Rivers as Sources of Water Supply.

A. C. HOUSTON, M.B.,


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Rivers as Sources of Water Supply

BY

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THIS LITTLE BOOK IS, WITH PERMISSION,
RESPECTFULLY DEDICATED BY THE WRITER TO
THE RIGHT HONOURABLE WALTER HUME LONG, M.P.,
SECRETARY OF STATE FOR THE COLONIES,
IN APPRECIATION OF
HIS INVALUABLE SERVICES TO SANITARY SCIENCE, WHEN PRESIDENT OF THE
BOARD OF AGRICULTURE (1895-1900),
AND OF THE LOCAL GOVERNMENT BOARD (1900-5 AND 1915-16).

PREFACE

THE favourable reception given in 1913 to the writer's little book, "Studies in Water Supply" (Messrs. Macmillan and Co.), led him to choose in 1916, as a subject for the Harben Lectures, the question of Water Supply, as one most likely to interest sanitarians generally, and one concerning which he was in a position to speak with some authority, owing to the exceptional opportunities accorded to him as Director of Water Examination to The Metropolitan Water Board. In the following pages, the lectures on "Rivers as Sources of Water Supply" are printed in much the same form as they were delivered at The Royal Institute of Public Health, but a chapter on sterilization has been added, as this is a matter which is now attracting wide attention.

There are several reasons which lead one to believe that rivers are likely to be used to an increasing extent as sources of water supply. In the first place, our sources of supply are limited, and many of the available watersheds are already appropriated. Secondly, many of us now think that our original misgivings, as regards the danger of using river water for potable purposes, have been somewhat exaggerated. Thirdly, some of us have reached the tentative conclusion that impure water can be purified to any standard of safety required. Lastly, there are cases where there is an economic gain in the choice, or the retention, of a river water supply, and, for many years to come, any *legitimate* means of saving money ought to be regarded as a national duty.

It is not inconsistent to advocate the choice of a pure source of water supply, and, at the same time, to state frankly one's opinion regarding the possibility of rendering initially impure water safe for domestic use.

In any case, it is both logical and desirable to readjust one's views from time to time, in order to meet the advance of knowledge and the growth of new ideas.

It is true that our knowledge is limited and that the responsibility attached to departure from old traditions is serious.

The writer, nevertheless, has no wish to disarm criticism by adopting colourless views on water questions. If the opinions expressed in these pages appear to err sometimes on the side of being too definite, the reader is asked to remember that the writer claims no more than that he has had exceptional opportunities of studying the problem of water supply.

Some persons may perhaps consider that too sanguine a view has been taken of the safety of rivers as sources of water supply, and of purification processes generally.

It is to be hoped that their criticism will be of a constructive character and thus usefully stimulate further investigations into the whole subject of water supply.

The writer's convictions, it is true, are settled and definite concerning most of the matters here considered, but only in the light of present-day knowledge. They remain permanently fluid and adaptable, so far as the reception of new ideas is concerned.

It is not out of place for the writer to conclude by expressing his respectful admiration of the policy of The Metropolitan Water Board in leaving no stone unturned to advance our scientific knowledge of water supply.

The writer feels that he lies under a deep obligation to the Board, which he has the honour to serve, and to a staff whose talent, loyalty and zeal it would be difficult to overpraise.

A. C. HOUSTON.

January, 1917.

RIVERS AS SOURCES OF WATER SUPPLY.

CHAPTER I.

RIVER THAMES.

Topographical and Geological Notes—Flow, Rainfall, and Barometric Pressure—Norma Relations of Flow and Rainfall for the Twenty-year Period, 1891-1910—Departures from the Average—Explanatory Notes as regards "Lag" of River—"Surface" or "Immediate" Effect of Heavy Rainfall—Temperature and Flow.

QUALITY OF RIVER THAMES, 1906-13.

Collective and Individual Comparisons as regards Rainfall, Flow and Quality—Yearly Results—Half-yearly Results—Quarterly Results—Monthly Results.

IN dealing with the difficult subject of "Rivers as Sources of Water Supply," it is desirable to limit consideration to the particular river (The Thames) concerning which my ignorance is least. The Thames rises about 370 ft. above sea level in Gloucestershire, near Kemble Junction and Cirencester. It flows between Gloucestershire and Wiltshire, Oxfordshire and Berkshire, Buckinghamshire and Berkshire, Middlesex and Surrey, Essex and Kent, and finally discharges into the North Sea. Its length from the source to the Nore is 210 miles, and it drains an area of over 6,000 square miles. Its average fall from Lechlade to London Bridge is about 21 in. per mile. The velocity above the tideway (Teddington Lock) is about 1½ miles per hour, rising in flood time, to 4½ miles in certain places, and falling, in dry summer weather, to about ¼ mile per hour. The extreme west of the Thames Basin is occupied by a thin, irregular band of Liassic strata, succeeded by a comparatively wide belt of Oolitic age. Between this and the Chalk, which above Kingston has a drainage area of 1,047 square miles, is a narrow strip of country composed of Upper Greensand, Gault, and Lower Greensand, forming the line of demarkation between the upper Thames, which formerly flowed into the Wash, and the lower

THAMES NATURAL FLOW AT TEDDINGTON WEIR.

Daily Average for each Month.

During Thirty Years, ended December 31, 1912.

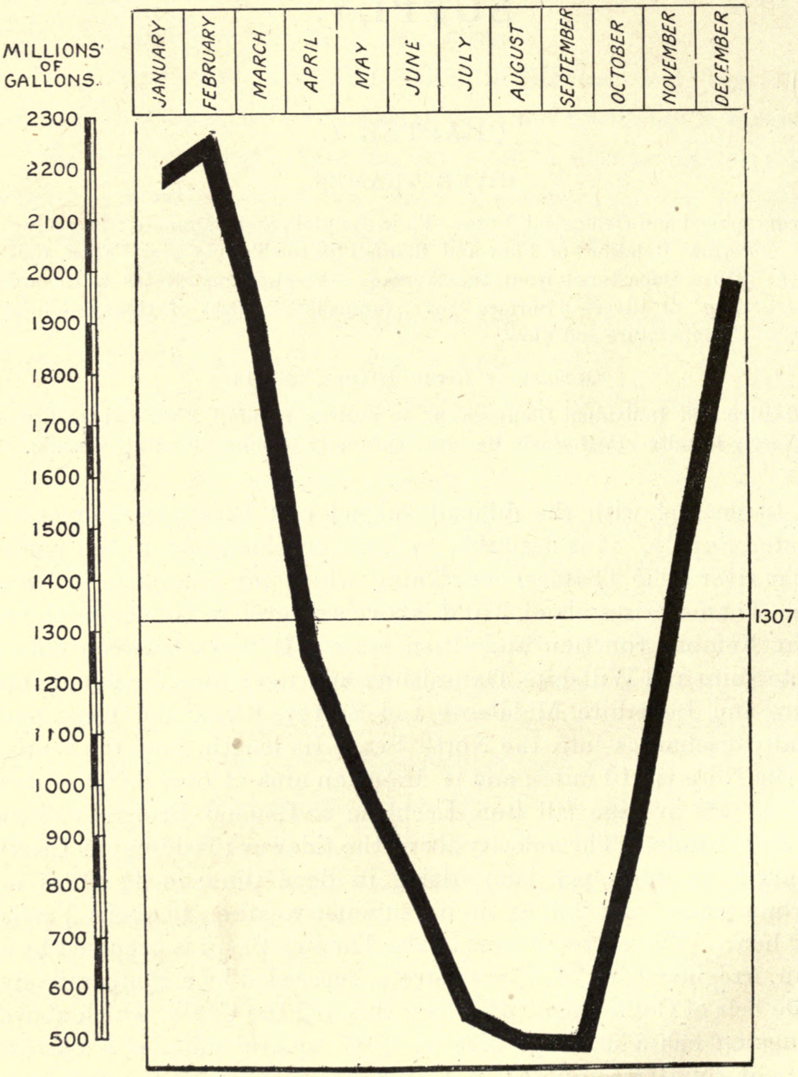


Diagram 1. (*After Lockyer.*)

river. From near Maidenhead, the river flows over Eocene and other Tertiary beds, until, after passing London, sufficient detritus has been accumulated for it to flow over recent formations, which terminate in the sandbanks at its mouth. Some of the southern tributaries of the Thames (the Mole, Wey, Medway, &c.), being of older date than the main river, have had time to cut their way through the chalk ridge of the North Downs, after flowing over Wealden, Greensand and Gault strata. In many places, notably at Maidenhead, Windsor and Slough, the river basin is covered by beds of gravel, occupying approximately an area of over 100 square miles, which retain a vast quantity of water.

Diagram 1 illustrates the average natural flow of the Thames at Teddington Weir. It will be noticed that the flow is highest in February, and lowest in September. In 1905, the Lockyers showed that the mean annual variation of the Thames flow "lags" about five months behind the mean annual rainfall of the British Isles. They found that the rainfall was at a maximum in October, and a minimum in April, and the flow was at a maximum about February, and a minimum about September. They also showed that the rainfall, river flow, and inverted barometric pressure are intimately related. The Lockyers suggested that if it were possible to forecast the pressure, it would enable a person to determine beforehand the rainfall, and, allowing for the lag of the river, a means might thus be afforded of prophesying excessive or deficient water in the River Thames.

Diagram 2 deals with a somewhat shorter period (1891-1910), but has the advantage of including the Thames Valley rainfall records, as well as those relating to Oxford. It will be noted that by far the heaviest rainfall occurs in October, and this rain, aided no doubt by the rainfall during November and December and the early part of the year, leads to a rise in the flow of the river. The rise commences about October, becomes decided in November, still more pronounced during December and January, and reaches a climax in February. The flow declines somewhat in March, and reaches average conditions about April. The falling-off in the flow continues during May and June; the river is at its lowest during July, August and September, and recovery sets in about October.

The rainfall during June, July and August, which is apt to be above the average, is probably largely discounted as a factor influencing the flow by high temperature, dryness of the soil,

RAINFALL AND THAMES NATURAL FLOW.

TWENTY YEARS, 1891-1910.

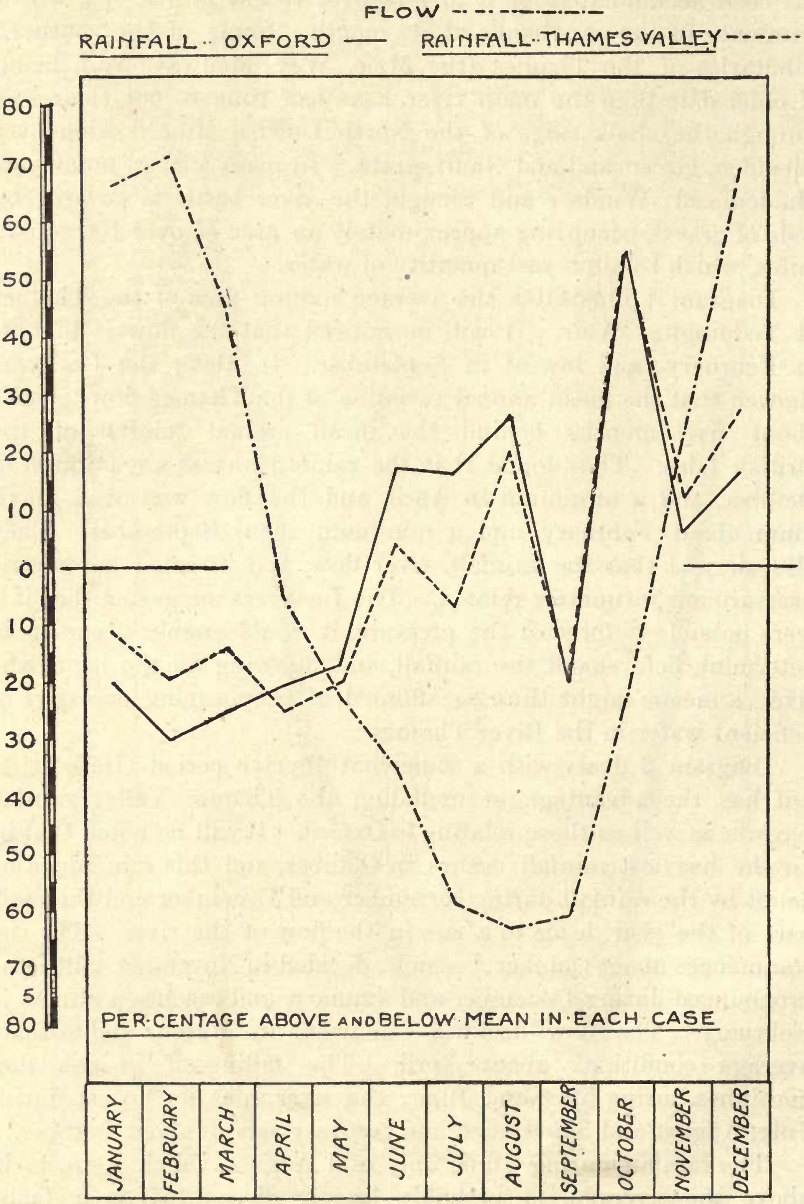


DIAGRAM 2.

luxuriant growth of vegetation and excessive evaporation. Conversely, the rainfall during January, February and March, although considerably below the average, has probably an important influence on the flow, as at that time of the year the temperature is low, evaporation slight, the soil impregnated with moisture, and vegetation in a latent condition. Although what has been said correctly interprets the average expectations, as regards rainfall and flow, it not infrequently happens that there is an abrupt departure from the normal.

JUNE, 1903.

THAMES NATURAL FLOW AT TEDDINGTON WEIR.

—In Million Gallons per day—

RAINFALL AT OXFORD.

—In Inches.—

(Trebled to Enlarge Scale.)

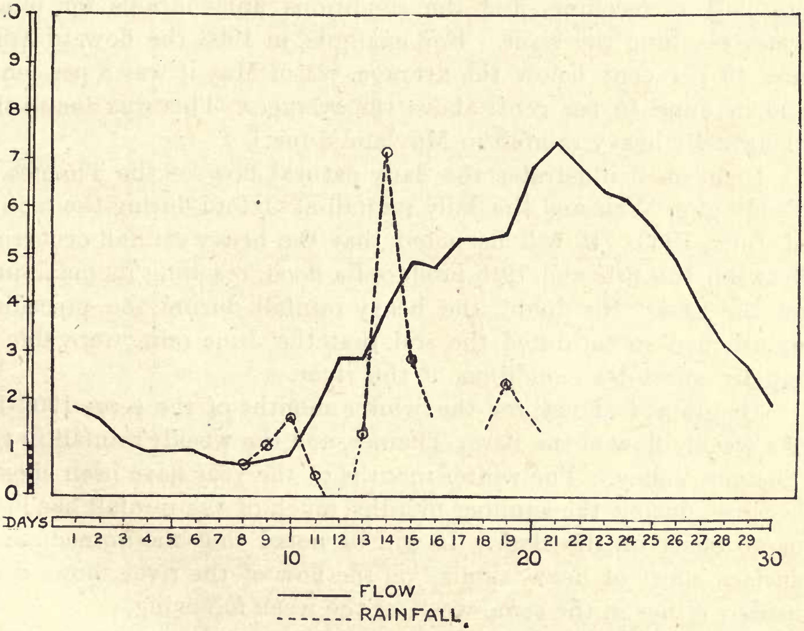


DIAGRAM 3.

Although it is possible to have a deficient flow in a normally excessive flow month, and an excessive flow in a normally deficient flow month, there are three months in the year (July, August and

September) during which the flow has *always* been below the average (1891-1910).

As regards rainfall, no month of the year is exempt from the most extreme departures from the average. It is obvious that neither the length of the Thames, nor its slow flow, nor its volume, can possibly account for a "lag" of some months between the flow and the rainfall. The explanation is to be found in the immense underground storage in the Thames basin. It has been stated that the chalk above Kingston occupies 1,047 square miles, and the immense water-holding power of the chalk is known to everyone. A cubic foot of water equals 6·23 gallons, and the storage capacity of a cubic foot of chalk is 2 gallons. Although the distant effects of rainfall on the flow of the Thames are more important than the "immediate" ones, it must not be supposed that the river is unaffected by recent rainfall. You may even have a flood occurring fairly rapidly during the months when the river normally is receding, and the conditions unfavourable for much water reaching the river. For example, in 1903 the flow in April was 45 per cent. below the average, yet in May it was 8 per cent., and in June 45 per cent. above the average. This was due to the abnormally heavy rainfall in May and June.

Diagram 3 illustrates the daily natural flow of the Thames at Teddington Weir and the daily rainfall at Oxford during the month of June, 1903. It will be noted that the heavy rainfall occurring between the 8th and 19th produced a flood, reaching its maximum on the 21st. No doubt, the heavy rainfall during the preceding month had so saturated the soil that the June rains were able to rapidly affect the condition of the river.

Diagram 4 shows, for the winter months of the years 1906-13, the weekly flow of the River Thames, and the weekly rainfall in the Thames Valley. The winter months of the year have been chosen because, during the summer months, much of the rainfall has little or no effect on the river. It will be noted that the immediate or surface effect of heavy rainfall on the flow of the river shows itself usually either in the same week, or the week following.

It might be anticipated that there would be some sort of inverse parallelism between the flow of the river and the temperature of the water. An examination of the records indeed shows that the approximate flow, under average conditions, could be deduced to some extent from the temperature, and *vice versâ*.

QUALITY OF THE RIVER THAMES.

In considering questions relating to the quality of the River Thames, it is obvious that much may depend on locality. During the year ending July 31, 1909, samples were collected weekly of the Thames at Pangbourne (55 miles above Hampton), Datchet (16 miles above Hampton), and Hampton. The most exhaustive chemical and bacteriological comparisons were made, and the general conclusion was arrived at that the differences were not so great as to force the conclusion that "up-river intakes" should be given the preference, having regard to the greater volume of water in the lower "reaches" of the river. In what follows, the Hampton results will alone be considered, as it is in this

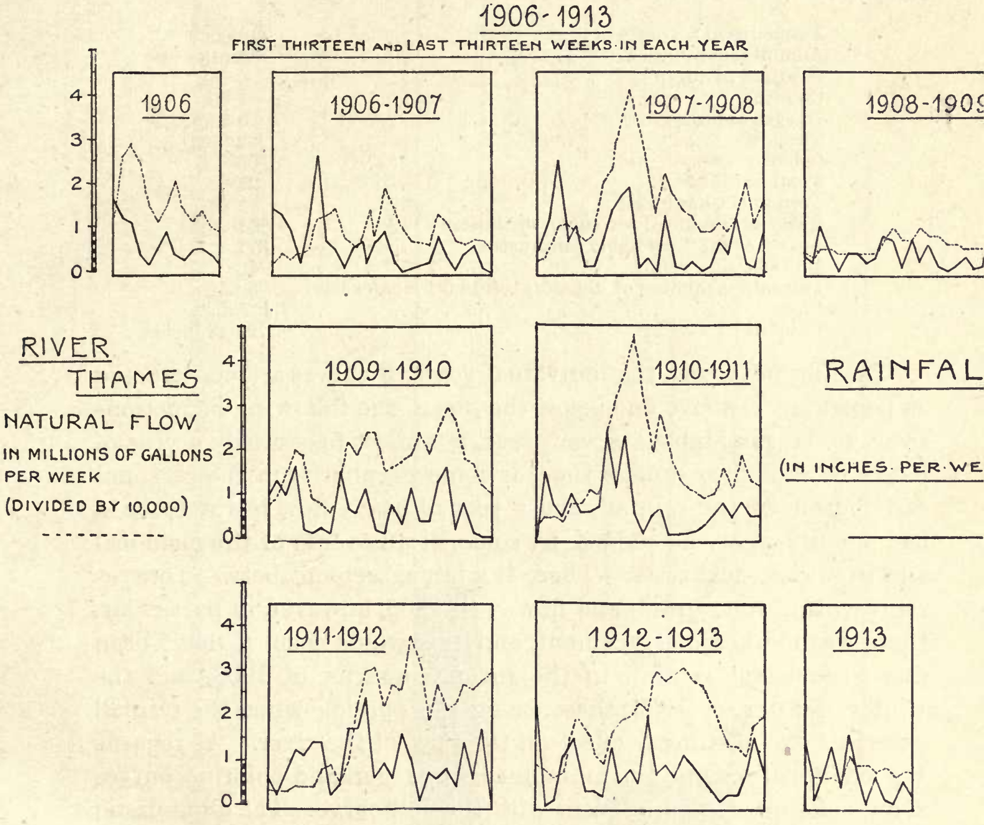


DIAGRAM 4.

neighbourhood that most of the "intakes" for waterworks purposes are situated.

Yearly Results.

The average chemical (parts per 100,000), bacteriological, flow, and rainfall results for the eight-year period 1906-13 were as follows :—

Ammoniacal nitrogen	0·0068
Albuminoid nitrogen	0·0153
Oxidized nitrogen	0·25
Chlorine...	1·69
Oxygen absorbed ...	0·2051
Turbidity	2·8
Colour ...	66
Total hardness ...	22·74
Permanent hardness	5·83
Gelatine "count" per cubic centimetre	4,894
Agar "count" per cubic centimetre	371
Bile salt agar count	46
Percentage number of *Bacillus coli* in 0·1 c.c. (or less)	50
Flow ...	1,457 mg.
Rainfall ...	29·33 inches

Dealing next with the individual years, if curves are constructed as percentages, above and below the mean, the following deductions seem to be justifiable : A wet year is almost necessarily a year of heavy flow of river, unless there is some peculiarity in the seasonal distribution of the rainfall, and a year of heavy flow is apt to be a bad quality year, as judged by some, at all events of the chemical and bacteriological tests. There is a fair agreement between curves representing the rainfall and flow. In 1909, however, in particular, there was marked disagreement, and this would seem to have been due to deficient rainfall in the autumn quarter of 1908, and the winter quarter of 1909, these being the periods when the rainfall exercises its maximum effect on the flow of the river. As regards the chemical results, the ammoniacal nitrogen and chlorine curves show some inverse parallelism with the flow curve. The albuminoid nitrogen, oxidized nitrogren and hardness curves do not agree well with the flow curve. On the other hand, the oxygen absorbed from permanganate, turbidity and colour results show a decided parallelism. The bacteriological tests do not always agree with each other, or with the flow curve. Still, it may be said that years of heavy flow are apt to be years of bacteriological deterioration, and years of reduced flow tend to be years of improved quality. It needs to be remembered that the yearly flow is influenced, not only by the total fall of rain in the year, but by its seasonal

RIVER THAMES.

Chemical and Bacteriological Results—Flow and Rainfall.

Summer (April to September) and Winter (October to March) Averages.
8-year Period, April, 1906, to March, 1914.

Total length of column = winter results.
Shaded ,, ,, = summer results.

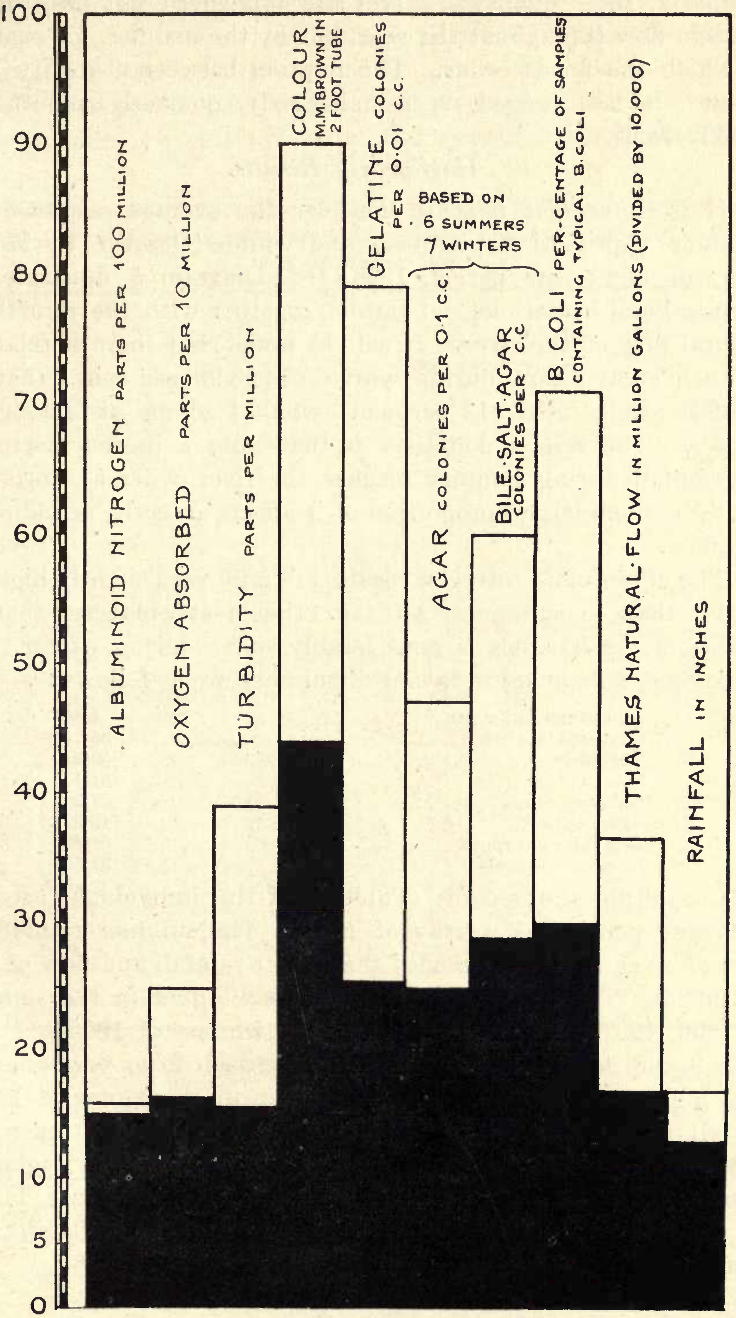


Diagram 5.

distribution and periodicity, and by the "lag" of the river. Similarly, the "quality" curves are influenced not only by the average flow throughout the year, but by the manner, for example, in which the floods occur. The relation between "quality" and "flow" is best judged on a half-yearly, quarterly, monthly, or weekly basis.

Half-yearly Results.

It is convenient next to consider the average results during summer (April to September), and winter (October to March), over an eight-year period, 1906-14. Diagram 5 illustrates the chemical and bacteriological results, together with the rainfall and natural flow of the river. It will be noted that there is relatively a much greater flow during winter (+ 53·99 per cent.) than the rainfall results (+ 25·13 per cent.) would lead one at first sight to expect. The reason doubtless is that only a limited portion of the rainfall during summer reaches the river, whereas, during the winter a much larger proportion of it affects directly, or indirectly, the flow.

The albuminoid nitrogen results are only very slightly higher in winter than in summer. All the other tests indicate that the quality of the Thames is considerably worse during winter. The percentage differences in favour of summer are as follows :—

Albuminoid nitrogen	4·46
Oxygen absorbed	35·75
Turbidity	59·9
Colour	51·1
Gelatine count	67·9
Agar count	46·9
Bile salt agar count	51·67
Bacillus coli test	57·65

Consulting the records (Table I) of the individual years, the following points are worthy of note : The summer rainfall and flow of river of 1908 exceeded the winter rainfall and flow of river of 1908-9. The albuminoid nitrogen was higher in the summers of 1906, 1907, 1908, 1911, than in the winters of 1906-7, 1907-8, 1908-9 and 1911-12. The oxygen absorbed from permanganate was higher in the summer of 1908 than in the winter of 1908-9. In all other cases, the rainfall, flow, albuminoid nitrogen, and oxygen absorbed from permanganate results were the highest in winter. The turbidity and colour readings were always highest in winter, and so were the number of bacteria and *Bacillus coli* results.

The results, as a whole, show conclusively that the Thames is much less impure, as judged by these tests, in summer as compared with winter. The question naturally arises: Why is the Thames apparently purer in the summer than in the winter months? Is not the expectation rather the other way in view of the presumed concentration of pollutions during the months of diminished flow?

TABLE I.—River Thames. Chemical and Bacteriological Results.
Rainfall and Natural Flow of River, Summer (April to September) and Winter (October to March).

		April, 1906, to March, 1914							Percentage of samples containing typical *B. coli* in 0·1 c.c. (or less)	Averages	
		Albuminoid nitrogen	Oxygen absorbed from permanganate	Turbidity	Colour mm. brown in 2 ft. tube	Number of microbes per cubic centimetre				Natural flow in millions of gallons	Rainfall in inches
						Gelatine at 20° C.	Agar at 37° C.	Bile salt agar at 37° C.			
		Parts per 100,000									
	1906	0·0157	0·1320	1·96	28	661	—	—	8·8	89,802	8·48
Summer.	1907	0·0170	0·1794	1·63	49	932	—	—	30·9	128,951	13·45
	1908	0·0142	0·1685	1·57	60	2,222	216	31	36·3	234,198	14·64
April	1909	0·0153	0·1695	1·85	46	1,381	304	40	42·1	130,480	16·33
to	1910	0·0161	0·1726	1·68	49	2,663	265	12	27·9	163,357	13·23
September	1911	0·0156	0·1450	1·55	41	6,623	270	34	29·9	126,398	8·12
	1912	0·0128	0·1500	1·46	38	2,857	216	32	37·2	223,365	16·86
	1913	0·0135	0·1518	0·73	40	3,222	204	16	29·0	236,870	11·19
	Averages	0·0150	0·1587	1·56	44	2,533	250	29	29·9	166,678	12·78
	1906-7	0·0145	0·1831	2·49	61	2,724	—	—	65·8	223,321	14·89
Winter.	1907-8	0·0160	0·2650	5·60	105	5,445	340	48	62·9	387,870	18·34
	1908-9	0·0121	0·1650	2·67	64	2,900	401	43	60·2	174,025	10·51
October	1909-10	0·0180	0·3120	5·37	105	9,187	727	90	86·2	446,642	16·67
to	1910-11	0·0173	0·2552	4·10	96	11,837	412	28	70·4	411,291	17·50
March	1911-12	0·0154	0·2634	4·99	96	11,522	441	61	76·6	485,909	23·91
	1912-13	0·0164	0·2704	3·64	93	10,275	647	138	72·5	493,819	17·46
	1913-14	0·0161	0·2620	2·24	100	9,207	383	23	70·7	280,687	17·30
	Averages	0·0157	0·2470	3·89	90	7,893	471	60	70·6	362,945	17.07

The answer would seem to be as follows: In the winter, the floods wash all sorts of impurities into the river. Some of these impurities come from manured and cultivated soil and flooded sewage farms; others from storm water sewage overflows. In effect, there is a sort of general washing and scouring effect over the whole of the drainage area, resulting in the river receiving a vast amount of accumulated filth. But this is not all.

The increased velocity of the river not only interferes with the normal settlement of suspended matters, but constantly disturbs the suspended matter which had previously collected in its bed. In the summer much of the water in the river being derived from underground sources, has been naturally stored and filtered. Again the storm-water sewage overflows, which in flood time discharge unpurified, or imperfectly purified, filthy water into the river, are no longer, or less often, in operation. Moreover, many of the sewage farms may be practically dried up, and consequently the effluents may not be discharging directly into the river. These effluents may indirectly reach the river lower down, but only after preliminary purification and mixture with underground water.

RIVER THAMES.

Rainfall, Flow and Chemical Results—8-year Period, 1906-13.

Arranged as Quarterly Averages.

Rainfall: Inches × 2. *Flow:* Million gallons ÷ 10,000. *Turbidity:* Parts per 100,000. *Colour:* Mm. brown 2·4-in. tube. *Oxygen absorbed:* Parts per 10 million. *Albuminoid nitrogen:* Parts per 100 millions.

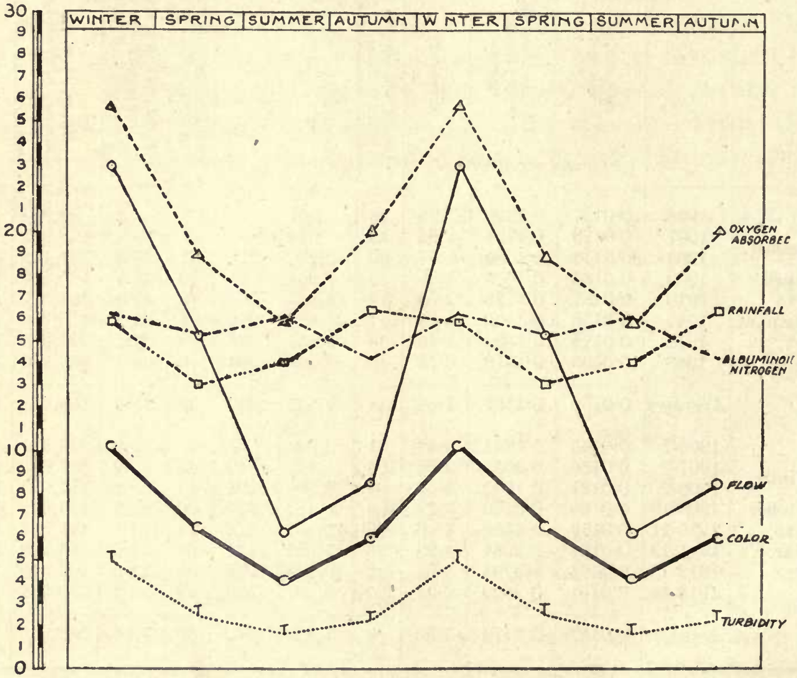


Diagram 6.

Again, the slow flow of the river no longer disturbs its bed, and any suspended matters in the water are constantly being deposited in the more stagnant reaches. Temperature, growth of vegetation, animal life, sunlight and other factors are also at work, but the foregoing statement appears to the writer to explain sufficiently the observed variations in the quality of the River Thames during winter and summer. It should, however, be borne in mind that the averages given are "inclusive," and the extremely high results which sometimes occur in winter are apt to dominate the averages for that period.

RIVER THAMES.

Flow and Bacteriological Results—8-year Periods, 1906-13.

Arranged as Quarterly Averages.

Flow : Million gallons ÷ 10,000. *Colonies on gelatine* : Per 0·01 c.c.

B. coli : Percentage in 0·1 c.c. (or less).

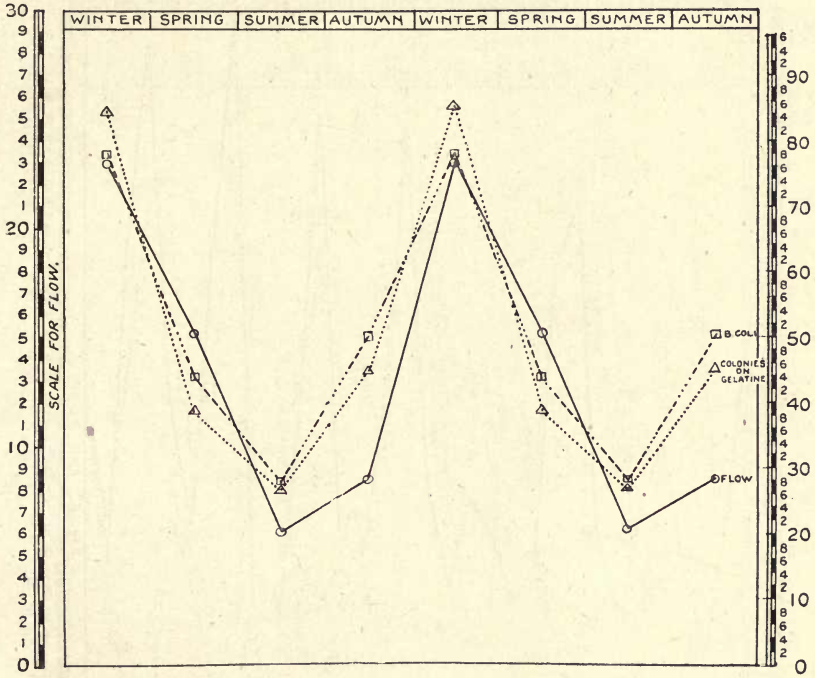


Diagram 7.

Quarterly Results.

On page 12 is a diagram (6) illustrating some of the chief average quarterly results for the period extending from December

1905, to November, 1913. It will be noted that the autumn and winter rains appear to dominate the winter and spring flow of the river. The albuminoid nitrogen curve is peculiar, inasmuch as

RIVER THAMES.

Thirty-two Quarters ended November, 1913.

FLOW,

Million gallons ÷ 10,000.

OXYGEN ABSORBED,

Parts per 10 million.

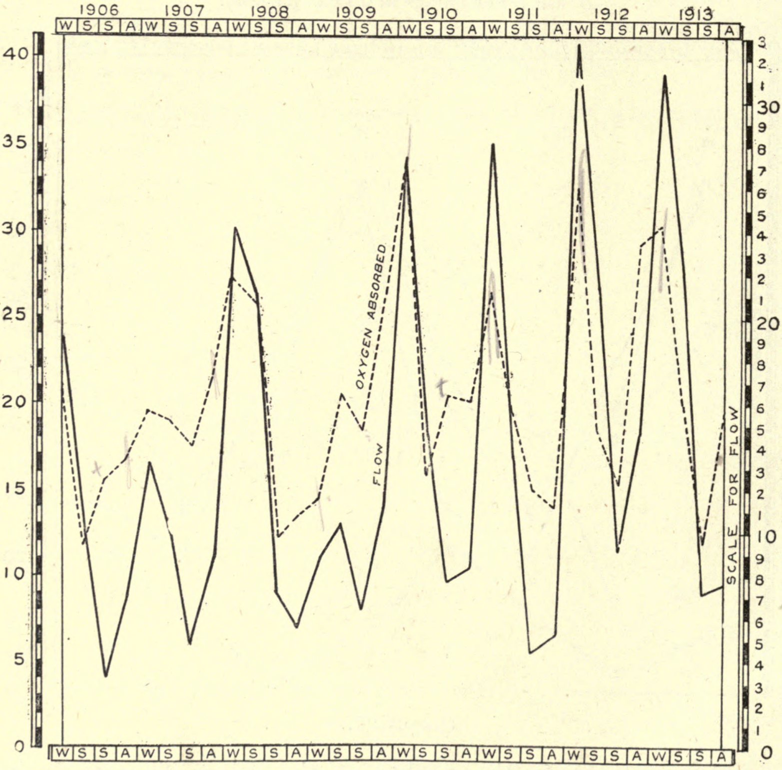


Diagram 8.

although it is high in winter, the spring fall is followed by a summer rise, and the lowest results are encountered in the autumn. The oxygen absorbed, colour, and turbidity curves follow the flow curve somewhat closely. The results are highest in the winter, and lowest in the summer. There is no very striking difference between the spring and autumn results, and in this respect they differ from the flow curve, which is much higher in the spring than in the autumn. Having regard to the much greater volume of water in the river, the spring quarter is obviously, as judged by these three tests, a better season for abstraction purposes than the autumn.

RIVER THAMES.

THIRTY-TWO QUARTERS ENDED NOVEMBER, 1913.

FLOW,

Million Gallons ÷ 10,000.

COLOUR,

M.M., Brown in 2-feet Tube.

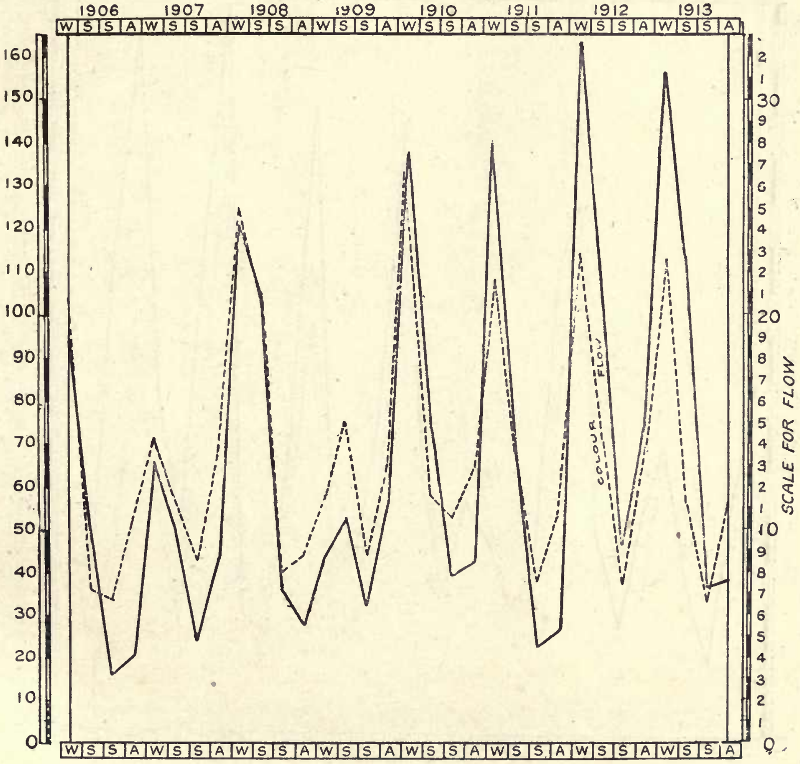


DIAGRAM 9.

Diagram 7 illustrates some of the bacteriological results. You will notice that the curves agree well with the flow curve. The results are worst in winter, better in autumn, and best in the summer. A striking feature is, that although the results are somewhat worse in autumn than in spring, the flow of the river is vastly greater in the spring, as compared with the autumn.

Dealing with the thirty-two quarters individually, the following notes are of interest: Excepting 1909, the *flow* has always been

RIVER THAMES.

Thirty-two Quarters, ended November, 1913.

FLOW,

Million Gallons ÷ 10,000.

TURBIDITY,

Parts per 100,000.

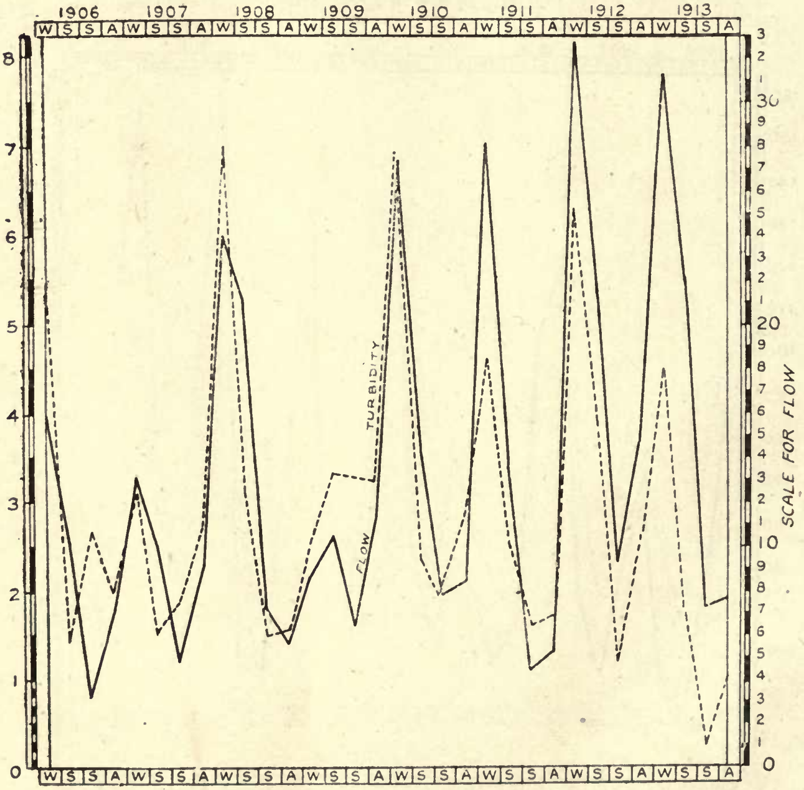


Diagram 10.

highest in winter and next highest in spring. This is not a very decided difference between the summer and autumn flows, but, except in 1908, the autumn flow has always been greater than that of summer. The albuminoid nitrogen curve is somewhat irregular and does not agree very well with the flow curve. The tendency is for it to be lowest in autumn, highest in winter, and higher in summer than in spring. The oxygen absorbed curve (*see* diagram 8) agrees fairly well with the flow. Excepting 1907 and

RIVER THAMES.

THIRTY-TWO QUARTERS ENDED NOVEMBER, 1913.

FLOW,

Million Gallons ÷ 10,000

COLONIES,

on Gelatine, per 0·001 *c.c.* 20°—22° *C.*

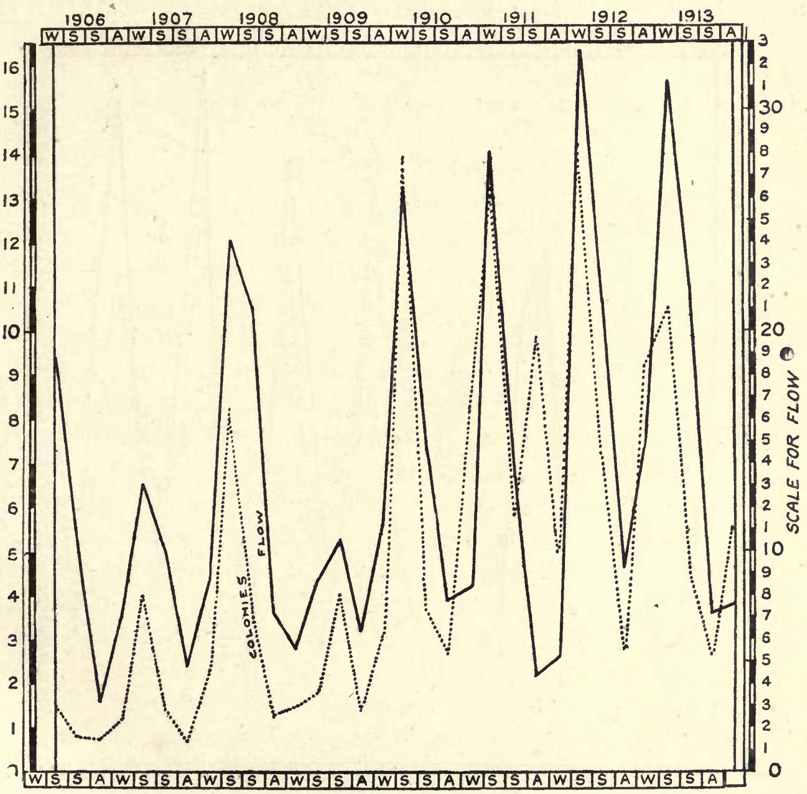


DIAGRAM 11.

1909, it has always been highest in winter. With the exception of 1908, 1910, 1911, and 1913, the results have been higher in autumn than either in spring or summer. Summer is not always the best quarter, as for example in 1906, 1909, 1910 and 1911.

Diagram 9 shows that the colour curve follows the flow curve very closely. Excepting 1909, the colour has always been highest in winter and invariably it has been lowest in summer. There is usually not much difference between the spring and autumn results,

RIVER THAMES.

THIRTY-TWO QUARTERS ENDED NOVEMBER, 1913.

FLOW,

Million Gallons ÷ 10,000.

B. COLI,

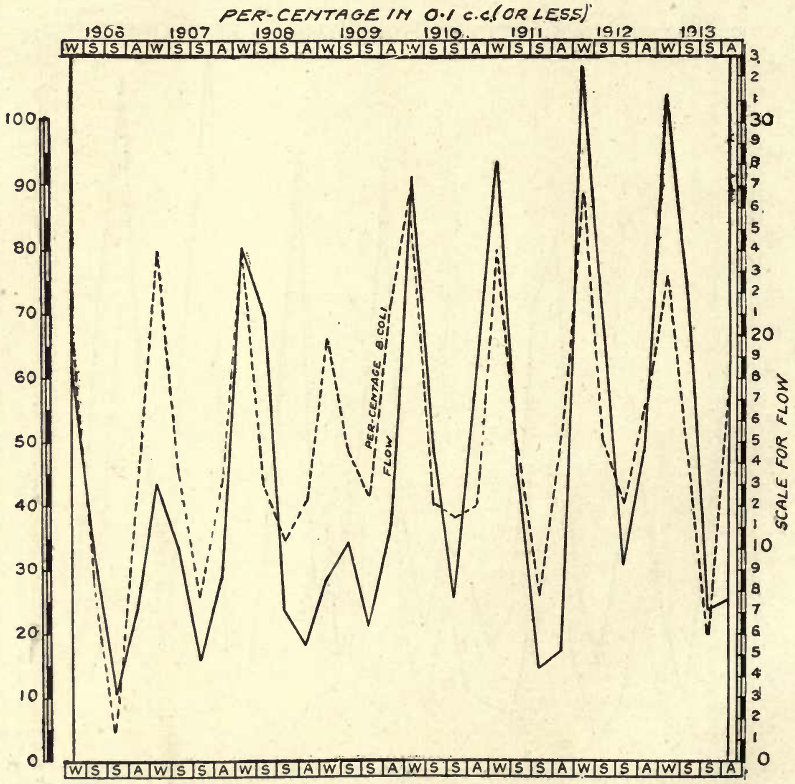


DIAGRAM 12.

sometimes one and sometimes the other quarter showing the best results. The turbidity curve (*see* Diagram 10) agrees well with the flow curve. With one exception (1909) it has been highest in winter and it has been lowest in summer with but two exceptions

(1906 and 1907). The spring and autumn results do not differ widely, but the tendency is in favour of the autumn being the better quarter of the two. In Diagram 11 are shown curves representing the flow and the number of bacteria. The general agreement is striking. Except in 1909, the number of bacteria has always been highest in winter, and summer (excepting 1911) has always yielded the best results. In a majority of years the results are worse in autumn than in spring. It will be seen from Diagram 12 that curves representing the flow and the *Bacillus coli* results show a well-marked agreement. Excepting 1909, the results have always been worst in winter. The best results have invariably been in the summer quarter of the year. In a majority of years, the results are somewhat worse in autumn than in spring.

Monthly Results.

The yearly, half-yearly and quarterly results have so far been considered, and it is convenient now to deal with the monthly results. It would be a difficult and lengthy task to consider individually the ninety-six months in the eight-year period (1906-13), so the averages for each of the twelve months only will be dealt with.

Diagram 13 illustrates the flow and rainfall, and neither of the curves quite agrees with those for the longer period of 1891-10, owing to the condition having been somewhat abnormal during part of the shorter 1906-13 period. The autumn and winter rains, as is customary, appear to have dominated the winter and spring flows, and the spring and summer rains, as usual, failed to maintain the flow of the river, which gradually fell month by month to a minimum in September. The heaviest rainfall occurred in October and December, and the biggest flow in December and January.

When curves are prepared of the flow and "quality" results, and carefully examined, the following points attract attention. There is a general similarity between the ammoniacal nitrogen and flow curves, but the ammoniacal nitrogen curve reaches a minimum in May, whereas the flow reaches its minimum as late as September. Little rises occur in June and August in the ammoniacal nitrogen curve, which may be due to the immediate effects of rainfall, although conceivably the summer traffic on the river should also be considered in this connection. It should also be noted that the ammoniacal nitrogen curve rises very sharply in

RIVER THAMES.

Average Results for each Month, 1906-13.

FLOW,
Million Gallons ÷ 1,000.
Rainfall: Inches × 10.

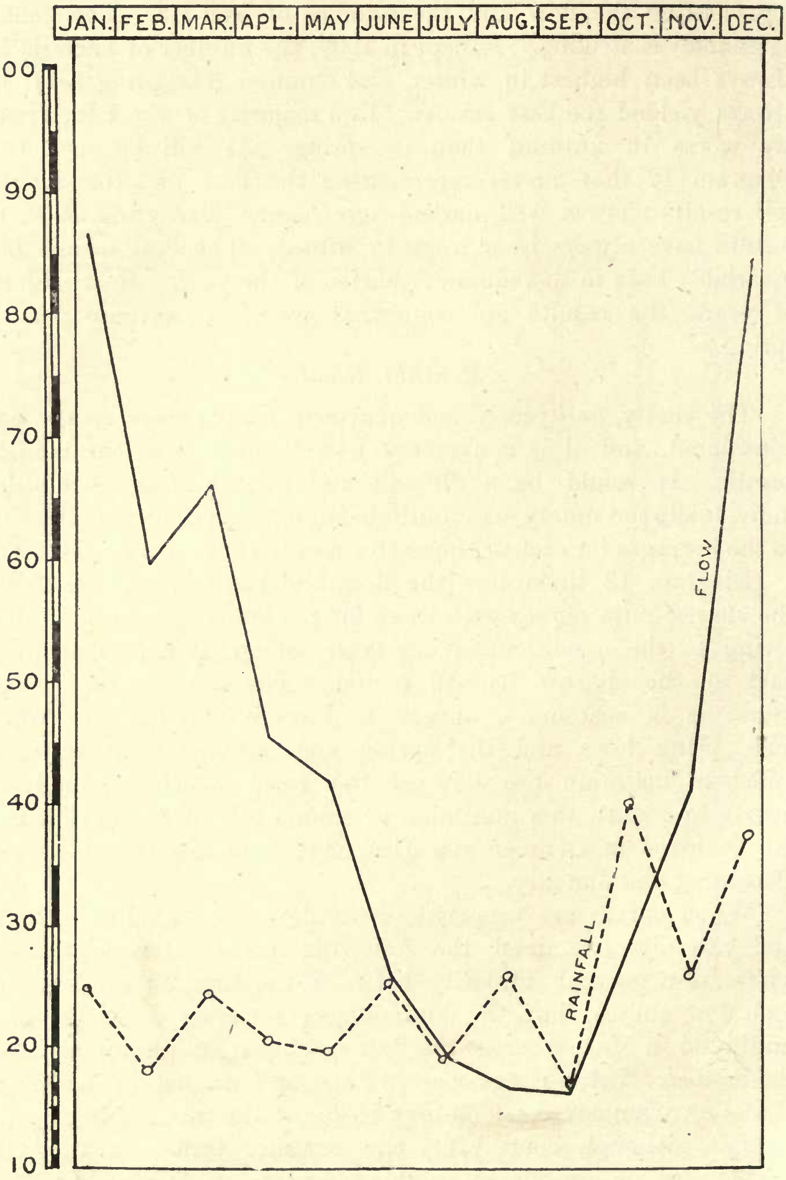


Diagram 13.

October and November as compared with the more gradual rise in the flow of the river. The albuminoid nitrogen curve does not agree very well with the flow curve. It is true it is lowest in September and highest in December, but it rises in May and June when the river is steadily falling. It might be said that this was due to a greater concentration of the pollutions, but the results yielded by most of the other tests hardly support this hypothesis. Moreover, during July, August and September, both the albuminoid nitrogen and flow curves agree in showing a progressive fall. Possibly the May and June rise is to be associated with a growing temperature, and the effect of temperature on living and dead organic matter, and perhaps also increased traffic on the river, may play some part in the change. The oxidized nitrogen curve resembles the flow curve, inasmuch as it tends to be lower in summer than in winter, but it reaches its minimum a month earlier, and is commencing its winter rise whilst the river is still falling. Further, the chlorine is least in May, and from that time it steadily, although only slightly, rises until it reaches a maximum in November. The water is hardest in February, and each month becomes gradually slightly softer, until it reaches a minimum in August. Perhaps this is due to some carbonate of lime passing out of solution and becoming deposited, owing to loss of carbonic acid, consequent upon temperature changes, and the activity of plant life and other growths. The permanent hardness is also least in August, and gradually rises to a maximum in December.

Diagram 14 shows the oxygen absorbed from permanganate, turbidity and colour results. The curves agree very well with each other, and with the flow curve. The results are lowest in September and highest in December. It will be noted that the water deteriorates more quickly than the flow increases, and recovers more rapidly than the flow recedes. April is in many respects a remarkable month. The ammoniacal nitrogen, albuminoid nitrogen, oxygen absorbed from permanganate, turbidity and colour results are all below their respective averages, whereas the flow of the river is still above its average. Contrast this with November when the converse is true, the flow being below its average, whereas the chemical results are decidedly worse than their averages.

Diagram 15 illustrates very clearly that although "quality" and "flow" are closely related, the departures from the mean are, for certain periods, disproportionate and even, in a sense,

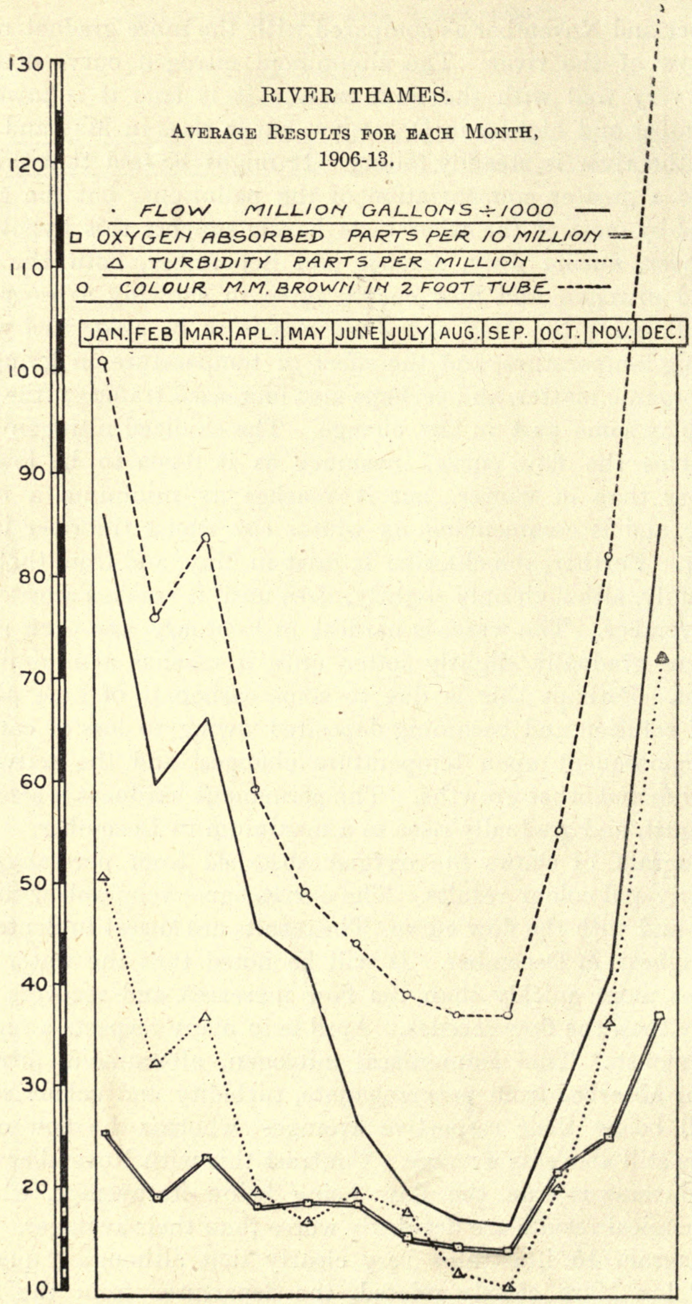
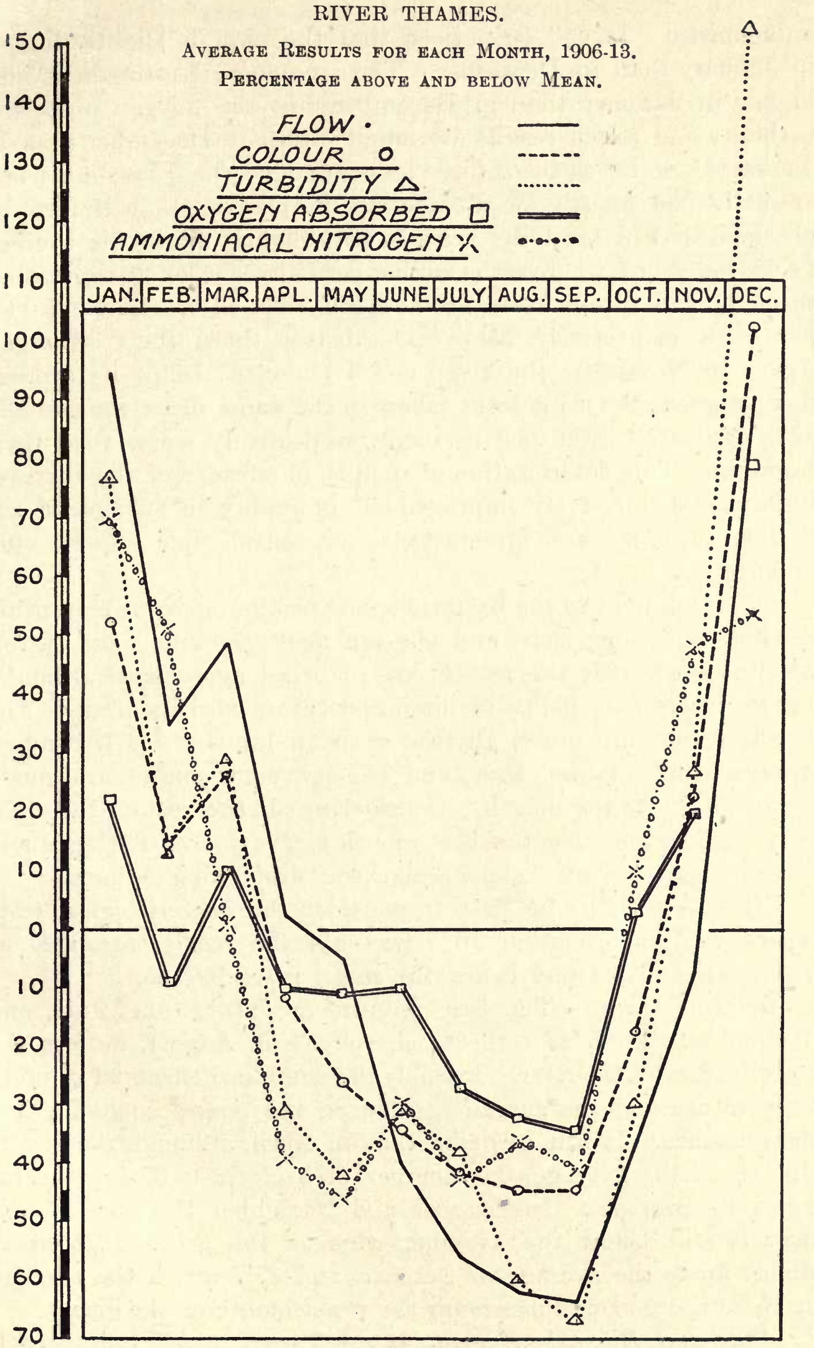

RIVER THAMES.
Average Results for each Month,
1906-13.
· FLOW MILLION GALLONS ÷ 1000
□ OXYGEN ABSORBED PARTS PER 10 MILLION
△ TURBIDITY PARTS PER MILLION
○ COLOUR M.M. BROWN IN 2 FOOT TUBE
JAN.
FEB
MAR.
APL.
MAY
JUNE
JULY
AUG.
SEP.
OCT.
NOV.
DEC.
130
120
110
100
90
80
70
60
50
40
30
20
10

Diagram 14



RIVER THAMES.

Average Results for each Month, 1906-13.

Percentage above and below Mean.

Diagram 15.

antagonistic. It will be noticed that the river is slightly higher in January than in December. The ammoniacal nitrogen is also higher in January than in December, but the oxygen absorbed, turbidity and colour results are much higher in December than in January. So far as these three tests are concerned, December is a specially bad month for abstraction purposes. It will also be observed that in April the river is still slightly above the average (+ 2·6 per cent.), whereas the ammoniacal nitrogen, oxygen absorbed, turbidity and colour tests are actually 38·5, 11·0, 31·2, and 11·3 per cent. respectively below (i.e., better than) their averages. Again in November the river is 7·6 per cent. below its average flow, whereas the same tests taken in the same order are actually 47·9, 20·0, 27·4, and 23·3 per cent. respectively worse than their averages. This deterioration of quality in advance of the increase in flow, and conversely improvement in quality in advance of the decline in flow, is a circumstance of considerable interest and importance.

Turning next to the bacteriological results, curves representing the flow—gelatine, agar, and bile-salt agar "counts," and *B. coli* results—show that the results are in broad agreement, although certain interesting points of dissimilarity are also apparent. The *B. coli* results are practically the same in January and December, whereas the gelatine, agar, and bile-salt agar counts are much worse in the latter month. Considering all the results together, May would seem to be the best month of the year. The agar and bile-salt agar "counts" show a marked "drop" in February.

It will perhaps be best to consider the bacteriological tests separately, and Diagram 16 represents the results arranged as percentages above and below the mean in each case.

Gelatine Count.—The best months are May, June, July, and September. There is rather a sharp rise in August, despite the receding flow of the river. Possibly the combined effects of rainfall, temperature and the summer traffic on the river account for this circumstance. It will be noted that in April, although the flow is still above the average, the number of bacteria is 35·4 per cent. below its average. In October and November the flow of the river is still below the average, whereas the gelatine count is almost up to the average in October, and 37·7 above the average in November. December is far the worst month of the year.

Agar and Bile-salt Agar Counts.—These curves follow each

RIVER THAMES.

AVERAGE RESULTS FOR EACH MONTH, 1906-13.
PERCENTAGE ABOVE AND BELOW MEAN.

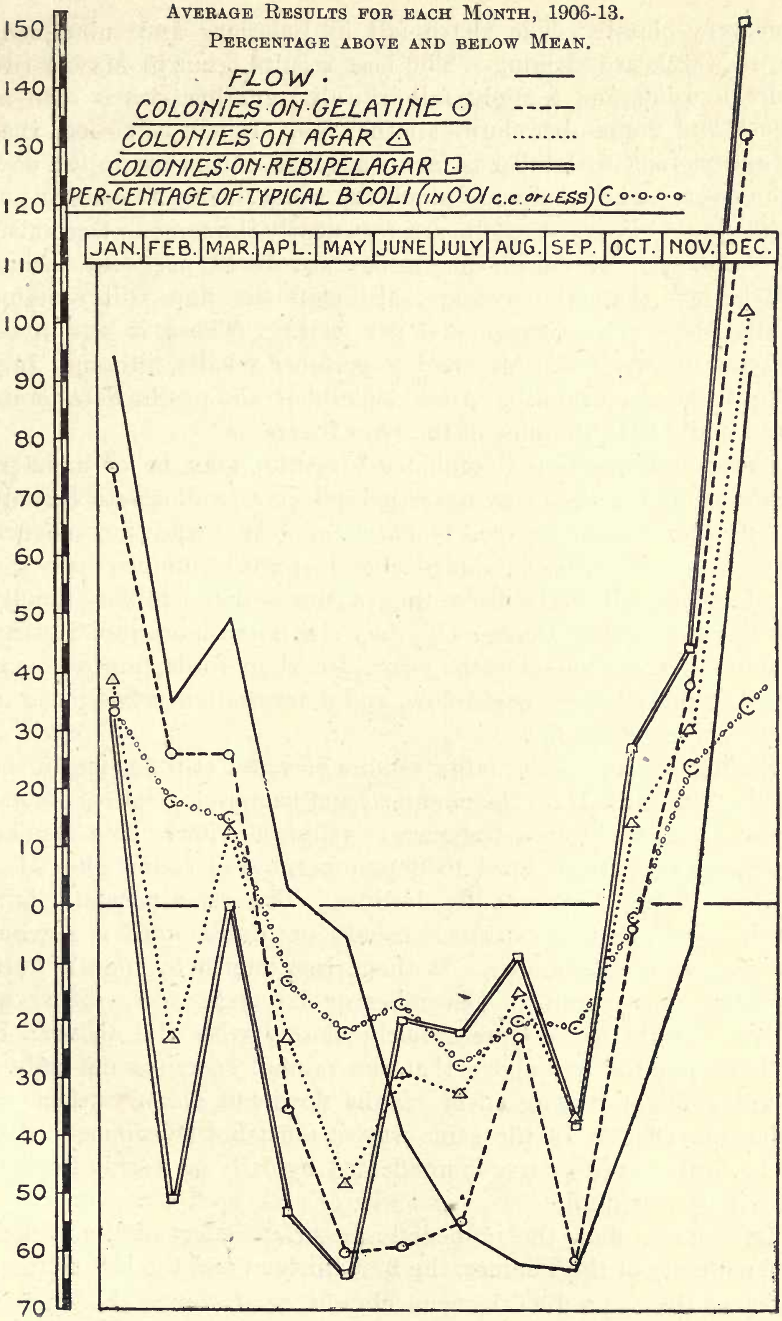


DIAGRAM 16.

other very closely. The sharp fall in February and subsequent rise in March are striking. The best results occur in May, a rise occurs in June, and a slight fall in July; another rise is seen in August, and September shows another fall. It will be noticed that the abrupt rise in October is far in advance of the rise in the flow of the river. The results are much the worst during December.

Bacillus Coli.—The results are very nearly the same in December and January. In April, the results are 13·43 per cent. below (i.e., better) than the average, although the flow still remains slightly above the average (2·6 per cent.). There is not much difference between the May and September results, although July is slightly the best month. After September, the results deteriorate more rapidly than the flow of the river increases.

Curves representing "combined" results may be of undeterminate value, but they may nevertheless serve to illustrate broadly the effect of season on quality of water. An inspection of such curves shows that the combined chemical and combined bacteriological curves fall at the beginning of the year much more rapidly than the flow curve. Conversely, they rise much more rapidly than the flow curve at the end of the year. In other words, improvement in quality precedes decreased flow, and deterioration takes place in advance of increased flow.

Having regard to the large volume of water still flowing in the river in April and May, the chemical and bacteriological results are very satisfactory from a waterworks point of view. The results, indeed, are good from April to September, but of course after May the flow of the river rapidly declines. The river normally falls month by month from about February or March until it reaches a minimum in September. It then rises month by month until it reaches a maximum in December or January.

The quality curve agrees fairly closely with the above. It has been pointed out above that the rainfall exercises not only a distant and dominating effect on the flow, but also a surface or immediate effect. In the same way, it must not be supposed that the monthly *quality* curve is unaffected by daily or weekly fluctuations in the rainfall.

In order to show the immediate or surface effect of the rainfall on the quality of the Thames, the first thirteen and the last thirteen weeks of the years 1906-13 were chosen, as of course the summer rains may produce little or no effect on the river. When curves are prepared of the weekly rainfall and flow, and the colour and number of bacteria results over this period, their examination shows that usually *heavy* rainfall has a very appreciable effect on the flow, the rise occurring in the same week, or more often in the week following. The gelatine "count" and colour results tend to rise and fall as the river rises or falls, although, of course, there are many instances of real or apparent lack of agreement between the various curves. There is thus during the winter months a frequent oscillation of the flow and quality curves produced by the more or less "immediate" or "surface" effects of heavy rain, although this does not affect the fact that the *general curves* of quality and flow are dominated by the rainfall of a much earlier period.

In brief summary of what has been said: The flow of the River Thames tends to be highest in February and lowest in September. The rainfall in the Thames Valley tends to be highest in October and lowest in April. There is thus a "lag" of some months between the flow and the rainfall, due to the immense underground storage in the Thames basin. Wet years tend to be years of heavy flow and the quality of the river water may suffer in consequence, but questions of periodicity of rainfall and "lag" of river, &c., have also to be considered.

When the year is divided into two halves, summer (April to September), and winter (October to March), the results show, on the average, that winter is characterized by increased rainfall, much augmented flow of river, and considerable deterioration in quality. The explanation seems to be that in winter the floods have a general washing and scouring effect over the whole drainage area, whereas in summer many sources of pollution become dried up or otherwise inoperative, and much of the water in the river is virtually stored and filtered water, derived from underground sources of supply.

As regards the quarterly results, the autumn and winter rains appear to dominate the winter and spring flow of the river. The flow is highest in the winter, then in the spring; there is not much difference between the summer and autumn flows, but the volume of water is least in the former quarter.

The chemical and bacteriological results generally agree with the flow. The albuminoid nitrogen results are peculiar, inasmuch as although high in winter, the spring fall is followed by a summer rise, and the lowest results are recorded in the autumn. The oxygen absorbed, colour, and turbidity results are highest in winter and lowest in summer. There is no very striking difference between the spring and autumn results, and in this respect they differ from the flow, which is much higher in the spring than in the autumn. The bacteriological results are worst in winter, improved in autumn, better in spring, and the summer quarter is the best.

As regards the average monthly results for the period 1906-13, the heaviest rainfall occurred in October and December, and the biggest flow in December and January.

Speaking generally, most of the chemical and bacteriological results agree well with the flow of the river, but towards the end of the year the river deteriorates in quality more rapidly than the flow increases, and improvement in quality in the spring takes place more rapidly than does the decline in the flow. Having regard both to questions of volume and quality, the months of April and May seem to be specially well adapted for abstraction purposes.

During the winter months of the year oscillations of the flow and quality of the river water may occur as the results of the more or less "immediate" or "surface" effect of heavy rain, but this does not affect the fact that the general curves representing quality and flow are dominated by the rainfall of a much earlier period.

CHAPTER II.

RIVER THAMES.

Search for Streptococci, the Typhoid Bacillus and Gärtner's Bacillus in River Water—Search for the Typhoid Bacillus in Crude Sewage—Inferential Conclusions.

"Resistance to Filtration" Experiments—Microscopical Appearances of the Suspended Matters in River Thames water—Description of Methods Employed—Filtration Results—Photographic Appearances.

Vitality of the Cholera Vibrio and the Typhoid Bacillus in Artificially Infected Samples of River Water—Difference between "Cultivated" and "Uncultivated" Bacilli.

Chemical and Bacteriological Changes occurring in River Water under Conditions of Storage—Chelsea Reservoir Results—Staines and Lambeth Reservoir Results—Other Reservoir Results—Summarized Advantages of Storage.

THE RIVER THAMES IN RELATION TO PATHOGENIC BACTERIA.

THE hygienic qualities of the River Thames water have so far been dealt with, and it is now desirable to consider the results of the application of special bacteriological tests.

During 1909, 52 samples of Thames river water were examined at approximately weekly intervals, in 1 c.c. amounts, for *streptococci.* Only 13 out of the 52 samples contained "lactose positive" streptococci, the total number isolated being 19. In two samples the 1 c.c. plates were so crowded that it was necessary to resort to the 0·1 c.c. plates. In one of these two samples a single streptococcus was isolated, and in the other sample none were found. Even if we consider that both contained streptococci in the proportion of 10 per c.c., this only raises the total number isolated to 39.

Now the average yield of streptococci (in excess of any streptococci already present in the water), when one part of excremental matter is added to one million parts of water, has been found experimentally to be about 17 per c.c. It follows, that in the 52 samples 884, instead of only 39, should have been isolated if the

Thames were contaminated to the small extent of one part of excremental matter per one million parts of water. Inferentially, it may be concluded that Thames water does not contain one part of *fresh* excremental matter in over twenty-two million parts of water.

As regards definitely pathogenic bacteria, a prolonged search has been made for the typhoid bacillus and Gärtner's bacillus. In the first place, 294 experiments, in eight series, were made with 156 samples of raw river water during the twelve months ended July 31, 1908; 7,329 microbes were studied, and not one of them proved to be the typhoid bacillus. Later, further and more elaborate investigations were carried out, and they included search for Gärtner's bacillus as well as the typhoid bacillus. Moreover, they differed from the first research in a most important particular.

Each sample of raw river water was divided into two equal portions of 500 c.c. (A and B). The A sample was inoculated with a very small number of typhoid bacilli, and Gärtner's bacilli, separately determined by agar plate cultures in the usual manner. The B sample was not so infected, and was, therefore, *normal raw river water*. A and B were then examined in a *strictly comparative* manner. 101 experiments were carried out altogether, 15 of the samples being derived from the Lee, and 86 from the Thames.

The results obtained are shown in Table II.

TABLE II.

Total number of colonies sub-cultured both in the case of the A and the B samples	Typhoid part of Experiment				Gärtner part of Experiment			
	Average number of *artificially* added typhoid bacilli per c.c. of the *raw* river water		Average number of typhoid bacilli recovered from :—		Average number of *artificially* added Gärtner bacilli per c.c. of the *raw* river water		Average number of Gärtner bacilli recovered from :—	
	In-fected Sample A	Non-infceted Sample B	In-fected Sample A	Non-infected Sample B	In-fected Sample A	Non-infected Sample B	In-fected Sample A	Non-infected Sample B
Columns (*a*) 22,141	(*b*) 1·17207	(*c*) None	(*d*) 10·6036 10·6036 —————— 1·17207 = **9·0469**	(*e*) None (? 2 out of 22,141 sub-cultures)	(*f*) 0·685	(*g*) None	(*h*) 13·2884 13·2884 —————— 0·685 = **19·4**	(*i*) None (? 1 out of 22,141 sub-cultures)

Taking the columns *seriatim*, it will be noted from column (*a*) that 22,141 colonies were subcultured from the A samples, and a similar number from the B samples. Column (*b*) shows that the average number of artificially added typhoid bacilli per cubic centimetre of the raw river water was 1·172 in the case of the A samples. The B samples, of course, received none—column (*c*). From column (*d*) it appears that on the average 10·6036 typhoid bacilli were recovered from the A samples. Now, as 1·172 typhoid bacilli were added per cubic centimetre of water and 10·6 recovered, it may inferentially be concluded that a positive result would still have been obtained, if the number added had been nine times less; or, to put it in a slightly different way, if there had only been one typhoid bacillus per 9 c.c. of water, this microbe could still have been recovered.

Now, turning to column (*e*) we find that with the exception of two "query typhoid," no typhoid bacilli were found in the B non-infected samples. This leads one to the conclusion that the rivers Thames and Lee do not uniformly contain typhoid bacilli in the proportion of one per 9 c.c., as otherwise positive results would have been obtained in the case of the B samples, which were examined under precisely the same conditions as the A samples. Columns (*f*, *g*, *h* and *i*) deal with the Gärtner part of the experiments, and correspond, except for the difference of microbe, with columns (*b*, *c*, *d* and *e*) just explained in detail. It will be seen that the average number of Gärtner's bacilli added per cubic centimetre of river water (A samples) was 0·685, the number recovered was 13·2884, and so, inferentially it may be concluded that a positive result would still have been obtained if only one Gärtner's bacillus had been added to 19 c.c. of river water.

Turning next to the B samples (column *i*) it is to be noted that with the exception of one "query Gärtner," the results were negative, so that inferentially the conclusion seems justifiable that the rivers Thames and Lee do not uniformly contain Gärtner's bacilli in the proportion of one per 19 c.c., as otherwise positive results would have been obtained.

Summarizing what has been already said, it may fairly be claimed that by *dint of great labour* it is possible to isolate the typhoid bacillus and Gärtner's bacillus from river water, when these microbes are present in the proportion of one per 9 and 19 c.c. of river water respectively. The failure, practically speaking, to find these same microbes in non-infected samples of river water examined under precisely similar conditions suggests that they cannot be uniformly present in the proportion of one to 9 and 19 c.c. of river water, respectively. At first sight, this may seem a conclusion of *scientific* rather than of *practical* importance, but the moment the subject is considered in relation to what may be called "*comparative bacteriology*," the whole complexion of affairs is altered. Take the water of the River Thames and the Thames-derived waters as actually supplied to consumers as an example. During the six years 1906-11 the River Thames contained typical *B. coli* in 1 c.c. (or less) in 83·2 per cent. of the total number of samples examined. Now the same water after purification, as supplied to consumers, contained during the same period *no* typical *B. coli* in 100 c.c. of water in 77·3 per cent. of the total number of samples examined. In the face of these results we are surely justified in concluding that any "microbial badness" in the raw river water is reduced *one thousand times* before the water is delivered to consumers. Clearly then, there is good ground for assuming that the typhoid bacillus and Gärtner's bacillus cannot uniformly be present in the water as supplied to consumers in the proportion of one per 9,000 and 19,000 c.c. of water respectively.

It may seem at first sight a curious divergence to pass from Thames water to crude sewage, but it is possible through the examination of sewage to draw *inferential conclusions* of *value* as regards the *quality* of Thames water. In examining sewage for the presence of typhoid bacilli, each sample was divided into two equal portions, A and B. The A portion was purposely inoculated with a known number of typhoid bacilli; the B portion was not so inoculated. A and B were then examined under precisely similar conditions, so that a positive result with A and a negative result with B justified the conclusion that whatever number of typhoid bacilli were added to A, that number could not have been present in B, as a positive result in that case would presumably have been obtained.

The results obtained are shown in Table III.

One hundred samples were examined altogether. The average number of excremental bacteria, as judged by the bile-salt agar test, was 1,066,650 per cubic centimetre—column (*b*). 23,353 colonies were studied under A, and a similar number under B—columns (*c*) and (*d*). Not one out of the 23,353 colonies on the B, non-infected side, gave the characteristics of the typhoid bacillus—column (*e*). The number of artificially added typhoid bacilli (A samples) was on the average 268 per 0·01 c.c. of sewage—column (*f*). It seems a fair procedure to divide (*f*) by (*g*) in order to arrive at the inferential number of typhoid bacilli which would need to have been added per 0·01 c.c. of sewage in order to have secured the isolation of a single typhoid bacillus, and it will be seen from column (*h*) that the figure is 15. Further, it seems not unreasonable to divide 0·01 by (*h*) in order to arrive at the proportion of 0·01 c.c., which, if it had contained a single typhoid bacillus, would still presumably have yielded a positive result, and therefore the amount of the non-infected parallel samples concluded not to have contained the typhoid bacillus. It will be seen from column (*i*) that the average figure thus arrived at is 0·00066 c.c., that is, the non-infected samples of sewage presumably contained fewer than one typhoid bacillus per 0·00066 c.c. of sewage.

TABLE III.

Number of samples examined	Number of microbes per c.c. bile-salt agar at 37° C.	Number of colourless colonies sub-cultured from the plates		Non-infected sample B	Infected Sample A			
		A Infected sample	B Non-infected sample	Number of typhoid bacilli isolated from ·01 c.c. of the sample	Number of typhoid bacilli artificially added per ·01 c.c. of sample	Number of typhoid bacilli actually isolated from ·01 c.c. of sample	Number of typhoid bacilli which would need to have been added to the ·01 c.c. to have secured the isolation of a single typhoid bacillus	Amount of sewage which if it had contained a single typhoid bacillus would still have yielded a positive result (when dealing with ·01 c.c.) and therefore the amount of the non-infected sample proved *not* to have contained the typhoid bacillus $\frac{\cdot 01}{h}$
Columns (*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)	(*g*)	(*h*)	(*i*)
100 (Total)	**1,066,649·5** (Average of 97 samples)	**23,353** (Total)	**23,353** (Total)	None	**267·9** (Average)	**17·56** (Average)	$\frac{267{\cdot}9}{17{\cdot}56}$ =**15·256**	$\frac{{\cdot}01}{15{\cdot}256}$ =**0·00066**

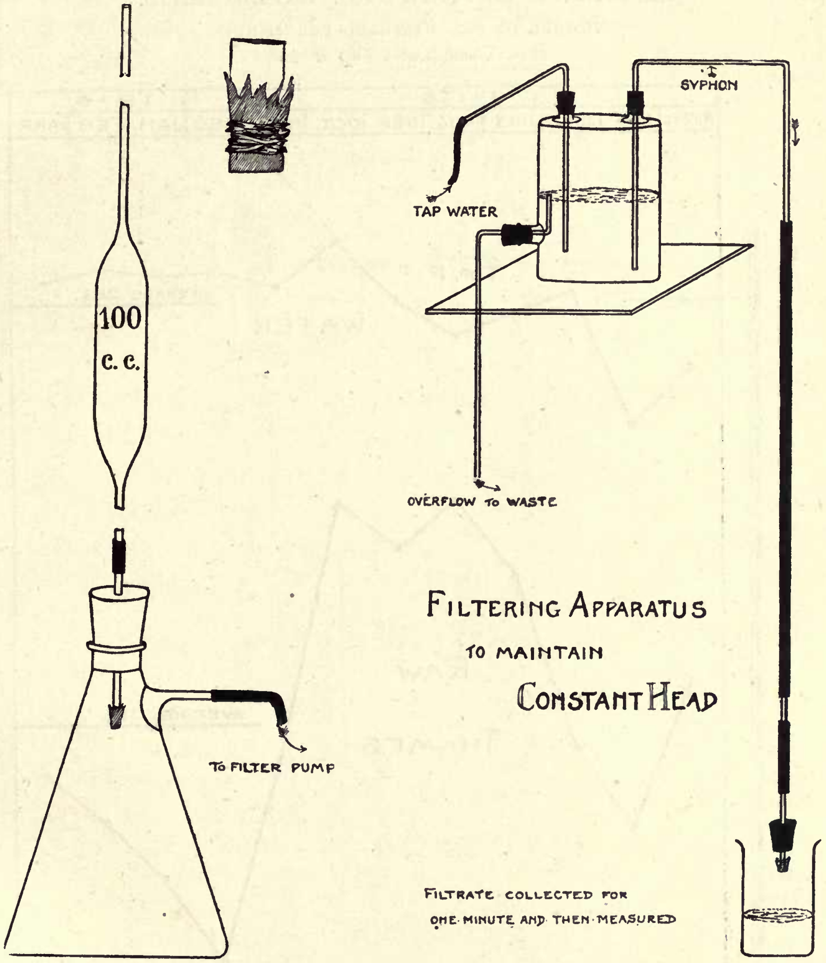
Reference to column (*b*) shows that the average number of excremental bacteria in the sewages examined was 1,066,650 per cubic centimetre or 704 per 0 00066 c.c. This figure of 704 thus becomes our *criterion figure* for judging the probable specific infective qualities of water supplies. For, if 0·00066 c.c. of sewage contains no typhoid bacilli, then *whatever volume of any water supply*, which contains no more than 704 excremental bacteria, cannot reasonably be supposed to harbour the typhoid bacillus in that volume.

Now let us consider what volume of Thames water contains 704 excremental bacteria. For the six years ended 1913, the number per cubic centimetre was 46 or 704 per 15·3 c.c. It follows inferentially that the Thames does not uniformly contain a single typhoid bacillus per 15 c.c. of water. It is easy to show by means of the *B. coli* test that the purification processes improve the river water at least 1,000 times, hence arises the further inference that there are *no typhoid bacilli in* 15 *litres* (3·3 *gallons*) *of the water as supplied to consumers*. This aspect of the question will be reconsidered under another heading.

RIVER THAMES WATER, ITS RESISTANCE TO FILTRATION, AND THE MICROSCOPIC APPEARANCES OF THE SUSPENDED MATTERS.

It is convenient next to deal with certain questions relating to the "resistance to filtration" of Thames water and also to its microscopical appearances. By "resistance to filtration" is meant the degree to which the suspended matters (living and dead) in a water interfere with its filtration by blocking the filtering material. Although the sand filter is the real test in this connection, quite useful results may be obtained in the laboratory in the following way (*see* Diagram 17): A piece of linen of superfine quality (96 meshes to the linear inch) is folded four times, moistened with water and tied round the end of a glass tube (¼ in. diameter) by means of a rubber band. The tube is passed through a rubber bung which is fitted into a filtering flask, connected with a filter pump. The other projecting end of the glass tube has a piece of rubber tubing attached to it and into this is inserted the end of a pipette containing 100 c.c. of the sample of water to be examined. The water passes through the linen into the flask and practically all the suspended matter is retained on the inside of the linen. The rubber bung and glass tube are then detached and fitted on to the additional piece of apparatus shown in Diagram 18.

This is merely a convenient arrangement for supplying tap water under a constant head (about 5 ft.). The water is filtered through the linen, with its skin of suspended matter derived from 100 c.c. of the original water, for the space of one minute, and the filtrate is then measured. A water having little or no suspended matter will, in these circumstances, give a filtrate of, say, 200 to 300 c.c. A water badly affected with algal growths may yield no measurable filtrate, and between these two extremes all kinds of results are obtained.



DIAGRAMS 17 AND 18.

Diagram 19 shows the laboratory filtration results yielded by

River Thames water from April, 1915, to March, 1916, based on bi-weekly examinations, together with the results yielded by tap water, which, in a relative sense, may be regarded as free from suspended matter. The averages are 282 and 112 respectively.

RESISTANCE TO FILTRATION EXPERIMENTS.

NUMBER OF C.C. FILTERED PER MINUTE.

Raw Thames and Tap Water.

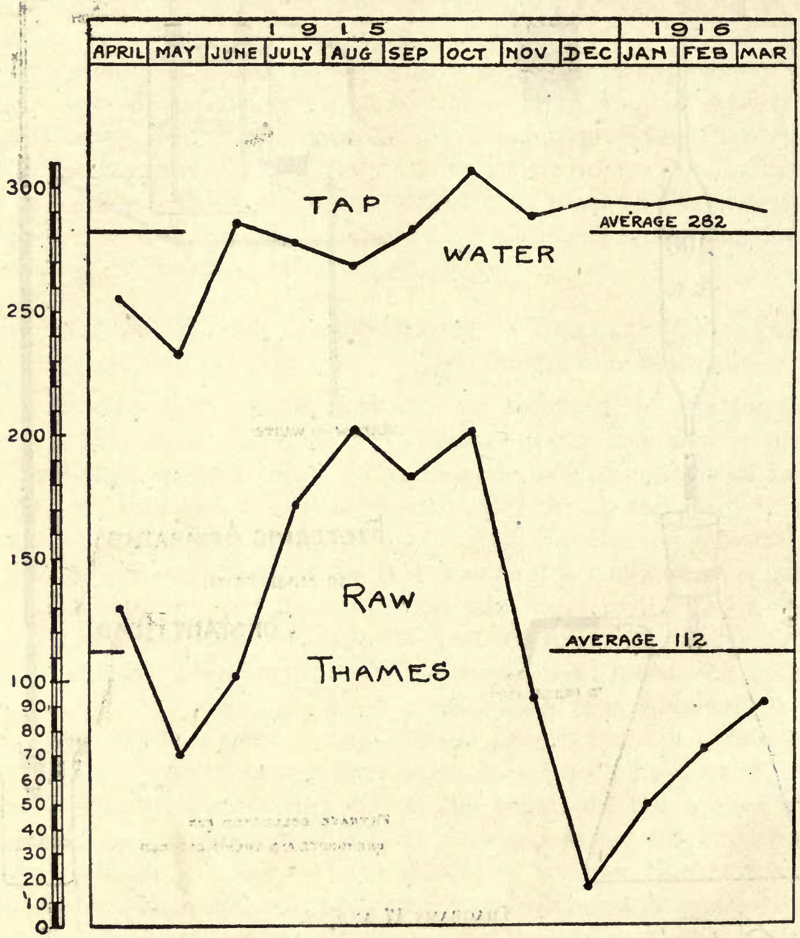


DIAGRAM 19.

The "falling off" in the river results in the spring is probably due to fermentative changes in the bed of the river, and to the presence of algal and other growths. The "falling off" in the winter is almost entirely due to flood water, most of the suspended matter being inorganic or composed of amorphous organic matter. The results during the summer months are remarkably good and, generally speaking, Thames river water, as judged by laboratory tests, may be said to be a water which exercises no serious blocking effect on filters.

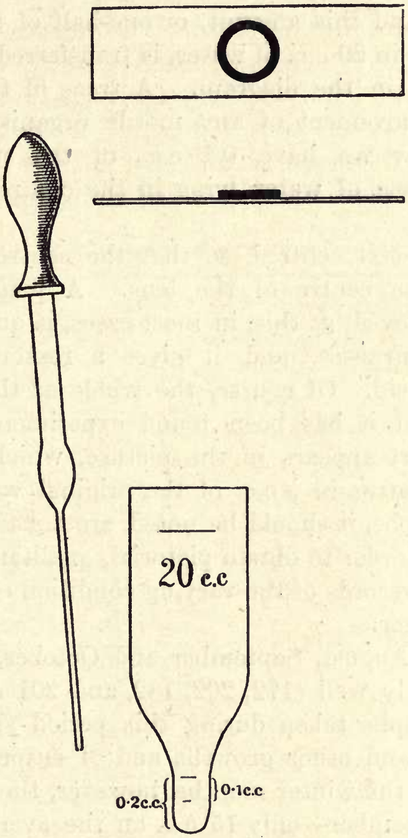


DIAGRAM 20.

Passing next to the microscopical appearances of the suspended matter in Thames river water, the following photographic method has been employed to give both a qualitative and quantitative picture of its nature (Diagram 20).

Twenty cubic centimetres of the water are placed in a glass tube and centrifugalized, the result being that all matters in suspension are driven to the bottom of the tube. The contents are then carefully poured off to a little above the 0·2 c.c. top mark on the narrower portion of the tube. The pipette is then used to suck out the water to exactly the level of the 0·2 c.c. top mark, care being taken not to disturb the sediment. This water is expelled from the pipette, which is then used to mix thoroughly the deposit with the water remaining in the tube. Between the two marks is exactly 0·1 c.c., and this amount, or one-half of the whole of the suspended matter in 20 c.c. of water, is transferred with the pipette to the small cell in the diagram. A trace of formalin is added to prevent the movement of any motile organisms that may be present, and now we have 0·1 c.c., or the suspended matter pertaining to 10 c.c. of water, lying in the cell ready to be photographed.

The slide is next centred, so that the centre of the cell lies exactly below the centre of the lens. A magnification of 50 diameters is employed, as this, in most cases, is quite large enough for diagnostic purposes, and it gives a reasonably flat and a relatively large field. Of course, the whole of the 0·1 c.c. is not photographed, but it has been found experimentally that about one-twentieth part appears in the picture, which corresponds to the suspended matter in ½ c.c. of the original water.

The photographs, it should be noted, are not taken for purposes of beauty, but in order to obtain pictorial, qualitative, quantitative, and comparative records of the varying condition of the river water throughout the year.

During July, August, September and October, the river water filtered exceedingly well (172, 202, 182, and 201 c.c. respectively), and the photographs taken during this period show the relative absence of algal and other growths and of suspended matters in general. During the winter months, however, the filtration results (especially in December—only 15 c.c. on the average) were widely different, and here the photographs were sometimes quite black, owing to the large amount of suspended matter present. This, however, was usually of an amorphous character, algal and other growths being relatively absent, so far as could be observed. In the spring there was again some "falling off" in the filtration results (May, 71 c.c. on the average), and this, judging from the photographs, would seem to have been due, not only to an increase of amorphous suspended matters, but also to the presence of algal and other growths in the water.

VITALITY OF PATHOGENIC BACTERIA IN RIVER WATER UNDER CONDITIONS OF STORAGE.

As London's water supply amounts to about 244 million gallons daily, of which about 80 per cent. is derived from the Thames and the Lee, it is fairly obvious that in times of drought a shortage of water would arise, if no provision had been made for its storage in huge reservoirs. The storage of Thames river water necessary for purposes of *quantity* has a marked influence on its *quality.*

Evidence has already been brought forward to prove that pathogenic bacteria (e.g., the typhoid bacillus) cannot be uniformly present in Thames river water, unless in very few numbers. It is desirable next to consider what would happen if these pathogenic bacteria really were present in river water in abundance.

TABLE V.—VITALITY OF THE TYPHOID BACILLUS.

Experiment	Initial number of typhoid bacilli per c.c. of the infected *raw* river water	Number of typhoid bacilli per c.c. of the infected *raw* river water, after storage in the laboratory for :—					Number of weeks required to effect the destruction of the typhoid bacillus in 100 c.c. of the infected *raw* river water
		Weeks					
		One	Two	Three	Four	Five	
1 T. ..	40	0	—	—	—	—	Five.
2 L. ..	40	0	—	—	—	—	,,
5 L. ..	170,000	53	2	0	—	—	,,
15 N.R. ..	525,000	29	3	0	—	—	,,
3 N.R. ..	40	0	—	—	—	—	Six.
4 T. ..	170,000	9	2	0	—	—	,,
6 N.R. ..	170,000	40	2	0	—	—	,,
8 L. ..	470,000	850	11	7	2	0	Seven.
9 N.R. ..	470,000	1,430	14	7	0	—	,,
14 L. ..	525,000	32	2	0	—	—	,,
18 N.R. ..	475,000	30	3	0	—	—	,,
7 T. ..	470,000	480	31	5	0	—	Eight.
10 T. ..	8,000,000	3,000	30	4	0	—	,,
11 L. ..	8,000,000	2,900	29	5	0	—	,,
13 T. ..	525,000	12	1	0	—	—	,,
17 L. ..	475,000	80	11	2	0	—	,,
12 N.R. ..	8,000,000	400	22	2	0	—	Nine.
16 T. ..	475,000	210	12	2	1	0	,,

T. = Thames, L. = Lee, N.R. = New River.

Table IV[1] shows what happens under laboratory conditions of storage, when vast numbers of cholera vibrios are added to river water. Column 2 shows the number added; column 3 the number one week later; and columns 5, 6, and 7 the number of weeks after

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[1] *See* p. 40.

TABLE IV.—VITALITY OF THE CHOLERA VIBRIO.

Experiment	*Initial* number of cholera vibrios per c.c. of the infected water	Number of cholera vibrios per c.c. *one week later*	Per-centage reduction in one week	Number of weeks after infection of the water when the cholera vibrio could no longer be isolated from 1, 10 or 100 c.c. of water			Range of tempera-ture during progress of experi-ment (deg. Fahr.)
				1 c.c.	10 c.c.	100 c.c.	
Columns (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1 T*., Nov. 2, 1908	3,750,000	+ 1 c.c. ; – 0·01 c.c.	99·9	2	2	2	50—64
2 L., Nov. 2, 1908	3,750,000	10	99·9	2	2	3	50—64
3 N.R., Nov. 2, 1908	3,750,000	20	99·9	2	3	3	50—64
4 T., Nov. 16, 1908	13,000,000	20	99·9	2	3	3	51—62
5 L., Nov. 16, 1908	13,000,000	20	99·9	2	2	2	51—62
6 N.R., Nov. 16, 1908	13,000,000	+ 1 c.c. ; – 0·01 c.c.	99·9	2	3	3	51—62
7 T., Nov. 30, 1908	9,532,500	10	99·9	3	3	3	53—60
8 L., Nov. 30, 1908	9,532,500	70	99·9	3	3	3	53—60
9 N.R., Nov. 30, 1908	9,532,500	20	99·9	2	3	3	53—60
10 T., Jan. 18, 1909	1,775,000	None	99·9	1	1	1	45—55
11 L., Jan. 18, 1909	70,000	+ 1 c.c. ; – 0·1 c.c.	99·9	2	2	2	45—55
12 N.R., Jan. 18, 1909	3,150,000	+ 1 c.c. ; – 0·1 c.c.	99·9	2	2	2	45—55
13 T., Feb. 1, 1909	680,000	None	99·9	1	1	2	45—60
14 L., Feb. 1, 1909	510,000	,,	99·9	1	1	2	45—60
15 N.R., Feb. 1, 1909	406,500	,,	99·9	1	2	2	45—60
16 T., Feb. 15, 1909	49,000	,,	99·9	1	1	1	48--56
17 L., Feb. 15, 1909	110,000	,,	99·9	1	2	2	48—56
18 N.R., Feb. 15, 1909	420,000	+ 1 c.c. ; – 0·1 c.c.	99·9	2	2	2	48—56

* The letters T., L., and N.R. in column 1 refer to *raw* Thames, Lee, and New River water respectively.

In experiments 1 to 6 a mixture of eleven strains of cholera (known in the laboratory as strains 1 to 11) were used. In experiments 7 to 9 a mixture of strains 3 and 4 were employed. In experiments 10 and 18 strain 5 was used. In experiment 11 and 16 strain 6 was employed. Strain 7 was used in connection with experiments 12 and 17. In experiments 13, 14, and 15 strains 2, 3, and 4 were employed respectively.

infection of the water when the cholera vibrio could no longer be isolated from 1, 10 or 100 c.c. of water. Practically, the cholera vibrio was dead, or non-recoverable, from one to three weeks after the water had been artificially infected.

Table V[1] deals with the vitality of the typhoid bacillus in river water under laboratory conditions of storage.

It will be noted that the number added was usually enormous, that there was a big reduction in one week, that in three weeks there were less than 10 per cubic centimetre, but that the total disappearance of the bacillus took from five to nine weeks.

These were all experiments with "cultivated" bacilli, i.e., typhoid bacilli, which, after isolation from the excreta or tissues of persons suffering from typhoid fever, had been cultivated in the laboratory on artificial media.

TABLE VI.—"Uncultivated" Typhoid Bacilli.

	Experiment 1 A	Experiment 2 A	Experiment 3 A	Experiment 4 A	Experiment 5 A	Experiment 6 A	Experiment 6 B
Initial number of typhoid bacilli per c.c. of infected river water	0·78	1,480	42	56	37,800	Unknown but assumed to be numerous	39 times fewer than A
Ultimate death of the typhoid bacillus, as judged by inability to isolate it from 100 c.c. of the infected water	One week	Two weeks	One week	One week	Three weeks	One week	One week

"Cultivated" Typhoid Bacilli.

	Experiment 1 B	Experiment 1 C	Experiment 2 B	Experiment 3 B	Experiment 4 B	Experiment 5 B	Experiment 5 C	Experiment 5 D	Experiment 6 C	Experiment 6 D
Initial number of typhoid bacilli per c.c. of infected river water	0·78	0·078	160	42	56	1,460	146	14·6	5,200	52
Ultimate death of the typhoid bacillus, as judged by inability to isolate it from 100 c.c. of the infected water	Eight weeks	One week	Eight weeks	Five weeks	Five weeks	Five weeks	One week	Five weeks	Seven weeks	Four weeks

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[1] *See* p. 39.

Very different results were obtained with "uncultivated" bacilli, i.e., typhoid bacilli as they existed in the urine of typhoid "carrier" cases, and which, of course, had never previously been cultivated in the laboratory. It was found that the "uncultivated" bacilli died in water much more rapidly than their "cultivated" brethren. Table VI illustrates this point.

The following experiments are directly comparable:—

1 A with 1 B and 1 C
2 A ,, 2 B
3 A ,, 3 B
4 A ,, 4 B
5 A ,, 5 B, 5 C and 5 D
6 A ,, 6 C
6 B ,, 6 D

It be will noted that the "uncultivated" typhoid bacilli died within one week in five out of seven experiments, and in the remaining two experiments loss of vitality occurred either in the second or third week. On the other hand, the "cultivated" typhoid bacilli died within one week in only two out of ten experiments. In the remainder, the bacilli died in the fourth, fifth, seventh or eighth week. It is obvious, according to these results, that the "uncultivated" bacilli die much more speedily in river water than their "cultivated" brethren. Inasmuch as the risk of acquiring typhoid from the drinking of polluted water is due to the possible presence of "uncultivated" typhoid bacilli, these observations would seem to be of far-reaching importance.

CHEMICAL AND BACTERIOLOGICAL CHANGES OCCURRING IN RIVER WATER UNDER CONDITIONS OF STORAGE.

In illustration of the chemical and bacteriological changes which occur in Thames water under conditions of storage, the case of the Chelsea reservoirs may be taken. This matter was specially investigated in 1907-8, when the nominal number of days' storage in these reservoirs was about fifteen days.

The chief results are summarized in Table VII. It will be noted that the percentage reduction in the gelatine, agar and bile-salt agar counts was about 95, 84 and 88 respectively. As judged by the *B. coli* test, the water was improved at least one hundred times. For example, 48·3 per cent. of the samples of river water yielded positive results with 0·1 c.c. of water, whereas only 32·5 samples of stored water yielded positive results with one hundred times as much water, namely 10 c.c. Chemically, the reductions effected by storage were as follows :—

Ammoniacal nitrogen	63·4 per cent.
Albuminoid nitrogen	29·4 ,,
Permanganate test	27·8 ,,
Turbidity test	84·9 ,,
Colour	45·8 ,,

TABLE VII.—BACTERIOLOGICAL.

	Number of bacteria per c.c.		
	Gelatine at 20—22° C.	Agar at 37° C.	Bile-salt agar at 37° C.
River Thames before storage	4,465	280	41
Chelsea stored water ..	208	44	5
Reduction per cent.	95·3	84·3	87·8

B. coli TEST (LACTOSE + INDOL +).

	Per cent. of samples yielding positive results.				
	+ 100 c.c. or less	+ 10 c.c. or less	+ 1 c.c. or less	+ 0·1 c.c. or less	+ 0·01 c.c. or less
River Thames before storage	99·9	97·7	83·1	48·3	10·1
Chelsea stored water ..	57·2	32·5	13·4	3·3	1·1

CHEMICAL (PARTS PER 100,000).

	Ammoniacal nitrogen	Albuminoid nitrogen	Permanganate test	Turbidity test	Colour test
Raw Thames before storage	0·0060	0·0153	0·2127	3·50	83
Chelsea stored water ..	0·0022	0·0108	0·1536	0·53	45
Reduction per cent.	63·4	29·4	27·8	84·9	45·8

Diagram 21 shows in graphic fashion the decline in the number of bacteria consequent upon storage. The gelatine figures were reduced from 4,465 to 208, the agar from 280 to 44, and the bile-salt agar from 41 to 5.

Diagram 22 deals with the *B. coli* test, and the improvement in the quality of the water as the result of storage is very apparent. For example, 48 per cent. of the river sample contained *B. coli* in

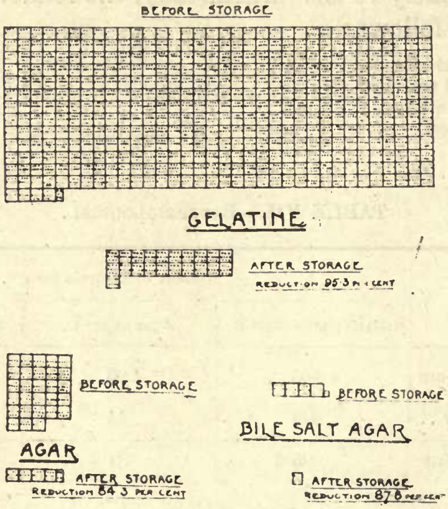


DIAGRAM 21.

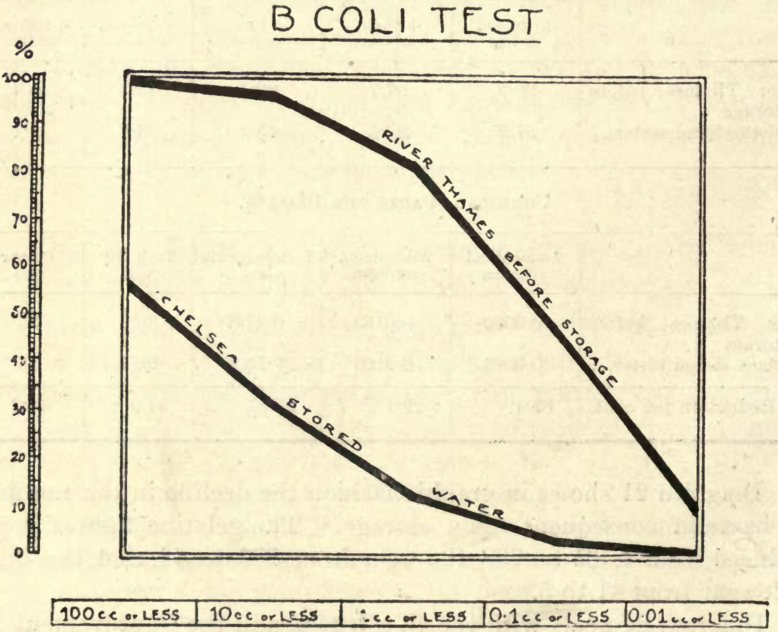


DIAGRAM 22.

THAMES WATER, BEFORE AND AFTER STORAGE (*B. coli* TEST).

0·1 c.c., whereas only 32·5 per cent. of the stored samples contained this microbe in *one hundred times* as much water (namely, 10 c.c.).

CHEMICAL RESULTS.

PERCENTAGE IMPROVEMENT DUE TO STORAGE.

Chelsea Reservoirs.

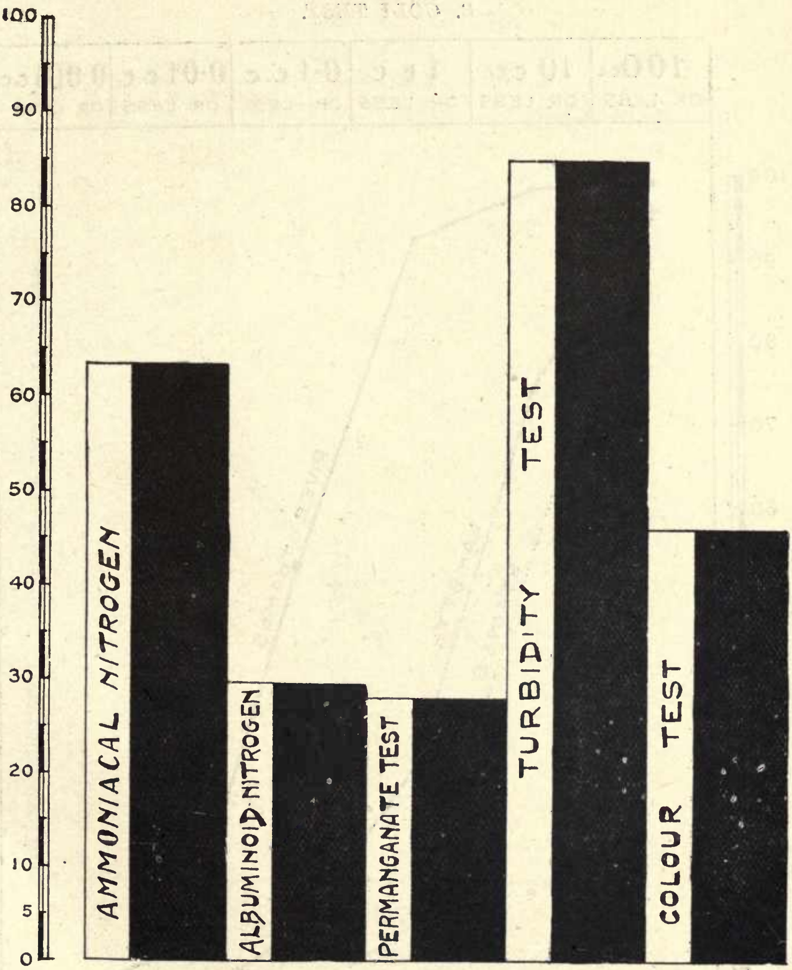


DIAGRAM 23.

The chemical results are shown in Diagram 23. The marked percentage reduction in the ammoniacal nitrogen, albuminoid nitrogen, permanganate, turbidity and colour tests, is very striking

The beneficial effect of storing River Thames water in the Staines and Lambeth (Island Barn) reservoirs will now be dealt with very briefly. The *B. coli* results are remarkable (*see* Diagram 24). For example, the river water, *before* storage, contained *B. coli* in 0·1 c.c. (or less) in 53·2 per cent. of the samples examined. *After* storage in the Staines reservoir, about the same

EFFECTS OF STORAGE.

River Thames Water in the Staines and Lambeth (Island Barn) Reservoirs, 1915.

B. COLI TEST.

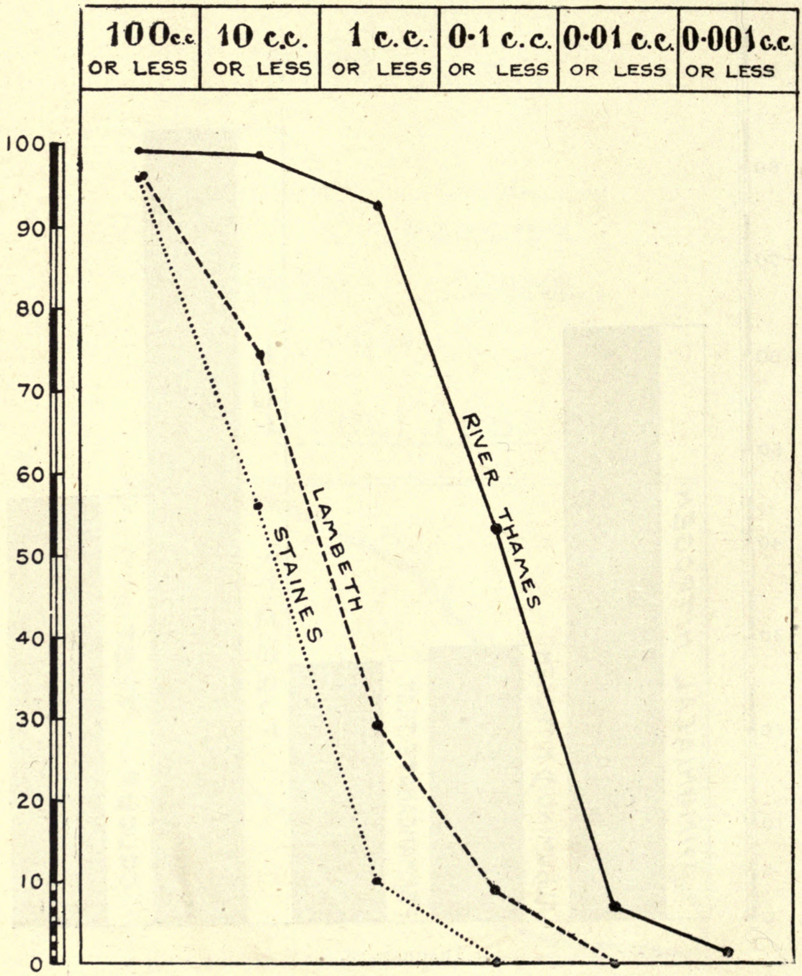


Diagram 24.

number (56 per cent.) of samples yielded positive results with one hundred times as much water, namely, 10 c.c. The Lambeth (Island Barn) results were not quite so good, but were still very striking.

EFFECTS OF STORAGE.

River Thames Water in the Staines and Lambeth (Island Barn) Reservoirs, 1915.

BACTERIAL COUNTS.

Percentage Reduction.

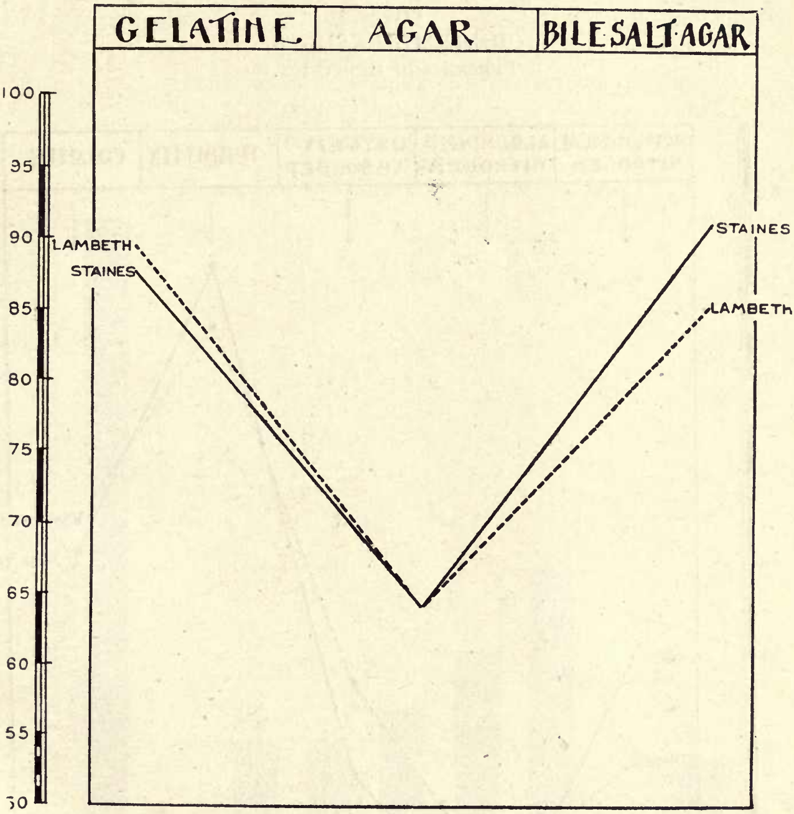


Diagram 25.

The next diagram (25) illustrates the remarkable percentage reduction in the bacterial "counts." You will see that the percentage reduction in the number of bacteria was as follows:—

	Staines	Lambeth
Gelatine count	87 per cent. ..	89 per cent.
Agar count	64 ,, ..	64 ,,
Bile-salt agar count ..	91 ,, ..	86 ,,

Diagram 26 shows the percentage reduction in the chemical results consequent upon storage:—

	Staines	Lambeth
Ammoniacal nitrogen	18·6	29·3
Albuminoid nitrogen	6·72	slight apparent increase
Permanganate test	27·5	17·7
Turbidity	66·4	73·1
Colour	45·2	42·1

EFFECTS OF STORAGE.

River Thames Water in the Staines and Lambeth (Island Barn) Reservoirs, 1915.

CHEMICAL RESULTS.

Percentage Reduction.

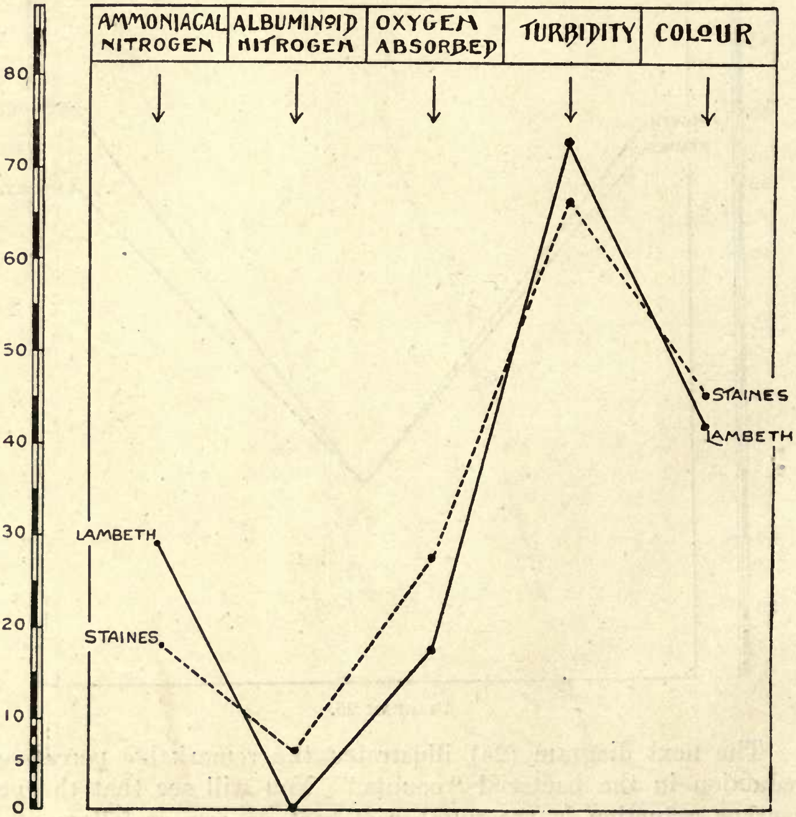


Diagram 26.

Some additional bacteriological results (Diagram 27) relating to other reservoirs containing Thames stored water for the eighty-one months ended December 31, 1915, may also be given. These have been arranged as the percentage number of samples yielding positive results with 1 c.c. (or less) of water (*B. coli* test) :—

	Per cent.
River Thames	95·0
Walton reservoir	22·6
W. Middlesex, No. 1 reservoir	35·2
,, ,, ,, 3 ,, ...	35·3
,, ,, ,, 4 ,, ...	39·4
,, ,, ,, 6 ,, ...	45·4
Sunbury reservoir	54·9
Grand Junction (Hampton) reservoir	19·5
,, ,, (Kew) ,, ...	33·4
Kempton Park	13·0

EFFECTS OF STORAGE.

PERCENTAGE NUMBER OF SAMPLES YIELDING
POSITIVE RESULTS
WITH THE *B. COLI* TEST,
(1 CC. OR LESS).
EIGHTY-ONE MONTHS ENDED DECEMBER, 1915.

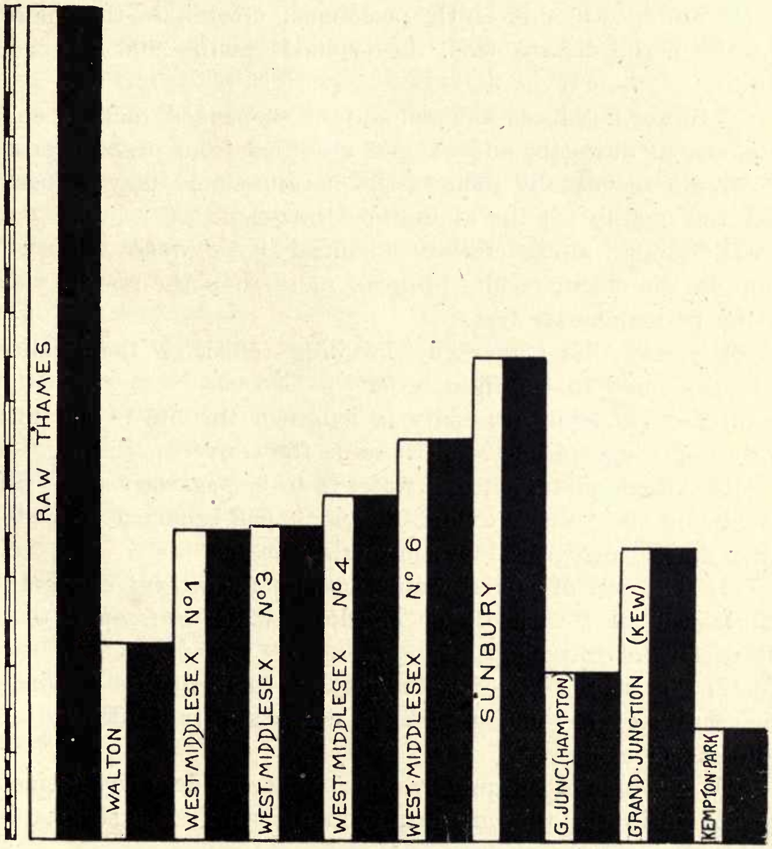


DIAGRAM 27.

It is obvious that the *improvement, consequent on storage*, is *very material.*

The advantages accruing from the storage of water may be summarized as follows:—

(1) Storage reduces the number of bacteria of all sorts: the number of bacteria capable of growing on agar at blood heat; the number of bacteria capable of growing in a bile-salt medium at blood heat, chiefly excremental bacteria.

(2) Storage reduces the number of coli-like microbes, and the number of typical *B. coli.*

(3) Storage may alter certain bacteriological river water ratios; for example, it may reduce the number of typical *B. coli* to a proportionately greater extent than it reduces the number of bacteria of all sorts.

(4) Storage, if sufficiently prolonged, devitalizes the microbes of water-borne disease (e.g., the typhoid bacillus and the cholera vibrio).

(5) Storage reduces the amount of suspended matter, colour, ammoniacal nitrogen, and oxygen absorbed from permanganate.

(6) Storage usually reduces the hardness and may reduce (or alter the quality of) the albuminoid nitrogen.

(7) Storage alters certain chemical river water ratios; for example, the colour results improve more than the results yielded by the permanganate test.

(8) Storage has a marked "levelling" effect on the totality of water delivered to the filter beds.

(9) Storage tends generally to lengthen the life of the filters. (Only under exceptional conditions is the converse true.)

(10) An adequately stored water is to be regarded as a "safe" water, and the "safety change" which has occurred in a stored water can be recognized by appropriate tests.

(11) The use of stored water enables a *constant* check to be maintained on the safety of London's water *antecedent* to and irrespective of filtration.

(12) The use of stored water goes far to neutralize or wipe out the gravity of any charge that a water supply is derived from polluted sources.

(13) The use of adequately stored water renders any accidental breakdown in the filtering arrangements much less serious than might otherwise be the case.

In summary of what has been said:—

The application of the streptococcus test to samples of river water led to the inferential conclusion that Thames water does not contain one part of *fresh* excremental matter in more than twenty-two million parts of water. Excepting three doubtful microbes, prolonged search for the typhoid bacillus and Gärtner's bacillus in samples of Thames water yielded negative results. It was concluded, inferentially, that the river water does not contain these microbes in the ratio of 1 to 9 and 19 c.c. of river water respectively.

Methods of testing the "resistance to filtration" of waters and photographing the suspended matters present in them, have been fully explained. It has been shown that the River Thames gave an average filtration figure of 112, as compared with a criterion tap-water figure of 282. The river water filtration results were very good during July, August, September, and October; not very satisfactory during the winter months, and in May there was also a "falling off" in the results. These results were due to the relative absence of suspended matters during the summer, their presence in excess during the winter flood months of the year, and in May the results were ascribed to an increase in the amount of amorphous suspended matter, and also (perhaps more particularly) to the presence of algal and other growths.

The question of the vitality of pathogenic bacteria artificially added to river water has been fully considered, and it is concluded that the cholera vibrio and the typhoid bacillus (especially if present in the "uncultivated" state) die out fairly rapidly, or become greatly reduced in number, under storage conditions.

The chemical and bacteriological changes occurring in river water, under conditions of storage, have been fully considered, the Chelsea, Lambeth, Staines, and other reservoir results being used as examples. The conclusion reached is, that river water is usually greatly improved, both chemically and bacteriologically, by storage, and that an adequately stored water is a "safe" water from an epidemiological point of view. The chief advantages accruing from storage have been briefly summarized in the concluding paragraphs.

CHAPTER III.

RIVER THAMES.

Physical and Biological Changes occurring in River, under Conditions of Storage —"Resistance to Filtration" and Microscopical Appearances of Stored Water—Walton, Chelsea, Staines and other Reservoir Results—Relation between Filtration Results and Acres of Filter Beds cleaned.

The Treatment of Algal Affected Waters—Copper Sulphate as an Algicide—Dose required—Considerations to be borne in mind—Hypochlorites as Algicides.

The Taste of Algal-affected Waters—Some of the Chief Offenders—Tabellaria an Example.

Thames-derived Filtered Waters—Chemical and Bacteriological Comparison between *Raw* Water and Stored and Filtered Water, as finally delivered to Consumers—Seasonal Comparisons.

Water and Disease—Typhoid Death-rate for London—Seasonal Incidence of the Disease—Lack of Agreement between Curves representing Incidence of Typhoid and Quality of Water—Experimental Evidence of the Absence of the Typhoid Bacillus from 9 c.c. of River Water and 0·00066 c.c. of Sewage—Deductions therefrom—Summary—Concluding Remarks.

PHYSICAL AND BIOLOGICAL CHANGES OCCURRING IN RIVER WATER UNDER CONDITIONS OF STORAGE.

RIVER water when stored in reservoirs undergoes certain physical and other changes, which are of great practical importance. Usually, there is a marked reduction in the suspended matter, and consequently a prolongation of the "life" of filters fed with such water. Sometimes, however, there is an excessive development of algal and other growths. When this occurs there is marked interference with filtration, and occasionally the water acquires an objectionable taste. There is considerable difference of opinion as to the best way of classifying the microscopic organisms found in water. Some use the word algæ in relation only to the Chlorophyceæ or green algæ, others include the Diatomaceæ, and also the Cyanophyceæ or blue-green algæ.

It is desirable here for the sake of simplicity to use the term "algal and other growths" so as to include all microscopic (or nearly microscopic) growths, exclusive of bacteria.

The "resistance to filtration," exhibited by the River Thames water, has already been considered, and it is now convenient to show what happens when this water is stored in reservoirs, for a longer or shorter period of time. The method of testing "resistance to filtration" and of obtaining photographic records of the suspended matters has previously been dealt with.

RESISTANCE TO FILTRATION EXPERIMENTS.
NUMBER OF C.C. FILTERED PER MINUTE.

WALTON

RESERVOIR WATER *compared with* RAW THAMES *and* TAP WATER.

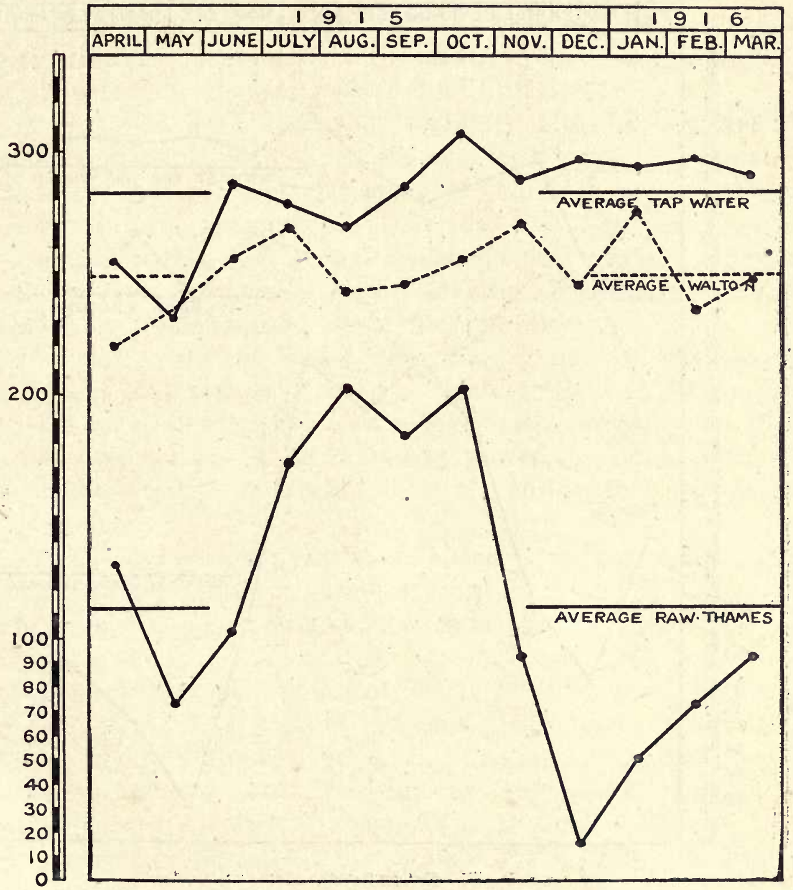


DIAGRAM 28.

It is desirable to begin with the *Walton reservoir water* (*see*

Diagram 28). These reservoirs were designed by the present Chief Engineer of the Water Board, Mr. Restler. Their joint capacity is equal to 1,198 million gallons, and they are the main source of supply to the Southwark and Vauxhall Works. There are three lines depicted in the diagram. One is of tap water, which may be regarded as the *criterion* line ; its average is 281. Another is of the river water before storage, and although the average

RESISTANCE TO FILTRATION EXPERIMENTS.

NUMBER OF C.C. FILTERED PER MINUTE.

CHELSEA

RESERVOIR WATER *compared with* RAW THAMES *and* TAP WATER.

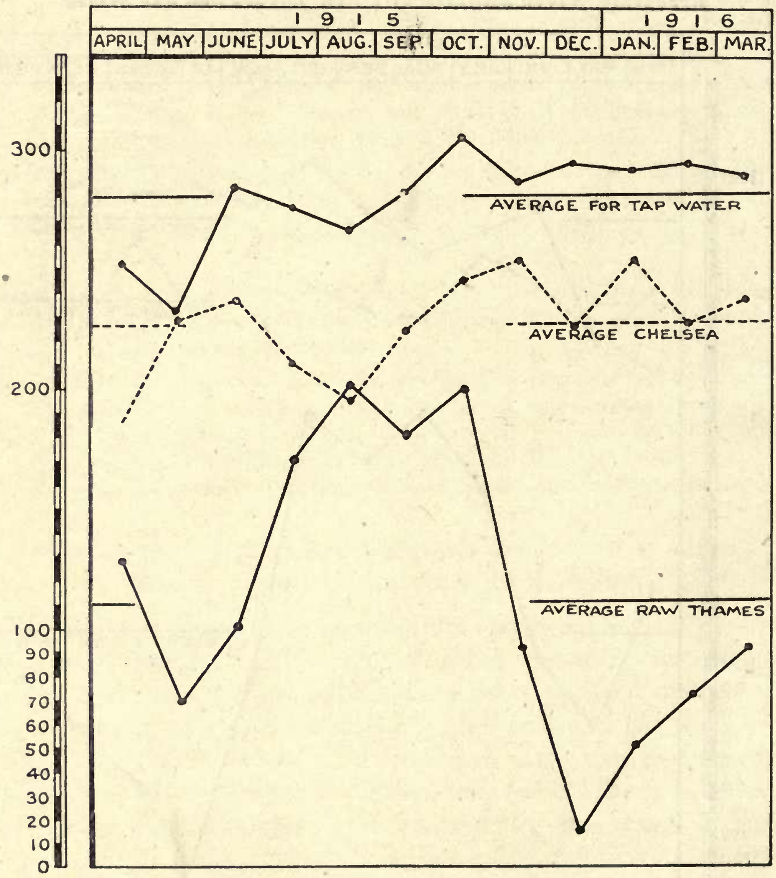


DIAGRAM 29.

result of 112 is far from unsatisfactory, it is obvious that the fluctuations in "filter-ability" are considerable. Lastly, there is the Walton Reservoir line which is remarkably satisfactory, whether judged on an average basis (249), or by its relatively unimportant departures from the normal. The diagram suggests some important inferences.

(*a*) *Raw* Thames river water filters satisfactorily on the average; very well for considerable periods, and decidedly badly during times of flood.

(*b*) The same water, under conditions of storage in the Walton reservoirs, filters most satisfactorily on the average, and throughout the whole year is excellently adapted for filtration purposes.

It is not claimed that the laboratory filtration results are strictly comparable with those obtained on a works, but they are sufficiently near to be of real practical value. Assuming this to be correct, it may reasonably be concluded that if storage conduces to chemical, bacteriological, and epidemiological perfection, it also, in the absence of algal growths, reduces the working cost of filtration by prolonging the life of the sand filters.

The reason why the Walton results are so good is undoubtedly due to the comparative absence of algal growths, and the settlement of most of the other suspended matters originally present in the river water. This is clearly proved by photographs of the sediment taken at weekly intervals during the year under consideration.

The Chelsea reservoir results are almost equally remarkable, the source of supply being the same (*see* Diagram 29). For the sake of comparison, the tap water and Thames results are included in the diagram.

The Chelsea average figure of 228 is twice as good as that of the Thames, and less than 19 per cent. lower than the tap water criterion figure. Further, no great fluctuations occurred during the period under review. The reasons why the Chelsea results were so good are exactly the same as in the case of Walton, as is clearly proved by the weekly photographs taken during the period under review.

It is convenient next to consider the Lambeth (Island Barn) reservoir, because this reservoir receives precisely the same water as the Chelsea reservoirs, and, like the Walton reservoirs, it is of recent construction.

The results are shown in Diagram 30, and it is obvious that here the curve is much less satisfactory (average 142) than the preceding ones (Walton and Chelsea), and subject to somewhat violent fluctuations. Beyond all doubt, the "falling off" in the filtration results was almost exclusively due to a development of algal and other growths.

RESISTANCE TO FILTRATION EXPERIMENTS.

Number of c.c. Filtered per Minute.

LAMBETH (*Island Barn*)

Reservoir Water *compared with* Raw Thames *and* Tap Water.

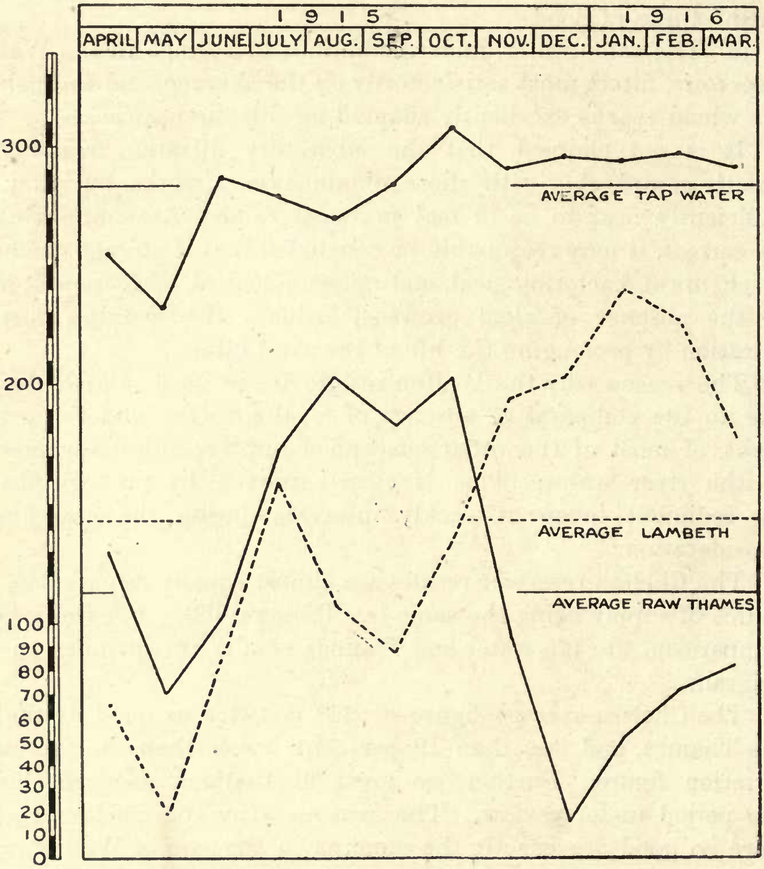


Diagram 30.

The microscopical appearances of the suspended matter in some of the samples are shown in fig. 1 (*see* p. 76).

Consideration may next be given to the Staines reservoir water, which flows down the Staines aqueduct to supply the Sunbury, Kempton Park, Grand Junction (Hampton and Kew) and West Middlesex Works (*see* Diagram 31). For the sake of comparison,

RESISTANCE TO FILTRATION EXPERIMENTS.

Number of c.c. Filtered per Minute.

STAINES

Reservoir Water *compared with* Raw Thames *and* Tap Water.

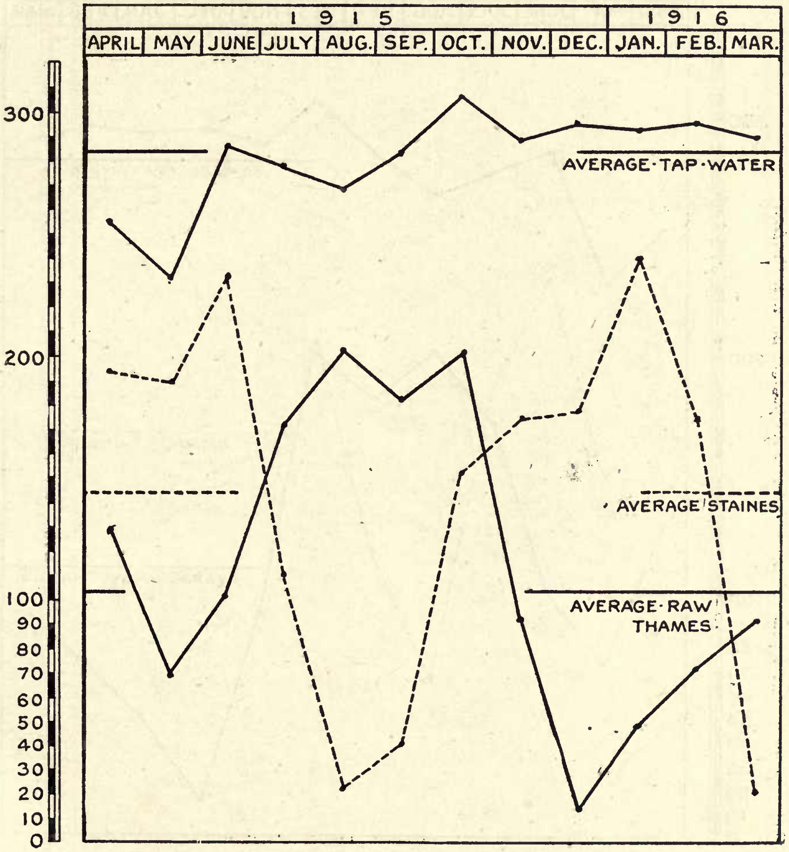


Diagram 31.

the tap water *criterion* figure and the River Thames figure are also given.

It will be noticed that although the Staines stored water is, on the average, somewhat better than the Thames, it is liable to most remarkable fluctuations in its filtration results. This was undoubtedly due to the excessive development of algal and other growths at certain periods. The deterioration in the results in August and September was due chiefly to Fragillaria; in March, the chief offender was Asterionella.

RESISTANCE TO FILTRATION EXPERIMENTS.

Number of c.c. Filtered per Minute.

SUNBURY

Reservoir *compared with* Raw Thames *and* Tap Water.

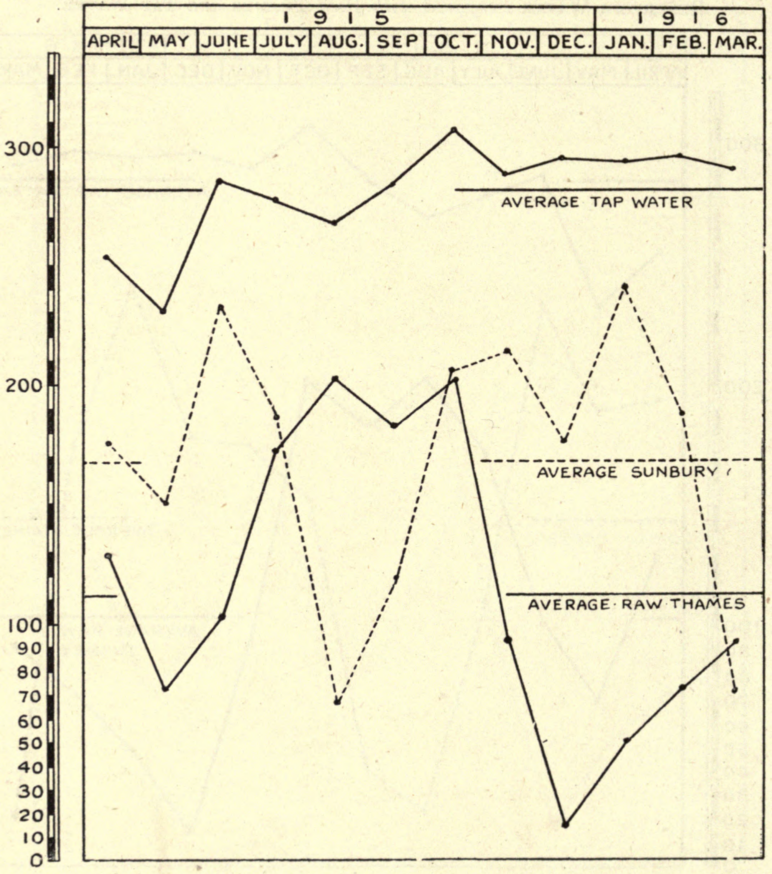
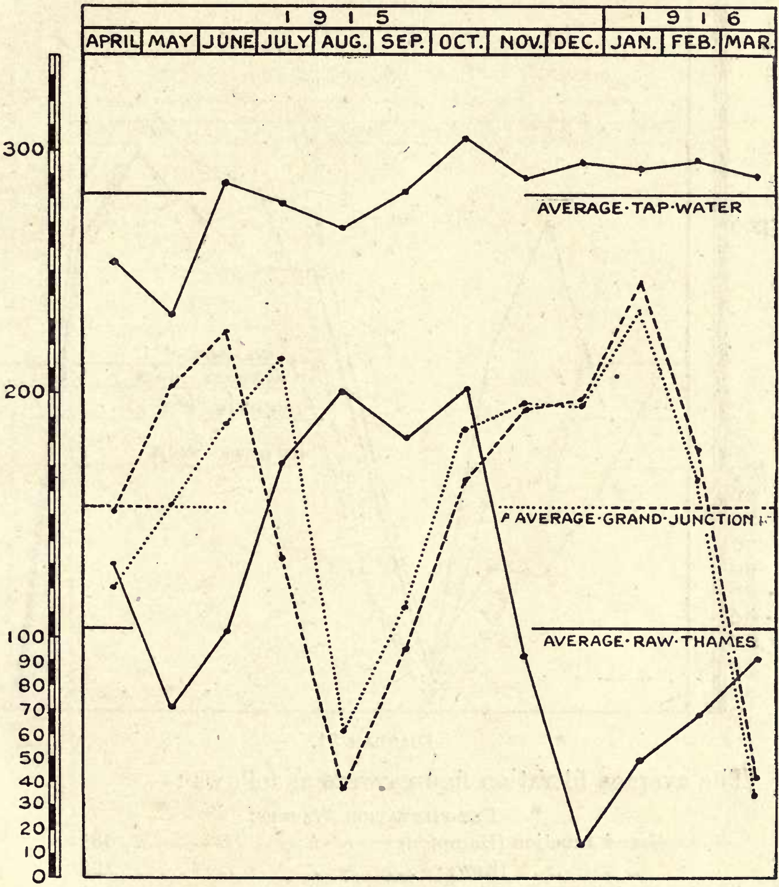


Diagram 32.

As this water supplies either directly, or indirectly after secondary storage, the aforesaid works, it might be anticipated that the pre-filtration waters at these places would give similar laboratory filtration results.

When curves representing the laboratory filtration results of the pre-filtration waters at the Sunbury, Grand Junction (Hampton and Kew), and West Middlesex Works are compared, it becomes at once apparent that the general appearance of them all is much the same (*see* Diagrams 32, 33, and 34).



RESISTANCE TO FILTRATION EXPERIMENTS.

Number of c.c. Filtered per Minute.

GRAND JUNCTION (*Hampton and Kew*)

Reservoirs *compared with* Raw Thames *and* Tap Water.

Diagram 33.

RESISTANCE TO FILTRATION EXPERIMENTS.

Number of c.c. Filtered per Minute.

WEST MIDDLESEX RESERVOIRS

Nos. 1, 3, 4, and 6.

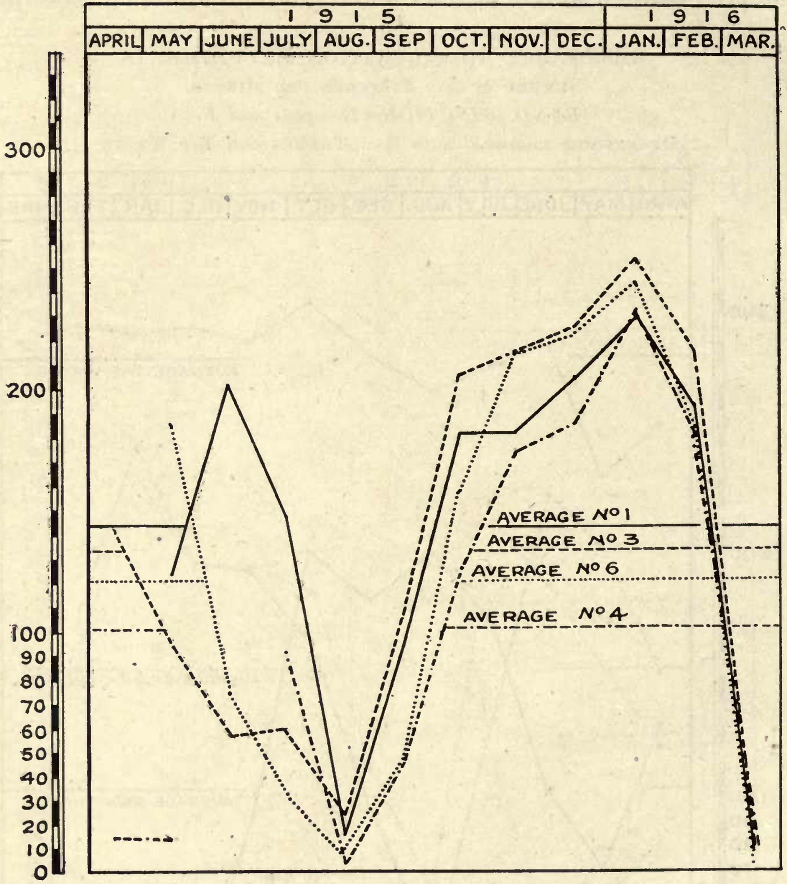


Diagram 34.

The average filtration figures were as follows :—

Pre-filtration Waters.

Grand Junction (Hampton)	154
,, ,, (Kew)	154
West Middlesex (No 6, May to March)	121
,, ,, (No. 4, June excepted)	102
,, ,, (No. 3)	134
,, ,, (No 1, May excepted)	144
Kempton Park (Staines Aqueduct)*	124
Sunbury	168

* This water usually "feeds" the Kempton Park filters, although the water from the Kempton Park reservoirs may also be used.

Sometimes, however, samples of these pre-filtration waters gave figures of less than ten, and when this occurred the practical difficulties associated with sand filtration became serious.

The weekly photographs of the suspended matters in these various pre-filtration waters resemble each other so closely that they might almost be considered identical. In each case, Fragillaria was in the ascendant, and was the main cause of the "blocking" effect observed about August and September, 1915, but in March, Asterionella was the chief offender. A reference to fig. 2[1]

RESISTANCE TO FILTRATION EXPERIMENTS.
NUMBER OF C.C. FILTERED PER MINUTE.
SUNBURY
PRE-FILTRATION WATER *compared with* INVERTED CURVE *showing*
NUMBER OF ACRES OF FILTER BEDS CLEANED.

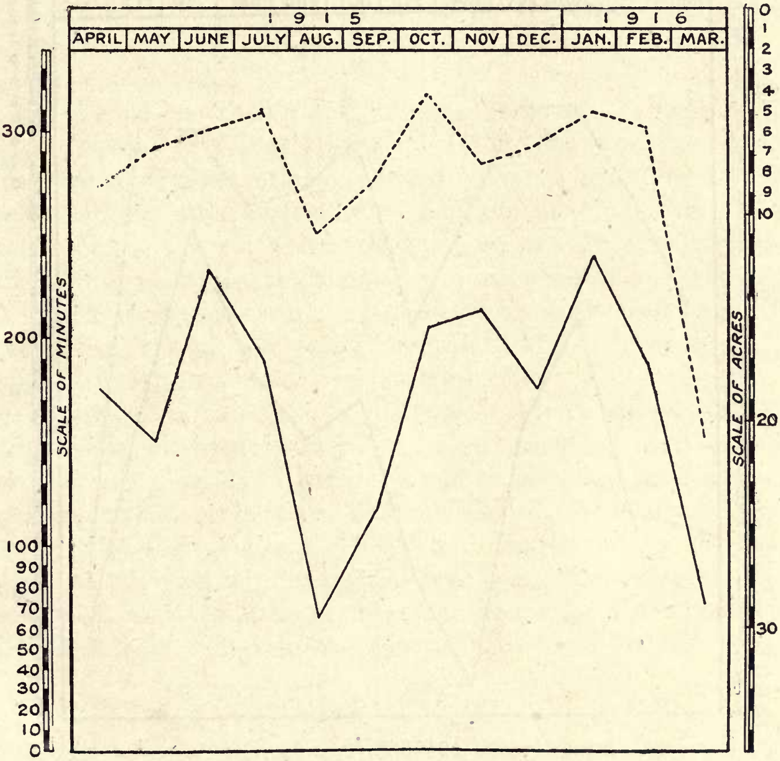


DIAGRAM 35.

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[1] *See* p. 76.

will sufficiently explain the microscopic appearances met with, and the reason why the filtration results fell off during these periods.

If the laboratory "resistance to filtration" results afford a useful index of the actual sand filtration experiences, it might be con-

RESISTANCE TO FILTRATION EXPERIMENTS.
NUMBER OF C.C. FILTERED PER MINUTE.
KEMPTON PARK
PRE-FILTRATION WATER *compared with* INVERTED CURVE *showing*
NUMBER OF ACRES OF FILTER BEDS CLEANED.

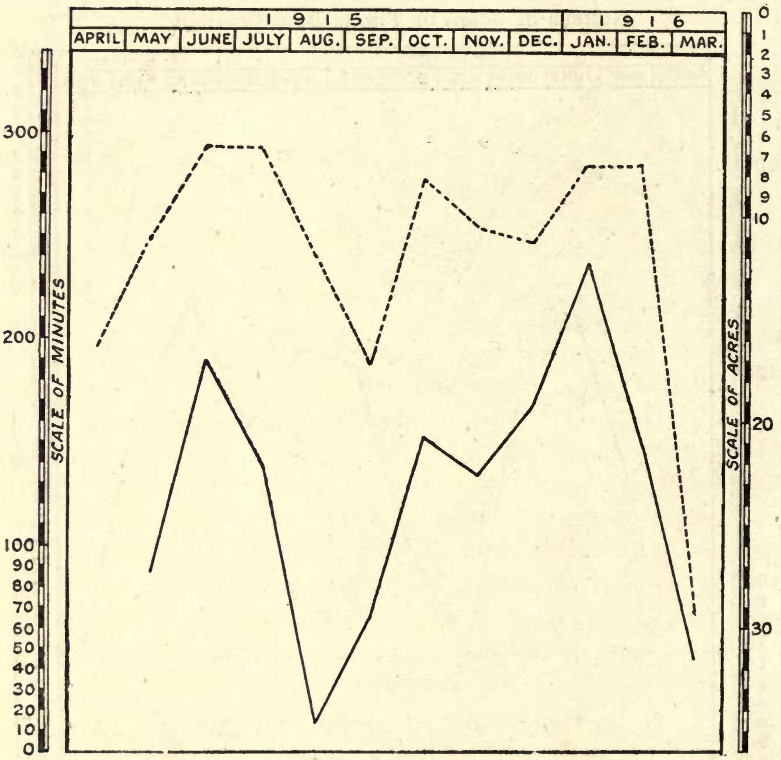


DIAGRAM 36.

jectured that the curve representing the laboratory results would agree fairly well with the curve (inverted) of the number of acres of filter beds cleaned. There are, however, a number of circumstances which render this comparison extremely difficult. For example, filter beds may be cleaned in advance of anticipated algal troubles.

Again, the rate of filtration varies considerably at different periods of the year. Further, there may be occasions when, in the presence of algal troubles, a works reduces its output, and another one not so affected makes up the deficiency of water. Also, there may be a fresh development of growths at other than the point where the samples were collected for the tests, for example, in the water lying on the top of the filter beds, or in the skin in contact with the surface of the sand. Yet, when these and other known factors have been considered, there remain puzzling cases, where the laboratory tests and sand filtration results appear to clash. Possibly a wider experience and more complete knowledge will in time explain satisfactorily these apparent discrepancies. Sometimes, however, the agreement is very striking, as is shown in Diagrams 35 and 36.

Experience has shown that there is frequently a considerable delay between the discovery (by laboratory filtration experiments and microscopic observations) that a reservoir is beginning to show signs of an excessive algal development and the "blocking" of the sand filters at the works fed with such water. Practically, this is important as it enables the engineers to make suitable provision for the trouble in advance. For example, by having a good proportion of the filter beds in a "young" condition, that is, near the beginning, not the end, of their normal working life.

In concluding this part of the subject it may be said: That in the comparative absence of algal and other growths, reservoir water filters much better than river water; in cases where excessive algal development *does* occur, there does not seem to be much difference between the reservoir and river water results during the worst period in each case, but during the best period the reservoir water filters best, and the average filtration figure for the whole year tends also to be better in the case of the stored water.

THE TREATMENT OF ALGAL-AFFECTED WATER.

Waters affected with algal and other growths may be "treated" successfully with various substances, e.g., copper sulphate, hypochlorites, &c. Copper sulphate may be used either to prevent or restrain development, or to kill a growth which has already developed. In the latter case, the water may filter badly for a long time afterwards, the dead bodies or skeletons still acting mechanically as "blocking" agents.

Kellerman gives the following dose as being fatal to the organisms specified:—

	Parts per million
Uroglena	0·05
Asterionella Anabæna Synura	0·1
Spirogyra Oscillaria	0·2
Fragillaria Volvox	0·25
Dinobryon	0·3
Synedra	1·0
Peridinium, and probably the allied Ceratium	2·0

The microscopic appearances of some of these growths are shown in figs. 3 and 4 (*see* p. 76).

It will be noted that the dose varies greatly for the different kinds of growths, and unless the maximum dose is used, which would destroy fish, and be otherwise objectionable, there is always the chance, with lesser amounts, of paving the way for the active development of another kind of growth or growths, at the expense of those inhibited or killed. In interfering with the balance of Nature, it is difficult to foresee all the possible consequences.

It is possible, experimentally, to give a dose of copper sulphate just strong enough to restrain the development of asterionella in water, and yet insufficient to check the active growth of the slightly more hardy fragillaria. Nor is it altogether inconceivable, that starting with the delicate uroglena, one might, by varying the dose, induce one set of organisms to multiply and take its place in one reservoir, another lot in a second reservoir, yet another in a third reservoir, and so on. Or a succession of doses in one reservoir, given at proper intervals, might conceivably produce the same effect.

Treatment with copper sulphate should always be left in the hands of experts. There is some evidence that a dose about February, before the spring growth of diatoms has properly commenced, attains the best results. But this may have to be repeated later on, as experience has shown that a recrudescence of vitality may occur.

Apart from sentimental objections to the use of copper sulphate, its employment presents certain economic advantages. For example, when a filter is dealing with good water, its life may be prolonged from weeks into months. When, however, the water is badly affected with algal growths, it may "block up" in the course of a very few days. Seeing that the normal working cost of sand filtration is about 8s. per million gallons, any considerable shortening of the life of the filters becomes a serious matter, because most of this sum is expended on cleaning operations. As the cost of treatment, even with a dose of 10 lb. of copper sulphate per million gallons of water, is only about 1s. 10d., it is obvious, that if the treatment can anticipate algal development, and prevent its occurrence, it may be a financially sound proposition.

Hypochlorites may be used in the place of copper sulphate, but their action appears to be more evanescent, although they have the advantage of freeing the water from undesirable bacteria. Copper sulphate would seem to be more of an algicidal than bactericidal agent, the converse holding true with hypochlorites.

THE TASTE OF ALGAL-AFFECTED WATERS.

Waters affected with algal growths are believed to be quite innocuous, but they may give rise to most unpleasant tastes and odours. Scientists are pleased to distinguish these tastes and odours by terms which carry small conviction to the consumers. For example: aromatic, geranium, violet, grassy, mossy, cucumber, nasturtium, &c. Consumers are apt to use more *forcible descriptions*, e.g., like *castor oil* or *rotten fish*. Many organisms are reputed to produce objectionable tastes in water—e.g.: asterionella, cyclotella, anabæna, oscillaria, dinobryon, volvox, uroglena, synura, &c.

Tabellaria (see fig. 4) may give rise to a geranium taste in water, which, if *concentrated*, passes into an oily fishy taste, which is *extremely unpleasant*. It is remarkable that the taste disappears almost at once on the addition to the water of potassium permanganate, in the small proportion of 5 lbs. per million gallons. Hypochlorites, in comparison, are of little use as "taste removers."

THAMES-DERIVED FILTERED WATER.

The Thames river water has been dealt with so far from the physical, chemical and bacteriological points of view, and in relation to the changes which occur in it under conditions of storage. It is convenient next to deal with the last stage in the purification process (namely filtration), and to consider the quality of the water as finally delivered to consumers.

Thames-derived filtered water is supplied from the following works: Sunbury, Kempton Park, Grand Junction (Hampton and Kew), Southwark and Vauxhall, Lambeth, Chelsea, West Middlesex.

RAW THAMES RIVER WATER AND THAMES-DERIVED FILTERED WATER, 1906-1916.

GELATINE, AGAR AND BILE-SALT AGAR COUNTS (1913-1916).

PERCENTAGE REDUCTION.

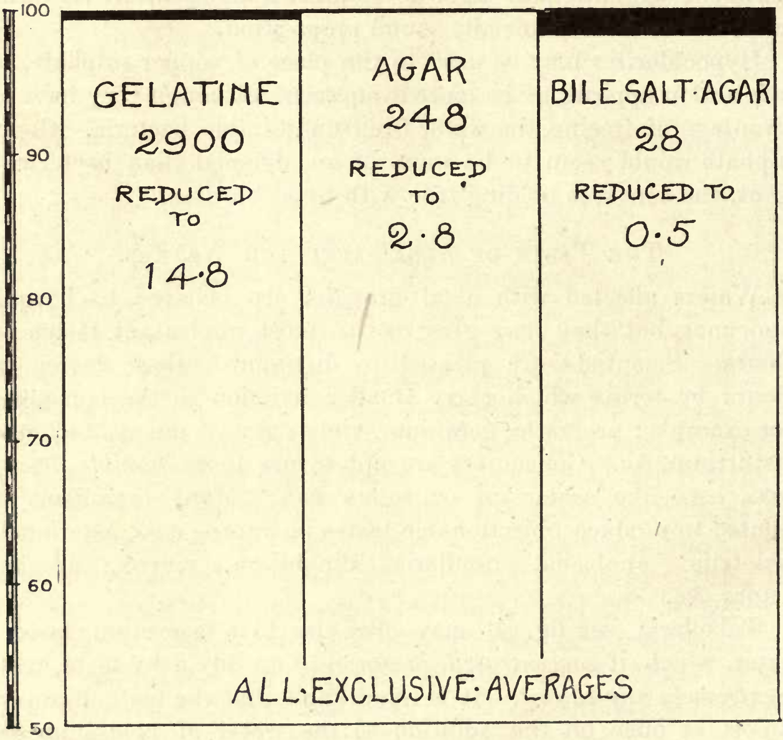


DIAGRAM 37.

For the ten-year period 1906-16, the average number of microbes per cubic centimetre (exclusive of samples containing 100 or more microbes) was satisfactorily low, namely: 14·8 gelatine count, 2·8 agar count, and 0·5 bile-salt agar count, the latter figure being based on the shorter period of 1913-16.

The reduction effected by storage and filtration will be appreciated best by reference to Diagram 37, which shows the following actual results and percentage reductions:—

Gelatine 2,900, reduced to 14·8, over 99 per cent. reduction.
Agar 248, reduced to 2·8, over 99 per cent. reduction.
Bilt-salt agar 28, reduced to 0·5, over 98 per cent. reduction.

THAMES-DERIVED FILTERED WATERS.
B. COLI TEST, 1906-1916.
PERCENTAGE NUMBER OF SAMPLES CONTAINING
B. coli in

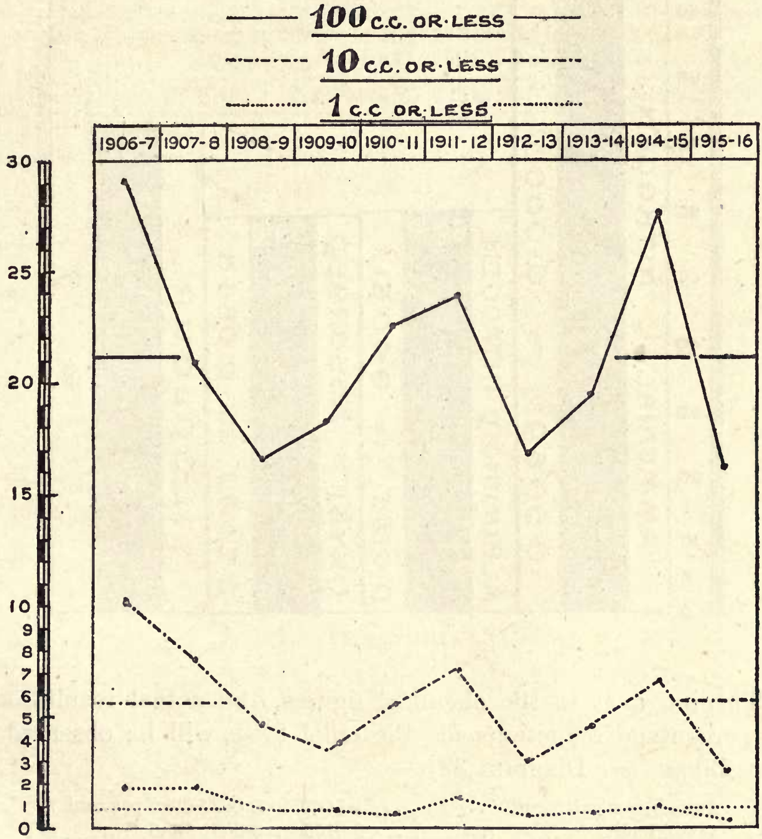


DIAGRAM 38.

Diagram 38 shows the *B. coli* results for the period 1906-16. On the average, only 21·2 per cent. of the samples contained *B. coli* in 100 c.c., only 5·7 in 10 c.c. and only 0·9 per cent. in 1 c.c. These results are remarkable, when it is remembered that 50·2 per cent. of the samples of Thames river water contain *B. coli* in 0·1 c.c., or less. In other words, the filtered water contains over 1,000 times fewer *B. coli* than the raw water.

RAW THAMES RIVER WATER AND THAMES-DERIVED FILTERED WATER, 1906-1916.

CHEMICAL RESULTS.

PERCENTAGE REDUCTION.

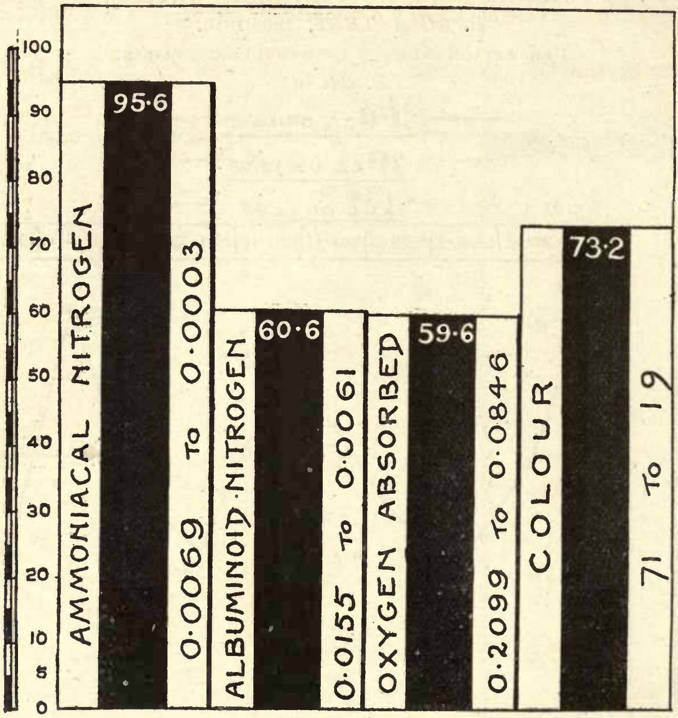


DIAGRAM 39.

Turning next to the chemical figures, the actual results, and the percentage reductions for the chief tests, will be observed to be as follows (*see* Diagram 39):—

Ammoniacal nitrogen	0·0069	to	0·0003	(95·6 per cent.)
Albuminoid ,, ...	0·0155	,,	0·0061	(60·6 ,,)
Permanganate test	0·2099	,,	0·0846	(59·6 ,,)
Colour..	71	,,	19	(73·2 ,,)

As regards season, Diagram 40 shows a comparison for the ten-year period 1906-16 of the *quarterly* bacteriological results. The gelatine, agar, and bile-salt agar results are expressed as "counts" per 10 c.c. of water (exclusive averages). The *B. coli* results are given as percentage number of samples, yielding positive results in 100 c.c. (or less) of water.

It will be noted that the gelatine, agar, and bile-salt agar "counts" are all lowest in winter, and all highest in summer. This might be attributed to more rapid rates of filtration during the summer, or a worse pre-filtration water to be dealt with, or to both these factors. More probably it is a temperature effect. At all events, it is noteworthy that the *B. coli* test yields the *worst* results in winter, as might be expected. As judged by this test, the spring is the best quarter of the year.

THAMES-DERIVED FILTERED WATERS, TEN YEARS, 1906-1916.
AVERAGE SUMMARY OF QUARTERLY RESULTS.

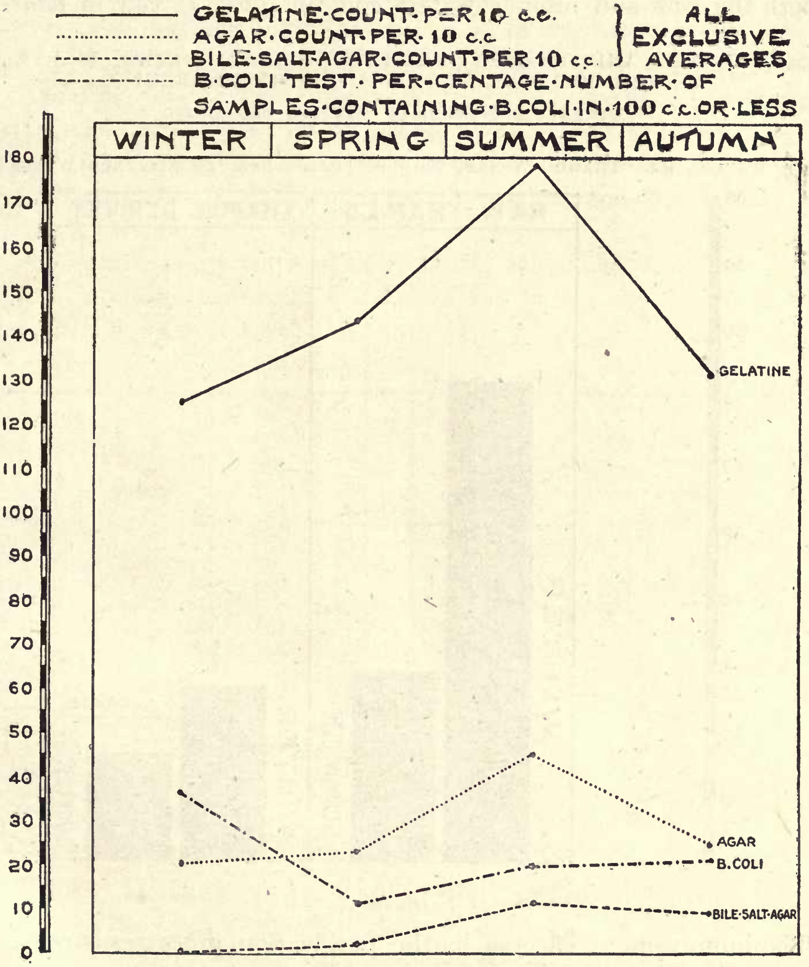


DIAGRAM 40.

Finally dealing with the half-yearly results, Diagram 41 is worthy of close attention. It deals with the raw Thames and the Thames-derived filtered waters, over the ten-year period of 1906-16, the years being divided into summers (April to September inclusive) and winters (October to March inclusive). It will be noticed that both the *raw* and filtered waters contain most *B. coli* in *winter*.

RAW THAMES AND THAMES-DERIVED FILTERED WATER, TEN-YEAR PERIOD, 1906-1916, WINTER AND SUMMER RESULTS.

Percentage Number of Samples containing
B. COLI
in 0·1 c.c. Raw Thames Water, 100 c.c. Thames-derived Filtered Water.

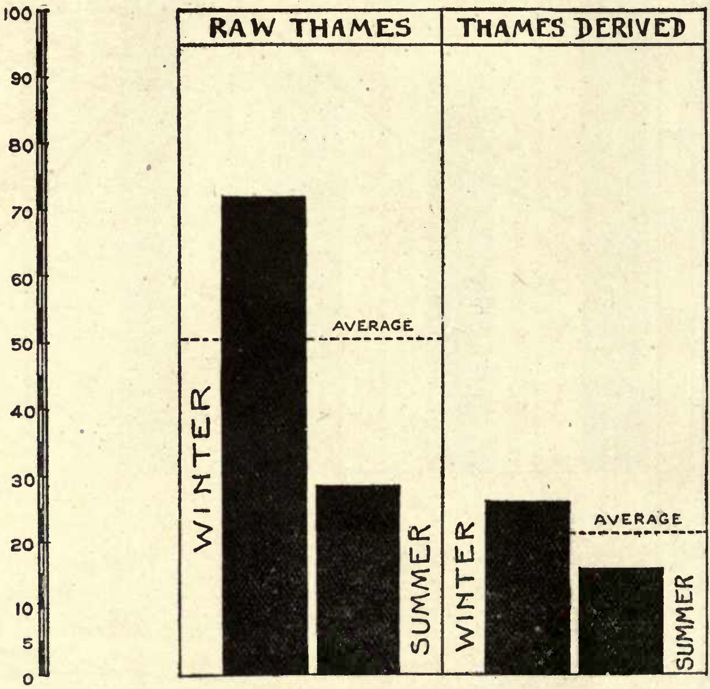


Diagram 41.

The improvement effected by the purification processes is remarkable. For example, on the average, 50·2 per cent. of the *raw* water samples contain *B. coli* in 0·1 c.c.; whereas only 21·2 per cent. of the *filtered* water samples contain the same microbe in 1,000 times as much water, namely, 100 c.c. In other words, if any danger exists in drinking the *raw* water, that danger, as judged by this test, is reduced over 1,000 times by the purification processes employed.

WATER AND DISEASE.

In conclusion, it is desirable to deal with water in its relation to disease, using once more the Thames and the Metropolis for purposes of illustration. It will probably be generally agreed that if London is protected from typhoid fever, there is small danger of its suffering from other water-borne diseases.

The Metropolis is supplied with Lee (about 20 per cent.), and well water (about 20 per cent), as well as Thames water; but as about 60 per cent. of the supply is of Thames origin, it is obvious, that if the purified product were gravely at fault, we should expect to see it reflected in the typhoid returns. Moreover, the results obtained with the River Thames may be applied, generally speaking, to the River Lee.

There are many ways of considering this difficult subject, but it is desirable to regard the matter, in the first place, from a broad and general point of view.

TABLE VIII.

European cities	Estimated population	Typhoid fever death-rates per 100,000	American cities	Population, 1910	Typhoid fever, death-rates per 100,000
Edinburgh	321,000	1·3	Cincinnati	363,591	8·8
Munich	600,000	1·4	Boston	670,585	11·3
Stockholm	340,000	1·8	Jersey City	267,779	11·5
Dresden	550 000	2·2	New York	4,766,883	11·6
Antwerp	316,000	2·3	Newark	347,469	13·1
Berlin	2,000,000	2·9	Chicago	2,185,283	13·7
London	7,250,000	3·3	St. Louis	687,029	14·9
Copenhagen	465,000	3·6	Philadelphia	1,549,008	17·5
Vienna	2,000,000	3·8	Cleveland	560,663	17·9
Liverpool	750,000	3·9	Buffalo	423,715	20·0
Belfast	385,000	3·9	Detriot	465,766	23·0
Birmingham	825,000	3·9	Washington	331,069	23·2
Hamburg	950,000	4·1	Pittsburg	533,905	27·8
Lyons	525,000	4·4	Milwaukee	373,857	45·7
Paris	2,750,000	5·6	Minneapolis	301,408	58·7

Table VIII shows the typhoid death-rates for a number of large cities. The very favourable position occupied by European, as compared with American, cities is very striking, and London takes an honourable place in the former group.

In the United States, it is customary to speak of a "*normal*" typhoid death-rate, and all typhoid deaths beyond the "normal" are attributed to impure water. The "normal" is a suppositional figure, arrived at by inferring the probable number of cases caused by such agencies as milk, uncooked food, shell fish, flies, &c.

In America, 20 is usually taken as the "normal." In London, the typhoid death-rate is less than 4 per 100,000; so that either we should have to conclude that water played *no part* in causing the disease, or reduce the "normal" five times, or more.

Next we may look at the matter from the point of view of season. Diagram 42 shows that in London, September, October and November are the worst typhoid months, and April the best. If a flooded impure condition of the Thames were a serious factor in the situation, one would expect to find some parallelism between the typhoid and flow curves. It will be noticed that quite the reverse is the case; the autumnal rise in the incidence of typhoid fever preceding in the most marked fashion the flow of the river. It has already been explained that there is a broad parallelism between the flow of the river and the chemical and bacteriological results, which normally attain their maxima in the winter quarter, and not in the autumn. It may, however, be said that the dominant factor in the position is the seasonal quality of the water, as actually delivered to the consumers. As regards this point, we certainly do see a slight apparent deterioration of the supply, as judged by *some* tests, at periods preceding, or coinciding with, the

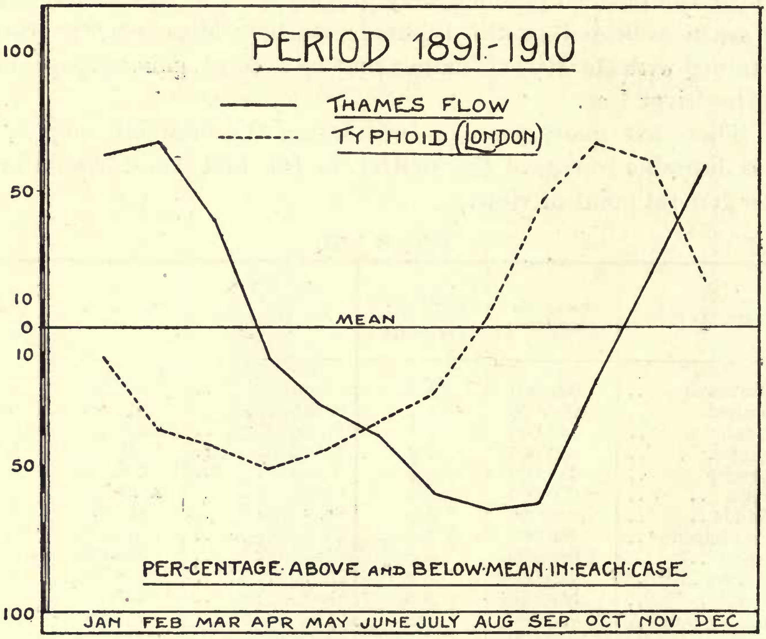


Diagram 42.

typhoid season. Most probably, this is a temperature effect, but it might also be argued that it was due to an increased consumption of water, leading to more rapid rates of filtration. At all events, other and presumably more important tests (e.g., the *B. coli* test) do not support such a contention. If the results yielded by the *B. coli*, albuminoid nitrogen, permanganate, and colour tests are "charted" out on a quarterly basis, it will be found that all the tests give the worst results during the winter quarter.

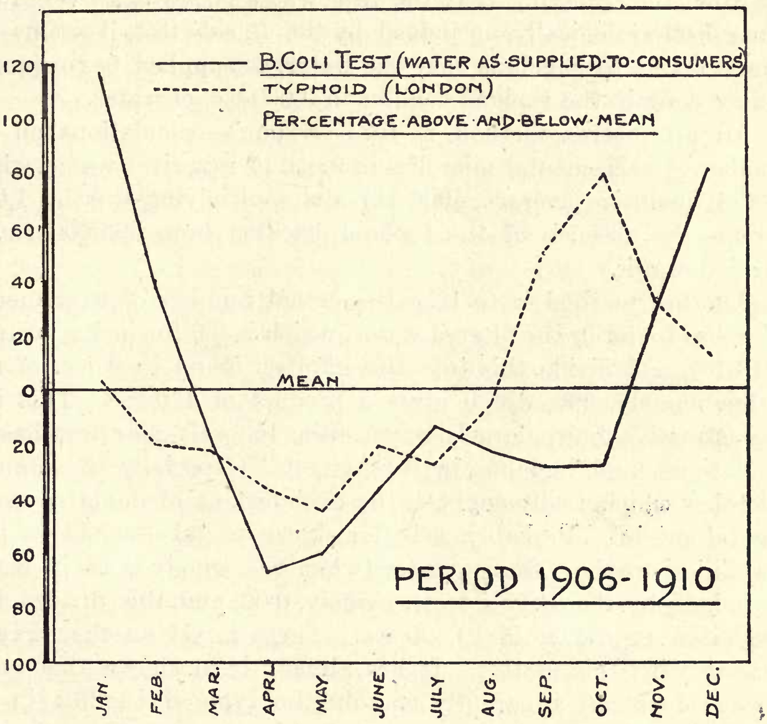


DIAGRAM 43.

Attention may now be directed to Diagram 43, which shows the *B. coli* results for all London waters, side by side with the notified cases of typhoid fever in the County of London, for the period 1906-10. It will be noted that there is a marked disagreement between the two curves. The subject may next be looked at from a fresh point of view (*see* Table IX).

Experimental reasons for concluding that the typhoid bacillus is not present in Thames water, in the proportion of 1 per 9 c.c., have already been given.

TABLE IX.—Table showing the Inferred Absence of the Typhoid Bacillus, from the following Amounts of Water, as supplied to Consumers, on the Bases about to be described.

9,000	c.c.	or	1·98	gallons
396,000	,,	,,	87·12	,,
440	,,	,,	0·0968	gallon
19,800	,,	,,	4·356	gallons
16,000	,,	,,	3-52	,,
782	,,	,,	0·172	gallon
35,200	,,	,,	7·74	gallons

Now, remembering that the *raw* water is purified over 1,000 times bacteriologically, as judged by the *B. coli* test, it seems not unreasonable to conclude that the water, as supplied to consumers cannot contain the typhoid bacillus in 9,000 c.c. of water.

An alternative method is to base one's calculations on the number of excremental microbes in 9 c.c. of raw river water, which is 396 (inclusive average, 1906-16), and multiplying this by 1,000, assume the absence of the typhoid bacillus from 396,000 c.c. of purified water.

Another method is to take the actual number of excremental microbes found in the filtered water, which is 0·9 (inclusive average, 1913-16), and divide this into the number found in 9 c.c. of raw water, namely, 396, which gives a product of 440 c.c. This is a less attractive figure, largely because the bile-salt agar test has its limitations, and includes in its "count" (especially in summer) microbes which really ought to be excluded, as of doubtful excremental origin. Probably a better figure to take would be that pertaining to the winter quarter (when the supply is at its worst, as judged by the *B. coli* test), namely, 0·02, and this divided into 396 gives a product of 19,800 c.c. There is yet another way of dealing with this matter. It has already been shown that crude sewage does not apparently contain the typhoid bacillus in the proportion of 1 per 0·00066 c.c., and this amount of sewage contains 704 excremental microbes. Now, as 16 c.c. of the raw Thames contains the same number of excremental bacteria, and as this water is purified at least 1,000 times, we may infer the absence of typhoid bacilli from 16,000 c.c. of the water, as supplied to consumers. Or, we may use the figures previously given of 0·9 and 0·02, and obtain the inferential figures of 782 and 35,200. The figures 440 and 782 are, in my opinion, much less reliable than the rest, because the calculations are based on inclusion of the relatively high summer bile-salt agar "counts," and the worse results then obtained are not confirmed by other and apparently more important tests. Excluding these, it would appear that from 9,000 to 396,000 c.c., or from about 2 to about 87 gallons, might be drunk without any risk of typhoid infection.

Some persons may consider the following argument equally conclusive. It has been shown that "uncultivated" typhoid bacilli artificially added to river water die, under conditions of storage, in about one to three weeks. Seeing that the average duration of storage is over forty days, and that the water is filtered so as to remove at least 98 per cent. of the microbes still remaining in the stored water, the chances of a single typhoid bacillus reaching the consumer seems extremely remote.

Another interesting point is whether *B. typhosus* occurs in water as clumps or masses, or as individual separated bacilli. In properly filtered water, at all events, it appears to be unlikely that *B. typhosus* could be present as aggregations of typhoid bacilli. If this is true, the further question arises whether a single bacillus can start an infection and also whether, and, if so, to what extent, succeeding draughts of water influence each other. It seems not unreasonable to suppose that each draught of water is, so to speak, a "hit" or "miss," and that infection cannot be produced by the cumulative effect of repeated draughts, when each one by itself is non-infective, assuming always that the draughts do not succeed each other too quickly. If a single typhoid bacillus can produce infection, it is obvious that if any typhoid bacilli pass the barriers of the purification process, it is only a question of proportion and of susceptibility how many persons are affected. Animals can be infected by ingesting food which has been inoculated artificially with cultures of microbes belonging, for example, to the food-poisoning group, but the dose, in my experience, has to be considerable, if not enormous. It is possible, however, that very much smaller doses may suffice when the bacilli have been recently discharged from the body of an animal suffering acutely from the disease, and are ingested in the fresh "uncultivated" state.

Is it unreasonable to suppose that the reason why typhoid fever does not supervene on the "worst water," or winter, periods is because, even during these periods, the water is not sufficiently "impure" to be *actually* infectious? Further, is it not permissible to believe (on the available evidence) that the autumnal incidence of the disease has really no constant relation to the quality of the water supply. Nevertheless, it must be freely admitted that our tests are not only indirect, but non-proven indices of the *actual specific* qualities of water supply.

In summary of what has been said : The physical and biological changes occurring in river water, under conditions of storage, were first dealt with. Usually the character of the water is greatly improved from a filtration point of view. Occasionally, however, owing to the active development of algal and other growths, the utmost difficulty may be experienced in filtration.

Questions of taste and treatment of algal-affected waters were considered at some length, including the use of copper sulphate as an algicidal agent, and potassium permanganate as a means of removing unpleasant tastes.

The quality of London water, as finally delivered to the consumers, was next dealt with, and comparisons were made between the raw source of supply, and the same water, after having passed through the purifying processes of storage and filtration.

The question of water in relation to disease was then considered. It was pointed out that the London typhoid death-rate is satisfactorily low, and that curves representing quality of water and seasonal incidence of the disease are in marked disagreement. Some reasons, based on experimental facts, for inferring the absence of the typhoid bacillus from large volumes of filtered water were also given.

In conclusion: In 1910, a Joint Select Committee of both Houses of Parliament endorsed the recommendation of the Water Supply Commission of 1869, as to the appropriation of sources; the Metropolitan Water Supply Commissions of 1893 and 1899, as to the keeping of suitable records by water undertakers; and of the Sewage Disposal Commission, as to the formation of rivers or watershed boards controlled by a Central Administrative Authority. They recommended the establishment of such a Central Administrative Authority as was contemplated by the Royal Commission on Sewage Disposal, and the division of the country into watershed areas, and the appointment for those areas of local Representative Boards, who, subject to the guidance and control of the Central Authority, should prosecute systematic and continuous inquiries into the water supply of their jurisdiction, take all necessary measures to husband such supplies, both surface and subsoil; secure their preservation from pollution, and advise on their allocation for sanitary, industrial and other purposes.

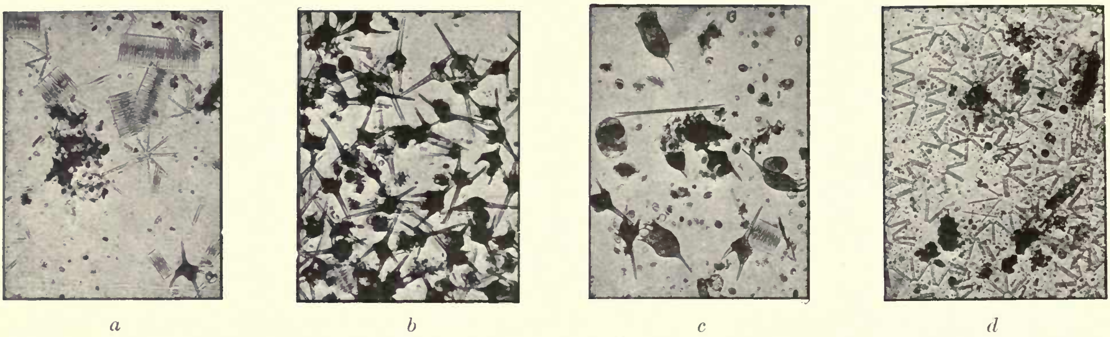
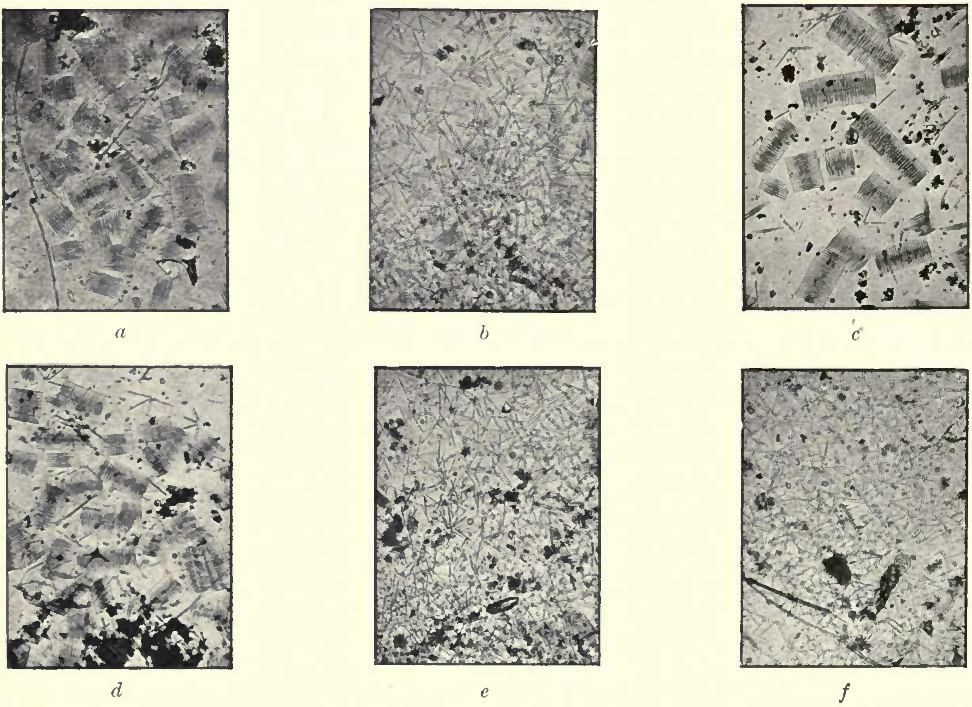
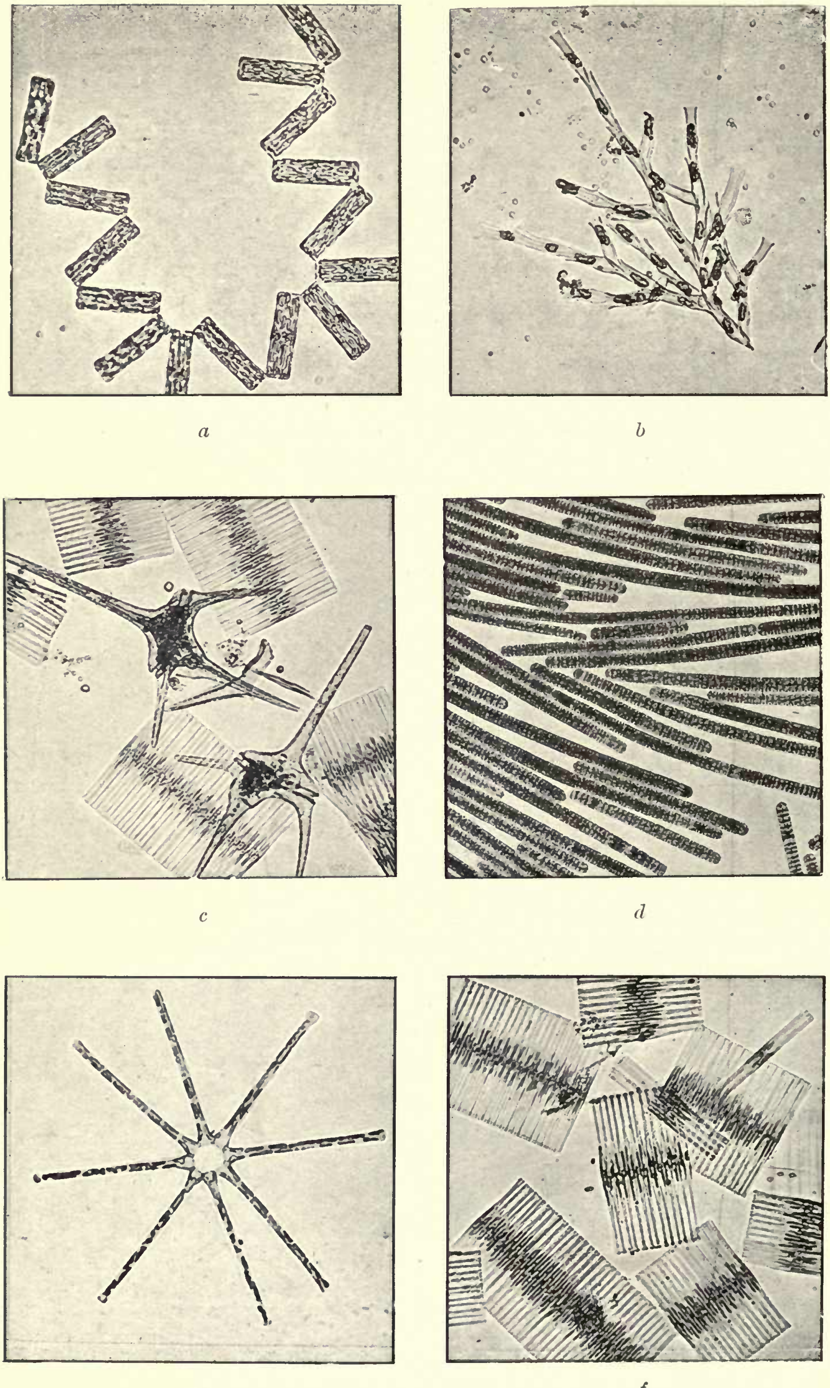

a *b* *c* *d*

FIG. 1.


a *b* *c*

d *e* *f*

FIG. 2.



a b c d e f

FIG. 4.

Visualizing the future, it is easy to foresee that a vast amount of work has yet to be done on water supply. In these pages, endeavour has been made to present, as faithfully as possible, one aspect of this great problem, namely, the question of rivers as sources of water supply.

It may be wise to consider, as a counsel of perfection, that the purest water supply is the supply that requires no purification; but this is not inconsistent with the view that river water, by adequate means, can be purified to *any standard of safety* required.

FIG. 1.—Micro-photographs of the suspended matter in about 0·05 c.c. of water (Island Barn Reservoir water). × 50.

(*a*) Collected July 26, 1915. Filtration rate 36. Note the presence of fragillaria, asterionella, and ceratium.

(*b*) Collected August 16, 1915. Filtration rate 122. Note the presence of ceratium.

(*c*) Collected October 18, 1915. Filtration rate 180. Note the presence of anuræa, synedra, fragillaria, and ceratium.

(*d*) Collected May 1, 1916. Filtration rate 57. Note the presence of tabellaria.

FIG. 2.—Micro-photographs of the suspended matter in about 0·05 c.c. of Staines-derived unfiltered water. × 50.

(*a*) Collected August 23, 1915. Filtration rate 3. Note the presence of fragillaria.

(*b*) Collected March 27, 1916. Filtration rate 60. Note the presence of asterionella.

(*c*) Collected August 16, 1915. Filtration rate 36. Note the presence of fragillaria and a few asterionella.

(*d*) Collected August 16, 1915. Filtration rate 30. Note the presence of fragillaria and a few asterionella.

(*e*) Collected March 27, 1916. Filtration rate 30. Note the presence of asterionella.

(*f*) Collected March 27, 1916. Filtration rate 27. Note the presence of asterionella.

FIG. 3.—Micro-photographs of algal and other growths. × 50.
(*a*) Uroglena and synedra.
(*b*) Anabæna.
(*c*) Synura (and a thread of oscillaria).
(*d*) Spirogyra.
(*e*) Volvox.
(*f*) Dinobryon.
(*g*) Fragillaria.
(*h*) Synedra.
(*i*) Ceratium.
In nearly all cases the water was derived from a reservoir (Thames supply).

FIG. 4.—Various growths occurring in London water before filtration, photographed by Dr. Albert Norman from my preparations.

(*a*) Tabellaria. × 280.
(*b*) Dinobryon. × 180.
(*c*) Fragillaria and ceratium. × 200.
(*d*) Oscillaria. × 250.
(*e*) Asterionella. × 320.
(*f*) Fragillaria. × 200.

CHAPTER IV.

STERILIZATION.

Excess Lime Method—Principles involved—Hard and Soft Waters—Questions of Dose—Advantages and Disadvantages—Thames River Water Experiments.

Hypochlorites—Lincoln Results—Advantages and Disadvantages—Questions of Dose—Thames River Water Experiments—Laboratory Experiments—Importance of Time Factor.

Liquid Chlorine—American Results—Writer's Experiences—Laboratory Tests—Conclusions.

THE sterilization of water is attracting such wide interest at the present time, and is likely to be employed so extensively in the future, that no apology is needed for devoting a special chapter to the subject.

There are many ways of sterilizing water, e.g., by means of heat, ozone, ultra-violet rays, &c. The methods, however, which are receiving most attention just now are sterilization by what is known as the excess lime method, by the use of hypochlorites and by the employment of liquid chlorine.

At this stage it is desirable to point out what is meant by sterilization. In a report[1] to the Royal Commission on Sewage Disposal in 1902, the writer suggested that the destruction of the spores of bacteria (complete sterilization) was almost impracticable and probably unnecessary, but that the elimination of bacilli (partial sterilization) was a feasible project. The opinion then given was that the death of the microbes causing epidemic water-borne disease (e.g., the typhoid bacillus) might fairly and reasonably be inferred from the destruction of *Bacillus coli.* This view

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[1] Provisional note on the bacteriological qualities of crude sewage and sewage effluents, and the question of standards in relation to potable and non-potable streams. Second Report of the Royal Commission on Sewage Disposal, 1902, pp. 27-28.

has come to be accepted generally by bacteriologists, and in what follows the use of the word " sterilization " implies partial sterilization (i.e., the death of *B. coli*).

EXCESS LIME METHOD.

This method was described by the writer in 1912.[1] It depends on the addition of lime, either as milk of lime or as lime water, to the water to be sterilized, in amount more than sufficient to combine with the dissolved carbonic acid and the bicarbonates.

It thus differs fundamentally from Clark's process, where exact neutralization is purposely slightly under estimated.

The amount "in excess" necessary is considerable, if the duration of contact is short, and exceedingly small if prolonged. The total amount of lime required varies greatly with the composition of the water to be treated, thus hard waters may require 1 part in 5,000 parts, and very soft waters 1 part (or less) in 50,000 parts. Against the cost of the lime in the former case must be set the advantages of a softened water, and in the latter cases questions of neutralization of acidity and increase of lime salts may prove to be not unimportant.

It is a mistake to suppose that mere neutralization of the dissolved carbonic acid and bicarbonates in an impure water, by means of lime, can be relied upon for effective sterilization purposes. There must be an excess, and the actual excess ought to be greater in the case of a hard than a soft water, because, in the former case, normal variations in the temporary hardness have a greater proportionate effect. Generally speaking, the more impure a liquid[2] is, the greater is the excess of lime required for sterilization purposes.

The most remarkable example economically of the use of lime for purification purposes is the case of Aberdeen. The results of the writer's excess lime experiments led the authorities of that city to give the process an exhaustive trial. The *net* result was that Parliament approved in 1915 the principle of a threefold scheme of purification, (excess lime treatment, storage for seven days and

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[1] Eighth Research Report, Metropolitan Water Board. *See* also Ninth, Tenth, and Eleventh Research Reports and Studies in Water Supply (Messrs. Macmillan and Co.).

[2] For example, London sewage requires a dose of from 1 to 1,500 to 1 to 2,500.

filtration at about double the ordinary rate) ; the saving in capital cost as compared with alternative schemes exceeding £100,000. It was found that with the exceptionally soft Dee water, sterilization could be effected within seven days with about 1 part of CaO per 100,000 parts of water (= 1 lb. per 10,000 gallons). The actual excess of CaO, beyond that required to neutralize the dissolved and half-bound carbonic acid in the water, was very slight. Of course, there are comparatively few water supplies quite so soft as that of Aberdeen, and in the case of really hard waters the amount of lime required for sterilization purposes is so material as to be almost prohibitive, if the advantages of a softened water are not allowed to enter into the calculation. The writer had ample and sustained opportunities of verifying, by personal experience, the completely successful results of the Aberdeen treatment. Taking lime (of 90 per cent. CaO strength) at 20s. per ton, the cost of this dose (1 in 100,000) per million gallons, works out at less than 1s.

Immense sums of money have been spent on the improvement of soft peaty moorland waters. Lime or soda salts have been added to counteract the acidity, alum to remove the colour, and filters of various kinds have been used to render the waters bright, clear and sparkling, and satisfactory bacteriologically. The writer should be the last to criticize these pre-War procedures, but, looking at the subject solely from the twin points of view of safety and economy, it is a question whether the excess lime method does not open out a field of great usefulness. For putting on one side the sentimental objections to a highly coloured peaty water, as unworthy of a policy of national retrenchment, the alum and the filters could reasonably be dispensed with, and the lime required in the case of very soft waters, to neutralize the acidity and provide an excess for sterilization purposes, would cost only about a shilling per million gallons. The immense storage for purposes of *quantity*, necessary in the case of moorland supplies, would presumably remove the last trace of caustic alkalinity, and the water would be free from all the microbes of water-borne disease. At all events, the matter is worthy of serious consideration in suitable cases, because the process not only safeguards health, but presents great advantages economically.

The writer's strong views on the public health aspects of the question may, perhaps, best be expressed by saying that in the case of an initially impure water he considers an excess-limed, but unfiltered, water safer than a filtered, but non-limed, water. The reason being that, as judged by bacterial tests, filtration is a relative, and sterilization an absolute, safeguard. It goes without saying that the writer does not suggest the unremunerative "scrapping" of existing plant and machinery. His remarks apply to new cases, or to old cases, where modifications are economically sound.

It should also be emphasized that the saving of money at the expense of security is inadmissible. The point to be aimed at is an increase of safety at the expense of sentimentality.

Turning next from a very soft to a somewhat hard river water, the following results are of interest: From March 18 to May 28, 1914, the raw River Thames water (about 168,000 gallons daily) at Sunbury was sterilized by means of lime. The lime-treated water passed through two tanks holding nominally 1·8 and 1·3 days' supply, but actually the period was much shorter, as "short-circuiting" undoubtedly occurred. The average dose employed was approximately 1 in 5,000,[1] or about twenty times the amount used at Aberdeen, owing to the much greater hardness of the London water. The average excess of lime (CaO) in the effluents from the first and second tank was 8·08 and 6·86 parts per 100,000 respectively. This is rather above the minimum excess dose required for sterilization purposes,[2] but it was considered desirable to use such an amount of lime as would more than ensure absolutely satisfactory bacteriological results being obtained throughout the whole period covered by the investigation.

The chemical results were as follows: The *turbidity* of the water was almost entirely removed, apart from the slight cloudiness due to particles of carbonate of lime still remaining in suspension. The *brown colour* was reduced to a remarkable extent, especially when the river was in high flood. The ten worst samples of the raw water, and of the outlet from the first tank, gave, on the average, colour estimations of 155 and 37 respectively, a reduction of 76 per cent. The *ammoniacal nitrogen* was increased, but the *albuminoid nitrogen* and the *oxygen absorbed from per-*

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[1] To be precise, 0·986 lb. of lime, calculated as CaO, per 500 gallons of river water.

[2] For fuller information as regards methods of determining the dose of lime required, &c., reference must be made to "Studies in Water Supply" (Messrs. Macmillan & Co.).

manganate were reduced 38·6 and 53·7 per cent. respectively, in passing through the first tank.

As regards *hardness*, under ideal conditions of exact neutralization of the excess lime, with a "non-hardening" substance, and excluding questions of super-saturation, the loss of hardness (soap test) would be over 71 per cent.

The bacteriological results were still more remarkable: The *gelatine* and *agar* "counts" were reduced over 99 and 91 per cent. respectively in the first tank. The *bile-salt agar* "count" in the raw river water was 50 per 10 c.c. as compared with *none* per 10 c.c. in the effluent from the first tank. *Typical B. coli* was present in 1 c.c. (or less) in 65 per cent. and in 0·1 c.c. (or less) in 23·8 per cent. of the samples of *raw* river water. None of the samples from the first and second tanks (ninety-two in all) contained *B. coli* even in 100 c.c. In addition, ten experiments were made on ten separate days with 10,000 c.c. (100,000 c.c. in the aggregate) of the water from No. 2 tank. The results were entirely negative as regards *B. coli.* The effluent from the second tank was mixed in a third tank with *untreated water* for neutralization purposes, and it was then finally filtered. This part of the process need not be gone into here, but it is necessary to deal with the general question of neutralization of waters containing an excess of lime.

In the case of limed waters stored for a long time in large reservoirs, enough carbonic acid may be absorbed from the air to effect neutralization.

Usually, however, a more rapid action is required, and coke ovens are specially made for producing CO_2 cheaply. The gas produced must, of course, first be washed; failing this, sulphur and other compounds give rise to taste troubles. There are many other acids, and acid substances, which may also be utilized for neutralization purposes. In selected cases sodium bicarbonate may alternatively be used, the resulting calcium carbonate being precipitated, and sodium sulphate taking the place of calcium sulphate, with consequent reduction of the permanent hardness.

Lastly, especially in the case of waters of great temporary hardness, a proportion of the water, which has purposely not been limed, may be used for neutralization purposes. *Adequately* stored water is sufficiently pure for this purpose, or, alternatively, raw river water after treatment with hypochlorites may be employed.

In the case of Thames River water about 67 per cent. could be limed, and 33 per cent. sterilized by means of hypochlorites, and the whole if mixed would be neutralized, sterilized and softened to the extent of about 16 parts per 100,000 parts (i.e., the hardness of the whole volume would be reduced about 71 per cent.). Of course, it may be said, why not save (in the case of hard waters) a large sum of money by sterilizing the whole volume of water with hypochlorites? Personally, the writer sees no objection to this course, but it is desirable to look at the subject from every point of view. One great advantage of the use of lime is that it is "hallowed by precedent," and that practically all drinking waters already contain lime salts. There is, indeed, no objection to the use of this substance, either on medical grounds, or on the score of taste, or for sentimental reasons. Quite the same, in the opinion of some persons, cannot be said of a hypochlorite-treated water. By the double treatment just described, the whole of the water is both softened and sterilized, and only one-third of the usual dose of hypochlorite is required. This is an extremely important point in relation to questions of taste. On the other hand, the expense of liming is undoubtedly a very serious one, if the advantages of a softened water are not allowed to enter into the calculation. The extreme advocates of softening, of course, claim that the saving in soap, coal, &c., far more than compensates for the cost of the treatment. The writer has shown the fallacy underlying some of these contentions, but still he feels that the benefits arising from a softening process are very material, although most difficult to place on a definite basis.

HYPOCHLORITES.

Turning next to sterilization by means of *hypochlorites*, the writer,[1] from 1905 to 1911, sterilized the Lincoln water supply (population about 50,000) with "Chloros" (an alkaline solution of sodium hypochlorite, containing about ten to fifteen per cent. of available chlorine). The best series of results occurred during a period of about ten months, when sixty-two samples collected consecutively contained no typical *B. coli* even in 100 c.c. of water.

For the results of earlier experiments (1902 onwards) by the

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[1] In conjunction with Dr. McGowan who controlled the chemical part of the investigation.

writer on the sterilization of effluents with hypochlorites, and fuller information on the Lincoln treatment, references may be made to the Fifth Report of the Royal Commission on Sewage Disposal, Appendix IV.

In 1908, Johnson treated successfully the Bubbly Creek water at Chicago with chloride of lime or bleaching powder (contains about 33 per cent. of available chlorine).

Since 1908, the use of hypochlorites for sterilization has increased enormously in the United States, but in this country progress has been very slow.

The example, however, set by the Metropolitan Water Board in 1916, and the successful results of the experiments (described in the writer's Twelfth Research Report) are bound to have far-reaching effects.

It is desirable to look somewhat closely into the advantages and disadvantages of this method of treatment.

Taking the disadvantages first, there is no doubt that the addition of chemicals to drinking water is repugnant to many persons. It is not desirable to ride rough-shod over sentiment in this matter. Far better is it to admit that there are two sides to every question, and to express the hope that time and experience will modify the opinions of present-day opponents. Next, there is the question of taste, and the writer is not one of those persons who assert that this is a factor to be ignored. Extremely puzzling cases of taste do sometimes occur, and there is no question that the margin between successful sterilization and a tasteless water is not nearly so great a one as some writers have contended. On the contrary, the greatest vigilance has to be observed in apportioning the dose to meet every varying circumstance and the necessity of skilled supervision is almost essential. Again, there are some people whose sensitiveness in the direction of taste is almost uncanny. Speaking generally, however, and excluding special and peculiar cases, it is quite feasible to produce a tasteless as well as a sterilized water.

Then there is the alleged harmfulness of sterilized water. It is easy, nowadays, to make light of these contentions, but the writer, as a pioneer, in 1905, at Lincoln, had to bear the full brunt of the well-meant, but hostile, criticism of his professional brethren, and this experience has rendered him very tolerant of the views of others in this respect. It is quite natural to believe, after all, that a substance powerful enough to kill bacteria may also be injurious to human beings when ingested. The following answer may be presented to these doubts. There are some substances which are much more toxic to human than microbial life; with other materials, like the hypochlorites, the position is reversed. The consumer does not, or should not, receive the treated water until the activity of the hypochlorites has been reduced or eliminated by their action on the oxidizable matters in the water. It is true that substitution products are formed which may also possess germicidal properties, but these too, in time, disappear or become inert. The circumstance noted at Lincoln in 1905, that microbes can multiply greatly in a chlorinated water, after the active substances have been used up or become inoperative, is presumptive but useful evidence of the innocuous character of properly treated water as finally delivered to consumers.

With the purpose of reassuring the inhabitants of Lincoln, the writer used to prepare and drink in the *fresh* state chlorinated water containing ten or more times the dose of hypochlorite supplied to the consumers. No injurious effects were felt, although undue stress should certainly not be laid on the results of individual experiments. More important is the circumstance that neither at Lincoln nor elsewhere has there been any tangible evidence, so far as the writer's knowledge goes, of injury to health owing to the consumption of chlorinated water. Indeed, so far as the prevention of epidemic water-borne disease is concerned, the advocates of chlorination may, not unreasonably, base their claims on the high plane of Preventive Medicine.

Fish suffer from *freshly* chlorinated water, if free chlorine is present above a certain proportion, but they thrive apparently in the same water after the more active substances have become exhausted, a circumstance which, like the multiplication of bacteria, tends to show that with a properly controlled chlorination plant there is no element of danger.

There is no reason to suppose, in the view of the writer, that the final products of the sterilizing action of hypochlorites on water have any sinister influence, or exercise a cumulative harmful action on the health of consumers.

Against these real or assumed disadvantages must be set certain advantages of a material kind, provided always the treatment is applied in suitable cases, and carried out efficiently under skilled supervision.

In the first place, all the microbes of water-borne disease (e.g., the typhoid bacillus and the cholera vibrio) are destroyed, as judged by the total elimination of *B. coli*.

Secondly, the treated water is innocuous, tasteless and odourless.

Thirdly, it is an exceedingly cheap process.

Lastly, but most importantly, the treatment confers absolute, not merely relative, protection against epidemic water-borne disease.[1]

It is here assumed that uniformly successful results can be obtained by the use of a dose insufficient to give rise to a taste, but more than sufficient to cover all variations in the quality of the treated water. The writer does not mean that in practice uniformly satisfactory results are obtained in all cases of hypochlorite treatment. The contrary may be the case for a wide variety of reasons. For example, the water may not be well suited for the purpose, the process may be carried out carelessly or without skilled supervision, improvement in quality, rather than complete sterilization, may be purposely aimed at, &c.

It is difficult to give any accurate figures as regards dose, as so much depends on the quality of the water to be dealt with, and the duration of contact. In the United States, the importance of the "time factor" appears to have been insufficiently recognized, and the amount of water used for cultural purposes has often been too small.[2]

Surprisingly small doses appear to be used sometimes in America, allowance being, of course, made for the difference between the British gallon (4·5459 litres, 10 lbs.), and the United States gallon (3·7854 litres, about 8·33 lbs.). Even 0·1 part of available chlorine per million parts (= 3 lbs. of bleaching powder of 33 per cent. strength per million English gallons) has been stated to be effective, but usually larger doses are employed. The

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[1] It is here assumed that the typhoid bacillus and the cholera vibrio are the causes of typhoid fever and cholera. Those who are not wholly convinced on these points must form their own separate judgment of the safety conferred by hypochlorite sterilization.

[2] Sometimes only 1 c.c. and usually only 10 c.c. appear to be used, instead of 100 c.c. The bacteriological bottles recommended in "Standard Methods of Water Analysis" (American Public Health Association, 1912) holds apparently only 2 oz. (56·7 c.c.), an amount insufficient for cultural purposes, unless the contents of more than one bottle are used.

writer's experience is that so wide a range of dose as from 0·2 to 1·0 part of available chlorine per million parts (= 6 to 30 lb. of bleaching powder of 33 per cent. strength per million gallons) may be required, and that not less than five hours' contact should be given.

Consideration may now be given to the results of the experiments with the Metropolitan Water Supply. It is true that these have been described in the writer's Twelfth Research Report, but the circumstances associated with the treatment were of so unique a character that no apology is needed for repeating the main facts.

It had been the custom to pump about seventy-five million gallons a day of Thames River water into the Staines reservoirs for purification purposes, and to withdraw a similar amount for the supply of certain filtration works of the Board. Owing to the War, the difficulty arose that not only was coal difficult to obtain and very expensive, but its conservation was most important in the national interests. In the circumstances, it was decided to allow the raw river water to gravitate to the filtration works and to chlorinate it before filtration[1] in such a way as to ensure that it was at least as pure as if it had been pumped into, and undergone storage in, the Staines reservoirs. The treatment was in full working order in June, 1916, and, apart from interruptions due to floods, has been continued ever since. During the summer and autumn months, the dose was nearly always 0·5 part of available chlorine in one million parts of water (=15 lb. of chloride of lime[2] of 33 per cent. strength per million gallons). The War cost per million gallons was about 3s. as against about 13s. previously expended on coal for pumping purposes. The saving per week was thus about £262. The gain was a double one, because the national interests were served by a material reduction of expenditure and by the conservation of a commodity of vital use to the country in the throes of war. Moreover, the water as supplied to consumers has been even safer, as judged by the tests employed, than is customary, and free from any smell, taste or noxious ingredient.

As regards the bacteriological results, reference must be made

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[1] It may be asked, why was the *filtered* water not chlorinated. Apart from the fact that this would have entailed the use of five separate chlorination plants, the works in question were but ill adapted for any such treatment.

[2] Also called "hypochlorite of lime" or bleaching powder.

to the writer's Twelfth Research Report, but a few particulars may be given here. It should be noted specially that absolute uniformity of result was not so much aimed at as bringing the raw water to a *purer* condition, on the average, than if it had undergone prolonged storage.

On the average, Thames River water contains *B. coli* in 1 c.c. in 89 per cent. and in 0·1 c.c. in 52 per cent. respectively of the samples examined.

After storage, it is improved over one hundred times, the percentage number of samples containing *B. coli* in 100 c.c. and in 10 c.c., being 80 and 40 respectively.

In other words, there are fewer positive results after storage, even when using 100 times as much water for cultural purposes.

The sterilization treatment of the river water[1] (June to September, 1916) achieved still better results.

The figure of 80 per cent. "positives" for the 100 c.c. cultures was reduced to 24 per cent., and the figure of 40 per cent. "positives" for the 10 c.c. cultures was reduced to 3 per cent.

Since October, 1916, to date (January, 1917) it has not been possible to continue the treatment uninterruptedly, owing to flood water. During these breaks in the continuity of the treatment, untreated stored water has been used in place of treated river water, and this stored water may be assumed to have been even safer epidemiologically than usual, owing to its having been stored for a much longer time than is customary.

The results of some laboratory investigations may also be touched upon. It appears that, *within certain limits*, cold and darkness rather operate against, and that warmth and light rather favour sterilization, under laboratory conditions of experiment.

The potassium iodide and starch solution test for free chlorine has not been found to be an altogether reliable guide to sterilization, especially if no account is taken of light and temperature.

A blue colour after five hours' contact may, in most cases (provided the water is not very cold), be taken to imply sterilization, but its absence in that time does not necessarily mean that sterilization has not taken place.

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[1] There were two separate plants, one at Staines and one at Hampton. The latter results are here given, because in the former case the results were to some extent prejudiced by contaminating influences affecting the water between the place where the water was being treated and the place of collection of the samples.

A blue colour after one hour's contact is certainly no criterion of sterilization, although its absence in that time, at ordinary temperatures, almost certainly implies that sterilization has not taken place.

Inasmuch as light and heat seem to favour sterilization and also to reduce the time during which a blue colour may still be obtained, it is obvious that these factors must be taken into consideration in the interpretation of results. Thus a blue colour persisting for some time in cold weather might mean very little, but the same result occurring under warmer conditions might suggest sterilization.

A chlorinated water inhibits algal and other growths to a very considerable extent (as had previously (1905) been observed at Lincoln), but the restraining influence seems to pass off, so that from this point of view it is disadvantageous to allow treated water to pass through too large reservoirs before being filtered.

Duration of contact is most important; thus multiple laboratory experiments with Thames River water show that better results are obtained with half the dose in five hours than with the full dose in one hour. Prolonged contact is to be advocated under all conditions, but its adoption in cold wintry weather is of vital importance. Indeed, it is not too much to say that when the Thames River water is near the freezing-point, sterilization with the *minimum* dose capable of effecting sterilization requires a contact of from twenty-four to forty-eight hours, as judged by laboratory experiments. Under these low temperature conditions sterilization cannot take place in a short period, unless an overdose is used, which means that the consumer is liable to receive a water containing active chlorine and having probably an objectionable taste as well.

The following diagram serves to illustrate two points, namely, that a positive reaction with the potassium iodide and starch test in one hour is no evidence of sterilization, and that at least five hours' contact should be given.

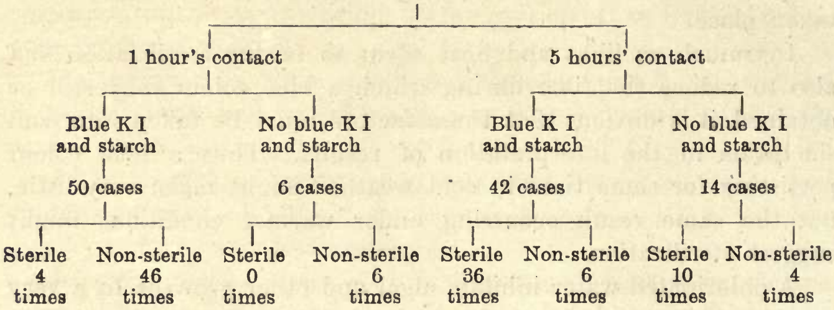
It will be noticed that a blue reaction was obtained in fifty out of fifty-six experiments in one hour, and yet sterilization occurred only four times.

On the other hand, with five hours' contact, sterilization was associated with a blue reaction in thirty-six out of forty-two experiments. In the remaining fourteen cases sterilization occurred ten times despite the loss of a blue reaction.

RAW RIVER WATER TREATED WITH HYPOCHLORITES.

Dose : 1 in 1·5 millions.

FIFTY-SIX LABORATORY EXPERIMENTS.



LIQUID CHLORINE.

Liquid Chlorine is now being used on a large scale in the United States, and the advocates of this method of sterilization consider it superior to hypochlorites for a variety of reasons.

Hale[1] summarizes the advantages liquid chlorine has over hypochlorite of lime as follows:—

"(1) Compact installation; (2) 90 per cent. less storage space required for chemical; (3) no loss of strength of chemical during storage; (4) no sludge problem; (5) no residual hypochlorite in water, hence less corrosive effect, no complaint of odour, and less danger from overdosing; (6) more effective per unit applied; (7) more uniform application; (8) better and easier regulation; (9) easier to handle generally and less obnoxious; (10) no increase of hardness in water; (11) labour cost less and chemical more efficient, making total cost about equal."

The writer, of course, does not necessarily endorse all these statements; Nos. 5, 6 and 11 appear, in particular, to be open to some doubt. Papers written on this subject are not always easy to follow. As bleaching powder (hypochlorite of lime) contains only about 33 per cent. of available chlorine it is obvious that, even with perfect mixing operations and assuming equal efficiency, three times as much of it must be used as in the case of liquid chlorine. Yet, not infrequently, the comparison is allowed to drift from available chlorine to hypochlorite of lime, which stand related as

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[1] Proceedings of the Fortieth Annual Meeting of the New Jersey Sanitary Association, Spring Lake, December 11, 1914.

1 to 3, in such a puzzling fashion that it is difficult to know precisely which is meant in relation to each isolated statement.

The writer has only had one opportunity of testing a sterilization plant working with liquid chlorine, and the results obtained were set forth on page 21 of his Twelfth Research Report, and may, with advantage, be repeated here:—

"The water being dealt with was pumped under pressure through a sand filter, working apparently at the high rate of 65 gallons per square foot per hour. It was then treated with chlorine in a closed vessel, the period of contact being stated to be only twelve minutes. The chlorine gas from the liquid chlorine, contained in a metal cylinder, was passed through an ingenious contrivance, which maintained a constant gas pressure. The gas passed out of the apparatus through a minute orifice and a manometer registered the dose. By a throttling device the dose could, within certain limits, be varied at will; the current dose being indicated on the specially calibrated scale of the manometer. The difference between the dose as determined by manometer readings and the dose as judged by gravimetric determinations of the loss of weight of the cylinder during trial "runs" is said never to exceed 3 per cent.

"The gas escaping from the above apparatus passed along a pipe to a porous diffuser contained in the water to be treated.

"(*a*) The *raw* water contained 120 excremental microbes per cubic centimetre (bile-salt agar test).

"(*b*) It yielded positive *B. coli* results with 0·1 c.c. (liquid lactose peptone bile-salt medium).

(*c*) The oxygen absorbed (5 minutes at 80° F.) figure was 0·319 parts per 100,000.

"After passing through the pressure filter the results for tests (*a*), (*b*), (*c*), were 150, 0·1 c.c., 0·291 respectively.

"Four series of experiments were carried out, the reputed dose of chlorine being 0·5, 1·0, 2·0, and 3·0 parts per million parts of water. Three 100-c.c. cultures were made on the spot at five-minute intervals for each of the above doses (twelve cultures in all), and at the same time twelve duplicate sterile bottles were completely filled with the effluent water, with the object of testing their contents after the lapse of five hours.

"It has been stated that one of the advantages of the use of liquid chlorine for sterilization purposes is that the sterilizing action is practically instantaneous. The results of the experiment do not support this contention, for it was found that all the twelve cultures made on the spot (i.e., after twelve minutes' contact) yielded positive *B. coli* results, with the exception of one of them belonging to the maximum dose; whereas the duplicate samples, after being bottled up for five hours, all gave negative results, with the exception of one of the bottles pertaining to the minimum dose of 0·5 part per million parts.

"Assuming the doses to be really as stated, the results seem to indicate that an impure water can be sterilized with a dose of about 0·5 to 1·0 part per million parts in five hours.

"A dose, however, of as much as three parts per million parts was ineffective (two out of three cultures) with only twelve minutes' contact."

It is a little difficult to understand why the available chlorine of hypochlorite of lime should give inferior results to liquid chlorine when the dose is the same in both cases.

Thirty experiments carried out in the laboratory with raw Thames River water, using chlorine water and hypochlorite of lime solution in the same dose, as judged by the available chlorine, yielded the following results:—

Dose 1 in 1 Million.—In one hour sixteen samples were sterilized in each case. In five hours twenty-nine samples were sterilized in each case.

Dose 1 in 1·5 Millions.—In one hour six samples were sterilized in the case of the chlorine water, and two samples in the case of the hypochlorite solution. In five hours twenty-seven samples were sterilized when using chlorine water, and twenty-six when employing hypochlorite solution.

Dose 1 in 2 Millions.—In one hour one sample was sterilized by the chlorine water, and none by the hypochlorite solution. In five hours twenty-three samples were sterilized in the case of the chlorine water, and seventeen samples in the case of the hypochlorite solution.

The experiments bring out several points; for example, the great importance in both cases of allowing the sterilizing agent to act for five hours instead of one hour.

The chlorine water appeared to act a little quicker and a little more effectively, but the differences were so slight as, perhaps, to be covered by the errors of experiment.

Possibly the chlorine water would have shown better results, *relatively*, if the duration of contact had been shorter, but in the writer's experience a short exposure is to be avoided as involving unnecessary doses of the germicidal agent.

Since this chapter was written, the attention of the writer has been drawn to some highly instructive experiments carried out by C. R. Avery.[1] The investigation was conducted with the idea of ascertaining what, if any, difference existed between the disinfecting quality of bleaching powder and liquid chlorine when used in water treatment.

The conclusion reached was that "*if a normal water supply be treated with the same amount of available chlorine, whether derived from bleaching powder or liquid chlorine, and provided proper mixing takes place, the disinfection in either case will be the same.*

In conclusion, it is of interest to note that recent work by Le Roy has shown that the iodide-starch test is far more sensitive when the chlorinated water is cooled below 10° C. before applying the test. Further, a new reagent has been described, which is more delicate than the iodide-starch test, and it works better at 20° C. than at 10° C. [*Compt. rend.*, 1916, 163, 226].

The writer is not pledged to support sterilization or any other special method of water purification. At the same time he feels that the War has taught us many lessons, including the necessity of subordinating sentiment to expediency. Pure water is a prime necessity of life, and the writer should be the last to preach a gospel entailing any diminution of security. Nevertheless, there are cases when safety may actually be increased and expenditure reduced in connection with water supply; and it has been his aim to indicate broadly some of the directions in which, possibly, progress may be made.

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[1] Provincial Board of Health, Ontario, "Canada Annual Report for 1914.

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