HORIZONTAL WELLS.

'There is a great dearth of water for all in the town; all the wells are dried up, and no one knows that they must take away the large square stone by the fountain in the market-place, and dig underneath it, and that then the finest water will spring up.'—*The Three Crows.*

'Then the soldier went out and told the people to take up the square stone by the fountain in the market-place, and to dig for water underneath; and, when they had done so, there came up a fine spring that gave enough water for the whole town.'—*Ibid.*

'Be so good as to find out why our fountain in the market-place is dry and will give no water. Tell us the cause of that, and we will give you two asses loaded with gold.'—*Giant Golden-Beard.*

HORIZONTAL WELLS.

A NEW APPLICATION OF GEOLOGICAL PRINCIPLES

TO EFFECT

THE SOLUTION OF THE PROBLEM

OF

SUPPLYING LONDON WITH PURE WATER.

BY

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OF THE GEOLOGICAL SURVEY OF ENGLAND.

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SYNOPSIS.

THE materials made use of in the following paper will be arranged in chapters under certain headings, viz.:—

1. To show need of a fresh supply of drinking-water to London.
2. Sketch of Geological Principles on which the proposition contained in this paper is based.
3. The Principles applied to the case of London. Account of Geological Formations from which supplies may be drawn.
4. Account of the excellent quality of their waters.
5. Statement of the main Proposition—How to obtain the largest possible proportion of quantity of Rain falling upon them.
6. Positions and heights above sea-level of Galleries.
7. Calculations as to probable quantities to be collected by them.

All details will be found to fall under one or another of these heads.

An Appendix, embodying the result of such observations as I have been able to make, has been added since the writing of the paper.

PREFACE.

Enough evidence is brought forward in the following pages to show that the larger accumulations of permeable beds are capable of yielding to subterranean galleries quantities of water far exceeding that which could be drawn from their surface. Before any definite measure of this quantity can be given, we require to register, and put together, a series of observations, such as the following: A large number of experiments on the permeability, absorbent and retentive power of the different formations. In addition to this,

1st. A daily register of the rainfall.

2nd. A daily register of evaporation from the various soils.

3rd. A daily register of the quantity absorbed in Dalton's gauge.

4th. A daily register of the amount flowing out as surface-springs.

5th. A daily register of the height of the water-line.

With these particulars, for a sufficiently long period of time we could estimate,

1st. The exact quantity passing down under the Gault and Tertiaries—now wasted.

2nd. The exact effect of the rise and fall of the water-line, and its value at different heights.

3rd. The exact quantity to be delivered by springs on any particular day, months beforehand.

4th. The maximum quantity that might be drawn off without causing the springs to cease flowing.

The importance of being able to predict the quantity of available water during droughts, and the quantity of storage on which we have to depend for supplies, cannot be too highly estimated in questions of water supply; and until we have a series of observations, as above, we can only form an approximate estimate as to the quantity likely to be available at the close of a long period of non-absorption.

Evaporation has the power of drying springs, which it exercises quite independent of the head of water which caused the spring to flow. My Epsom gaugings prove this beyond a doubt. On March 22, 1873, the Church-street Bourne mentioned below ran dry. The water-line in the chalk then occupied almost identically the same position as when the spring was running ten gallons a minute. The following week was hot, and the surface dried till the roads were clouds of dust. Still a slight rise was manifested in the water-line, and for days it stood higher than it did during part of the time when the spring was flowing.

As long as the soil was supersaturated, the water brought down by the channel of the spring flowed on the surface, but when it was dried by the great heat of the sun, the water was diffused through the porous surface and evaporated. Independently of their enormous practical value, the high scientific interest added to the subject by a series of such observations as I have pointed out, should in this age of advancement be their sufficient recommendation.

Looking forward to a time when the necessities of the rapidly advancing population of our numerous large towns outstrip the supplies which can be gained from surface collections, I venture to express the confident hope that a series of such observations may be authorised by Government, and an observatory for the purpose established on the lower greensands of Surrey. The pecuniary saving which will arise from causing the same natural reservoirs to furnish larger supplies than at present is incalculable. The great practical advantage of supplying each district from its own basin furnishes an additional recommendation for the system of collection recommended in the present pages.

HORIZONTAL WELLS.

I.

London Water-Supply.

WITH regard to the need of a fresh supply of drinking-water in London, it is not my intention to go over more of what has been said before than is absolutely necessary for the particular object I have in view.

I shall discuss the subject under two heads—the first in respect to the quality of the water now brought into London, and the second as regards the quantity necessary for present and future consumption.

Under the head of quality will be treated the amounts of organic and inorganic matters in the water; of which the organic impurities have a far greater influence upon health than the solid mineral contents.

In accordance with the order of arrangement adopted in the Report of the Commissioners on Water Supply, 1869, the solid mineral contents of the water will be first treated of, and afterwards the organic impurities.

'The mineral or inorganic contents of the Thames water supplied by the Companies from Hampton appear to amount usually to from 15 to 20 grains per imperial gallon of water, of which more than one-half is carbonate of lime, and the rest sulphate of lime, with salts of magnesia, soda, potash, and silica, and traces of alumina and iron. The waters of the Lea Valley, as supplied by the New River and East London Companies, differ little from those of the Thames; but those of the Kent Company, being drawn directly from the chalk, contain a considerably larger quantity of the salts of lime.'[1]

'The point connected with these mineral contents, which is of main importance in our present inquiry, is their influence, chiefly caused by the presence of lime, in giving to the water the peculiar quality called hardness.'[2]

'The effects of hardness have been discussed, in regard to the use of the water,

'*a.* For drinking.
'*b.* For culinary purposes.
'*c.* For washing and manufacturing.'[3]

a. From the evidence taken before the Commission, the Commissioners are of opinion that 'there is no reason whatever to suppose that the hardness of the Thames water would be in the least degree prejudicial to health.'[4]

b. For culinary purposes the inconvenience consists chiefly in the incrustations formed in kitchen boilers and pipes, as well as in kettles.[5]

c. For washing and manufacturing purposes the 'evidence is conclusive and cogent as to the great advantage of soft water over hard for washing, and, with some few important exceptions, for general manufacturing purposes.'[6]

Thames water, and that from the chalk, have the advantage of not acting on lead or iron. Great inconvenience has been caused by the action of soft water on both those metals in the pipes of certain towns.[7]

As regards quantity of solid matter in the waters, London is worse off than fifteen out of twenty-seven towns, of which Glasgow is best off; London waters reaching 20·17 grains per gallon, against only 1·90 grains per gallon in Glasgow. (Fig. 1.)

Of hardness, Metropolitan waters average 13·0 deg. against 1·0 deg. in Glasgow; but, after boiling, London waters show only 4·5 degrees. (Fig. 2.)[8]

'On the whole,' the Commissioners write, 'we cannot see that the advantages of soft water, in respect of manufacturing, are of sufficient

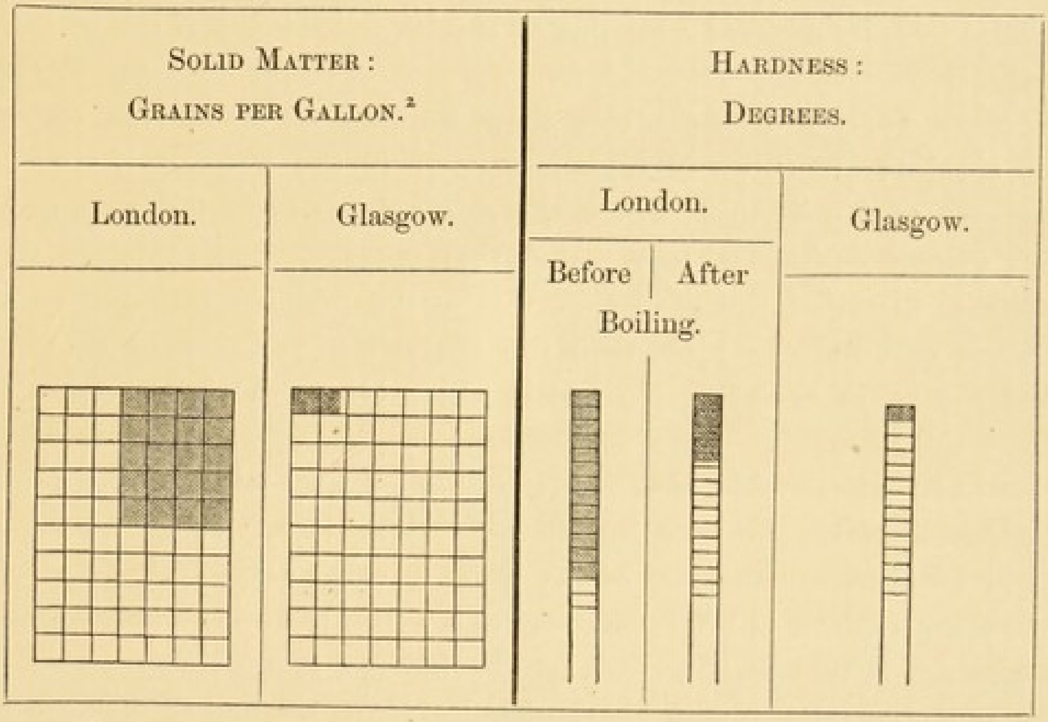
[1] Report of Commissioners, 155, p. lx., Royal Commission on Water-Supply, 1869.
[2] Report, 156, p. lx. [3] Report, 161, p. lxii. [4] Report, 165, p. lxvi.
[5] Report, 169, p. lxviii. [6] Report, 173, p. lxxi. [7] Report, 174, p. lxxii.
[8] Appendix A. G., Table V. p. 77.

importance to justify going to a great distance to obtain it, in place of the ample supply nearer at hand.'[1]

To recapitulate results. For drinking purposes hard and soft waters apply equally well. For culinary purposes soft waters have advantages over hard, as well as for washing and manufacturing purposes.

Therefore it is clear that, if a softer water could be obtained within a reasonable distance of London, since the advantages which it possesses for general purposes are in almost all cases superior to those possessed by harder waters, sufficient justification is thereby offered for taking

Fig. 1. Fig. 2.



prompt measures to obtain it, in place of the harder waters now drawn from the Thames.

In respect to the quantity of organic impurities, London falls very low, being worse off than twenty out of twenty-seven towns. It contains 1·10 grains per gallon, against 0·07 grains in Preston and 0·30 in Glasgow. Southport and Guildford show 2·63 and 2·50 grains per gallon respectively, and occupy the lowest position in this respect.

It must be remembered that 'the effect of organic matter in the water depends very much upon the character of that organic matter. If it be a mere vegetable matter, such as comes from a peaty district,

[1] Report, 173, p. lxxii.

[2] The tablets represent 70 grains, or 1-1000th of a gallon.

on being exposed to the air the vegetable matter gets acted upon by the air, and becomes insoluble, and is chiefly deposited, and what remains has no influence upon health; but where the organic matter comes from drainage, it is a most formidable ingredient in water, and is the one, of all others, that ought to be looked upon with apprehension when it is from the refuse of animal matter, the drainage of large towns, the drainage of any animals, and especially of human beings.'[1]

The supreme importance of obtaining a water for drinking purposes quite free from organic impurities is shown, not by mere chemical analyses of waters with and without them, but, if they can be had, by medical statistics of results following the use of both kinds.

Mere analytical tables can show nothing of themselves, except the absolute quantities of organic matters in the waters. If, as in the case of the Thames, where the original purity of the springs in this respect is known, it is found that, after natural oxidation and artificial filtration, the proportion due to the previous introduction of sewage still remains high, then the analysis is valuable, as showing that the water is not so pure as it was prior to the introduction of the sewage.

That 'considerable sewage contamination may take place without indication of its presence by nitrites and nitrates,'[2] is a fact which deprives chemical analyses of any claim to value as indications of the wholesomeness or unwholesomeness of a water, more especially as 'the noxious part of sewage exists there in the form of minute germs which are probably smaller than blood globules,'[3]—so small that they are as yet beyond the reach of chemical science. 'With microscopic living organisms, especially, chemistry is incompetent to deal.'[4]

When we know, as a fact, that a river such as the Thames receives in its course various contributions from town sewers, the above considerations compel us to admit that, if a purer water can be obtained within a reasonable distance of London, no justification could be found for not using prompt measures to obtain it.

'The discharges of cholera patients cannot be filtered out of a water by a degree of filtration never attained by the water companies,'[5] and

[1] Dr. Lyon Playfair, Minutes of Evidence, 2681.
[2] Report, 194, p. xciii.
[3] Dr. Frankland, Minutes of Evidence, 6244.
[4] Report, p. 194, xciii.
[5] Dr. Frankland, Minutes of Evidence, 6240.

'when water is once contaminated with sewage, there is no process to which it is afterwards subjected that will effectually remove all that sewage contamination from the water.' These are facts which point cogently to the conclusion that 'it should be made an absolute condition for water supply that it should be incontaminable by drainage.'[1]

Now, not only is the Thames water not incontaminable by sewage, but it does receive large quantities from various sources.

The conclusion is, that the admission of town sewage into a water, however pure originally, at once unfits that water for drinking; and, as sewage is introduced into the Thames, that river is not a proper source from whence to draw supplies of water for drinking.

Apart from the question of health, I feel that it is altogether loathsome and revolting that persons should lie under the disgusting necessity of drinking water that ever has been sewage, as the inhabitants of the districts in London supplied from the Thames are now doing. The act of supplying 'water into which sewage has been discharged is an experiment on the health of the population, and obviously that experiment ought not to be tried.'[2] Moreover, as much disease must of necessity be introduced into the Thames in the sewage, and as we do not know how long the eggs or germs may be capable of living after the resolution of their vehicles into nitrites and nitrates, and as they can pass undetected by the most searching chemical investigation, it is, to say the least, culpable to supply water from it if better is to be had.

In reporting on the general effect of Thames water on the health of the population of London, medical statisticians have overlooked the fact that water is not the staple beverage of the inhabitants. Dr. Letheby says, 'My opinion of the London waters is founded, in the first place, upon the monthly analyses of the waters over a long period of time; secondly, upon an observation of the use of those waters very extensively: and I am bound to admit that there is no evidence whatsoever that those waters are in any way objectionable as a public supply. I am now speaking of the whole of the Metropolitan waters.'[3]

The effect might be more manifest, were all the inhabitants water-drinkers. We have no measure of the amount of disease taken up in the water from the Thames at Hampton, as much of it is rendered

[1] Mr. Simon, Minutes, 2812. [2] Ibid. 7141.
[3] Dr. Letheby, Minutes of Evidence, 3879.

innocuous by boiling, brewing, mixing, &c.; and though the water may be pure enough, in a general sense, when most of the population only rarely drink water, yet the evil effects at present due to it would have to be multiplied many fold were all the inhabitants water-drinkers. This consideration is an important one when dealing with the question of health, for the worst effects are those to be considered, and not the average effect on a mixed population of water-drinkers and persons who rarely touch plain water. The average result is deceptive, and tends to lower the standard of purity of water requisite; thus causing the bad results to fall very heavily upon those who drink much water. No tables are at hand to help out this line of argument, but the ultimate result is plain, and may be thus stated: that, until it can be proved that the noxious qualities of sewage all disappear on the oxidation of their vehicles in a water, it is a dangerous experiment to offer that water for drinking, even after the oxidation of the sewage; and no chemist or medical man has, as yet, any right to say that such a water is harmless. This is the case with the Thames.

To recapitulate. Much sewage finds its way to the Thames above Hampton, the point from whence the Companies draw their supplies; though this sewage is nearly entirely oxidized before then, still so much of it remains in the water as to leave the water far less pure than it exists at points near the springs from which the river derives: therefore it is capable of further purification than it receives before delivery in London. Medical analysis cannot pronounce upon its ultimate purity, since it cannot detect the presence of minute living germs of disease or organisms in a water, and therefore cannot tell whether some may not survive till the water is again imbibed. As such organisms are probably mostly killed by the process of boiling, brewing, &c., the water is thereby rendered pure enough for general consumption when mixed; but the standard of purity requisite for the water to attain to is thereby lowered. This lowering of the standard is in itself bad; and, since the above remarks apply to the Thames and the water taken from it, it would be safer to condemn that river as a source of supply, and quit it if a better can be found within a reasonable distance of London.

With respect to the quantity of water required, Mr. Bateman and Messrs. Hemans and Hassard remark that 'it is scarcely possible for the Companies to afford a supply much larger in quantity or better in quality than that at present furnished.' 'They will hardly be permitted to increase the draught from the Thames.' 'The limit they can attain has nearly been reached; and if the Metropolis is to have a supply of pure water, it is high time to secure a suitable district from which to attain it.'

The truth of these remarks received remarkable confirmation in June, 1872, when there was 'a great dearth of water in South London, from the 16th to the 23d, owing to the lowness of the Thames above Teddington Lock.'[1]

Mr. Bateman considers no scheme worthy of consideration that would bring in less than 200,000,000 gallons a-day at an elevation which would supply the whole of the Metropolitan district by gravitation, without pumping. Messrs. Hemans and Hassard express the same opinion.

However, I hope to show in the present paper that there is another way of effecting the supply of London, by gravitation, and without necessarily drawing the whole supply from one district, and at a cost which, for its comparative smallness, does not subject my proposed scheme to the overwhelming objections that prevented the adoption of either Mr. Bateman's or Messrs. Hemans and Hassard's schemes.

Retrospect of the Year 1872 *and part of* 1873.

Various articles and letters have appeared in the daily papers since the completion of the inquiries instituted by the Royal Commissioners on Water Supply and the publication of their Report, which show with greater or less force the unsatisfactory quality of the water supplied from the Thames.

Not to go farther back than last year, I find the Vestry of St. Mary, Newington,[2] complaining of the quality of the water supplied by the Southwark and Vauxhall and the Lambeth Waterworks' Companies. This was stated in explanation to be owing to the water having been imperfectly filtered during the progress of alterations in

[1] Whitaker's *Almanac*, 1873. [2] *The Times*, March 9, 1872.

the Companies' works, at a time when the water was rendered more foul than usual by heavy floods.

'Mr. Frank Bolton, the water examiner, appointed under the "Metropolis Water Act, 1871," in a letter to the Board of Trade, thus alludes to the result of the chemical analysis by Dr. Frankland of the water supplied to the Metropolis during the month of January 1872, contained in the weekly return of the Registrar-General. . . . . 'Doubtless the organic elements are in the water, but the organic matter is so changed into harmless inorganic compounds, that it becomes a question whether it can in any way be considered as prejudicial to the quality of useable water.'[1] The *Pall Mall* adds, 'Whether this expression of opinion will reconcile people to drinking organic elements remains to be seen; but beyond the question of the quality of the water supplied to us remains that of cost; and even if the Companies clear themselves of the charge of homicide, they still have to deal with that of extortion. Under present arrangements only the wealthy can afford to be teetotalers, and total abstinence is a luxury far beyond the reach of the poor.'[2] This notice indicates *the low opinion in which the water supplied by the Companies was held early in last year.*

Again, on April 16, we find evidence of the same feeling. An article appeared in the *Times* containing the following passage:—'As long as they (the said Companies) are content with their present intake, it is not likely that their filter-beds will ever be fairly abreast of the demands upon them.' The Lambeth Waterworks Company were then proceeding with works for securing water from above the confluence of the Mole, with a view to avoiding the water of that river, a step towards which they were urged by the necessities of the case. This, with numerous other cases, may be cited to show *that the Companies have not the power to refuse to provide a better supply of water as from time to time required.*

At a Meeting of the Metropolitan Board of Works (reported in the *Times*, May 11th, 1872), great dissatisfaction was expressed at the mode proposed by the Companies for providing a constant supply. The 'constant supply,' as given by the Companies, was denounced as a farce; and it was shown that not more than two gallons could be obtained in fifteen minutes under the system then in use. The delivery pipe or aperture was so small as not to admit a stocking-needle.

In a letter to the *Times*, of June 3rd, Dr. Frankland, replying to

[1] *The Times*, March 9, 1872. [2] *Pall Mall Gazette*, March 11, 1872.

one of Dr. Letheby's, published the day before, says, 'By analysis I get out of the waters supplied to London a certain quantity of solid matter, some of which, if not always noxious, is at any moment liable to become so; the rest of this solid matter is utterly useless for all purposes to which potable water is applied in London, and by far the greater part of it acts injuriously in the operations of washing and cleansing.' He shows that Dr. Letheby himself prefers water which is free from these matters, quoting the words, 'It (the water) contained a very small proportion of saline matter, which I regard as an advantage. . . . The water was absolutely free from organic matter, and it was very soft. I am of opinion, from these results, that the water is very wholesome, and is well adapted for all domestic purposes.' Dr. Frankland then defends his use of the term 'previous sewage contamination,' and states that 'water polluted by the sewage of Windsor, Reading, and Oxford, has ample time to reach the intake of the water Companies before the animal matter is destroyed, and the results of my analyses are entirely in conformity with the conclusion that it does so reach the intake.' . . . 'When the London waters are delivered to consumers in an imperfectly filtered condition, I see in them, sometimes with the naked eye,—generally however with the aid of the microscope,—living and moving organisms; but I have never found them in any water that has been efficiently filtered.' . . . 'The presence of living organisms of any kind in water which has been polluted by sewage implies the possibility of the presence of those zymotic germs which are not recognizable by the microscope, but which are believed by almost all our physiological and medical authorities to be the cause of epidemic disease.'[1] Dr. Frankland considered it to be his duty to declare and report frankly the facts which his examinations reveal. Thus we see that *in June* 1872 *Dr. Frankland considered the London waters to be unfit for domestic use.*

On June 18th the *Globe* commented on the difference existing between Dr. Frankland and Dr. Letheby as regards the length of time required to oxydize sewage introduced into water.

On June 22nd a public meeting was held in Bermondsey, when the

[1] 'The ova of worms are at times conveyed into the system by water, and it is always dangerous, therefore, to drink the waters of rivers into which water-closet sewers empty. There is no reason to believe that these ova . . . . are oxydized; instead of being destroyed, they may be sustained by oxygen.'—Dr. FARR, 33*rd Annual Report of Registrar-General*, 1872.

scarcity of water in the neighbourhood was made the subject of grave complaint. It was resolved to draw up a memorial for presentation to the Board of Trade.

In the *Times* of October the 11th, 1872, is given a quotation from the *British Medical Journal*, in which 'Mr. Wanklyn writes to say that the water supplied by the Southwark and Vauxhall Drinking Water Company is remarkably impure at the present time. According to his analysis it yields in 100,000 (?) parts[1]—

	Analysis 1.	Analysis 2.
Free Ammonia . . .	0·06	0·06
Albuminoid Ammonia . .	0·13	0·12

There ought not to be more than 0·02 of "free" and 0·06 of "albuminoid" ammonia. The presence of the excess of free ammonia shows very recent sewage contamination. As will be remembered, this Company has been uniformly supplying bad water ever since the year 1867, when delicate analyses of the water were first made.' *Here then we have evidence of the bad quality of the water supplied in October* 1872.

In November a step was made by the East London Water Company towards effecting a constant supply over their district. They published 'such information as will enable the local authorities, the owners and occupiers, &c., to understand the duties imposed and privileges conferred on themselves and the Company.'[2]

So far unsatisfactory were the arrangements, as Mr. Marcus Beresford points out in a letter to the *Times* on Nov. 29, that 'A company for building workmen's dwellings was prevented from building one block at the East End of London eighty feet high, because the East London Company would only deliver water forty feet high.' Mr. Beresford brings forward facts to show that the present condition of the water supply is as dangerous to property as sanitary authorities represent it to be to health in the event of any epidemic visitation. He says, 'At the present time not one quarter of the mains throughout the metropolis are kept charged to meet any great fire.'

Here, then, in November, we have evidence of the deficiency in quantity of water kept for immediate use in case of emergency.

Captain Shaw writes in the Report upon the year 1872, 'In my Report of last year I ventured to express a hope that the constant-

[1] '1,000,000' in the *Times*. [2] *Times*, Nov. 21, 1872.

service provision of the new Water Act would have at least the effect of making every fire-plug represent an immediate supply of water: but although this Act was supposed to come into force on the 21st of April last, I regret to have to mention that I am unable to point out as much as one instance in which the work of the Fire Brigade has been affected by it, and that in fact, as far as our business is concerned, the Act remains still, at the end of more than eight months, wholly inoperative.'

At a meeting of the Whitechapel District Board of Works, it was resolved unanimously that it would be oppressive to require compliance with the regulations authorized by the Board of Trade in respect to fittings providing for a constant supply.[1] A similar resolution was passed at the Mile End Old Town and the St. George's-in-the-East Vestries. This mode of arrangement for a constant supply, though a matter of detail, points to a want of regard for the public, and a selfishness on the part of the Companies much to be regretted.

Dr. Frankland, in the Public Health Report in the *Times* of January 2nd, 1873, states that 'the waters of the Thames and Lea, *even after filtration*, are unsuitable for consumers' use.' Mr. James Odams points out the fact that the manure of market gardens, sewage farms, phosphate sewage works, is sent into the Lea; and that, as no provision had been made for flood-waters by the sanitary engineers employed upon the river, the result is, 'That the vast population at the East End is condemned to drink these very waters, though charged with an amount of sewage unequalled before the regulations were enforced.'[1]

It appears that this state of things must recur every time there is a flood.

In the *Pall Mall Gazette* of January 23rd, 1873, there appears the following article. After explaining that the Lambeth Vestry considered the regulations in respect to constant supply as 'oppressive,' 'vexatious and conflicting,' the *Pall Mall* adds, 'Judging, however, from the last Report of the Medical Officer of Health for this district, *it is perhaps as well that the supply is at present only intermittent.*' A number of cases of typhus fever have occurred, and, on analysis of the water, the medical officer reports it as 'unfit for domestic use, unless thoroughly filtered.'

The Shoreditch Vestry have condemned the regulations as unneces-

[1] *Times*, Jan. 3, 1873.

sarily expensive, and totally inapplicable to the class of houses for the benefit of whose inhabitants they were intended. The Mile-End Vestry, the District Boards of Works for Whitechapel, Limehouse, and St. George's-in-the-East, have passed resolutions expressing their strong disapproval of the regulations. This wonderful unanimity on the part of the local authorities certainly seems to indicate something more than usually exacting in these regulations; and if this is the case, the sooner the attention of Parliament is called to the subject the better.[1]

In Whitaker's *Almanac* for 1873 the following occurs, at page 243:—'*Pure Water.*—The Reports of Government Medical Officers and others during 1871–1872 lead to the belief that *the greater part of the water-supply of the Metropolis is utterly unfit for domestic use.* It is generally loaded with animal or other organic matter, arising from its contamination with sewage in the rivers from which it is drawn. Dr. Frankland has invented an ingenious filter, which not only makes the water clear and transparent, but greatly purifies it from organic matter. In the absence of such a filter, water should be boiled and allowed to remain till cold in the open air before used for drinking purposes.'

The Chelsea Waterworks Company have lately been engaged in forwarding a scheme for constructing a large new reservoir on lands belonging to Lord St. Leonards, near the confluence of the Mole with the Thames.

Had the Company succeeded in carrying out their scheme, they would have been going to an enormous expense to achieve the storage of the bad or indifferent water now provided by them; and I urge that the same necessity which drives them to undertake this vast work offers an assurance of a safe market to other persons who may contrive any scheme for conveying supplies of pure water into London.

The following is a summary of the returns as to the composition and quality of the Metropolitan waters in January, 1873, made by the Association of Medical Officers of Health:—

[1] This was written before the publication of the Minutes of Evidence relating to Constant Supply, taken before the Board of Trade, 1873.

	Total Solid Matter per Gallon.	Oxygen required by Organic Matter, &c.	Nitrogen.		Hardness.	
			As Nitrates, &c.	As Ammonia.	Before Boiling.	After Boiling.
Thames Water Companies:	Grains.	Grains.	Grains.	Grains.	Grains.	Grains.
Grand Junction .	20·30	0·134	0·166	0·003	15·0	3·8
West Middlesex.	20·83	0·112	0·181	0·001	15·4	3·8
Southwark and Vauxhall	20·13	0·141	0·146	0·004	15·0	3·8
Chelsea . .	19·40	0·130	0·146	0·004	15·0	3·8
Lambeth . .	20·27	0·163	0·130	0·004	15·0	4·0
Other Companies:						
Kent . .	27·80	0·010	0·234	0·000	20·5	5·8
New River. .	21·27	0·076	0·167	0·000	16·3	3·6
East London .	23·83	0·109	0·204	0·001	17·0	4·2

Note.—The amount of oxygen required to oxydize the organic matter, nitrites, &c., is determined by a standard solution of permanganate of potash acting for three hours; and in the case of the Metropolitan waters the quantity of organic matter is about eight times the amount of oxygen required by it.

The water was found to be clear and nearly colourless in all cases but the following—when it was slightly turbid—namely, Chelsea, Grand Junction, Lambeth, and Southwark and Vauxhall Companies.

The average quantity of water supplied daily to the Metropolis during the preceding month was, according to the returns of the water Companies to the Association of Medical Officers of Health, 100,931,281 gallons; and the number of houses supplied was 500,229. This is at the rate of 30·3 gallons per head of the population daily.[1]

Table I. (Appendix) contains analyses of the waters drawn from springs flowing from rocks from which it is proposed in the present paper to obtain supplies for at least part of London.

In comparing the columns showing the quantity of nitrogen as nitrates, and as ammonia, we see that the water from the deep chalk

[1] *Times*, Feb. 4, 1873.

well of Caterham contains less than that of two chalk surface springs, and less than any water supplied by any of the Companies after filtration. The minimum quantity in Caterham well is ·027 grains in 100,000; the maximum ·551 is attained by the Croydon well, which, being in the centre of the town, is unavoidably exposed to filtration, though tubed some distance down. A well in Lower Greensand, at Moor Park, contains only ·034 grains.

In themselves the nitrates are harmless.

Of ammonia, the waters of the Kent Company, drawn from deep chalk wells, as well as those of the New River Company, and that from Caterham Well and Amwell Spring, contain none.

As Prof. Frankland's results are given in respect to 100,000 parts, and those of the Association of the Medical Officers of Health are given in respect to an imperial gallon of 70,000 grains, I have reduced the latter by proportion to Dr. Frankland's scale, as far as the ammonia column is concerned.

The following table is arranged in order of magnitude of the quantity of ammonia:—

Parts of Ammonia in 100,000.

Kent	·000	Caterham Well . .	·000
New River . . .	·000	Amwell Spring . .	·000
		Croydon Well . .	·001
		Moor Park Well . .	·001
West Middlesex . .	·0014		
East London . .	·0014		
		Otter Springs, Watford .	·002
Grand Junction . .	·0043		
Southwark and Vauxhall	·0057		
Chelsea . . .	·0057		
Lambeth . . .	·0057		

On the left hand are arranged the names of the present supplies, and on the right hand those of the positions from which waters are proposed to be drawn in the present paper. The quality of the waters proposed to be brought into London is represented by that of the deep wells standing at the head of the list. The Kent and New River waters are from deep wells and chalk springs. The Chelsea Waterworks Company are now endeavouring to provide for a larger supply of the disgusting commodity known as Thames water, standing at the bottom of the list. The state of the case is well expressed by Mr. W. Watts, the Hon. Sec., to the Committee, for opposing the Bill in Parliament, in a letter to the *Times*, Feb. 5th, 1873. He says,—

'The ample supply of pure water to the Metropolis, with its 4,000,000 inhabitants, must before long engage the attention of the Legislature, and it is worth serious consideration whether any further interference with the Thames banks by Water Companies should be permitted.

'It is an ascertained fact that no amount of filtration can get rid of the soluble impurities of the most noxious and disgusting nature now contained in the Thames water, and which must continue to increase with the growth of the large and populous towns on and near to the Thames and its tributaries.

'Are the inhabitants of London for the next twenty years to drink the polluted water of the Thames, instead of pure spring water, which can as easily be supplied to them?

'In his annual report the Registrar-General states that London, within its widest limits, has now upwards of 4,000,000 souls, and had in the middle of 1872, within the limits of the Health Returns, 3,311,298 inhabitants. The estimated increase of population was 44,839. The average mortality of the year was 21 per 1000, and the Registrar-General explains the disappointment that may be felt that the figure does not descend, as it ought, below 20, by the fact that much of the water supply of the metropolis is still drawn from the Thames.'[1]

During the year between March 1873 and March 1874 various similar notices have appeared. According to Dr. Frankland's report, the water supplied in London in March 1874 by each of the Metropolitan companies—except the Kent, New River, and West Middlesex—was slightly turbid, and contained in each case living and moving organisms. Such water is, Dr. Frankland assures us, *not fit to be used for dietetic purposes.* All the leading papers have expressed the strongest indignation at this hopeless state of affairs, but they have not said half enough.

[1] *The Daily Telegraph*, March 27, 1873.

II.

Statement of the Geological Principles upon which the Proposition contained in this paper is based.

1. The crust of the earth, where externally formed of sedimentary rocks, consists of alternations of hard and soft, or porous and non-porous beds, or formations.

2. Experience shows that where these sedimentary beds crop out at the surface, water sinks into those which are porous, and flows upon those which are impervious to water.

3. The tendency of the water is to sink through a permeable bed, under the influence of gravity, till it reaches the top of an impervious bed, when it will flow down the dip of the beds. The power which it may have of following this tendency will be regulated by,—

(i.) The porosity of the mass of the bed, and the power which it has of retaining, by capillary attraction, the maximum quantity of water which it can take in by virtue of its porosity. Thus water filters at once through sand, but, in the case of chalk, which can hold two gallons of water in a cubic foot of its own mass by mere capillary attraction, the rate of transmission is so slow that it takes four or six months to pass from the surface to the line of water-level at the depth of 200 to 300 feet.[1]

(ii.) The frequency or non-frequency of divisional planes of bedding.

Thus water would sink more nearly vertically through the massive uniform bed, *a* (fig. 3), than it would through the flaggy bed, *b* (fig. 4),

[1] Prestwich, Anniversary Address to Geological Society, 1872.

Fig. 3.

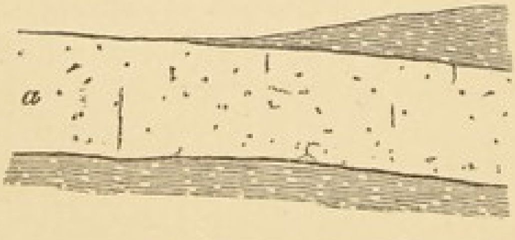
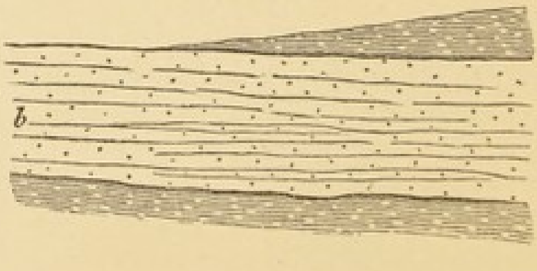


Fig. 4.



in which the direction of its flow would coincide mainly with the planes of bedding; and the angle which a particle of water, in its descent through the bed, would make with the vertical would be regulated by the individual porosity of the bed *b*.

(iii.) The occurrence or non-occurrence of vertical fissures, or joints.[1]

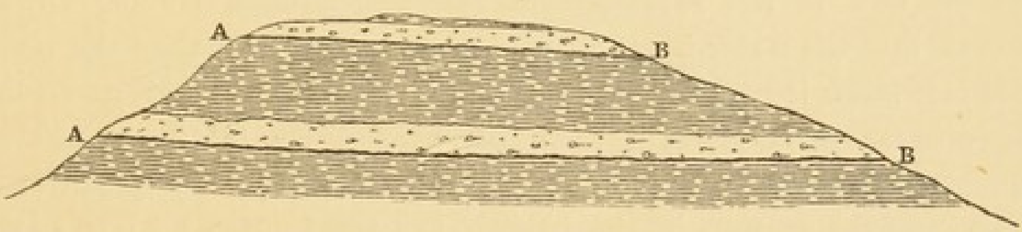
(*a*.) Hard beds, whether limestones or sandstones, are usually jointed in a greater or less degree. Sometimes the joints run parallel, and one set is then not unfrequently crossed by another nearly at right angles, so that large blocks are cut out by them; at others, however, the joints are near together, and cross each other at all angles, so that the mass of the rock presents the appearance of being much shattered.

(*b*.) In soft rocks, from their nature, open joints do not occur; so that, though a bed of sandstone may be much jointed, the shales above and below it may be quite free from them. The effect of this will be to collect water at the base of the sandstone, when it will flow down the top of the shale or clay below.

4. In consequence of this difference of porosity of different beds, springs which break out at the surface mostly do so from the line of junction of a porous and an impervious bed, when the porous bed is uppermost, or, in other words, from the base of the porous bed. This is regulated, in a great measure, by the dip of the beds in relation to the neighbouring ground.

a. In fig. 5, where the beds are not dipping so fast as the slope of

Fig. 5.



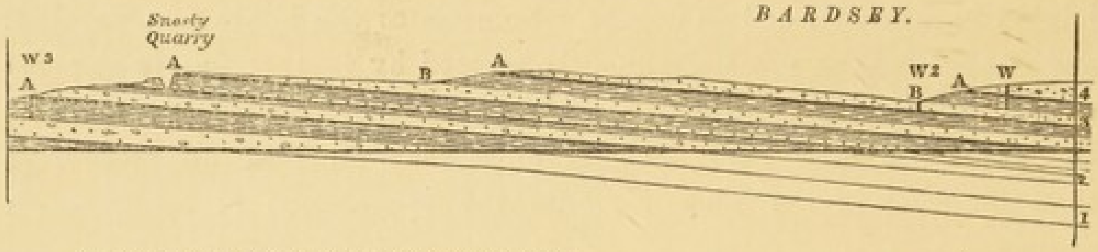
the ground, permanent springs will break from the positions B, but only few, except at times of great rain, from the positions A, when the reservoir will be full.[2]

[1] The effects of faults will be considered separately later on, and may therefore be omitted here.

[2] Although the fissures in a porous bed may be numerous, an intercommunication does not necessarily exist between them all. Thus, when all points on the outcrop of a bed are not of the same elevation, it often happens that some of the lower lying

b. If the beds are dipping faster than the slope of the ground, springs will still break mostly from the absorbent beds, but not necessarily mostly from their base. They will be found to issue from the body of the bed at the surface, and from its top, or the line along which it is covered up by a higher impervious bed. In fig. 6 springs

Fig. 6.



Section from the Millstone Grit—6 inches to a mile

will be thrown out permanently from the positions A and B, and from the intermediate surfaces of the porous beds. Their number will, of course, vary with the season; but a relation exists between the number of permanent springs issuing from the base, body, and top of a porous bed, and its thickness, area exposed, and the lengths of its base and top lines, as well as with the dip, the slope of the ground from A to B, and the relative heights of A and B.

Now, all the water that has been absorbed upon the surface A B (reading from left to right) does not escape again at lower surface-levels. A large quantity filters down with the dip of the bed, in obedience to gravity, and ultimately becomes, by hydrostatic pressure, forced out to sea. That which does escape by surface-springs is only an overflow of the subterranean reservoir of each porous bed, and means that the water is supplied at the surface faster than the porous bed can allow it to pass down. A well sunk at the point W would have to go as far as the top of the next sandstone below (D, fig. 4) before it would reach water, and it might have to go farther if any part of the surface of the ground in the immediate neighbourhood lay at a lower level than D; whereas a well sunk at W^2 would probably meet with water soon, and would be certain to do so at the base of the sandstone.

If the plane of the dip remains constant, the yield to the well W

springs are the first to run dry, from which it appears that each vent is in connexion with a separate set of fissures, and when the water in those fissures falls below the level of the vent the spring will run dry.

will bear a direct relation to the breadth of the exposed area A B, as long as the point D lies above the line of permanent saturation, a broader exposure offering a larger absorbing surface. Thus the well W^3 would not gain so much water as W and W^2, though the difference would be slightly lessened by the accession to bed No. 1 of the water that flows down the face of the superincumbent shale, furnished partly by rainfall on the shale and partly by springs from the base of bed No. 2.

This last figure, variously modified,[1] represents the general case; and it is the rescue of the wild waters contained in the subterranean reservoirs 1, 2, 3, 4, for the purpose of utilising them, that forms the object of this paper.

Note.—In the above statement details of experiences have been omitted, so as not to encumber the after parts of the paper with repetitions. Thus several illustrations of the truth of the foregoing principles will be found to occur naturally under the next head.

[1] See for instance Fig. 8, p. 22.

III.

Application of the above Principles to the Subject of the Water-Supply of London or other Towns.

Miners find, as a matter of experience, that the strongest feeders of water, which flow into shafts sunk through alternations of porous and impervious beds, come from the line of junction of a porous and an impervious bed, at the base of the porous bed. This junction is sometimes found to have been so eaten away by the water flowing down the impervious bed, that a thick stick might be thrust between the two beds in many directions from the sides of the shaft.

When the shaft is a deep one, and many beds, say of sandstone, which is porous, and shale, which is impervious, are passed through, each bed of sandstone yields its quantum to the total amount of water in the shaft. In one shaft which passed through fifty fathoms of sandstones (with partings of clay), at a depth of twenty-five fathoms, water flowed in at the rate of 1900 gallons, and at a depth of fifty fathoms from the surface at the rate of 3500 gallons per minute.

Some of the collieries in the Durham coalfield, which have shafts sunk through the magnesian limestone, are troubled with as much as five thousand gallons a minute. So great, however, is the imperviousness of shale, that five feet of it at the bottom of a shaft forty or fifty fathoms deep through the limestone, will turn back that amount of water, allowing none of it to pass through.

In a certain shaft, not a coal-pit or on the Durham coal-field, 168 feet of porous strata are passed through, below which 396 feet of absolutely impervious shales. A level which cuts the shaft at the top of the shales, carries off the water from the beds above at the rate of 400 gallons a minute. This water is now used by the proprietors of the mine, and a saving to them is thereby effected of 1000*l.* per annum.

The shaft is sunk to procure a certain stratum, but were water the object, in this as in all other cases, it would certainly be followed along its bed, at the junction of the sandstones with the shales, by levels in a manner similar to that in which the ordinary water-levels of a mine a[illegible]rried along the bed mined for. Nothing could exceed the purity of water that has been filtered through hundreds of feet of pure quartzose sandstone. The springs of clear water that break from the base of sandstones at their outcrop, in all formations, give striking proofs of the truth of this statement. The waters drawn from wells sunk in such beds, of which analyses will be found below, also corroborate it.

If, then, a large town require water supplies, and at no great distance from it there lies a formation containing alternations of porous and impervious beds, which rise above the level of the town, then there should be no difficulty in supplying water at high pressure on the constant system. Such formations occur within easy reach of London.

The lower greensands of Surrey form high hills, two of which, Hind Head and Leith Hill, rise to 894 and 967 feet respectively. Another part of the ridge rises to 800 feet, west of Leith Hill.

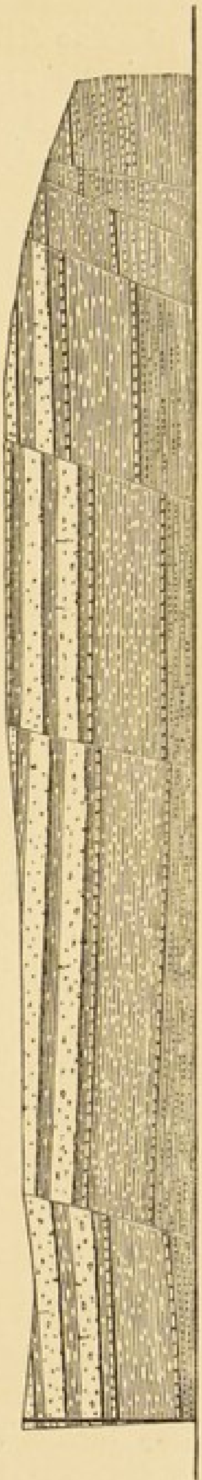


Fig. 7.

The lower greensands in Surrey consist of a series of highly porous sands, sandstones, and limestones, 400 feet thick. The Folkestone sands and the Hythe Beds, resting upon a bed of absolutely impervious clay, the Atherfield clay. All the water that sinks through the porous beds of the formation must flow down the top of this bed. This was found to be the case in the Sevenoaks tunnel. The lower part of the Atherfield bed is an impervious clay, but the upper part is sandy, 'and this upper portion contains a vast amount of water, which was a source of much difficulty to the excavators,'[1] and 'which pours out in a fully formed stream from the tunnel's mouth.'[2] A gallery driven along the strike of the beds, or water level, must of necessity arrest all the water that is flowing down it as far as the gallery is carried.

[1] Caleb Evans, Proc. Geol. Soc. vol. ii. p. 2.

[2] W. Topley, Geology of Straits of Dover, p. 9.

The subdivisions of this formation have been thus described by Mr. Topley, of the Geological Survey of England, who surveyed them, in ascending order.

1. The Atherfield clay. Impervious.
2. The Hythe beds. Alternate beds of limestone and calcareous sand. Highly porous.
3. The Sandgate beds (not always present in Surrey). Clay and sandy clay. Compared with the Folkestone beds above them, they are impervious to water, but much less so than the Gault. (See below.) Their outcrop is frequently marked by a line of springs, and the water of wells sunk through the Folkestone beds is held up by this division.
4. The Folkestone beds. Sand, which is highly porous, water passing through it with great rapidity.

Thus, from the Folkestone beds down to the top of the Atherfield clay, there are two porous and two impervious beds. Sometimes, as in Surrey, the upper of these impervious beds is wanting, leaving the Folkestone and Hythe beds as one pervious series; the Folkestone beds much more so than the Hythe beds.

We have, in fact, in the lower greensands of Surrey, a combination of the circumstances most favourable for gathering and storing water. The height of the range attracts a high rainfall; the breadth of the absorbing surface causes much of this to be absorbed. The thickness of the porous beds, owing to the absence of the Sandgate beds, affords a large reservoir for water absorbed. The complete imperviousness of the retaining clays, Atherfield and Gault, prevents the escape of these waters, which are thus held in a subterraneous reservoir, whose lowest rim is at the deepest valley cutting through the Gault clays.

Upon the Folkestone sand lies the Gault, which is a stiff bluish and blackish clay, wholly impervious to water, and makes a strong dividing line between the partially porous beds above and the alternations of highly porous and partially impervious beds below.

The upper greensand is a permeable bed, or one through which water passes with tolerable freedom. From its thinness in Surrey it is of no value there; but as it becomes thick and well developed in Wiltshire, it may be made a source of supply to towns in that neighbourhood.

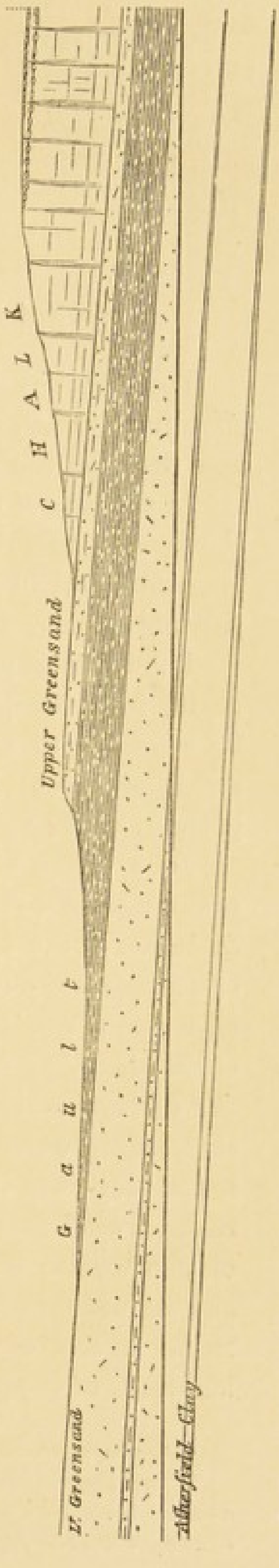
The chalk-hills south of London also rise to 800 feet, and form a slope northwards for seven miles, terminating at about 100′ above sea at the lowest part; that is, between Ewell and Croydon. Here also the absorbing surface is very large, and the storage capacity is very great.

'The upper chalk is more pervious to water than the lower chalk, in that the water does not pass at all readily through the mass of the chalk, but runs along joints and fissures, and especially along the lines of flint. In sinking wells through the chalk, it is frequently found that water is got at some of the bands of flint, whilst the intermediate bands of chalk are either without such water, or else allow it to pass much more slowly. The lower chalk, as regards water, consists of an upper and lower division, of which the upper resembles the upper chalk, save that flints are absent. The lower part is less pure in composition, contains some clayey matter, &c.,'[1] and is probably quite impervious to water.

Further remarks on the nature of chalk in its relation to its water-bearing capacities will be found under head VI.

[1] W. Topley, Geology of Straits of Dover.

Fig. 8.



Partly from Geol. Surv. Section, Sheet 76.

IV.

Account of the excellent Quality of their Waters.

The physical capabilities of the chalk and lower greensands for affording storage and supplies of water having been mentioned, I will now describe the quality of the waters derived from each.

In the case of the chalk-water, it is universally felt and admitted in the London neighbourhood that, except for its hardness, it is in other respects equal in quality to any water. As a beverage it is a very palatable drink, and is preferred in London before any other.

London is at present supplied with chalk-water in the eastern parts. Apart from the question of profit, on account of its hardness, it would be advisable to subject water drawn from the chalk to a process of softening, invented by Dr. Clark, of mixing it with lime-water, in the proportion of 40 gallons of lime-water to 400 of chalk-water.

In a letter to the Duke of Richmond[1] Mr. Clark points out the advantage of softened chalk-waters over all others. He says, 'The exclusion of the scourings of occasional showers, and the entire absence of animalcules and other organisms, are very signal advantages, and at once put a mark of superiority on the waters raised from the depths of the chalk.'[2] 'It is also on account of the prevailing temperature of the springs, which around London is generally about 50° Fahrenheit, that spring water from the chalk derives its superiority. Each spring keeps very near its own normal or standard temperature all the year round; whereas any river or other surface-water, such as may now or may hereafter be brought into London, will in summer be too hot and in winter too cold for drinking, and moreover will in winter be liable to cool down below the freezing point, thus causing numerous burstings of the pipes by the freezing of the waters they contain, &c.'

[1] Appendix C. Royal Commission on Water-Supply, 1869.

[2] 'Mr. Dugald Campbell states that the water of the shallow chalk wells invariably contains a notable quantity of nitrates, whilst that of the deep chalk wells contains scarcely a trace.' Appendix, p. 21.

The evidence brought before the Commission showed that, though the waters flowing off hard and insoluble rocks were, from their much greater freedom from mineral matter, more economical for many domestic and manufacturing purposes, yet for drinking purposes waters such as those derived from our chalk and oolitic districts were, on the whole, as good and wholesome as those derived from any other sources.

Table I.[1] shows the results of analyses of chalk and lower greensand waters.

The water from the deep well at Caterham contains the minimum of impurities attained by any potable water except rain-water.[2] This well passes through the lower chalk and the upper greensand; half the water comes from the chalk, and half from the upper greensand.[3]

The only possible objection to these waters is their hardness; but this may be got rid of, to a very great extent, by Clark's process. As regards the applicability of this process to large quantities of water, Mr. Homersham, who has had very large experience in the matter, says,[4] 'If you take spring-water—which, as I have said before, is essential to the success of this process—you may apply it to any quantity of water. It is much easier to apply it to 100,000,000 gallons a-day than it would be to 1,000,000 gallons a-day, inasmuch as the adjustment of the exact quantity of lime to the water is much more easily accomplished on a very large than on a small scale.'

Generously considered, there cannot be a shadow of doubt that water from the chalk supplied to London should be previously softened. The great expense of the process is much to be regretted, as 'this softened chalk-water is entitled, from its chemical quality, to a preference over all others for the future supply of the Metropolis.'[5]

The Croydon and Kent Waterworks distribute the waters of the chalk in an unsoftened state, and doubtless at first the water from the chalk, taken in the manner proposed in the present paper, must be so delivered to consumers, though at Caterham the softening process is now carried on.

The waters from the lower greensand are as pure as any natural water could possibly be. They have been long ago pointed out as a

[1] Appendix to this paper. [2] Prestwich, Anniv. Address to Geol. Soc. 1872, p. 46.
[3] S. C. Homersham, Minutes of Evidence. [4] Minutes of Evidence, p. 407, 6787.
[5] Report of Chemical Commissioners, 1851, p. 54.

suitable store from which to supply part, or otherwise, of London. The right method of obtaining them has, however, not yet been proposed.

'The quality of the water flowing from the lower greensands is excellent for all domestic purposes, being bright and limpid, of a degree of hardness varying only from about 3° to 9° of Clark's test, and generally very free from organic matter.'[1]

'The two undermentioned chemists agree in their conclusions on this point, as will be seen by the following table, the quantities having reference, in the first case, to 100,000 parts, and in the second to a gallon of water:—

		Dr. Frankland.			Prof. Wanklyn.
		Organic Carbon.	Organic Nitrogen.	Nitrogen as Nitrates and Nitrites.	Albuminoid Ammonia represents the Organic Matter containing Nitrogen.
Chalk.	Caterham Well	·020	·006	·027	000
	Otter Spring	·026	·012	·422	—
Lower Greensand.	Moor Park Spring	·030	·010	·045	—
	Cold Harbour	—	—	—	0·000

At the same time the water is kept at an uniform low temperature, and protected from light and air—conditions unfavourable to the existence of living organisms. Springs from such sources probably represent potable waters in their best state; and amongst the favourable specimens of such waters may be instanced many chalk springs, the water from the lower chalk at Caterham, and some of the springs of the lower greensands of Surrey.'

'It is satisfactory to know that there exists within easy reach of London a supply of the best and purest spring-water, which, in case of need, could readily be rendered available as an auxiliary source of water-supply for the Metropolis, in quantity sufficient, at all events, for drinking, if not for other purposes.'[2]

[1] Report of Commissioners on Water-Supply, 1869, p. xxxviii. [2] Ibid. p. 40.

The purity and excellent quality of chalk and lower greensand water are therefore seen to be admitted, and in fact pointed out, by the highest chemical authorities— a circumstance which warrants the statement that we have in them the true source of water-supply for the Metropolis.

V.

Statement of the Main Proposition.

At page 22 it is shown that a gallery driven along the strike of the beds at the top of the Atherfield clay must catch all the water that flows along the top of that bed as far as the gallery is carried. In Surrey the Lower Greensands form a range of hills from 300 to 900 feet high, cut through down to about 150 feet by a tributary of the Wey, which joins that river between Guildford and Godalming. When the Atherfield clay is reached in valleys within the Lower Greensand area, it 'then always throws out strong springs, as at Loose and Leeds Abbey in Kent, and in many valleys of the Leith Hill district.'[1]

I propose to collect water from this range by means of horizontal galleries driven along the strike of the beds on the Atherfield clay, as by that means very large quantities of water may be gained. The height of the range, and the breadth of the absorbing surface presented by it, together with the great thickness of the porous beds, all point to the suitability of the area from a geological point of view.

The great natural reservoir of the chalk of the North Downs of Surrey may also be tapped in a similar manner. The galleries will be placed in a different position, as the water bearing part of the chalk is near the top of that formation.

As regards actual experience, as regards the Lower Greensands, the case of the Seven Oaks Tunnel has already been mentioned (see page 22). That tunnel was driven at right angles to the strike of the beds, and therefore cannot be viewed as a criterion of the quantity of water to be gained by a gallery of equal length carried along the strike, on the Atherfield clay. This quantity would of course be enormously larger.

In the case of the Saltwood tunnel, the shafts were sunk through the Folkestone sands, and the tunnel is formed about the junction between those and the Sandgate beds. The direction of the tunnel is about E. 8° S., and that of the strike of the beds about E. 29° S. The tunnel is 954 yards in length, and is stated by Mr. Simms to have been driven on the same geological horizon all the way.

[1] W. Topley, Agricultural Geology of the Weald.

The tunnel is inclined towards Dover at the rate of twenty feet per mile, or 1 in 264; and the dip of the bed is towards the north-east at a much higher angle.

A heading was driven to drain the tunnel, as much water was met with on the Sandgate beds. It was when complete 1250 yards in length, as it not only extended throughout the length of the tunnel, but also under the open cutting at the east end before an outlet could be obtained for the water. A gauge was fixed at its outlet, which at first showed a discharge of 359 gallons a minute, or 516,960 per day; but this quantity afterwards diminished, and for a length of time it averaged 257 gallons per minute, or 370,280 gallons per day. The size of the gathering-ground formed by the Folkestone beds is not large, and very large quantities of water could not be expected to occur at this horizon, more especially in this case, as an outfall was found into a transverse valley, which would tend to drain the beds at lower levels.

Under these circumstances this quantity of little more than half a million gallons a-day for a gallery of 1250 yards cannot be taken as a criterion of the quantity to be expected from a gallery of equal length driven on the Atherfield clay in West Surrey.

I do not know how large an absorbing area is represented by this flow, or drained by the heading, but obviously it cannot be large, as the Folkestone beds do not form large spreads on high ground.

In the case of the chalk, the Tring cutting of the North-Western Railway, which also was driven across the strike of the beds, notwithstanding the height of the ground, yielded 1,000,000 gallons a-day.

Neither can this quantity be taken as a criterion of what may be expected for a given length of gallery, as that cutting too was taken at right angles to the direction I propose. A cutting driven across the strike cuts the water-bearing bed only once, whereas the proposed gallery will be driven along this bed horizontally all the way.

Adits or headings have been resorted to on many occasions in chalk and other wells. In Table II. a list of all I know is given, with such particulars as show the great advantage derived from them. I do not know that any of these were driven along the strike, but I do know that some of them were not.

This Table may be compared with Table IV. to show the great gain resulting from the use of galleries when judiciously placed. The Tables may be thus read:—

The well at Reid's Brewery, Liquorpond Street, in which galleries were driven into the chalk at a depth of 200 feet from the surface and 64 feet deep in the chalk, yielded 192 gallons per minute, or 101,178,000 gallons annually. The total depth of the well is 262½ feet, of which 136 feet are tertiary strata, and the remaining 126½ chalk. The shaft was carried to a depth of 222½ feet, and the remaining 40 feet were bored. Water rose in the well to a height of 121 feet below the surface, which is 70 feet above sea level. The water level therefore stands at 51 feet below sea level.

The well at Bishops Stortford, in which galleries were driven in the chalk at a depth of 154 feet from the surface, and 38 feet deep in the chalk, yields 10,000 gallons a minute, or 5,256,000,000 gallons annually. Only 25 gallons a minute came from the shaft, the remainder being supplied by the galleries. The advantage of the galleries is conspicuously pointed out by this enormous increase of supply, which would furnish exactly one-seventh of London. Seven such wells would supply the whole of London,—or rather galleries seven times as long, with equal conditions would do so

Again, in the well for the supply of Western Heights, Dover, when it was sunk to the depth of low water, no water came into the well, and in consequence a horizontal gallery was driven at the bottom of the well. After proceeding some distance a small stream appeared, two blows from the pickaxe brought it in such quantities that it was with difficulty the workmen escaped, for the water filled the shaft nearly as fast as the men could be drawn up.[1]

Mr. W. P. Barlow, C.E., found several powerful springs issuing from the chalk on the south side of the Thames; in one small district near Gravesend they amount to 10,000,000 gallons per day. He believes that *by driving a tunnel parallel with the river, twenty miles long,* from Lewisham to Gravesend, or a little beyond, 60,000,000 *gallons per day* might be obtained.[2]

This idea, which is almost identical with my own, was not acted upon; had it been there can be little doubt that it would have answered to Mr. Barlow's expectations. The work has been left for some one else to do. I am persuaded that it will be done, and that it is the only philosophical way of dealing with water supplies from the chalk.

[1] Report to Directors of London (Watford) Spring Water Company, 1850, Appendix N. S. C. Homersham, C.E.

[2] Royal Commission on Water-Supply Report, p. xxxiii.

VI.

Positions and Heights above the Sea-level of Galleries.

This question must be considered, first geologically, with reference to the horizons at which most water is likely to occur; secondly, geographically, in reference to the lowest available level attained by these horizons. First, I shall take the case of the chalk, as it is worth while at least to inquire how far it may be made a source of supply; and afterwards that of the Lower Greensands in Surrey.

Table III. should be referred to for details of some chalk wells.

Chalk.

The chalk of Surrey consists of three main divisions:—

The Upper Chalk, the Middle Chalk, and the Lower Chalk.

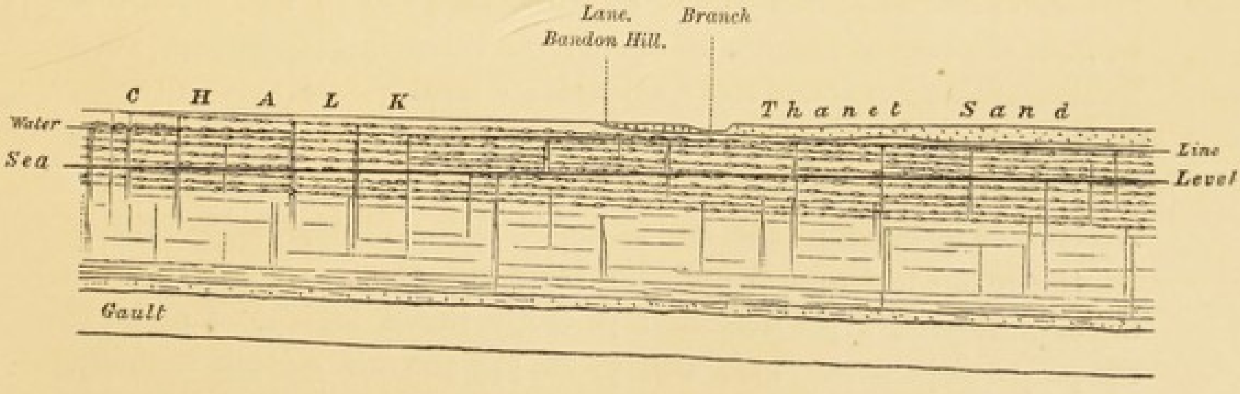
The Upper Chalk is subdivided into three parts, of which the middle one contains the greatest number of layers of flint, while the top and bottom beds have less.

In consequence of the tendency of water to follow the lines of flint, this middle part of the Upper Chalk seems best suited for our purpose, neglecting the Middle and Lower Chalk on account of the absence of flints.

Mr. Whitaker observes that it seems to be generally the case, that flints are fewer in the higher part of the Upper Chalk. It is doubtless for this reason that the wells in the London basin have to go on an average 100 feet into the chalk before they meet with sufficient water,

Fig. 9.

Epsom and Croydon—L. B. & S. C. Railway.



Partly from Geol. Surv. Section, Sheet 79.

as above that height flint layers do not occur often enough for all their contributions added together to meet the demands on the well. Therefore a gallery should be driven within that distance from the top of the chalk, so as to cut the largest number of flint layers. Now, since no acquisition of water to a porous bed can take place after it becomes covered up by an impervious bed, it is clearly unnecessary to place a gallery anywhere *under* this impervious covering. At the same time, in order not to sacrifice any of the absorbing surface, it is advisable to keep as nearly along the line of the base of the impervious bed as other considerations will allow. The limiting considerations in the case of London, are (1st) the minimum height at which a gallery could be placed to be of service to the largest area with a population of the greatest density.

Thus the most thickly populated parts of London lie on an area situated below the elevation of 100 feet above sea level.

Therefore, commercially considered, the profits of supplying those districts would bear a larger proportion to the capital expended in doing so, than would those derived from supplying the higher lying parts of the suburbs, and the rate of profits would diminish with every foot of altitude added to the elevation of the gallery above 100 feet.

Now singularly enough the elevation at which the gallery should lie to suit the most favourable commercial conditions, is precisely that, indicated geologically, at which the largest proportion of water might be expected to be gained.

For in the chalk after the coming on of the Tertiary Beds, a great diminution in the number of fissures takes place, and a consequent damming back of the waters percolating the body of the chalk.

Much of this water runs over the Tertiaries to the Thames, but below the various points of issue the chalk is saturated to the depth of about 100 feet. The elevation of the lowest of these points at Croydon is 123 feet above sea, so that a gallery driven about 30 to 50 feet below this, will cut the largest number of flint layers below the permanent water level, and lie at or about 100 feet above sea level.

Table III. is a list of wells in which details have been given as to the structure of the chalk passed through, as well as the places at which most water flowed into the wells.

In one of the Croydon wells the main spring was 40 feet from the top of the chalk, a position most perfectly suited for the elevation of the proposed gallery. This well yields 547,000,000 gallons annually, principally from this fissure—or enough to supply the whole of London for five and a half days. The yield of this and a second well pumped jointly through a common pipe is 1,103,760,000 gallons annually.

In a well at New Wimbledon, sunk 75 feet into the chalk, all the water was got in the first 25 feet, a circumstance that appears to be explained by the large number of flint layers down to that depth, and the massive structure of the chalk below, together with the comparative absence of flint layers.

On the other hand, a well in the Old Kent Road went through 70 feet of loose chalk before meeting with water, and the next 100 feet contained it.

These cases show that no general rule can be laid down to suit all cases, as to the part of the chalk which is most fertile in water. Local circumstances have the entire control over this position, and since we know the details of the Croydon wells, we may safely assert that our gallery will lie between 25 and 45 feet below the top of the chalk. If its bottom lie at 45 feet, its roof might reach as high as 30, thus giving a height of 15 feet. Its width should not be great, say five feet.[1]

The highest permanent spring at Carshalton is 111 feet above sea,[2] and the lowest probably about 100. One gallery will probably lie 100 feet below the top of the chalk in this neighbourhood, also at an elevation of about 100 feet above sea.

I will now enter upon the geographical part of the inquiry. It is of course mainly a simple hydrological one, concerning the area containing most water.

The line bounding the tertiary beds between Leatherhead and Croydon lies almost the whole way between the 100 and 200 contours. At one place, two miles east of Leatherhead, it just rises over the 300 contour, and at this extreme elevation it continues for about a mile. Between this and Epsom it falls to below 200 feet, and between Ewell and Sutton it falls to nearly 100 feet. At this height it reaches Croydon, when two fingers from it stretch up to the 200 contour again. The lowest lips of the line lie on the Mole below Leatherhead, and from about a mile west of Sutton to Croydon.

At the first of these, the Mole, water breaks out again, the river having sunk into the chalk south of Leatherhead. At Ewell a con-

[1] A well at Mitcham pierced 22 feet into the 'chalk with layers of flints every 3 feet, and abundance of water in every layer;' 'A large jet of limpid and excellent water rose several feet above the surface of the ground.'—Prestwich, Waterbearing Strata, p. 54; Mem. Geol. Surv. vol. iv. part 1, p. 550.

[2] Trinity High-water Mark, 123 feet 8 inches above Ordnance datum.

siderable stream breaks out at the line bounding the tertiaries, and flows over them to join the Thames at Kingston.

At Little Cheam another bursts up through the permeable Thanet sands, and flows over the Reading beds and London clay to the Thames above Putney.

From Carshalton eastwards, as far as Croydon, spring various sources of the Wandle; and, demonstrating the complete saturation of the chalk in that locality, the river at Waddon flows upon chalk itself for half a mile.

The distance along the line, omitting sinuosities, between Leatherhead and Croydon, is 11½ miles.

Between Leatherhead and Epsom, or in the western four miles, not one single spring breaks from the chalk at its junction with the tertiaries. From this circumstance the inference may safely be drawn that the chalk at the base of the tertiary beds is very far from being saturated between Leatherhead and Epsom, and is in fact, for our purpose, practically nearly dry.

On the other hand, from Epsom eastwards as far as Croydon the top of the chalk gives rise to five separate streams, two of which unite and form the Wandle.

Next we have to find out what part of the chalk area is drained by the outflowing streams, so as to be able to place our gallery in such a position that it will catch the drainage of the largest possible area.

Areas drained by Outflowing Streams.—The Bournes, or intermittent streams, as well as the permanent springs, break out in hollows or shallow valleys in the chalk, just at the junction with the tertiary beds. These valleys, though of some size in the chalk hills, gradually grow less and less till they disappear altogether on approaching the tertiary beds. On the chalk they are found to be partly filled with gravel composed of angular flints, which have never been rolled. These flints are the representatives of a greater or less thickness of solid chalk, which has been dissolved away along lines of underground drainage, now marked by the dry valleys. These valleys are not all of them always dry. The Bourne Valley, south of Croydon, sometimes has a surface stream. This happens after long-continued heavy rain, when the level of the water in the chalk rises above the level of the bottom of the valley. In the case of the Croydon Bourne, the appearance of a surface stream takes place only after the rainfall of the previous twelve months is over 30 inches.[1]

[1] *Times*, Jan. 8, 1873.

In a paper on the Medway Gravels, Messrs. Foster and Topley, of the Geological Survey, remark, 'The dry valleys of the chalk have usually a considerable thickness of flints in their lowest parts. These flints are entire, or, if broken, are sharply fractured by weather, never rounded or water-worn. These valleys are probably due to the dissolving away of the chalk along lines of underground drainage.'[1]

The presence of angular flint gravel in the dry bottoms of these valleys amounts to demonstration of the mode of their origin.

Starting on this basis, in order to gain an idea of how large an area of chalk drainage is represented by the Wandle, I have drawn on Map A thin lines along the lines of chalk valley, and find that the basin represented by the outflow of each chalk river — such as the Hogs Mill River, the Beverley, the Wandle, and the Ravensbourn — can be accurately determined. I have marked the boundaries of each by thick black lines on the map, and find that the Wandle basin is by far the largest. In order that no misapprehension of my meaning can arise, I explain that by 'basin,' as referring to the subterranean drainage of the chalk,—I mean the superficial area which collects the rainfall, part of which sinks and flows down under the tertiaries, and part of which flows out again in rivers such as the Wandle. This area is represented at the surface by the outflowing stream.

The areas of the various basins, as calculated by this means, are shown by the following table:—

		Areas. Square Miles.	Galleries. Miles.	
Hogs Mill River	Divisions	4½	½	Column 1 shows area of collecting ground. Column 2 the number of miles of gallery necessary to arrest the down-flow of the waters of each area.
		3	2½	
		3½	½	
	Totals	11	3½	
The Beverley		2	1	
The Wandle	Divisions	1¼		
		8	3	
		43¼	1½	
	Totals	52½	4½	
The Ravensbourn		21	4¼	

[1] Proc. Geol. Soc. 1865, p. 446.

Of these basins the Wandle is the most important, both as regards size and shape: it is an irregular triangle, having its base along the escarpment of the North Downs, and its apex near the tertiary boundary. Nothing could be more eminently favourable for our purpose, for the water collected over this large area is made to pass through a comparatively narrow pass, in which I propose to arrest it.

I propose, then, to construct two galleries in the chalk—one to gather water collected by the basin of the Wandle, and the other water collected by the basin of the Ravensbourn.

The joint area of the two basins is $73\frac{1}{2}$ square miles; and as the area of the chalk west of the eastern boundary of the basin of the Ravensbourn, as far as the Mole, is only 94 square miles, it is clear that we lose very little by neglecting the smaller basins of the Beverley and Hogs Mill River.

To obtain the waters of the joint areas of the Ravensbourn, Wandle, Beverley, and Hogs Mill River, a gallery $18\frac{7}{8}$ miles would be necessary. The joint area of these basins is $85\frac{1}{2}$ square miles; whereas, to obtain the waters of the Wandle and Ravensbourn basins, only $8\frac{3}{4}$ miles of gallery are required. The united areas are $73\frac{1}{2}$ square miles. In the latter case the number of miles of gallery is diminished by more than a half, while the area is diminished by only about one-fifth.

The probable positions of these galleries will be found indicated on Map A.

Ravensbourn Basin.—In the case of the Ravensbourn basin, the lowest point attained by the tertiary base is rather over 200 feet above sea; so that the gallery to collect the waters of this basin (21 square miles) will lie at 175 feet, or 75 feet above that of the Wandle. The water collected in this area may be made to furnish a partial supply to the higher districts which cannot be supplied from the Wandle basin without pumping.

In the case of the Wandle gallery, a short outfall gallery will be required, which will debouch into the Wandle Valley at Wallington, at 100 feet above ordnance datum. The probable length of this gallery will be half a mile.

In the case of the Ravensbourn gallery, also, an outfall gallery will be necessary, which will cut the Ravensbourn Valley at 170 feet, or thereabout.

These two outfall galleries may be adapted in size to the capacity required, and be smaller than the collecting galleries.

The Lower Greensand.

The extraordinary development of the sandy beds of the lower greensand in the basin of the Wey is shown in Table VIII.

In it they occupy an area of 108½ square miles and range in thickness from 490 feet on the west to 365 on the east side of the basin.

The Hythe Beds occupy the high ground and form the principal catchwater, while the Folkestone Sands occupy the lower parts of the northern slopes of the hill, and pass under the gault in the valley between the Hythe Beds and the Chalk.

In consequence of this arrangement the water that has been absorbed by the Hythe beds breaks out again lower down, and flows over and through the Folkestone Sands, and, breaking out all along its top line, floods the low land formed by the gault clay. This explains the number of miles of stream flowing upon the surface of each bed, which given in the more simple form of yards per square mile is greatest on the Folkestone Sands, and next on the gault.

The number of springs which break from the surface of each bed of sufficient size to form streams marked on the Ordnance Map is also seen to be greatest in the case of the Hythe beds, caused by the valleys being cut down to the permanent line of saturation. The Folkestone Sands are too loose and incoherent to produce many decided springs, but the water oozes out anywhere and everywhere at the low lines of escape.

The whole system is peculiarly 'absorbent of water which issues in springs of the greatest purity, but 50 or 60 square miles of the more elevated portions are eminently so.' These 50 or 60 square miles are occupied entirely by the Hythe Beds. 'They are arid wastes or sandy deserts in which the sand is generally uncovered by soil or vegetation of any kind, except stunted heather. Here the rain is almost wholly absorbed as it falls, abundant evidence being afforded of the large amount of rain, and the humidity of the climate by the quantity of moss which clothes the trees, and the lichens which cover the walls on the confines of the sandy commons.'[1]

The streams flowing on the lower ground determine the line of saturation, as is shown by their being fed by innumerable small springs

[1] J. F. Bateman, Report contained in a Return to an Order of the House of Lords, 1852, No. 258.

as they go. 'The Potsford stream, for instance, the whole length of which from its source in Hurtwood Common to where it falls into the Albury brook, is under four miles, gradually increases to a volume of nearly 5,000,000 gallons of water per day. After running one mile it amounts to 800,000, in another mile it is augmented to 1,400,000, and at the end of the third mile to 4,400,000.' In the third mile then it more than trebles its volume.

'Most other streams present the same characteristic.'[1] Rivers flow on the surface up to a considerable elevation. A gallery at 150′ would have a very large head of water above it.

As mentioned in Chapter II., the experience of miners shows that the strongest feeders of water come from the line of junction of a porous with an impervious bed. If placed on the Atherfield Clay the gallery might lie at 125′ above sea when it would pass beneath, or rather south of Thursley, Witley, and Hambledon, but bending to the north before reaching Hascombe would cross under the Arun, a branch of the Wey, near Shamley Green, and then traversing the broad extent to Wotton would pass south of that place to Rookery and Milton Green. Between these latter places a fault would be crossed which from throwing down on the north would probably yield very large quantities of water to the gallery. This gallery would debouch into the Mole valley.

[1] J. F. Bateman, Report contained in a Return to an Order of the House of Lords, 1852, No. 258.

VII.

Estimate as to Probable Quantities of Rainfall absorbed and retained by Basin (Chalk area) of Wandle.

The data for forming an estimate as to the proportion of the rainfall absorbed by any permeable bed are generally exceedingly defective. In the case of the chalk, however, the quantity percolating three feet of soil has been registered at Nash Mills, Hertfordshire, for forty years, and the quantity percolating three feet of chalk for twenty years. The gauge consists of an iron cylinder sunk in the ground and turfed over. A pipe at the bottom ran off the water percolating to that depth into a graduated receiver, in which it is measured. The gaugings, excepting those of the rainfall which refer to the Wandle basin, are from a paper on the 'Rise and Fall of the Wandle,' by Mr. Braithwaite, C.E., read before the Institution of Civil Engineers, 1861. The other rainfall amounts are from a Table of the Greenwich gaugings since 1815.

Table V. shows the quantity of rainfall in inches that filtered through three feet of soil, and in some cases of chalk, in Dalton's gauge, during the six summer, and six winter, months, of twenty-five consecutive years, near Watford.

The minimum fall during the six summer months was 8·07 inches, in 1844. This occurred only once in the twenty-five years. The quantity absorbed or percolating Dalton's gauges was 0.

The minimum winter fall was 8·58 inches, of which 1·44 inch percolated Dalton's gauge. A fall so low as this only occurred once out of twenty-five years.

The lowest recorded quantity absorbed during the six winter months was ·09 inch. This occurred only once, and when the rainfall for the six months was only 9·64 inches.

The average winter rainfall for the twenty-five years was 13·17 inches, and the average quantity percolating through three feet of soil 7·506 inches.

The average summer rainfall during the same time was 13·292 inches, and the average summer percolation ·721 inch.

The minimum quantity recorded as absorbed during twelve consecutive months is ·09 inch.

The annual average during the same time was rainfall 26·609 inches.
" " quantity absorbed 8·229 "

During the seven years, from 1853 to 1860, the winter average rainfall was 11·909, the average quantity percolating three feet of soil was 4·601 inches, and through three feet of chalk was 6·914 inches.

The average summer rainfall was 14·583 inches.

The quantity percolating three feet of soil, 1·150 inches.
" " " chalk, 2·958 "

The annual average for the seven years was,—

Rainfall	26·499 inches
Percolating through soil	5·751 "
Chalk	9·872 "

The minimum winter rainfall during the seven years was 9·64 inches; quantity absorbed in soil ·09 inch, in chalk 2·69 inches.

The minimum summer rainfall was 9·47, and absorption 0.

The minimum summer and winter rainfalls did not occur in the same year; nor did the smallest absorption occur in the summer, or in the same winter with the smallest rainfall.

In the eighteen months of the summer of 1840, the winter of 1840–41, and the summer of 1841, only 3·10 inches passed through Dalton's gauge, 2·57 of that was absorbed in November 1840, and the remaining ·53 in March 1841.

In the eighteen months of the summer of 1853, the winter 1853–54, and the summer of 1854, only 2·64 inches percolated three feet of soil in Dalton's gauge, of which 2·45 inches was absorbed in February and March, and the remaining ·19 in April, 1854. In the same period, and at the same place, only 5·75 percolated through chalk under the same conditions.

Notwithstanding these long periods of non-absorption, the chalk springs feeding rivers like the Wandle never run dry.

The smallest quantity recorded as percolating soil and chalk to a depth of three feet in Dalton's gauge, during eighteen consecutive months, including two summers, from May, 1858, to October, 1859, was, through soil, ·09 inch; through chalk, 8·81 inches.

Though the rainfall of the first summer was barely below the average, the absorption after April amounted to nothing. The rainfall of the winter months was four inches below the average, and the absorption in soil ·09, and in chalk 2·69 inches. The rainfall of the second summer was 18·31, or five inches above the summer average for the twenty-five years, and the absorption in soil ·0, and in chalk 4·22 inches.

Longest period of Non-absorption.—Thus, in fact, the longest recorded period during which little or no absorption took place was eighteen months. Notwithstanding this, the minimum recorded flow of the Wandle amounts to 10,000,000 gallons a-day. Assuming that the tertiary part of the basin contributed nothing to this flow, then a flow of 10,000,000 gallons a-day represents ·4090 inch of rain absorbed on 51 square miles,—the chalk area feeding the Wandle. That is, the water stored in the super-saturated chalk descended through the pores of that rock by gravitation, at such a rate as to deliver 10,000,000 gallons a-day through the natural channels to the surface, and would continue to flow during a period of non-absorption until all the surplus storage had been run off. This event has never happened with the Wandle basin, as no drought has yet occurred long enough to drain the chalk reservoir. It follows that the storage power of the chalk in the Wandle basin must be equal to a demand of more than eighteen months' duration, while supplying a minimum of 10,000,000 gallons a-day, through the natural channels to the surface. This minimum would be raised (indefinitely) by galleries in the chalk of four miles in length, owing to the large surface of chalk exposed in them.

Wandle Basin.—The area of the Wandle Basin (Chalk) is 51¼ square miles. This is the area of the collecting ground, whose absorbed waters overflow as the river Wandle.

There are two divisions in the basin, one sending out its surplus water as the Croydon branch of the Wandle, the other as the Carshalton branch.

The area of the basin feeding the Croydon branch is 43 square miles; that of the basin feeding the Carshalton branch is 8¼ square miles.

The flow of these two main sources in the early spring of 1853 was as follows:—

Croydon Branch..	21,246,770	Gallons per day
Carshalton ,, ...	17,909,910	
Total	39,156,680	

The flow at the junction of the two streams was 63,488,520 gallons per day; from this subtract 39,156,680, the yield of the two main springs, which leaves 24,331,840 gallons per day derived from other sources, or rather more than one-third of the volume of the Wandle just below the junction of the two arms.

These other sources are the natural drainage of the tertiary area into the Wandle, and several minor chalk springs at Beddington.

The maximum rainfall of the district is				36·3 inches.	
,, minimum	,,	,,	,,	16·8	,,
,, mean	,,	,,	,,	25·36	,,

The year 1852, or the year immediately preceding the date of the above gaugings, was a very wet one; 34·2 inches fell at Greenwich.

The amount of percolation or absorption corresponding with this rainfall is 12·16 inches,[1] which is equal to 89,229,388,800 gallons, on 51¼ square miles, or an average flow of 244,464,078 gallons daily for one year. Subtract 39,156,680, and we have left 205,307,398 gallons daily, or 74,936,990,270 gallons stored in the chalk or passing under the tertiaries, in 1852. In only three years out of fifty-three did so much as 34 inches fall; and the mean fall of 25·3 inches was reached or exceeded twenty-six times out of fifty-three years, the remaining twenty-seven being below the mean.

The greatest number of consecutive years in which the rainfall exceeded the mean was nine, in the last of which, 1821, the maximum was reached. The total number of inches above the mean, fallen in those nine years, was 41.

The greatest number of consecutive years in which the rainfall stood below the mean was five. The total defect in inches below the mean during these five years was 28·6.

In 1833 the Croydon branch of the Wandle, at Waddon Mill, ran 9,000,000 gallons per day, as gauged by Telford. Early in 1853 it ran 19,000,000 per day. (Braithwaite.)

A flow of 9,000,000 gallons per day for one year represents ·527650 inch of rainfall absorbed on 43 square miles. In 1832 the rainfall

[1] At Nash Mills, Hertfordshire, the rainfall in 1852 was 41·14 inches, and the quantity percolating through 3 feet of soil was 14·63 inches, as actually measured. At Greenwich the rainfall being 34·2, by a proportion the quantity absorbed was 12·16 inches. Of the 14·63 inches absorbed and measured at Nash Mills 9·47 were absorbed in October, November, and December; none in August and September; 1·5 in July; none in March, April, May, or June; and 3·66 in January and February.

was 19·3 inches (or 6 inches below the average). The annual absorption corresponding to 19·3 inches of rainfall is 7 inches, so that if 9,000,000 a-day be not far below the average flow for the year 1833, about $6\frac{1}{2}$ inches must have been stored partly in the chalk, and partly passed under the tertiaries, or an amount equal to 110,868,843 gallons per day for one year, viz.:—40,487,128,000 gallons.

A flow of 19,000,000 gallons a-day represents 1·1139 inch absorbed on 43 square miles. The rainfall of 1852 was 34·2 inches, of which 12·16 inches would be absorbed. Subtracting 1·1139 inches, we have left 11·0461 inches stored and passing under the tertiaries; that is, 68,736,218,483 gallons, or $188,315,613\frac{8}{365}$ gallons a-day for one year. Thus we see that at a time of year when the river would be high, the flow amounted to little more than one ninth of what it would have been had the average flow due to the storage of the previous year been given out by it.

If this proportion holds in all cases, then at the time of the minimum flow of 10,000,000 gallons per day in the Wandle, 80,000,000 gallons a-day must be passing down through the pores and crevices of the chalk to the deep-seated parts of that formation under the tertiaries.

I think that it would not be possible to arrest nearly all of this large amount, but a very large proportion of it may be gained by a gallery driven in the most flint-bearing part of the chalk, as that is the principal channel or conducting part of the chalk.

The upper surface of water in the chalk is not a level, but an inclined surface. Starting from the springs at the base of the tertiaries, it rises at an increasing rate as it enters the chalk hills until the summit of the dome is reached, when it rolls over and falls again to the springs at the base of the chalk escarpment. Starting again from the river level in the transverse valley of the Mole, it rises in going east, and falls again to the valley of the Bourne, south of Croydon. After periods of drought the upper surface of this body of water is depressed below the level of the bed of the Mole, when that river is not seen at the surface. The Bourne valley is generally dry, as the normal position of the curve lies below the bed of the valley. When the rainfall of the preceding year has exceeded 30 ins., the curve rises above the bed of the valley, in consequence of the extra quantity absorbed, and a surface stream appears. At such times the permanent springs run stronger than usual, and numerous intermittent springs break out and continue to flow during the period of the depression of the upper surface of the dome of water in the chalk, until it falls below the level of the vents through which they flow. If the upper surface has been very considerably raised, a great depression of the dome takes place before even the highest intermittent springs run dry. For instance, in Church Street, Epsom, a spring broke out in January, this year, 1873, and has been flowing ever since till March 10th. Since January 28th, the rate of rise of the water line in the chalk has considerably diminished; so much so, that the level of the water in a well just over half a mile to the south, has fallen seven feet. The spring breaks out at 153 feet above sea, and the level of the water in the well stood, on Jan. 28th, at about 173 feet, but had fallen on March 22nd to 165′ 9″. On Jan. 28th the spring was flowing about 10 gallons a minute, and ceased to flow on March 22nd.

Fig. 10 shows this in section, taking in intermediate wells. Now since at so short a distance from the tertiary base, the upper surface of the dome has been lowered so much without draining the intermittent spring, it should be also possible to lower the permanent curve of saturation to a certain definite extent, without draining the permanent springs of the Wandle and other chalk-deriving rivers.

Again the surplus water which has been carried off by the Church Street Bourne, has been running to waste, and taking the average flow since the middle of January at two gallons a minute (Jan. 16th to March 10th,[1] 54 days) 155,520 gallons have been lost by it. Obviously this might have been stored by a gallery of capacity sufficient to contain it. Approximately 1 cubic foot = 6 gallons. And the chalk occupying the position from which the gallery would be excavated, contains 2 gallons to every cubic foot of its mass, besides a certain quantity of free water in fissures and flint beds. Neglecting this free water, whose amount we have no means of estimating, we gain by every cubic foot of chalk removed capacity for 4 gallons of water. Dividing 155,520 gallons by 4, we have 38,880 cubic feet the capacity required—or a gallery five feet wide, twenty feet high, and 390 feet long. By these means, on a large scale, very large quantities of water, now habitually running to waste as floods, may be stored; and after the amount in the galleries has been drawn off, we still have left to draw upon the head of water which is in excess of that required to keep the permanent springs flowing for eighteen months, for which period we have seen the storage power of the chalk in the Wandle basin is equal to a minimum surface supply of 10,000,000 gallons a-day.

[1] After which date the flow was very small.

From Tables VI. and VII., it appears that if the upper surface of the water in the chalk were lowered only about three inches on an average for the whole area of the Wandle basin, an average and even flow of over 20,000,000 gallons a-day might be drawn off from it. As the free water lies in fissures, I cannot yet estimate the amount of fall in them for the same number of gallons.

The conditions of the water level or curve in the Lower Greensands are the same as in the chalk, and in reference to this subject in these rocks, Mr. Prestwich says: 'If Artesian wells were established in the Lower Greensand beneath London, their action would tend to lower slightly the line of water level, so that a larger quantity of water could be added to it from the surface without a general outflow to the same extent as before, and a larger annual amount now running to waste might probably be retained and stored in the strata. At the same time no general depression of the line of water level, such as would interfere with the more local issue by springs, need be necessary. For this line forms a curve rising many feet above the points at which the springs issue, and the summit of this curve may fluctuate within certain limits without its extremities being materially affected.' 'A rather greater fall in the water level at the end of summer than now occurs, being equivalent to an increase in the dimensions of the reservoir, would enable the water-bearing strata to receive and store much of the surplus winter waters, now lost by floods.'[1]

In the case of the lower greensands, I have no gaugings of the rainfall absorbed, as in the case of the chalk.

Table IX. shows the results of various gaugings of streams in the basin of the Wey springing mostly from the Hythe beds, and all from either those or the Folkestone Sands. The dates of the gaugings are also given. Mr. Napier's taken in August 1850.

From October 1849 to March 1850 the smallest quantity of rain fell recorded during the same months between 1833 and 1860. Between March and December 1849 none of the rainfall was absorbed in Dalton's gauge at Nash Mills, Hertfordshire, or for a period of eight whole months. During this period a large proportion of the previous storage must have been run off.

In December 1849, 1·03 inch was absorbed; in January 1850, 0·0 inch; in February 1850, ·41 inch; making 1·44 in three months.

[1] Water-bearing Strata, pp. 125, 126.

During the succeeding nine months no rain was absorbed, what little there fell being at once evaporated.

Now the quantity of water which descends under the impervious covering of any porous bed must of necessity be a constant, since the pores and fissures are always kept charged delivering their maximum quantity at high pressure. Any variations due to excess or defect of rainfall cannot affect the quantity delivered at any given point below the limit of permanent saturation, but are felt at the surface as floods or droughts. If the storage capacity of the bed above the line of saturation at its lowest is very high, it lasts out longer than the longest drought, having always head enough of water to keep the springs flowing. After a very long drought, such as that of March 1849 to Nov. 1850, twenty months, the water line could not fail to be reduced to its lowest level, the quantity percolating the deep-seated parts of the bed remaining the same as during periods of excessive absorption.

And it would have been so then, as appears from the following remarkable fact, had it not happened that the period of drought was broken by two short periods close together of absorption. Therefore towards the end of the whole drought the quantity given out by the springs would be furnished by the rain absorbed during this intermediate period of absorption.

This quantity was 1·44 inch, which, absorbed on 50 square miles, the area drained by the springs gauged by Mr. Napier, gives an average daily flow of 29,520,132 gallons for one year.

This approximates very closely to the quantity as actually gauged by Mr. Napier, and still more is almost identical with that measured by Mr. Rammel two months later or in October, 1850. For comparison I have put these figures under their gaugings in Table IX. In November 1850, or the last month of the drought, as might be expected, the quantity of water was rather smaller, amounting to 24,000,000, as gauged by Mr. Quick. Had our galleries been then in operation, at a considerable depth below the water line, we should have drawn off the same quantity as during wet seasons, for we could never gain more than would naturally filter down to our galleries; and this I have stated before is always at high pressure, until the surface springs were dried, which has never been the case, even during the longest drought on record, 1849–1850. In fact, the minimum quantity recorded as delivered by them at the close of that long period of non-absorption, amounted to 24,000,000 gallons daily. In the Wandle basin of about the same area, the minimum registered flow amounts to 10,000,000 gallons.

In December 1850 a period of absorption began. Between the beginning of that month and April 1851, or during five months 8·53 inches were absorbed, and during the succeeding eight months 0·0 inches. Mr. Bateman's gaugings were taken, August 1851, or in the fifth of these dry months. He registered 25,302,609 gallons daily.

8·5 inches absorbed on 50 square miles, gives an average daily flow of 312,971,343 gallons for a year. But there is a limit to the quantity that can pass away either downward or outwards in a year. The remainder in excess becomes stacked up, so to speak, in the body of the formation, and forms a dome-shaped mass of water to keep springs flowing during long droughts.

In the absence, however, of detailed evidence, it is not possible to make any very definite estimate as to the minimum quantity available. One thing is certain, the more water that is drawn off from the subterranean reservoir during the dry season of one year, by so much will storage accommodation be afforded for the surplus rains of the next wet season, and by so much will the winter floods be diminished, and the water carried off by them as waste will be saved.

I cannot lay too much stress on this point, and with respect to the chance of draining temporarily towards the end of each dry season the surface springs, I entertain great doubts whether, if the gallery were sufficiently deep and distant from them, they would be so affected, as the limited capacity of the pores of the rock for delivery would tend to prevent the downward flow of their waters at more than a certain rate.

In the case of the London chalk wells, the underground reservoir has become considerably exhausted, but this could never happen with galleries where no pumping was employed, as the water would be descending at its own natural pace. The effect in this particular depends absolutely upon the depth of the gallery below the surface of the water-line. If not too far below it, the storage capacity of the bed may be largely increased. By use the underground water-channels become worn larger, and the construction of a gallery such as I propose would tend to enlarge all the channels leading to it, and so to lower the water-line, and afford storage room for what now is wasted in floods.

The Brighton Water Company during part of the summer of 1849 raised more than a million of gallons of water daily from a well in the chalk about 11 feet in diameter, with four adits at the bottom, each about 2 yards square and 18 yards long, the adits being about on a level with low-water mark. Since this well was sunk, *the fissures in the chalk leading to the well have considerably increased in size*, and the well is in consequence capable of yielding much more water than when first made. The level of the water in this well annually varies about 50 feet, being sometimes as much as 63 feet above high-water mark, and at others only 13 feet above the same datum. It is usually lowest in the months of November or December.[1]

To sum up, I cannot make any actual estimate of the minimum quantity available. All we know is, that the minimum flow of the surface streams at the close of a drought of twenty months' duration, amounted to 30,000,000 gallons daily. This quantity represents 1·44 inch of rain absorbed. The average quantity of water held by specimens of lower greensand, as shown in Table X., is about one-third of their bulk. This would cause the 1·44 inch to occupy a depth of three times that amount, or 4½ inches nearly. The water-line over the 50 square miles would be depressed at an average rate of 4½ inches daily during the continuance of the drought, or as long as the streams continued to deliver 30,000,000 gallons a-day—plus the fall due to the descent of water under the gault.

[1] Appendix O, Report to Directors of London (Watford) Spring-Water Company, 1850. S. C. Homersham.

APPENDIX.

I HAVE only had an opportunity of making a few observations on a part of the chalk tract of the North Downs since working out the above paper; and, such as they are, I give them as an Appendix, much regretting their fragmentary nature.

TABLE XI.—The specimens in this table, before being weighed, were heated on the bar of the fire almost to redness, and were weighed to a twelfth of a grain when just cool enough to hold. They were then immersed in water, and, after lying for eight days, were weighed again. They are arranged in the table according to the quantity imbibed, or the gain in weight.

The moderately coarse quartzose sandstones show the largest increase, and the fine-grained ones the smallest. The water ran out of the very coarse sandstones so quickly that it was impossible to weigh them *full* of water, as they had no argillaceous cement to retain it. The inference to be drawn from the table is, that very coarse sandstones and sands without cement afford the easiest passage to water, and that in sandstones of fine grain water can travel by fissures alone.

The consequence of this inference is, that in a bed of sand the water stored may, by a sufficient series of observations, be tolerably accurately measured; but in fine sandstones no measure of the amount can be given, nor indeed in any fine-grained rock which holds in itself, by capillary attraction, a quantity of water approximating to that which would fill it. This, indeed, renders the mass of the rock impermeable, and the fissures alone form the reservoir.

Thus, given the water-line, the quantity of water held in the formation is calculable, by means of a sufficient Table such as the present, and Table X.

The following Tables are an epitome of the results of my observations:—

TABLE XII. shows the heights of various springs breaking from the chalk at the tertiary base, with the river basins into which they flow.

Between Epsom and Croydon permanent springs issue at heights lying between 108 and 136 feet; but at Epsom a bourne breaks out, after very wet seasons, at 153 feet.

TABLES XIII., XIV., XV., and XVI. show the actual rise of the surface of the water in the chalk from the springs southwards in April, 1873, when the water was nearly at its highest.

TABLES XVIII. to XXII. show the same thing when the water was nearly at its lowest in December 1873.

Figs. 11 to 16 show the same thing in a diagrammatic form.

TABLE XVII. shows the variation in the height of water in certain wells near Epsom during the period between January and the end of April, 1873. Diagram, Plate 2, shows the same thing. These gaugings were taken almost daily between the hours of four and six in the afternoon. Commencing when the water was at its highest, the observations were continued until in the highest well the water had fallen 8 feet in almost exactly three months. They were continued for five weeks after the bourne in Church Street ran dry, which it did on March 22nd.

Mr. Elson's sawpit is distant from the bourne only about twenty yards, and at the time when the spring dried up the water in the sawpit stood at a lower level than it did for the next ten days. These ten days were very hot, and the ground became dried up; so that the small quantity of water representing the bourne was absorbed by the soil, instead of flowing as a small surface spring, which it would have continued to do for the ten days had the weather been wet. The water in the sawpit fell 13 inches between February 28 and April 28. During the same period the water in Common Fields Well fell 28 inches. The distance between the sawpit or the bourne and Common Fields Well is rather over half a mile, straight.

The general fall is due to the running off of the extra quantity absorbed during the heavy rains of the autumn of 1872; and the minor fluctuations follow the daily rain during the period of observations.

During the short period of my gaugings it became evident that all the minor or daily fluctuations could not be assigned to the same cause, viz., the fall of rain at Epsom. A minute wave, such as that on March

7th, which appeared in all the wells at once, was clearly the effect of rain falling at Epsom the previous day. I knew when there would be a rise after local rain, but I did not know when to expect *every* rise that actually took place. Such rises as were merely passing waves took me by surprise, as they were the result of rain that may have fallen high up the basins, one, two, or three weeks before they were felt in the Epsom wells. The date given as that of the waves is that of the day on which their highest parts passed the wells.

Instances of rises following immediately upon and caused by local rain at Epsom are March 7th, 17th, and 27th. Instances of passing waves due to rain fallen on the hills towards Headley and Banstead are, February 28th in No. 9, still running off at Pikeshill on March 1st; March 12th in No. 9, at its highest in Nos. 7, 5, and 2 on the 13th; and April 15th in No. 9, which appeared in the other wells on the 16th.

In the case of the former, as is beautifully shown on Plate 2, the local rise on March 17th was due to rain which fell between that day and the 15th. On the 13th, ·06 in. of rain fell at Epsom;[1] on the following day no rain fell, and well No. 9, which had been falling for the two previous days, showed a further fall of 3·75 in. On the 15th ·09 in. of rain fell, and No. 9 showed a rise of ·25 in.; on the 16th ·10 in. of rain fell, and No. 9 showed a rise of in.; on the 17th ·16 in. of rain fell, and No. 9 showed a rise of 2·25 in. since the 15th. Unfortunately, I did not measure No. 9 on the 16th. The amount of its rise on that day may be calculated by dividing 2·25 into two parts of which the less shall be to the greater as 10 to 16. This gives ·8653 in. as the rise for that day, and 1·384 in. as the rise for the 17th.

Thus the total fall of rain for the three days was ·35 in., and the total rise of the water in well No. 9 for the three days was 2·5 in., or the amount of rise in the well was 7·142 times the depth of the rain which caused it. The disproportion must be still further increased. At Nash Mills during the same three days three quarters of the rain that fell was absorbed.[2] This indicates a saturated state of the soil and a humid atmosphere. Applying the proportion to Epsom, we have $·35 \times ·75 =$ ·2625 in., or about a quarter of an inch absorbed, so that in this case a quarter of an inch absorbed caused a rise of two and a half inches—or ten times its own depth.

[1] The rain fall at Epsom is registered by Mr. J. R. Harding, C.E., who kindly supplied me with tables.

[2] For a daily register of rainfall and percolation at Nash Mills, I am obliged to Mr. John Evans, F.G.S.

At that time of year the chalk between the surface and the water-line is so charged with water that any rain passing through the soil descends at once to the water-line, and is immediately appreciable. In dry seasons the case may be different. But in any case it will not be safe to multiply the time it takes rain to pass through the three feet of soil by any given depth to find how long it will take in descending, as if the chalk above the water-line be not charged, and the quantity absorbed be small, it may be held for some time, until more is absorbed; or if the season be wet, and the soil saturated, it will descend at once, as shown above.

It took six days for the water in the well to fall to the same position as that from which it began to rise on the 14th; but, as the water was then normally falling at an average rate of rather over half an inch a-day, to find the actual duration of the wave we have to calculate as if the water had continued to fall until it reached the position it would have occupied had it fallen at the average rate since the 14th. After the summit of the wave passed, the normal average rate of fall was maintained for two days, after which the water began to fall faster, and for the next two days it fell about 1·75 in. a-day. At this rate, it would have reached the average on the 22nd, or eight days after the rise began; so that the actual duration of this wave, had it not been cut into by another, would have been eight days. This brings us to the 22nd, the day on which the Church Street Bourne ran dry.

I cannot state actually on what day the water ceased to fall, or began to rise, but the rise was very rapid. No rain fell on the 18th, 19th, or 20th. On the 21st, ·02 in. fell, and on the 22nd, ·05 in.; on that day the water was rising fast. On the 23rd ·19 in. fell, water still rising; on the 24th, ·09, water still rising; on the 25th, no rain, water still rising; 26th and 27th, no rain, water at its highest on 27th. Now in the four days, 21st to 24th, ·35 in. of rain fell, or exactly the same quantity as had raised the water 2·5 in. in the previous few days, but now in six days we find the water risen 10 in., and, on the showing of the above, we have found no adequate cause. We have 2 inches over from the last wave. These added to 2·5 make 4·5 inches, which leaves 5·5 inches rise unaccounted for. I have no accurate data as to the rate at which the waves that passed the wells were travelling, or else by referring to the Headley rainfall record I could probably point to the date at which the rain fell that caused the waves. It is clear that in this case two waves merged together to produce the total rise of 10 in.

—one of local origin, and one derived from higher up the basin. ·38 in. of rain fell at Headley in the four days, 18th to 21st. In the six days from the 6th to the 11th, ·95 in. fell at Headley, which would by the above mode of calculating be equal to 7·2 inches rise, so that it appears not unlikely that we have to look to this date for the source of the 5·5 inches unaccounted for in the 10 inches rise, or about three weeks before the effects were felt—which supports, and is supported by other calculations.

An inspection of the diagram Plate 2 will demonstrate,

1. That the amount of variation is greater, that is, that the waves are larger in the higher wells, and that the amount diminishes gradually as we descend the series, until in Mr. Elson's saw-pit close to the Bourne, it departs but little on either side from the average rate of fall.

2. That the waves are a series independent of each other. They depend in fact upon separate falls of rain, and if generated by a fall upon the upper part of a basin a wave flows down the inclined plane of the water in the chalk, raising all the wells on its route during its transit from the upper part of the basin to the lower part. It is often followed immediately by another wave, but sometimes there is a considerable interval during which the water constantly falls.

The great annual rise and fall is the same thing on a larger scale. It is registered in feet instead of inches, and it depends upon the aggregate fall in seasons instead of days.

In viewing Plate 2 the observer sees the variations of each well registered at their actual height above sea level, and the actual variation in the surface of the water for each day. Well No. 2 is the nearest, and well No. 9 is the most remote, as the observer stands at Church Street Bourne. The distances from Church Street Bourne are given in yards on the right hand margin of the plate.

All these wells are open draw-wells, seldom or never used. No well is of any use for daily registration which is frequently drawn from, or which is provided with a pump, unless a special register allowing for and registering the quantities abstracted be kept. For instance, I have a daily register of the variations in the depth of water in the well at Russell Hill School, as observed between October 1871 and April 1873, which was kindly supplied by the engineer. The measurements were taken under the following circumstances:—Water is pumped from the well by steam power from 10 A.M. to 1 P.M. daily. After the cessation of this pumping the depth of water left in the well is taken, and it is this series of measurements which constitute the register supplied to me. The well is again pumped from, from 2 P.M. till 5 P.M., and on Fridays in addition from 6 P.M. till 9 P.M. These circumstances, unfortunately, render the register almost valueless, as we cannot be sure that exactly the same quantity was pumped from the well every day.

The depression caused by the pumping is very great. Its effect on April 5th, 1873, is shown in Fig. XIV. The well at Tudor Cottage, distant from Russell Hill, rather under half a mile, is scarcely if at all affected, and the Croydon Bourne is flowing above ground at 200 feet in the neighbouring valley. The water in Russell Hill well stood at 110 feet after the first pumping, and the well at Keeper's Lodge at 168′ 9″. The well at New Barn Farm also appears to have been affected, as it stood at 165′ 5″, and the well at Windmill Cottage not at all. A broken line on Fig. XIV. shows where the water would have stood had there been no pumping. From this I gather the following approximation:—

	Amount of Depression. Feet.
Tudor Cottage	0
Russell Hill	90
Keeper's Lodge	18
New Barn Farm	15

The section, Fig. XIV., shows a conical depression from Keeper's Lodge to Tudor Cottage, but its exact size and shape cannot be given. As drawn, it is at the maximum possible size. The curved, dotted lines show a probable form of the cone. It is better to consider the effect of the pumping at its maximum, and rather to exaggerate than to lessen it. The effect of the pumping can be traced nearly to Windmill Cottage, and one mile in the direction of Beddington. This line is the longer axis of an ellipse, over which the effects of the pumping are felt, at one of whose foci Russell Hill stands. The major axis coincides with the dip, which is here N.N.W.

I have from these materials laid down approximately the internal contours of the cone at its maximum size. Those which lie above the level of the highest of those which run round were pulled back from their normal position as follows:—

200 contour	$\frac{1}{8}$ of a mile
190 ,,	$\frac{5}{8}$,,
180 ,,	$\frac{7}{8}$,,
170 ,,	$\frac{9}{8}$,,

This deviation of the contours from their normal position at that date is shown upon Map A, and in a different pattern, the contours are also shown in the position they would have occupied had there been no pumping. The total area affected more or less appears to be about a square mile and a half.

The remainder of the water contours of this date on Map A have been laid down from the materials comprised in Tables XIII. to XVII.

Subject as they are to advance and recede north and south with the rise and fall of the water, they are shown on Map A, probably in their most northerly position. Now, if a gallery were driven level from Beddington Springs to cut Russell Hill Well at 110 feet, the quantity of water delivered to such gallery at the well would be precisely the same as that pumped from the well during the first pumping of the day, provided of course that no such pumping were to take place. In addition to this, there would flow into the gallery a large quantity of water in consequence of the lowering of the water-line to the level of the gallery, which would take place between Beddington and Russell Hill. Instead of the inverted cone, there would arise, as it were, a valley in the water, the bed of which would be at the level of the gallery—110 feet, and the deflected contours would run back along the sides of the valley until they would eventually coincide with those running round the southern and eastern sides of the cone.

An idea of the run of the contours thus deflected may be gained from those shown on Map A, south of Carshalton, running round behind the Grotto Spring. It must be borne in mind, however, that the recess would be deeper.

The quantity actually yielded by the well when pumped down to any given point, say 110 feet, depends upon the *natural* height of the water-line at the time of pumping, or, in other words, on the height of the natural column above that given point.

The quantity yielded by the gallery would of course depend upon the same thing; but at the driest time, unless there were another powerful source of out-draught in its neighbourhood, the water could never fall *below* 110 feet. At times the gallery, for a great part of its length might lie many feet deep below the water-line.

I do not propose to make any such gallery. I merely use Russell Hill Well and this hypothetical gallery to illustrate what the effect of driving such gallery would be.

There are many towns lying along the northern skirt of the chalk, now gaining their supplies of water by pumping, at a considerable cost, defrayed by local rates, which could, by pursuing the water to higher levels in the manner just indicated, secure a constant supply of running water, thereby dismissing the necessity of pumping, in part, or entirely perhaps in some cases, and in consequence enabling the local rates for water to be readjusted on a lower scale. It might be necessary to drive one, two, or three miles through dry chalk before the water-line at its lowest position could be met with at a sufficient elevation for their purpose. My investigations show that for each town there is one line, and only one, that would be suitable, and any other must involve failure.

Now, setting aside the case of London, the rapid and permanent advantage which would accrue to such towns, which have indisputably a more equal claim to it, by the accession of water acquired in the above manner, in lieu of by pumping, forms a most cogent argument in favour of having the whole of these great water-bearing formations subjected to a deliberate and scientific survey by Government. Thus, in view of future contentions, each district would have its legitimate and appropriate area so indicated and assigned under the finger of authority that no such contentions could possibly arrise.

It was not my intention to lay before the public any so fragmentary work as the present; but my distant opportunities of visiting the chalk and lower greensand, combined with the growing expenses of the work itself, have compelled me to abandon my original plan of publishing a complete survey of the tracts discussed in the body of this work.

I live in the hope that this drop of water may swell into—not a big river, but a vast number of streams, forming a permanent supply to as many water-pipes for the use of towns.

In allusion to the possibility of the chalk area of the north downs being brought to bear on the water supply of London, I have shown on Figs. XI. to XVI. by dark shading, the head of water above the level of 100 feet.

In allusion to the possibility of Croydon drawing a large part of its requirements by means of a horizontal well, I have, in addition, distinguished the head of water above the level of 200 feet in Figure XV.

The area occupied by this head of water consists of some 24 square miles available for Croydon, etc.

The section (Fig. XV.) is far west of where the gallery for Croydon should lie, and the distance at which the water would be found along its line at 200 feet is, perhaps, more than twice as far as it would have been if the section had been carried south-east from Croydon.

Having discussed the various observations which I have had the opportunity of making, I will not add one word beyond the limit of those matters of fact.

Objects and Mode of Constructing a Hydro-geological Survey of the Water-bearing Formations.

WITH respect to the objects of the survey, I doubt not that I have already made them abundantly clear. A brief recapitulation will not, however, be out of place.

First, the facts to be surveyed.

Rainfalls, and, in respect of any given area, of which details are required to be known,

a. Part is again raised by evaporation.

b. Part sinks into the body of the formation.

Of that which sinks:

c. Part flows out as springs.

d. Part sinks under the overlying impervious beds.

e. The water which sinks, owing to the inclination of the formation itself mainly, and partly to the relative heights of the vents at the top and at the base of the formation, lies in an inclined position.

The amount of this inclination is regulated in various localities by the difference in the amount of the dip of the beds themselves—rising faster when the beds rise faster, and more gradually when the beds are less steeply inclined, though rarely coinciding with the dip. The inclination is subject also to seasonal variations, which depend upon and follow regularly, differences in the amount of rain fallen during certain periods.

Thus, after a dry season the water in the formation falls, and after a wet season it rises.

The reason of a fall is that the fissures leading to the vents are of a capacity sufficient to carry away more water than is supplied; and the reason of a rise is that more water percolates into the formation than can be carried away by the fissures, so that the water becomes stacked up, till decrease in the rain-fall enables the fissures gradually to run off the extra quantity absorbed.

These variations in the height of the water-line are confined within certain limits. There is a minimum position below which the water never falls, and there is a maximum height above which it never rises.

When the water-line is at its lowest, *prima facie*, it appears that the springs must be at their smallest; and, when the water-line is at its highest, that the springs must be at their strongest. If on examination this were found to be the case, and it seems likely to be so, then the volume of discharge by springs might be expressed in terms of the height of the water-line, or of the head of water, or *vice versâ*.

The quantity of water below the minimum position of the water-line must be treated as rock, and not as water. By this means, starting from a date at which this minimum obtains, and basing our calculations on the observed percolation previous to and on the observed discharge of the springs after this date, as well as on the accelerated rise of the water-line, we may calculate the fourth term, viz., the quantity passing under the overlying impervious beds. For instance, suppose the water-line at its lowest, our percolator shows that within a short time previously rain has been absorbed which we may expect to be felt at the water-line shortly. When at the minimum, the springs have a certain definite discharge. In due course the water-line rises, the springs strengthen. We know the whole quantity absorbed, Q. We can measure the quantity discharged by the springs before the rise attains its maximum height, D; and the quantity discharged between that time and the time at which the water again stands at the minimum, P, and from the result of experiments on the absorbent and retentive power of the bed under notice, we can assign the quantity of free water in the fissures between the minimum position of the water-line and the maximum head of water, and that absorbed by the saturated chalk between the same limits, which would flow out again with the falling water, and that which would be retained by capillarity to drain out more slowly. The quantity of free water in the fissures with that absorbed by the chalk, but not retained, let us call H; and the part retained, C. The quantity which passes below the minimum water-line before H is attained, call *y*. That which passes below, after H is attained, will be H − P.

If no more rain falls, as the head of water decreases, the springs become weaker, and by observation we can tell how long at a diminishing rate it would take for H to be discharged. As a matter of fact, if no more rain fell, it would take longer than the time so gained for H to be discharged, for part of H would have sunk below the minimum before the water again stood so low as that line. This part is H − P.

Then the whole value of Q is

D + H + *y* + C, of which D, H and C are known, and *y* is unknown; and H = P + (H − P) of which both are known. The value of *y* + H − P, which represents the quantity passing under the overlying impervious beds, can thus be easily found. To find this is one object of the survey, and another is to find how much of Q might be drawn off at high, or any, levels, without reducing D + P below a minimum allowable limit.

On the mode of Conducting the Survey.

1st. As regards rain-fall. There are so many accurate registers kept over the chalk and lower greensand areas, that few, if any additional gauges need be added. This subject needs no special comment.

2nd. As regards evaporation. Hitherto, or rather previously to the experiments of Mr. G. J. Symons and Mr. Rogers Field, C.E., it was not generally recognised that no evaporation registers of the slightest value were kept in this country. In an elaborate memoir on evaporation published in *Symons's British Rain-fall*, 1869, the author shows that 'The great objection to nearly all evaporators hitherto used has been their diminutive size, and the consequent fact that the pint or two of water they contain has become unduly heated, and therefore the recorded evaporation has been largely in excess of what it would have been had this artificial elevation of temperature not been produced.' The paper also shows that 'the only true way to ascertain the amount of evaporation,' [from a water surface] 'is by an evaporator fixed in the midst of a large piece of water.' The evaporation which we require to measure is not that from the surface of water, but from the surface of soil. In reference to this Mr. Symons says, 'It seems impracticable to measure, with any degree of accuracy, the evaporation from the soil, because the evaporation will vary according to the varying condition and composition of the soil. Thus the amount of evaporation from a sandy, porous soil will greatly differ from that of a stiff clay soil.' No doubt there is a real difficulty in furnishing an evaporation register for a large country containing all kinds of soils, but this difficulty is reduced to a minimum when the evaporator registers the amount raised from an area containing one kind of soil only. In the case of the lower greensands of Surrey, evaporators filled with the soil taken from some half-dozen places on that area, will be found to give a mean result, probably sufficiently accurate. In the case of the chalk, it is on the north downs much covered by clay and sand, but the *kinds* of surface soils are few, and separate registers can be kept of each. The geological survey can furnish accurate measurements of the superficial area of each kind, and of bare chalk, in proportion to which areas the register can be adjusted, and the net amount of evaporation obtained for each day.

It is to be hoped that the public will soon have the benefit of the results of Mr. Field's investigations.

3rd. As regards Dalton's gauge. This percolator purports the part of the rain-fall not drawn up again by evaporation. At Nash Mills there are two percolators, one filled with chalk and the other with local soil. The soil percolator shows a less percolation, or a larger evaporation than the chalk percolator. Both show a general correspondence between the rain-fall and the quantity absorbed ; but there the correspondence ceases, for both show so many apparent anomalies in this respect, that 'any notion of forming an average, based upon the rain-fall, would be erroneous.'[1]

In both gauges the rain-fall sometimes passes through at once, and sometimes it is detained for six days after the last rain fell before any passes through.

The rate at which it is to pass down, or whether any is to pass, is regulated by the joint agency of evaporation and gravitation. The downward tendency caused by gravitation is a constant amount, while the check or upholding power exercised by evaporation is a variable one.

[1] J. Evans in Discussion on Paper by Braithwaite, 'Rise and Fall of Wandle,' p. 37.

Sometimes it is of sufficient power to prevent any percolation, and sometimes only strong enough, as it were, to put on the drag and cause the rain to descend at so slow a rate that it reaches the depth of three feet only after the lapse of six days from the date of the last rain. And, with a saturated soil, and no evaporation, the whole rain falling in a day has passed through at once.

Mr. Evans said of these gauges:

'The results obtained from these gauges had been confirmed by actual experience. In the manufacture of paper large quantities of lime were used for boiling the materials, and chalk was burnt for that purpose. It was not dug from a pit in the ordinary manner, but a shaft was sunk, from which headings were driven as in mining. When the gauges showed the water to have percolated into the earth, he had generally found, *after the lapse of one or two weeks,* that it had also percolated into the chalk pit, a depth of 50 feet or 60 feet below the surface; he could even hear it dripping.[1] Now, my Epsom experiences show that rain falling on a saturated soil penetrates to depths of 50 feet the same day. The percolator can, of course, take no account of this circumstance, when the cylinder is only three feet deep, and I think the depth would be advantageously increased to five, or even six feet, as I have observed frequently, that clays are often changed to quite that depth in both colour and character. Blue clays are oxidized, and become yellow, white, or reddish; and the red clay of Cleveland, in some places, loses its clayey character and becomes a hungry loam, passing water freely, for that depth. In the clay cliffs between Sands End and Whitby, in a dry summer, I observed a line of moisture at a depth of six feet, and more along the face of the cliff, due to the above cause.

Dalton's gauges are no doubt susceptible of improvement, and it is a difficult matter to know at present how much faith ought to be placed in their results.

4th. With regard to the gauging of the springs, there is no physical difficulty in the way. Dams and weirs of moderate size, self-registering, can be constructed, so as to answer all the purpose.

5th. Daily register of the height of the water-line. It is obviously impossible, without a large staff of observers, to watch, and register, the daily variations in the height of the water-line in the water-bearing formations, over any but a very small area by hand measurement alone.

[1] Braithwaite, 'Rise and Fall of Wandle,' p. 38.

It takes half-an-hour to measure a well of 300 feet deep, so as to secure the depth, and depth to water with anything like accuracy. On the average of wells of all depths, from 30 to 300 feet, it takes perhaps a quarter of an hour. I have found that with the utmost exertion of which I am capable, eight is the largest number of wells I have been able to measure in one day, situated as they are apt to be at considerable distances apart in the country. Hand measurement in the case of deep wells possesses also the obvious disadvantage, that absolutely extreme accuracy is difficult of attainment. I do not say that it cannot be had, for I believe I have measured the depth to water in many very deep wells to a hair's breadth.

A lead or iron clock-weight, not too heavy to carry comfortably, is indispensable. The line is gently lowered until, if the water be visible, the bottom of the weight is seen to be approaching it, when, still gently lowering the line with one hand over the sharp edge of the woodwork at the well mouth, a series of taps should be given to the line with the forefinger of the other hand, about two inches below the woodwork, of sufficient strength to send a wave down the line, and cause the weight to vibrate sharply. By this means if the bottom of the weight be flat, the edge of the woodwork sharp, and the line sufficiently closely graduated, a measurement to the sixteenth of an inch may be taken at a depth of thirty or forty feet. Wells of this and far greater depth may be measured to a quarter of an inch with ease.

The power of sight alone cannot be trusted beyond depths of a very few feet. Sound is the only safe guide, and it is an infallible one. The pat of the weight, when agitated as just described, on the still water of the well, is transmitted to the surface from depths up to at least 330 feet, as I have found by experience, as plainly as from a few feet down, especially if the head be lowered to within the rim of the well. Accuracy so far may be insured, but this done, the most difficult part is to come. How to draw out and measure correctly 300 feet of string, is not an easy matter with a tape line of only 66 feet to measure it with. When there is an open space, run out the line as far as possible a known distance in feet, say 50 feet, and walking back towards the well, taking care to prevent the line from slipping back into the well, draw out a second length, and so on. Often there is no such open space, in which case obvious and unavoidable difficulties have to be surmounted, especially when the well is surrounded with bushes. The utmost care and patience are then needed. It is advisable not to wet the line more than is absolutely necessary, for a line very soon wears out. The depth of the well once taken, subsequent measurement to water should be made by sound. I have dwelt thus long upon hand measurement for two reasons: firstly, because in case I should excite any curious persons to follow up my observations, it would be their only means of proceeding, and secondly, to show the impracticability of forming an organised survey of any large tract, which would have to depend upon hand measurement. In the first instance, all available wells should be measured, and the variations in the most convenient, watched as often as possible. From these measurements, spots should be chosen at which to put down bore-holes of 18 inches diameter at the least, for the purpose of establishing self-registering gauges. Their construction is a matter of extreme simplicity. These gauges should be visited periodically, as often as required, and the paper containing the self-written record removed.

The Tape Line.

An ordinary tape line is practically useless for measuring wells on the chalk. Very few are so shallow as 66 feet, and a large number run above 300 feet. I therefore had a line made by the Messrs. Stanley of Great Turnstile, 400 feet long.

Its weight, 22¼lbs., is unfortunately so great as to make it impossible to carry it for any distance. The diameter is 16½ inches, the width of the tape 1½ inches, and the width of the case 2 inches. The actual length of the line is 425 feet, Mr. Stanley having allowed an extra 25 feet. The length of the lever is 6 inches, and of the handle 1 inch. It is also provided with a shoulder strap running round the circumference. Now, the tape is unnecessarily heavy—100 feet of line, as painted, weighs 4 lbs. It is not necessary to have a tape of greater width than 1 inch, which would reduce the weight of 100 feet to 2 lbs. 10 oz., and of 400 feet to 10 lbs. 8 oz., from 16 lbs. The case and strap weigh 6 lbs. 4 oz., which could not be much reduced. This would make the weight 16 lbs., below which I do not see that it could be reduced. This, however, is quite a portable weight.

The handle of the lever is 3 inches too short, as 1 inch involves winding up the line with the forefinger and thumb. The handle should be at least 4 inches long, made to screw off the lever, and provided with an ivory holder. A tape-line thus amended would be a very serviceable article.

At present, with the small handle, and allowing for all contingencies, it takes at the outside five minutes to wind up my line. With a longer handle, it will be done quicker. The saving of time, measuring a well of 300 feet deep, is not less than 20 minutes. The whole measurement could be finished in 10 minutes instead of half-an-hour.

TABLE I.—*Analyses of Chalk and Lower Greensand Waters.*

Localities.	Geological Formation.	Appearance of Sample in a bottle.	Total solid Residue from 100,000 parts of Water evaporated and dried at 100° C.	Lime.	Magnesia.	Potash.	Soda.	Sulphuric Acid.	Carbonic Acid.	Silica.	Chlorine.	Nitrogen as Nitrates and Nitrites.	Ammonia.	Organic Nitrogen.	Organic Carbon.	Hardness before boiling.	After boiling.	Total Organic Matter.	Iron, Alumina, and Phosphate.
Caterham Well	chalk	clear and colourless	31·08	10·60	2·48	1·11	1·44	1·96	10·68	2·59	1·35	·027	0·0	·006	·020	23·4	9·0		
Croydon Well	..	..	32·0	..	..	..	—	..	..	..	..	·551	·001	·007	·040	22·0	9·1		
Otter Springs, Watford ..	..	..	32·36	14·50	·80	·26	1·22	·747	12·06	1·67	1·26	·422	·002	·012	·026	24·7	3·7		
Amwell Spring	..	..	31·88	14·10	·86	·46	1·28	1·68	11·35	1·36	1·39	·406	·000	·009	·076	22·4	5·9		
Moor Park, near Farnham ..	lower green-sand.	..	4·55	..	..	..	..	..	..	..	..	·034	·001	0·10	0·30	·7			
				Carbonate of Lime.	Sulphate of Lime.	Silicate of Lime.	Sulphate of Soda.	Carbonate of Magnesia.	Free Carbonic Acid.		Chloride of Sodium.	Chloride of Potassium.	Sulphate of Potassa.	Silicate of Magnesia.					
Velwood, near Haslemere ..	..	..	5·17	..	0·86	0·45	0·44	trace	trace	0·93	0·87	..	0·40	..	..	1·86	..	1·24	
Devil's Punchbowl, Hindhead	..	..	4·34	..	0·59	1·0	0·04	..	trace	0·10	0·74	..	0·09	0·30	..	2·45	..	1·30	0·02
Barford Mill Stream	..	..	5·64	2·39	0·40	..	..	0·27	trace	0·72	0·94	0·03	0·20	..	..	2·70	..	1·05	0·08
Springs at the Moors, Gosford House.	..	..	15·75	8·31	2·48	1·17	0·22	0·60	trace	..	1·40	..	0·77	..	..	10·8	..	0·95	0·08

Note.—The analyses of the waters of the last four wells refer to an imperial gallon of 70,000 grains, and are from *The Agricultural Geology of the Weald*, by W. Topley.

TABLE II.

List of Wells with Galleries.		Number in Geol. Surv. Mem. vol. iv.	Depths of Well: to Chalk.	Depths of Well: in Chalk.	Depths of Well: Total.	Depths of Well: Shaft.	Depths of Well: Boring	Depths of Gallery: from Surf.	Depths of Gallery: in Chalk.	Depths of Water Level: from Surf.	Depths of Water Level: below Sea.	Height of Well Mouth above Sea.	Yield from Shaft or Bore: per Min.	Yield from Shaft or Bore: per Ann.	Yield from Gallery: per Min.	Yield from Gallery: per Ann.	Yield Total: per Min.	Yield Total: per Annum.
			Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Gallons.	Gallons.	Gallons.	Gallons.	Gallons.	Gallons.
Bishops Stortford ..	1	102	116½	183½	300	160	140	154	38	140	..	..	25	..	..	..	10,000	5,256,000,000
Slough*	2	29	90	27	117	117	0	..	..	7	..	..	..	..	..	..	..	..
Orange Street to Trafalgar Square† ..	3	327	250	50	300	174	126	..	..	115	73	42	..	..	..	..	..	292,000,000
Well, Trafalgar Square	"	371	248	135 or 148	363 or 396	168	..	..	..	100	71	29						
Truman's Brewery, Shoreditch ..	4	355	199	331	530	300	..	285	46	30	..	..	..	..	..	..	..	6,570,000
Reid's Brewery, Liquorpond Street ..	5	307	136	126½	262½	222½	..	200	64	121	51	70	..	..	..	..	192	101,178,000
Meux and Co., Tottenham Court Road ‡	6	369	158½	207	365½	188	..	181–6	..	93	..	85	..	..	..	..	..	..
Crystal Palace Gardens §	7	463	361	149	510	250	..	150	..	90	..	..	..	..	..	..	..	..
Plumstead Waterworks	8	..	..	..	..	..	..	..	..	..	..	..	..	..	416	..	416	218,649,600
Western Heights, Dover	9	..	..	..	..	..	..	at low	water	level.	..	..	None	..	Large	quantit	ies.	..
Brighton	10	..	..	..	..	..	..	..	..	..	63-13 above h. w. m.	..	..	..	..	..	..	..

* Chalk, with flints and water, at 91 feet from surface.
† Two wells joined by a tunnel, 400 feet long. Yield of the two wells given in Table.
‡ Well and galleries drained. Water has been gradually going every year. Original water level 71 feet below surface of ground.
§ White chalk with flints, the fissures discharging water.

TABLE III.

DETAILS OF STRUCTURE, DEPTHS OF PRINCIPAL FEEDERS, ETC.

No. in Geol. Surv. Mem. Vol. iv.		List of Wells.	DEPTHS			
			to Chalk.	in Chalk.	Total.	
			Feet.	Feet.	Feet.	
413	1	Bermondsey	91½	140½	232	
432	2	Croydon	15	62	77	The greatest supply of water comes from the 'Hard Crust.'
433	3	Croydon..	9¾	137	152	
448	4	Lambeth	245	173	418	Chalk, with many layers of flint and strongly charged with water.
459	5	Mortlake	315	50	365	
461	6	Old Kent Road.. ..	30	170	200	
462	7	Peckham	100	123	223	Chalk with flints, water at bottom.
463	8	Penge	361	149	..	White chalk with flints, the fissures discharging water.
487	9	Wimbledon	193	75	..	
44	10	Enfield Lock	152½	132	..	
75	11	Stratford	106	294	400	
84	12	Walthamstow Marsh ..	152	140	292	
102	13	Bishop's Stortford ..	116½	183½	300	Water rises to within 140′ of the ground. Supply 10,000 gallons a minute, only 25 gallons a minute from the bore, the rest from two headings N. & S., at a depth of 154 feet. Can be pumped down to the headings.
147	14	Chatham Dockyard ..	..	626	626	No water.
166	15	Farnborough.. ..	..	603	603	
229	16	Horticultural, Chiswick	261½	67½	329	At 56′ deep in the chalk water flowed in at the rate of 6 gallons a minute to 15′ above the ground. Chalk and flints 65′, then a bed of flint, from which water overflowed 7½ above ground at 40 gallons a minute.
245	17	Fulham..	250	66	316	
261	18	Hampstead	378	72	450	
270	19	Dawley Court, Hayes ..	231	88	319	
286	20	Sion House, Isleworth ..	420	115	535	Loose chalk 35′ over firm, and hard chalk 80′. A strong spring from the Thanet Sand rose to 30′ from the surface. A spring from the solid chalk rose with it to 5′ above the surface at 5 gallons a minute.
298	21	Kentish Town	324½	644¾	1302	
300	22	Kingsbury	132	108	..	
307	23	Reid's Brewery	136	126½	262½	
311	24	Combe's Brewery ..	223	258	481	
315	25	Charrington's, Mile End	202½	2½	205	
369	26	Meux's, Tottenham Court Road	158½	207	365½	

TABLE IV.

SHOWING HEIGHT OF WATER-LEVEL AND YIELD.

List of Wells.		Depths			Dist. from base of Chalk.	Direction.	Fall of base from outcrop.	Heights				Yield in Gallons	
								of Well Mouth.	To which Water rose.			per Minute.	per Annum.
		to Chalk	in Chalk	Total.					Above Ground	Below Ground	Below sea level		
		Feet.	Feet.	Feet.	Miles.		Feet.	Feet.	Feet.	Feet.	Feet.		
Kingston	1	371	99	470	11	S E by E	..	25	over	flows	..	..	16,060,000
Isleworth, Sion House	2	420	115	535	18	,,	..	..	5	..	..	5	2,628,000
Hanwell Asylum..	3	290	30	320	..	,,	..	..	..	..	..	..	5,256,000
Mortlake Brewery	4	287	31	318	19	,,	..	25?	..	50	..	..	5,110,000
,, Mr. Randell's.. ..	5	315	50	365	19	,,	..	25	over	flows	..	..	1,805,000
Chiswick, Horticultural Gardens	6	261½	67½	329	20	,,	..	..	15	..	..	6	3,153,600
Hammersmith, Near Bridge ..	7	232	72	304	21	,,	..	..	..	..	..	30	15,768,000
,, Mr. Bird's E. of above ..	8	264	70	336	,,	,,	..	..	..	..	..	5½	2,690,800
,, Mr. Hoare's ..	9	270	114	384	,,	,,	..	..	..	..	..	1	525,600
,, Mr. Macculloch's	10	252	66	318	,,	,,	..	..	..	..	..	7	3,679,200
,, Mr. Dortnell's..	11	250	68	318	,,	,,	..	..	..	..	..	20	10,512,000
,, Mr. G. Cloud's..	12	283	58	341	,,	,,	..	..	..	..	..	5	2,628,000
,, Mr. Brooks' ..	13	246	65	311	,,	,,	..	..	..	..	..	15	7,884,000
,, Mr. J. Millwood's	14	257	56	313	,,	,,	..	..	..	..	..	10	5,256,000
Walham Green, Swan Brewery	15	..	..	333	19	,,	..	..	..	..	..	..	3,153,600
Fulham, Bishop's Palace ..	16	250	66	316	..	,,	..	..	7½	..	..	40	21,024,000
Wandsworth Prison	17	357	126½	483½	17	,,	..	90	..	80	..	..	14,016,000
Battersea, Beaufoy's Works ..	18	240	0	240	2	,,	..	..	..	..	..	..	5,475,000
Pimlico, Stag Brewery	19	272½	116	388½	19½	,,	..	..	..	..	..	..	5,942,200
St. George's Hospital	20	319¼	18	337¼	21	,,	..	..	..	..	..	..	29,108,000
Victoria St., Vickers's Distillery	21	249	51	300	20	,,	..	..	..	..	..	..	56,706,400
Vauxhall Distillery	22	224	102	326	19	,,	..	20	..	55	..	..	1,051,200,000
Croydon { Connected by Pipe .. }	23	13	62	75	6¾	,,	..	150	..	11½	..	..	547,500,000
,,	23a	15	137	152	6¾	,,	..	..	..	11½	..	..	556,260,000
Orange Street { Connected by Tunnel. }	24	250	50	300	21	,,	..	..	..	..	..	..	292,000,000
Trafalgar Square	25	248	148	396	21	,,	..	..	..	..	..	..	
Guy's Hospital	26	196	102	298	..	,,	..	2	..	62	..	..	21,024,000
Rotherhithe, Thames Tunnel Mill	27	125	135	260	19	,,	..	15	..	..	..	80	42,048,000
Rotherhithe, Brandram's Works	28	106	145	251	19	..	..	5 below	..	27	..	..	73,000,000
Bermondsey, Donkin & Co. ..	29	91½	140½	292	19	..	..	7	..	16	..	..	15,768,000
Bromley Waterworks, Southlands	30	70	180	250	..	..	..	..	..	..	..	..	1,825,000,000 (can pump)
Clay Hill, Bromley	31	109	100	209	..	..	..	..	..	61	..	..	8,760,000
Greenwich Hospital	32	124	180	305	..	..	..	7	..	19	..	120	63,072,000
Booth's Distillery, Brentford ..	33	315	53	368	..	..	..	..	3	..	..	80	42,048,000
Reid's Brewery, Liquorpond St.	34	136	126	262	..	..	..	70	..	121	..	192	101,178,000
Charringtons, Head & Co. Mile End	35	202½	2½	205	..	..	..	33½	..	..	..	..	25,550,000
Truman's Brewery, Shoreditch..	36	..	..	..	..	..	..	..	..	..	..	..	6,570,000
												Total ..	4,889,359,400

TABLE V.

Year.	April to September. Rainfall.	Filtration. Soil.	Filtration. Chalk.	Year.	October to March. Rainfall.	Filtration. Soil.	Filtration. Chalk.
1860	20·40	3·16	8·94	1852-53	20·27	10·74	..
1852	19·97	1·50	..	1835-36	16·39	14·27	..
1859	18·31	·0	4·22	1836-37	16·71	13·81	..
1839	17·41	2·60	..	1841-42	16·56	..	..
1841	16·95	·0	..	1859-60	16·49	9·27	12·44
1853	16.79	·24	..	Mean	16·79	12·45	..
Mean	16·87	·12	..	1843-44	15·41	8·86	..
1843	14·04	·99	..	1847-48	15·84	8·94	..
1856	14·86	2·79	3·09	Mean	15·62	8·90	..
1857	14·11	1·11	1·32	1839-40	14·71	12·59	..
Mean	14·936	1·63	2·205	1850-51	14·71	8·49	..
1848	13·0	·70	..	1855-56	14·48	6·82	10·47
1849	13·91	·0	..	Mean	14·63	9·30	..
Mean	13·45	·35	..	1842-43	13·46	9·34	..
1836	12·20	2·10	..	1844-45	13·11	7·10	..
1842	12·15	1·30	..	1845-46	13·93	9·10	..
1855	12·66	·19	2·30	1848-49	13·49	6·22	..
1858	12·27	·80	·84	Mean	13·49	8·44	..
Mean	12·32	1·10	1·52	1838-39	12·58	8·59	..
1845	11·57	·0	..	1846-47	12·93	5·84	..
1846	11·50	·28	..	Mean	12·75	7·215	..
1847	11·31	·0	..	1856-57	11·96	3·72	7·19
1850	11·82	·0	..	1857-58	11·81	5·64	7·16
Mean	11·2	·07	..	Mean	11·885	4·68	7·175
1838	10·81	·12	..	1840-41	10·32	3·10	..
1837	9·80	·10	..	1851-52	10·75	3·66	..
1840	9·68	·0	..	Mean	10·535	3·38	..
1851	9·25	·04	..	1837-38	9·81	5·45	..
1854	9·47	·0	·0	1853-54	9·66	4·22	5·0
Mean	9·55	·02	..	1854-55	9·32	2·45	3·45
1844	8·07	·0	..	1858-59	9·64	·09	2·69
				Mean	9·1075	3·0525	3·713
				1849-50	8·58	1·44	..

TABLE VI.

To show Number of Gallons due to various Depths of Rain absorbed on an Area of 43 Square Miles, and the Average Flow per Day necessary for same to pass out in one Year.

Proportion of Rainfall absorbed.		Average Flow per Day.
Inches.	Gallons.	Gallons.
$0\frac{1}{2}$	3,112,856,000	8,528,372
1	6,225,712,000	$17,056,745\frac{75}{365}$
2	12,451,424,000	$34,113,490\frac{150}{365}$
3	18,687,136,000	$51,170,235\frac{225}{365}$
4	24,902,848,000	$68,226,980\frac{300}{365}$
5	31,128,560,000	$85,283,726\frac{10}{365}$
6	37,374,272,000	$102,340,471\frac{85}{365}$
7	43,589,984,000	$119,397,216\frac{160}{365}$
8	49,805,696,000	$136,453,961\frac{235}{365}$
9	56,031,408,000	$153,510,706\frac{310}{365}$
10	62,257,120,000	$170,567,452\frac{20}{365}$
11	68,482,832,000	$187,624,197\frac{95}{365}$
12	74,748,544,000	$204,680,942\frac{170}{365}$

TABLE VII.

To show Number of Gallons due to various Depths of Rain absorbed on 8 Square Miles, and Average Flow per Day necessary for same to pass out in one Year.

Proportion of Rainfall absorbed.		Average Flow per Day.
Inches.	Gallons.	Gallons.
$0\frac{1}{2}$	579,136,000	1,586,674
1	1,158,272,000	3,173,348
2	2,316,544,000	$6,346,695\frac{325}{365}$
3	3,474,816,000	9,520,044
4	4,633,088,000	$12,693,391\frac{285}{365}$
5	5,791,360,000	15,866,740
6	6,949,632,000	19,040,088

TABLE VIII.

BASIN OF THE WEY.

	Thicknesses. West Side of Basin.	Thicknesses. East Side of Basin.	Areas.	Miles of Stream flowing upon surface.	Yards of Stream per Square Mile.	Lengths of Boundary Lines. Base.	Lengths of Boundary Lines. Top.	Number of Springs from Base.	Number of Springs from Body of Bed.	Number of Springs from Top.	Number of Springs. Total for each Bed.	Number per Square Mile.	Minimum yield of Springs from each bed in gallons per day.	Corresponding amount of Rainfall absorbed on respective areas.
	Feet.	Feet.	Sq. Miles.			Miles.	Miles.							
Chalk	...		...	...	...	20								
Upper Greensand	60	50	8	$0\frac{1}{2}$	110	24	20	0	5	...	5			
Gault	120	55	$15\frac{1}{2}$	$13\frac{5}{8}$	1526	30	24	0	12	...	12			
Folkestone Sands	190	165	$44\frac{1}{2}$	$48\frac{1}{4}$	1900	$46\frac{1}{2}$	30	0	13	...	13			
Sandgate Beds...	Local		2	...	...	4	$46\frac{1}{2}$	0	2	...	2		Of 28 draining 50 square miles. 27,000,000	
Hythe Beds ...	300	200	64	$24\frac{1}{2}$	686	35	4	10	34	0	44	...		
Atherfield Clay	...		...	...	...	28	35							
Porous Beds { U. G. S.	60	50	8	$0\frac{1}{2}$	...	...	...	...	5	...	5			
Porous Beds { L. G. S.	490	365	$108\frac{1}{2}$	$72\frac{3}{4}$	...	...	...	10	47	...	59			
Impervious Beds	120	55	$17\frac{1}{2}$	$13\frac{5}{8}$	...	...	...	...	14	...	14			
Totals ...	670	470	134								76			

TABLE IX.

GAUGINGS OF SURFACE SPRINGS AND STREAMS ON THE LOWER GREENSANDS OF SURREY, IN GALLONS, PER 24 HOURS.

	Names of Springs and Streams.	Napier. August, 1850.		Rammel. 19th to 29th Oct. 1850.		Areas.	Rowlandson.		Quick. 18th to 20th Nov. 1850.		Bateman. 7th to 18th Aug. 1851.		Ranger. 1st to 10th Jan. 1852.	
						sq. miles.								
Hind Head and Blackdown.	Holy Water	1,350,000	..	2,703,000	..	..	..	..	5,702,400	..	2,132,878	..	2,917,724	
	Bramshot..	13,399,714	..	7,953,000	..	..	..	..	100,800	..	10,206,000	..	12,701,040	
	Downlands (a)	540,000	..	803,000	..	..	..	..	1,166,400	..	..	..	341,100	
	Downlands (b)	..	..	600,000										
	Headly Down	239,731	..	313,000	..	..	..	..	..	..	239,731	..	314,250	
	Barford Mills (a)	3,880,000	..	810,000	..	..	..	..	..	..	..	..	724,500	
	Barford Mills (b)	..	..	630,000	..	..	..	..	..	..	648,000	..	367,919	
	Wishange	..	..	..	..	..	..	..	..	..	486,000			
	Devils' Jumps (a)	..	..	58,000	..	25	12,000,000	..	..	..	..	..	43,350	
	Devils' Jumps (b)	360,000	..	885,000	..	..	..	..	..	..	382,000	..	394,656	
	Devil's Punch Bowl (a) ..	299,995	..	305,000	..	..	..	..	..	..	..	..	51,750	
	Devil's Punch Bowl (b) ..	..	..	544,000	..	..	..	..	..	..	414,000	..	655,950	
	Cosford House	674,928	..	3,417,000	..	..	..	..	777,600	..	550,000	..	943,648	
	Grays Wood	84,240												
	Cotchet	32,568												
	Five other springs ..	127,562	20,988,738											
	Lea	..	..	632,000	..	..	..	..	..	..	950,000	..	607,500	
Hascombe Hills.	Sweetwater Pond	1,066,795	..	378,000	..	..	..	..	1,864,800	..	760,000	..	1,142,838	
	Hide Stile	..	..	..	..	..	..	..	..	..	248,000			
	Bushbridge	529,200	..	632,000	..	10	4,750,000	..	..	..	190,000	..	356,488	
	Chapel Copse	224,697	..	..	..	..	..	16,750,000	..	..	..	..	150,300	
	Hascombe	229,116	23,038,546	..	..	..	..	..	..	..	1,539,000			
Leith Hills.	Potsford	1,799,798	..	3,510,000	..	..	..	..	..	..	4,400,000	..	3,725,520	
	Wotton	890,956	..	1,316,000	..	15	7,250,000	..	3,477,600	..	1,100,000	..	1,066,604	
	Rookery	1,436,400	..	2,000,000	..	..	..	..	8,100,000	..	957,000	..	585,360	
	Totals ..	..	27,165,700	..	29,104,000	..	..	24,000,000	..	24,189,600	..	25,302,609	..	27,090,497
	Compare with Mr. Napier's and Mr. Rammell's gaugings:— Oct. 1849 to Mar. 1850, Rainfall 8·58, Filtr. 1·44; April to Sept. 1850, " 11·82, " 0·0		1·44 inch absorbed on 50 sq. miles gives an average daily flow, for 365 days, of 29,520,132	..	29,520,132			Rain 3·29	Oct. and Nov. 1850, Filtr. 0·6					

TABLE X.

SHOWING THE ABSORBENT POWER AND RELATIVE PERMEABILITY OF THE LOWER GREENSAND.

FROM PRESTWICH'S 'WATER-BEARING STRATA.'

Formation.	Division.	Locality.	Lithological Character.	Quantity of Water absorbed by 1 Cubic Foot.		Quantity permeating through equal portions of the Sand in 1 Hour.
				Cubic Inches.	Gallons.	Cubic Inches.
Lower Greensand	Upper	Limpsfield	Very fine white and pure silicious sand . .	518	1·87	9·6
,,	,,	Chelworth	Fine bright ochreous	615	2·21	18·0
,,	,,	Leighton	Bright ferruginous sand	712	2·56	14·4
,,	Lower	Reigate	Fine yellow sand slightly argillaceous . .	734	2·64	4·8
,,	,,	Chilworth	Rather coarse light greenish sand . . .	605	2·18	7·5
,,	,,	Betchworth	Very coarse sand with small pebbles of quartz	605	2·18	8·4

NOTE.—The experiments on the absorption of water were made with portions of sands measuring 40 cubic inches; the specimens were well dried, and a measured quantity of water then added, until they were fully saturated without alteration of bulk. The permeability, which is only shown relatively, was determined by measuring the quantity of water that passed through 15 inches of the different sands, in a glass tube 1¼ inches in diameter and bent at right angles, under a pressure of 6 inches of water in the longer branch of the tube. **A cubic foot contains 1728 cubic inches or 6·232 gallons.**

TABLE XI.

TABLE SHOWING QUANTITY OF WATER ABSORBED BY ONE CUBIC INCH OF VARIOUS SANDSTONES AND LIMESTONES, AFTER IMMERSION FOR EIGHT DAYS.

No. of Speci-men.	Formation.	Locality.	Qualities.	Weights.		Difference.	
				Dry.	Wet.	Gain.	Loss.
				Grains.	Grains.	Grains.	Grains.
1	Lower Oolite	Guisborough	Ferruginous, moderately coarse quartzose sandstone ..	$507\frac{6}{12}$	$557\frac{3}{12}$	$49\frac{9}{12}$	
2	"	Wilton, Redcar	Reddish ditto and micaceous sandstone ..	$529\frac{6}{12}$	$576\frac{10}{12}$	$47\frac{4}{12}$	
3	Old Red Sandstone	Kendal	Deep red ditto ditto ..	$413\frac{8}{12}$	$460\frac{3}{12}$	$46\frac{7}{12}$	
4	Lower Oolite	Top Quarry, Skelton	Light brown ditto fine-grained micaceous ditto ..	$507\frac{7}{12}$	$555\frac{1}{12}$	$45\frac{6}{12}$	
5	"	Lumpsey, Saltburn	White, coarse, quartzose, slightly ditto ..	452	$492\frac{4}{12}$	$40\frac{4}{12}$	
6	"	Brotton, Saltburn	Light brown, fine-grained, quartzose, and slightly micaceous ..	$481\frac{1}{12}$	$520\frac{7}{12}$	$39\frac{6}{12}$	
7	"	Upleatham	Moderately coarse, friable, quartzose; little cement, ferruginous sandstone	$414\frac{8}{12}$	$452\frac{8}{12}$	38	
8	"	Ingleby	White, fine-grained, quartzose, very little mica; sandstone ..	433	$470\frac{1}{12}$	$37\frac{1}{12}$	
9	"	Castleton	Dark brown, with white specks; fine-grained ..	$491\frac{7}{12}$	528	$36\frac{5}{12}$	
10	Caen Stone	..	Very compact, soft, yellowish white limestone ..	$453\frac{1}{12}$	$487\frac{11}{12}$	$34\frac{10}{12}$	
11	Carboniferous	Hare Hills, Leeds	Fine-grained micaceous clean sandstone ..	$491\frac{3}{12}$	526	$34\frac{9}{12}$	
12	Lower Oolite	Low Quarry, Skelton	Dark brown ditto, slightly micaceous ditto ..	$537\frac{7}{12}$	$569\frac{6}{12}$	$31\frac{11}{12}$	
13	Carboniferous?	Darlington	Reddish ditto ditto ..	450	$481\frac{5}{12}$	$31\frac{5}{12}$	
14	"	Dun House, Durham	White ditto quartzose and micaceous ditto ..	539	$568\frac{5}{12}$	$29\frac{5}{12}$	
15	Carboniferous	Robin Hood Quarry, Leeds	Very fine-grained grey calliard; silicious sandstone ..	$552\frac{7}{12}$	580	$27\frac{5}{12}$	
16	"	Penhill, Yorkshire	Coarse, quartzose, white grit	$526\frac{8}{12}$	$553\frac{7}{12}$	$26\frac{11}{12}$	
17	" ?	Cockfield, Durham	Highly porous, coarse, quartzose grit	441	$467\frac{6}{12}$	$26\frac{6}{12}$	
18	Permian	Cadcastle, Durham	Red conglomerate, large quartz grains	$560\frac{3}{12}$	$585\frac{7}{12}$	$25\frac{4}{12}$	
19	Carboniferous (?)	.. ?	Fine-grained, slightly ferruginous, micaceous sandstone ..	$480\frac{3}{12}$	505	$24\frac{9}{12}$	
20	"	Penhill	Reddish, fine-grained, micaceous flaggy ditto ..	$560\frac{6}{12}$	$584\frac{8}{12}$	$24\frac{2}{12}$	
21	"	"	Grey, with black streaks, fine-grained, micaceous, flaggy, ditto ..	$550\frac{11}{12}$	$574\frac{11}{12}$	24	
22	"	"	Light grey, with dark streaks, very compact, fine-grained ditto ..	$553\frac{10}{12}$	$576\frac{9}{12}$	$22\frac{11}{12}$	
23	"	.. (?)	Grey, streaked, fine-grained, micaceous ditto ..	$558\frac{1}{12}$	$579\frac{8}{12}$	$21\frac{7}{12}$	
24	"	Penhill	Brownish grey, fine-grained, micaceous ditto ..	$500\frac{7}{12}$	$520\frac{11}{12}$	$20\frac{4}{12}$	
25	"	..	Encrinital, quartzose, calcareous, sandstone ..	$539\frac{11}{12}$	$559\frac{6}{12}$	$19\frac{7}{12}$	
26	"	Penhill	Hard silicious compact calliard	$605\frac{2}{12}$	$611\frac{9}{12}$	$6\frac{7}{12}$	
27	Keuper Marls	Eston	Gypsum	$565\frac{9}{12}$	$564\frac{6}{12}$	..	$1\frac{3}{12}$

Note.—The specimen, absorbing most water after immersion for 8 days, took up rather more than $\frac{1}{10}$ of its dry weight. That taking up least was a hard silicious rock, which also weighed heaviest when dry, took up nearly $\frac{1}{92}$ of its dry weight. A specimen of pure gypsum became partly dissolved, and lost more than a grain in weight.

TABLE XII.

NAMES OF SPRINGS.				Height above Ordnance Datum. Feet.	Inch.	DATE.	AUTHORITY.
Basin.							
Wandle.	Croydon Branch	Waddon New Road		136	4	...	Braithwaite
Wandle.	Croydon Branch	Beddington		110	0	...	6-in. Ordnance Maps
Wandle.	Carshalton Branch	C. Park	Grotto	118	4½	Early Spring, 1853	Braithwaite
Wandle.	Carshalton Branch	C. Park	Hogpit	123	8	"	"
Wandle.	Carshalton Branch	Carshalton House		121	9¼	"	"
Beverley.		Lower Cheam					
Beverley.		Cheam Park					
		Nonsuch Park					
Hog's Mill River.		Ewell		108	0	...	6-in Map.
Hog's Mill River.	Inter-mittent.	Epsom, Church Street		153	0	January–March 22nd, 1873.	Levelled by me.
Hog's Mill River.	Inter-mittent.	Worple Road					

TABLE XIII.

SHOWING RISE OF WATER-LINE BETWEEN SUTTON AND BANSTEAD AND ITS FALL BETWEEN BANSTEAD AND CROYDON.

Basin.	NAMES OF WELLS.	Date, 1873.	Depth of well. Feet. In.	Depth to water. Feet. In.	Height of well-mouth above Ordnance datum. Feet. In.	Height of top of water above Ordnance datum. Feet. In.	Distance from nearest Springs.	
Beverley.	Sutton, near the Cock	April 12	80 0½	64 0½	200 0	136 0		
Beverley.	Sutton Lodge Farm	April 7	84 0	79 0	260 0	181 0	1½ mile	from Carshalton House. Just over a mile from Lower Cheam Bourne.
Beverley.	Turf Cottage . .	,,	174 0	154 5	about 350 0	195 7	1$\frac{5}{6}$,,	from Carshalton House. 1⅓ mile from Lower Cheam Bourne.
Beverley.	Hundred Acres .	,,	263 0	239 0	420 5	181 5	2 ,,	from Carshalton House. 1⅜ mile from Lower Cheam Bourne.
	Banstead . .	,,	,,	282 6	521 0	238 6	3 ,,	from the Grotto. 2¾ miles from Lower Cheam Bourne.
Wandle.	The Oaks Park .	,,	221 0	197 0	about 370 0	173 0	1$\frac{5}{6}$,,	from the Grotto. 1$\frac{7}{12}$ mile from Lower Cheam Bourne.
Wandle.	Little Woodcote .	,,	189 9	155 0	,, 320 0	165 0	1$\frac{7}{12}$,,	from the Grotto.
Wandle.	Woodcote Lodge .	,,	122 3	88 3	,, 250 0	161 9	¾ ,,	from the Grotto.
Wandle.	New Barn Farm .	,,	,,	64 7	230 0	165 5	1 ,,	from Beddington Springs.
Wandle.	Croydon Waterworks	,,	,,	11 6	about 150 0	about 140 0		

TABLE XIV.—SHOWING RISE FROM SPRING AT CARSHALTON HOUSE TO OAKS PARK.

	Date 1873.	Depth of Well.		To Water.		Height of Well Mouth above O.D.	Height of Top of Water above O.D.		Distance from Spring.
		FT.	IN.	FT.	IN.	FT.	FT.	IN.	
Carshalton House Spring	Apr. 12	..		..		..	121	9¼	
Sutton Hill Well ..	,, ,,	70	1	63	1	200	136	11	¼ mile.
Barrowhedges Farm ..	,, ,,	48	9	28	7½	170 (abt.)	141	4½	¾ ,,
Barrowhedges	,, ,,	69	7	46	1	205 (abt.)	158	11	1 ,,
Oaks Park	,, 7	221	0	197	0	370 (abt.)	173	0 (abt.)	2 ,,

TABLE XV.—SHOWING RISE FROM GROTTO, CARSHALTON PARK, TO LITTLE WOODCOTE.

	Date 1873.	Depth of Well.		To Water.		Height of Well Mouth above O.D.	Height of Top of Water above O.D.		Distance from Grotto.
		FT.	IN.	FT.	IN.	FT.	FT.	IN.	
Grotto	..	..		..		..	118	4½	
Well	Apr. 12	35	8	25	4	150 (abt.)	125	0 (abt.)	¼ mile.
Woodcote Lodge ..	,, 7	122	3	88	3	250 (abt.)	161	9	¾ ,,
Little Woodcote ..	,, 7	189	9	155	0	320 (abt.)	165	0	1½ ,,
Woodcote Grove ..									

TABLE XVI.—SHOWING RISE FROM BEDDINGTON SPRINGS TO RUSSELL HILL.

	Date 1873.	Depth of Well.		To Water.		Height of Well Mouth above O.D.	Height of Top of Water above A.D.		Distance from Spring.
		FT.	IN.	FT.	IN.	FT.	FT.	IN.	
Beddington Springs ..	Apr. 12	..		..		..	110	0	
Windmill Cottage ..	12	..		51	3	210	158	9	½ mile.
New Barn Farm ..	7	..		64	7	230	165	5	1⅛ „
Keeper's Lodge	12	167	7	139	3	308	168	9	1¾ „
Russell Hill	5	287	?	251	0	360	110	0	2 „
Reedham Asylum ..									

TABLE XVII.

		Height of Well Mouth above Sea.	Jan. 28	February 27	February 28	March 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Mr. Elson's Sawpit	2	156 10	..	..	1 2	..	..	..	..	1 4¾	1 5¼	1 4	1 5¼	..	1 4¾	1 5	1 6	1 5¾	1 6¾	1 7¼	..	1 7	1 7¼	1 7¼	..	1 7¼	..	..	..
Mr. Hawes's Well ...	3	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Pikeshill Well ...	4	178 2	..	..	19 1	19 1	..	..	19 5	19 6½	19 6¾	19 6	19 9	..	19 8	19 6¾	19 5½	19 6¼	19 9	19 10	..	19 8¾	19 8½	19 9	..	19 9	..	..	..
Pitplace Farm Well	5	191 0	..	..	..	..	..	..	..	..	..	..	..	..	32 7¾	32 4	32 3	32 1¼	32 4½	32 6¾	..	32 4¾	32 5	32 5	..	32 10¾	..	..	..
Juniper Cottage ...	6	203 8	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" "	7	210 10	..	..	..	..	..	..	..	..	..	..	..	..	49 3¾	..	48 8	48 6¾	..	48 11¼	..	48 7¼	..	48 10¼	..	48 7	..	..	..
Olive Cottage ...	8	219 1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Common Fields' Well	9	219 7	46 4	52 11	52 0	52 6	52 6	..	53 2	53 3	53 5	53 4¼	53 7½	..	53 7½	53 4½	53 1	53 2¼	53 6	53 5¾	..	53 3½	..	53 4½	..	53 7¾	..	..	..
Amato Inn	10	190 0	..	..	..	..	..	..	..	..	..	31 10¾	33 1	..	32 11¼	..	..	32 9	..	..	..	..	..	..	..	..	..	..	..
Longdown Cottage	11	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	78 10	..	..	..	..	..	..	..	..	..	..
Northlieu Farm ...	12	250 0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Grand Stand ...	13	430 0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

		Height of Well Mouth above Sea.	March 25	26	27	28	29	30	31	April 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	24	25	28
Mr. Elson's Sawpit	2	156 10	1 8	..	1 7½	..	..	..	..	..	1 8¾	..	1 8½	..	..	..	..	1 9	..	1 7½	..	..	1 9½	1 9½	1 10	2 0¾	..	2 3¼
Mr. Hawes's Well ...	3	..	..	..	..	..	..	..	..	..	6 7¾	..	..	..	..	..	..	..	..	..	..	...	..	..	7 0	..	7 7	7 9¼
Pikeshill Well ...	4	178 2	19 8	..	19 7	..	19 7¾	..	..	..	19 10¼	..	19 10¾	..	..	..	..	19 10½	..	19 11¾	..	..	20 3	20 2¼	19 10¾	20 4½	..	..
Pitplace Farm Well	5	191 0	32 2½	..	32 2¼	..	32 2¼	..	..	..	32 5½	..	32 6½	..	..	..	..	32 6	..	32 6	..	..	32 10	32 9½	32 5¼	33 9½	..	..
Juniper Cottage ...	6	203 8	..	..	..	..	43 4	..	..	..	43 6½	..	43 7½	..	..	..	..	..	..	43 8¼	..	..	43 11	43 7¾	43 7¼	44 3¼	..	..
" "	7	210 10	48 6½	..	48 4¾	..	48 5	..	..	..	48 8½	..	48 9¾	..	..	..	..	..	..	48 10½	..	..	49 3	49 2¼	48 9½	49 6¼	..	..
Olive Cottage ...	8	219 1	..	..	..	..	50 1¼	..	..	..	50 6	..	50 6½	..	..	..	..	50 7	..	50 7½	..	..	50 10½	50 10¼	50 6	51 2	...	..
Common Fields' Well	9	219 7	52 11½	..	52 10¼	..	52 11½	..	..	..	53 3	..	53 4¾	..	..	..	..	53 5	..	53 6	..	..	53 7½	53 5½	53 9½	54 4	..	..
Amato Inn	10	190 0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	33 2	..	33 5½	..	33 3½	33 4½
Longdown Cottage	11	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	79 6½	..	..
Northlieu Farm ...	12	250 0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	88 10½	..	..
Grand Stand ...	13	430 0	..	..	..	..	..	..	..	..	..	...	..	..	..	..	..	..	..	..	262 6	..	..	..	..	..	..	..

Note.—Heights in feet and inches. The numbers in the first column refer to Map B and Fig. 10. The Table indicates the depths to water from the surface at each well.

TABLE XVIII.

	Date 1873	Depth of Well.		Height of Well Mouth above O.D.		To Water.		Height of Top of Water above O.D.		Height of Water above Wandle.	
		FT.	IN.	FT.	IN.	FT.	IN.	FT.	IN.	FT.	IN.
Wandle		..		..		..		141	4	..	
Croydon Water-works ..		..		..		..		..		..	
Croham	Nov. 27.	79	8	270	0	71	5	198	7	57	3
Addington	" "	73	2	265	0	53	11½	211	0	69	8
Addington Lodge ..	" "			490	0	204	0	286	0	144	8

TABLE XIX.

	Date 1873.	To Water.		Height of Top of Water above O.D.		Amount of Fall since April 24th.		Average rate per day.
		FT.	IN.	FT.	IN.	FT.	IN.	IN.
Pikeshill	Dec. 1.	34	3¼	143	10¾	13	11	·75
Pitplace Farm	" "	47	4	143	8	13	6½	·73
Olive Cottage	" "	65	0	..		13	10	·75
Juniper Cottage (1) ..	" "	57	6½	146	1½	13	3¼	·72
" " (2) ..	" "	63	0			13	5¾	·73
Common Fields ..	" "	73	3	146	4	18	11	1·03

TABLE XX.

	Date.	Height of Surface above O. D.	Depth of Well.	Depth to Water.	Height of Top of Water above O. D.	Distance from Wandle. Straight.	Amount of Rise in Surface of Water from Wandle.	Rise per Mile between Stations at Rate of.
		FT.	FT. IN.	FT. IN.	FT. IN.	MILES.	FT. IN.	FT. IN.
Wandle, Croydon ..	..	..	..	..	141 4	..	...	..
Old Stables, near Red Deer	1873, Dec. 3	abt. 180	25 4	19 10	160 2	1½	18 10	12 6
Tudor Cottages	”	215	36 5	30 0	185 0	2½	43 8	24 10
Flint Cottages	”	230	43 4	35 0	195 0	3¼	53 8	13 6
Stoatsnest	”	240	51 0	43 0	198 0	3½	56 8	12 0
Hope Cottage	”	245	49 0	43 4	201 6	4	60 2	7 0
Red Lion	”	250	53 0	47 2	202 10	4	61 6	..
Marlpit Lane	”	285	77 6	66 7	218 5	4¼	77 1	..
Hooley Cottage	”	360	130 0	91 0	269 0	5½	127 8	..

TABLE XXI.

	Date 1873.	Depth of Well.	Height of Well Mouth above O. D.	To Water.	Height of Top of Water above O. D.	Amount of Fall since April 12.	Average Rate per Day.
		FT. IN.	FT. IN.	FT. IN.	FT. IN.	FT. IN.	IN.
Sutton Hill ..	Dec. 4	..	200 0	72 0	128 0	8 11	·45
Barrow Hedge Farm	,,	..	170 (about)	42 6	127 6	13 8½	·69
Woodcote Grove ..	,,	313 0	450 ,,	296 6	153 6	..	..
Woodmanstone ..	,,	310 0	460 ,,	309 0	151 0	..	..

TABLE XXII.

	Date 1873.	Depth of Well.	Height of Well Mouth above O. D.	To Water.	Height of Top of Water above O. D.	Amount of Fall since April 24.	Average Rate per Day.
		FT. IN.	FT. IN.	FT. IN.	FT. IN.	FT. IN.	IN.
Manor Farm ..	Dec. 6	78 2	190 (about)	68 6½	121 5½	..	..
Well	,,	60 0	190 ,,	55 0	135 0	..	..
Priestshill Farm ..	,,	81 2	219 0	70 3½	148 8½	..	..
Northlieu Farm ..	,,	110 1½	250 (about)	99 4	150 8	10 3½	·55
Walnut-tree Farm ..	,,	171 (about)	315 ,,	157 0	158 0	..	..
Warren Farm ..	,,	191 2	350 ,,	189 2	160 10	..	..

The Citations on the Fly Leaf.

In Gammer Grethel's collection of so-called Fairy Tales, as written down by MM. Grimm, there are some which bear the unmistakeable stamp of high antiquity. They have also a strong Oriental colouring, and are, without doubt, very ancient Eastern traditions. Of these, M. Grimm has named two, 'The Three Crows' and 'Giant Golden Beard.'

In each of these there is a record of a dearth of water. In 'The Three Crows' the difficulty is overcome by the accidental discovery of an Artesian well, which overflowed. In 'Giant Golden Beard' the people were not so lucky, and the extent of the calamity to them is manifested in the extravagant remuneration offered to the person who will restore their spring.

I have cited these passages on account of the deeply-interesting reflection, inspired by this backward glance into ages so remote, that those early communities were subject to the very same difficulty which we, with all our accumulated experience and acquired knowledge, are so little better able to manage to-day.

'The Three Crows' proves the Artesian well to be of no modern discovery, but to have been in use in the East in very remote antiquity. No amount of digging would produce 'a fine *spring* that gave water enough for the whole town,' except a true overflowing Artesian Well.

List of Books and Papers consulted in the Preparation of this Work.

Books.

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2. Prestwich's 'Water-bearing Strata of London.' 1851.
3. 'Practical Tunnelling.' Sims.
4. Hughes's 'Waterworks.' 1872.
5. 'Memoirs, Geological Survey,' Vol. IV. W. Whitaker, &c.

Papers.

1. 'On the Periodical Alternations and Progressive Permanent Depression of the Chalk Water Level under London.' By Rev. J. C. Clutterbuck, M.A., Minutes of Proc. Inst. C.E. 1850.

2. 'Report to Directors of London (Watford) Spring-water Company.' S. C. Homersham, C.E. 1850.

3. 'Report on proposed gathering grounds from the Soft Water Springs of the Surrey Sands. Hon. William Napier, *General Board of Health Reports.*' 1851.

4. 'Rowlandson's Report on Mr. Napier's proposition.'

5. 'Report contained in a Return to an Order of the House of Lords, dated June 22nd, 1852.' By J. F. Bateman, C.E.

6. 'Report to Directors of London (Watford) Spring-water Company.' S. C. Homersham, C.E. 1852.

7. Ditto. By Peter Redfern, M.D. Part of the 'Report on Waters from the Greensand Formation in Surrey.'

8. Caleb Evans, in Proc. Geological Society, Vol. II. p. 2.

9. 'On the Rise and Fall of the River Wandle.' 1862. By Frederick Braithwaite, C.E. Minutes of Proceedings, Institute C.E., Vol. XX.

10. Wells, 'Variation in their Depth.' Symons's 'Monthly Meteorological Magazine,' May 1866.

11. 'On Evaporation.' Symons's 'British Rainfall.' 1869.

12. 'Report of the Engineer on the Boring Operations at the Crossness Pumping Station,' &c. 1869. *Metropolitan Board of Works Reports.*

13. 'Report of Royal Commission on Water Supply,' and Appendices to ditto. 1869.

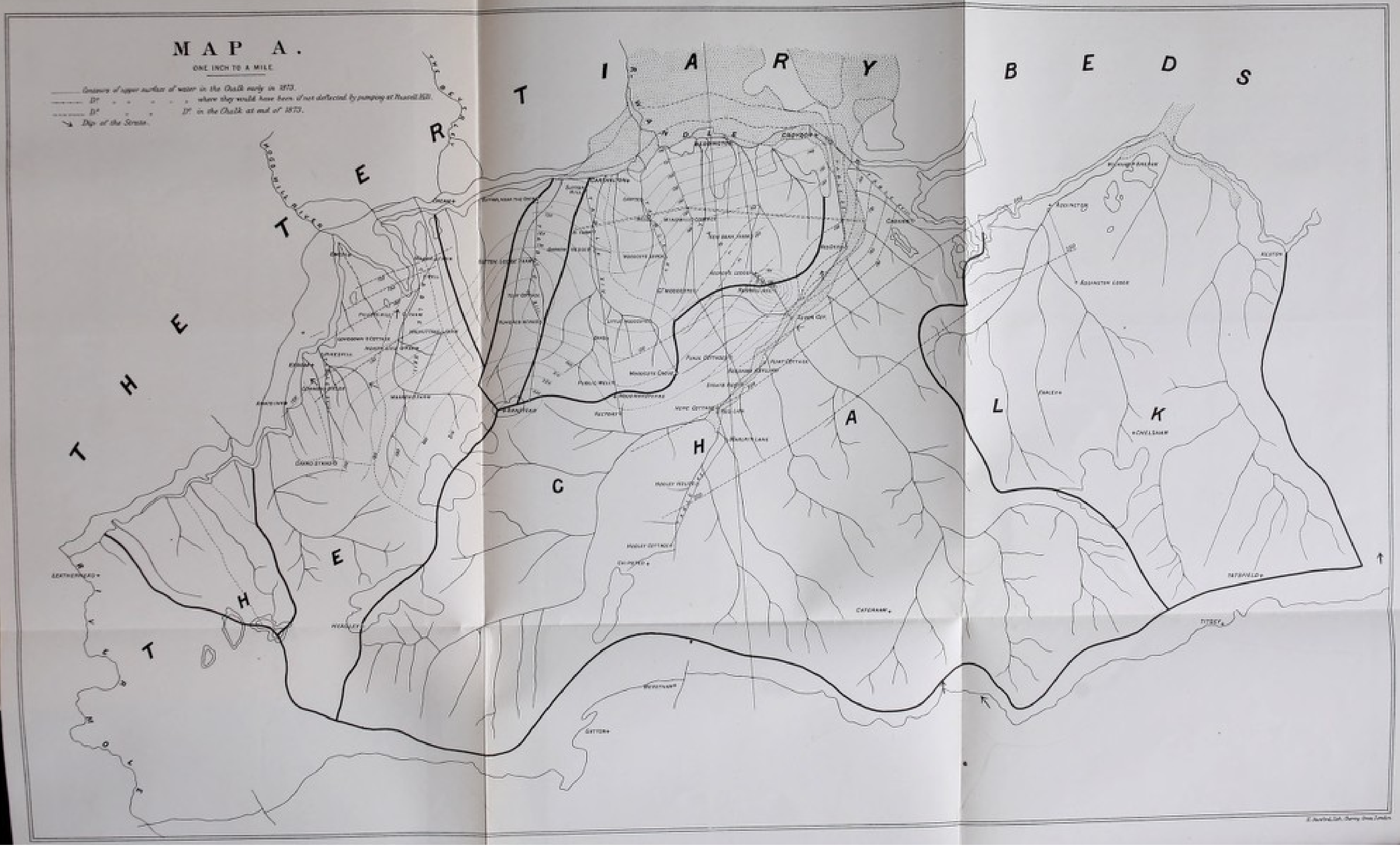
14. 'Geology of the Straits of Dover.' W. Topley.

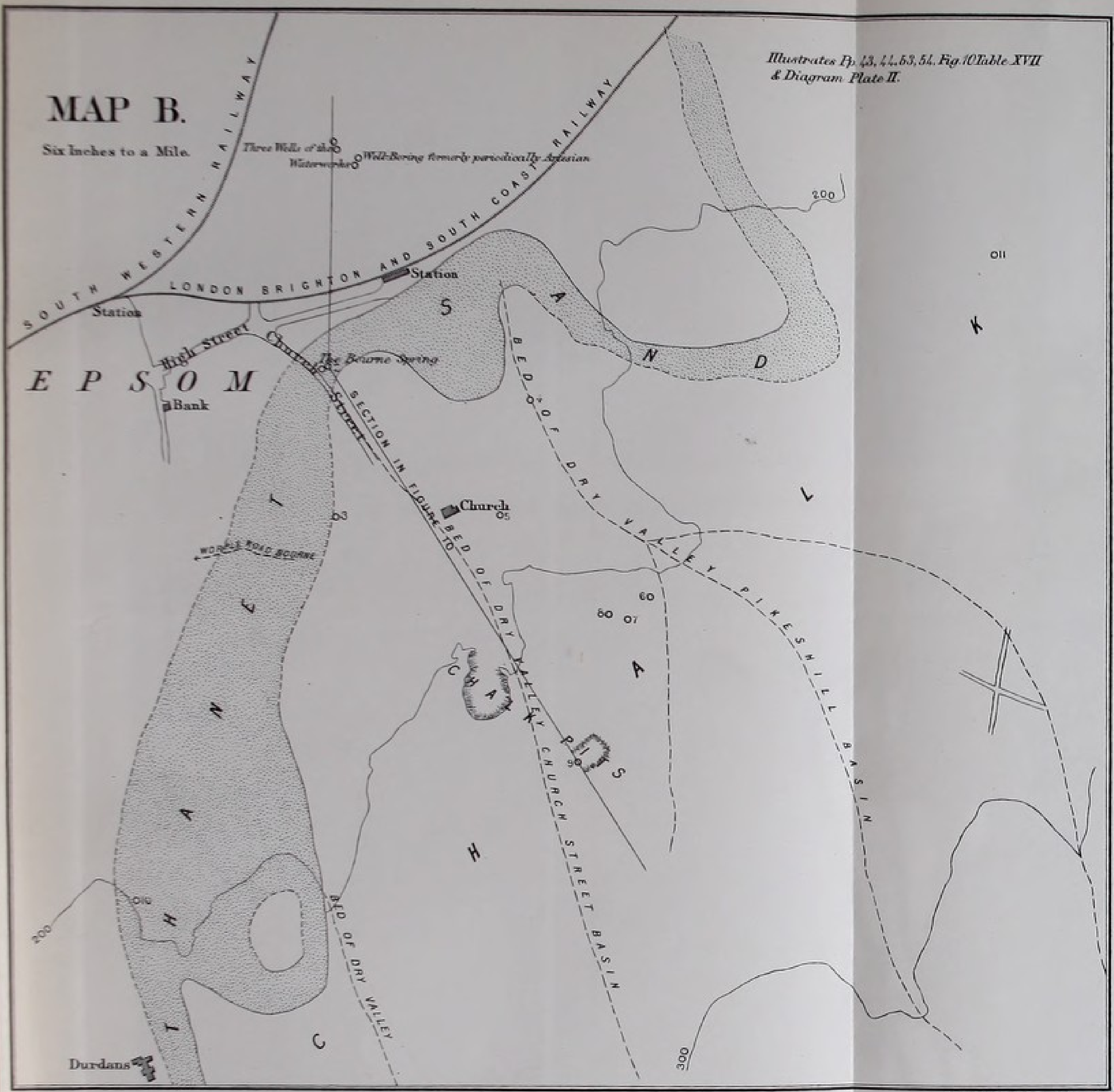
15. 'Agricultural Geology of the Weald. W. Topley. Journal of Royal Agricultural Society,' Vol. VIII.

16. 'Prestwich's Anniversary Address to Geological Society.' 1872.

17. 'Minutes of Evidence as to the Regulations for a Constant Supply of Water to the Metropolis,' 1873. *Board of Trade Reports.*

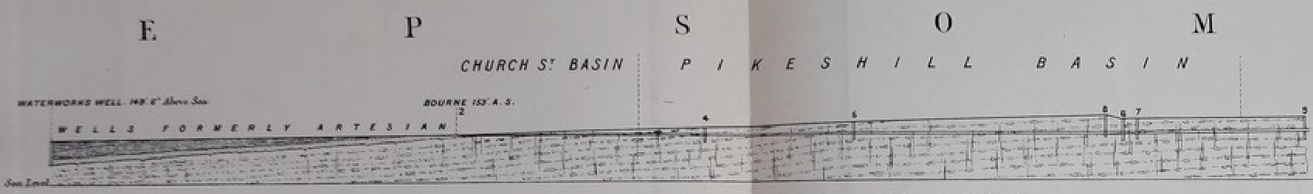
LONDON:
Printed by JOHN STRANGEWAYS, Castle St. Leicester Sq.


MAP A.
ONE INCH TO A MILE.
Contours of upper surface of water in the Chalk early in 1873.
Do where they would have been if not deflected by pumping at Russell Hill.
Do Do in the Chalk at end of 1873.
Dip of the Strata.
THE TERTIARY BEDS
THE CHALK
CROYDON
CARSHALTON
BANSTEAD
CATERHAM
CHELSHAM
TATSFIELD
TITSEY
GATTON
LEATHERHEAD



E. Stanford, lith. 6 & 7 Charing Cross, S.W.

FIGURE X.

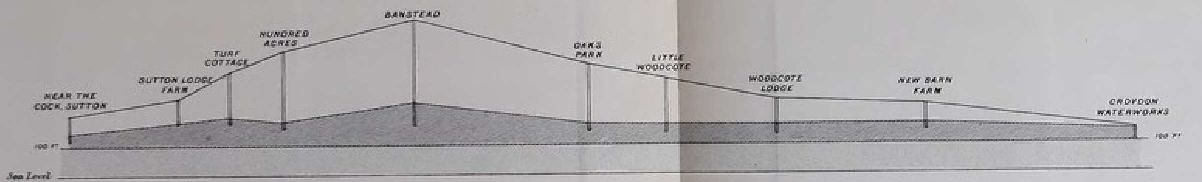


Scale 12 Inches to a Mile. Illustrates Pages 44, 53, Table XVII, Diagram, Plate 2, & Map B.

The inclined converging lines shew the observed amount of fall in the surface of the water in the chalk, as registered in Table XVII. It is slightly exaggerated in this figure

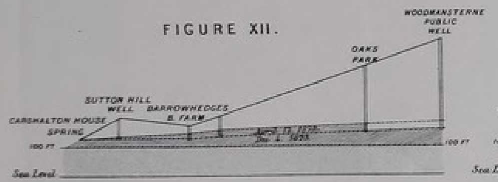
FIGS. XI. to XVI. *Vertical Scale 12 Inches Horizontal Scale 1 Inch to a Mile.*

FIGURE XI.



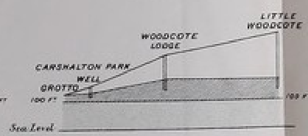
Illustrates Table XIII.

FIGURE XII.



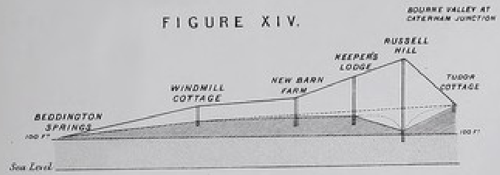
Illustrates Tables XIV & XXI.

FIGURE XIII.



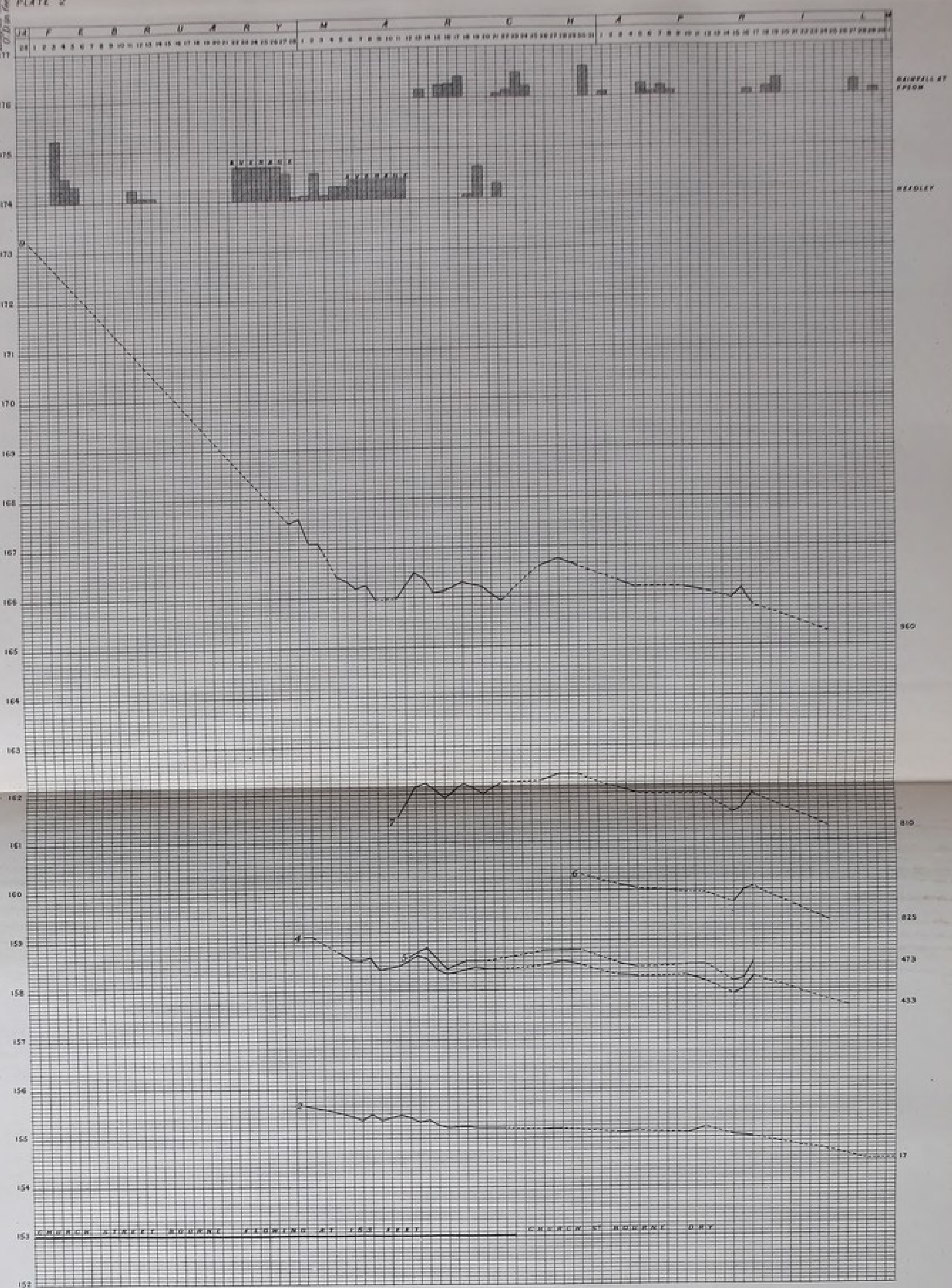
Illustrates Table XV.

FIGURE XIV.



Illustrates Table XVI.

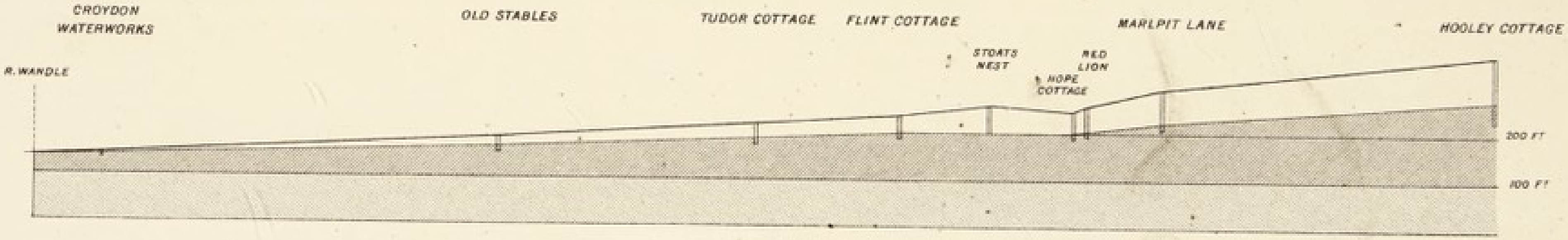
PLATE 2



Illustrates Pp. 44, 53, Table XVII, Map B and Fig. 10.

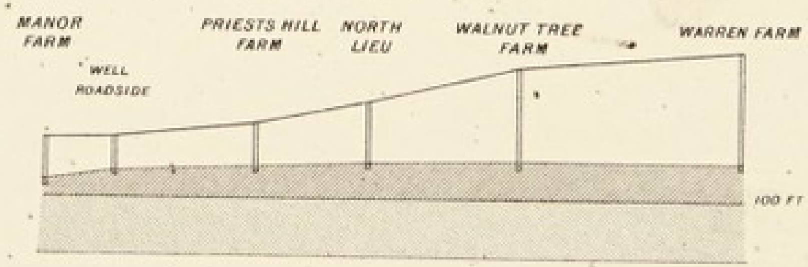
Plate 3.

FIGURE XV.



Illustrates Table XX.

FIGURE XVI.



Illustrates Table XXII.