactory results which had been secured in the boring of the Southampton wells, as referred to in Mr. Matthews' Paper, were matters of general interest to all engaged in well-sinking. The greater speed at which the work could be executed, and the costs saved in pumping under this system, were most material, and would probably lead to its more general adoption.

Mr. Matthews.

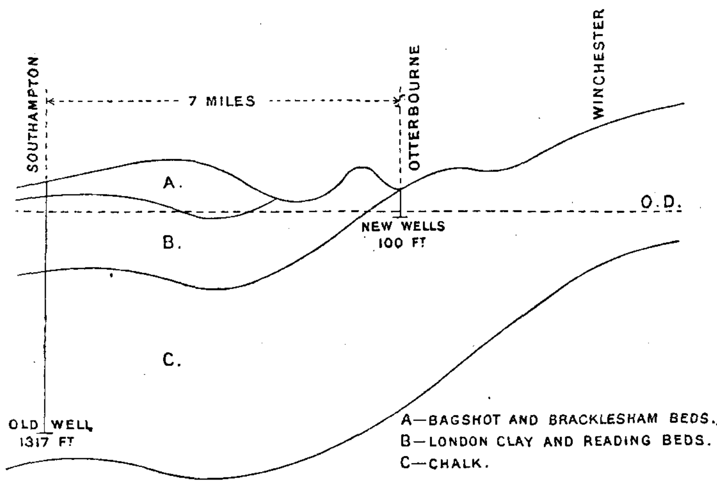
Mr. MATTHEWS said he was glad to hear Sir R. Rawlinson's opening remarks with reference to sinking wells to a comparatively shallow depth. In a well of small bore there was a very small surface from which the water could get in, and consequently, in a small bore as against a large one, the water-level must be greatly lowered by the draught, and the cost of pumping thus increased. Dr. Evans had spoken of a dual supply for potable and sanitary purposes. Mr. Matthews had partially adopted that scheme, and

Mr. Matthews. it did very well, as it was confined to road-watering and sewer-flushing, but it was difficult to introduce a dual supply into houses. In one case in which it was introduced, although the taps were marked—one for kitchen purposes and the other for drinking—it failed; sufficient care was not exercised by children in going to the taps, and the plan had to be discontinued. There appeared to be a pretty general consensus of opinion as to the desirability of sinking at the outcrop rather than under heavy beds, and Mr. Latham's single example of failure was not sufficient argument in opposition to this opinion. He thought that Mr. Latham was under a misapprehension with reference to his remarks and those of Mr. Whitaker's as to the old well on Southampton Common. Neither of them suggested that no water got into the well at all; 130,000 gallons per day flowed in, but the upheaval tended to retard the flow. The superincumbent weight of the London Clay and other beds always made the Chalk very compact, and that also had a tendency to retard the flow. That case was hardly comparable with the London Basin, because the superincumbent beds were there about 200 or 250 feet in depth, while at Southampton they were 460 feet. Geologists did not recognize any fault near Hammersmith; there might be an uprise, and if it held the water back, why should not the same happen at Southampton as was suggested? Mr. Latham had asked whether Fig. 2, p. 89, really represented the geological features in the neighbourhood of Southampton. It was approximately the result of the most recent geological investigation. If reference was made to the Geological Survey maps, great inaccuracies would be found. It had been proved that a little to the eastward of the line of section, at a somewhat lower level, the London Clay actually appeared at the surface, whereas it was marked on the map as Bracklesham beds, showing that there was a considerable uprise there. In sheet 80 of the Geological Survey, in the neighbourhood of Fareham, an upheaval was shown corresponding with the old well, and another further north, at Gander Down, corresponding with Winchester. He had not said that the wells described were the largest sunk, but he said "he believed that they were." Mr. Latham had spoken of one sunk at Croydon. He had looked carefully through all the authorities on wells, and had found that Mr. Latham, in a work published in 1865,[1] spoke of the well as being sunk. In other parts of the same Paper, he spoke of wells as "sunk and bored," and of wells "partly sunk and partly

[1] Papers upon the Supply of Water to Towns, p. 45.

bored." There was no evidence therefore to show that the Croydon well was bored. He had, however, no doubt that it was so, and was willing to yield the palm to Mr. Latham. He was glad to know that, at Croydon, the cost was found to be much in favour of boring, and he felt all the more justified for having carried out his borings for Southampton. The neighbourhood had been said to be full of faults; but that was hardly correct. There were certain upheavals, but the idea of there being faults was a relic of the geology of the past. Whatever had been done in the past, the adoption of this scheme had not been made a party question, and it had been unanimously approved of by the Southampton Corporation. The site selected, or thereabouts, had for Mr. Matthews.

Fig. 2.



many years been recommended, and naturally, as it was the nearest point to Southampton situated upon the bare chalk. With regard to the doubt thrown by Mr. Latham upon the probable yield of the new wells, the Pole's Hole Spring, ½ mile away on the line of section A, Plate 1, Fig. 1, yielded 1,500,000 gallons per day very regularly in dry times, at a height of about 6 feet above the standing level of the water in the wells. The actual discharge, when pumping to keep the foundation-pits dry, was at the rate of 750,000 gallons per day with a loss of only 9 feet head of water, and accepting Mr. Latham's formula, the ultimate yield of the wells must exceed 2,250,000 gallons daily if the water came in from the bottom of the wells only; whereas it

Mr. Matthews. had been proved that the actual increased discharge was much in excess of the theoretical amount upon this basis, and water evidently came in all round, as might be expected. The watershed drain upon it was over 150 square miles, of which 50 miles were on the same side of the valley as the site of the works, and the annual rainfall could not be taken at less than about 30 inches. The lines of flow (Plate 1, Figs. 1 and 2) were not meant to indicate that there was an actual flow of water towards the well upon all those lines; but the wells were connected for the purpose of getting the water gradients. He thought it clearly showed that while there was a flow eastward and westward towards the valley, there was at the same time a flow down the valley, and consequently at the point where it emerged into the London Clay and Tertiary beds there was a large amount of water to be obtained. No doubt much of the water coming from the east passed into the river; that coming from the west would be intercepted before it got there. The river was not so near as Mr. Latham thought. In passing the site by train, he had no doubt been misled by what appeared to be the river, but which was in reality the old Itchen navigation, at a higher level than the river which was farther off. Reference had been made by Mr. Hogg to the well at Netley. He was not well acquainted with it, but he had heard that there was an increase of volume at high-tides. That might be accounted for by the fact that there were extraordinary double-flood tides at Southampton, and when heavy gales were blowing no doubt the water was held up for an abnormal period, which would give a large increase of water in the well. The well being sunk through Tertiary beds, the tides might be in communication with it. In the well at Gosport[1] also there was a tidal flow. As to the well sunk at Bourn, the statement with regard to it, made by Mr. Taunton, had been borne out by a well that had come under his own observation, described in a Paper a few years ago by Mr. Addy on the Peterborough Waterworks.[2] It was sunk in the same oolitic formation at Braceboro' Spa, $3\frac{1}{2}$ miles south of Bourn, and the amount of water obtained from this formation was enormous. In answer to Mr. Spon, he would point out that the fracture of a chisel-blade was referred to in the Paper, and it was after this mishap that the safety-chains were added.

[1] "A comprehensive treatise on the Water-Supply of Cities and Towns." By William Humber, p. 262.

[2] Minutes of Proceedings Inst. C.E. vol. lxxiv. p. 146.