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THE

METROPOLITAN WATER SUPPLY

BY

W. SCOTT TEBB, M.A., M.D., CANTAB., D.P.H.

FELLOW OF THE INSTITUTE OF CHEMISTRY, PUBLIC ANALYST TO THE

METROPOLITAN BOROUGH OF SOUTHWARK.

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Fellow of the Institute of Chemistry, Public Analyst to the

Metropolitan Borough of Southwark.

Owing to various complaints of the quality of the drinking water in the Southwark district, a number of analyses were carried out during the year, and it was found that in consequence of the heavy and continued floods the water supplied by the Thames Companies was on many occasions of very bad quality. A pure water supply is of such far-reaching importance to the public health, that I propose to treat the matter in some detail, and include a brief sketch of how London has grown to its present position with regard to one of the prime necessaries of life.

In very early times the water was taken direct from the River Thames or from brooks or streams in its vicinity ; later recource was had to springs in the higher districts, the water being conveyed by earthen or leaden pipes often of considerable length to conduits or fountains conveniently situated for distribution ; the conduits were artificial hydraulic constructions of some magnitude and were inspected annually with much formality by the Mayor and Corporation. Such names as Conduit Street, Lamb's Conduit and White Conduit still survive to remind London of the early efforts of its citizens.

By the middle of the sixteenth century the increased growth of the population rendered some further public supply necessary. To meet this want an enterprising Dutchman, Peter Morrys conceived the idea of forcing water from the Thames by mechanical pumping power. In 1581 the Corporation granted him a lease for 500 years, and a water-wheel was erected under the first arch of London Bridge which was turned by the tide, and worked forcing pumps which impelled water through the streets to the houses. The lease and business were subsequently converted into the London Bridge Waterworks Company which flourished until the early part of the last century.

As London continued to extend in area, Morrys's mains and pumping power became inadequate for the wants of the more elevated and distant parts of the town, and in 1606 an Act was obtained by the Corporation to bring a stream of water from springs near Ware. The City, however, became alarmed at the magnitude of the plan, and it was left to Mr. (afterwards Sir Hugh) Myddelton to carry the project through. Thus arose the New River Company which has continued to this day to serve a portion of the Metropolis.

The London Bridge Waterworks, the New River Company together with springs and wells continued to supply the Metropolis during the seventeenth century, but the quantity again became insufficient, and five London Companies were formed at different times during the hundred years from 1723 to 1822 to remove water from the Thames in the neighbourhood of London.

The following table gives the date of formation, district supplied, and situation of intake :—

TABLE A.

Description of Company.	Date of Formation.	District Supplied.	Situation of Intake.
Chelsea ...	1723 ...	Westminster ...	Chelsea
Lambeth ...	1785 ...	Lambeth ...	Opposite Charing Cross
West Middlesex	1806 ...	Western Suburbs	Hammersmith
Grand Junction	1820 ...	North-West Suburbs	Chelsea
Southwark ...	1822 ...	South London...	By London Bridge (later at Battersea)

Thus were initiated the five London Companies which together with the New River and the River Lea have continued to supply the needs of London until quite recently, when they were bought up for the Metropolitan Water Board by Arbitration under the Metropolis Water Act of 1902. It will be seen from the above that by the year 1822 the Thames Companies had full control of the public water supply.

This system of granting powers to individuals and Companies to abstract water from rivers and streams for purposes of profit has not only proved costly to consumers, but has greatly delayed the introduction of a pure water supply, and can only have arisen from the lack of a proper public spirit on the part of the inhabitants. The law of England assumes that water flowing in a stream is *publici juris* a thing which as property belongs to no individual, but is for the use of all. This is clearly shewn by Blackstone who remarks " there are some few things, which notwithstanding the general introduction and continuance of property, must still unavoidably remain in common being such wherein nothing but a usufructuary property is capable of being had. . . . such (among others) are the elements of light, air and water."*

The monopoly or vested interest in water is therefore as contrary to the principles of English law as it is to the general well-being of the community, and for this dereliction of public duty, the people have duly suffered not only in pocket but also in health.

No sooner did the Companies discover their power and authority than they combined to raise the rates; this caused a public outcry, and in 1821 a Committee of the House of Commons was appointed to examine into the question. After careful inquiry they recommended that maximum rates should be fixed by Parliament. No legislation followed this recommendation but the inquiry had the effect of inducing the Companies to remove the chief causes of dissatisfaction. A few years later feeling was aroused on the question of the quality of the water, and a public meeting was held at Willis's Rooms, on April 9th, 1827. The following resolution was moved and carried unanimously, " That the water taken up from the River Thames at Chelsea for the use of the inhabitants of the western portion of the Metropolis, being charged with the contents of the great common sewers, the drainings from dunghills and laystalls, the refuse of hospitals, slaughter-houses, colour, lead and soap works, drug mills and manufactories, and with all sorts of decomposed animal and vegetable substances rendering the said water offensive and destructive to health, ought no longer to be taken up by any of the water Companies from so foul a source."

* Commentaries on the Laws of England, ii., 14, Oxford, 1766.

The public meeting which was influentially attended led to a petition to Parliament who appointed a Commission without opposition. Accordingly in 1828 was appointed a Royal Commission consisting of Mr. Thomas Telford, a civil engineer, Professor W. T. Brande, a chemist and Dr. P. M. Roget, Secretary of the Royal Society.

As the result of their Inquiry the Commissioners reported that the "present state of the supply of water to the Metropolis, is susceptible of and requires improvement; that many of the complaints respecting the quality of the water are well-founded; and that it ought to be derived from other sources than those now resorted to, and guarded by such restrictions as shall at all times ensure its cleanliness and purity." The Commissioners further pointed out that only "insects and suspended impurities" could be separated by filtration and that "the purity of the water as dependent upon matters held in a state of solution, cannot be improved by any practicable modification of the process," and that as the water was largely contaminated by dissolved impurities "the most perfect system of filtering can effect only a partial purification."

The Companies became alarmed at the prospect of sweeping and costly changes in the sources of supply, foreshadowed by this report and directed their attention to purification by filtration. The first large filter on a working scale was that constructed by the Chelsea Company in 1829. This was found to be efficacious as far as the removal of the suspended particles were concerned, but it was soon discovered that there was little or no improvement in the noxious organic matters in solution. The other Companies although they did not adopt filtration still made improvements in some way or other. Thus the West Middlesex constructed settling reservoirs, the Grand Junction removed their intake to a point higher up the river, and the Southwark abolished the old sites and established new works at Battersea. It must be remembered that about this time old methods of sewage disposal were being given up, and that drainage and sewerage schemes were becoming more and more in vogue. The water-carriage system, however advantageous for the rapid disposal of the sewage, becomes a menace to health when the latter is discharged into the stream above the intake of the drinking water. This was the plight of Londoners for many years after the Companies were established. They were in reality drinking their own diluted sewage and the position was rapidly becoming more serious. The first attempt to remedy this condition of affairs was made by the Lambeth Company in 1848, which obtained powers from Parliament to remove their intake to Thames Ditton, beyond the reach of London sewage.

Meanwhile the subject was taken up by the Board of Health consisting of the Earl of Carlisle, Lord Ashley (afterwards the Earl of Shaftesbury), Mr. Edwin Chadwick and Dr. Southwood Smith. The Board reported, May 28, 1850, on the Metropolitan Water Supply, as follows:—

1. That for domestic use it is inferior to the average quality of waters supplied to towns.

2. That its inferiority as a supply for domestic use arises chiefly from an excess of hardness.

3. That even when taken above the reach of pollution from the sewers of the Metropolis, it contains an excess varying with the season of animal and vegetable matter.

4. That the water taken by the Lambeth Company from the Thames opposite Hungerford Market is charged with animal and vegetable impurities apparently the effect of the discharge of sewer water, which render it wholly unfit for use, and highly dangerous to the health of the persons who drink it.

5. Whilst we believe that Thames water taken up beyond the influence of the Metropolitan drainage, and filtered, may be used without injury to the public health, and may be employed temporarily until other sources can be laid under contribution we advise that Thames water and other water of like quality, as to hardness, be as early as practicable abandoned.

The Government now felt that something would have to be done, and early in 1851 they appointed a Commission of three eminent chemists, viz: Professor Graham, Master of the Mint; Dr. W. A. Miller, Professor of Chemistry at Kings' College; and Dr. A. W. Hofmann, Professor of Chemistry of the Royal College of Chemistry.

A careful inquiry was made including a number of analyses, and the Commission found that "when in good condition, the Thames water also possesses the peculiar and agreeable brightness of chalk waters," they further described it as a "palatable water," and that there existed "no sufficient grounds for believing that the mineral contents of the water supplied to London are injurious to health"; but against these grounds of commendation there were certain disadvantages, thus, the Thames water was liable to "turbidity" from floods, and the water acquired a yellow colour, which was of an "unusually persistent character," and only very partially removed by sand filtration. The river they said was particularly liable to this contamination "in the latter part of autumn and early months of winter, from the extensive decomposition of vegetable matter in the highly cultivated district through which it flows. . . . For the present London supply this contamination is a serious evil. As the main drain of a large and populous district, the Thames becomes at all seasons polluted by the sewerage of several considerable towns, and by the surface drainage of manured and ploughed land. Even above Kingston a population of three-quarters of a million is found upon the banks of this river and its tributaries. The diverting the sewerage of the various towns entirely from the Thames would be attended with so much difficulty that the project need not be taken into account. . . . The contamination by sewerage however cannot faii to become considerable and offensive with the increase of population, and the more efficient and general drainage of towns. And it appears to be only a question of time, when the sense of this violation of the river purity, will decide the public mind to the entire abandonment of the Thames as a source of supply, unless indeed artificial means of purification be devised in the meantime and applied."

It will thus be seen that the two Commissions and the General Board of Health recommended leaving the Thames as a source of supply, and in 1851 the Government brought in a Bill to amalgamate all the Companies into one great whole, whereby improvements might be introduced more effectively and economically than by dealing with them singly. One of the conditions was that the new Company should be compelled to obtain water from such sources as the Secretary of State might direct. The Companies fought the Bill and in the end proved too powerful for the Government, but in the following year by the Act of 1852, 15 and 16 Victoria, c. 84, all the Thames Companies were compelled to follow the example of the Lambeth Company, and remove their intakes above the risk of contamination of Metropolitan sewage, with the result that the quality of the water in each case was very materially improved.

In the year 1857, Dr. Hassall, a pioneer in the reform of food adulteration made a report on the "Microscopical examination of the Metropolitan Water Supply," and stated that while a great improvement had taken place since the drinking water was removed from a place higher up the river, "the Metropolis is still supplied with water containing considerable numbers of living vegetable and animal productions, which are not present in the purer waters."

The next Inquiry was entrusted to the Rivers Pollution Commission, consisting of Mr. Robert Rawlinson, the eminent engineer; Mr. J. Thornhill Harrison, and Mr. J. T. Way, late Consulting Chemist to the Royal Agricultural Society. They reported on March 29, 1866, as follows :—

"The number of persons whose sewage daily finds its way into the water from which London principally draws its supply amounts to hundreds of thousands; that this number is destined greatly to increase, not only by the growth of population, but by the development of the sewerage system." They pointed out that during the flow down the river: That the sewage tended to undergo oxidation, and that the volume of sewage as compared with the volume of water was small, but in their opinion "neither the one nor the other is a satisfactory ground of assurance that the Metropolitan supply is wholesome."

In consequence of this report Her late Majesty appointed a Commission in December, 1866, to enquire into the supply of unpolluted and wholesome water obtainable for large towns by the collection and storage of water in the high grounds of England and Wales, and which of such sources were best suited for the supply of London, and how the remaining sources might be beneficially distributed among the principal towns. The terms of this Commission clearly indicated the intention of the Government of the day to abandon the Thames for domestic supply. But this Commission for some reason or other was revoked and another appointed in April 1867. The new Commission was still to enquire into the sources of supply in the high grounds of England and Wales, but instead of being asked to report "which of such sources" were desirable for the Metropolis and other towns they were to enquire into the present state of the Metropolitan Water Supply, and whether there were "other districts in addition to the high districts of England and Wales from which a good supply of unpolluted and wholesome water can be obtained," and if so which were best suited for the supply of the Metropolis, &c.

The Commissioners who were presided over by the Duke of Richmond, collected a vast amount of valuable evidence, and issued their Report in 1869. They examined into certain Lake District and Welsh projects for bringing water to London, and offered no formidable opposition, on the other hand they found that Mr. Bateman's Welsh scheme was, "in an engineering point of view, feasible and practicable, and that by it a large supply of water might be obtained for the Metropolis . . . that the quality of the water would be satisfactory as regards its purity."

As to the London water, they found that the Thames would furnish a supply sufficient for any probable increase of Metropolitan population. Further that the Thames water had "many good qualities." It was "clear, bright, colourless, agreeable, and palatable, and the nature and amount of its saline constituents are considered by many to contribute to its general acceptability for drinking," as to the "organic impurities," there were "great diversities of opinion." They had had before them "many eminent men of science," whose testimony was "worthy of respectful attention." Thus Dr. Angus Smith, the Government Inspector of Alkali Works, who had had much experience of the analysis of potable waters detected the presence of "organic matter" of a "very active kind, probably dangerous," and which he "believed to be caused by sewage" in every sample of Thames water he analysed below the town of Reading. (Q 7199, 7200).

Sir Lyon (afterwards Lord) Playfair was of the opinion that "where the organic matter comes from drainage, it is a most formidable ingredient in water, and it is 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." (Q 2681).

Dr. Edmund Parkes. the eminent hygienist, said "I should certainly say that the London water has been impregnated with sewage . . . and therefore being impregnated with sewage I should think that there would be considerable danger in the use of it (Q 3249). Dr. Farr a great sanitary authority and statistician, informed the Commission, "my view is generally that those waters in which human excreta enter to any extent are dangerous." (Q 2885).

Sir John Simon said, "the rule ought to be that no sewage should go into any water that can be used for drinking purposes," and he characterised it as "an experiment on the health of the population, and I do not think that that experiment ought to be tried." Elsewhere in his evidence he said, "it ought to be made an absolute condition for a public water supply that it should be incontaminable by drainage," (Q. 2812). Such were the scientific opinions offered to the Richmond Commission but the Commissioners would not admit that they were "sufficiently well established to form any conclusive argument for abandoning an otherwise unobjectionable source of water supply," and the Commission concluded that when "efficient measures are adopted for excluding the sewage and other pollutions from the Thames and the Lea and their Tributaries, and for ensuring perfect filtration, water taken from the present sources will be perfectly wholesome, and of suitable quality for the supply of the Metropolis."

The Commission unfortunately do not make it clear what they thought of water with the "organic impurities" included (as was inevitable). They certainly did not think it so good as the Welsh water which was "satisfactory as regards its purity," or they would probably have said so. A fair summary of their report would be that although they were not satisfied with the purity of the Thames water as compared with water procurable in sufficient quantity from other sources still they were not convinced that this was a conclusive argument for abandoning the supply hitherto used.

In the meanwhile another Rivers Pollution Commission was sitting and they reported in 1874, giving a detailed account of their investigations which included the examination of over 2000 samples of drinking water. They found that when the sewage of towns was discharged into running water the "foul organic matters in solution are very persistent; they oxidise very slowly. . . . there is no river in the United Kingdom long enough to secure the oxidation and destruction of any sewage which may be discharged into it, even at its source." They pointed out that the Thames above the intakes of the Water Companies receives the sewage of a large number of towns and other inhabited places, and the washings of a large area of highly cultivated land. That in times of flood a large proportion of both "suspended and dissolved filth" is conveyed to the intakes of the Metropolitan Water Companies, and that even in ordinary weather a considerable proportion of the soluble organic matter of sewage is discharged into the river and its tributaries and likewise makes its way down to the works of the Water Companies. They further express the opinion that "there is no hope of this digusting state of the river being so far remedied as to prevent the admixture of animal and other offensive matters with the filtered Thames water as delivered in the Metropolis." The Commissioners conclude their valuable report by recommending "That the Thames should as early as possible be abandoned as a source of water for domestic use." I have here given a brief abstract of the result of six public inquiries into the quality of the Thames water, and with the exception of the Richmond Commission* they have all condemned the water and voted in favour of a change of supply. There is only one other Inquiry yet remaining to be considered, that is to say the Balfour Commission to which I shall take occasion to refer presently. I will now deal as briefly as possible with the two diseases which are alleged to be propagated by drinking water.

Cholera.—In this country cholera has appeared in epidemic form in 1831-2, 1848-9, 1853-4 and 1866. An examination of the cholera history of several of the large towns suggests that drinking water was at least one of the causes by means of which this disease has been disseminated. Prior to 1851 Manchester and Salford† were supplied partly from the River Irwell and partly from shallow wells. During

* A careful examination of the Report of the Richmond Commission will shew that although the Commissioners did not consider the water organically pure they hesitated to recommend a change of supply.

† Sixth Report of the Rivers Pollution Commission, p. 153.

this year the new supply of upland surface water from Lake Thirlmere was distributed to the two towns. The deaths from cholera during the four epidemics were as follows :—

TABLE B.

CHOLERA MORTALITY IN MANCHESTER AND SALFORD.

Years.			Cholera.
1832	...	...	890
1849	...	...	1115
1854	...	...	50
1866	...	...	88

Also with regard to Glasgow,* until the year 1847, this town was entirely supplied by water pumped from the Clyde, which was polluted by drainage from towns higher up the river, if not by the sewage of Glasgow itself. In 1847, a small portion of the polluted supply was substituted for unpolluted water, from Gorbals seven miles south of Glasgow. It was not until 1859 that a wholesome supply of drinking water was finally obtained from Loch Katrine. The following table gives the figures for the four cholera epidemics :

TABLE C.

CHOLERA MORTALITY IN GLASGOW.

Years.		Deaths from Cholera.		Deaths from Cholera per 10,000 of population.
1832	...	2842	...	140
1849	...	3772	...	106
1854	...	3886	...	119
1866	...	68	...	1·6

Thus in neither Manchester nor Glasgow did cholera spread to any considerable extent after the introduction of a pure drinking water supply to these towns, but it must be remembered that owing to the efforts of Edwin Chadwick and Southwood Smith, the fifties and sixties were periods of great sanitary activity, and the cessation of cholera must not be put down to this one cause of changed water supply, but to the improved sanitary condition of the towns generally.

Typhoid Fever.—With reference to typhoid fever official reports are full of cases of alleged waterborne disease, but personally I should doubt whether in all these epidemics the alleged connection with drinking water had been completely made out, and whether enough allowance had been made for other means by which the disease may be spread. One of the best instances on record is that which occurred at Lausen near Basle and

* Ibid, pp. 153, 154.

was investigated by Dr. Hägler.* This village of 780 inhabitants had never within living memory been visited by typhoid fever. Suddenly in August 1872 a large number took the disease, in a few days there were 57 cases, and by October 130 were attacked, or 17 per cent. of the population. Except in six houses which were supplied by wells, the cases were distributed evenly throughout the village. These six houses were exempt from typhoid. The public water supply came from a spring some distance south of Lausen, at the foot of the Stockhalden ridge, which separated Lausen from the parallel valley of the Fürlerthal. In this valley in a solitary house a peasant was attacked with typhoid fever on June 10th, after his return from a journey. A girl was attacked in the same house on July 10th, and the peasant's wife and son sickened in August. Observations on a brook in the Fürlerthal valley which received the excreta from the peasant's cottage showed that there was a communication with the Lausen spring, and all doubt was removed by Dr. Hägler, who poured into the Fürlerthal brook a strong solution of salt which subsequently appeared in the Lausen spring. This is one of the most carefully investigated cases on record and is, I think, suggestive of the possibility of waterborne typhoid. Further well-attested instances might be given, and particularly the Caterham epidemic investigated by Dr. Thorne. There seems therefore some reason to believe that cholera and typhoid may be propagated by impure drinking water ; it thus becomes necessary to discuss the essential agencies of the dissemination of these diseases. Murchison† the greatest authority on fever, perhaps who ever lived taught the spontaneous origin of typhoid from foul sewer gases and contaminated drinking water, or in other words the *de novo*‡ origin in filth. During the last forty years we have travelled far away from these views, but I do not know whether we have arrived much nearer to the truth. What is new since that time is that micro-organisms or bacteria capable of independent life and of propagating their species have been discovered in association with certain infective diseases. The behaviour of the different bacteria has been minutely recorded, and the new science of Bacteriology has been founded largely on the assumption that a micro-organism is the actual cause of

* Sixth Report of the Rivers Pollution Commissioners, p. 463.

† A Treatise on the continued Fevers, 1862, p.p. 436-455.

‡ Murchison in discussing the objections to this theory said, "the poison of a fever has been compared to a plant or an animal, and because there is no such thing as spontaneous generation of plants and animals it is maintained that there can be no such thing as the generation *de novo* of a fever poison. But the conclusion is unjust as there exists no analogy between the poison of fever and an organised being. The belief that the acute specific diseases are propagated by means of minute sporules is a pure hypothesis. Contagious diseases were not created with plants and animals, and must therefore have been produced subsequently, and if so it is equally reasonable to believe in the possibility of their spontaneous origin at the present day."

disease. Elsewhere I have alluded to doubts among leading authorities whether the micro-organism by itself, and independently of any condition of soil in which it is planted, can give rise to disease in man.* In this thesis I should be inclined to go further and suggest a doubt whether in some diseases, and particularly the diseases under consideration, the manifestation of the malady is produced by a bacterium at all, that is to say by any kind of organism similar to that hitherto discovered. The consideration of this question has been rendered all the more necessary from the words used by the Water Commission presided over by Lord Balfour of Burleigh in 1893. The Commissioners report "The water question has, in fact, passed from the domain of chemistry into that of biology." In other words the Commission accept it as proved that the actual cause of waterborne disease is to be found in the micro-organisms. They are thus able, at one stroke of the pen, to ignore all the accumulated evidence of chemical pollution. Further on in the report they shew that 98, 99, or even a larger percentage of the microbes in water are removed by filtration before the water is distributed to the consumer. They give other reasons to prove that "cholera" or "typhoid" bacilli could not exist long in Thames water, and they then conclude "this much, however, we can state without hesitation, that, as regards the diseases in question which are the only ones known to be disseminated by water, there is no evidence that the water supplied to the consumers in London by the Companies is not perfectly wholesome." In order to contest this position it becomes necessary to refer at some length to the history of Koch's "cholera" bacillus.

Professor Koch, who formed one of a German Cholera Commission, went to Egypt to study cholera in 1883. He examined a number of bodies of those who had died of this disease, and in his first Report, dated Alexandria, September 17th, 1883 he announced that "a particular kind of bacteria was found in the coats of the intestine. These bacteria are rod-shaped, and belong accordingly to the genus bacilli; they resemble most nearly in size and form the bacilli found in glanders." It appears that a year previously Koch had found the "the same bacilli" in the "same location" in preparations made from the intestine in four Indian cholera cases.

From the first Egyptian report Koch was evidently of opinion that cholera was caused by a rod-shaped or straight bacillus. Owing to lack of material the Commission towards the end of the year 1883 started for India where the cholera was more prevalent. In a report dated Calcutta January 7th, 1884, in reference to the examination of further cholera

*Report on the condition of the air on the City and South London Railway, 1903.

subjects, Koch says, " microscopic examination demonstrated the presence in all these cases of the same bacilli in the cholera intestine as had been found in Egypt." Shortly after this there was issued another report dated Calcutta, February 2nd, 1884. We then learn that "the bacilli are not quite rectilinear like the other bacilli, but slighly curved like a comma. The curviture is sometimes sufficient to give the bacillus a semi-circular form."

Dr. Timothy Lewis followed this matter up in a letter to the *Lancet* of September 20th, 1884. He stated that it was "highly probable" that the specimens which Koch had examined from the four Indian bodies, were specimens which Dr. Lewis himself had made and of which he retained duplicates, Dr. Lewis says " in not one of them have I been able to detect any invasion by unmistakeable ' commas,' though at least one of the specimens may fairly be characterised as abundantly infiltrated by straight putrefactive bacilli." From this evidence and from Dr. Koch's first description of the cholera bacilli as " rod-shaped," and subsequently as " commas," Dr. Lewis very naturally arrived at the conclusion that " apparently it had become necessary to abandon the microbe first fixed upon." Professor Ray Lankester has repeated Lewis's charge against Koch in these words. " Dr. Timothy Lewis asserts that Dr. Koch had *not* recognised the 'comma bacillus' previously to his visit to India, and that in Egypt Dr. Koch attributed the causing of cholera to a totally different organism from that which he put forward after his arrival in India, and that, although he had thus shifted his ground, Dr. Koch did not admit at the time and has not since admitted that he was at one time convinced that cholera was caused by one organism, and a few months after was convinced that it was caused by another."* Professor Lankester added that this charge if true " must tend to lessen the confidence reposed by some in Dr. Koch's conclusions ; and secondly, it must also lessen our belief in the candour with which he states all the circumstances attending his observations and inferences." Koch† was well aware of Lewis's contribution to the *Lancet* but from that day to this he has preferred to leave the criticism unanswered.

I now wish to say a few words concerning the curved or comma bacillus which Koch described after his arrival in India. This bacillus we are told penetrated beneath the mucous membrane of the bowel, but was not found in the blood, organs or tissues.

It occurred " neither in those who suffer from other diseases, nor in healthy people." But considering that the organism was not to be found

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* Nature, 1884, xxxi., 170.

† See Deutsche Medicinische Wochenschrift, November 6th, 1884, x, 726.

in either the blood or tissues, even the discoverer of the bacillus thought that some further proof might fairly be demanded, and above all that the cholera process might be experimentally produced in man or animals. Koch made a number of feeding experiments on every description of animal, and came to the conclusion that they have "all of them an immunity from cholera" which could not be produced artificially in them and hence "we must give up this method of proof." He still however adhered to his theory that there was "a casual connection between the comma bacilli and the cholera process." Meanwhile Klein and Gibbes* who had made investigations in India, published a paper in 1885 which completely traversed Koch's contention. They had found the comma bacillus not only in cases of cholera but also in dysentery, diarrhœa and in one case of chronic phthisis in which the commas "were as numerous as in many cholera stools that we have examined." On the whole then "we maintain, contrary to Koch's emphatic statement, that comma bacilli occur also in other cases of intestinal disease than cholera." Koch also stated that the comma bacilli penetrated the coats of the bowel, where they were found in large numbers, and his inference was that they there set up a quantity of chemical ferment to which the acute illness of cholera was ascribed. Klein and Gibbes made a large number of microscopical sections of the mucous membrane, of the villi, of Lieberkuhns Glands, and of the lymphatic tissue of Pyer's and the solitary glands in typical cases of cholera, and found that "in these places the comma bacilli, or any other organisms are conspicuous by their absence," and that "it is difficult to explain how much a statement could have been made," and if Koch's statement "is not in conformity with the facts . . . his whole edifice as to the relation of the comma bacillus to the disease . . falls to the ground." They pointed out that the comma bacilli were only present in the mucous flakes of cholera, *i.e.* in dead tissue, and that these facts pointed clearly to the comma bacilli being putrefactive organisms.

Klein and Gibbes then refer to Koch's experiments showing that animals were immune to cholera, and that he had practically given up this method of proof. Later, however, in 1884, Koch† in imitation of some experiments of Professors Rietsch and Nicati, injected choleraic matter into the intestines of dogs; the animals so treated died in one and a half to three days. The mucous membrane was reddened and the contents watery and flaky and contained comma bacilli in large numbers. Koch concludes thus "the experiments on animals to test other points have been resumed, and have shown that comma bacilli undoubtedly

* Cholera Inquiry by Doctors Klein and Gibbes, and Transactions of a Committee convened by the Secretary of State for India in Council, 1885.

† British Medical Journal, 1884 ii., 1036.

possess pathogenic properties, under these circumstances it will be more advisable to abandon the idea of the experiments recently proposed on human beings, who offer to swallow pure cultivations of comma bacilli, and for the present to confine oneself to experiments on guinea-pigs and other animals used for experimental purposes." Klein and Gibbes suggest that after Koch's large number of negative experiments this " remarkable change " was " most astounding," and attributed it to a challenge by Pettenkoffer to supply him with a pure cultivation of comma bacilli, they say " Koch could not easily leave unanswered such a challenge, it was therefore, very urgent to show that such an experiment would be unnecessary, since the pathogenic properties of the comma bacilli can be tested on animals."

Klein and Gibbes carried out a large number of experiments with the same negative results as those originally made by Koch, and they concluded " that the animals operated on by Nicati and Rietsch; and by Koch and others did not die of cholera, but in consequence of the operation, must be evident to everyone who has much experimented in Europe," and their final conclusion is that " no micro-organism that can be in any way connected with the disease is present in the body of a person affected with cholera."

Other competent observers have also demonstrated the unsoundness of the position taken up by Professor Koch. Thus in 1885, Roy, Graham Brown and Sherrington* investigated cholera in Spain and concluded thus " we have not been able to convince ourselves that the pathogenic effects which Koch, Van Ermengem and others find to result when comma bacilli are given to certain animals are identical with the phenomena which characterise cholera asiatica in man. Further the complete absence of comma bacilli, both in the contents of the intestine, and in the tissue of many of our cases makes it impossible for us to accept Koch's views as to the casual relation of the bacillus in question with cholera asiatica."

Further evidence against Koch's thesis is shewn by the number of cases now on record of comma bacilli being eaten with perfect impunity. The most classic experiments are those of Pettenkoffer and Emmerich at Munich. Professor Pettenkoffer used a pure agar culture obtained in the Hamburg epidemic, he took every precaution in the details of the experiment and the most that happened was a little diarrhœa. He says, " I did not suffer at all from poisoning, was quite well, retained my appetite, had no trace of nausea, no fall of temperature, no albumin in the urine,

* Proceedings of the Royal Society, 1886.-xli.-174.

went about my daily avocations so that I could not but conclude that although comma bacilli may cause diarrhœa they cannot cause cholera either European or Asiatic."* Professor Emmerich and others have had similar experiences.†

The harmlessness of comma bacilli is explained if we take the view of Klein and Gibbes and consider them as putrefactive organisms, and in support of this it may be mentioned that Metchnikoff‡ in the absence of epidemic cholera found bacilli "very similar" to Koch's comma bacilli in the stools of a healthy person.

From the above facts it appears that there is no evidence that cholera is caused by the comma bacillus or even by a bacillus at all, and it can also be shewn that the same argument applies to typhoid fever. The so called "bacillus typhosus" was discovered by Eberth§ in 1880 in the spleen and mesenteric glands of patients who had died of typhoid fever. The cultural characteristics were afterwards pointed out by Gaffky‖ in 1884, and there appeared no hesitation in the profession in accepting this organism as the actual cause of typhoid fever. In 1885, however, what is known as the colon bacillus was discovered by Escherich in the faces of man. and this latter bacillus so resembled the bacillus of Eberth that many authorities have held that the two bacilli are identical.

Thus Rodet and Roux who gave great attention to the subject concluded that "the organisms described under the names bacillus coli communis and the bacillus of Eberth belong to the same pathogenic species of which they form two varieties removed one from the other when they present their classical characters but related the one to the other by a series of intermediate forms."¶ More recently Dr. McWeeney the bacteriologist of the Local Government Board in Ireland said that "he did not believe that there was an essential distinction between the typhoid bacillus and the bacillus coli communis."** These opinions are important, for as I shall presently shew, the colon bacillus is nothing but an extremely common putrefactive organism of an ubiquitous distribution and there seems to be good reason for believing that the typhoid bacillus has a much wider distribution than originally supposed. Thus Remlinger and

* Münchener Medicinishe Wochenschrift, 1892, xxxix, 809.

† See also experience of Klein (Royal Commission on Vaccination, 1896, vi., Q 27167) and a work on "Asiatic Cholera" by A. J. Wall, p. 132.

‡ Annales de L'Institut Pasteur, 1893. vii., 565.

§ Archiv fur Pathologische Anatomie und Physiologie, 1880. lxxxi., 58.

‖ Mittheilungen aus dem Kaiserlichen Gesundheitamte, 1884. ii., 372.

¶ Lyon Médicale, 1891. lxviii. 325.

** "Lancet," 1896. i. 995.

Schneider* after a large number of carefully conducted experiments came to the conclusion that the "typhoid bacillus is diffused widely in nature externally to the sick. It occurs in potable waters, in the soil, and in the digestive canal of persons unaffected with typhoid fever, and without doubt contributes to the microbial flora with which we are surrounded."†

Prescott and Winslow point out that if the typhoid bacillus be the essential cause of typhoid fever and at the same time so universally distributed, "the human race would long since have been exterminated."‡

There must, therefore, be some flaw in the argument, so let us then consider what is actually known about this bacillus.

Crookshank in his textbook of bacteriology in referring to Eberth's bacillus says, "whether this bacillus is really peculiar to typhoid is much disputed." Again "sufficient has been said to shew that bacteriological reports in which it is stated that the typhoid fever bacillus has been found in water causing typhoid epidemics must be accepted with great reserve," and in his concluding paragraph on the subject he says, "no one is justified in stating that the typhoid fever bacillus is undoubtedly the cause of typhoid fever; it is not found in every case of typhoid, it is not found in the blood, but it is found in those tissues which are commonly the seat of secondary invasion of epiphytic bacteria, whose normal *habitat* is the intestinal canal. Lastly, as the disease does not exist in the lower animals, the crucial test cannot be applied. The etiology of typhoid fever is still enveloped in doubt and the nature of the contagium has not yet been determined."

These remarks were made about nine years ago and are as true now as when they were written. Thus recent writers on bacteriology Prescott and Winslow in referring to reports of the isolation of the typhoid bacillus from water say, "all but the most recent are quite discredited on account of the insufficiency of their confirmatory tests, and even the latest results should be received with caution." They refer to the method of diagnosing typhoid fever introduced by Widal§ in 1896. In this test if the blood serum of typhoid patients be added to a culture of typhoid bacilli in certain proportions the bacilli are supposed to loose their motility and "agglutinate" or clump together, but in no other disease nor in healthy persons is this reaction said to take place. Of

* Annales de L'Institut Pasteur, 1897. xi. 65.

† Cushing and Livingood in their experiments on the "Intestinal flora of dogs" isolated "on not a few occasions organisms indistinguishable from bacillus typhosus" (Johns Hopkins Hospital Bulletin, 1900. xi. 169.)

‡ Elements of Water Bacteriology, p. 54.

§ Bulletins de la Société Médical des Hopitaux de Paris, 1896. 3s. xiii. 561.

course if this were invariably the case it would be a ready means of detecting typhoid fever and conversely a good test for typhoid bacilli, but as Prescott and Winslow say, "serum tests are notably erratic"* and Klein himself found that in a certain percentage of cases the organism which agglutinates well with typhoid blood "turns out not to be the bacillus typhosus"† since on sub-cultures it failed to give the tests of this microbe.

Recent discoveries have also tended largely to discredit the typhoid bacillus as a cause of typhoid fever. Thus Shiga claims to have found the essential cause of dysentery in the shape of a bacillus which he says is "exclusively found in those ill with dysentery, and never found in other diseases or in healthy persons."‡ Miss Sheldon Amos shows that this bacillus is "culturally excessively difficult to distinguish from the typhoid bacilli and the bacillus coli communis,"§ and the latest opinion of bacteriologists appears to that "the discovery of the bacillus dysenteriæ of Shiga, which closely resembles the typhoid bacillus, has made the identification of the latter more dubious than ever."‖ We have therefore made no progress since Crookshank wrote in 1896, that is to say the etiology of typhoid fever is still enveloped in doubt, and the nature of the contagium has not been discovered.

Thus it cannot be too strongly insisted upon that we know nothing of the essential cause of either typhoid or cholera, that the medical profession is as much in the dark now as it was forty years ago, and to suppose as inferred by the Balfour Commission that a few thicknesses of sand and gravel in a filter will hold back these diseases is a very dangerous doctrine, and against which it has been my chief object in writing this paper to protest.

Before I come to standards of purity in drinking water it is necessary to discuss rather fully the significance of the presence of bacteria. It was at one time thought that the total number of bacteria gave some indication of pollution, and Professor Koch stated that "filtered water containing more than 100 germs capable of development in a cubic centimetre should not be allowed to reach the pure water reservoir."¶ This standard however can no longer be defended and no water would be condemned because this number of bacteria was exceeded. A more hotly

* Elements of Water Bacteriology, p. 53.

† Royal Commission on Sewage Disposal, 1904. Fourth Report, ii. Q. 17769.

‡ Deutsche Medicinische Wochenschrift, 1901, xxvii., 783.

§ Journal of Pathology, 1903, viii., 360.

‖ Elements of Water Bacteriology, p. 53.

¶ Zeitschrift für Hygiene, 1893.-xiv.-417.

disputed question is whether water should be condemned on account of the presence of certain micro-organisms, and more particularly the bacillus coli communis, and the bacillus enteritidis sporogenes.

This latter bacillus was discovered in connection with certain cases of diarrhœa at St. Bartholomew's Hospital, and it was claimed that the outbreak "appeared referable" to the bacillus enteritidis sporogenes "a diarrhœal organism."* It has been shown, however, by Dr. Glynn that this organism "has a very wide distribution, is commonly present in the air and in dust, and is frequently consumed in food without producing diarrhœa."† Another authority, Dr. McWeeney, says "I very much doubt the significance of the presence of bacillus enteritidis . . . It appears to me to be one of a number of anaerobic saprophytes normally occurring in putrescent organic matter, whether of animal or vegetable origin."‡ Considering the wide distribution of this organism its presence in drinking water can be a matter of little or no consequence, and certainly affords no evidence of sewage contamination.

The bacillus coli communis has probably occupied more of the attention of bacteriologists than any other micro-organism with which we are acquainted. It was discovered as I have said by Escherich § in the human intestine where it abounds, and very early acquired importance among sanitarians who urged that the presence of this bacillus was evidence of sewage contamination. Subsequently it was discovered that this organism was to be found in the intestines of every kind of creature, including fish and birds; and in herbivorous animals as well as in those which eat meat.|| With regard to the general distribution of this organism Kruse was of the opinion that "such bacteria are found everywhere, in the air, in soil, and in water from all different sources."¶ The late Professor Kanthack entirely endorsed this opinion "the bacterium coli," he says, "is present in the intestines and in fæces because it is ubiquitous, and it is illogical to assume that its presence outside the digestive tract signifies direct fæcal or filth contamination."**

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* Twenty-Fifth Annual Report of the Local Government Board. Medical Officers' Supplement, 1895-6, p.p. 197, 204.

† Thompson Yates Laboratories Report, 1901. iii. Pt. 2. 150.

‡ Royal Commission on Sewage Disposal, 1904. Fourth Report, ii., 208.

§ Fortschritte der Medicin, 1885. iii. 515, 547.

|| *See* Dyar and Keith. Technology Quarterly, 1893, vi. 256.
Fremlin. Archiv für Hygiene, 1893. xix. 295.
Theobald Smith. American Journal of the Medical Sciences, 1895. cx. 283.
Flint. Journal of the American Medical Association, 1896. xxvi. 410.
Eyre. Lancet 1904. i. 648.

¶ Zeitschrift für Hygiene, 1894. xvii. 53.

** British Association. Liverpool Meeting, 1896. Annual Report, p. 985.

Prescott has quite recently given confirmation of the wide distribution of this organism. Thus in a "series of 47 cultures of lactic acid bacteria, 25 were found to give the reaction of bacillus coli. These organisms were isolated chiefly from cereals and products of milling such as flour, bran, corn-meal, oats, barley, &c., while others were in technical use for producing the lactic fermentation. There is no evidence that any of these organisms were of intestinal origin, and yet they possess all the characters of typical colon bacilli, even to the pathogenic action when inoculated into guinea pigs."*

Prescott and Winslow allude also in their book to the results obtained by Klein and Houston† and conclude that "bacteria corresponding in every way to bacillus coli are by no means confined to animal intestines, but are widely distributed elsewhere in nature."

But the most importance evidence is that which shews the connection of the colon bacillus with putrefactive processes. Thus as early as 1892, Van Ermengem and Vanlær found "that the micro-organisms of the group coli, shew well marked properties of saprophytes and ferments. Like yeast, &c., they have the power of living at the expense of the most simple mineral compounds. Besides this they are the ferments of putrefaction characterised by the presence of indol, of phenol, and of other products of putrid decomposition to which they give rise."‡ In 1894, Dallemagne§ made an investigation into the bacteria of the intestine after death, and he found that the varieties tended to a kind of "unification," more especially in favour of the bacillus coli and another organism. Malvos,|| collected a number of facts with reference to the bacteria which aid in putrefactive processes after death, and he was surprised to find that so few authors had alluded to the action of the bacillus coli in decomposition. In his own experience of a number of post mortem examinations "the microbes the most frequent and the most abundant in bodies left to decompose belonged to the bacillus coli type and to divers kinds of proteus."

Further there is evidence that it is not only in animal, but also in vegetable putrefaction that the colon bacillus exercises its functions. Gordan found it, together with the bacillus fluorescens in decomposing fruit and vegetables, including apples, carrots, cabbages, onions, &c., and

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* Elements of Water Bacteriology, p 79.

† Klein and Houston reported that they found typical colon bacilli in three out of twelve samples of wheat and oats obtained from a wholesale firm (29th Annual Report of the Local Government Board, Medical Officers Supplement, p. 593.)

‡ Annales de la Société de Médecine de Gand, 1892.

§ Bulletin de l'Académie Royale de Médecine de Belgique, 1894. 4S. viii. 825.

|| Annales D'Hygiène Publique de Médecine Légale. Paris, 1899. 3S. xlii. 329.

he concluded that "while in animal decomposition different kinds of bacilli appeared and also micrococci in large numbers; in vegetable putrefaction there were found a few constantly recurring bacilli, and among these the bacillus coli of Escherich played an important *role*."* Colon bacilli are likewise found not only in bad fruit and vegetables but in decomposing vegetation in general. Thus Russell and Bassett state that "vegetable mould from the forest, rotting leaves, and tree trunks have been found to harbour gas formers of this class."†

We see therefore that these bacteria are the means by which the carbon and nitrogen circulation in Nature is carried on. That is to say they break up or decompose the organic matter of the animal and vegetable kingdoms into elementary gases such as carbonic acid, hydrogen, &c. During putrefaction certain half-way compounds such as indol, phenol and skatol are often produced, and it is from the presence of the gases and compounds, as well as from the appearance of its growth on nutrient material that the colon bacillus is recognised. From the association of this organism with vegetable putrefaction it would be surprising if it were not frequently found in the water supplies. Thus Jordan says "we ourselves have found, in spring water beyond any suspicion of contamination bacteria which in form, size, and growth in gelatin, potato, &c., were indistinguishable from bacillus coli communis."‡

Again Poujol verified the presence of the bacillus coli in 22 out of 34 waters analysed. The waters were taken from divers sources, that is it say from springs, wells, rivers, &c., and several were quite free from possibility of contamination. Poujol concluded that "fæcal contamination can only exceptionally be invoked to explain the presence of bacillus coli in water."§

Weissenfeld ‖ reported on the analysis of 30 samples of water supposedly pure, and 26 samples supposed to be contaminated. Colon bacilli were found in all the samples. The author concluded that "the so-called bacterium coli may be found in waters from any source, good or bad, if only a sufficiently large quantity of the water be taken for analysis." This has been confirmed recently by Savage, he says "bacillus coli appears to be habitually present in upland surface waters if a

* Uber Fäulnisbaketerien in Obst und Gemüse. Paul Gordan, 1897.

† American Public Health Association Proceedings, 1900, xxv. 573.

‡ Experimental investigations by the State Board of Health of Massachusetts upon the purification of Sewage. Boston 1890. Pt. ii., 824.

§ Société de Biologie, Paris, 1897. 10 S. iv. 984.

‖ Zeitschrift fur Hygiene, 1900. xxxv. 78.

sufficient quantity of water is examined, and further it is not infrequently present in considerable numbers, and that in waters which appear to be absolutely free from sewage or human pollution, and which on chemical analysis show no evidence of contamination." Again he says "to state for example, that because of its proved presence in say 10 cubic centimetres of a water, that water should be condemned as showing dangerous contamination would, in my opinion, be a very unreliable and an unjustifiable deduction, and would at least for Glamorganshire, condemn many of the best waters in the country."*

We have seen that wherever organic matter is in a state of putrefaction colon bacilli are to be found, and hence they must be practically everywhere. Of course fæces or sewage like other decomposing substances likewise abound with these organisms, but this is no reason why their presence in food or drinking water should be evidence of sewage contamination. In my analyses of Thames water many examinations have been made for colon bacilli, and on several occasions the bacillus was found in one cubic centimetre of water. Its presence, as I have shown above, even in so small a quantity of water, is no indication of sewage pollution, and thus little or no significance can be attached to the results. We now come to the more important question of chemical standards.

Albuminoid Ammonia.—This method devised by Professor Wanklyn is the measure of the nitrogenous organic pollution of a water. Well known authorities have "assigned 0·006 or 0·007 part per 100,000 of albuminoid ammonia as the limits which distinguish clean from unclean water." †

Organic Carbon and Organic Nitrogen.—The carbon and nitrogen are estimated by combustion. This method discovered by Frankland and Armstrong has acquired importance from the fact that it has been used for the last 37 years in the official water analyses. The Rivers Pollution Commissioners (including Sir Edward Frankland) considered that "potable water which contains organic matter, even only partially derived from animal sources should not yield much more than 0·1 part of organic carbon per 100,000 parts of water."‡

This however is quite an impossible standard to aim at with Thames waters. In 1890 Frankland was of opinion that "surface water or river water which contains in 100,000 parts more than 0·2 part of organic

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* Journal of Hygiene, 1902, ii., 334.

† Manual of Public Health, 1874. Edited by Ernest Hart, p. 324.

‡ Sixth Report of the Rivers Pollution Commissioners, p. 5.

carbon or 0·03 part of organic nitrogen is not desirable for domestic supply, and ought whenever practicable to be rejected."*

Even this amended standard would condemn many samples of Thames water.

Oxidizable Organic Matter.—The figures are stated in terms of the oxygen required to oxidize the organic matter of drinking water. According to Dr. Tidy the ordinary outside limit would be about 0·14 part of oxygen per 100,000.

Having fixed our standards we now have to consider the present condition of the Thames water as supplied by the Companies. I believe that only a few of the Metropolitan Boroughs make a routine practice of water analysis, but in consequence of several complaints (one by a medical man in the district) of the Lambeth and Southwark supplies, it was felt by the Public Health Committee of the Southwark Borough Council that some action would have to be taken, and samples from both Companies have been analysed. The analyses which cover the period of one year from June, 1903, are given at the end of this paper.

Southwark aud Vauxhall Company.—Thirty-six samples of the Company's water were examined during the year. On inspection through the 2-ft. tube, twelve of the thirty-six samples were of a yellow colour instead of the greenish-yellow ordinarily seen.

The limit of albuminoid ammonia is 0·007 part per 100,000; of the thirty-six samples none conformed to this standard. Five had less than 0·01 part, and twenty-six between 0·01 and 0·02 per 100,000. 0·02 part was exceeded on five occasions and in one sample, that taken on June 26th, 1903, the albuminoid ammonia reached the enormous figure of 0·0246 part per 100,000. In twenty-six samples the oxygen test was applied and on twelve occasions the commonly accepted standard was exceeded.

Lambeth Company.—Thirty-six samples, likewise of this Company's water were analysed during the year. Through the 2-ft. tube one shewed a brown colour, and seven a yellow colour, the remainder having the ordinary greenish-yellow tint.

With regard to albuminoid ammonia none of the samples reached the recognised standard of purity; three only were less than 0·01 part per 100,000; twenty-six between 0·01 and 0·02 part per 100,000, while seven exceeded 0·02 part per 100,000. In eleven out of twenty-seven samples examined the oxygen limit was exceeded.

It thus appears that from whatever point of view we look at the question whether we consider the colour of water, the albuminoid

* Water Analysis for Sanitary purposes, p. 124.

ammonia or the oxygen, and even if we are satisfied with a low standard it will be found that a considerable proportion of the samples examined during the year were organically polluted and liable to be injurious to health. That the Thames water in 1903 was of very bad quality is fully borne out by the analyses of the Government Analyst.

The following table gives the maximum amounts of organic carbon, organic nitrogen, albuminoid ammonia, and oxidizable organic matter found during the year :—

TABLE E.

(The results are stated in parts per 100,000.)

Water Company.	Organic Carbon.	Organic Nitrogen.	Albuminoid Ammonia.	Oxygen consumed 4 hrs. at 26·7 °C.
Chelsea ...	0·455	0·038	0·017	0·515
West Middlesex	0·441	0·039	0·018	0·280
Southwark ..	0·659	0·049	0·025	0·471
Grand Junction	0·512	0·044	0·021	0·368
Lambeth ...	0·476	0·041	0·019	0·346

Dr. Thorpe the official Analyst says, " From the table it will be seen that highest albuminoid ammonia was 0·025 part per 100,000 in a sample of the Southwark Company's water in June, when the water was of a very unsatisfactory quality." Again he says referring to this sample, " the worst sample examined during the year was one taken from the Southwark Company's service in June, when the organic carbon was over 0·6 part per 100,000, and this amount has, I believe, never been exceeded in a summer month since the Metropolitan supply has been officially examined."

In addition to the Government analyses it should be mentioned that Cassal in his official capacity, as public analyst to several of the London Boroughs, has for a number of years made systematic analyses of the water supplied by the Thames Companies, and has on many occasions reported to the Local Authority on the pollution of the London drinking water.*

The official analyses of the Thames water were commenced in 1868, and I should now like briefly to trace the quality of the water since that date. In the Report for 1868, Sir Edward Frankland says " In January, the Thames overflowed its banks, above the point at which the Metropolitan Water Supply is drawn, and washing the surfaces of cultivated fields, mingling with the stagnant ditches and ponds, and receiving the contents of the suddenly flushed sewers of Oxford, Reading and Windsor became

* Some of Cassal's analyses are detailed in his evidence given before the Court of Arbitration under the Metropolis Water Act.

contaminated to an intolerable degree, as evidenced by the unusually large proportion of organic carbon and nitrogen." In the Report for 1872 he says "the organic substances with which the Thames and Lea are polluted are to a large extent of animal origin . . . during the months of January, February, March, April, November, and December, the Thames water as delivered in London, was even when well filtered rarely in a fit condition for domestic supply."

In the Report for 1874, we read that the maximum organic pollution was in March, April, and December "when the river was in a very objectionable condition." In the Report for 1876, Sir Edward writes, "when the heavy rains of December set in, the accumulated filth of the summer and autumn was swept into the neighbouring streams, the Thames overflowed its banks, washing the manure from cultivated land, and liberating the water from stagnant ponds and ditches. Thus during the last month of the year the Thames was laden with organic matters of the most objectionable origin which, carried down to the intakes of the Metropolitan Water Companies, passed through the filters and were distributed to customers. Since January 1873 the Thames has never been in such a filthy plight." In referring to filtration he says "no care, foresight, or appliance could convert the 'puddle' (to quote an entry in the books of the West Middlesex Company), which entered the Company's works, into wholesome potable water fit for dietetic purposes. These uncontrollable and frequently occurring outbreaks, render this river a very undesirable source of water for domestic use."

In the next Report for 1877 it states: "In the months of January, April and December, the Thames water was delivered to consumers in such a polluted condition as to be utterly unfit for dietetic purposes," and lastly, in the Report for 1879, the official analyst says: "the Thames was often in high flood even in summer, and much filthy matter from sewers, cesspools, and cultivated fields was swept into the river during those periods of the year when they are usually kept back by the absence of heavy rain."

The only continuous set of figures over a long period of time are those for the organic carbon and the organic nitrogen. Except for the years 1875 and 1898, the statistics are complete since the year 1868, and may conveniently be divided into periods of five years.

TABLE F.

ORGANIC CARBON IN PARTS PER 100,000.

Water Company	1868-71 4 Years.	1872-77	1878-82	1883-87	1888-92	1893-97	1899-03
Chelsea	0·197	0·211	0·206	0·149	0·159	0·154	0·179
West Middlesex ...	0·173	0·181	0·231	0·160	0·168	0·166	0·191
Southwark ...	0·213	0·212	0·245	0·167	0·159	0·179	0·187
Grand Junction ...	0·193	0·198	0·226	0·156	0·158	0·167	0·212
Lambeth	0·212	0·211	0·228	0·155	0·161	0·183	0·209

TABLE G.

ORGANIC NITROGEN IN PARTS PER 100,000.

Water Company	1868-71 4 years.	1872-77	1878-82	1883-87	1888-92	1893-97	1899-03
Chelsea	0·028	0·036	0·037	0 029	0·028	0·021	0·020
West Middlesex ...	0·024	0·029	0·039	0·030	0·028	0·022	0·021
Southwark ...	0·032	0·034	0·042	0·030	0·028	0·024	0·021
Grand Junction ...	0·028	0·035	0 040	0·029	0·028	0·022	0·022
Lambeth	0·030	0·037	0·036	0·027	0·027	0·024	0·023

If the last period be compared with the first there has been a diminution in the organic nitrogen, but in several of the Companies this reduction has been very small.

If we trace the organic carbon, starting from the year 1868, this appears to go up to a maximum to the year 1882, and then declines for ten years or so, to again increase in the period 1899-1903. This can hardly be taken as showing a satisfactory improvement over the whole period of 35 years, and in two of the Companies, viz: the West Middlesex and the Grand Junction there has been an actual increase.

With regard to the other two chemical tests of organic pollution we have no continuous figures, but certain analyses were made by Dr. Tidy during the years from 1870 to 1878, which may be compared with the years for which we have official statistics, viz., from 1900 to 1903

TABLE H.

OXIDIZABLE ORGANIC MATTER.

(The Results are stated as Oxygen in parts per 100,000.)

Water Company.	1870-78 9 years.	1900-03 4 years.
Chelsea	0·108	0·085
West Middlesex	0·074	0·091
Southwark	0·112	0·091
Grand Junction	0·115	0·095
Lambeth	0·110	0.101

The later statistics show a slight improvement which is probably greater than appears, inasmuch as Dr. Tidy's figures refer to the oxygen absorbed by organic matter in three hours, whereas in the official statistics for 1900-03, the experiment is allowed to run for four hours so that a larger amount of oxygen might be taken up by the organic matter.

Table I.

Albuminoid Ammonia in parts per 100,000.

Water Company.	1871-78 8 years.	1900-03 4 years.
Chelsea	0·0101 ...	0·0085
West Middlesex	0·0082 ...	0·0091
Southwark	0·0107 ...	0·0091
Grand Junction	0·0102 ...	0·0092
Lambeth	0·0107 ...	0·0096

Except in the case of the West Middlesex, the later figures 1900-03, show some slightly more favourable results as compared with the earlier years 1871-78.

The general conclusion from all these statistics, taking into account the organic carbon and nitrogen, the oxidizable organic matter and the albuminoid ammonia, is that there has been a slight improvement, that is to say that the water is not quite so highly polluted as it was 35 years ago, the improvement, however, is not a very material one, and certainly not sufficient to warrant any alteration of policy adopted by the earlier analysts, with regard to leaving the river as a source of supply.

In addition to the chemical analyses there is abundant other evidence to show that the Thames water is seriously contaminated In 1892, at the instigation of the London County Council, examinations were made of the Thames and its tributaries with the view of enabling an estimate to be formed of the risk to which the river, as a public water supply, was liable from pollutions of various kinds. The examination above Oxford was entrusted to Dr. Fosbroke, the Medical Officer of Health to the County of Worcester, and the portion between Oxford and the intakes of the London Water Companies at Hampton to Dr. Ashby, the Medical Officer of Health to Reading.

Dr. Fosbroke* found that the rivers and streams of the watersheds of the Upper Thames and Cherwell received the drainage from many towns, villages, dwelling houses, farmyards and industries, including that from 8,000 to 9,000 water closets. In consequence a great amount of refuse reached the river more or less directly, and that in times of flood this was intensified and particularly obvious. With regard to the condition of the Thames in relation to the Metropolitan water supply even granting that purification took place, any result would be materially interfered with by what passed into the river lower down. He thought that the present pollutions of the Upper Thames would increase, and he was "firmly convinced that water drawn from such sources cannot be used for ordinary domestic purposes without great risk."

Dr. Ashby,* who examined the river below Oxford discovered the following sources of pollution :—

1. Many farmsteads drained into the stream presenting innumerable opportunity for pollution by cattle, and washings from manured land, &c.
2. Parts adjacent to canals communicating with the river were often manured with house and other foul refuse from London. "I have seen large deposits of such refuse fouling the streams."
3. Decomposing Animals.
4. Filthy bilge water from barges carrying offensive cargoes.
5. Pollution from floating population of canal boats, house boats, &c.
6. Pollution from laundries, tanneries, fellmongers yards, breweries, and paper mills.
7. Direct sewage and slop pollution from towns and villages.
8. Effluents from sewage works.

With regard to the so-called purification of sewage, Dr. Ashby thought it was quite a mistake to assume that because the sewage of a place was cut off from the rivers, and treated by some chemical process or land irrigation that there was necessarily no pollution; he found that "although the sewage of Oxford, Uxbridge and Watford is treated, I nevertheless found much pollution by excessively foul effluents from those places." He was of opinion that the safety of the river as a source of drinking water was imperilled to a greater extent when a town is completely sewered, and the effluent discharged into stream, than when drained by cesspools.

Dr. Ashby concludes as follows: "Having regard to all the facts I have ascertained, and, bearing in mind the various chances of pollution which cannot be avoided, however carefully the sewage of inhabited places may be excluded, I cannot but regard the river Thames as an undesirable and unsafe source for the water supply of London."

* Royal Commission on Metropolitan Water Supply, 1893. Appendix pp. 179, 190.

Since 1892, the date of these investigations, the Thames Conservancy has increased its Staff, and it appears from an examination of their reports that certain improvements have been made, but from an incident which came to light in 1897, it is evident that much still remains to be done. The matter to which I wish to refer is the carrying up and down the river of the refuse of London in leaky barges.

The Thames Conservancy informed the London County Council that on the portion of the river above Teddington, during the year 1897, there had been "*one case* only (a quite recent one) where it was reported that refuse of a foul character was being carried," and further that the refuse in question was "only ashes."* It was subsequently shown that the barge named the "Lothair," was filled with Lambeth Vestry refuse, that she passed through Teddington Lock on September 6th, and was entered as containing rubbish, it afterwards appeared that she was so leaky that she had to be run ashore. Dr. Knox, in an official report dated October 6th, to the Molesey District Council, stated with reference to this barge, "I found a most abominable nuisance existing in the shape of all sorts of refuse, and in addition, there was in her hold over 24 inches of the foulest fluid I ever smelt . . . (the removal), was actually performed by the Thames Conservancy, who had been informed of the fact by your officials." Mr. Kemp, Surveyor to the Hampton District Council, in his report dated October 12th, said, "the contents at the top appeared to be house refuse, while there were blood and rags at the bottom, and some liquid that looked like blood from a slaughter house."

In his evidence, given before the Kingston County Bench, Dr. Knox stated that the smell was very offensive, and that there was 24 inches of "absolute cesspool water," not house refuse in the hold.

This "absolute cesspool water," the Thames Conservancy describes as "only ashes," and hence it is difficult to ascertain from their reports the actual condition of the Thames, so far as the fouling of the river and its tributaries is concerned, but even allowing for a certain amount of improvement, if we have regard to the increase of population, to the augmentation of pollution from sewage works, and to the increasing number of persons using the river as a pleasure resort, the total result especially in times of flood, is probably not very different from what it was in 1892, and this conclusion is borne out by the analyses of drinking water made during the present year.

In this Report on the Metropolitan Water Supply, I claim to have shown—

* Proceedings of the London County Council, 1897, p. 1330.

1. That five out of the seven Commissions* or Committees of Inquiry, which have investigated the quality of the Thames water, have condemned the river as a source of domestic supply to the Metropolis.

2. That the quality of the water as indicated by the analyses has shown no substantial improvement during the last thirty years.

3. That the River and its tributaries are at the present time extensively polluted by sewage, sewage effluents, foul house refuse, and other obnoxious matters.

4. That it is doubtful if this excessive pollution can ever be prevented, especially in times of flood, from gaining access to the river.

5. That there is no reason to suppose that the poison of cholera or typhoid can be eliminated from drinking water by any practicable process of purification such as filtration.

In advocating the necessity of a change of water supply, I venture to point out, and this was the reason urged by the Board of Health in 1850 that the substitution of a less hard water would be of great advantage on economic grounds. It was estimated by careful computation, at the time of the introduction of soft water from Loch Katrine for Glasgow that the saving which resulted in domestic establishments was equal to £36,000 a year upon a population of 400,000, and this was the substitution of one degree of hardness for that of the River Clyde which averaged from seven to nine degrees.† The Thames water averages about 14 degrees, and therefore if a soft water supply was obtained, the saving per head would probably be greater than at Glasgow.

In conclusion, and in logical deduction from the various facts and arguments given in this paper, I beg to recommend that London should as soon as possible, abandon the Thames as a source of domestic supply. Other large towns such as Liverpool, Glasgow, Manchester, and quite recently Birmingham, have now obtained pure water for their inhabitants, and it is much to be deplored that our great Metropolis should still lag behind in a matter which so vastly concerns the health and happiness of her citizens.

* Of the two remaining Commissions: (A) the Richmond Commission were not satisfied with the purity of the Thames water, but hesitated to make any recommendation. (B) The Balfour Commission evaded the chemical evidence of pollution by concentrating their attention on the "bacilli of cholera and typhoid," which they affirmed were held back by the water companies' filters.

† Royal Commission on Water Supply, 1869 Appendix, p. 26.

ANALYSES OF THAMES WATER, 1903—04.

SOUTHWARK AND VAUXHALL WATER COMPANY.

(The results are expressed in parts per 100,000.)

	June 26.	July 10.	July 20.	Sept. 14.	Sept. 30.	Oct. 15.
Appearance through 2 foot tube	Clear : yellow colour	Clear: greenish yellow	Clear: greenish yellow	Clear: greenish yellow	Clear: greenish yellow	Clear : yellow colour
Odour	None	None	None	None	None	None
Taste	None	None	None	None	None	None
Reaction	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
Total Solids	29·0	25·0	25·0	24·0	24·0	28·0
Appearance of Solids on Ignition	Marked brown colour	Slight brown colour	Slight brown colour	Slight brown colour	Slight brown colour	Marked brown colour
Total Hardness	22·4	19·0	20·8	23·4	22·8	21·8
Chlorine as Chlorides ...	1·83	1·92	1·9	1·95	1·85	1·75
Nitrogen as Nitrates ...	Amount too small to estimate accurately	0·116	0·110	0·10	0·13	Amount too small to estimate accurately
Nitrites	Nil	Nil	Nil	Nil	Nil	Nil
Saline Ammonia	0·0004	0·0004	0·0004	0·0004	0·0006	0·0004
Organic Ammonia ..	0·0246	0·0117	0·011	0·0095	0·01	0·021
Oxygen consumed (4 hours at 26·7° C.)	—	—	—	—	—	—
Lead, Copper, Iron ...	Absent	Absent	Absent	Absent	Absent	Absent

	Oct. 19.	Oct. 21.	Oct. 23.	Oct. 26.	Oct. 28.	Oct. 30.
Appearance through 2 foot tube	Clear : yellow colur	Clear : yellow colour	Clear : yellow colour	Clear : yellow colour	Clear : yellow colour	Clear : yellow colour
Odour	None	None	None	None	None	None
Taste	None	None	None	None	None	None
Reaction	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
Total Solids	35·0	35·0	36·0	34·0	33·0	30·5
Appearance of Solids on Ignition	Brown colour	Marked brown colour	Brown colour	Brown colour	Marked brown colour	Marked brown colour
Total Hardness	21·0	22·5	22·8	22·0	22·9	22·5
Chlorine as Chlorides ...	1·7	1·55	1·58	1·6	1·7	1·6
Nitrogen as Nitrates ...	Amount too small to estimate accurately	Amount too small to estimate accurately	Amount too small to estimate accurately	Amount too small to estimate accurately	Amount too small to estimate accurately	Amount too small to estimate accurately
Nitrites	Nil	Nil	Nil	Nil	Nil	Nil
Saline Ammonia	0·0008	0·0008	0·0009	0·0009	0·0006	0·0008
Organic Ammonia ...	0·021	0·0208	0·018	0·019	0·0198	0·019
Oxygen consumed (4 hours at 26·7° C.	—	—	—	—	0·239	0·258
Lead, Copper, Iron ...	Absent	Absent	Absent	Absent	Absent	Absent

	Nov. 4.	Nov. 13.	Nov. 27.	Dec. 1.	Dec. 4.	Dec. 9.
Appearance through 2 foot tube	Clear : yellow colour	Clear: greenish yellow	Clear: greenish yellow	Clear: greenish yellow colour	Clear : yellow colour	Clear: greenish yellow colour
Odour	None	None	None	None	None	None
Taste	None	None	None	None	None	None
Reaction	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
Total Solids	34·0	34·5	34·0	34·5	36·5	36·3
Appearance of Solids on Ignition	Marked brown colour	Brown colour	Slight brown colour	Brown colour	Brown colour	Brown colour
Total Hardness	23·1	22·5	23·0	23·2	22·8	23·2
Chlorine as Chlorides ...	1·6	1·8	1·75	1·75	1·7	1·75
Nitrogen as Nitrates ...	0·05	0·15	0·17	0·11	0·07	0·16
Nitrites	Nil	Nil	Nil	Nil	Nil	Nil
Saline Ammonia	0·0008	0·0008	0·0004	0·0004	0·0007	0·0004
Organic Ammonia ...	0·0244	0·0112	0·0082	0·0108	0·0174	0·0138
Oxygen consumed (4 hours at 26·7° C.)	0·306	0·144	0·073	0·136	0·21	0·13
Lead, Copper, Iron ...	Absent	Absent	Absent	Absent	Absent	Absent

	Dec. 14.	Dec. 16.	Dec. 18.	Dec. 21.	Jan. 15.	Jan. 28.
Appearance through 2 foot tube	Clear: greenish yellow colour	Clear : yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour
Odour	None	None	None	None	None	None
Taste	None	None	None	None	None	None
Reaction	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
Total Solids	36·1	34·8	34·6	35·3	36·0	36·0
Appearance of Solids on Ignition	Brown colour	Marked brown colour	Brown colour	Brown colour	Slight brown colour	Slight brown colour
Total Hardness	22·2	22·5	22·8	22·5	22·0	23·0
Chlorine as Chlorides ...	1·7	1·7	1·75	1·75	1·8	1·8
Nitrogen as Nitrates ...	0·23	0·22	0·23	0·22	0·2	0·16
Nitrites	Nil	Nil	Nil	Nil	Nil	Nil
Saline Ammonia	0·0014	0·0008	0·0004	0·0008	0·0005	0·0004
Organic Ammonia ...	0·016	0·018	0·0166	0·0128	0·0112	0·0082
Oxygen consumed (4 hours at 26·7° C.	0·29	0·18	0·138	0·08	0·127	0·096
Lead, Copper, Iron ...	Absent	Absent	Absent	Absent	Absent	Absent

	Feb. 4	Feb. 6	Feb. 10.	Feb. 12.	Feb. 16.	Feb. 18.
Appearancs through 2 foot tube	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear : yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour
Odour	None	None	None	None	None	None
Taste	None	None	None	None	None	None
Reaction	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
Total Solids	34·0	36·0	35·0	32·0	32·0	34·0
Appearance of Solids on Ignition	Slight brown colour	Slight brown colour	Brown colour	Marked brown	Brown colour	Brown colour
Total Hardness	23·0	22·0	22·0	20·5	20·5	22·2
Chlorine as Chlorides ...	1·75	1·7	1·8	1·75	1·65	1·7
Nitrogen as Nitrates ...	0·16	0·19	0·185	Nil	0·08	0·16
Nitrites	Nil	Nil	Nil	Nil	Nil	Nil
Saline Ammonia	0·0005	0·0005	0·0004	0·0008	0·0005	0·0009
Organic Ammonia ...	0·0106	0·0145	0·0135	0·018	0·0148	0·0148
Oxygen consumed (4 hours at 26·7° C.)	0·13	0·14	0·13	0·22	0·19	0·18
Lead, Copper, Iron ...	Absent	Absent	Absent	Absent	Absent	Absent

	Feb. 20.	Feb. 25.	Mar. 26.	April 30.	May 20.	June 13.
Appearance through 2 foot tube	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour
Odour	None	None	None	None	None	None
Taste	None	None	None	None	None	None
Reaction	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
Total Solids	34·0	35·0	34·0	30·0	30·0	32·0
Appearance of Solids on Ignition	Slight brown colour	Slight brown colour	Slight brown colour	Slight brown colour	Slight brown colour	Slight brown colour
Total Hardness	23·0	23·4	23·6	23·2	22·8	21·7
Chlorine as Chlorides ...	1·65	1·65	1·85	1·8	1·7	1·8
Nitrogen as Nitrates ...	0·082	0·19	0·16	0·055	Nil	0·076
Nitrites	Nil	Nil	Nil	Nil	Nil	Nil
Saline Ammonia	0·0009	0·0005	0·0005	0·0005	0·0007	0·0007
Organic Ammonia ...	0·015	0·0116	0·0088	0·0086	0·0112	0·0114
Oxygen consumed (4 hours at 26·7° C.)	0·2	0·15	0·028	0·069	0·07	0·096
Lead, Copper, Iron ...	Absent	Absent	Absent	Absent	Absent	Absent

ANALYSES OF THAMES WATER, 1903—4.

LAMBETH WATERWORKS COMPANY.

(The results are expressed in parts per 100,000.)

	July 10.	July 20.	Sept. 15.	Sept. 30.	Oct. 15.	Oct. 19.
Appearance through 2 foot tube	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: yellow colour
Odour	None	None	None	None	None	None
Taste	None	None	None	None	None	None
Reaction	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
Total Solids	25·0	25·5	25·0	25·0	26·0	32·0
Appearance of Solids on Ignition	Brown colour	Brown colour	Slight brown colour	Slight brown colour	Brown colour	Brown colour
Total Hardness	19·2	21·1	23·0	24·0	21·7	21·0
Chlorine as Chlorides ...	1·98	1·88	2·0	1·9	1·88	1·75
Nitrogen as Nitrates ...	0·13	0·13	0·111	0·13	0·069	0·055
Nitrites	Nil	Nil	Nil	Nil	Nil	Nil
Saline Ammonia	0·0004	0·0004	0·0006	0·0006	0·0005	0·0028
Organic Ammonia ...	0·013	0·0125	0·0125	0·0115	0·0133	0·021
Oxygen consumed (4 hours at 26·7° C.)	—	—	—	—	—	—
Lead, Copper, Iron ...	Absent	Absent	Absent	Absent	Absent	Absent

	Oct. 21.	Oct. 23.	Oct. 26.	Oct. 28.	Oct. 30.	Nov. 4.
Appearance through 2 foot tube	Clear : yellow colour	Clear : yellow colour	Clear : brown colour	Clear : yellow colour	Clear : yellow colour	Clear : yellow colour
Odour	None	None	None	None	None	None
Taste	None	None	None	None	None	None
Reaction	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
Total Solids	32·0	29·0	36·0	34·0	34·0	33·0
Appearance of Solids on Ignition	Marked brown colour	Marked brown colour	Marked brown colour	Marked brown colour	Marked brown colour	Marked brown colour
Total Hardness	21·0	21·0	21·0	20·8	21·1	20·5
Clorine as Chlorides ...	1·75	1·75	1·7	1·7	1·7	1·65
Nitrogen as Nitrates ...	Amount too small to estimate accurately	Amount too small to estimate accurately	Amount too small to estimate accurately	0·055	0·055	0·12
Nitrites	Nil	Nil	Nil	Nil	Nil	Nil
Saline Ammonia	0·0032	0·0032	0·0033	0.002	0·0022	0·0017
Organic Ammonia ...	0·0215	0.0213	0·0256	0·0218	0·0252	0·0242
Oxygen consumed (4 hours at 26·7° C.)	- -	—	—	0·282	0·306	0·290
Lead, Copper, Iron ...	Absent	Absent	Absent	Absent	Absent	Absent

	Nov. 13.	Nov. 27.	Dec. 1.	Dec. 4.	Dec. 9.	Dec. 14.
Appearance through 2 foot tube	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour
Odour	None	None	None	None	None	None
Taste	None	None	None	None	None	None
Reaction	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
Total Solids	33·0	32·0	36·0	35·0	36·0	33·0
Appearance of solids on Ignition	Brown colour	Slight brown colour	Brown colour	Brown colour	Brown colour	Brown colour
Total Hardness	22·0	22·1	23·0	23·0	22·5	21·5
Chlorine as Chlorides ...	1·7	1·8	1·75	1·75	1·8	1·7
Nitrogen as Nitrates ...	0·16	0·19	0·29	0·31	0·30	0·28
Nitrites	Nil	Nil	Nil	Nil	Nil	Nil
Saline Ammonia	0·0018	0·0026	0·0008	0·003	0·0004	0·0032
Organic Ammonia ...	0·0154	0·011	0·012	0·0154	0·0136	0·0142
Oxygen consumed (4 hours at 26·7° C.)	0·176	0·109	0·124	0·120	0·131	0·09
Lead, Copper, Iron ...	Absent	Absent	Absent	Absent	Absent	Absent

	Dec. 16.	Dec. 18.	Dec. 21.	Dec. 24.	Jan. 15.	Jan. 28.
Appearance through 2 foot tube	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear : yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour
Odour	None	None	None	None	None	None
Taste	None	None	None	None	None	None
Reaction	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
Total Solids	35·0	32·0	35·0	36·0	33·0	36·0
Appearance of Solids on Ignition	Brown colour	Brown colour	Marked brown colour	Brown colour	Slight brown colour	Slight brown colour
Total Hardness	21·8	21·0	22·5	22·5	23·0	23·0
Chlorine as Chlorides ...	1·7	1·8	1·8	1·8	1·75	1·8
Nitrogen as Nitrates ...	0·30	0·29	0·27	0·25	0·26	0·20
Nitrites	Nil	Nil	Nil	Nil	Nil	Nil
Saline Ammonia	0·0032	0·0015	0·0027	0·0027	0·0028	0·0009
Organic Ammonia ...	0·0162	0·0158	0·018	0·015	0·011	0·009
Oxygen consumed (4 hours at 26·7° C.)	0·119	0·138	0·14	0·126	0·11	0·11
Lead, Copper, Iron ...	Absent	Absent	Absent	Absent	Absent	Absent

	Feb. 4.	Feb. 6.	Feb. 10.	Feb. 12.	Feb. 16.	Feb. 18.
Appearance through 2 foot tube	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour
Odour	None	None	None	None	None	None
Taste	None	None	None	None	None	None
Reaction	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
Total Solids	33·0	32·0	32·0	29·0	33·0	29·0
Appearance of Solids on Ignition	Slight brown colour	Brown colour	Marked brown colour	Marked brown colour	Marked brown colour	Marked brown colour
Total Hardness	22·0	22·0	22·0	22·0	21·5	22·5
Chlorine as Chlorides ...	1·8	1·75	1·8	1·7	1·8	1·7
Nitrogen as Nitrates ...	0·25	0·095	0·2	0·13	0·13	0·13
Nitrites	Nil	Nil	Nil	Nil	Nil	Nil
Saline Ammonia	0·003	0·002	0·0024	0·002	0·0026	0·003
Organic Ammonia ...	0·012	0·0155	0·0148	0·0164	0·017	0·0166
Oxygen consumed (4 hours at 26·7° C.)	0·14	0·165	0·2	0·2	0·18	0·19
Lead. Copper, Iron ...	Absent	Absent	Absent	Absent	Absent	Absent

	Feb. 20.	Feb. 25.	March 26.	April 30.	May 20.	June 13.
Appearance through 2 foot tube	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour	Clear: greenish yellow colour
Odour	None	None	None	None	None	None
Taste	None	None	None	None	None	None
Reaction	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
Total Solids	31·0	35·0	35·0	30·0	28·0	32·0
Appearance of Solids on Ignition	Slight brown colour	Slight brown colour	Slight brown colour	Slight brown colour	Slight brown colour	Slight brown colour
Total Hardness	23·0	23·5	23·0	21·8	21·8	21·3
Chlorine as Chlorides ...	1·75	1·8	1·8	1·8	1·75	1·75
Nitrogen as Nitrates ...	0·13	0·19	0·27	0·25	0·027	0·108
Nitrites	Nil	Nil	Nil	Nil	Nil	Nil
Saline Ammonia	0·0026	0·003	0·0009	0·0012	0·0008	0·0012
Organic Ammonia ...	0·0158	0·013	0·0084	0·0096	0·011	0·0128
Oxygen consumed (4 hours at 26·7° C.)	0·20	0·14	0·062	0·09	0·07	0·15
Lead, Copper, Iron ...	Absent	Absent	Absent	Absent	Absent	Absent