Mr. P. W. BARLOW, in allusion to the published map and sections of the district around London, by which the paper was illustrated, said it would be observed, that on the south-east there was an area of about 192 square miles, over the greater part of which the lower beds cropped out, and that they were very permeable. This was about six times the available area of the north-western district, where moreover the upper beds, usually clays, cropped out to the surface, which was thus rendered impervious to water, whilst the lower beds, generally sands, came to the surface in the east and south-east, which would explain the cause of so much water being found to the east of the fault, at Deptford.

Mr. F. BRAITHWAITE suggested the necessity of defining very distinctly the meaning of the term "water-bearing strata." Chalk when containing flints and intersected by numerous fissures, might be considered as water-bearing, or rendering, like sand; but pure solid chalk, although it easily absorbed water to saturation, did not part with it readily; this difference must be borne in mind, in discussing the question.

The Rev. Mr. CLUTTERBUCK, said he must preface the few remarks he had to make, by stating that subsequent investigations had strengthened his confidence in the correctness of the views, expressed in the several papers, presented by him to the Institution and discussed at the meetings in 1842, 1843, and 1850;¹² indeed his opinions had been confirmed, not only by the facts which had come under his own observation, but also by those which had been communicated to him by others. In speaking of the water-bearing strata of the London basin, it would be necessary clearly to understand their power of absorbing and retaining, as well as of yielding, or giving out water. That which was retained, was by the power of capillary attraction; that which was given out, was by hydrostatic pressure; to the latter the term of "Free-water" might aptly be applied. Professor Ansted's paper on the "Absorbent Power of Chalk,"¹³ had induced further investigation, whence it appeared that pure chalk would absorb one-third of its bulk and one-fourth of its weight of water, with which it would part only by evaporation. Thirty, or more pieces of perfectly dry chalk, piled on each other in a glass tube 3 feet in length, would on the immersion of the lowest piece in water become, in about three months, so perfectly saturated, that on immersion the upper piece would not take up more than a few grains of water. Chalk "in situ," below the reach of evaporation, was frequently found in the same condition of super-saturation, and from the water, so

¹² *Vide Minutes of Proceedings Inst. C. E.*, vol. ii., 1842, p. 155; vol. ii., 1843, p. 156; and vol. ix., 1849-50, p. 151.

¹³ *Vide Minutes of Proceedings Inst. C. E.*, vol. ix., 1849-50, p. 360.

held, it would not part. The "free-water" derived from it, was that contained in, or percolating through the fissures and beneath the beds of flints.

There might be circumstances under which the indication of Dalton's rain-gauge, as used by Mr. Dickinson, might be questioned, though the instrument would usually represent accurately the quantity of water sinking into the chalk. Mr. Clutterbuck's own practice had been, to gauge wells at various points, and the experience of fifteen years' observation enabled him to judge of the relative quantity of water in the chalk, at any period; by this means he was enabled, in December 1852, to predict the time, to within a few days, when the bourns would burst at such places as at Bourn-End in Herts, at Assendon near Henley, and at Lambourn in Berks, although he had only the gaugings of a few wells in Hertfordshire, and the indications of the ordinary rain-gauge to guide him. It was difficult to ascertain the amount of water evaporated from and beneath the surface of the soil, by heat and by wind, all which must be replaced, before any free-water could descend to the water-level in the chalk, or in any other stratum. If it were possible to evaporate, to dryness, the chalk to a depth of 6 feet below the surface, it would require 24 inches of rain, or the total average rain-fall of London, to replace the water so evaporated. Experiments made at the close of the dry weather, ending in September, as well as previous observations during drainage operations, showed that at the close of a dry season, such as the present year, about 3 inches of continuous rain would be required, to replace the water evaporated. In the paper under discussion, the outcropping band of sand, under the plastic clay, was noticed as receiving a certain supply of water on its surface, but it must be remembered, that in addition to the rain so received, large quantities of water, running from the surface of the London and plastic clays, percolated by means of the swallow-holes into the sand, and through it into the chalk beneath.

Mr. Clutterbuck had been hitherto unable to find, that there was any distinction, or division, between the water in these strata; the water was only found in the sand, when it dipped below the water-line in the chalk, as might be proved by tracing the water-line, or level, to that point. With reference to the bourns, which occasionally burst out at higher levels, it would be found, on carefully taking the relative levels, that the phenomena originated in the angle at which the water rose in the chalk, being greater than that formed by the surface of the soil; the water was first seen rising in depressions in the soil until it attained a level at which it could flow away, and it would sometimes sink into the earth again, when it met with any elevation of surface to impede its course.

As to the experiments at Hampstead, for procuring water from the greensand, he must again refer to the paper read in 1850,¹⁴ where calculations, on the basis of those shown to be accurate, in the case of the Artesian well at Grenelle, were applied to the London basin; and though the project of sinking to the lower greensand was then almost universally pronounced to be absurd, the problem was now in the course of practical solution.

As to the assumed possibility of drawing water, under any circumstances, and with any amount of precaution, from wells, or shafts in the chalk, without depressing the surface-level of the water in the immediate neighbourhood of such wells; the position was contradicted by every well-directed experiment, by sound philosophical deduction, and certainly by every well-authenticated fact. The depression of the water-level necessarily affected the yield of the streams issuing from the chalk. Nature had given the rivers, as a source of supply for this Metropolis, and it was to that only the public must look; there might be certain localities, such as Brighton, and possibly in the particular district in Kent, spoken of in the paper, where water could be taken from the chalk, without injury to existing interests, but it would be quite impossible to do so in the neighbourhood of rivers, without at least diminishing their volume.

MR. SIMPSON,—President,—directed attention to that portion of the paper, where the Artesian well of Grenelle was spoken of, as affording an unvarying, and regular supply of water; he had also been under the impression that this was the case, until having had an opportunity of examining it, he ascertained that a steam-engine was occasionally employed in pumping water from the Aqueduc d'Arcueil, when the supply became inconstant, which it did under certain circumstances, arising probably from the variable amount of infiltration, or from a greater degree of evaporation at one time than at another. In estimating the quantity of water percolating through certain strata, the question of the amount of evaporation required great attention, as in the seasons of the least fall of rain, there was frequently the most evaporation. Whilst on this subject he would mention the experiments made by Mr. S. Clegg, jun., in 1849, on pumping water from a well sunk into the chalk, at a distance of about one mile and a half south of Tring, Herts.

MR. S. CLEGG, Jun., through the SECRETARY, explained that he brought the account of the experiments, before the Institution, because the results tended to prove, that the level of the water contained in the chalk of the London basin, was depressed by pumping from it, and that the springs and wells in the neighbourhood of the pumps, were almost immediately influenced, to an ex-

¹⁴ *Vide Minutes of Proceedings Inst. C.E., vol. ix., 1849-50, page 151.*

tent both in quantity, and in area of surface, according with the degree of pumping.

In the early part of 1849, the Grand Junction Canal Company, caused a well to be sunk to a depth of 75 feet, with bore-holes below that depth, into the chalk and erected a steam engine, with two pumps, each of 12 inches diameter, and having a length of stroke of 6 feet, to raise water from the chalk, for the supply of the summit level of the canal.

This well was $6\frac{1}{2}$ chains north of the highest source of the Bulbourne, a stream feeding the river Colne.

The observations commenced on the 23rd of May, 1849, and it was soon perceived, that the level of the water in a well situated five chains to the west, and in a pond three chains to the east, was always lowered, to an extent corresponding with the quantity of water drawn from the Canal Company's well.

For instance, on the 24th of May, the pumps worked at the rate of about fifteen strokes per minute for six hours, and lowered the water in the small well 13 inches, and in the pond 6 inches. On the 11th of June, fourteen hours of pumping, at the same speed, reduced the water in the well and in the pond 17 inches and 9 inches respectively. Almost immediately on the cessation of pumping, the waters invariably rose, until the former level was reached. These observations were sufficiently satisfactory to induce Messrs. Dickinson and Co. to give instructions for making more extensive and accurate experiments. Accordingly three gauges were placed across the Bulbourne; the highest being 528 yards, the second 660 yards, and the third 957 yards from the pumps, and the depths to the surface of the water, in various wells in the neighbourhood, were correctly measured. The one at Norcott Court, to which the most attention was paid, being about three quarters of a mile distant.

Arrangements being made for the pumps working for ten days, from the 27th of June, without cessation; after ten hours' pumping, the water ceased to flow over the highest gauge, on the ninth day, the second gauge was dry, and on the tenth day the depth over the third gauge was reduced from $7\frac{3}{8}$ inches to $5\frac{1}{8}$ inches. The water in the small well was lowered 4 feet 5 inches, and that in the well at Norcott Court, was reduced 1 foot 3 inches, whilst the pond was entirely dried up.

On the 7th of July the pumps were stopped, and remained at rest for ten days, and during each day the waters were observed to rise. On the second day the water reappeared in the pond, on the third day it ran over the middle gauge, and on the tenth day it had risen at the lower gauge to within $\frac{1}{8}$ th of an inch of its original depth, whilst in the well at Norcott Court, it had arrived at within 9 inches of its original level.

It was argued, on the part of the Canal Company, that the water sources of the Bulbourn were from the upper portion of the chalk, and that if the brick steining of the well was rendered water-tight, by being surrounded with puddle, the higher chalk water would be prevented from draining into it, and therefore that the pumping would not affect the stream. This alteration was made in the steining, but after the operation, the results of the pumping were quite as conclusive as before. Indeed, the effect extended over such an area, that the water at a gauge across the Bulbourn, three miles below the pumps, was lowered more than half an inch.

Other corroborative evidence was afforded by the gaugings of the river Wandle, carefully taken from May to October 1842, and during September of the year 1854, which showed that the pumping well of the Croydon Water Works, was causing a similar depression of the water in the chalk in that district, and was sensibly affecting the quantity in the river.

Mr. P. W. BARLOW explained, that making two sections of the London basin, one from Hoxton, on the north, through Rotherhithe, to New Cross on the south, would show the position of the great fault, and the other from Woolwich, in the east, to Kensington in the west, would exhibit the fault in the former locality, and would illustrate how completely the water supply would be intercepted, and the observed phenomena must be produced.

Mr. BEARDMORE said the river Lea offered many peculiarities, and if a gauge were placed below some of the rivers, a deficiency would in some instances be apparently exhibited. The nature of the strata in the bed of the river varied considerably; in some places there was much clay, whilst in others the chalk was partially denuded; again the water was almost entirely absorbed, in certain sandy and gravelly spots, or where the chalk was broken, to be thrown again to the surface, either by faults, or by bands of clay; indeed the existence of springs might generally be traced to a fault, or to some other subterranean obstruction. The celebrated Chadwell spring was of that character; it appeared at the foot of a cliff, to which the water had percolated along crevices and beds of flints.

The river Lea had five branches, the Mimram, the Beane, the Stort, the Rib, and the Ash; all differing somewhat in the nature of their beds, and in their capacity for delivering water; for instance the water of the Stort was foul and clayey during floods, whereas that of the Mimram was copious and rarely discoloured, even when floods existed in other branches of the river Lea. Along the valley, between Chadwell Spring, near Ware, and the beautiful pool of spring water, supplying Hoddesden Mill, springs flowed out, at frequent intervals, along the foot of the chalk cliff, rising out of the gravel forming the basis of the marshes, on the

southern side of the valley. These springs were probably derived from infiltration all over the out-crop of the chalk and its superficial deposits, and also from that through the permeable strata of the valley itself; but the sources were not clearly defined. The effect upon all the adjacent wells, when heavy pumping occurred in any particular locality, showed the common source of all the springs, and the intimate connexion of the wells with each other, through the sources.

Mr. DICKINSON said he had, from necessity, been long acquainted with the peculiarities of the springs of the chalk formation; they were affected by a great variety of circumstances, to which must, in some degree, be attributed the conflicting opinions as to the water-bearing properties of the stratum. The character of the chalk varied in an extraordinary manner, from a dense compact silicious formation, as hard as stone, through all degrees of solidity to a broken-up soft chalk, frequently mingled with marl; the substratum was generally marl, and the superincumbent stratum was sometimes clay and in other places loam and gravel. Of course the water percolated easily through the chalk formation; but when marl, or clay opposed an obstruction, the infiltration of water was as much precluded as when the strata were densely compact. He was aware of the influence of the inequality of the upper strata on the quantity of water to be expected, but no opportunity had hitherto been afforded, for ascertaining whether an inequality existed in the lower strata conformable to the superficial irregularity of the ground above, which might produce anomalous results. In one instance, when he expected to have found a great number of springs, he was disappointed, but in some other districts he had observed, that the springs, above the ordinary level, after being dry, for a certain time, would burst out and flow freely. These outbursts occurred higher up the valley than the level of the springs, and they must be attributed to a considerable quantity of water percolating through the strata over some vein of clay, or marl, more copiously than in ordinary seasons. There did not appear to be any other way of accounting for these apparently anomalous springs. They were found both on the north and the south sides of the Thames, and the greater their distance from that river, the higher were the levels at which they appeared, and the higher the hills, the greater was the outbreak of water. This was probably due to the shape of the chalk basin under London. Abbot's Langley was situated upon a bed of gravel overlying a natural basin of clay, which became saturated with water during the winter, and when there was a surcharge, the water poured over the sides of the basin, in which it was collected, and numerous springs were formed; this only occurred after a wet season, and the springs were invariably dried up in the summer. Whatever

were the causes of the phenomena, to which he had alluded, no one could deny the circumstance of water continually pouring out of the earth, upon a level above that of the general streams.

Mr. S. C. HOMERSHAM must venture to hesitate, in implicitly accepting the statement brought forward by Mr. Clegg, who had not even informed the Meeting what quantity of water had been pumped out of the Grand Junction Canal Company's well, the steining of which, had been stated, before a Committee of the House of Commons, never to have been made impermeable, which would completely account for the effect upon the neighbouring wells, stream, and pond.

He agreed with Mr. Dickinson, as to the variable character of the seams of chalk, as regarded their density, hardness, and water-bearing qualities. In examinations of specimens from twenty, or thirty different localities, he found great discrepancy in the powers of absorption; for instance, there was chalk from beneath the clay, about London, which would not take up a gallon of water per cubic foot; whilst that from near Tring would contain nearly three gallons per cubic foot. It was the difference in the permeability, or the hardness of the various strata that caused the water to flow more, or less freely in different directions, and would account for many of the observed phenomena.

On sinking a well at Tring, water was commonly found, in the chalk, standing at a level of about 450 feet above Trinity high-water mark; from whence the water-level gradually declined, in a south-easterly direction, to the level of the sea, and could be traced, issuing in large volumes, at various places, along the coast. There could not be any difficulty in isolating wells in such a way as to oblige them to obtain their supply from the lower strata alone. He believed it was practicable to obtain water, to almost any extent, in suitable localities, from the chalk, without affecting the general supply of the district, if the sides of the wells were rendered water-tight and they were carried down to a hard stratum of chalk, so as to cut off all communication with the superficial springs.

The case of the water supply for the new Docks at Great Grimsby deserved attention. In consequence of the Humber being heavily charged with silt, it was considered desirable by Mr. Rendel, that a copious supply of pure water should be obtained, for the use of the docks, and for working Armstrong's hydraulic machinery for manœuvring the lock-gates, cranes, &c., for which purpose he directed a well to be sunk down to and into the chalk, through a bed of superposed clay of about 60 feet in thickness; the sides of this well were rendered perfectly water-tight, and a bore-hole of two feet diameter was made into the chalk, to a depth of not more than 50 feet, from the bottom of the

well, when such a supply was obtained as enabled about eight, or nine millions of gallons of water to be pumped out per day, without affecting any of the overflowing wells around. Nearly similar results had been obtained in other localities, and he was thus confirmed in his opinion of the feasibility of obtaining good supplies of water from the chalk under favourable circumstances.

It was true, that at Great Grimsby, as in the neighbourhood of Uxbridge and Watford, the lower strata of the chalk appeared to be supersaturated with water, as it sufficed to make a bore-hole some depth into the chalk and an overflowing well was immediately produced. At Plumstead, the supply for Woolwich and Charlton—a somewhat extensive district—was obtained from a well and bore-hole sunk into the chalk, with adits, or small tunnels, driven below the line of saturation with water; and although the engine had been constantly working day and night, it had not hitherto practically affected any of the wells around.

Mr. F. BRAITHWAITE said the immediate question being the capability of water supply of a given district, it was incumbent first to entertain the consideration of what constituted water-bearing strata; that position should be clearly defined, before proceeding to the discussion of the other parts of the subject. After all that had been said and written on the subject, Mr. Braithwaite must retain his previously expressed opinion, that the chalk was not *per se* a water-bearing formation, except through and by means of its fissures and layers of flints; it was absorbent, but it was not so capable of conveying water as a sand formation, through the interstices of which quantities of water could percolate. With respect to the statement relative to the well at Great Grimsby, he must contend that there was no analogy between the local circumstances; but he understood that even there the supply, which at first was very copious, had now become almost insignificant, and the pumping from the great well had partially affected all the others in the vicinity. It was recorded, that within the last century it sufficed to sink a shallow well, in almost any position in the London basin, to be inundated with water; the constant drain upon the basin had, however, now produced its natural effect, and though it was still asserted, that by boring to the depth of only a few hundred feet, a supply of water, to the extent of twenty, or thirty million gallons, could be obtained, he must hesitate to assent to such a doctrine; indeed he was well assured, that a certain degree of exhaustion had occurred, and the water-level under London had suffered gradual and progressive depression. Such, at all events, was the condition of the districts on the north and on the west of London; it was probable, that in the south-eastern district, the conditions might be different,

and as there had not been any great demand for water, the strata might be surcharged in that locality, and for a time would yield very copiously.

He disagreed with the opinion of the water in the chalk being intercepted and thrown up to the surface by faults; on the contrary, the chalk basin was very free from disturbances of that description; the great faults at Lewisham, the extent and direction of which were well known, being the only causes of disturbance near London. There were numerous fissures and beds of flints, which served as conduits for the water, and from which, he believed, the only considerable supply was obtained, but that must soon be exhausted, unless it was regularly replenished by the infiltration of rain and snow water, and the diagrams, that had so frequently been exhibited to the Institution, showed that the rate of exhaustion, by pumping, exceeded that of the supply from the sources before alluded to; in fact he did not think that any such quantities of water, as had been presumed upon, did really exist in the chalk basin under London. The circumstance of a copious supply for two, or three small parishes, being procured from a new and comparatively untouched district, was not a valid argument for the probability of obtaining a copious supply for the metropolis; and it remained still to be shown, whether a considerable amount of pumping would not produce exactly the same prejudicial effects in the south-eastern, as in the other districts around London. The degree of pumping, to which a district could be subjected, varied with the nature of the strata; at the Kilsby Tunnel it was found, that as soon as the water was reduced to a certain level, or that the speed of the pumps exceeded a certain rate, sand was brought up, and serious inconveniences arose.

At the new well, now boring at Hampstead for the waterworks, it was found that in traversing the chalk, there was little, or no water, except in the fissures; the bore-hole had been now extended through the gault, into the lower greensand, and still without obtaining the anticipated supply; this to some extent confirmed the opinion of the water being derived from the greensand and not from the chalk, which could only absorb more, or less water, in the ratio of its compactness or density.

Mr. HAKEWILL, in answer to questions from the PRESIDENT, said the locality of the well now being sunk at the Hampstead Water-works, was at a height of 172 feet above the level of Trinity high-water mark; it was sunk for the purpose of obtaining a supply of water from the chalk. A brick shaft 8 feet in diameter was carried down 272 feet, at which point the tertiary sand was found, under the mottled clay; iron cylinders, 7 feet in diameter, were driven through the bed of sand, into the chalk, which was reached at the depth of 320 feet. As soon as the necessary pumps

and machinery were fixed, the shaft was continued, but without finding any water. The chalk was perfectly free from fissures, and too hard, and compact, to permit any infiltration through the mass, throughout which the flints were generally distributed, instead of being deposited in layers, or beds, so as to form a medium for percolation. A few layers were met with, but they were so closely packed in the chalk, that they yielded no water. After proceeding to a depth of 218 feet in the chalk, it was considered useless to sink the shaft any deeper, and ultimately it was determined to bore through the remainder of that formation, in the hope of deriving a plentiful supply from the upper, or lower greensands. The boring which was commenced in June 1853, had been continued without intermission from that time, and had now reached a total depth of 1,130 feet from the surface, without having traversed anything that could be termed "water-bearing strata."

The strata passed through, from the commencement of the well, had been—

Brown clay	28 feet
London blue clay	206 „
Mottled clay	38 „
Sand and pebbles	48 „
Chalk	540 „
Chalk marl	107 „
Upper green sand	13 „
Gault (greyish blue)	130 „
Red clay with grains of coloured sands	20 „

1,130 feet.

The boring was still proceeding, in the last-mentioned bed of red clay, which probably rested immediately upon the lower greensand.

It had been presumed, that some water would be found in the upper greensand, but that bed was so mixed with clay as to be impermeable.¹⁶

Mr. HAWKSHAW said it appeared to be contended, that wells might be sunk into the chalk, and pumping to any extent might take place, without interfering with the rivers, or streams. If the supply of water was derived from the rain and melted snow, which

¹⁶ Since the period of the discussion the boring has been continued and has now reached a depth of 1,266 feet; the red clay, which was found at a depth of 1,110 feet, still continues, sometimes with small veins of chalk and greyish-blue clay, and occasional thin bands of a kind of sandstone; at present, there is a mixture of very fine ferruginous sand, indicative of some further change of stratum.—

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percolating through the out-crop, saturated the permeable strata, and then burst forth at certain levels for the supply of the streams, it was clear that it would not be possible to sink such wells and pump from them, without to some extent draining the surrounding strata, and immediately affecting the streams, unless it was supposed that there existed a pre-Adamite reservoir under the crust of the earth, whence a constant quantity could be derived, which would be compensated for, by the rain-fall; but even in that case, if the amount of pumping in any year exceeded the supply derived from the rain, the original source must be drawn upon, and under any circumstances it appeared, that if the quantity pumped up was very considerable, the supply for the streams must be interfered with, as that was derived from the surplus which flowed from certain issues at given levels, into the beds of the streams intersecting the lower out-crop of the strata.

The statement of the quantity of water likely to be obtained from the chalk appeared to have been greatly exaggerated. It had been assumed, that a certain quantity of rain fell annually, —that a portion of it was evaporated, and the remainder found its way into the earth. Now he believed, that these were partly vague assumptions, as the recorded experiments and observations, were not by any means conclusive. The experiments of De la Hire, as recorded by Chevalier, showed that at Paris, during fifteen years, with tubes 8 feet deep, no water had penetrated to that depth. Dr. Dalton with tubes 3 feet deep, and a rain-fall of 33 inches, obtained a result of 8 inches of water. Mr. Dickinson, in a larger experiment, with a rain-fall of 26 inches, obtained 10 inches of water at a depth of 3 feet; and Mr. Charnock, with a rain-fall of 24 inches, recorded $4\frac{1}{2}$ inches of water, at a depth of 2 feet. Thus the three last experimenters obtained 27 per cent. of the rain-fall, and if this result could be admitted as generally correct, it would give about 4 inches of rain per annum as the percolation through the upper strata and flowing outwards in the shape of springs. Beyond that quantity then, any supply must be derived, by pumping, from the constant quantity held in suspension in the various strata, and that source would be soon diminished in certain localities. Nor could this amount of percolation be always reckoned upon, as the degree of permeability of the various strata must be considered, as well as the accidental features of a country, where the intersection of the lower out-crop of the strata might draw off the water, as fast as it percolated from the upper out-crop. After due consideration of all the points, he was induced to believe the quantity of water, really to be obtained, was much less than had been assumed. No doubt there was a large supply at Watford, but after a dry season nearly all the wells in the vicinity of the Colne were low, and any considerable accession to the present rate of pumping from the

district, might entirely drain it and go far towards drying up the river Colne. He thought it was incorrect to assume, that any very large supply of water could be obtained by pumping. Experience had shown, that there was only a certain supply to be obtained from that source, and that it would diminish annually, and he felt convinced, that statements to the contrary were only likely to mislead expectation, and must end in disappointment and probably in great pecuniary loss.

Mr. PRESTWICH before endeavouring to elucidate, briefly, a few points which had been touched upon in the course of the discussion, must admit the clear definition given by Mr. F. Braithwaite of the features of water-bearing strata. He also was of opinion, that water was only obtained from chalk, chiefly, if not entirely, by infiltration through fissures, and along the beds of flints; that although chalk was a rapid absorbent of moisture, it did not readily part with it again, nor in its normal condition would it afford a free passage for water, therefore it could not be correctly denominated a water-bearing stratum; whereas sand could be correctly so termed. The chalk was, however, in certain districts, so intersected by fissures, and had such numerous beds of flint, that practically the effect of a water-bearing stratum was obtained; in such cases the excessive pumping of one well would affect all around, as also the sources of the streams. In other districts the chalk possessed such compactness, that it was vain to hope to obtain from it, under the tertiary strata, any large quantity of water. The character of the chalk under London was as various as the depths at which it was reached from the surface. The variable densities of different portions of the chalk formation were well known. If a cavity was excavated in the upper face of a block of common chalk, and it was filled with water, it would absorb from one to two gallons per cubic foot; nor was the rate of absorption very slow, but the water rarely passed so freely as to more than drop from the under side of the block. In fact, chalk in its normal condition did not give a free passage to water. He had found by various experiments, that whilst a mass of chalk only gave passage to $\frac{1}{16}$ ths of a cubic inch of water, in the same time 3840 cubic inches would pass through an equal mass of sand. He therefore agreed with Mr. F. Braithwaite, that water could only be obtained freely through the fissures, but they were often so extensive and numerous as to give, in certain localities, a very large quantity of water. Throughout the areas, to the north of Maidstone and of Watford, and indeed through the whole north of Kent and of the London basin, there was a large surface of exposed chalk through which the water frequently passed freely, because of the existence of numerous fissures and crevices. In such districts it might be expected, that the pumping at one well would in some measure decrease

the water in others around, an effect which had been particularly observed between Maidstone and Sittingbourne, where, however, the chalk rose to an elevation of nearly 400 feet above the level of the Thames. Both at Croydon and at Watford, adjoining the edge of the tertiary formation, the fissures, though fewer in number, became more charged with water, although the chalk became more compact. In some places solid chalk was found close under the tertiary formation, and there no water could be immediately obtained, whilst in other cases, the chalk in similar situations was much fissured. At Mitcham, for instance, an excellent supply of water was obtained under the tertiaries, at a depth of 20 feet in the chalk; whereas at the Crystal Palace at Sydenham, the chalk was so compact that it had to be penetrated 200 to 300 feet before a fair supply of water could be obtained. The depth at which water could be obtained from wells sunk into the chalk under London was very uncertain, as fissures were reached at very different depths. The same feature was observable in and near Paris, where it was very rare that an equally copious supply of water was obtained from similar depths. In fact, at Surennes no water was found, after boring to the depth of about 540 feet in the chalk, whilst at Grenelle, it had been necessary to bore through the chalk, which was there 1,400 feet thick. Again at Saffron Walden, boring to the depth of 1,000 feet in the chalk had failed in obtaining a sufficient supply of water. It might, therefore, be stated that no general reliance could be placed upon finding a water-supply in the chalk in its normal state; it was only where there was a considerable disturbance of the strata—where they were much shattered—that it was obtained in any large quantity. Such appeared to be the condition of the district described by Mr. Barlow, and it accounted satisfactorily for the large quantities of water stated to be given out by the low-level springs at Woolwich and other places along the Thames. Such, however, was not always the case even in Kent, for at Rochester a well had to be sunk full 200 feet before the water was obtained. He conceived, therefore, that in its normal and dense state, chalk could not properly be considered a water-bearing formation. Sand, on the contrary, was essentially a water-bearing stratum; the facility of its yielding the water depending generally on the size, and therefore the collective compactness, or openness, of the grains. It was as susceptible of saturation as the chalk, but not as capable of retention of moisture, inasmuch as it gave out its water more readily. In some districts, the lower tertiary sands were mixed with clay, which interrupted the flow of water; whilst in others, they afforded a free passage. The respective facilities of solid chalk and of a rather coarse quartzose sand, for transmitting water, were about in the ratio of 1 to 6,400.

The hills between Sittingbourne and Maidstone were composed of chalk, resting on and skirting the greensands; the water-level in the wells in the chalk varied, between winter and summer, as much as 6 feet, whilst in the greensands the variation scarcely exceeded 3 inches. It was evident that the sand permitted large quantities of water to pass freely, thereby enabling the wells to draw uniformly from a large area and affording a large source of water-supply. The rain-fall must supply both the rivers and the springs, and any drain of water, by means of wells sunk into the water-bearing strata, must interfere more or less, with the supply for the springs; it was only a question of time and degree, and of how much water could be pumped out of the water-bearing strata, without overdrawing the annual supply received from the rainfall. Properly arranged, the effect might often be very trifling. Experiments had been made for testing the capability of the tertiary strata, and it had been deduced, that the supply obtained by the sinking of wells, would not be sufficient for such a demand as that of the Metropolis; because, taking these strata from Hungerford to the Isle of Thanet, exclusive of the associated clay beds, their average thickness did not exceed 19 feet, extending over 39 square miles, 18 only of which were however available for water-supply. Therefore, supposing there were wells drawing 1,000,000 gallons daily, as the replenishment by rain would not exceed 500,000 gallons, the result must inevitably be the exhaustion of the strata, and the lowering of the water-level.

The Lower Greensand was, however, of very considerable thickness, and extended over 240 effective square miles,—the greater part, moreover, was free from clay and afforded an easy passage for water. The Artesian well carried down to the Lower Greensands, at the Plaine de Grenelle, was a very interesting experiment, and inasmuch as Paris was not so favourably situated as London, the success attained there induced sanguine expectations as to the supply of water in and below the chalk formation, and which might be more readily reached here by bore-holes properly made. The well at Grenelle gave a constant supply, subject only to stoppages from the pipes becoming filled with sand, or foreign substances. The system of Artesian wells was of comparatively recent introduction for common use, and had as yet hardly afforded sufficient data, for judging of the applicability of the system, for the supply of large towns, although generally all experience yet obtained showed that, when under proper regulation, they were extremely favourable. Tours was now largely supplied with water, by means of Artesian wells; so also were many other smaller towns in France. In Venice, Artesian wells had lately been introduced with much success. There were some wells of ancient date, though not important in depth, or in yield of

water. Arago mentioned a well sunk at Lillers in the twelfth century, the quantity of whose water had been noted, and been found not to have diminished. Belidor also mentioned another well in the north of France, sunk about a century ago; this also was examined a short time since, and the supply was found to be equal to what it originally was. M. Hericart de Thury had long advocated the introduction of Artesian wells more generally. There was but little doubt, that in favourable situations, such as was afforded in and around London, the system might be very advantageously employed.

Mr. P. W. BARLOW said objections appeared to be taken to the term "water-bearing stratum" as applied to chalk. The definition he meant to give, was that of a stratum which received water at the surface, and permitted it to pass, by infiltration, to the lower beds, as distinguished from a stratum which was impervious to the passage of water. He had adopted the experiments which had been made by Mr. Dickinson, as to infiltration into chalk. Two results had been obtained. The first was $11\frac{1}{2}$ inches and the second $8\frac{1}{2}$ inches, and he had assumed the lower result, which had been used elsewhere, to show that the infiltration was less than that given by Professor Ansted.

Reference had been made to Dr. Dalton's experiments, which were said to have demonstrated the amount of infiltration to be only $4\frac{1}{2}$ inches; it must, however, be understood that these experiments were made upon different soils, whereas those of Mr. Dickinson were made upon chalk alone, and hence there would probably arise some discrepancy. The experiments had been made only upon a small scale, and it was not as yet clearly estimated what was the actual amount of infiltration in chalk, but there was reason for believing it to be very considerable. In Hertfordshire, for instance, the River Lea was formed from the infiltration of four hundred miles of chalk country; and what he chiefly desired to point out was, that in the south-eastern districts there were no springs on the surface, but as the rainfall in that locality produced an amount of water equal to the River Lea, it must be evident, that there was a large amount of water in that district, and it would be very desirable to render it useful for the wants of the Metropolis.

Mr. DICKINSON said, it had been stated that the effect of the pumping, upon the wells, in the neighbourhood of the well sunk for the Woolwich, Plumstead, and Charlton Waterworks, was not perceptible, except in the immediately vicinity of the work. Now Mr. Dickinson could state from personal knowledge, that the wells on a property, where his mother had resided for fifty years, immediately adjoining the present waterworks, were gradually drained of their water, whilst the pumping was in operation at the water-

works, but when the pumping ceased they recovered their ordinary supply of water. He would not have it generally received, that wells of that description could be pumped from, without affecting the other wells in the same neighbourhood. The district he alluded to, was covered with cottages furnished with wells, but they were too shallow to afford any test of the question. The well to which he referred, being a very deep one, reaching into the chalk, did afford a fair criterion, and was important evidence, to prove the fallacy of the statement, of the alleged possibility of drawing a large quantity* of water from a deep well, without affecting the wells and sources in the neighbourhood.

Mr. S. C. HOMERSHAM said it was quite true, that whilst the well for the water-works at Woolwich, was being sunk, and the adits being driven, the level of the water in some of the wells around was partially lowered; those wells were however shallow, and no attempt had been made to prevent such an effect. The pumps were worked very hard and continuously, during the sinking of the well, and whilst driving the adits to the east and west, for the purpose of opening into fissures and catching water; when however the pumps were only worked at a regular speed, the water in most of the wells recovered its former level, which had not since been affected. If there had been any great object in preventing this temporary draining of the wells, it could have been done, but it was not thought necessary to incur the expense. As far as he was aware of the facts, there were not now any complaints of interference with the water of the wells in the neighbourhood, except in the case of that, just mentioned, on the property of the late Mrs. Dickinson, which was situated close to the water-works. With respect to the subject of infiltration of rain-fall, which had been introduced into the discussion, he must take exception to the assumed accuracy of the inferences, drawn from the tabulated results of the experiments by the Dalton rain-gauge used by Mr. Dickinson, and published by him, in the Minutes of the Institution, as data to be relied upon.¹⁷ Two, or three years ago he made careful inquiries as to the construction and condition of the instrument, and whether it was similar to that of Dr. Dalton, when to his great surprise he found that the case of the gauge was constructed of wood, and being sunk into the ground, of course it would shrink very much in dry weather; in fact, when he examined it, the top joints had opened in some parts to such an extent that a shilling could be inserted, where the wood had shrunk; besides which there was not any recipient attached, to measure the water from the overflow pipe.

The drawing exhibited, of the sectional structure of the gauge

¹⁷ *Vide* Minutes of Proceedings Inst. C.E., 1843, vol. ii., page 160.
[1854-55. N. S.]

(Fig. 1) had been made for a Parliamentary inquiry in 1852, and the information was given by Mr. W. L. Tyers, a millwright, formerly in the employment of Mr. Dickinson, and who had actually constructed, or superintended the construction of the instrument, from instructions given to him by Mr. Dickinson.

Fig. 1.

SECTIONAL ELEVATION OF THE GAUGE USED BY MESSRS. J. DICKINSON AND CO., AT APSLEY MILL, HEMEL HEMPSTEAD, HERTS.

In Rees' Cyclopædia, article "Evaporation," the construction of a gauge by Mr. Hoyle and Dr. Dalton, of Manchester, of which the instrument at Apsley Mill professed to be a copy, was thus described :—

"They took a cylindrical vessel of tinned iron, ten inches diameter, and three feet deep; there were two pipes soldered into it, one at the bottom, the other at the top, for water to run into the bottles. The vessel was filled with gravel, sand, and soil, and

subsequently the soil was covered with grass and other living vegetables. It was nearly buried in the ground in an open situation, and provision made for placing bottles to the two pipes; in this manner it was exposed to receive the rain, and to suffer evaporation from the surface, the same as the surrounding green ground. A regular register was kept of the water which percolated, through the soil and gravel, into the bottles, and a rain-gauge, of the same surface, was kept close by, for the sake of comparison."

Thus it would be seen, that the body of Dr. Dalton's gauge was of metal, with a bottle to receive the water from the overflow-pipe, in addition to the recipient for measuring the water from the bottom of the gauge; whereas the vessel of Mr. Dickinson's gauge was made of wood, and there was not any means of ascertaining what quantity of water ran off by the overflow-pipe. It would be observed also, that immediately beneath the mould in the gauge there was a layer of 2 inches in thickness of peat, which would fill up the pores of the stratum below it, and materially affect the correctness of the record of the infiltration. In fact, the gauge could not be considered trustworthy, and therefore no confidence could be placed in its indications.

He must also record his dissent from the opinions insisted upon by Mr. Clutterbuck, in his papers previously read at the Institution, and again enunciated on the present occasion.

It had been maintained, by some authorities, that the level of the water in the chalk-wells, under London, was becoming lower every year, and Dr. Buckland had given as his opinion, in a discussion at the Institution,¹⁸ that "as the entire supply of this subterranean stock of water is derived from rain that falls on the surface of permeable strata, within the London basin, the abstraction of water from any part of this reservoir, would diminish the quantity remaining to be discharged by springs into the rivers in the vicinity of such abstraction, by the total amount of water, so transferred to any other than its natural channels."

Now on the other hand Messrs. Easton and Amos, deliberately stated, that the level of the water, in the well near Trafalgar-square, was quite as high now as when the well was first sunk, ten years since; the level of the water could be lowered during the day by pumping, but it rose again during the night, and there was not any evidence of permanent depression of the general level of the water, nor of any prejudicial effect upon the wells around. During the last few years the quantity of water extracted from that well was enormous, and yet the water remained at its original level.

It was stated, also, by disinterested observers, that there was

¹⁸ *Vide Minutes of Proceedings Inst. C.E., 1842, vol. ii., page 160.*

not any permanent depression of the level of the water in the wells at Watford. Messrs. Dickinson and Co. obtained large quantities of water from the bore-holes sunk down into the chalk, by Mr. Paten, at the paper-mills. At the well in Bushey Meadows, near Watford, the water was still overflowing. These and other cases induced the conviction, that there was not any artificial lowering of the level of water in the great body of the chalk, in and under London, except perhaps in the cases of some few wells, which, from local causes, were influenced by deeper wells recently sunk in their immediate vicinity. The quality of the chalk, under a thick stratum of London clay, varied very much, and in some places was so hard as almost to preclude the possibility of the infiltration of water.

Mr. S. CLEGG, Jun., through the SECRETARY, explained, that in his former statement he only wished to show the fact of water being absolutely abstracted, not only from the wells, but from the streams and ponds in the neighbourhood of the well, where the pumping took place; he would now add a more detailed statement.

From the 17th to the 22nd of November, 1849, the lowest gauge showed the flow in the 'Bulbourne' to be 170 cubic feet per minute; on the 22nd the pumps began to work, and on the 29th the flow was reduced to 154 cubic feet per minute,—a difference of 16 cubic feet per minute. At this time the stream was dried up for three-quarters of a mile from its source, at the commencement of the pumping.

With respect to the puddling round the steining of the well. It was performed by the workmen of the Canal Company, who were allowed ample time to execute it, and in fact it occupied them from the 16th of July to the 8th of November;—the work appeared to be extremely well and soundly executed, and as it was the interest of the Canal Company that it should be perfect, he contended there was every reason to believe that the wall of the well was rendered perfectly water-tight. The quantities stated were those of an experiment made subsequent to the puddling of the well; and it was carefully noted, that the drying-up of the bed of the stream corresponded, exactly, with the result of a similar experiment made at a period antecedent to the puddling.

Mr. DICKINSON reiterated his previous statement, as to the continued depression of the water in the well adjoining the premises of the Woolwich Water-works Company, and legal proceedings would have been commenced, but for the decease of the occupier of the property.

The statements as to the defective construction of his gauge, were very incorrect; it had been made from the instructions of Dr. Dalton; the case was made with staves and hooped like a barrel, and being originally perfectly water-tight, was not likely,

whilst it remained buried in the damp earth, to have shrunk to such an extent as that the joints should have opened as had been described; indeed such was not the fact; the top rim, above the ground, had rotted from alternate wetting and drying, but beneath the surface the whole vessel was in its original condition and was still perfectly water-tight. The object of Dr. Dalton, in attaching to the overflow-pipe of his gauge a recipient for measuring the surplus water, was to obtain a record of the quantity of water presumed to have run off the surface of the ground during storms, and to prevent too large a proportion being attributed to evaporation. Mr. Dickinson's object being merely to ascertain what portion of the rain-fall did infiltrate to a certain depth in the earth, it was not considered necessary to complicate the question, by measuring also the water running off the soil at the top of the gauge; the use of a recipient at the end of the overflow-pipe was therefore discontinued, as it was observed that very little if any water passed. The table of results, therefore, merely recorded the total rain-fall, as given by the common rain-gauge, and the quantity registered by the buried gauge as having filtered through the soil, to the bottom of the vessel; the difference was assumed to have been carried off by evaporation, or by vegetation.

The drawing of the gauge, now exhibited, had been got up for the purposes of a parliamentary contest, and was not correct in its details; which were stated to have been supplied by a person who had been discharged from Mr. Dickinson's employment. Larger gauges of cast iron had been in use for two years, and their results quite confirmed those of the former gauges.

One glaring error in the drawing was the layer of peat, shown below the upper layer of mould; now, he must state, most positively, that no peat at all had been put into the gauge, and that the arrangement of the soils had been that which was considered most absorbent, in order to arrive at as true results as possible.

The differences between the indications of the gauges, during two succeeding years, were very striking; one year 19 inches and the next year only 3 inches were indicated; this discrepancy must arise from some peculiar state of the atmosphere, or of the soil, or a combination of both; the surface might be very dry and hard, and the rain heavy and not of long duration, with subsequent great heat, or drying winds, which would occasion rapid evaporation, before the rain had time to percolate to the lower strata. The summer average was less than one inch, the chief supply being from the continued rain and snow of the winter. In some months so little rain percolated as not to give any supply to the subterranean reservoir, and water could only be supplied from the chalk, or any other strata, in proportion to its infiltration to a depth far below the surface. The indications of

the gauge enabled him to calculate upon the supply of water from the streams during the ensuing season; he had always found the indications perfectly reliable, and must contend for the accuracy of the tabulated results.

Mr. BEARDMORE said, that last year there were only 17 inches of rain, in the district of the Lea: probably on the hills there might have been $1\frac{1}{4}$ or 2 inches more; but in the highest parts of Hertfordshire not more than 19 inches were indicated.

Mr. EVANS said the statements relative to the construction and the actual state of the 'Dalton' gauge at Mr. Dickinson's mill were very erroneous, and the drawing purporting to show the nature of the soils, with which the gauge was filled, was equally inaccurate. The object in constructing the instrument, about twenty years ago, was to obtain, from actual observation of the quantity of rain percolating to a certain depth, some data whence might be estimated the probable supply of water in the river, for the use of the mills. It was not therefore at all probable, that a defective instrument would have been erected; it was, in fact, built in accordance with the instructions of Dr. Dalton; the case was formed of staves jointed and hooped like a barrel; the saucer-shaped bottom was of lead, with a pipe of the same metal, for conducting the water to the graduated gauge, and the overflow-pipe was also of lead. The materials with which it was filled, consisted, at the top, of a layer of about 10 inches in thickness, of the ordinary soil of the district; then a thickness of about 15 inches of sandy gravel, gradually becoming coarser as it approached the main mass, which was composed of clean coarse gravel, perfectly free from sand and clay. It must be evident that any water, penetrating through the upper layers, would descend vertically through the lower strata, directly to the centre of the leaden cup and thence to the gauge; and even if the exterior had been defective, the water would have had a greater tendency to percolate directly to the pipe, than to pass off laterally; but the joints, far from being open, as had been asserted, were perfectly close in consequence of the swelling of the wood in the damp earth, and the instrument was thoroughly water-tight. It was found, on carefully watching the over-flow pipe, for some time after the erection of the instrument, that such an addition was useless, in consequence of the absorption of all the rain by the surface earth within the gauge; therefore when the upper portion of the staves, above the ground, gradually became rotten, no attempt was made to restore the upper ring, as the efficiency of the gauge was not at all affected by the partial decay of the upper portion. There was reason to believe, that the amount of percolating water, registered by the gauge, was really greater than existed in practice; the soil in the gauge being of a more absorb-

ent nature than that of the greater part of the surrounding country. He must therefore assert strenuously, that the statement as to the alleged inefficiency of the gauge was not accurate, or just.¹⁹

Mr. HAWKSHAW said there could not be any doubt of the possibility of the rain falling in such a manner, that none of it would reach the bottom of the gauge; it might fall slowly and irregularly, and only in a quantity equal to the actual evaporation, or violently and in large quantities, in which latter case it would run off the surface, and, as in the former case, none would percolate to the chamber of the reservoir; so on the large scale a gentle rain-fall was evaporated from the surface, and heavy storms were carried off by the brooks and rivers. He was so impressed with the correctness of this view, that he must reiterate his conviction that not more than 20 per cent. of the rain-fall found its way into the subterranean reservoirs of any district. Experiments upon the absorbent powers of chalk could not serve as guides in the case, as that stratum was generally covered with soil and grass, on the extensive downs of the chalk district; therefore unless the lower strata would absorb the moisture, as fast as it percolated through the sod and earth, a large quantity of the falling rain must run off the surface. The numerous depressions and swallow-holes, in the chalk district, served to convey the greatest portion of the rain-fall to the crevices in the lower strata. The indications

¹⁹ On the 6th April, 1855, Mr. EVANS furnished to the SECRETARY the following additional particulars:—

"On the 19th April, 1853, there were 26 feet of water in the well at Milebarn, a farmhouse in the valley of the Gade, 5 miles to the N.W. of Hemel Hemsted, and the source of the river Gade was, at that time, about 600 yards to the S.E. of the well, although earlier in the year it had been 200 yards to the north of Milebarn, 800 yards higher up the valley. As the present time the well at Milebarn was dry, and the Gade rose two miles and a-half lower down the valley, than its ordinary source during the period of full water.

"On the 19th April, 1853, the depth of water in the well at Church-end Farm, Studham, on the ridge, or space of high ground between the rivers Gade and Uer, was 61 feet 3 inches. In January, 1854, this well was dry, but it had since been deepened by about 20 feet, and there was now about 10 feet of water in it; showing a subsidence of fully 70 feet in the water level, between April, 1853, and the present time.

"On the 19th April, 1853, there was a depth of 54 feet 5 inches of water in the well at Dell Farm, Whipsnade, about a mile within the chalk escarpment, and seven miles N.N.W. of Hemel Hemsted. That well was now dry, and had been so for some months.

"The present state of subsidence was ascertained on the 19th July, 1854, after a fall, during that month, of $4\frac{1}{2}$ inches of rain.

"In the six months from September, 1852, to April, 1853, the Dalton Gauge showed an infiltration of 10·74 inches, from a rain-fall of 20·27 inches; while from September, 1854, to April, 1855, it showed an infiltration of only 2·45 inches from a rain-fall of 9·32 inches.

"These facts elucidated the dependence of the subterranean supply on the fall of rain, and the present exhausted state of the reservoir was practically felt in the loss of water-power at the mills."—EDITOR.

of Mr. Dickinson's gauge could only be approximative, as the only water, finding its way to the reservoir, was the surplus which percolated through the mass after it had become saturated, and in fact that which passed by the crevices; if the lower portion of the gauge had been filled with one block of chalk, it was a question whether any water at all would ever have reached the reservoir; so that with the exception of clay, or a similar soil, it was almost immaterial as to what the gauge was filled with, provided the upper layers would permit the rain to traverse, and the lower layers contained crevices. It was a fallacy to assume that by puddling the steining of the upper part of a deep well, it was possible to prevent the pumping from affecting the streams of the district; that must be an erroneous view of the case, unless it was assumed that there was a subterranean manufacture of water, or a vast and deep reservoir whence it could be drawn with impunity; if the water percolated from the surface, no puddling could prevent the springs from being affected; the fact was, that all the water taken from any wells, whether deep, or shallow, would otherwise have found its way out by streams, so that if a fresh well was sunk, it was evident that it must, more or less, affect some previously existing wells, or the flow of some neighbouring stream. With regard to chalk itself, a very large proportion contained no water at all. Those who in constructing railways had examined chalk cuttings, knew very well that it was nearly the driest formation through which they could excavate; very frequently, at depths of 60 or 80 feet in chalk, scarcely any water was found; therefore he must contend, that the calculations of chalk containing any given number of gallons of water per cubic foot, must be regarded as erroneous, except under certain peculiar and exceptional circumstances, of the strata being pervaded by crevices, or beds of flints, serving merely as conduits. Whether a cubic foot of chalk was capable of absorbing one gallon, or twenty gallons of water, was foreign to the question. The quantity pumped out of it was just that quantity which must otherwise have escaped somewhere, and exactly to the extent the supply was drawn upon by any new well, would a diminution occur in the quantity running out naturally at some other spot. This principle would be found to apply equally correctly to the Wandle, or the Colne, or any other similarly circumstanced river.

Mr. P. W. BARLOW was aware of the fact of the greater portion of the chalk district being covered by green-sward and soil, and of a portion of the rain-fall being conveyed to the lower strata by the swallow-holes, which probably communicated with the crevices in the chalk. It must be observed, that in the districts of the south-east of England, there were scarcely any streams, but there were large beds of clay, the water flowing from which

was received by swallow-holes into the chalk; some of these occurred near Canterbury and others to the north of London, and thus the chalk not only received the water from the surface of the chalk downs, but also from the clay which overlaid that stratum. Mr. Dickinson's experiments could not be open to the objection that they had shown too small an infiltration, and yet the paper had been objected to, although the lowest result quoted by Mr. Dickinson had been assumed as a standard; indeed in taking $8\frac{1}{2}$ inches, Mr. Barlow thought he had gone too low. The river Lea, in Hertfordshire, which received the drainage of 400 miles of surface, would show that such was the case. It was argued, that more water escaped out of the chalk, under the clay, into the sea, than was actually exhibited in the river Lea; but on examining a district devoid of streams, it would be found, that there was an amount of water fully equal to what was represented by the river Lea, which was above the 20 per cent. assumed by Mr. Hawkshaw, and which Mr. Barlow believed to be too small a result.

Mr. DICKINSON said he had carefully estimated, from the Ordnance map, the extent of country which he considered to be the feeding-bed of the Colne, and had found, that the delivery of water into the middle branch of that river, corresponded, as nearly as possible, with the estimated quantity received into the chalk, as assumed from the indications of his gauge. The experiments had been carried on, with a view of practically ascertaining what would be the probable supply of water for the mills, during the summer months of each year; and in fact the flow, or yield of the river, corresponded with the quantity estimated from the area of country feeding that stream; this might not be a perfectly accurate test, but the result corresponded so nearly with the indications of the gauge, as to be received as accurate by the whole district. The experiments made by other observers, in different situations, showed a smaller quantity of percolating water, than was indicated by his gauge, but the results they obtained, corresponded, as nearly as possible, with the surface of the country and the various strata, through which the water had to percolate in the respective localities.

Mr. PRESTWICH announced, that the lower greensand formation had just been reached in the Kentish-town well, at a depth of 1114 feet from the surface, or 940 feet below Trinity datum; it was a coarse clayey sand, interstratified with red clay and sandstone, which prevented the water from rising; at present the auger had only penetrated a few feet into that stratum, sufficient to demonstrate the fact of the gault being traversed, and in a short time the correctness, or the fallacy of the views of the anticipated quantity of water to be derived from the lower greensand, would be proved.

The various chances of obtaining supplies of water from chalk might be aptly illustrated by the geological conditions presented in many mining operations, where in certain rocks metalliferous veins irregularly swelled out for short distances and then disappeared, rendering the success of the operation very uncertain; whilst in another series,—where the mineral formed a sedimentary stratum for instance,—the miner not unfrequently arrived at beds which might continue, with nearly the same thickness and yielding identical results, over many square miles. So with water in the chalk,—in some places the fissures were large and water abundant, whilst in other parts no water could be obtained, whilst in beds of sand water must necessarily percolate freely in all directions. It now remained to be ascertained, whether the lower greensand was sufficiently permeable to allow the water to pass to the Kentish-town well, from Surrey on the one side, and from Bedfordshire on the other, so as to render it available. Such a result had been obtained in some instances, at short distances from the outcrop, but the well of Grénelle was the only case, where the outcrop was at so great a distance as 100 miles from the place where the well was sunk. In London, the outcrops were not more than 25 to 35 miles distant from the Kentish-town well.

In questions of this kind, it was essential to have exact data to guide the calculations on the probability of the supply, and hitherto there had scarcely been any data as to the permeability of the various strata; therefore Mr. Dickinson's experiments must be considered of great value, in showing the results for a certain district; the results would however vary essentially as the geology of the country changed, and in accordance with the nature of the outcrop, so would be the probability of infiltration of water; it was therefore necessary to prosecute investigations over various parts of the country. The earliest recorded experiments were those made at the end of the last century, when this question of springs was discussed, rather with reference to the now exploded theory that they were not dependent upon rain, and when also the geological structure was not taken into consideration. It was then estimated by Lahire, that there was only a percolation of 6 inches during three years; whilst Marriotte attempted to show that at no time did the water percolate to a greater depth than 2 feet. Buffon stated, that in a pile of earth exposed for fifteen years, the water had at no time penetrated more than 3 feet. But all these experiments were made only with the surface soil; and though of value to the agriculturist, as showing how retentive of moisture various soils might be, they did not fairly meet the present question. The geological structure of the country must be considered both together with, and independently of the surface soil. In the chalky districts of Wiltshire, there were not in

some places more than 3 inches of soil upon the chalk; in some places the rocks were bare and denuded, while in others they were covered by more or less permeable drift. This caused the percolation to be excessive in some places, and in others exceedingly small. The surface soil was formed by the mixture of the debris of the outcropping strata and by the decomposition of vegetable matter: it was generally retentive of water. In some experiments made to ascertain the relative powers of percolation through surface soil and sands, he took three tubes 15 inches in length; one was filled with surface soil, another with the lower tertiary, and the third with greensand, and taking the percolation of the surface soil as 1, he found that of the lower tertiary sands to be 1·73, and of the lower greensand, 4·5. In addition to the experiments made by Mr. Dickinson, there were those of Mr. Charnock and Dr. Dalton; but they were made chiefly with reference to agricultural objects, and in the new red sandstone district. The surface soil and *débris*, consisting of gravel mixed with a large proportion of marl and clay, was more retentive than the gravel of the London district. Mr. Charnock's experiments were in fact specially made for the Royal Agricultural Society, with a view to ascertain at the same time the amount of percolation, and of evaporation in the vegetable soil. Notwithstanding the turning of the soil to represent ploughing, the percolation amounted to 19 or 20 per cent.—about half that obtained by Mr. Dickinson.

The solution of the problem which he hoped would be presented in a short time at the Kentish-town well, depended also upon the area of the outcrop of the lower greensand. The Artesian wells in the tertiary sands, below London, had been in existence for some years, but they had been too heavily drained to afford now a sufficient supply. The effective surface area occupied by those sands was about 24 square miles, and their average thickness, excluding the subordinate clay beds, was 19 feet; whereas the area of the lower greensand was 200 square miles, and the thickness 200 feet,—a difference so great, that he anticipated a result equally dissimilar in the water supply.

The well at Grénelle had raised the question of an intermittent supply. There was no doubt of its being somewhat intermittent, but it must be remembered, that the well was commenced in 1833 and was not finished until 1841. There were long intervals in the work, therefore it was not so perfectly executed as it would be at the present time, and if done at once. When the boring had passed through the chalk and arrived at the gault, the tubes were not sunk to the full depth of the boring, and the water rose to the surface before the latter part of the bore-hole was protected. A large quantity of sand was forced up along with the water, and the

tube was choked up for a time, but subsequently the passage had become comparatively uninterrupted; still he believed the work had never been rendered perfect, and would always be liable to temporary stoppages of the pipe, as a disconnected pipe of only about half the size of the tubing had been inserted at the end of the bore-hole, consequently the velocity of the water through the smaller lower pipe being diminished, when it passed into the larger upper pipe, induced a deposition of sand, which thus tended to choke the tube. There were, however, some wells at Tours, which were sunk into sands of the same geological position, and had been in operation fifteen years, during which time the flow had been uninterrupted and without variation. That was a fair test of the results to be obtained from strata of the same nature as those under Paris and London. At Cambridge there were many wells in the lower greensand, the supply from which was abundant. A remarkable case, as to the yield of water from sand, was alluded to by Mr. Robert Stephenson, in a report to a projected Metropolitan water company in 1841, where he incidentally mentioned, that in one bed of sand in the coal measures, 14,000,000 gallons of water were pumped daily.

Mr. RAWLINSON observed, that large tracts of land had been drained to a depth of 6 or 8 feet, from which the rain ran off very freely; after very dry weather, it would require one, or two days of heavy rain, before the water reached the drains at depths of 6 feet. He agreed with the remarks as to the uncertainty of the results in well-sinking, and numerous instances might be cited in corroboration of this position. The depths to which it was necessary to sink for water, must depend upon the nature of the strata; it was, however, a common error to suppose that it would suffice to go sufficiently deep to insure an abundant supply. There were shafts which had been carried to depths of 1,200 and 1,800 feet into the red sandstone and the coal measures, which were essentially regarded as water-bearing formations, but in each case the lower strata were dry, therefore bore-holes might be made, even into the inferior strata, without obtaining water. He would not pretend to contest the general aptitude of chalk for absorbing and retaining water, because he could state, from his own experience, that it sometimes gave out very large quantities. In the neighbourhood of Portsmouth, Havant, and Bedhampton, there were springs which yielded probably not less than 100,000,000 gallons of water per day. Nature provided in her own way for discharges of water, and would not always yield it as, and when required; well-sinking was always an uncertain undertaking, especially when very large quantities of water were sought for, and in almost all cases it would be safer to seek for regular and large supplies from the surface.

Mr. P. W. BARLOW agreed with the observations just made; his calculations of the water-bearing capability of the South-Eastern district were founded upon similar reasoning, and he was convinced of the correctness of his views. With respect to the dryness of chalk, he believed he had executed more cuttings in that stratum, than any other engineer, and he looked upon the general dryness, above the water-level, as a proof of its being a water-bearing stratum. He had made six tunnels in the Thanet sand, or lower London tertiary, and from the almost invariable dryness, near the surface, he was induced to believe in the water-bearing capability of the inferior strata. In bringing his paper before the Institution, chiefly with the object of eliciting a useful discussion, he had endeavoured to avoid giving a partial view of the case, nor did he aver, that the present supply of water was insufficient, but it was admitted, that the consumption, in London, doubled every twenty-five years: therefore the subject must be regarded as one of considerable importance, and he hoped that the district he had pointed out would eventually be rendered useful, in augmenting the supply, for the Metropolis.

Mr. SIMPSON, —President,—said with respect to Mr. Clutterbuck's description of the chalk as a water-bearing strata, it must be observed, that the masses of solid chalk became saturated with water, but did not give it out freely; it was therefore in the fissured, fractured, and porous chalk that the principal conduits must be wrought; that stratum, however, was not generally so open, or cavernous in its structure, as the lias and other limestone.

In the Isle of Wight, many positions of the chalk might be seen, which conveyed clearly to the geologist the character of the underlying strata. In the Undercliff there was a great mixture and confusion, and large masses had fallen close to the edge

Fig. 2.

of the sea. Near Ventnor there were some singular disturbances, where, in consequence of repeated slips, the chalk and the greensand appeared at three several elevations, as shown in

the section, Fig. 2; the cause of this mixture of strata was very evident.

It was necessary to mark, distinctly, the difference between the chalk with flints and that of more compact character without flints. So far as his observations extended, Mr. Simpson believed the largest supplies of water were to be found in the latter, although the percolation might not be so rapid; the lower beds of the chalk formation appeared, with few exceptions, to be entirely filled with water, and in those districts there were large tracts entirely dependent upon the porous nature for absorption. The rain and snow falling on the outcrop of the strata, percolated downwards to the blue clay, and hence the accumulation of water, until it rose to such a height as to flow out upon the adjacent lands, in the shape of springs; thus small rivulets might be discovered at the foot of nearly every chalk hill.

The percolation of water in chalk was obstructed by a variety of accidental circumstances in the strata; dense continuous masses of block chalk were frequently met with; calc-spar might so abound as to impede transmission, and the faults were sometimes filled with clay and other impermeable earth.

In the north of London, the water produced from the chalk, by means of wells, did not amount to any considerable quantity. In fact the wells now yielded, collectively, less than eight million gallons per diem, and the level of the water had certainly been sinking during the last thirty years. The late Mr. Beaufoy first drew Mr. Simpson's attention to this circumstance, in the year 1824, at which period the water rose, in the deep spring wells, when not affected by pumping, to within 10 feet of H. W. M.; whereas it was now 60 feet below that level.

The southern and south-eastern portion of the Metropolis, to which Mr. Barlow had directed the attention of the meeting, appeared to offer many advantages, and the water was now at times very abundant, especially after wet seasons and heavy rains. The same condition was, in fact, the characteristic of the chalk on the west of the Metropolis, when first tapped, many years ago, but the multiplication of Artesian wells, especially at Hammersmith and in that vicinity, soon demonstrated that the supply was not so abundant as had been supposed, and the sinking of a well, or boring, from 2 to 3 feet below a previous one, in many instances drew off the water, even where not more than two, or three gallons per minute were permitted to flow from the new Artesian well. The same remark might indeed be made, relative to nearly all the Artesian wells; those which were sunk to the greatest depth, and the water from which was drawn at the lowest levels, robbed the others of their supply. In Cambridge this was particularly the case, until at last few persons could get the water to rise, from

Artesian wells, even into the cellars of their houses, although for some time after the springs were first tapped, several of them rose from 15 to 20 feet above the ground.

Wherever Mr. Simpson had any opportunity of examining the chalk strata and the springs issuing from it, he had found considerable fluctuation in the quantity of water, and where such a supply, as one or two million gallons per day, was required, it would be found extremely difficult to command it at all seasons.

The subject possessed great interest, not only for the profession, but for the public generally, and it was desirable that all who had devoted attention to the water-bearing capacity of any district, or particular geological formation, should transmit to the Institution the results of their investigations.

December 12th, 1855.

JAMES SIMPSON, President,
in the Chair.

THE discussion upon the paper No. 919, "*On some peculiar features of the Water-bearing Strata of the London Basin*," by Mr. P. W. BARLOW, having been renewed, was extended to such a length as to preclude the reading of any other communication.

[ANNUAL GENERAL MEETING.]