THE PRESENT AND PROPOSED FUTURE WATER SUPPLY OF THE CITY OF PHILADELPHIA.

By Dr. Albert R. Leeds.

This inquiry was entered upon in January, 1883, at a time when the taste and odor of that portion of the water-supply taken from the river Schuylkill (the remainder being from the Delaware river) were so nauseous that it was non-potable. This preliminary investigation was devoted entirely to the question of determining the origin of this taste and smell. In its conduct I found that the determinations ordinarily made in the course of water analysis were of no value so far as the settlement of the question at issue was concerned. They showed very strikingly that a large amount of sewage was present, but this was no new fact; the sewage, in quite as large amounts, being present at other seasons when the taste of the water was excellent and when the water had no odor. The circumstances which were unusual and which presumably had a bearing upon the problem were the three following:—

1st. The flow in the Schuylkill river had been much less than the usual minimum both during the preceding Autumn of 1882 and ever since winter had set in, and the rain fall in the valley of the Schuylkill had not been more than half of what is usual during the same period.

2d. During this period of extremely low water, the river, the long line of canals following its banks, the many dams in which the water was impounded for the use of the Reading Canal Co., and the tributary water-courses, were covered with a thick coating of ice.

3d. Whilst the main river was thus ice-covered the canals and eleven dams were drawn and their waters went down the river, as it were, through a covered sewer and without access of light and air.

Finding that the ordinary course of water-analysis was of no avail, I had recourse to determinations of the temperatures and densities of the water at the top and bottom of the stream. From these it appeared that the temperature of the water in the Schuylkill in mid-winter and when the river had been for some time entirely covered with ice, was about one Fahrenheit degree above freezing-point at the surface, and about 1.4 degrees above freezing

point at the bottom, or four-tenths of a degree warmer. Furthermore, that connected with this difference of temperature there was a corresponding difference of density, from which a resulted that there was a current of colder water flowing immediately beneath the ice and another current of warmer water, but of greater density and probably flowing much more slowly at the bottom of the stream.

Inasmuch as it appeared probable that the taste and odor were due to putrefactive changes which could not fail to affect the percentages of dissolved gases in the water, and inasmuch as the conditions affecting the aeration of a flowing stream were necessarily essentially different when this stream had been sealed in for months with a coating of ice, from the conditions affecting it during the remainder of the year, I deemed it of the greatest importance to determine the percentage of dissolved gases. Herein I found the solution of the problem. The percentage of oxygen was much smaller in all the samples than its percentage under normal conditions, and diminished in amount as the water encountered larger and larger amounts of sewage in its approach to the city. It was only 5.64 cubic centimeters per liter in the best water examined (that taken from the bottom of the river at Roxborough Pumping Station, above all city sewers), and only 4.34 cubic centimeters in the sample from the surface at Spring Garden Station. Furthermore all the samples taken from the bottom of the river contained more oxygen than those taken from the top immediately below the ice. This result startled me at the time, there being no literature on the subject so far as I was aware, but similar results have subsequently been obtained. They led, in connection with the other factors of the sanitary analyses of the Delaware river at the Kensington Pumping Station at a later date, to the abandonment of the surface intake and the construction of a trunk 200 feet in length reaching along the bottom of the stream into the thread of the current.

The foregoing analytical data led to the performance of the following laboratory experiments. A liter of water from the bottom of the river at the Spring Garden Station was aerated by prolonged contact with a current of air at ordinary atmospheric pressure. Its percentage of air was raised from 4.41 c. c. to 6.3 c. c. Another liter was aerated by exposure to the air for a number of days in flasks plugged with cotton wool. Its dissolved oxygen was increased to 6.2 c. c. per liter.

These aerated samples were afterwards subjected to sunlight in the presence of nitrate of silver, when it was found that the amount of oxygen required to oxidize the organic matter in that portion of the Spring Garden water which had been aerated by a constant current of air had been reduced from 0.218 part in 100,000 to 0.044 part. The required oxygen in the other portion, aerated merely by exposure, had deen reduced from 0.218 part to 0.103 part. I simply record here the chemical data obtained at that time, and which were relatively then of much greater import than they are now. They led to a prolonged series of experiments, still in progress, between the connection existing in the amounts of dissolved gases, the nature and amounts of sewage constituents, and the relative abundance of bacterial life. They also led, in the sequel, to the adoption of aeration by proper engineering appliances at Hoboken, Philadelphia, Brooklyn and other places in this country.

The final conclusion and the interpretation of the observed phenomena were embodied in a report to the Board of Experts then engaged in an examination of the Philadelphia water-supply. After pointing out the fact of the anomalous accumulation of the products of decomposition, the free ammonia exceeding the albuminoid, and the albuminoid steadily increasing in the course of the flow of the water down the river; the fact of the reduction of the nitrates to the form of nitrites, and the progressive increase of the latter; the fact of the progressive increase in the percentages of chlorine; the fact of the deficiency of oxygen in all the samples examined; the fact of the more complete oxidation of the decomposable organic matter when the samples were allowed to absorb their full complement of oxygen—all of these facts, and the origin of the nauseous taste and smell, I connected with the state of partial or arrested oxidation and of incomplete aeration at that time existing. Moreover, I stated that the bodies which gave rise to the non-potability were products of decomposition of organic substances contained in the water or deposited as sewage-mud at the bottom of the stream, the nature of these bodies being determined by the fact of their being formed by processes of putrefactive decay out of contact with oxygen. Under these conditions it is well known that hydrocarbons belonging to several isologous and homologous series are formed, the lower members of which are gases; the members of greater molecular condensation oils, and the highest solids. As a

matter of fact the combustible gases present beneath the ice were so large in amount that when openings were made and a match applied, the flames arose to a considerable height. And the general complaint throughout the city was that the water possessed a nauseous oily taste and smell, these properties being so persistent as to be communicated to the food cooked in the water, and to be readily noticeable in house and kitchen where culinary operations were being carried on.

Fortunately for the best interests of the city of Philadelphia, the eminent engineer, Col. W. Ludlow, was placed at the head of its water department during the Spring of 1883. This gentleman forthwith instructed me in colaboration with Mr. Rudolph Hering, C. E., to enter upon the examination of all the streams in Eastern Pennsylvania which appeared available for future water supply. Referring to the magnitude of this survey, the chief engineer stated :—"The area of country to be examined, whether by accurate surveys or reconnoisances, is larger than ever has been attempted in this country and, in this connection, a comparison of the necessary extent of the Philadelphia surveys with those made by other cities will be instructive."

New York has a topographical area to be covered of about 2,000 square miles, of which 100 have been mapped and 250 carefully reconnoitred.

Of the Baltimore surveys only the Gunpowder project, which has since been successfully completed, was seriously considered and the length of the conduit was seven miles only.

In Boston the areas surveyed were about 50 square miles, and examinations were made of a total of about 5,500 square miles. The length of conduit line was 15¼ miles.

The Philadelphia investigation required the careful survey of 468 square miles, conduit lines, 183 miles, and a general examination of about 6,500 square miles. It has been prosecuted without interruption during the past three years, and is now, so far as the chemical investigations are concerned entirely, and so far as relates to the engineering data, nearly concluded. Along with the chemical and engineering work, sanitary surveys were carried on to locate and tabulate the sources of all polluting agencies, whether from sewage, manufactures or agriculture.

The watersheds compared in this manner were those of the Schuylkill, the upper Lehigh, the Perkiomen, and the Delaware, together with the Tohichon, Neshaminy and other affluents of the last named river. The first step in the investigation was made in the Spring of 1883 by preliminary surveys and analyses of all these streams, the samples being collected by the various surveying parties on the same date. These preliminary surveys resulted in excluding from the necessity of future consideration a large number of streams, and in permitting future study to be concentrated on those which remained. Thus, of the streams included in the watershed of the Perkiomen river, the Skippack, the West Swamp Creek and the Northeast Branch were found to be inferior, as regards quality of water, to the East Swamp Creek and to the Perkiomen itself above Zeiglersville, and above Green Lane. The first three mentioned were also inferior to other available sources mentioned later on, so that, for these reasons, future analyses of the Perkiomen water were restricted to samples taken above Zieglersville and Green Lane. An investigation of the upper waters of Lehigh river and of Tobyhanna Creek showed that these were so pure, and so unexposed to future contamination, that their purity was established and needed no further confirmation.

The sanitary analysis of the Tobyhanna (Sept. 10th, 1883), which was regarded as the purest water examined during the entire course of the investigation, afforded the following figures:

	Parts per 100,000.
Free Ammonia	0.002
Albuminoid Ammonia	0.0105
Oxygen required [Permanganate]	0.25
Oxygen required [Silver]	0.187
Nitrous Acid	none
Chlorine	0.20
Hardness	2.1
Total Solids	3.5

I speak of this as the purest water, although many other analyses are given in the reports of this survey in which much lower percentages of albuminoid ammonia will be found than what is above stated. And in this connection it is interesting to note the relative composition of river, snow and rain water. Thus, taking the Dela-

ware at the Water Gap, which is a point above the influx of sewage, I find the following:

	Delaware above, Water Gap, Nov. 10, 1883.	Snow water, Hoboken, Feb. 6, 1884.	Rain water, Hoboken, Feb. 17, 1884.
Free ammonia	9.002	90.04	0.04
Albuminoid ammonia	0.014	0.015	0.0145
Oxygen required [Permang.]	0.15	0.15	2.31
Oxygen required [Silver]	0.25	0.13	0.037
Nitrous acid	none	0.0004	0.0005
Nitric acid	0.27	0.09	0.01
Chlorine	0.20	0.55	0.20
Total solids	5.00	3.50	11.50
Diss. oxygen per liter	5.50 cc	6.00 cc	6.00 cc

These results are not peculiar to atmospheric conditions in this country. A still higher result for the free ammonia (0.05 parts per 100,000) was obtained by the Royal Rivers Pollution Commission from seventy-three analyses of rain, all collected, with two exceptions, in the country at Rothamsled. The same series gives for the chlorine 0.63 parts per 100000. In the reports on "The Composition and Quality of the water supplied to London," from December 20, 1880, to November 31, 1881, I find among hundreds of analyses of the seven London companies, in the majority of samples, *no ammonia whatsoever.* The largest amount reported is 0.004 parts per 100000, and this is attained in very few instances. At the same time the nitric acid in these London waters is enormous, frequently exceeding 1.4 parts 100000.

Finding so considerable an amount of free ammonia in rain and snow. I was interested to know the percentage in ocean water, and to settle this point I obtained a sample, five miles south of Barnegat and seven miles East of the New Jersey coast, in eight fathoms of water. It contained:

	Ocean Water.
Free ammonia	0.00 parts.
Albuminoid ammonia	0.013 "
Oxygen required [Permang.]	0.22 "
Oxygen required [Silver]	0.25 "
Nitrous acid	0.00 "
Nitric acid	0.018 "

Comparing these results with those obtained in hundreds of cases for the streams analyzed, it was evident that a fall of rain might increase rather than diminish the apparent contaminations, and that the composition of rain water was of no service in studying the question of purity in surface waters.

A preliminary analytical examination of the Schuylkill River waters demonstrated that there would be no advantage in multiplying the points at which samples should be collected, but, on the contrary, there would be great gain in restricting these points to three, viz.: the Phœnixville Pumping Station, the Roxborough Pumping Station, and the Spring Garden Pumping Station; the first as representing the best water obtainable from the Schuylkill, and the second and third, the relative amounts of deterioration at these two actual sources of the city's supply, respectively. By such restriction the frequency and thoroughness of the comparison were greatly increased.

The preliminary surveys and analyses of the Delaware River, from the Water Gap down to Kensington Pumping Station, showed that the difference in quality between the water at the two extreme points is great, and resulted in a recommendation to abandon the intake located at the latter point. Furthermore, whilst omitting the future study of the water at Kensington for the reason mentioned, it was shown to be desirable to make systematic analyses of the Delaware at Frankford, at Point Pleasant, and at the Delaware Water Gap, and also of certain tributaries of the Delaware of promising quality, more especially of Neshaminy, Tohickon, and Mill Creeks.

The third step was the systematic weekly comparison of the waters of the Delaware River with those of the tributaries mentioned, and with those of the Schuylkill River, and of the Perkiomen. The places from which the samples were taken were fourteen in number, and the comparison extended from the month of April, 1884, to the close of December in that year. These comparisons established the following points:

1st. That the waters of the upper Delaware at the Water Gap, and at Point Pleasant, those of the Schuylkill above Phœnixville, and those of Mill Creek, Tokickon and Neshaminy Creeks, can all be placed in the category of wholesome and palatable waters, their relative quality being in the order mentioned. Apart from sanitary

considerations, the Phœnixville water had the disadvantage, in common with the Schuylkill supply in general, that it is not so soft as the waters of the Delaware, Perkiomen, and their tributaries.

2d. The Perkiomen waters are inferior in quality to those mentioned above.

3d. That the water supply from Spring Garden and Fairmount is very variable in quality, sometimes yielding favorable results on analysis, at other times showing gross pollution.

The conclusions above formulated have been confirmed by the work subsequently performed, this work being principally devoted to the following topics:

1st. To the amount of deterioration of the Schuylkill River in the course of its flow from Phœnixville to the Spring Garden Pumping Station.

2d. To the degree of pollution of the Schuylkill River water at Spring Garden Pumping Station at various times and seasons.

3d. To discover whether the Delaware River at a point opposite Yardleyville had the same characteristics as to wholesomeness and purity as it exhibits at Point Pleasant.

4th. To certain simultaneous chemical and biological analyses of the waters of the Schuylkill, Perkiomen, and Delaware Rivers.

5th. To experiments upon the improvement of the present water supply.

I.

Amount of Pollution of the Schuylkill River in the course of its flow from Phœnixville to Fairmount.

No plan can be adopted more liable to lead to erroneous results than that of basing conclusions as to the character of waters in flowing streams upon the testimony of a few isolated analyses. For this reason the waters herein reported upon have been compared under the most dissimilar conditions with regard to volume of flow, rainfall, etc. For purposes of comparison, it would have been somewhat more satisfactory to have the averages made out upon the same number of samples in every case, and to have had each set of samples collected simultaneously under identical conditions. But the latter achievement was practically impossible, and even as they stand these averages have great value. For, in the first place, they are computed upon the results of analyses of a

large number of samples; and, in the second place, they represent a comparison extended through all seasons of the year, and that too for three consecutive years. As the labor of computing these averages was very considerable, only a limited number of the constituents which were determined in the course of analysis are represented in the accompaning table:

SCHUYLKILL RIVER.

Average Results of Analyses.—[Parts per 100,000.]

	Phœnixville Pumping Station.	Roxborough Pumping Station.	Spring Garden Pumping Station.
Number of samples	17	21	59
Free ammonia	0.0035	0.0048	0.008
Albuminoid ammonia	0.0097	0.014	0.015
Nitrous acid	0.00012	0.0006	0.0006
Nitric acid	0.369	0.435	0.39
Oxygen required to oxidize organic substances	0.188	0.229	0.22
Chlorine	0.324	0.346	0.523
Total solids	13.32	12.67	11.95

Along with the analyses of the waters of the Schuylkill I give the mean of 44 analyses of the Delaware River at Byram or Point Pleasant:

DELAWARE RIVER AT BYRAM (POINT PLEASANT).

Average of 44 samples.—[Parts per 100,000.]

Free ammonia	0.0028
Albuminoid ammonia	0.00988
Nitrous acid	0.00002
Nitric acid	0.254
Oxygen required to oxidize organic substances	0.315
Chlorine	0.266
Total solids	6.88

Now it will be noted that there is a sudden break or difference in the character of the Phœnixville samples as compared with those taken at the two lower points on the stream. The percentage of free ammonia rises abruptly 37 per cent., that of albuminoid ammonia 44 per cent., that of nitrous acid 400 per cent., that of nitric

acid 18 per cent., of oxygen required to effect the oxidation of organic substances 22 per cent., and of chlorine 7 per cent.

The origin of this abrupt alteration in character is in part attributable to the impurities entering into the Schuylkill River from the population located upon its two banks, beginning with the 7,500 inhabitants of the borough of Phœnixville, down to the Roxborough Pumping Station. But a much more potent factor in bringing about this change of character in the Schuylkill River waters is the influence of the drainage from the Perkiomen water shed. This is best seen by comparison of the figures given below, which represent the composition of the Perkiomen waters at Zieglersville and Green Lane, and also the general average for the entire 24 samples.

PERKIOMEN WATER SHED.

[Parts per 100,000.]

	Zieglersville.	Green Lane.	Mean.
Number of samples	11	13	24
Free ammonia	0.003	0.0043	0.0037
Albuminoid ammonia	0.017	0.015	0.016
Nitrous acid	0.00009	0.000176	0 00013
Nitric acid	0.343	0.36	0.352
Oxygen required to oxidize organic substances	0.343	0.293	0.316
Chlorine	0.425	0.39	0.406
Total solids	10.31	9.88	10.08

It should be borne in mind that the average for the Perkiomen water shed excludes the results obtained by the analysis of samples from the Skippack, the West Swamp Creek and the Northeast Branch, these figures having been previously set aside, on the testimony of the preliminary surveys, as unworthy of comparison with those of the Schuylkill above Phœnixville, the Delaware at Byram, and the Perkiomen at Zieglersville and Green Lane. And whilst the Perkiomen at the two points last mentioned is frequently limpid and exhibits little or no color, after it has received the drainage from its affluents it pours a turbid tide into the Schuylkill, so that the junction of the two streams becomes very apparent to the eye.

Yet even without including the deterioration of the Perkiomen in the lower portion of its course, the averages given above show that

its entrance into the Schulkill River must necessarily bring about a considerable alteration in the composition of the latter. Thus the amount of albuminoid ammonia in the Perkiomen waters is usually relatively high. Its average quantity (0.016 parts) is not very different from the average of this constituent at Roxborough, whilst it is considerably higher than the percentage in the Schuylkill about Phœnixville, which is 0.0097 parts. Another characteristic of the Perkiomen waters is that the oxygen required to effect the oxidation of the organic matters contained in them, is ordinarily greater than in the Schuylkill waters. In this respect we have an average in the Perkiomen of 0.316 parts, as against 0.188 parts above Phœnixville. This increment is largely due to decaying vegetable matters, and is markedly apparent especially in the Summer months and in Autumn, in the waters of streams draining extensive areas of alluvial lands. In this respect the waters of the Delaware River compare more closely with the Perkiomen than they do with the Schuylkill, as will be seen by inspection of the various analyses of these streams. But it would be absurd to suppose that such an increment in the gross amounts of oxidizable matter in the Perkiomen was attended by any corresponding increment in the quantity of fresh sewage. And in this connection the figures for the relative amounts of nitrous acid which are indicative of the quantities of fresh sewage entering the streams, are eminently suggestive. For these amounts are about the same in the Perkiomen waters as they are in the Schuylkill River above Phœnixville, whilst below Phœnixville, at Roxborough, at Spring Garden and at Fairmount the average amounts of nitric acid are more than twice as great.

Leaving now the comparison of the Roxborough samples with those of Phœnixville, let us pass to the comparison of the former with those of Spring Garden. It will be noted, in the first place, that the free ammonia is 67 per cent. greater at Spring Garden than at Roxborough; the albuminoid ammonia only 7 per cent. greater; the quantities of nitrous acid are the same; the nitric acid and oxidizable organic matters are less. The most significant increase is found in respect of chlorine, which is 0.175 parts more at Spring Garden than at Roxborough. The peculiar importance of this large absolute increase is due to the fact that chlorine is an invariable constituent of sewage. Furthermore, the compounds of

chlorine are mineral substances, and differ from the organic constituents of sewage in being incapable of destruction by oxidation. Hence it is that every increment of sewage to the waters of a flowing stream is represented by a permanent increase in the percentage of chlorine. On the other hand, such increments may not be represented by a permanent increase in the organic constituents, the latter being represented in the analysis by the ammonia, nitrogen acids and oxidizable organic substances. Instead of an increase, the factors representing the organic constituents may actually diminish in amount. They increase when the processes of natural oxidation in a flowing stream are inadequate to cope with the burden of sewage, whilst they diminish (even though the absolute quantity of sewage added is very large), when the reverse is the case. But in either event the percentage of chlorine goes on steadily increasing.

These various phenomena are strikingly exemplified in the present instance. The chlorine increases steadily, the increase between Roxborough and Spring Garden being 51 per cent., whilst the free ammonia increases 67, and the albuminoid ammonia only 7 per cent. It may properly be objected to this explanation of the increase in the percentage of chlorine, that this substance is contained, in the form of common salt and other chlorides, in the refuse of many factories. But, whilst a portion of the increase is due to manufacturing establishments, yet another large portion is unquestionably due to sewage ; for were it all due to factory waste, then the total amount of solids in solution would increase in the course of flow past Norristown, Manayunk, Falls of Schuylkill and other points. As a matter of fact, such is not the case ; it is chlorine, or the non-oxidizable constituent of sewage, which alone of all the other factors shows a considerable increase in flowing past these points.

The facts above stated are in exact harmony with those which the author found to be true of the sewage polluted water of the city of Albany, the investigation having been made during September and October of this year, under instructions from the Special Water Commission of that city. For whilst a considerable volume of sewage enters the Hudson River at Troy, which is located 7 miles above Albany, and at a number of points below Troy, progressive oxidation and destruction of the organic constituents of this

sewage occur in the course of its flow down the river, whilst *the percentage of chlorine goes on regularly increasing.*

Certain conclusions of the greatest importance follow from the facts dwelt upon above, and whilst a portion of the evidence upon which they are based is connected with certain biological inquiries detailed later on, yet it is expedient to follow the preceding discussion with an immediate statement of the resultant conclusions. They are :

1st. That there is no point on the Schuylkill River from Phœnixville down to Fairmount, where incompletely oxidized sewage, that is to say, sewage in a more or less decomposed and noxious condition, is not revealed by analysis to be ordinarily present in the water.

2d. The condition of the Schuylkill River at Roxborough cannot be taken as representing the composition of unpolluted Schuylkill River water. The composition of the water at Phœnixville is very different and very much superior, and whilst the Phœnixville water is not at all times and seasons satisfactory, yet its average quality and purity are such that I have taken it throughout as the basis of comparison for the Schuylkill River samples. That its selection as a basis was justifiable and correct, is abundantly shown by the superiority evinced by the figures given for the average composition of the Schuylkill River at this point, as contrasted with those at Roxborough.

3d. The difference in regard to quality between the water at Roxborough and at Spring Garden, is small, the superiority as a general rule being on the side of the Roxborough samples, so that the average quality of the Roxborough water is slightly better than that of the Spring Garden water. This is not always the case, for the following reason :

4th. Owing to the natural processes of oxidation in the course of flow, it sometimes happens that the water at Spring Garden shows a smaller quantity of non-oxidized sewage than at Roxborough. In fact, were the sewer so far completed as to intercept the sewage from Manayunk down, this occasional superiority of the Spring Garden water would be both natural and permanent.*

* The tables of analytical data are omitted for want of space. ED.

II.

The great variations in quality of the Schuylkill River at the Spring Garden Pumping Station.

I have repeatedly called attention to this point, the variations in quality being so great, that very many analyses of the Spring Garden water can be found in my various reports, which compare favorably with those of the best water supplies in the United States, while many others, on the contrary, show the fact of gross pollution in the most unmistakable manner.

Instead of appealing to impressions gathered from cursory examinations of elaborate and perplexing tables of figures, I can best establish this point by comparing the average composition of the Spring Garden water, with its extreme variations, and with the number of times each constituent exceeds or falls below the average. This latter datum is of even more significance than the amounts, by which the maxima and minima differ from the mean results.

VARIATIONS IN COMPOSITION OF THE SPRING GARDEN WATER.

	Average of 59 samples.	Maximum.	Minimum.	Above average.	Below average.
Free ammonia	0.008	0.019	0.0005	21	37
Albuminoid ammonia	0.015	0.031	0.0085	23	31
Nitrous acid	0.0006	0.01	none	13	36
Nitric acid	0.39	0.80	0.09	36	23
Oxygen required to oxidize organic substances	0.22	0.96	0.08	20	35
Chlorine	0.523	1.00	0.175	29	29
Total solids	11.95	19.00	6.00	25	33

From this table it will be seen that were the character of the Spring Garden water sought to be established by the favorable analyses, it would rank very high indeed, whilst if the desire were to vilify it, abundant disparaging testimony could be gathered from the list of maximum figures. Furthermore, the maximum free ammonia exceeds the average 137 per cent., whilst the minimum is 94 per cent. below it. The maximum albuminoid ammonia exceeds the average 107 per cent., the minimum falls below it 43 per cent. These various considerations establish in the most forcible manner, the fact of the great variability in composition of the Spring Garden samples.

But irrespective of the circumstance that either a very good or a very bad character might fairly be ascribed to it, in case isolated samples were made use of, yet the fact remains that its average composition, as deduced from no less than 59 samples, shows not only the certainty of sewage contamination, but also that the average amount of this sewage contamination is considerable.

III.

Yardleyville or Byram.

I present, in the accompanying table, comparative analyses of the samples taken during the last two weeks of October, and the first week of November, these analyses having been made with a view to determining the relations in quality between the waters of the Delaware River at Yardleyville, and as they are at Byram, and of these again with those of the Schuylkill River at Spring Garden forebay. In order more readily to discuss the results, I have epitomized them in the following table of averages:

	Delaware River.		Schulkill River.
	Byram.	Yardleyville.	Spring Garden.
	Parts per 100,000.		
Free ammonia	0.004	0.005	0 011
Albuminoid ammonia	0.016	0.014	0.014
Nitrous acid	none	none	0.0011
Nitric acid	0.12	0.13	0.21
Oxygen required [Permang]	0.48	0.45	0.27
Oxygen required [Silver]	0.38	0.35	0.33
Chlorine	0.275	0.283	0.575
Hardness	3.3	3.37	7.10
Total solids	6.30	6.53	14.07
	Cubic centimeters per liter.		
Dissolved oxygen	4.39	3.52	4.52
" carbon dioxide	1.49	1.43	1.31
" nitrogen	15.39	17.33	13.20
" total gases	22.27	22.28	19.03
Temperature, Fahrenheit	52°.2	52°.8	55°.3

As between Byram (Point Pleasant) and Yardleyville, these results show that there is but little difference as to quality. The most striking difference between them is connected with a process of oxidation taking place between the two points, this process

resulting, as would properly be expected, in an increase in the amounts of free ammonia and nitric acid, and a diminution in the amounts of albuminoid ammonia, of required oxygen, and of dissolved oxygen. The percentage of total solids, of chlorine, and of hardness, increases slightly in going from Byram to Yardleyville. These three factors, however, are very small, the total solids at the latter point amounting to only 6.53 parts per 100,000, or 3.8 grains per gallon, as compared with 14.07 parts per 100,000 (8.2 grains per gallon) at Spring Garden ; and the relative hardness to 3.4, as compared with 7.1 at Spring Garden.

The Schuylkill River contains unoxidized sewage, as shown by the considerable amount of nitrous acid and a relatively larger quantity of oxidized nitrogenous matters, its free ammonia being 0.011 parts per 100,000 as compared with 0.004 and 0.005 parts in the Delaware samples, and its nitric acid 0.21 parts as compared with 0.12 and 0.13 parts respectively.

At the season of the year during which these samples were taken, there appears to be a considerable amount of decaying vegetable matter in the Delaware River water, as is shown by the relatively large amount of oxygen required to effect the oxidation of the organic substances, and as evidenced by the smell, which is that of vegetable matter undergoing decay. In the effort of nature to oxidize these organic matters, the oxygen dissolved in the water is largely used up, its average amount at Yardleyville falling 3.52 cubic centimeters per liter. As the season advanced, the amount of dissolved oxygen increased, for while it was only 2 cubic centimeters per liter on October 21st, it became 4.04 cubic centimeters on October 28th, and 4.52 cubic centimeters November 4th. With the disappearance of vegetable matters in streams at the close of autumn, and with the falling temperature of the water, the percentage of dissolved oxygen rises. But the facts above mentioned show the speed with which the water in the Delaware was disposing of the vegetable matters naturally leaching into it during the Summer months. Such matters must always find their way into flowing streams, but they are not dangerous to health, and only temporarily affect the flavor of the water, which returns to its best condition as soon as they are oxidized and eliminated. Similar processes of oxidation were undoubtedly taking place in the waters of the Schuylkill. But that they had not

had sufficient time and opportunity to dispose of the sewage, and that a considerable amount of it remained in a non-oxidized condition is shown, as I have above stated, by the considerable percentage of nitrous acid.

The average temperature of the Byram samples was the lowest, being 52°.2; that of the Yardleyville samples a little higher, or 52°.8, and that of the Schuylkill samples highest, being 55°.3.

An impartial conclusion, therefore, in regard to the points discussed under this third caption, would appear to be as follows, viz.: that the difference in quality between the water at Yardleyville and at Byram is not great, the Byram water being somewhat the better of the two.

Delaware River at the Water Gap, Byram and Frankford.

As the above results at Byram were obtained only for a short period, it will be well, before leaving this part of the subject, to give the average results obtained by a comparison of the Delaware River at various points at very many times and seasons. I append, therefore, below, such a tabular statement of the Delaware averages:

DELAWARE RIVER,

Average results of Analyses.

[Parts per 100,000.]

	Water Gap.	Byram.	Frankford.
Number of samples	13	41	17
Free Ammonia	0.00249	0.0028	0.00385
Albuminoid Ammonia	0.0105	0.00988	0.0149
Nitrous Acid	0.000005	0.000022	0.00004
Nitric Acid	0.2393	0.2543	0.328
Oxygen required to oxidize Organic Substances	0.2892	0.315	0.308
Chlorine	0.227	0.266	0.329
Total Solids	4.910	6.880	8.300

It will be seen from the above that the quality of the water at the Water Gap is superior to its quality at Byram, and both are very much better than at the Frankford Pumping Station.

IV.

Certain Simultaneous Chemical and Biological Analyses of the Waters of the Schuylkill, Perkiomen and Delaware Rivers.

In Table IV. I give a series of analyses of samples collected from the Schuylkill, Perkiomen and Delaware, a duplicate set of samples having been collected at the same time in sterilized flasks, and submitted to biological study.

At Roxborough, Falls of Schuylkill, Spring Garden and the Frankford Pumping Station, water was taken both from the top and from the bottom of the stream. The quality of the surface samples was uniformly inferior to that of those taken from near the bottom, both in the Schuylkill River and in the Delaware. In no respect is the inferiority of the surface samples more strikingly shown than in the quantity of dissolved oxygen, which is least at the surface where the water is in contact with the air. This result is quite unintelligible until we come to the results of the biological examination. So likewise, instead of the greatest amounts of dissolved solid matters being found at the bottom, they are at the top, the excess being due to a corresponding excess of dissolved decomposable organic substances. All of the Schuylkill samples, according to the testimony of the chemical analyses, contain incompletely oxidized sewage, and this fact is connected with their all containing less oxygen than they should contain, provided that the sewage matter had been destroyed and, by processes of oxidation in a flowing stream, the percentage of oxygen had risen to its proper figures.

In estimating the character of the samples from a biological standpoint, I have placed those waters at the top of the list which, in the course of culture experiments, developed the smallest number of micro-organisms.

This order is as follows :

I. Phœnixville and Frankford.
II. Falls of Schuylkill, bottom.
III. Perkiomen.
IV. Roxborough, bottom.
V. Spring Garden, bottom.
VI. Roxborough, surface.
VII. Spring Garden, surface.
VIII. Falls of Schuylkill, surface.

This order does not correspond exactly with the order which I should assign from the chemical data. But it does tally with the statement previously made, that *pari passu* with the deterioration (as evidenced by the chemical factors) produced by the presence of sewage, there is a greater development of bacteria and a more rapid absorption, with a correspondingly large deficiency in the percentage of dissolved oxygen. The importance of not using the surface waters of a flowing stream is very great, since they are, relatively as compared with the under waters, far more impure than is usually supposed. Even where, as at Roxborough Pumping Station, the depth of the river is small, yet the benefit of extending the intake to a point well in the current of the river, and so that the water might be taken about two-thirds of the depth below the surface, would be very considerable.

Weighing the evidence presented by all the data, both chemical and biological, I should infer from the results above detailed that the water taken at the bottom of the Delaware River at Frankford and from the Schuylkill at Phœnixville, whilst they were not of a satisfactory degree of purity, were the least impure of the specimens examined in this series.

V.

Experiments upon the Improvement of the Present Water Supply.

The most important of these experiments are those which have been made upon a large scale by the saturation of the water with dissolved oxygen at the Belmont Pumping Station. At this station the water has been charged with 20 per cent. of its volume of air, the air having been forced by an air compressor into the main leading from the pumping engine to the reservoir at a point in the main just beyond the pumps. I have understood that the people using this aerated water have accounted for its sparkle and liveliness on the supposition that the water was full of sewer gas. As a matter of fact, the water is super-saturated with oxygen, and a lesser percentage of injected air would have been adequate. The following analysis illustrates, in a striking manner, the change of composition in the Belmont water.

The non-aerated sample was collected by Assistant Engineer Lloyd Bankson, at 9:25 A. M., December 24, from the mouth of the forebay of the Belmont Pumping Station. The aerated sample was taken from the mouth of the main delivering the water into the Belmont Reservoir, at 11:20 A. M. on the same day. The former specimen was delivered to me December 25, the latter December 26, but with the cork and seal which secured it partially lifted out by the pressure of the excess of air over that which the water was able to hold in solution.

	Non-Aerated.	Aerated.
Color	0.75	0.50
Taste	Normal	Pleasant.
Smell	Vegetal	None.
Free Ammonia	0.017 parts per 100,000.	0.004 parts per 100,000.
Albuminoid Ammonia	0.011 " "	0.007 " "
Oxygen required to Oxidize Organic Substances	0.133 " "	0.117 " "
Nitrous Acid	0.0008 " "	0.00 " "
Nitric Acid	0.45 " "	0.54 " "
Total Solids	9.00 " "	8.70 " "

Gases in solution, as cubic centimeters per liter:

Oxyen	7.83 cubic cent.	9.54 cubic cent.
Carbon Dioxide	0.65 " "	0.90 " "
Nitrogen	16.31 " "	19.77 " "
Total Gases	24.79 " "	30.21 " "

It will be seen that the albuminoid ammonia has diminished nearly forty per cent., and, what is the most noteworthy feature of all, the nitrous acid has undergone complete oxidation, none being present in the aerated sample. At the same time, by oxidation of the nitrogenous portions of the organic matter, the nitric acid has been increased twenty per cent, and by oxidation of the organic constituents in general, the total solids have been diminished from 9.00 parts per 100,000 to 8.7 parts, and the carbon dioxide has been raised from 0.65 cubic centimeters per liter to 0.90 cubic centimeters.

The same experiment has been in continuous operation in Hoboken for a year and a half, the entire water supply of four million gallons per diem being aerated, although it has been customary to inject air only to the extent of 5 per cent. of the volume of the water pumped. During the whole of that time, the monthly

analyses have shown the aerated water to be of excellent quality. It should be borne in mind also, that the testing of the aerated water taken directly from the outlet of the delivery main into the reservoir, as was done at Belmont, is not a fair index of the total benefit which the water in the reservoir receives. Even under ordinary conditions, water improves on lifting into reservoirs where there is a constant inflow and outflow, a small amount of oxidation and improvement taking place, but the benefit is much greater when the water receives its full complement of oxygen to start with. Where the capacity of the receiving reservoirs is quite large in comparison with the volume of water flowing through them, there is a still further advantage in that, after oxidation of the impurities has occurred, they undergo precipitation and sedimentation along with the suspended earthy matters, so that the clear water racked off from the lees, may be made, and as a matter of fact generally is, superior to the same waters at the time of their pumping from the river.

Conclusions.

1st. The present water supply of Philadelphia is not satisfactory in regard to purity.

2d. The water taken from the Frankford Pumping Station is superior in its average quality to that taken from the Schuylkill Pumping Stations.

3d. The quality of the water in the Schuylkill is very variable, sometimes approximating to a high standard of purity, at other times exhibiting gross pollution and ordinarily revealing the presence of more or less incompletely oxidized sewage at all points after the stream has received the sewage from the borough of Phœnixville down to the Fairmount Pumping Station.

4th. For the above reasons, the supply from the Schuylkill River should either be abandoned or it should be subjected to purification, this purification requiring for its successful accomplishment the following measures, viz.:

(*a.*) The exclusion to the greatest practicable extent of the sewage at present entering the river.

(*b.*) The construction of the intakes in such a manner that surface water should not find its way into the pump wells at the pumping stations. This precaution indeed should be observed on the Delaware River as well.

(*c.*) The thorough aeration of the water followed by storage and sedimentation in reservoirs of large capacity, properly cleansed at reasonable intervals.

(*d.*) The removal of earthy and other suspended impurities by the application of suitable methods of filtration, so that the water may be rendered at all times clear and limpid.

5th. In the selection of a new water supply for the city of Philadelphia, the Blue Mountain tributaries of the Delaware and Lehigh rivers are to be preferred before all others. And whilst of the Delaware River waters, that at the Water Gap is entitled to the first place, that gathered at Byram (Point Pleasant) is uniformly wholesome and of satisfactory purity and quality.

NOTES ON SOME SANITARY EXAMINATIONS OF WATERS.

By E. Waller, Ph.D.

Croton Water.

The results of a semi-monthly examination of the Croton water for the past year are herewith presented as being possibly of some interest to the members of the Society.

In contrasting the results for the last half of 1885 with those given by Prof. Breneman (this journal Vol. VIII., 1) for the same period, some differences are noticeable, no doubt due to differences of manipulation, as well as to difference in location. It may therefore be advisable to state the methods used, though they contain nothing novel.

For *chlorine* one litre of the water was evaporated down to small bulk before making the titration with silver nitrate in the usual manner. By a series of experiments I satisfied myself that a small error was introduced by directly titrating waters as weak in chlorides as the Croton without evaporation. The results on evaporating one litre were, however, found to be identical with those obtained