REPORT

TO THE

HON. SAMUEL H. ASHBRIDGE

Mayor of the City of Philadelphia

ON THE

EXTENSION AND IMPROVEMENT

OF THE

WATER SUPPLY

OF THE

CITY OF PHILADELPHIA

BY

RUDOLPH HERING
JOSEPH M. WILSON
SAMUEL M. GRAY
COMMISSIONERS

PHILADELPHIA
1899

April 6, 1908.

To the Mayor,

City of Philadelphia,

Philadelphia, Pennsylvania.

Dear Sir:-

We should greatly appreciate a copy of Rudolf Hering 's Report on the Extension and Improvement of the Water Supply of the City of Philadelphia, published in 1899, for permanent preservation and active use in this library.

Yours very truly,

Librarian.

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OFFICE OF THE COMMISSION

ON THE

EXTENSION AND IMPROVEMENT

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CITY OF PHILADELPHIA

Philadelphia, September 15th, 1899.

Hon. Samuel H. Ashbridge,
Mayor of the City of Philadelphia.

Sir:—In accordance with a resolution of the Select and Common Councils of the City of Philadelphia, adopted April 20th, 1899, authorizing your Honor to select and employ three experts as a Commission to consider and report upon the question of the improvement and extension of the Water Supply for the City, acting in conjunction with the Director of the Department of Public Works and the Chiefs of the Bureaus of Water and Surveys, your Honor was pleased to name for this purpose, the undersigned, Messrs. Rudolph Hering, Joseph M. Wilson, and Samuel M. Gray, all of whom, after being duly advised, made acceptance of their appointment.

At a conference with the Commission, held on May 9th, the various questions to be considered were very fully discussed, and your Honor outlined what was desired, afterwards incorporating the instructions in a letter as follows:—

[Copy]

OFFICE OF THE MAYOR
PHILADELPHIA

MESSRS. RUDOLPH HERING, JOSEPH M. WILSON
AND SAMUEL M. GRAY,

Commission to Investigate the Extension and Improvement of Philadelphia's Water Supply.

May 18, 1899.

GENTLEMEN:—The Director of the Department of Public Works, Mr. William C. Haddock, has informed me that you desire the remarks which I made at our conference on Tuesday of last week, as to the scope of your work, reduced to writing, with a view to the incorporation of the same, in your report. It gives me pleasure to send you herewith as nearly as I can recall, what I said upon that occasion.

The resolution under which your appointment was made passed the Select and Common Councils on April 20th of this year, and is as follows:

"WHEREAS, The quality of water furnished by the "municipality is such as to require purification by filtra-"tion or otherwise, and

"WHEREAS, There are on record in the Bureau of "Water authoritative and exhaustive plans, surveys and "reports heretofore drafted and made by various com-"missions, engineering experts and departmental officials "dealing with the water supply and upon which no "action has been taken. Therefore be it

"*Resolved, by the Select and Common Councils of the* "*City of Philadelphia*, That the Mayor be, and is hereby "authorized and directed to select and employ three "experts to act in conjunction with the Director of the "Department of Public Works, and the Chiefs of the "Bureaus of Water and Survey, to take up the question "of the immediate improvement and extension of the "water supply, provided that a preliminary report shall "be made by said experts within sixty days of their "appointment, and the final report shall be presented "not less than three months thereafter, so that it may be

" presented to Councils immediately after the summer
" recess in September.

* * * * * * * * * *

In outlining what was desired, I took the foregoing resolution as the basis for instructions. Your work naturally divides itself into three great problems, First,—What is necessary for the immediate betterment of our water system. Secondly,—If the remedy be filtration, what is the best method, and Thirdly,—In what direction is it most desirable to extend our present supply, so that for years to come, the water problem may not give anxiety to our people.

Your first duty will be to take up the question of the immediate relief of present conditions. I would request that you visit all of our pumping stations and reservoirs and make a thorough investigation of everything appertaining thereto. I would ask you to take into consideration and compare the waters of the two rivers, ascertaining, if possible, and approximating the decrease in the flow of the Schuylkill River.

It would also be well to consider the Schuylkill Valley as a region of great industrial activity, where manufacturing enterprises must increase in the years to come, with the danger of pollution of the Schuylkill, the natural drain of the Valley, as a consequence. Is it, therefore, wise to continue the Schuylkill as the principal source of our supply?

* * * * * * * * * *

Secondly:—If your investigations show that filtration is the remedy for the conditions which confront us, I would then ask that you recommend a system, calling attention, however, to the fact that slow sand filtration is generally recognized as the best. I would ask a careful estimate as to the cost of installation of a plant, sufficient to filter the entire supply of the city, with the annual cost for maintenance per million gallons daily, this estimate to include depreciation and renewals of plant. In the cost of the installation, I would ask that the proposed sites of the filtering beds be specified, together with the approximate cost per acre. I would ask you to take into consideration whether the severity of the temperature of the weather in Philadelphia, during the winter months, would not necessitate the erection of roofs over the filtering beds, and how much additional this would cost.

It is also a question whether filtered water could remain in the subsiding basins any length of time, without deterioration. It is but proper for me to call your attention, officially, at this time, to the constant and increasing growth of our municipality and the extension of its business enterprises, and would ask you to take into consideration, in connection, with filtration, whether that system could be extended to accommodate within a reasonable degree, the people of Philadelphia for the next half century.

The third and final duty which devolves upon you under the resolution is to look forward to the future. Personally, I would like to see a lasting solution of the water question. For forty years this city has been confronted with a problem, both as respects quality and quantity. Measures which brought about temporary relief alone have been instituted, but the question has never ceased to be a vexatious burden to succeeding generations. I would ask you to consider the present consumption of water, its increase and how it probably will increase in the future, and to recommend what means should be introduced to give the City of Philadelphia an ample supply, without unnecessary restrictions, for at least fifty years to come.

Your suggestion, I might add, should be broad enough to provide for a subsequent extension of the system proposed, so that the water problem could be solved for at least a century.

Should you be able to cover this vast problem, so as to make a final and definite report, to be laid before Councils when they assemble in the Fall, you will have performed a magnificent work, not only for this generation but for generations yet unborn. Your task is no light one. It has puzzled the best engineering brains for one hundred years or more, and if you solve the question, it will not only redound to your honor, but increase the health of the community, advance all its varied interests, and be a monument forever to the credit of Philadelphia.

It will strengthen and stimulate our people in all their various lines of activity, and place us far in advance of all other cities on this continent, if not in the world.

Very respectfully yours,

[Signed] SAMUEL H. ASHBRIDGE,
Mayor.

These instructions, presenting to us a problem of vast proportions, both as to time and scope, placed upon us a great responsibility, in view of the few months at our disposal. As your Honor, however, kindly granted us immediately all the assistance we required, it has been possible to cover the ground with such care that we can now report our conclusions on at least the essential features of the problem, with the fullest confidence that they present the means of providing a supply of water for the City of Philadelphia equal to the best, and capable of being secured at a reasonable cost.

At meetings had from time to time with your Honor, as occasion required, various modifications in the details of procedure were brought up and discussed, in further amplification of the subject. All of these modifications have been duly considered and acted upon.

The resolution authorizing our appointment required that, in considering the subject placed before us, we were to act in conjunction with the Director of the Department of Public Works, Mr. William C. Haddock; the Chief of the Bureau of Water, Mr. John C. Trautwine, Jr., and the Chief of the Bureau of Surveys, Mr. George S. Webster. These gentlemen have aided us by furnishing desired information during the entire investigation, and we take pleasure in acknowledging our indebtedness on this account. Special mention in this respect should be made concerning the assistance rendered by the Chief of the Bureau of Water, who supplied us in ready and convenient form not only with the material already available in his office, but also with information prepared at our request and collected by him elsewhere.

We desire also to acknowledge our indebtedness to the many engineers, in this country and abroad, who have furnished us with valuable data.

The shortness of time allotted to us made it advisable, in some instances, to draw upon the special experience of certain engineers in other cities. For instance, to verify our estimates of cost for the aqueducts from the Blue Mountains and for the filter plants to be located in this city, we obtained the co-operation of Mr. Charles S. Gowen, Principal Assistant Engineer of the Croton Aqueduct Commission, New York, and of Mr. William B. Fuller, late Principal Assistant Engineer of the Albany Filter Plant.

Finally, we desire to mention, with credit, the services of Mr. James H. Fuertes, Civil Engineer, who with much skill, untiring devotion and unusual dispatch, collected for us most of the information we required.

A preliminary report of progress was submitted on July 3rd, in accordance with your instructions, and we have now the honor to present our final report.

INTRODUCTORY.

It is proper that we preface our report with a brief review of the present works, since you have asked our suggestions as to the measures which should immediately be taken respecting the improvement of the existing plant.

Population.

The City of Philadelphia contains at the present time about 1,300,000 inhabitants. It is difficult to make a reliable estimate of the future increase in population, as much depends upon local conditions. After a careful study of the rate of increase in the past, and a comparison with the growth of other cities, a conclusion has been reached. Plate XVI illustrates how this was obtained. One diagram shows the actual growth of the city to 1890, another shows the percentage of increase of population by decades, including the probable percentage of future increase, and a third diagram shows the probable population as far into the future as the year 1950. This last diagram gives, for the year 1925, a maximum of 2,250,000 and a minimum of 1,900,000 persons, and for the year 1950 a maximum of 3,300,000 and a minimum of 2,700,000 persons.

We have thought it proper to provide at present for a population of 1,300,000 persons and also to make estimates of cost for works serving 3,000,000 persons.

Existing Conditions.

The present supply is taken from the Delaware and Schuylkill rivers within the geographical limits of the city, about 95 per cent. of it from the Schuylkill, and the remaining 5 per cent. from the Delaware. All of the water is pumped, normally to reservoirs, artificially constructed on elevated sites, from which it is distributed through cast iron pipes. Certain elevated suburban districts are supplied by high-service pumping stations, drawing from the reservoirs.

Delaware River.

The Delaware river rises in the southeastern part of the state of New York, about 190 miles above Philadelphia, and for about 130 miles of its course, before reaching Philadelphia, it forms the boundary between the states of Pennsylvania and New Jersey. The upper part of its watershed is mountainous and very sparsely settled. At the Delaware Water Gap it breaks through the Blue Mountain, and from that point downward its course becomes generally less precipitous, until, below Trenton, it is a tidal estuary, flowing through alluvial flats, generally under a high state of cultivation, but with no very large towns.

The area of the water-shed is about 8,600 square miles. The principal affluent of the Delaware, above Philadelphia, is the Lehigh, which flows through the anthracite coal fields of the same name, and reaches the Delaware at Easton, 75 miles above Philadelphia. The area of the Lehigh water-shed is 1332 square miles.

The largest towns upon the banks of the Delaware, above Philadelphia, are Easton, Pa., 14,500 population, 75 miles above Philadelphia; and Trenton, the capital of New Jersey, 57,500 population, 30 miles above Philadelphia.

But little manufacturing is carried on along the banks of the Delaware above Philadelphia; but the Lehigh valley is a very important iron manufacturing district.

The principal source of pollution of the Delaware, as a source of water supply for Philadelphia, is the city itself. The river, within the city limits, being tidal, the water taken is subject to pollution from the city's sewers, several of which discharge large quantities of sewage at points within a mile of the present intake, both up and down stream.

The Delaware receives from the Lehigh, at Easton, the drainage of the Lehigh anthracite region, and, at the same time, passes through a broad limestone belt, traversed also by the Schuylkill. Below Trenton it receives the washings of the alluvial plain through which it flows. Its volume, however, is so large that the effects of these influences are seldom very strongly marked. The water of the Delaware, at Philadelphia, is quite soft, forming no scale in boilers.

During the drought of 1895, the water of the Delaware, opposite Market street, Philadelphia, was sensibly brackish at high tide, but no such effect was noticed at the pumping station at Lardner's Point.

The Delaware river water above the Water Gap is of fair quality. The water from its mountain tributaries, between the Gap and Bushkill, is equal to the best of mountain waters, but the river itself brings down the pollutions from Port Jervis and other towns situated on its banks above. Below the Gap the river is augmented by tributaries, and particularly by the Lehigh river, which brings considerable pollution from Easton, Bethlehem, Allentown and other cities. Further down, the river, by its increase of size, becomes relatively less polluted, but it receives the sewage from a number of towns as far down as Philadelphia. Owing to the large volume of flow, the dilution of the impurities is much greater than is the case with the Schuylkill water.

The Delaware water contains only about one-third the amount of sulphate of lime found in the Schuylkill water, which accounts for the superior softness of the former, and, therefore, its advantage for use in boilers.

The Lehigh river, below White Haven, is not only much contaminated with sewage, but also, for a considerable portion of its length, with coal refuse. The territory east of the river between the Lehigh Gap and White Haven, and the entire water-shed of the river above White Haven, furnish water free from natural and artificial impurities, and, like the tributaries of the Delaware above mentioned, would provide an excellent mountain water supply.

The Tohickon creek flows into the Delaware at Point Pleasant, and Big and Little Neshaminy creeks enter the Delaware river below Bristol. The waters of these streams would require storage and filtering. Lack of time prevented a reconsideration of these projects on the basis of filtering their supply. They were fully described in the annual reports of the Bureau of Water from 1883 to 1886. The Tohickon creek furnishes a better water than either of the Neshaminy creeks, but, in our opinion, with the light that is now available regarding the sanitary dangers of raw water obtained from populated districts, and with the known efficacy of filtration, we do not now consider these streams available sources without a prior filtration. It may be that they can be made available in the future, by filtering their water and delivering it into the reservoirs of the City by gravity at an elevation of 170 feet above city datum. The same may be said of the lower Perkiomen sources.

Schuylkill River.

The Schuylkill river, which joins the Delaware at the southern extremity of Philadelphia, rises in the anthracite coal region of Schuylkill county, Pennsylvania, about one hundred miles above Philadelphia. In its generally southeasterly course, it intersects most of the ridges and geological formations traversed by the Delaware below the Water Gap.

The principal towns on the Schuylkill are:

	Distance above Philadelphia. Miles.	Population, 1890.
Pottsville	80	14,120
Reading	60	58,660
Pottstown	38	13,280
Phœnixville	26	8,500
Norristown	22	19,790

The water-shed area of the Schuylkill is about 1,915 square miles.

At Port Clinton, the Schuylkill breaks through the Blue Mountains, forming a gap similar to the Delaware Water Gap. Below that point it intersects generally the same ridges and the same geological formations traversed by the Delaware.

The Schuylkill is tidal as far up as Philadelphia, where the flow of the tide is stopped by the Fairmount Dam.

The range of tide in the Schuylkill at Fairmount, below the dam, is about 6 feet.

Fairmount dam furnishes water power for the seven turbines at Fairmount station. These are the only water power works employed by the city.

Many years ago the navigation of the Schuylkill was improved by the construction of a series of dams and canals, forming a slack water navigation extending from Philadelphia to Pottsville, a distance of about 100 miles. Its navigation is still in use from Philadelphia to Port Clinton, a distance of about 77 miles. It is under the control of the Philadelphia and Reading Railway Company, lessee of the Schuylkill Navigation Company.

The available storage capacity of all the existing pools above Philadelphia, is 563,000,000 cubic feet, or about 4,200,000,000 gallons.

With the exception of the lowest, or Fairmount Dam, which was built by the City of Philadelphia, all the works were built by the Schuylkill Navigation Company, in the early part of the present century.

The Schuylkill flows through a densely populated region, and its banks are dotted by important manufacturing towns.

The anthracite coal mines pour into the river large quantities of sulphuric acid, which, however, is completely neutralized by the subsequent passage of the river through the limestone beds which it intersects, so that the water, upon reaching Philadelphia, has a hard or alkaline reaction, and it gives considerable trouble by the formation of scale when used in the boilers.

In 1885 the city, for the better protection of the water of the Fairmount pool, constructed an intercepting sewer along the east bank of the river, and this sewer now receives the discharge from the numerous and extensive mills from Manayunk within the city limits, and pollution from many other sources, and discharges it into the river below the Fairmount Dam, or below the pools from which the city pumps its water.

The ordinary low summer flow of the Schuylkill river at Philadelphia is about 200,000,000 gallons per day, and the extreme minimum flow should, perhaps, for safety, be taken as low as 150,000,000 gallons per day.

When the Schuylkill river was originally selected, the population of the city was small. Its buildings were grouped along the Delaware river, extending hardly half way across to the Schuylkill river, which then furnished an excellent supply. Few towns existed along its banks, and the water was almost uncontaminated by sewage, by the output of coal mines or by other impurities. Time has changed all this.

For some years the development of the coal regions caused no perceptible injury to the water, although a considerable quantity of acid from the mines mingled with it; thanks to the limestone beds, already mentioned.

Of late years, however, water is being very extensively employed in the coal breakers as an aid in the separation and cleaning of the coal, and the mountains of culm, which have been accumulating for years about the mines, are now being worked over by a similar process, with the result that a large amount of coal dust is washed down the river to the city, especially in freshets.

The progressive settlement and cultivation of the country have brought another increasing trouble. The ploughing up of the soil allows the rains to wash quantities of mud into the streams, until the water, originally clear and palatable, is now often most objectionable, being repulsive in appearance and unpleasant to the taste.

A vital trouble, however, has arisen from the great increase in population and from the almost unrestricted disposal of much of the sewage and the refuse of manufactories, these matters entering directly into the streams, until the water, in its present condition, has become dangerous to health and unfitted for domestic use.

In 1884–5 a sanitary survey of the Schuylkill valley was made by the Water Department, and the reported facts and figures indicate that this pollution was serious even then, or fifteen years ago. Fairmount Park was originated and laid out for the purpose of controlling the banks of the river and protecting the water from pollution. Since then, further efforts have been made for the improvement of the conditions within the park, mainly by the construction of the intercepting sewer along the east bank of the river. But there is at present no adequate protection against pollution of the river beyond the City line, and matters remain very much as they were years ago. An investigation of the river reveals contaminations of the most abominable kind. On one of our recent visits we saw at least a dozen privies discharging their contents directly into the Schuylkill river between Conshohocken and Norristown.*

A systematic examination of the Schuylkill water, undertaken two years ago by the Bureau, has since been regularly continued. Samples have been taken twice a week at the intake of the Spring Garden Pumping Station, and a determination has been made of the organic and mineral constituents. The results furnished give information of practical value on the subject of purifying the water for the city's use.

A comparison between the samples taken from the intake, from the reservoir, and from the outlets of service

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*** See also: A joint report of the Philadelphia and Pennsylvania Boards of Health on the sources of pollution of the Schuylkill river from Philadelphia to Reading, 1898. Illustrated.**

pipes, shows a gradual diminution in the amount of organic matter in the water; in other words, an improvement after leaving the river. Observations in regard to this matter have almost uniformly given the same results, due, no doubt, to sedimentation, to oxidation, or to both.

When the river is frozen over, the water is generally clearer and brighter than at other times, and the amount of organic matter is less. This would lead to the inference that a large amount of impurity is usually received from the washings of the surface of the country from rain water.

The amount of suspended matter in the Schuylkill and Delaware waters has been determined by Mr. James H. Eastwick, of the Bureau of Health. The results are given in Appendix I to this report.

The greatest amount of suspended matter is that reported on March 13, 1899, when it reached 1,026 parts per million parts of water. While this amount appears excessive, and represents very muddy water, yet it does not equal that found in the Ohio river water, which is stated by Mr. G. W. Fuller, in his Cincinnati report, to have been as great as 2,333 parts per million, or over twice the amount which is considered very objectionable in the Schuylkill river.

This large amount of suspended matter indicates that at times a filtration of the Schuylkill water must necessarily be preceded by sedimentation, to remove most of the suspended matter, and that at periods of great turbidity even a coagulant would be of great service and economy, for the purpose of more rapid and thorough precipitation.

The tables show that the Schuylkill river clears up rather rapidly. For instance, the suspended matter was reduced from 1,026 parts to 130 parts per million in seven days.

At low stages of the Schuylkill river, 80 parts of alkaline sulphates per million have been found in the water, indicating the degree of its permanent hardness. During freshets the quantity diminishes to about one-third of this amount. Samples of very turbid Schuylkill water, treated with sulphate of alumina, have shown a greatly accelerated sedimentation. The mineral constituents of a sample of the Schuylkill water, taken at the intake of the Spring Garden station, October 29, 1898, were:

Sulphate of Lime and Magnesia........	80	parts per million.
Carbonate of Lime and Magnesia......	60	" "
Chloride of Sodium......................	10	" "
	150	" "

Those of a sample taken on March 13, 1899, were:—

Sulphate of Lime and Magnesia........	24	parts per million.
Carbonate of Lime and Magnesia......	38	" "
Chloride of Sodium......................	4.64	" "
	66.64	" "

These analyses give approximately the extremes in mineral constituents, the first having been taken during a long drought and the second after heavy rains.

The principal tributaries of the Schuylkill river, above Reading, on account of their contamination from the coal regions, are not available as a water supply. One of its lower and larger tributaries, the Perkiomen creek, in the upper 120 square miles of its water-shed, furnishes a good mountain water. Its water is rendered but slightly turbid by rains, and it is comparatively free from sewage pollution. The water from lower branches of the Perkiomen creek, such as the West Swamp creek and the North East Branch is highly discolored after rains, and also much more polluted, on account of the larger population residing on their watersheds.

Present Works.

The plant of the Philadelphia Water Works, one of the largest in the world, comprises:

(1) Thirty-seven pumping engines, with a rated total pumping capacity of 399,040,000 gallons daily. Of these pumps, thirty are operated by steam, and seven (turbines) by water power.

(2) Eleven reservoirs, two stand-pipes and three tanks, with a combined capacity of 1,417,860,000 gallons.

(3) A system of more than 1,250 miles of water mains, varying in diameter from 4 to 48 inches, together with the necessary valves, fire hydrants, etc.

(4) Fairmount and Flat Rock dams, the latter belonging to the Schuylkill Navigation Company.

The pumps vary in capacity from 250,000 to 30,000,000 gallons each per 24 hours, and are contained in ten pumping stations, five of which obtain water directly from the Schuylkill river and one from the Delaware river; four are high-service pumping stations.

The five stations located on the Schuylkill river are the Fairmount, where pumping is done by water, Spring Garden, Belmont, Queen Lane and Roxborough, where pumping is done by steam. The station on the Delaware river is at Frankford, where pumping is done by steam. The four high-service stations are at Belmont, Mount Airy, Chestnut Hill and Roxborough.

Of the five Schuylkill stations, four, viz.: Fairmount, Spring Garden, Belmont and Queen Lane, take their water from the lowest or Fairmount pool, formed by the Fairmount dam, while the remaining, or Roxborough station, takes its water from the Flat Rock pool, formed by the Flat Rock dam, belonging to the Schuylkill Navigation Company.

Pumping Stations.

Fairmount Pumping Station.—The station contains seven turbine wheels, with pumps having a combined capacity of 33,290,000 gallons in 24 hours, lifting the water into Fairmount reservoir.

The new or lower house contains:

No. 1 turbine with 2,000,000 gallons daily capacity.
No. 3 turbine with 5,330,000 gallons daily capacity.
No. 4 turbine with 5,330,000 gallons daily capacity.
No. 5 turbine with 5,330,000 gallons daily capacity.

The old or upper house contains:

No. 7 turbine with 5,100,000 gallons daily capacity.
No. 8 turbine with 5,100,000 gallons daily capacity.
No. 9 turbine with 5,100,000 gallons daily capacity.

All the pumps excepting Nos. 1 and 3 are so connected that they can pump also to Corinthian Reservoir, having a slightly higher elevation. Nos. 1 and 3 can pump only into Fairmount Reservoir.

Spring Garden Pumping Station.—This station contains forty-four boilers and nine steam pumping engines, giving a total daily capacity of 170,000,000 gallons. When the water in the river is clear, No. 8 Worthington engine pumps directly into the Queen Lane distribution system.

The old or upper house contains the following pumping engines:

No. 5	Southwark,	with 20,000,000 gallons daily capacity.
No. 6	Simpson,	with 10,000,000 gallons daily capacity.
No. 7	Cramp,	with 20,000,000 gallons daily capacity.
No. 8	Worthington,	with 10,000,000 gallons daily capacity.
No. 11	Gaskill,	with 20,000,000 gallons daily capacity.

The new or lower house contains:

No. 9	Worthington,	with 15,000,000 gallons daily capacity.
No. 10	Worthington,	with 15,000,000 gallons daily capacity.
No. 2	Holly,	with 30,000,000 gallons daily capacity.
No. 3	Holly,	with 30,000,000 gallons daily capacity.

Belmont Pumping Station.—At this station there are nineteen boilers and four Worthington duplex pumping engines, aggregating 38,000,000 gallons daily pumping capacity.

The water pumped is delivered into Belmont reservoir.

The house contains the following pumping engines:

No. 1 Worthington with 5,000,000 gallons daily capacity.
No. 2 Worthington with 5,000,000 gallons daily capacity.
No. 3 Worthington with 8,000,000 gallons daily capacity.

A rough wooden shed contains:

No. 4 Worthington with 20,000,000 gallons daily capacity.

Queen Lane Pumping Station.—Here there are twenty-four boilers and four Southwark vertical triple expansion engines, with single acting pumps, having a total daily capacity of 80,000,000 gallons.

Roxborough Pumping Station.—At this station there are nineteen boilers and three pumping engines, with a total capacity of 24,500,000 gallons daily:

No. 1 Southwark with 12,000 gallons daily capacity.
No. 2 Worthington with 5,000,000 gallons daily capacity.
No. 3 Worthington with 7,500,000 gallons daily capacity.

The Worthington pumps Nos. 2 and 3 are duplex and lift directly into the old reservoir, and, when this is full, into the new reservoir.

The No. 1 Southwark is a cross-compound bell-crank engine with vertical steam and horizontal water end, and usually forces its water directly to Germantown and Mount Airy reservoirs. Some of the water flows into Mount Airy reservoir and is pumped into the high-service mains.

It is probable that the pumps do not pump over 75 per cent. of their rated capacity.

The city has contracted for four new Worthington pumping engines, each to be of 5,000,000 gallons daily capacity.

Frankford Pumping Station.—This pumping station has twelve boilers and three pumping engines with an aggregate capacity of 42,000,000 gallons daily. The pumps are:

No 1 Cramp with 10,000,000 gallons daily capacity.
No. 2 Wetherill with 10,000,000 gallons daily capacity.
No. 3 Southwark with 22,000,000 gallons daily capacity.

The Southwark is a vertical cross-compound engine. It was tested by a Venturi meter and by a weir measurement, showing less than 5 per cent. loss by slip.

The Cramp engine is vertical cross-compound and is in good order. It has not been tested, but it is stated that the slip is not more than 2 per cent.

The Wetherill is a horizontal Corliss cross-compound engine. When tested by a Venturi meter and by a weir, it indicated less than 2½ per cent. loss by slip. This engine is more sensitive to a variation of pressure in steam or water than the other two engines. With a loss of pressure in steam of five pounds or an increase in pressure of water of but a few feet, the engine will slow down.

Belmont High-service Pumping Station.—This station has two pumps, No. 1 Worthington, with 2,000,000 gallons daily capacity, and No. 2 Snow, with 500,000 gallons daily capacity, and it has four boilers.

The Worthington engine was bought in 1869. A contract has recently been made for a new 5,000,000 gallon Worthington engine.

These pumps can take water either from Belmont reservoir or from the mains leading to it. They pump directly into a standpipe near by.

Roxborough High-service Pumping Station.—It is located near the old reservoir, and contains a Worthington pumping engine of 5,000,000 gallons daily capacity and four boilers. It takes water either from the old or from the new reservoir, as the case may be, and pumps it into a standpipe near by, from which it flows to the water tower at Chestnut Hill.

The pump at this station was first put in service in 1871 at Otis street wharf for the Kensington Water Works, to pump Delaware water into the Lehigh reservoir. The city has contracted for a new 5,000,000-gallon pumping engine.

Mount Airy High-service Station.—This station adjoins the Mount Airy reservoir, and contains four boilers and three pumping engines, having an aggregate capacity of 3,000,000 gallons daily, as follows:

No. 1 Davidson, with 1,000,000 gallons daily capacity.
No. 2 Davidson, with 1,000,000 gallons daily capacity.
No. 3 Knowles, with 1,000,000 gallons daily capacity.

These pumps take their water from Mount Airy reservoir and deliver into the water tower at Chestnut Hill.

Chestnut Hill High Service Station.—This station contains one Knowles pumping engine, with a capacity of 1,000,000 gallons; one Worthington pump, with a capacity of 500,000 gallons, and one boiler.

A list of the City reservoirs and standpipes, with their capacities, depths and elevations, is given in Appendix II.

Pumping Systems.

The Frankford station, on the Delaware river, forces its water through two parallel mains, $4\frac{1}{2}$ miles long, to the Wentz Farm reservoir, at an elevation of 167 feet, which supplies Frankford and other districts in the north-eastern portion of the city.

The Lehigh reservoir, at Sixth street and Lehigh avenue, is filled by gravity from the Wentz Farm reservoir, but owing to its low elevation, it is only occasionally used for distribution.

Fairmount station, with its seven turbines, pumps into the Fairmount reservoir, close by, with an elevation of 94 feet, and into Corinthian reservoir, distant about one-half mile, with an elevation of 120 feet. These reservoirs supply a small district comprising the lowest levels in the city, and the elevation of Fairmount reservoir is so slight that, although usually kept full of water, it is now used only occasionally for distribution.

Spring Garden Pumping Station, about half a mile above Fairmount, pumps about one-half of all the water consumed by the city, sending it into the largest, or East Park, reservoir, about one-half mile distant, with a capacity of 689,000,000 gallons. This reservoir supplies the greater part of the city proper. A portion of the supply from Spring Garden goes also to the small Spring Garden reservoir, for the exclusive supply of Girard College, which is in the vicinity of the reservoir.

The Belmont works pump the entire supply of West Philadelphia, sending it into the Belmont reservoir, distant about one mile, with an elevation of 212 feet. From this supply a special 12-inch main crosses the river for the exclusive supply of the City Hall, at Broad and Market streets.

The Queen Lane Pumping Station, with the reservoir of the same name, distant one mile, was constructed for the relief of what was formerly known as the "direct pumpage district," which was supplied from the Spring Garden station. The Queen Lane system, although not yet completed as originally designed, is now in full service, and direct pumpage is now used only occasionally, and never when the river is in relatively bad condition.

The Roxborough station, drawing from the upper, or Flat Rock pool, pumps into the old and new Roxborough reservoirs, for the supply of Roxborough, Manayunk, Chestnut Hill and Germantown.

The nominal pumping capacity of all the works pumping from the rivers is nearly 381,000,000 gallons, but the fact that the pressures throughout the city are low, and that incipient water famine exists at many points, show that the actual pumpage capacity is barely equal to the demand.

Repairs Immediately Needed.

Fairmount.—The roof of the upper house leaks freely, so that it is impossible to protect the pumps and machinery from injury by rust. The internal appearance of the house is so unsightly that it is deemed proper to exclude the public from it. The roof over the lower pump-house will shortly need renewal. The forebay leading from the river to the flumes which conduct the water to the turbines is obstructed by a deposit of sand and mud in that portion where the velocity of the water is reduced. The form of the forebay, as seen in plan, should be changed as proposed by the Bureau of Water.

Spring Garden Pumping Station.—Both bell-cranks of No. 5, Southwark Engine, have been broken and renewed, and both pump chambers are now badly cracked in spite of patches applied for the purpose of preserving them. In No. 7 Cramp engine the pump cylinders are cracked and should be repaired. The large new Holly engines, Nos. 2 and 3, are crippled by the cracking of their pump chambers, five of these having cracked in No. 2, and six in No. 3. Contracts have been awarded for replacing six of these chambers, and provision should immediately be made for replacing the remainder.

The fly-wheel of No. 11 Holly-Gaskill engine fits its shaft imperfectly, and it is therefore difficult to hold it in place. This defect should be remedied, and the diaphragms and valves of the pumps should be renewed where necessary.

Each of the new Holly pumps Nos. 2 and 3 is connected directly with the river by two 48-inch pipes. All the other pumps take their water from a forebay which is supplied by one 10-foot conduit and two 48-inch pipes. This forebay is partially filled with sand, which interferes with the operation of the pumps, and has to be removed at considerable expense, besides forming a bed for the growth of long grass, which, during the summer, requires that four men be kept constantly at work keeping the forebay clear.

New conduits should at once be built through this forebay, and the latter then filled up, as recommended by the Bureau of Water.

Belmont Pumping Station.—The diaphragms and steam valves of Worthington Engines Nos. 1, 2 and 3 are in poor condition and should be repaired.

No. 4 Worthington High-duty Engine, since its removal from Belmont to Spring Garden in 1894–95, has remained unprotected except by a rude frame shed erected by employees of the Bureau. Designs for a new engine house have been prepared. A suitable house for this engine should immediately be constructed.

Queen Lane Pumping Station.—Owing, probably, to the admission of air through the joints of the long suction main, the pump chambers in the four pumps at this station have been cracked. Some of them have been replaced by new pump chambers. The remaining ones should immediately be replaced, and the suction mains should at once be lowered so as to discharge by gravity into a well placed as nearly as possible directly under the pumps.

The coal shed and tunnel for the proper supply of coal to the station, designed by the Bureau of Water in 1895, should at once be constructed in order to save the present extra cost of about 23 cents per ton for handling the coal.

Roxborough Pumping Station.—No. 1 Southwark engine has long been in a precarious condition, and within the last few weeks it has finally become so fractured as to place one-half of it out of service.

Inasmuch as proper repairs to this engine would be expensive, we recommend that it be abandoned when it reaches a condition forbidding its further use.

This station has long been unable to cope with the demands upon it.

With the recent breakdown of the large Southwark engine, the conditions have become even more critical, and a new 3,500,000-gallon Worthington pumping engine has been purchased.

Contracts have been awarded for four new Worthington pumping engines, each of 5,000,000 gallons daily capacity. When these are installed, the annoying conditions in the district will be materially relieved, and it will then be possible to make needed repairs to the present Worthington pumps.

Frankford Pumping Station.—Owing to the insufficiency of the distribution system by which the water is delivered from the Wentz Farm reservoir, this station has, at present, a surplus of pumpage capacity and the engines are generally in good condition.

High Service.—At Belmont and at Roxborough high-service pumping stations, the operations have long been carried on under precarious conditions, owing to the fact that each has had only one pumping engine of capacity sufficient for the requirements of the district, but contracts have recently been awarded for a new 5,000,000-gallon pumping engine at each station.

Mount Airy Pumping Station.—There are no special requirements at this station.

Chestnut Hill High-service Station.—The two small pumps at this station, when in operation, take water from an adjacent well, fed from a reservoir, which is supplied partly by springs and rain water, and partly by overflow from the pumpage of Mount Airy and Roxborough high-service stations.

Proposed Frankford High-service Pumping Station.—Contracts have recently been awarded for the construction of a high-service pumping station adjoining the Wentz farm, or Frankford reservoir, for the purpose of supplying the village of Fox Chase, distant about two and one-half miles, and the intervening district.

A 3,000,000 gallon pumping engine has been ordered for this station from the Holly Manufacturing Company, of Lockport, N. Y.

Reserve Pumpage Capacity.—If the present system of pumpage and distribution is to be maintained, it is highly advisable to furnish additional machinery at the several pumping stations, except the Frankford station, in order, not only that there may be sufficient capacity for the demand, but also a surplus in case of break-down or needed repairs.

Cost of Operation.

In Appendix IV is given a table, in itemized form, showing the earnings and expenditures of the Bureau of Water for each year of the ten years from 1889 to 1898, inclusive.

In column "e," of this table, are given the expenditures upon pumping stations and reservoirs, including salaries and wages of all employees at pumping stations and reservoirs, fuel, lighting, repairs to boilers and machinery, ordinary repairs to reservoirs, and all other expenses, for operation and maintenance and incidental to buildings, grounds and reservoirs.

It is with the figures given in this column that our estimates of the annual expense in each of our several projects should be compared. The other columns represent also expenditures for general maintenance, operation and extensions. If the entire expenditure, necessary for the City's water supply, is desired, the figures in these columns should be added to our figures, which represent only the cost of delivering water into the reservoirs. In making such comparison, however, it must be borne in mind that in our estimates we have included interest on the cost of construction and an allowance for depreciation, items which are not included in the Bureau's figures in column "e." Deducting these, we find our estimates lower than the expenses reported by the Bureau. This difference may be accounted for by two facts, viz.:

(1). In our estimate we have not included maintenance of stations and grounds, and certain other general items included in the Bureau's figures.

(2). We have estimated upon a somewhat less consumption than the quantity now actually pumped, believing that with reasonable provisions for preventing waste the consumption can presently be reduced below our estimates.

The cost of maintaining the high-service stations and the annual expenses of the distribution system, of the construction and repair shop, and of administration, are common to all projects. Hence we have not included them in our estimates, these being intended, primarily, to afford a means of comparison between different projects.

For the same reason, and although we have included the cost of laying such mains as will be necessary for bringing the water from the new sources, or from the filter stations, into the distributing reservoirs, we have not included the annual cost of extensions of the distribution system.

WATER CONSUMPTION.

Quantity Furnished in Philadelphia.—The latest annual report of the Bureau of Water, that for 1898, gives 102,241,835,372 gallons as the total amount of water pumped during the year, including the double pumpage for high service stations. It states that the "average daily pumping was 272,670,777 gallons" and, estimating the population of the City at 1,400,000, the consumption was 196.2 gallons per capita per day.

The Bureau freely admits that, in spite of allowances on account of slip and other defects in the pumps, these figures, based on the plunger displacements of the pumps, exaggerate the actual quantities of water pumped. Recent observations, made by the Bureau of Water with the Venturi meter, at certain of the pumping stations, indidate that the actual average daily pumpage in 1898 was not more than 220 million gallons, or 169 gallons per capita per day.

We recommend that Venturi meters be placed on all the pumping mains, in order to measure the actual quantity of water pumped at each station.

The records of the Bureau of Water, based upon plunger displacement, with allowance for slip, etc., show a consumption of water per capita per day of only 36 gallons in 1860, 54 gallons in 1870, and 68 gallons in 1880, during a period when water was lavishly used by householders in daily washings of pavements, etc., now much less general. A gradually increased and more universal introduction of sanitary appliances, closets, lavatories, baths, elevators, etc., accounts for some of the recent increase in the consumption of water. When it is found from the records that the per capita consumption in 1890 had mounted to 132 gallons, and in 1897 to 212 gallons, it is evident that the figures do not represent the actual use per capita per day, but that there is added an unnecessary waste.

Quantity Used Elsewhere.—On Plate XVI. a diagram shows the quantity of water consumed in various cities between the years 1860 and 1898, per capita per day, as compared with that consumed in Philadelphia. The figures in the vertical line to the left give the per capita consumption for the years indicated on the horizontal line at the foot of the diagram.

The consumption of water per capita, as deduced from the total population and the total consumption, does not always furnish a true statement of the average amount actually used by each individual, particularly when cities are newly supplied with water, as many of the residents may, in the earlier days of the water plant, be supplied from other sources, and in such cases, a computation based upon the total population gives, of course, too low a consumption per capita. As the number of consumers increases, the error diminishes.

Philadelphia is represented on the diagram by a heavy line. Buffalo, N. Y., and Washington, D. C., are the only cities exceeding Philadelphia in the per capita rate, and it is noticed that the Buffalo consumption has been decreasing quite rapidly since 1895, due to some reduction of waste. Some cities show remarkably uniform results, for instance, Montreal, Quebec, and Glasgow, in Scotland. Many of these cities have introduced meters, the effect of which will be discussed further on.

Quantity Required in Philadelphia.—Careful estimates of the amount of water required per person, on the most liberal basis, give results considerably below the probable present consumption. The investigations of the Bureau show that there certainly is a large amount of unnecessary and preventable waste throughout the city.

After giving this subject serious study we have decided that about 150 gallons per capita per day, or a total of 200,000,000 gallons per day, would be an ample and even liberal allowance for the actual requirements of the present population. Our estimates of cost are, therefore, based on this amount of water being required at present.

In the year 1950, when the population will probably have increased to three million inhabitants, the supply presumably needed will be 450,000,000 gallons per day.

Meters.—No restriction should be placed upon the use of water required for health, comfort and cleanliness; nor should a part of the community be encouraged to deprive another part of its full quota of water. We are therefore emphatically of the opinion, and strongly urge, that all practicable means should be adopted to secure a fair and equitable distribution of the City's water.

We know of no better means to this desirable end than the introduction of water meters, not only for all business properties and manufacturing establishments, but also for such private consumers as are found, by the Department of Public Works, to be carelessly wasting water from the public supply. This remedy is available and simple, and it has been already adopted in many cities with entire satisfaction.

Plate XVII shows graphically the decrease in consumption per tap in a number of cities where meters have been introduced. In 1880, the City of Milwaukee, Wisconsin, had only 26 meters and the daily water consumption per tap was 1,781 gallons. In 1898 it had 22,096 meters. with a daily consumption per tap reduced to 644 gallons, About 70 per cent. of all private buildings, all railway stations, all business properties and manufacturing establishments were metered. There remain only 30 per cent. of consumers whose supplies are not metered, and yet the amount generally taken through this 30 per cent. for domestic purposes, equals in amount the whole quantity of water delivered by the meters to the remaining 70 per cent. Notwithstanding the extravagant waste through the unmetered connections, the total consumption per capita per day was reduced from 220 to 80 gallons. Many other cities show similar results. Our plate shows several of them.

The City of New York, which certainly requires as much water as Philadelphia, consumed in 1898, for the boroughs of Manhattan and Bronx, 121 gallons per capita per day, for a population of about two million inhabitants. It had in use over 35,000 meters in these two boroughs, covering, it is said, every place where water was used extensively for other than domestic purposes.

The report of the Commissioners for the City of Pittsburgh advises very strongly the introduction of meters in connection with their new supply.

The consumption per tap for Detroit, as given on Plate XVI, commenced to decrease after meters came into use, and in 1898 it was only 730 gallons per day as against nearly 950 gallons in 1888. In 1888 the Sunday waste is said to have been from 50 to 60 gallons per capita and the average waste for the entire year was thought to have been from 30 to 45 gallons per capita per day. A system of inspection was established and this appears to have been very effective. A careful record was kept of the condition of the plant, but the per capita waste was still about 6 gallons daily. It is stated that at present practically all manufacturing, business, municipal, public and semi-public consumers and about 4,000 private families have meters.

We earnestly recommend the introduction of meters for the City of Philadelphia with perfect confidence that the private consumer is given full and ample use and enjoyment of all water for his needs and comforts, at no greater cost, and probably, in many cases, even less cost than the present rates impose. The meter is not proposed to increase the revenue, but to prevent one citizen from depriving another one of his rightful share of water. A private corporation would introduce meters at an early day if not restricted by law, and would at the same time encourage consumption in every way.

The lack of a sufficient supply of water, in various parts of the city, is due either to a deficiency of distributing pipes, to the lack of pressure from the reservoir, to the want of pumping machinery, to a waste of water, which reduces the head, or to two or more of these causes combined. The remedies are apparent.

Deficiency of Local Supply.

There is hardly a district in the city in which some portion is not suffering more or less from want of water. The trouble is greatest during the summer months when more water is needed than at other times. In some locations, as for instance in portions of the Belmont district, it is difficult for days in succession to obtain water even on the second floor of the residences. The natural supposition of the inhabitants is, that the trouble is caused by a lack of reservoir capacity, but this is not the case. It is due to the several causes mentioned above.

Four-inch pipes have been found to be nearly filled by incrustation, and six-inch pipes, laid in 1834, have been found incrusted to the extent of one-half inch in thickness. The only means of remedying this trouble is to lay larger distributing mains.

In several cities corroded mains are reported to have been successfully cleaned with scrapers. The operation has cost about two-thirds that of laying a new pipe, and it obliges the shutting off of the supply during the time of cleaning. Cleaning the pipe leaves the interior surface in a condition to more readily corrode than before. In some cases such cleaning may be advisable, but it will more generally be preferred to allow the incrustation to continue as long as possible and then to lay a new pipe. If pipes are laid of sufficiently large size in the beginning and thoroughly protected with a proper coating, they will give little or no trouble in this respect.

The shortness of the time at our disposal forbade any attempt to investigate in detail the condition of the city's elaborate system of distribution; and we are therefore, of course, unable to make specific recommendations as to which portions of it should be immediately relaid, or where additional mains should be placed, excepting in such cases where there appeared to us no doubt whatever.

Condition of Reservoirs.

Of the three large reservoirs, East Park, Queen Lane and new Roxborough, the last two have, during the past four years, been re-lined with asphalt. East Park has been in full service ever since its completion, ten years ago, and Queen Lane ever since its re-lining. Owing to inability of the pumps to keep pace with the demand, the new Roxborough reservoir has never been filled; in fact, it has recently been necessary to shut it off from the distribution, to prevent its being entirely emptied. None of the three reservoirs gives evidence of material leakage.

Opportunity has been lacking for systematic observation of the behavior of the smaller reservoirs. Except Wentz farm, which is not in good condition, they are in fair order and repair, and holding their intended quantities of water. A hasty observation of the behavior of Wentz Farm reservoir indicated a very moderate amount of leakage; but it was impossible to ascertain positively that some of the pumpage did not enter the reservoir through partly-open stops. As the reservoir has but one basin, it cannot be thoroughly repaired without being put out of service.

The coping of the retaining wall at Queen Lane reservoir should be finished, and a new watch-house should be built. The northwest corner of the new Roxborough reservoir has an undesirably steep slope. This should be remedied by carrying the slope across Port Royal avenue.

The Lehigh (or Fairhill) reservoir is too low to be advantageously used at present. With its height increased, it would make a useful clear-water reservoir.

At Wentz Farm, a clear-water reservoir should be constructed on the lot (belonging to the city) adjoining the present one on the east, and between it and the Second street road. The existing structure should then be converted into a similar reservoir.

The Corinthian reservoir, likewise, may eventually be converted into a clear-water reservoir, when the demand for its capacity occurs.

Uses of Reservoirs.

Reservoirs for municipal water supplies are required for the purposes of storage, sedimentation, and distribution.

Storage.

It is well known that the flow of a river or smaller water course varies with the rainfall, that it is greatest shortly after rain storms, and least at the end of a long season of drought. In order to best utilize the flow of a stream, it is, therefore, necessary to provide storage reservoirs in which the flood water is collected and stored, and from which it can be drawn out to augment the flow of the stream when this is low.

Storage reservoirs are also used for the purpose of retaining a supply of comparatively clear river water to be furnished to the city when the natural flow of the streams is very turbid, as, for instance, during the first wash after a storm.

Sedimentation.

When using surface waters, particularly from streams running through territory that is readily eroded, and, therefore, charged with much suspended solid matter, it is desirable to allow the water to come to comparative rest for a short time in order that the suspended matter may settle, and, thereby clarify the water. Settling reservoirs are used for this purpose in either of two ways: By one the water is merely checked in its velocity, but flows through continuously; and by the other the water comes to an absolute rest, and is discharged intermittently. The time necessary for the water to remain in the settling reservoirs, whether by the continuous or intermittent system, depends largely upon the nature and quantity of its suspended matter. It is found that in most cases the deposition which takes place during twenty-four hours is practically sufficient, inasmuch as by far the greatest deposit usually results within this period.

Distribution.

Owing to the fact that the consumption of water in a city varies from hour to hour, and that it is greater during day-time than during night-time, and greater during some hours of the day than during others, it is necessary to provide a reserve within the city sufficient to balance the irregular draughts that may occur. This irregularity of draught is caused mainly by the domestic use of the water; but a conflagration or the bursting of a water main would also affect it. The larger the city, the less noticeable, comparatively speaking, is the effect due to the draught for a large fire or to the breaking of a pipe, because the regular domestic consumption is then large in proportion to the other draughts. For this reason, distributing reservoirs in large cities may provide for a smaller proportionate daily reserve than those in small cities. In the former, one-quarter to one-half day's supply is ample.

Distributing reservoirs in different parts of the city are used also for the purpose of maintaining approximately even pressures in the pipe system.

Reservoirs in Philadelphia.—In this city reservoirs have been used for all three of the above purposes. It was desirable to provide a sufficient amount of storage, to enable the reservoirs to supply the citizens while the Schuylkill river was running very muddy, and thus somewhat lessen the turbidity of the water as finally turned into the pipes. Incidentally, the reservoirs were also efficacious for the purpose of allowing sedimentation to proceed during the comparatively quiescent state of the water while stored. Thirdly, they were used for the purpose of balancing the irregular draught during the different hours of the day.

At the present day, the people are no longer satisfied by a mere lessening of the turbidity of a city's water supply through sedimentation. Perfectly clear, and practically pure water is now demanded. Storage reservoirs are, therefore, no longer necessary for ordinary river or lake water, unless they are used for sedimentation to be followed by filtration.

Storage reservoirs, for the purpose of compensating the yearly flow of the streams, would be required for this city only in the event of the supply being taken from the comparatively small streams in the mountainous districts. If the Delaware and Schuylkill rivers are to be used, at points near the city of Philadelphia, the former at least, owing to its large size, constitutes its own storage reservoir, and, therefore, no special structures are needed here for the specific purpose of equalizing the seasonal flow.

Sedimentation or settling reservoirs have been wanted in this city only because the waters of the Delaware and Schuylkill rivers are now used in their raw state, and, particularly the latter, are very muddy after rain storms. If clear mountain water is used, they are not required. If a filtered supply is obtained from these two rivers, sedimentation reservoirs are required to give the water a preliminary clearing.

Distributing reservoirs within the city are wanted only for the purpose of providing for the variation in the daily draught, and they may, therefore, be comparatively small.

Clear-water reservoirs, a term used when filtered water is supplied, are identical with distributing reservoirs so far as their purpose and their sizes are concerned. Inasmuch as filtered water, like spring water, is apt to permit of a rank growth of algæ and similar plants on exposure to sunlight and air, these reservoirs are generally covered to avoid a deterioration of the water. Such a covering is usually of masonry, rather than of wood or iron. The former has the advantage of keeping the water cooler, and also for this reason is less likely to induce the growth of minute vegetal organisms.

In the case of a filtered supply, the Schuylkill and Delaware rivers form the storage reservoirs, like those afforded by the lakes at Chicago and Detroit. There are no artificially built reservoirs within those cities. The only use for clear-water reservoirs in Philadelphia is for the purpose of providing for the irregular daily consumption, for accidents to the mains, fires, etc. It is, however, necessary, when the sizes of the reservoirs are limited to half a day's supply, to have a sufficient reserve of pumping capacity in case of accidents to any of the machinery.

A surplus of mains and machinery for pumping and for distribution affords as effective protection as does a large surplus capacity of clear-water reservoirs, and is generally less costly and more serviceable.

Quality of Water.

Standard of Purity.—A water for the City's supply should have a bacterial purity fully up to the best recognized standard. It should be clear, palatable, and free from chemical and organic pollutions. These qualities can be obtained by using either natural waters which are free from organic and mineral pollutions, or by artificially purifying waters already polluted.

With regard to natural waters, one of the first steps towards maintaining their purity is to reduce their pollution by every possible means, and principally by enacting and enforcing stringent laws against pollution.

Legislation.—In the State of Pennsylvania the statutes governing the question of preserving the purity of streams are somewhat deficient. Attention may be called to the good results achieved by the statutes enacted in Massachusetts.*

The State Board of Health should have supervision of all sources of domestic water and ice supply, with authority to inspect, to make examinations and analyses, and to enact and enforce regulations for the purpose of preventing pollution and securing proper sanitary protection of all sources of water supply for cities. It should have

* Manual for the use of Boards of Health of Massachusetts, and containing statutes relating to the public health, Boston, 1889.

authority to appoint agents to enforce the provisions of statutes and those of its own regulations.

The Board should have authority, and it should be its duty, to cause investigations to be made and to prohibit the pollution of any water course by any city, town, village or habitation, and to require such modifications in any operation, or plant, as it may deem necessary, for the abatement of the nuisance.

While legislation can do much towards lessening the pollution and thus improving the quality of natural water courses, it cannot wholly eradicate the dangers due to contamination. There will still remain surface drainage from cultivated lands, treated by the ordinary processes of agriculture, the use of legitimate fertilizers, manures, etc., and undetected defilements of a minor character, which cannot be controlled. It is well-known that, with certain diseases, such as cholera and typhoid fever, a very slight pollution by excreta from the patient, may produce widespread and most serious results in any community using the water directly as it comes from the streams. The epidemic at Plymouth, Pennsylvania, after the Centennial Exposition, is one of many cases which have demonstrated this fact.

During the late war strong evidence has come from the Surgeon General's office in support of an already well-known fact that winged insects may carry disease germs from one place to another and thus may infect surface water supplies.

FUTURE SUPPLY.

Earlier Studies.—The subject of obtaining a pure and ample supply of water for the City of Philadelphia is one that has been before the public for nearly half a century.

As early as 1856 suggestions were made for securing better water, and, in 1858, Mr. H. M. P. Birkinbine, Chief Engineer of the Water Department, drew attention to the

Wissahickon Creek, the Delaware and Lehigh rivers at Easton, and the Schuylkill river above Reading.

In 1864 a reconnaissance was made of all the streams around the city, within a radius of forty miles, and a gravity supply recommended from the Perkiomen creek.

In 1867 a special Committee of the Park Commission made a report, concluding that the Schuylkill river could be relied upon for many years if proper means were taken to guard it from pollution.

In 1875 a Commission of Engineers was appointed to consider the entire subject of present and future water supply, with special reference to immediate needs. Owing to the lack of information at their disposal, this Commission made no recommendation as to the question of future supply.

Agitation of the subject was continued by the Water Department and by private citizens, until, in 1882, the imminent prospect of a water famine resulted in the appointment of another Board of Experts. They reported not only that a marked deficiency existed in the capacity of the plant for the required supply, but also that complete and accurate surveys should be made of all available sources from which a future supply might be obtained, and that a thorough investigation should be made of the increasing pollution of the water of the Schuylkill river, with the possibility of its control by engineering works and legislative enactments, so as to restore it in some measure to its "pristine condition of comparative purity and wholesomeness."

The result was the appointment of a corps of engineers under Col. (now General) William Ludlow, Chief Engineer of the Water Department, by whom topographic, sanitary and hydrographic surveys were made, important data collected, and maps and approximate estimates of cost prepared for a supply from all available sources. All of the information thus secured is contained in the annual Reports of the Water Department of this city.

We have availed ourselves of the data collected by the previous Commissions, and of the surveys, reports, etc., on record in the Water Bureau, particularly of the data contained in the reports made to Col. Wm. Ludlow by Mr. Rudolph Hering in 1883–6, and we have made examination of the various areas of country comprised within the watershed lines of the tributaries of the Schuylkill and Delaware rivers in Pennsylvania, including the Lehigh river. We have considered all available sources of supply and have investigated the question of the pollution and purification of streams. We have also examined the present plant of the Water Bureau, including the reservoirs, the pumping stations and the distribution service.

The possession of still other data would have been desirable, regarding conditions such as the turbidity and pollution of the water of both rivers at different seasons, the tidal distribution of sewage in the Delaware river, particularly at spring tides and when the upland flow is a minimum. The allotted time was too short, however, to obtain such information. Nor would it have brought out any new facts to change our main conclusions, because it affects only details, which can be considered later.

Character of Present Supply.

The water supplied to some parts of the city is scarce in quantity, and in all parts inferior in quality.

As already stated, the pressures throughout the city are generally lower than they should be, and many important districts are almost entirely without a supply, notwithstanding that several of the pumping stations are driven to their utmost to keep pace with the demand.

The quality of the water is also very far below what is now considered a proper standard, the water being not only exceedingly turbid after storms, but also subject to serious sewage pollution. The typhoid rate of the city is unusually high, and this condition is no doubt chargeable, in great degree, to the sewage pollution at all times present in the water.

The deficiency of the supply, as to quantity, can be remedied by diminishing the waste, or by increasing the pumpage.

In many cases the supply to buildings is restricted by the lack of capacity of the distributing mains, but there are instances where, if the condition of these were improved, the draught would exceed the capacity of the pumping engines. We have elsewhere recommended the adoption of efficient measures for the reduction of the waste.

The defects in the matter of quality can be remedied either by abandoning the present sources of supply and adopting purer ones, or by applying to the water taken from the present sources well-known methods of purification.

Projects Specially Investigated.

The projects which we have investigated in detail may be grouped under two principal heads: Mountain waters, supplied in their natural state; and filtered waters, supplied from the Delaware and Schuylkill rivers.

The impounding or storage reservoirs may discharge directly into aqueducts or into the beds of the streams below them. In either case the water is received in other storage reservoirs further down stream, from which aqueducts convey it to the city.

Filtered vs. Mountain Water.

Where ample supplies of relatively pure water are obtainable at sufficient elevations and within short distances of the community to be supplied, it will usually be found best to take advantage of them; but where, as in our case, these sources are found at long distances from the city, it is necessary to estimate very carefully, and to balance still more carefully, the relative costs and advantages of different methods.

A gravity supply obviates the heavy operating expenses incident to a supply by pumpage, and thus naturally commends itself at first sight, but it may readily happen that the interest on the cost of construction of the gravity supply considerably overbalances the saving due to this consideration.

To utilize a gravity source of supply in our case requires not only the construction of long and expensive aqueducts, but also that of large and numerous impounding dams on the various small streams which would be taken as sources. These dams are necessary in order that the heavy winter and spring flows may be saved and made to compensate for the droughts of summer; thus regulating and rendering more nearly uniform the available yield of the stream throughout the year.

An advantage of the pumpage over the gravity system consists in this, that the former is capable of indefinite extension by small additions, whereas, when the capacity of an aqueduct has been fully taxed, a second one, usually of at least equal capacity, must be built.

In comparing the relative advantages and disadvantages of a mountain and a filtered water supply, it must be borne in mind that a filtered water supply is ordinarily susceptible of gradual and indefinite extension, as the demands upon it increase; whereas the construction of a gravity system, for a growing community, requires an outlay much in advance of requirements. It is true also that, owing to the greater length of time required for the construction of a gravity system, large sums of money must be invested long before the system can be put into operation.

The adoption of any project for bringing mountain water to the city by gravity, at sufficient elevation to flow into our reservoirs, involves, of course, the abandonment of the pumping stations supplying these reservoirs.

In our own case, another consideration to be borne in mind is that the sums represented by the present value of the pumping plants would be lost in the case of the construction of a gravity supply.

In comparing the relative advantages of filtered and mountain water supplies, it is important to bear in mind the lengths of time which would probably be required for their installation. It is quite safe to say that the completion of all plants of any one of the slow filter systems herein suggested, could be accomplished within three years; whereas the construction of any of the mountain water systems would probably require not less than seven or eight years.

In bringing mountain water to the city, there would always be a question as to its absolute purity, because there is no guarantee against an accidental pollution. Nor is there a guarantee that the water, coming from territory sometimes densely covered with forests, would not, in the late summer, have a slight vegetal taste such as we find in most supplies from similar sources. In view of recent progress in the methods of water purification, and of the growing demand for better water, it seems not at all improbable that water procured from the Blue Mountains might in the future require filtration before being delivered to the city, thus adding materially to the expense of the project. The New York supply, although not coming from the mountains, is derived from a territory which is carefully protected against pollution, but it is an almost annual occurrence that, in the summer, the water has a vegetal taste. A former Health Officer of New York City, Dr. Jenkins, is on record as saying that the New York water would no doubt eventually have to be artificially filtered in order to remove this taste and a slight turbidity.

Another advantage of a filtered water supply lies in the fact that, in case it should ever, in the future, be found necessary to change the source of supply—as, for instance, to abandon the Schuylkill and take filtered water from the Delaware—the loss in money would be less than if a mountain source had been used and a purification of such water had been found necessary.

In cases where the issue was doubtful, as to yield of water, or as to cost of construction and operation, we have, as a rule, given the benefit to the mountain water supply.

Quantity of Water Available.

As to the quantity of water obtainable from the sources at command under present conditions, it is self-evident that the minimum flow is all that can be relied upon throughout the year in any stream without reservoir storage, and the minimum flow usually occurs at a time of year when water is most needed.

Minimum Flow of Schuylkill.—On the Schuylkill river are a number of reservoirs which have been constructed by and which belong to the Schuylkill Navigation Company. The company uses these reservoirs for the purpose of supplying water for the maintenance of its navigation and for power at certain points. The City cannot depend upon the use of this impounded water to supply its need in time of drought, as the Navigation Company is under no legal obligation in this respect, although it has on several occasions acceded to the City's requests for assistance.

Various opinions have been given as to the extreme minimum flow of water in the Schuylkill river. After considering these we have decided that it would not be safe to rely upon taking from the river in times of drought, more than 150,000,000 gallons per day. This quantity may be less than the minimum flow, but even if the City had a plant for purifying the water, we do not consider it safe or proper to provide for using the entire flow, particularly at a time when the relative pollution of the river is greatest.

Yield of the Delaware River.—The Delaware river from its mouth to Trenton, N. J., is a tidal estuary. The minimum flow at the Water Gap, situated about 100 miles above Philadelphia, is estimated at about 700,000,000 gallons per day, only one-half of which, or 350,000,000 gallons per day, could be appropriated by the City of Philadelphia.

At this point it should be stated that while the City has the right to one-half of the flow, it has no right to cause injury to any of the riparian owners, resulting from a material lowering of the water level during a drought, the exposure of shoals, and the recession of the low water line from where it is at present. We have included in our estimates of cost no allowance for such damage, nor for diminishing any water-power rights below the intake.

Yields from Watersheds with Storage.—The upper Perkiomen creek comprises a drainage area of 120 square miles and, with storage reservoirs for which satisfactory sites exist, this source may yield a supply of 90,000,000 gallons per day.

The available safe yield of the Tohickon, the Big and Little Neshaminy creeks, according to the recent reports of the Water Bureau, are: Tohickon, 61,000,000 gallons per day, and Neshaminy, 83,000,000 gallons per day.

The upper Lehigh river drains an area of 377 square miles, while Big and Aquanchicola creeks, to the east of the river, south of Mauch Chunk, drain an area of 165 square miles. The watersheds of all these streams combined include 542 square miles, which, with storage, can be depended upon for a supply of 360,000,000 gallons per day.

The sources of the Delaware river above the Water Gap, from which good mountain water can be obtained, cover a drainage area of 430 square miles, and, with storage, will furnish 260,000,000 gallons of water daily.

Quantities available.—The quantities available, therefore, from the several sources mentioned are:—

Mountain Water, Unfiltered.

Lehigh river, including Big and Aquanchicola creeks	360,000,000	gallons per day.
Upper Perkiomen	90,000,000	" "
Sources near Delaware Water Gap	260,000,000	" "
Total	710,000,000	" "

Water Requiring Filtering.

Schuylkill river at Philadelphia	150,000,000	gallons per day.
Delaware river at Philadelphia	Practically unlimited.	
Delaware river at Water Gap	350,000,000	gallons per day.
Tohickon and Neshaminy creeks, with storage	144,000,000	" "
Perkiomen creek above Schwenksville, with storage	160,000,000	" "

It is of course practicable to increase the minimum flow of the Schuylkill river by the storage of water on its affluents, particularly on the Perkiomen creek. As the pollution to which the water of the Schuylkill river is subjected will be greater, in spite of all legal restrictions, than the pollution of the Delaware river, which has a smaller resident population, we have deemed it rather better to increase the city's supply by taking water from the latter stream, than by artificially increasing the minimum flow of the former. We have been guided in this decision also by the question of cost and by the existing rights of the Schuylkill Navigation Company.

Artificial Purification..

When water, to be used for a domestic supply, has become contaminated, it should be artificially purified by filtration, preceded by sedimentation where necessary. This method of purification has been in successful use in Europe for many years, and its use is growing in this country.

The investigations and experiments of the Massachusetts State Board of Health, which have extended over a number of years, have placed the subject of water puripurification upon a scientific basis, and it is possible now to effect any desired degree of purification with a certainty of results which, previous to such investigations, was impossible.

Water Filtration.

As we have already stated, it is rarely, if ever, that water obtainable in large quantities from natural sources can be used for domestic purposes in its natural condition with absolute safety. The very existence of such quantities of water generally involves the co-existence of a population more or less dense, with the corresponding certainty of more or less serious pollution ; and, even where a supply is normally of a high degree of purity, as in the oft-quoted case of Plymouth, Pa., we are never free from the menace of accidental and temporary pollution, such as decimated that unfortunate town. Hence, it is becoming more and more the conviction of water-supply engineers that proper regard for the health of the community demands the artificial purification of all surface waters, however promising the sources from which they are drawn.

Nature's process of filtration in the production of spring and well waters has long been understood in a general way, and its artificial imitation, on a small scale, is probably as old as history itself. Within the last half century the same process has been extensively applied to the purification of the large volumes of water supplied to cities. London furnishes the most noteworthy example of this, and the system there adopted is still the one most generally employed.

In that system, the water is, if necessary, first allowed to remain at rest in sedimentation reservoirs, in order that it may free itself of its grosser mechanically suspended impurities, and is then allowed to filter slowly through beds of sand.

Until within a very few years, the sole function of this process seems to have been regarded as consisting in the removal of the mechanically suspended impurities and the consequent improvement in the *appearance* of the water; the turbid water of the Thames, for instance, being converted into a bright and sparkling liquid, probably quite as attractive in appearance, and as palatable, as the finest spring water; and it was freely conceded, even by the advocates of the process, that, in the language of an authority, the micro-organisms contained in the water "could pass a hundred or a thousand abreast through the interstitial spaces of ordinary sand as used for this purpose," and hence that "while filtration certainly clarified, it could not purify"—while it removed the visible dirt, "it could not remove the bacteria."

During recent years, however, the investigations of biologists and the sanitary results of filtration have clearly demonstrated its very important usefulness in the true purification and sanitation of the water—efficient filtration commonly removing 98, 99 and even more per cent. of the bacteria existing in the water.

The consequence of modern discoveries is a complete change in the accepted standard of purity of water. Whereas, previously, clearness and a satisfactory chemical analysis were considered sufficient evidence of wholesomeness, we now insist, also, that a certain permissible maximum number of bacteria—usually placed at 100 per cubic centimeter—shall not be exceeded.

Hence, while the science of filtration may be said to be still in its infancy, it cannot truly be said that "filtration is only an experiment."

One of the most striking instances of the efficiency of filtration in checking the spread of disease is the well-known case of Hamburg and Altona, in Germany. These cities, side by side on the banks of the Elbe, both take their water supplies from that stream, the Altona intake being placed below the point where the sewers of Hamburg discharge into the Elbe the sewage of nearly 800,000 persons. The two cities are practically one, the line of demarcation being, at most, a narrow street. In the winter of 1892–3, when the cholera visited Hamburg and when the deaths from that disease, in Hamburg, which used the Elbe water unfiltered, reached 1,250 per 100,000 of population, Altona, which used the same water filtered, had but 221 per 100,000. The boundary line between the two cities can be clearly traced, upon a map on which are plotted the cases of this disease, by the large number of such cases on the Hamburg side of the line, and their nearly complete absence on the Altona side. The few cases which appeard in Altona were generally traceable to the use of the Hamburg water, by transient visitors to the other city.

Filtration is found to remove, not only disease germs, but also the unpleasant vegetal taste which often characterizes the water of small streams during summer and autumn.

It has also been well established that, in the system already mentioned, the sanitary work is done, not always directly by the sand itself, but, in the case of continuous filters, rather by matter deposited from the water upon and within the sand, which thus serves merely as a mechanical support for what may be termed the true filter, the deposit of "bacterial jelly," or, in German, the "*Schmutzdecke*," which we may freely translate into "dirt-cover."

It is not to be supposed that all, or even most, of the bacteria found in ordinary surface waters, are hurtful. On the contrary, many of them are beneficent; and it is, indeed, upon the operations of these, that the biological processes of purification upon and within the sand filter largely depend; but it is practically impossible to discriminate between the beneficient and the harmful bacteria, and hence the removal of the hurtful or pathogenic bacteria, brought into the water by sewage pollution, requires that the depopulation of the water be made as complete as possible.

It is stated, upon good authority, that more than twenty million people in Europe are now being supplied with water filtered by slow-filters, and the number of persons thus supplied is annually increasing. The first filter of record appears to have been constructed about seventy years ago.

The slowness of operation of the system now being considered, requires an acre of ground space for every two or three million gallons filtered daily; so that, for a daily supply of 200 million gallons, from 70 to 100 acres would be required for the filter beds alone, in addition to that which might be required for the sedimentation basins.

To obviate the necessity for acquiring so much land, American inventors have sought to take advantage of the method, known to the ancients, of using alum or some other coagulant, to hasten the formation of the true filtering medium, as well as to expedite, in other ways, the entire process.

Besides, the "*Schmutzdecke*" sometimes requires several days for its formation, and, during this time, the water is but imperfectly filtered, and should be allowed to run to waste. Again, the filters naturally become clogged with sediment, and require cleansing usually every few weeks, and this cleansing is a slow process, throwing the filters out of use for a still further time.

The result of these efforts is the so-called "mechanical" filter, which consists usually of a tank, from ten to twenty feet in diameter, and containing a sand filter bed. Either at or prior to its admission to the filter, the water receives a small quantity of alum, or other coagulant, the proper behavior of which depends upon the presence, in the water, of some base, such as lime. This base unites with the sulphuric acid of the coagulant, thus setting free the alumina, which, in the form of aluminum hydrate, settles slowly through the water, carrying down with it much of the impurity of the water, while the new sulphate formed by this process is deposited with it.

Another distinguishing feature of the "mechanical" process consists in the arrangement for cleansing the filter. This consists (1) of a set of rakes, set in revolutoin by machinery when required (whence the term "mechanical") and (2) the reversal of the normal current of water, the water already filtered being forced backward through the bed, not only facilitating the revolution of the rake, but carrying with it most of the impurities deposited upon and within the bed by the water previously filtered.

For convenience, we apply the term "slow" to the system first described, and represented most prominently by the great filter beds of London, Berlin and Hamburg, and sometimes called the "English" system; and the term "rapid" to the so-called "mechanical" or recently called "American" type of filter. Our reason for selecting the terms "slow" and "rapid" is that they designate the most important distinguishing feature. The former system allows from 6 to 12 cubic feet, the latter from 200 to 300 cubic feet of water daily to pass through one square foot of filter surface.

By virtue of some operation not yet thoroughly explained, rapid filters appear to be able to secure equally as satisfactory bacteriological results as the slow filter, although filtering at from thirty to fifty times the rate. In other words, for a quantity of water requiring from thirty to fifty acres of filter beds by the slow process, one acre of surface of rapid filters would suffice, provided the conditions of the given case were equally favorable to the two systems.

It is now generally recognized that, as a rule, the slow system is best adapted to waters containing relatively little suspended matter, although they may be highly polluted by sewage, and the rapid system to the treatment of highly turbid but less seriously polluted waters, or in those cases where, as in certain manufacturing processes, clearness is the first consideration, and wholesomeness of less or no account. As a matter of course, the rapid filter commends itself especially for those cases where suitable ground for the large slow filter bed is not practically available.

The functions of the rapid filter, however, are by no means confined to the mere clarification of the water. It is also a very efficient purifier. Hence, it has found extensive and successful application, especially in this country, for the purification of the water supplies of towns and cities. In these cases, usually a considerable number of the filtering tanks, or "units," are installed side by side, in connection with suitable machinery for operating the revolving rakes, and with appliances for the admixture of the coagulant and the regulation of its quantity.

Where lime, or its equivalent, is deficient in the water in its natural state, it must be added artificially, in order to insure the necessary decomposition of the coagulant.

We have already given the results of investigations to determine the effects of the use of coagulants upon the wholesomeness of water and upon their availability for use in boilers.

The hardness of the Schuylkill water adapts it to the use of the rapid system, with its necessary employment of coagulants, the lime in the water acting favorably in the decomposition of the coagulant, and it is our opinion that the use of the coagulant would not materially, if perceptibly, increase the hardness of the water. With slow filters, a coagulant would be used only when the river runs very muddy, as happens only occasionally even with the Schuylkill water; and we doubt whether it would ever be required with the much softer and less turbid water of the Delaware.

If precisely the proper quantity of coagulant could be applied, it would all be decomposed, and all of the lime in the water would unite with all of the sulphuric acid of the coagulant. Hence, none of the coagulant could pass out with the filtered water. The only effect, in this respect, would probably be the diminution of the "temporary" hardness (that due to carbonate of lime) and an increase of the "permanent" hardness (that due to sulphate of lime).

The maximum quantity of sulphate of alumina used in the rapid filter rarely exceeds two grains per gallon, and it is often much less. The Rhode Island Board of Health, for instance, has stated that 0.6 grain per gallon is sufficient.

Sedimentation in reservoirs is accomplished in two ways. In one of these the water is allowed to pass through the basin continuously; in the other it is admitted and drawn off intermittently. By the continuous method, the water enters at one side of the basin, and its velocity very greatly decreases as the water flows to the other side, whence it is drawn off near the surface. The reduction of velocity permits the gross particles of suspended matter to subside. By the intermittent method the water enters the reservoir generally with a greater velocity than in the continuous method, but it is then shut off, comes practically to rest, and remains at rest for a sufficient time to allow the suspended matter to settle. The clear water is then drawn off. Both methods have their advantages and disadvantages; and, in the lack of sufficient information regarding the quantity of suspended matter in the water furnished to this city throughout the year, it is impossible to say which of the two methods would be the better one to use in this city. The estimates of cost presented are, however, in our opinion, sufficiently liberal to cover approximately either case.

In the case of the Schuylkill river water, and when settling reservoirs are used for its preliminary treatment, it may be necssary to add alum to the water at times when suspended matter is in very large amount or when it is very fine. Our opportunities of observation do not enable us to state to what extent such a treatment would be necessary in the case of Philadelphia, but we think it would hardly be necessary on more than from ten to twenty days in the year.

In the case of slow filtration, the use of a coagulant would be found advisable, only during, or just after, heavy freshets. At such times the amount of alkaline sulphates naturally in the water are approaching a minimum, the organic matter being then most diluted. Any increase in these sulphates due to the decomposition of the natural carbonates by the use of sulphate of alumina, would in all probability not make the total percentage of alkaline sulphates as high as during a drought, when it approaches a maximum. The use of a coagulant during freshets, therefore, could make no appreciable difference in the quality of the water.

Filter Plants and Various Projects Examined.

Sundry methods of filtration, purification, sterilization, etc., have been presented to us for examination, and a hearing has been given to those proposing or suggesting them.

Wilmington Filter.—A visit was made to the water purification plant at Wilmington, Delaware. The system there adopted is based on a treatment of the water with iron, a subsequent thorough aeration and an upward filtration through a bed of 20 inches of gravel and 18 inches of sand. There are five filter beds in use, each 16 by 125 feet, filtering at a daily rate of over 40,000,000 gallons per acre (about 133 cubic feet per square foot) per day. The ordinary cleaning of the beds is accomplished by reversing the current and washing the material in place with both air and water.

The iron treatment is secured by means of a series of revolving bundles of small iron rods, suspended transversely in a long trough through which the water flows. A small portion of the iron is removed by attrition and oxidation, and acts like the iron used in the Anderson process. No repeated analyses of the water had been made before and after this treatment, and no data were available to establish its real efficacy. This fact, and the lack of success of the similar Anderson process, rendered a further investigation inadvisable.

Albany Filter.—We next visited the new filter plant at Albany, N. Y., designed by Mr. Allen Hazen. At that time it was not quite completed, but it has since been put into operation. It is the largest filter plant now in use in the United States. It consists of an open sedimentation basin holding 16,000,000 gallons, and 8 filter beds, each 0.7 acre, with a total area of 5.6 acres, and a total filtering capacity of about 15,000,000 gallons per day, being at the rate of about 3,000,000 gallons per acre (about 9 cubic feet per square foot) per day. The filter beds are covered with groined concrete arches; and all appurtenances necessary or advisable for effective operation, such as regulators to control the rate of filtration, sand washing apparatus, a bacteriological laboratory, etc., are provided. The filters have apparently been built with great care and excellence. The filtered water is pumped into an uncovered distributing reservoir in the western part of the city.

Poughkeepsie Filter.—We also visited Poughkeepsie, where a filter plant has been in existence for more than 27 years and is still in active use, filtering about 1,600,000 gallons per day, or, with a population of 23,000, about 70 gallons per capita.

This plant was designed and erected under the supervision of the late James P. Kirkwood, who had investigated the filtration systems of Europe in the interest of the City of St. Louis, Mo. It is located on the east bank of the Hudson river and the original plant comprises a settling basin, 25 by 50 feet by 12 feet deep, a filtering basin, 150 by 200 feet by 12 feet deep, and a filtered-water basin, 28 by 88 feet by 17 feet deep, with an intermediate chamber, 6 feet by 88 feet by 16 feet deep. The filtering materials are 24 inches of coarse broken stone, 24 inches of gravel of varying sizes and 24 inches of sand. The filtered water is pumped up to a large uncovered distributing reservoir on a hill back of the city. This reservoir has a capacity of 12,000,000 gallons or about 7 days' supply.

In 1896 an additional filter was constructed, doubling the capacity of the plant. It is fed from the old settling basin, the water discharging into a delivery well and thence to the old filtered-water basin.

All of the basins are uncovered, except that for filtered water, which also was originally open. So much trouble was experienced from the growth of algæ that in 1891 it was covered, and it has since given no further trouble. The fact that the filters are uncovered has caused much difficulty in operating them. In summer the growth of algæ at times almost stops their action, and in winter the frost causes difficulty in cleansing the beds and keeping them in proper working condition.

On account of the expense an attempt was made, in 1874, to substitute simple subsidence in the distributing reservoir, but after a trial this was abandoned. The annual report of 1878 states that "the consumers accustomed to drink filtered water will accept nothing else, nor will they consider any circumstances or complication of circumstances as offering any excuse for the non-use" of the filters.

We were informed that the filters are operated only for three or four days in the week. The rate of filtration was about 4,500,000 gallons per acre (about 14 cubic feet per square foot) per day, until the construction of the additional filter in 1896. With the latter in use, the rate is now about 2½ to 3 million gallons per acre (about 9 cubic feet per square foot) per actual day of operation. The filters are usually cleaned at intervals of from one to five weeks, but sometimes not for two months, depending upon the condition of the raw water, the accumulation of algæ, etc. With good management, the plant seems to have produced satisfactory results, even under adverse conditions.

Reading Sewage Filter.—During our investigation of the Schuylkill region, we made an examination of the sewage filtering plant at Reading, erected under the patented system of Mr. John Jerome Deery, President of the Pennsylvania Sanitation Company, Mr. Deery having presented plans for filtering the water of Philadelphia by the same method.

The plant has been in operation about three years. It is designed to act first as a strainer, then as a filter, passing, as we understand, about 10,000,000 gallons per acre per day. Much reliance is placed upon aeration and sunlight to purify the water. Repeated examinations of the filtrate at Reading since the plant has been in operation, revealed faint sewage odor and color. The process as proposed for Philadelphia would not by itself yield a safe drinking water, if judged by established principles and the results of experience.

Maignen Filter.—Our attention was called to the Maignen method of water purification, and a special examination was made of a model plant of experimental filters in operation.

The new and special feature of the Maignen system is the use of an asbestos film resting on top of the sand of the filter bed, to take the place and perform the useful office of the dirt cover (*Schmutzdecke*) on the bed of the ordinary filters, in retaining bacteria.

The water passes through Mr. Maignen's experimental filters at the rate of about 10 to 12 million gallons per acre (about 30 to 37 cubic feet per square foot) per day. It is clear, and, according to the analyses made by the chemist of the Company, also nearly free from bacteria. It is stated that in all the examinations made of the effluent water, the bacteria have never been found to exceed one hundred to the cubic centimeter, the standard limit adopted by the German Imperial Board of Health.

While the models show good results, and while the treatment of the problem has been carefully considered by the inventor, experiments have indicated the existence of a troublesome feature, in connection with the asbestos film, due to the collection of air bubbles below the same and a consequent interference with the required percolation of water. A remedy has been suggested by the inventor, but, until the system has been successfully used on a sufficiently large scale, we cannot recommend it for the City of Philadelphia. It could, however, at any time be readily added to any of the usual slow filtering plants, if its usefulness were established, and thus obviate their otherwise necessary areal extension *pari passu* with the growth of the city.

New York Filter Manufacturing Company.—A conference was held with the New York Filter Manufacturing Company, represented by Messrs. Samuel L. Morison, General Manager, and Edmund B. Weston, Consulting Engineer, to consider the method of filtration employed by that Company, and the cost of constructing and maintaining such a plant.

This Company uses a system of rapid filtration, the rate being 100,000,000 gallons per acre (about 300 cubic feet per square foot) per day. They claim to have made an advance in their latest apparatus, by joining the compartments for sedimentation and filtration in such a way that they can dispose of from 75 to 80 per cent. of impurities by sedimentation, before the water reaches the filter. The water is first treated with a coagulant (sulphate of alumina) and then passed through a settling basin, where it is subjected to a rotary movement which hastens the precipitation of the hydrate of alumina and other matter in suspension; thereby shortening the necessary time for sedimentation, and obviating the use of much larger settling basins.

A design for a unit filter was shown us, consisting of a cylindrical tank, 26 feet outside diameter, and appurtenances, giving an inside filtering area of 452 square feet. The water is first treated with the required amount of sulphate of alumina from a supply tank by means of an automatic feed, known as the old Warren Chemical Feed, which secures the delivery of a quantity of alum in exact proportion to the quantity of water entering the filter, and which is provided, also, with means of regulation to meet the requirements of the varying character of the water.

Having received the proper amount of this coagulating solution, the water enters a lower basin in the bottom of the cylindrical filter tank in a tangential direction through a deflecting elbow. This gives it a rotary motion about the centre of the tank, which motion materially facilitates coagulation. When filtering at the rate of 100,000,000 gallons per acre (about 300 cubic feet per square foot) per day, the water is detained in this lower basin for the period of about one hour, although in continuous passage to the filter bed above. During this time a large amount of the small particles of matter in suspension, with bacteria, etc., are gathered together in larger masses, many of them being of sufficient weight to fall to the bottom of the settling tank, about 75 per cent. of such matter being removed. The fresh supply tends to the outer edge of the tank by the centrifugal force due to rotation, and the water remaining longest under the action of the coagulant gradually reaches the centre. The water is then fed from the centre of the tank by an upright central pipe to the filter bed above.

The water is distributed upon the filter, and deposits thereon matter remaining in suspension, together with the lighter particles of hydrate of alumina not already deposited in the settling tank below. The water passes through the accumulating film, and then through four feet of sand to the screen system. There are about 1800 separate screens, made of aluminum bronze, laid as a pavement on the floor of this upper tank to prevent the sand from escaping. Through these screens the water passes to a central manifold, and then to the controller.

The controller, designed by Mr. Weston, is one of the most important improvements in this type of filter.

A filter bed, when clean, operates more rapidly than after it becomes clogged with deposit, the speed becoming less and less until a condition is reached when washing is required. The controller regulates this speed automatically, determining the number of gallons per minute that shall pass through the filter, and thus making its action uniform. When a certain height of water is reached and the available friction head has been entirely consumed, the sounding of an automatic signal shows that the time for washing has arrived.

To wash the filter, clear water is pumped back through the pipes leading to the screens in such quantities as to give an upward velocity through the sand about three times as great as the velocity of filtration. It raises the entire bed in the form of quicksand, leaving the sand grains completely in suspension. At the same time a mechanical agitator is started, consisting of a series of iron rods suspended from arms revolving over the filter bed. The rods penetrate the bed nearly to the bottom. This facilitates the loosening of foreign matter in the bed, and both this matter and the wash water are carried off over the edge of the tank forming the filter proper, down the annular space between this and an outside tank, and thence to the sewer.

Information was given us as to the experience of this filter company in treating Schuylkill and Delaware river waters. Private filter plants of their installation were mentioned, of which three were on the Delaware river connected with sugar refineries and one of 5,000,000 gallons on the Schuylkill river.

Sterilization by Boiling.—Our attention was called, by Mr. John Forbes, of the Waterhouse-Forbes Company, to an ingenious method of sterilizing water by boiling. By a simple contrivance, two vertical currents of water are kept flowing past each other in contiguous passages, so that their heat is equalized by convection. The water, upon reaching the top of one column, is heated to the boiling point, and then, in descending, gradually imparts its heat to the water rising in the first column, and finally escapes with a temperature only 2 to 5 degrees higher than the original temperature of the water. The water is thus actually boiled with a very small expenditure of heat. In our judgment, this process, irrespective of financial reasons, falls short of solving the question before us, inasmuch as it does not remove the turbidity of the water.

Recent Reports on Filtration Experiments.

Reports have recently been made by Filtration Commissions of Louisville, Cincinnati and Pittsburgh, containing the results of investigations and experiments which have been valuable to us. The character of the waters of the Schuylkill and the Delaware rivers is not necessarily the same as that of the waters of the Ohio and Allegheny rivers. The latter vary considerably in quality, but there is much that is common to all river waters. As it was impossible, within the limited time at our disposal, to undertake any investigations with experimental filters at Philadelphia, desirable as it would have been, we were obliged to depend largely upon experience gained elsewhere, and we have taken all possible advantage of the above mentioned reports.

The investigations at Louisville and Cincinnati were reported by Mr. George W. Fuller, Consulting Expert, and those at Pittsburgh by Mr. Allen Hazen, Consulting Engineer, with Mr. Morris Knowles, Resident Engineer. Reference must be made to the reports for details:

Louisville.—At Louisville seven different types of filters were investigated: the Jewell, the Warren, the Western gravity, the Western pressure, the Harris magneto, an electric system, Palmer and Brownell water purifier, and the MacDougall Polarite system. Daily tests were made from October 21, 1895 to August 1, 1896.

The area of 85,000 square miles, comprised within the water-shed of the Ohio river, exhibits wide extremes in geological formation. The population above Louisville is 4,500,000, of which 1,575,000 are in 220 towns and cities, with an increase of 15 per cent. in six years. With great and rapid changes in the character of the river water, depending upon the section of country from which freshets come, (and these freshets are occasionally very heavy,) the problem was not a simple one. At no time is the water entirely clear. The ratio between maximum and minimum weights of suspended matter was found to be as great as 5311 to 1, and the color varied from light grey to dark red. As a rule the water had a slight odor, which, however, was occasionally quite pronounced, in fall and spring musty, sometimes aromatic and resinous. In spring after rains it had a vegetable odor. The sediment consisted at times of large amounts of fine particles of silt and clay, requiring weeks to settle. Individual particles were sometimes as small as 0.00001 inch in diameter.

Mr. Fuller states, in his general conclusions, that "it is proved conclusively that the general method embodying subsidence, coagulation and filtration is most suitable for the proper and economical purification of the Ohio river water at this city (Louisville). With regard to the use of coagulants, it may be stated in unqualified terms that their use is imperative for this water, because for at least six or ten weeks in the spring and early summer, the Ohio river water contains such large quantities of fine clay particles, many of which are smaller than bacteria, that clarification and purification without coagulation would be impracticable if not impossible."

Further investigations were conducted from April to July, 1897. In the final summary and conclusions there are some points that may here be noted. When the water is high and muddy it is not specifically injurious. When it is low and comparatively clear it is most to be feared. Filtration, preceded by subsidence, is the correct method, and the use of coagulants is imperative.

An effluent water, free from turbidity, could be secured with an English (slow) filter plant at a net rate of about 1.5 million gallons per acre (4½ cubic feet per square foot) daily, but there was a marked indication that fine clay was passing into the sand-layers, necessitating a cleansing at frequent intervals. A preliminary subsidence was necessary, and sulphate of alumina was found to be the most suitable coagulant. There were times when coagulation, in conjunction with subsidence, could be employed to advantage. The experiments with American (rapid) filters indicated that by taking advantage of a preliminary subsidence, the amount of sulphate of alumina could be held at from 1.5 to 2 grains per gallon, with an annual average of 1.75 grains.

With regard to the use of water in steam boilers, from filters using a coagulant, more incrusting constituents were found than in the raw river water, although their annual average amount contained in the filtered water was only about 60 per cent. of the quantity normally present in the river water during the fall months. The effect of adding coagulant would be largely if not wholly offset by the removal of the suspended matters. Compared with the waters of other cities, that of Louisville would be classed as a satisfactory boiler water.

Cincinnati.—Mr. Fuller's investigations at Cincinnati are of later date. He says: "This work had for its object an investigation in the practicability of the method proposed by the Engineer Commission of 1896, by which, as a part of the extension and betterment of the municipal water supply, the Ohio river water should be partially clarified by plain subsidence for several days and then filtered, as suggested, through filters of the English type." "Owing to the fact that the Ohio river water at Cincinnati differs materially in its character for about six months in the year from those waters where this method of purification has long been successful, it was recommended both by the Board of Expert Engineers of 1896 and the Chief and Consulting Engineers of the present Board that, before proceeding further, sufficient reliable data should be obtained with reference to the exact local conditions." Experimental filter plants were erected and operated, chemical and bacterial analyses were made, weight of suspended matter determined in special samples, etc., etc.

"Specific difficulties and complications in the treatment of the local river water by plain subsidence and English filtration" were encountered and there were "features wherein plain subsidence for three days and English (slow) filtration failed essentially in the clarification and purification."

To prolong the average period of plain subsidence "beyond about three days would not be practicable on the ground of cost." The use of coagulants was therefore found to be imperative at certain periods on account of the fine clay particles contained in the water. Mr. Fuller further states that "so far as present knowledge upon this subject goes, there is only one way in which these clay particles can be removed, and that is to apply a chemical which shall aggregate them into flakes or masses, so that it is practicable to remove them subsequently by subsidence and filtration."

To assist the process of filtration at times of heavy freshets, a coagulant was introduced into the settling basins "only when economical provisions for plain subsidence are incapable of preparing the turbid water adequately for filtration, and in such amounts that the water going upon the English (slow) filters may be properly and readily filtered." He found it essential to allow the coagulated matters suspended in the water to subside in the settling basins so that they would not rapidly close up the pores of the sand layer at the surface. "That is to say, the water applied to the English (slow) filters must be substantially free from coagulated masses of clay."

Mr. Fuller finally concluded that "it is practicable to clarify and purify the Ohio river water in a satisfactory manner by either the modified English system (slow filtration with accelerated sedimentation) or by the American (mechanical or rapid) system." He recommends the adoption of the latter system as "somewhat cheaper," and giving substantially the same quality of filtered water. This decision is of course based on local conditions.

Pittsburgh.—A report upon the investigations made by the Pittsburgh Commission was issued in January last. Personal visits were made by its members to the experimental plants at Louisville and Cincinnati and several of the members also visited filter plants in Europe.

The City of Pittsburgh is supplied with water from the

Allegheny and Monongahela rivers, principally from the former, and the water is objectionable on account of the mud it carries and because of its pollution by sewage. "Elaborate experiments extending over a period of time of sufficient length to show the effect of filtration upon the water of the Allegheny river in all seasons and at all stages" were carried on, and it is stated in the report that the "investigations show the entire feasibility of so treating the water by several methods as to remove both the mud and the deleterious vegetable growths contained therein."

Of the various methods of filtration examined, "two have proved themselves efficient, the method of mechanical (rapid) filtration and the method of sand (slow) filtration". "The latter has yielded upon the whole somewhat better results than the former." "As is fully put forth in the report of the Experts employed by the Commission, etc., the method of sand (slow) filtration not only yields a supply of water free from mud and objectionable bacterial life, but also furnishes a supply of water of a quality adapted to mechanical purposes, suited to the uses of industrial establishments." These conclusions, like those reached in Cincinnati, are based on local conditions.

The use of meters was also investigated and strongly recommended, it having been concluded, after careful investigation, that the city was wasting "more than twice as much water" as it had any use for.

The Pittsburgh Commission had special experiments made to determine the adaptability of filtered water to use in boilers. It was originally intended to experiment at the city's pumping station, but difficulties occurred in regard to this, and three new 25-horse-power boilers were loaned to the Commission. These were operated respectively with the effluent from the sand filters, with the effluent from the mechanical filters and with unfiltered river water. The report states that the boiler using unfiltered river water was found in the best condition, and, although considerable scale and sediment were deposited, the deposit was soft, adhered loosely and could easily be washed off and removed. The other boilers showed about the same results, although, in the one in which water from the mechanical or rapid filter was used, the rivets were badly corroded and a thicker incrustation formed in the tubes than in the one taking its water from the slow filter.

Regarding all the methods of purification, the report concludes "that filtration of the Allegheny river removes the mud and insoluble matter which would, by depositing, cause the boilers to be frequently cleaned and washed out. The incrusting properties which remain, while they may not make scale as quickly or as thick as if greater amounts of other material (mud, etc.) were present, yet, when the deposit is formed, it is hard, of a character which gives it the name of 'porcelain scale,' and difficult to remove except by tools."

Filtration is no longer an experiment. All filter works, so far constructed and properly operated, have demonstrated their efficiency beyond any question.

In comparing the slow with the rapid filter, it should be borne in mind that any accidental disturbance in the process of filtration is likely to interfere with the purification of the water nearly in proportion to the rate of filtration.

Projects Presented.

We present, for your consideration, several projects for the radical improvement of the entire water supply of the city, viz.:

A.—200,000,000 gallons daily of mountain water, from the tributaries of the Upper Lehigh and from the Upper Perkiomen, delivered by gravity into Queen Lane reservoir.

An 8-foot aqueduct, extending from Big creek, on the Lehigh river, to Treichlersville, on the Upper Perkiomen, carries the impounded waters of the Upper Lehigh tributaries into one of the reservoirs on the Perkiomen creek.

A dam at Green Lane, on the Perkiomen, impounds the combined waters of the two streams, which are carried thence by a 12-foot high-level aqueduct to the Queen Lane reservoir.

B.—200,000,000 gallons daily of mountain water, from the tributaries of the Upper Delaware, near the Water Gap, delivered by gravity into a new reservoir to be constructed near Twelfth street and Olney avenue.

A 14-foot aqueduct extends from the Delaware Water Gap to the proposed new reservoir at Twelfth street and Olney avenue, conveying thereto the impounded waters of the Upper Delaware tributaries, which it receives through several feeders at the Water Gap.

C.—450,000,000 gallons daily of mountain water, from the tributaries of the Upper Lehigh, and from the Upper Perkiomen, delivered by gravity into Queen Lane and East Park reservoirs.

The Lehigh aqueduct extends from White Haven, on the Lehigh, to Treichlersville, on the upper Perkiomen, and the combined waters of the Lehigh tributaries and of the upper Perkiomen are carried from the impounding reservoirs at Green Lane through a 12-foot high-level aqueduct to Queen Lane reservoir, and through a 12-foot low-level aqueduct to East Park reservoir.

D. 450,000,000 gallons daily of mountain water, viz.: 225,000,000 gallons delivered by gravity from the tributaries of the upper Delaware, near the Water Gap, into the new Olney avenue reservoir, and 225,000,000 gallons delivered by gravity from the tributaries of the upper Lehigh and from the upper Perkiomen, into Queen Lane reservoir.

The 14-foot Delaware aqueduct extends from the Delaware Water Gap to the Olney avenue reservoir, as in Project B, and the 8-foot Lehigh and 12-foot high-level Perkiomen aqueducts extend from Big Creek, on the Lehigh, to Queen Lane reservoir, as in Project A.

E. 700,000,000 gallons daily of mountain water, from all of the above-named sources, delivered by gravity into the new Olney avenue reservoir, into Queen Lane reservoir and into East Park reservoir.

This project, forming, in fact, a combination of the preceding projects, is suggested merely to indicate what provision may be made in case the consumption of water should continue increasing as it has done in the past. But, if proper precautions are adopted to prevent unnecessary waste, so large a quantity as 700,000,000 gallons daily will not be required even fifty years hence. Indeed, it is likely that 450,000,000 gallons per day will meet all requirements at that time.

F. 200,000,000 gallons daily, of filtered Schuylkill and Delaware river water, from slow filter at Torresdale, Queen Lane, Roxborough and Belmont and from rapid filters at East Park, delivered by pumpage into existing reservoirs.

The Delaware water filtered through slow filters at Torresdale, and the Schuylkill water filtered through slow filters at Roxborough, Queen Lane and Belmont, and through rapid filters at East Park, is pumped into the existing reservoirs.

G. 450,000,000 gallons of filtered Schuylkill and Delaware river water daily from the same system enlarged.

H. 450,000,000 gallons of Delaware river water daily, filtered by rapid frlters at Portland, and delivered by gravity into the new Olney avenue reservoir.

Annual Cost of Operation and Maintenance.	Cost per Thousand gallons. Cents.
$1,205,000	1.65
2,480,000	1.51
2,925,000	1.78

Annual Cost of Operation and Maintenance.	Cost per Thousand gallons. Cents.
$1,227,373 35	1.68
2,971,801 26	1.81

Annual Cost of Operation and Maintenance.	Cost per Thousand Gallons. Cents.
$3,239,379 21	1.97
3,170,805 46	1.93
3,108,606 00	1.89

35,000, and the annual expense

The rapid filters at Portland are supplied with water pumped at that point from the Delaware river, the supply of which, in dry seasons, is to be augmented by a maximum of 100,000,000 gallons daily of impounded mountain water from the tributaries of the upper Delaware near the Water Gap. Two 12-foot aqueducts carry the filtered water from Portland to the new reservoir near Olney avenue.

J. 450,000,000 gallons daily of Delaware river water, filtered by rapid filters at Torresdale, and delivered by pumpage into existing reservoirs.

The rapid filter plant at Torresdale is supplied with Delaware river water pumped at that point. After filtration the water is pumped to existing reservoirs.

K. 450,000,000 gallons of water daily delivered by gravity into the new Olney avenue reservoir, viz:—190,000,000 gallons of Delaware river water taken and filtered by rapid filters at Portland, supplemented by 260,000,000 gallons of mountain water brought to Portland by gravity from tributaries of the Delaware river near the Water Gap.

The rapid filter plant at Portland is supplied with 190,000,000 gallons daily, pumped from the Delaware at that point, and the filtered water delivered into the aqueducts there is supplemented by 260,000,000 gallons daily of mountain water brought from the tributaries of the upper Delaware through an aqueduct.

Two 12-foot aqueducts carry the combined mountain water and filtered Delaware water to the new reservoir near Olney avenue.

The costs of construction, operation and maintenance of these various projects are set forth in the table opposite.

Mullica River Project.—In addition to the Schuylkill and Delaware rivers and their tributaries, attention was drawn to another source, viz.: a locality some thirty miles southeast of Camden, in the State of New Jersey, comprising the area drained by the Mullica river and its branches, and of this some investigation was made.

This source appears to offer peculiar advantages in some respects, namely: contiguity to the city, abundance and comparative purity of the water, with but little danger of pollution in the future, and reasonableness in the cost of constructing the works. But the acquisition of the right to draw upon this water supply in another state would require legislation, and this would certainly involve considerable delay, if, indeed, the necessary authority could be obtained at all; a matter which, in the opinion of the Law Department of the city is, at least, doubtful. In the event of adverse action, the whole question of water supply for your city would revert to its present status, with nothing accomplished. We, therefore, abandoned the consideration of the subject.

The method to be adopted for distributing the water into the city's reservoirs will depend upon the amount required, and also upon whether it is brought from the mountains or is taken from the Schuylkill and Delaware rivers near the city.

If the water is brought from the Perkiomen and Lehigh watersheds, it can be delivered by gravity into Queen Lane reservoir (238 feet above city datum), and into all the other reservoirs of the city, excepting those at Roxborough and Mount Airy, into which the water must be pumped. For the present consumption it would be necessary to build but one aqueduct from the Lehigh watershed into the Perkiomen valley, and thence to the city. A consumption of 450,000,000 gallons daily would require the building of another aqueduct, from Perkiomen creek to the city, which would deliver its water into East Park reservoir.

If the water is brought from the Delaware Water Gap, it would be delivered by gravity into all the reservoirs of the city, including a new one proposed near Olneyville, excepting the Queen Lane, Roxborough, and Belmont reservoirs, into all three of which the water would have to be pumped from the level of the aqueduct (170 feet above city datum).

If the water is obtained near the city from the Schuylkill and Delaware rivers, it will require pumping into all of the reservoirs.

Mountain Water Supplies.

In our estimates of gravity supplies we have given preference to aqueducts of masonry, where these were practicable. In other situations, such as the crossings of deep valleys, we resort to the use of steel pipe. Where mountains or hills are encountered, tunnels are frequently necessary.

Where steel pipes are used, it is preferable to lay several of smaller size side by side rather than to use one large pipe of nearly equal cross-section, because, in the former case, the result of a break is far less disastrous.

The building of a gravity or aqueduct system involves the construction not only of intakes and gate-houses where the water leaves the reservoirs, but also of gate-houses at different points, with arrangements for shutting off, upon occasion, any portion of the pipe.

The Delaware river aqueduct begins at the mouth of the Bushkill creek, Pike county, follows the western side of the Delaware river as far down as Point Pleasant, and thence takes the most available course to the city. It collects the water from the various mountain creeks, which is to be stored in large reservoirs to equalize their yearly flow.

The Lehigh-Perkiomen aqueduct begins at White Haven on the Lehigh river, follows this river down to near Slatington, and thence takes the most direct course to the Perkiomen watershed, which it reaches through a tunnel terminating near Treichlersville. It collects the water from the upper Lehigh river and from several mountain creeks, the water of which is stored in large reservoirs for equalization. These waters mingle with those of the watershed, and together they are taken into two aqueducts at Green Lane, one being a high-level and the other a low-level aqueduct, which convey the water to the city.

The following plates illustrate the projects for mountain water supply:

Plate I. Plan of watersheds of Delaware and Lehigh rivers, and Perkiomen and Tohickon creeks, with aqueducts.

Plate II. Profile of Delaware aqueduct, Water Gap to Kintnersville.

Plate III. Profile of Delaware aqueduct, Kintnersville to Philadelphia.

Plate IV. Profile of Lehigh aqueduct, White Haven to Aquanchicola creek.

Plate V. Profile of Lehigh aqueduct, Aquanchicola creek to Treichlersville.

Plate VI. Profile of Perkiomen high-level aqueduct.

Plate VII. Profile of Perkiomen low-level aqueduct.

Plate VIII. Typical aqueduct sections.

Filtered Water Supplies.

The slow filters are all designed for an average rate of 3,000,000 gallons of water per acre of effective area (about 9 cubic feet per square foot) per day. The number of filter beds erected at each site at first would be only for present demands, and each plant could be increased thereafter from time to time, as found necessary, by additional filter beds, ample ground having been reserved for this purpose, except in the case of the Queen Lane.

The area available for slow filters at Queen Lane is limited, so that provision cannot be made at that site to filter more than 58,000,000 gallons per day, although the amount used in that district will hereafter be considerably greater. This deficiency will be made up from East Park, and for that purpose high-service pumps at East Park will be required.

A rapid filter plant has been adopted at East Park.

In considering the Schuylkill and Delaware rivers as sources of supply to be filtered for the city, we have decided upon the following main points:

a. To utilize and adopt the present plants as far as possible and to the best advantage.

b. To use the Schuylkill water for the districts of Belmont, Roxborough and Queen Lane, with such surplus as may remain of the limited 150,000,000 gallons supply per day, for East Park.

c. To abandon the reservoir at Fairmount, which is now in use only for about seven months in the year, and to connect the turbine pumps with Spring Garden station, so that they may be placed in service whenever the supply of water will allow, thereby relieving the steam plant of a corresponding amount of work.

d. To abandon the Corinthian reservoir.

e. To retain the Fairhill reservoir, which, although not now designated for use, will hereafter undoubtedly be found valuable as a centre of distribution for filtered water and can be so adapted by modification and covering.

f. To adopt slow filtration for Belmont, Roxborough and Queen Lane districts, and rapid filtration for such remaining portion of the Schuylkill water as is delivered at East Park.

g. To establish a slow-filter plant on the Delaware river below Torresdale, from which all the water not supplied from the Schuylkill will be obtained.

h. To make use of the present reservoirs, whenever possible, for sedimentation and for the storage of filtered water.

j. To allow at least 24 hours for sedimentation, and to provide storage capacity for one-half day's supply of filtered water.

k. To cover all storage reservoirs for filtered water.

l. To cover all filters.

It is, of course, eminently desirable that the water supplies for filtration should be as free from impurities as possible, so as to reduce to a minimum the duty on the filters; and every effort should be made, by legislation and otherwise, to prevent the pollution of streams; yet such water as exists to-day, in the Schuylkill and Delaware rivers at the City of Philadelphia, can be purified by filtration and rendered wholesome and fit for all domestic purposes.

Within the city limits it is possible to locate the filter plants at places where the water supplied them will not be subject to direct sewage polution. A point can be selected on the Delaware river within the city limits, but above such direct contamination, and the present intakes on the Schuylkill are well situated in this respect. The locations and conditions of existing pumping stations and reservoirs are such that it is advisable to continue the use of the water in this river up to a quantity equal to its minimum flow, at least so long as the present plant can be made serviceable. For additional supply, and for future extensions, the Delaware is the proper source, and in time it is not impossible that the whole supply may come from that river.

In order to ascertain the suitability of certain sands, obtainable in the vicinity of Philadelphia, for use in filter plants, we have had mechanical analyses made of a number of samples. The results, which are given in Appendix V, indicate that there will be no difficulty in obtaining suitable material for the purpose.

If the annual rates remain the same, the surplus earnings of the Bureau of Water would, to all appearances, be sufficient to pay for the continual extension of the plant as required by the growth of the city.

Owing to the improvements constantly being made in the operation of filtration plants, it is probable that our estimated cost of filtration will be found, in the future, to have been too high, rather than too low.

It will be noticed that the estimated cost of filtering on the Delaware is slightly less than on the Schulkill.

When the present reservoirs are converted into settling reservoirs for use prior to the filtration of the water, it will be necessary, in some instances, to re-adjust the water intakes and outlets, so as to accomplish the highest possible degree of sedimentation during the time that the water is passing through the reservoir.

It is advisable that filters and clear-water reservoirs be covered or roofed, to prevent the formation of ice on the surface and to protect the filtered water from pollution by the dust in the air which carries the seeds of lower life. There is abundant evidence of the deterioration of filtered water, or of spring water, kept in open reservoirs. In covered reservoirs, the water is also cooler in summer, than when exposed to sunlight. There is an erroneous idea that sunlight and air are advantageous to stored water. The contrary has been frequently demonstrated, and everyone appreciates the excellence of spring water, which issues, so to speak, from the bottom of a large natural filter, without having been exposed to either sunlight or air. There are both chemical and biological reasons for these facts.

The slow-filter plants contemplated in our recommendations are similar, in general arrangement, to those of London and of Hamburg, and to the recently completed filter plant at Albany, N. Y. The latter is the largest filtration plant in this country.

The following plates illustrate the plans for the several filter plants and show how it is proposed to utilize the present reservoirs for subsidence and for filtered-water reservoirs.

Plate IX. Locations of filter plants and mains recommended for immediate relief.

Plate X. Belmont filter plant.

Plate XI. Roxborough filter plant and Queen Lane filter plant.

Plate XII. East Park filter plant.

Plate XIII. Torresdale filter plant.

Plate XIV. Plan and sections of typical slow filter.

Plate XV. Details of sand washers and regulating apparatus.

We have said that we consider it inadvisable during dry years to obtain a greater amount of water from the Schuylkill river than 150,000,000 gallons per day. A provision for supplying the city with 200,000,000 gallons daily, therefore, requires 50,000,000 gallons a day to be obtained from the Delaware river; and all future increase of supply is assumed to be taken from this river. We have selected the neighborhood of Torresdale as the site for the new pumping station on the river because the present site at Lardner's Point will, in our opinion, not be suitable in the future, on account of the several large sewers now delivering, or which will soon deliver, a large amount of sewage into the river in that neighborhood.

From data at hand and from our estimates of the growth of the city, we have made the distribution of the total daily quantity of water required as follows:

For a supply of 200,000,000 gallons per day:

Belmont station	27,000,000 gallons daily
Roxborough station	15,000,000 gallons daily.
Queen Lane station	58,000,000 gallons daily.
Spring Garden station	50,000,000 gallons daily.
Torresdale station	50,000,000 gallons daily.
Making a total of	200,000,000 gallons daily.

It is proposed to add, at Belmont station, one new pumping engine of 20,000,000 gallons daily capacity.

For a supply of 300,000,000 gallons per day:

Belmont station	37,000,000 gallons daily.
Roxborough station	25,000,000 gallons daily.
Queen Lane station	58,000,000 gallons daily.
Spring Garden station	30,000,000 gallons daily.
Torresdale station	150,000,000 gallons daily.
Making a total of	300,000,000 gallons daily.

It is proposed to erect, at East Park filter plant, two 12,000,000-gallon pumping engines to pump from East Park reservoir into the Queen Lane district, in order to supply the deficiency between the amount pumped directly at Queen Lane station and the consumption of Queen Lane district.

For a supply of 450,000,000 gallons per day:

Belmont station	55,000,000 gallons daily.
Roxborough station	37,000,000 gallons daily.
Queen Lane station	58,000,000 gallons daily.
Spring Garden station	....
Torresdale station	300,000,000 gallons daily.
Making a total of	450,000,000 gallons daily.

If the future water supply is obtained from the rivers and filtered, it will be necessary to make a few changes in the pumping machinery and reservoirs.

At Fairmount, the reservoir is too low for a proper service, being only 94 feet above tide. Also it is inexpedient to filter the water at this station, and for these reasons we have recommended the abandonment of the Fairmount reservoir.

The Spring Garden reservoir would be of no use in the new apportionment and might be abandoned as a reservoir, unless retained for the use of Girard College.

At Belmont, the present reservoir, with slight alterations, could be used as a settling reservoir. A new 20,000,000-gallon pumping engine should be added to the station at the Schuylkill river, to be used as a reserve.

By limiting to 150,000,000 gallons per day the amount of water to be obtained from the Schuylkill river, it became necessary to re-apportion the amounts to be supplied to each station, as it was evident that at the present time more than the above amount is actually pumped from the Schuylkill river. We found it to be more economical, therefore, to limit the amount of water to be supplied to the Queen Lane district from the Schuylkill river, and to furnish the deficiency hereafter from the Delaware river.

The quantity thus supplied to the Queen Lane district from the Schuylkill river is to be secured from the East Park reservoir by a new pumping station at the East Park filter plant, with proper engine capacity to pump from this resevoir into the Queen Lane district.

A portion of the Queen Lane reservoir is to be converted into a clear-water reservoir discharging into the City mains.

The East Park reservoir, being very large, will not only serve as a storage reservoir for Schuylkill water, but also for the excess delivered in the future from the Delaware river. A part of this reservoir is to be converted into a clear-water reservoir delivering into the city mains.

The new Roxborough reservoir is to be kept in use, but a part of it is to be converted into a clear-water reservoir.

The Mount Airy reservoir will be used, and the old Roxborough reservoir may be temporarily put out of use.

The Frankford reservoir will be converted into a clear-water reservoir.

The Lehigh reservoir can be temporarily placed out of use, and eventually converted into a clear-water reservoir if found necessary.

In assigning the quantity of water to be supplied to the several districts, and the capacity required of the filtration plant for each, consideration has been given to their probable relative growth and increase in population, as some districts, particularly those of suburban character, will undoubtedly show a much greater annual increase than others.

The lower levels in the Roxborough district, now supplied from the new reservoir, with its great elevation of 414 feet, could be more economically supplied from the Queen Lane reservoir if proper mains were laid for the purpose. Indeed, a portion of the lower Roxborough district is already supplied by a main which taps the Queen Lane pumping main near the station.

In connection with the gravity supply from the Delaware River, a new distributing reservoir near Olneyville, at the point of discharge of the conduit, is proposed. The cost of this reservoir is estimated at $1,000,000.

A new reservoir at Belmont, adjoining the present reservoir, for the sedimentation of raw water, may be required when the present consumption has been materially increased. It probably need not be more than half as large as the reservoir recently proposed.

As the demands of the Belmont, Roxborough and Queen Lane districts increase, the surplus of the Schuylkill water delivered at East Park during minimum flow will gradually diminish; and this deficiency, together with what will be required for increased consumption all over the city, is to be supplied from the Delaware through the Torresdale filter plant. When the Schuylkill is flowing above its minimum, which will be during most of the year, the supply will be ample to keep the East Park plant in full service as well as the others.

To abandon completely at this time the present Schuylkill plants would mean the abandonment of much valuable pumping machinery and other works, and also a loss of time in making the change. This change would require not only that a large additional plant be in operation on the Delaware before the Schuylkill plant could be removed, but also the laying of large and costly mains to bring the water to the city.

Upon the completion of the proposed Torresdale pumping station, the Frankford station would be abandoned.

The standpipes at Belmont, Roxborough and Chestnut Hill will be kept in use, but will be supplied with filtered water instead of with raw water.

RÉSUMÉ AND CONCLUSIONS.

We now desire to re-state briefly what has been stated at length in the preceding pages, and to present the conclusions derived from our examinations.

The deplorable condition of the City's water supply, which it is sought to remedy, is due to the pollution of its sources, to the lack of effective pumping machinery, and to the insufficient capacity of the distributing system.

The question of first importance is the source of supply, and to this nearly all of our thought and time has been devoted.

Most of the water is now obtained from the Schuylkill river, within the city limits. Five pumping stations take from it about 200,000,000 gallons daily. One pumping station is located on the tidal estuary of the Delaware river at Lardner's Point, and supplies about 15,000,000 gallons daily.

The Schuylkill water is being polluted at many points from its source down to the city line. Beginning with the mine waters, the coal dust and some sewage from the upper parts of the water-shed, the pollution is increased below by the sewage of cities and villages situated along the river and its chief tributaries, by the manufacturing refuse and by the surface water from agricultural districts, all of which render the water sometimes turbid, unpalatable, impure and dangerous to health.

The Delaware water at Lardner's Point is less turbid after rains than the Schuylkill water; it is also softer and less polluted. Its flow is many times larger. While this water is, therefore, now somewhat better than the Schuylkill water, the growth of the city, the newly-built or projected sewers above and below the intake, and the tidal oscillation of the water, tend to a continually increasing pollution also of the water taken from the Delaware river.

It, therefore, becomes imperative, either to select a new source of supply or to improve the present one, so that it will become thoroughly satisfactory to the citizens both as to quality and quantity. The first project requires the bringing of Blue Mountain water to the city; the second requires a thorough filtration of the Schuylkill and Delaware waters taken within the city limits. A decision as to which of these alternative projects is the better one must be based on the quality and quantity of water to be supplied and on the cost.

It was, therefore, necessary first to make certain preliminary assumptions, then to make designs for both projects, and to ascertain the cost of construction and operation. The assumptions as to population, and as to quality and quantity of water are as follows:

The present population, to be supplied from the city's pipe system as soon as practicable, is taken at 1,300,000 persons. The population to be held in view in the design for new works is assumed at 3,000,000 persons.

It was considered that the waters collected from the affluents of the Delaware and Lehigh rivers in the Blue Mountains, and from the Upper Perkiomen creek, could be used in their natural condition. While these natural sources are the best obtainable at a reasonable cost, and while their average standard of purity is high, it must be remembered that a guarantee against an occasional and temporary pollution of the water by disease germs from man and animals, cannot be given for such large and exposed water-sheds. Nor can an occasional taste, due to vegetal matter, be entirely avoided.

The alternative source of supply is the water of the Schuylkill and Delaware rivers, within or near the city limits, artificially purified to the required standard. The purification is obtained by filtering the water through sand; no better and cheaper method is known.

The progress made in this country and in Europe in ascertaining the laws of the mechanical and biological process of filtration, and the practical success obtained in filtering water for many years in large cities of Europe, confirm and warrant the conclusion that this method of purification can furnish this City, from both rivers, with water that will be clear and palatable, and will conform to the best bacterial and chemical standards.

When the raw river water carries much suspended matter with it, this must be allowed to subside, as a preliminary to filtration, so as to lengthen as much as practicable the time between the filter cleanings. Settling reservoirs are therefore essential as preliminaries to the filtration of the water of these two rivers. In order to secure the greatest practicable efficiency, the filter plant must not only be built with skill, and be provided with the best means for regulating the flow, and for cleaning the sand, but it must also be carefully operated by trained men, in accordance with the daily condition of the river water and of the filters.

The quantity of water required for city consumption depends on local conditions. In some cities much less water is used than in others. The quantity with which Philadelphia has generally been credited, is somewhat misleading, due to the absence of proper measuring appliances; as a matter of fact, it is less than appears on the records. There is also, in this city, an undoubted waste of water, the amount of which cannot now be accurately determined, and which confers no benefit whatever, either to persons or property, or for street or sewer cleaning. It, therefore, subjects the citizens at large to an entirely useless expenditure, which should be stopped at the earliest practicable moment.

We consider that, at present, a daily supply of 200,000,000 gallons, being 150 gallons per capita, is a very liberal allowance. We recommend that this quantity of pure water be immediately provided for. At the same rate, a population of 3,000,000 persons will require a daily supply of 450,000,000 gallons.

Comparative estimates of cost have been made for eventually supplying these quantities. In order to indicate the legitimate outcome of an extravagant use of water, we have made a further estimate of cost for supplying the city daily with 700,000,000 gallons of mountain waters.

The Blue Mountain water projects deliver water to the city reservoirs by gravity. In one, mountain water is obtained from the upper Perkiomen creek and from the

Lehigh river with its tributaries. In another, mountain water is taken from the Delaware tributaries near the Water Gap. Still another project was considered using the Delaware water at Portland below the Water Gap, but after filtration. Other projects were considered, but were found to possess no special advantages, and were also more expensive.

The filtered water project which has been specially considered, is confined to taking water from the Schuylkill and Delaware rivers within the city limits.

Two methods of filtration are in common use; one allows the water to percolate slowly through a bed of sand, while the other allows it to pass through much more rapidly, and, in order to give it the same degree of purity, requires the use of a coagulating substance to prevent objectionable organisms and suspended matter from passing through the filter. The first we have called a slow, and the second, a rapid filtration.

Inasmuch as it has been impossible, in the time at our disposal, to make the necessary experiments showing the precise effects of filtering both the Schuylkill and Delaware waters, either through slow or rapid filters, it is also impossible now to state which of the two systems would be the more economical. But we know, and can positively assert, from experience obtained elsewhere, that, for the plants which we have recommended, a slow filter system will not materially differ in annual expense from a rapid filter system. We likewise know that the slow filters, from long experience, and from their successful operation in many cities, can, without question, yield satisfactory results with the waters of the above-mentioned rivers. The rapid filters have only recently been sufficiently developed to command a high degree of confidence in their results under all circumstances.

We are of the opinion that for the present supply, slow filters should be adopted at every station in the city, excepting at the one near East Park reservoir. We believe that at the latter station a rapid filter plant would be more serviceable.

A comparison of the estimates of cost shows the following results:

The most economical project for a supply of mountain water is that taken from the upper Perkiomen and from the Lehigh water sheds. For immediate needs, its cost of construction is $33, 410,000. Its annual cost, for operation, interest on investment, and all expenses, to deliver the water into the City reservoirs, is $1,205,000.

For a daily supply of 450,000,000 gallons, the total first cost would be $66,740,000, and the annual cost $2,480,000.

The most economical project for a supply of filtered water is that by which the waters of the Schuylkill and Delaware rivers are filtered within the City limits. Its cost of construction, for present requirements, would be $10,974,000. Its annual cost, for operation, interest and all other expenses, to deliver the water into the City reservoirs, is $1,227,000.

For a daily supply of 450,000,000 gallons, the total cost of the filter plant, including special mains from Torresdale to the centre of the city, would be $34,155,000, and the annual cost $2,972,000.

The estimates of cost have shown three important results:

1. The original cost of any of the mountain water supplies is very great for the large quantities of water which the city requires.

2. A filtered water supply can be obtained at a first cost which is within the present borrowing capacity of the city, and the plant can be operated at a cost which will not exceed the probable annual net earnings of the water works.

3. The total annual cost of delivering the water into the City reservoirs, by either method, is about the same, and the annual earnings will cover the operation and extension.

In conclusion we recommend :

1. The adoption of that project by which the waters of the Schuylkill and Delaware rivers, taken within the City limits, are purified by filtration.

2. The immediate improvement of the existing plant, in accordance with the detailed recommendations of our report.

The necessity for the second of these recommendations is manifest. Our reasons for the first are as follows:

The entire works can be built for a sum which the City can secure at this time through a loan.

A supply of pure water for the entire City can be obtained within a comparatively short time, and the City can thus at an early day be protected against a continuance of those diseases which are known to be caused by the present polluted water supply.

A filtered water supply, under skillful management, offers a greater security against the effects of accidental pollution of the water, than is possible when the supply is taken from open, unprotected water courses. Filtration can, without difficulty, be made to render the water thoroughly wholesome.

The two large rivers at Philadelphia, or even the Delaware river alone, can furnish, at all times, a quantity of water sufficient for a very large city.

The foregoing is respectfully presented.

RUDOLPH HERING.
JOSEPH M. WILSON.
SAMUEL M. GRAY.
Commissioners.

APPENDICES

CONTENTS.

APPENDIX I.

Furnished by Bureau of Health.

A

Total Residue Precipitated in Parts per Million.

Semi-Weekly Observations of Schuylkill River Water.

Date.	Residue.	Date.	Residue.	Date.	Residue.	Date.	Residue.
1898. Jan. 3......	10.	April 4......	12.	July 5......	7.	Oct. 3......	5.
6......	3.	7......	5.	7......	14.	6	8.
10......	3.	11......	8.	11......	17.	10......	12.
13... ..	4.	14......	8.	14......	13.	13......	12.
17......	47.	18......	9.	18......	22.	17......	11.
20......	7.	21......	14.	21......	9.	20......	14.
24......	183.	25......	17.	25......	13.	24......	15.
27.... .	53.	28......	22.	28......	27.	27......	19.
31......	10.	May 2......	13.	Aug. 1......	16.	31......	20.
Feb. 3......	5.	5......	13.	4......	21.	Nov. 3......	14.
7......	2.	9......	149.	8......	107.	7......	10.
10......	11.	12	37.	11......	152.	10......	8.
14......	16.	16......	88.	15......	41.	14......	20.
17......	19.	19......	23.	18......	29.	17......	9.
21......	545.	23......	51.	22	80.	21......	40.
24......	35.	26	28.	25.....	25.	24......	14.
28......	2.	30......	18.	29......	17.	28......	15.
March 3......	6.	June 2......	23.	Sept. 1	10.	Dec. 1......	5.
7......	2.	6......	12.	6	11.	5	416.
10......	6.	9......	9.	8......	20.	8......	71.
14......	11.	13......	10.	12......	16.	12......	6.
17......	7.	16	20.	15......	7.	15......	14.
21	23.	20.....	17.	19......	7.	19	7.
24	18.	23......	16.	22......	11.	22......	52.
28......	12.	27......	13.	26......	7.	27......	32.
31......	50.	30......	33.	29.. ...	7.	29......	18.

Total Residue Precipitated in Parts per Million in Schuylkill River Water—Continued.

Date.	Residue.	Date.	Residue.	Date.	Residue.	Date.	Residue.
1899 Jan. 5......	9.	Mar. 2......	77.	May. 4......	15.	June. 26......	10.
9......	17.	6......	325.	8......	7.	29......	17.
12......	6.	9......	27.	11......	15.	July. 3......	104.
16......	5.	13......	1026.	15......	15.	24......	15.
19......	48.	23......	130.	18......	20.	27......	15.
23......	4.	27......	23.	22......	21.	31......	17.
26......	403.	30......	116.	25......	18.	Aug. 3......	31.
30......	13.	April. 4......	21.	29......	8.	7......	48.
Feb. 2......	5.	6......	10.	June. 1......	17.	10......	12.
6......	26.	10......	92.	5......	9.	14......	35.
9......	8.	20......	21.	8......	8.	17. ...	71.
15......	6.	24......	21.	12......	15.	21......	12.
20......	38.	27......	36.	15......	7.	24......	10.
23......	224.			19......	9.	28......	48.
27......	642.	May. 1......	10.	22......	22.	31......	41.

B

Total Residue Precipitated in Parts per Million. Daily Observations.

Date.	Delaware Water at Lardner's Point.			Schuylkill Water at Spring Garden.		
	By acid.	In 24 hrs.	In 48 hrs.	By acid.	In 24 hrs.	In 48 hrs.
1899.						
July 19	16.	6.5	9.	13.5	12.6	6.5
20	9.1	7.5	6.	9.9	3.7	6.5
21	7.5	8.6	5.	10.6	5.	6.5
22	13.5	14.6	10.	17.6	12.5	8.5
23	....	....	....	....	....	....
24	10.	9.5	9.6	14.5	23.6	7.
25	15.	12.5	19.6	13.5	16.6	10.5
26	16.	10.5	9.6	18.5	19.6	19.5
27	10.	17.5	9.1	16.5	22.6	7.5
28	14.4	7.5	9.1	10.5	14.6	7.5
29	15.	17.	18.6	4.5	6.6	12.
30	....	....	....	....	....	....
31	26.	29.5	29.5	16.5	19.6	21.5
August 1	24.5	22.5	22.5	18.5	16.5	17.5
2	20.	19.5	21.	28.5	26.	29.
3	41.7	46.	50.	39.5	31.	38.
4	24.	21.	26.	49.	59.5	63.
5	15.	14.5	16.	23.	30.	34.
7	15.	15.	16.	33.	36.	39.
8	13.	15.	15.	27.	26.	32.
9	15.	14.	18.	28.	22.	27.
10	16.	16.	15.	19.	13.	17.
11	22.	24.	27.	131.	130.	144.
12	24.	21.	22.	362.	315.	334.
13	....	....	....	103.	72.	74.
14	20.	16.	18.	65.	40.	42.
15	29.	24.	27.	67.	48.	48.
16	29.	22.	26.	104.	57.	71.
17	31.	22.	28.	78.	47.	50.

Total Residue Precipitated in Parts per Million. Daily Observations—Continued.

Date.	Delaware Water at Lardner's Point.			Schuylkill Water at Spring Garden.		
	By Acid.	In 24 hrs.	In 48 hrs.	By Acid.	In 24 hrs.	In 48 hrs.
1899.						
August 18	31.	19.	24.	47.	25.	27.
19	20.	17.	18.	21.	15.	17.
20	15.	14.	17.	23.	14.	18.
21	19.	18.	20.	16.	14.	15.
22	31.	21.	23.	19.	19.	19.
23	19.	15.	15.	23.	13.	18.
24	14.	16.	13.	19.	16.	13.
25	13.	8.	9.	14.	8.	9.
26	14.	12.	14.	11.	11.	15.
27	9.	11.	11.	25.	30.	30.
28	19.	11.	11.	55.	47.	47.
29	17.	16.	16.	44.	38.	43.
30	13.	11.	12.	69.	48.	43.
31	18.	12,	14.	53.	40.	38.
September 1	12,	14.	12.	25.	18.	19.
2	14.	13.	13.	26.	12.	14.
3	12.	10,	14.	16.	16.	18.
4	14.	11.	14,	30.	22.	34.
5	13.	11.	12.	32.	23.	28.
6	15.	10.	11.	22.	21.	19.
7	17.	12.	17.	30.	26.	24.
8	20.	17.	21.	25.	15.	12.
9	15.	13.	15.	28.	16.	16.
10	19.	16.	16.	28.	19.	18.
11	14.	11.	12.	22.	23.	21.
12	17.	11.	14.	23.	21.	22.
13	14.	12.	13.	25.	21.	21.
14	18.	14.	19.	23.	21.	24.
15	20.	15.	21.	22.	18.	19.
16	14.	12.	13.	17.	16.	16.

APPENDIX II.

Reservoir and Standpipe Data.

Name.	Surface High Water above City Datum. Feet.	Depth of Water. Feet.	Capacity in Gallons.	Number of Compartments.	Future Use if Water is Filtered.
Fairmount	94	12	26,350,000	4	To be abandoned.
Corinthian	120	27	37,341,000	1	To be temporarily out of use.
Spring Garden	120	17	12,950,000	1	To be temporarily out of use.
East Park	133	25	688,618,000	3	To be used and partly converted into clear water basins.
Belmont	212	25	39,758,000	2	To be used with slight alterations.
Queen Lane	238	30	383,100,000	2	To be used and partly converted into clear water basins.
Mount Airy	363	15	4,546,000	2	To be used.
Roxborough (Old)	366	20	12,838,000	1	To be temporarily out of use.
Roxborough (New)	414	25	147,032,000	2	To be used and partly converted into clear water basins.
Frankford	167	23	36,046,000	1	To be converted into clear water basins.
Lehigh	114	{ 19 13 }	28,910,000	2	To be temporarily out of use.
Belmont Standpipe	364	148	106,000	......	To be used.
Roxborough Standpipe	491	148	106,000	......	To be used.
Chestnut Hill Tank	481	12	52,000	......	To be used.

APPENDIX III.

ESTIMATES OF COST.

Construction, Operation, and Maintenance.

APPENDIX III.

BASIS OF ESTIMATES.

Cost of Pumping,

Per million gallons raised one foot high, including coal, labor, oil, waste and supplies, and ordinary repairs; but excluding interest and depreciation:

High-Lift Pumps.

For a daily supply of

200,000,000 gallons,	300,000,000 gallons,	450,000,000 gallons,
3.5 cents.	3.25 cents.	3.0 cents.

Low-Lift Pumps.

For a daily supply of

200,000,000 gallons,	300,000,000 gallons,	450,000,000 gallons,
5.25 cents.	4 875 cents.	4.5 cents.

For stations away from railroad sidings add to all above prices 0.5 cent.

Cost of Filtration,

Per million gallons of filtered water, including labor, cost of wash and waste water, lost sand, sanitary analyses of water, chemicals, superintendence, watchmen, ordinary repairs, and all incidental expenses; but excluding interest, depreciation and cost of pumping water to filters:

	Schuylkill River.	Delaware River, At Portland.	Delaware River, At Torresdale.
Slow filters	$3.60	....	$3.00
Rapid filters	4.80	$3.20	4.00

Interest and Depreciation.

Interest on cost of works is assumed at 3%.

Depreciation of works is assumed as follows:

Structures, Apparatus, etc.	Life, in Years.	Annuity on One Dollar.
Masonry Conduits	Permanent.	
Covered Masonry Filter Beds	Permanent.	
Covered Reservoirs	Permanent.	
Permanent Buildings	100	.00165
Cast-iron Pipe	80	.00311
Railroad Sidetracks	80	.00311
Steel Pipe	35	.01654
Air Valves, Blow-offs and Gates on Pipe Lines	35	.01654
Engines and Pumps	30	.02102
Boilers	20	.03722
Rapid Filters and Appurtenances	20	.03722
Electric Light Plants	20	.03722
Tramways and Equipment	20	.03722
Iron Fences	20	.03722
Telephone Lines	10	.08724
Sand-washer Apparatus	10	.08724
Regulating Apparatus for Slow Filters	10	.08724

Unit Prices.

Aqueducts, Tunnels, Steel-Pipe Lines and Dams.

Clearing and grubbing, per acre	$100 00
Earth excavation, per cubic yard	30
Borrowed earth, per cubic yard, per 1,000-foot haul	20
Overhaul, 5 cents per 1,000 feet; limit, 60 cents.	
Rock excavation, granite, etc., in tunnel, per cubic yard	5 00
Rock excavation, shale and soft rock in tunnel, per cubic yard.	4 00
Rock excavation, open cut, per cubic yard	1 20
Shaft excavation, per linear foot, Perkiomen	40 00
Shaft excavation, per linear foot, Lehigh and Delaware	100 00
Dry rock filling over arch in tunnel, per cubic yard	2 50

Unit prices, continued.

Rubble masonry filling in tunnel, per cubic yard	$5 00
Brick masonry in tunnel, per cubic yard	12 00
Brick masonry in trench, per cubic yard	12 00
Arch culvert masonry, per cubic yard	15 00
Rectangular culvert masonry, per cubic yard	10 00
Foundation masonry, per cubic yard	6 00
Retaining walls and cradling, per cubic yard	5 00
Rubble stone masonry in trench, per cubic yard	5 50
Paving, per cubic yard	2 00
Portland cement concrete in tunnel...... 1 : 3 : 6	7 00
Portland cement concrete in trench...... 1 : 3 : 6	6 00
Portland cement concrete...... 1 : 2½: 4½	7 50
Portland plastering on arch, per linear foot, 12-foot aqueduct	25
Portland cement wash, invert and sides, per linear foot of aqueduct	08
Riveted-steel pipes, coated and erected, per pound	06
Manholes, each	15 00
Blow-offs for 72-inch and 80-inch pipes, each	500 00
Blow-offs for 60-inch pipes, each	300 00
Air valves for 72-inch and 80-inch pipes, each	150 00
Air valves for 60-inch pipes, each	100 00
Gate-houses, including gates etc.	
With 4 lines of 80-inch pipe, each	$40,000 00
With 3 lines of 80-inch pipe, each	35,000 00
With 3 lines of 72-inch pipe, each	30,000 00
With 2 lines of 72-inch pipe, each	25,000 00
With 2 lines of 60-inch pipe, each	25,000 00
Railroad crossings, each, extra	2,000 00
Culverts over brooks, each, extra	10,000 00
Telegraph and telephone lines, per mile	600 00
Stone wall fence (two sides), per linear foot	40
Iron fence (two sides), per linear foot	2 00
Dressing and seeding banks, per square yard	08

MOUNTAIN WATER SUPPLY.

Cost of Construction.

Summary.

A.—For a daily supply of 200,000,000 gallons from the Upper Perkiomen creek and Lehigh river tributaries.

Perkiomen high-level aqueduct, 12-foot diameter	$9,490,000	
Lehigh aqueduct, 8-foot diameter	6,550,000	
Storage, Perkiomen	8,330,000	
Storage, Lehigh	7,720,000	$32,090,000
Distribution to Belmont reservoir	$245,000	
Distribution to Roxborough reservoir, including pumping station	370,000	
Distribution to East Park reservoir	235,000	
Distribution to Wentz Farm reservoir	470,000	$1,320,000
Total		$33,410,000

B.—For a daily supply of 200,000,000 gallons, from tributaries of Delaware river near the Water Gap.

Delaware aqueduct, 14-foot diameter	$31,690,000	
Storage, Delaware	14,850,000	$46,540,000
200,000,000-gallon reservoir, near Twelfth street and Olney avenue	$1,000,000	$1,000,000
Total		$47,540,000

C.—For a daily supply of 450,000,000 gallons from the UpperPerkiomen creek and Lehigh river, with tributaries.

Perkiomen high-level aqueduct, 12-foot diameter	$9,490,000	
Perkiomen low-level aqueduct, 12-foot diameter	9,050,000	
Lehigh aqueduct	18,700,000	
Storage, Lehigh	19,020,000	
Storage, Perkiomen	8,330,000	
		$64,590,000

Distribution to Belmont Reservoir from Queen Lane	$245,000	
Distribution to Belmont Reservoir from East Park.	155,000	
Distribution to Roxborough Reservoir, including pumping station	525,000	
Distribution to Wentz Farm Reservoir	990,000	
Distribution to East Park	235,000	
		$2,150,000
Total		$66,740,000

D.—For a daily supply of 450,000,000 gallons from the Delaware river tributaries, near the Water Gap, from the Upper Perkiomen creek, and from the Lehigh river tributaries.

Delaware aqueduct, 14-foot diameter	$31,690,000	
Storage, Delaware	14,850,000	
Perkiomen high-level aqueduct	9,490,000	
Lehigh aqueduct, 8-foot diameter	6,550,000	
Storage, Perkiomen	8,330,000	
Storage, Lehigh	7,720,000	
		$78,630,000
Distribution to Belmont reservoir	$475,000	
Distribution to Roxborough reservoir, including pumping station	525,000	
Distribution to East Park reservoir from Olney avenue	1,500,000	
Distribution to Wentz Farm reservoir from Queen Lane	470,000	
Distribution to Wentz Farm reservoir from Olney avenue	350,000	
Distribution to East Park reservoir from Queen Lane	235,000	
200,000,000-gallon reservoir near Twelfth street and Olney avenue	1,000,000	
		4,555,000
Total		$83,185,000

Annual Cost of Operation and Maintenance.

Summary.

A.—For a daily supply of 200,000,000 gallons from the Upper Perkiomen creek and Lehigh river tributaries.

Interest on $33,410,000	$1,002,300	
Depreciation of works	91,820	
Sanitary inspection	8,040	
Ordinary repairs	23,700	
Keepers' wages and pumping	68,490	
Sanitary analyses of water	11,000	
Total		$1,205,350
Say		$1,205,000
Cost per 1,000 gallons for the water delivered into the city reservoirs		1.65 cents.

C.—For a daily supply of 450,000,000 gallons from the Upper Perkiomen creek and Lehigh river, with tributaries.

Interest on $66,740,000	$2,002,200	
Depreciation of works	218,450	
Sanitary inspection	15,640	
Ordinary repairs	50,860	
Keepers' wages and pumping	166,650	
Sanitary analyses of water	25,000	
Total		$2,478,800
Say.		2,480,000
Cost per 1,000 gallons delivered into the city reservoirs		1.51 cents.

D.—For a daily supply of 450,000,000 gallons from the Delaware river tributaries near the Water Gap, from the Upper Perkiomen creek, and from the Lehigh river tributaries.

Interest on $83.185,000	$2,495,550	
Depreciation of works	198,640	
Sanitary inspection	16,620	
Ordinary repairs	49,150	
Keepers' wages and pumping	140,770	
Sanitary analyses of water	25,000	
Total		$2,925,730
Say		2,925,000
Cost per 1,000 gallons delivered into the city reservoirs		1.78 cents.

SLOW FILTER SUPPLY.

Cost of Construction.

Summary.

F.—For a daily supply of 200,000,000 gallons: 150,000,000 gallons from the Schuylkill and 50,000,000 gallons from the Delaware river, near the city.

Belmont filter plant, complete	for 27 millions daily	$1,802,786 00
Roxborough filter plant, complete	for 15 millions daily	729,099 31
Queen Lane filter plant, complete	for 58 millions daily	2,416,566 30
East Park filter plant, complete	for 50 millions daily	1,288,740 89
Torresdale filter plant, complete	for 50 millions daily	3,216,398 55
Totals	200 millions daily	$9,453.591 05
Mains to connect Torresdale filter plant with East Park distribution system		$1,520,000 00
		$10,973,591 05

G.—For a daily supply of 450,000,000 gallons: 150,000,-000 gallons from the Schuylkill and 300,000,000 gallons from the Delaware river, near the city.

Belmont filter plant, complete......for 55 millions daily.....	$3,751,386 00	
Roxborough filter plant, complete..for 37 millions daily.....	1,782,457 79	
Queen Lane filter plant, complete..for 58 millions daily.....	2,416,566 30	
East Park filter plant, complete	1,594,640 89	
Torresdale filter plant, complete...for 300 millions daily.....	13,629,628 53	
Totals..............................450 millions daily.....	$23,174,679 51	
Mains to connect Torresdale plant with East Park distribution system...	10,980,000 00	
	$34,154,679 51	

ANNUAL COST OF OPERATION AND MAINTENANCE.

Summary.

F.—For a daily supply of 200,000,000 gallons from the Delaware and Schuylkill rivers, near the city.

Interest on $10,973,591.05..............................	$329,207 74	
Depreciation of plant....................................	57,916 25	
Cost of pumping into reservoirs..................	566,499 36	
Cost of filtering water....................	273,750 00	
Total		$1,227,373 35
Cost per 1,000 gallons for the filtered water delivered into the city reservoirs....................		1.68 cents.

G.—For a daily supply of 450,000,000 gallons from the Delaware and Schuylkill rivers near the city.

Interest on $34,154,679.51........................	$1,024,640 39	
Depreciation of plant..................	205,539 65	
Cost of pumping into reservoirs................	1,216,021 22	
Cost of filtering water..............................	525,600 00	
Total..		$2,971,801 26
Cost per 1,000 gallons for the filtered water delivered into the city reservoirs........		1.81 cents.

RAPID FILTER SUPPLY.

Cost of Construction.

Summary.

H.—For a daily supply of 450,000,000 gallons from the Delaware river at Portland (two 12-foot aqueducts to Philadelphia).

Cost complete, including aqueducts, filter plants, all accessory works and distribution pipes to city reservoirs............ $67,862,747

J.—For a daily supply of 450,000,000 gallons from the Delaware river at Torresdale.

Cost complete, including filter plant, pipe lines and distribution pipes to city reservoirs....................................... $21,918,376

K.—For a daily supply of 450,000,000 gallons: 260,-000,000 gallons of mountain water from storage in the Delaware watershed above the Water Gap, and 190,000,000 gallons from the Delaware river filtered at Portland with rapid filters (two 12-foot aqueducts to Philadelphia.)

Cost, including storage reservoirs, aqueducts, rapid-filter plant, all accessories, and distribution pipes to city reservoirs....... $78,645,052

Annual Cost of Operation and Maintenance.

Summary.

H.—For a daily supply of 450,000,000 gallons from the Delaware river at Portland.

Interest on $67,862,747	$2,035,882 41
Depreciation of plant	222,558 80
Maintenance of aqueducts, storage reservoirs, etc.	46,400 00
Cost of pumping into city reservoirs	408,938 00
Cost of filtering water	525,600 00
Total	$3,239,379 21
Cost per 1,000 gallons for the filtered water delivered into the city reservoirs	1.97 cents.

J.—For a daily supply of 450,000,000 million gallons from the Delaware river at Torresdale.

Interest on $21,918,376	$657,551 00
Depreciation of plant	311,670 00
Cost of pumping into reservoirs	1,411,796 00
Cost of filtering water	727,589 00
Total	$3,108,606 00
Cost per 1,000 gallons for the filtered water delivered into the city reservoirs	1.89 cents.

K.—For a daily supply of 450,000,000 gallons: 260,000,000 gallons of mountain water from storage in the Delaware watershed above the Water Gap, and 190,000,000 gallons from the Delaware river filtered at Portland with rapid filters.

Interest on $78,645,052	$2,359,351 56
Depreciation of plant	202,465 90
Maintenance of aqueducts and storage reservoirs	63,540 00
Cost of pumping into city reservoirs	323,528 00
Cost of filtering water	221,920 00
Total	$3,170,805 46
Cost per 1,000 gallons for the water delivered into the city reservoirs	1.93 cents.

SLOW FILTER SUPPLY.

Cost of Construction.

Belmont Filter Plant.

Capacity, 27,000,000 gallons daily.

Land	$322,500 00
Excavation	31,200 00
Piping, including specials	211,022 00
Piping for sand washers	800 00
Drains	1,530 00
Sand washers	2,400 00
13 Filter beds, complete	490,568 00
Pumping machinery	225,000 00
Filtered-water reservoir, (capacity, 15,000,000 gallons)	220,000 00
Electric light plant	10,000 00
Double-track tramway, cars and equipment	5,120 00
Residence for superintendent	5,000 00
Proportional part of cost of bacteriological laboratory	3,500 00
Office and store-room	5,000 00
Shelter, lunch-room and conveniences	10,000 00
Fencing	15,000 00
Cleaning up, etc.	9,000 00
	$1,567,640 00
15 per cent	235,146 00
Total	$1,802,786 00

Belmont Filter Plant.

Capacity, 55,000,000 gallons daily.

Land	$322,500 00
Excavation	62,500 00
Piping, including specials	387,205 00
Piping for sand washers	1,200 00
Drain pipe	3,910 00
Sand washers	4,200 00
26 Filter beds, complete	974,910 00
Pumping plant at sedimentation basins	424,000 00
Filtered-water reservoir, (capacity, 26,000,000 gallons)	400,000 00
Additional sedimentation basin at Belmont reservoir	100,000 00
Electric light plant	15,000 00
Additional pumping plant at river station	484,300 00
Double-track tramway, cars and equipment	11,250 00
Residence for superintendent	5,000 00
Proportional part of cost of bacteriological laboratory	6,100 00
Office and store-room	5,000 00
Shelter, lunch-room and conveniences	20,000 00
Fencing	15,000 00
Cleaning up, etc	20,000 00
	$3,262,075 00
15 per cent	489,311 00
Total	$3,751,386 00

Roxborough Filter Plant.

Capacity, 15,000,000 gallons daily.

Land	$35,000 00
Excavation	19,250 40
Piping, including specials	64,242 00
Water mains for sand washers	1,000 00
Drain pipe	1,130 00
Sand washers	1,200 00
8 Filter beds, complete	303,697 00
Pumping plant	58,400 00
Roofing filtered-water reservoir	106,480 00
Double-track tramway, cars and equipment	2,800 00
Residence for superintendent	5,000 00
Proportional part of cost of bacteriological laboratory	2,000 00
Office and store-room	5,000 00
Shelter, lunch-room and conveniences	10,000 00
Fencing	10,800 00
Cleaning up, etc	8,000 00
	$633,999 40
15 per cent	95,099 91
Total	$729,099 31

Roxborough Filter Plant.

Capacity, 37,000,000 gallons daily.

Land		$35,000 00
Excavation		38,526 80
Piping, including specials		113,540 50
Water mains for sand washers		1,500 00
Drain pipe		2,510 00
Sand washers		3,000 00
18 Filter beds, complete		680,536 00
Pumping Plant:		
At river station	$174,800 00	
At filters	87,200 00	
		262,000 00
New force main from river station to reservoir		142,500 00
Roofing filtered-water reservoir		212,960 00
Double-track tramway, cars and equipment		6,000 00
Residence for superintendent		5,000 00
Proportional part of cost of bacteriological laboratory		4,100 00
Office and store-room		5,000 00
Shelter, lunch-room and conveniences		15,000 00
Fencing		10,800 00
Cleaning up, etc.		12,000 00
		$1,549,973 30
15 per cent		232,496 00
Total		$1,782,469 30

Queen Lane Filter Plant.

Capacity, 58,000,000 gallons daily.

Land	$310,000 00
Excavation	66,382 50
Piping, including specials	158,331 50
Piping for sand washers	3,000 00
Vitrified drain pipe	7,390 00
Sand washers	4,200 00
27 Filter beds, complete	1,009,949 00
Pumping plant at sedimentation reservoirs	100,000 00
Roofing filtered-water reservoir (capacity 40,000,000 gallons)	349,169 00
Electric light plant	15,000 00
Double-track tramway, cars and equipment	11,840 00
Residence for superintendent	5,000 00
Office and store-room	8,000 00
Shelter, lunch-room and conveniences	20,000 00
Fencing	15,600 00
Proportional part of cost of bacteriological laboratory	7,500 00
Cleaning up, etc	10,000 00
	$2,101,362 00
15 per cent	315,204 30
Total	$2,416,566 30

East Park Filter Plant.

Capacity, 50,000,000 gallons daily.

Rapid-filter plant, complete	$347,112 00
Building, including stack	215,000 00
Piping and specials, outside of building	51,850 00
Pumping plant for rapid filters	55,500 00
Roofing filtered-water reservoir	421,182 25
Changing roadways, sodding, etc	25,000 00
Proportional part of cost of bacteriological laboratory	5,000 00
	$1,120,644 25
15 per cent	168,096 64
Total	$1,288,740 89

East Park Filter Plant.

No water to be filtered at this station when total city consumption is 450,000,000 gallons daily.

Cost of plant as above	$1,120,644 25
New pumps to supply deficiency of 32,000,000 gallons daily in Queen Lane district	266,000 00
	$1,386,644 25
15 per cent	207,996 64
Total	$1,594,640 89

Torresdale Filter Plant.

Capacity, 50,000,000 gallons daily.

Land	$284,800 00
Excavation	55,382 80
Piping, including specials	77,014 50
Piping for sand washers	2,000 00
Drain pipe	6,060 00
Sand washers	3,600 00
24 Filter beds, complete	904,236 00
Pumping plant	848,655 00
Filtered-water reservoir at Torresdale	60,000 00
Filtered-water reservoir at Wentz farm	175,000 00
Sedimentation reservoirs	307,420 00
Double-track tramway, equipment and cars	9,700 00
Residence for superintendent	5,000 00
Proportional part of cost of bacteriological laboratory	7,000 00
Office and store-room	8,000 00
Shelter, lunch-room and conveniences	20,000 00
Fencing	5,000 00
Sidetrack from Pennsylvania Railroad	8,000 00
Cleaning up, etc	10,000 00
	$2,796,868 30
15 per cent	419,530 25
Total	$3,216,398 55

Torresdale Filter Plant.

Capacity, 300,000,000 gallons daily.

Land	$284,800 00
Excavation	314,555 80
Piping, including specials	504,354 50
Raw-water conduit	224,964 00
Filtered-water conduit, including manholes, gate houses, etc.	77,975 60
Water mains for sand washers	13,000 00
Drain pipe	41,648 00
Brick drains	46,226 00
Sand washers	21,600 00
138 Filter beds, complete	5,159,087 00
Pumping plant	2,325,620 00
Filtered-water reservoir at Torresdale	322,500 00
Filtered-water reservoir at Wentz farm	528,000 00
Sedimentation reservoirs	1,712,420 00
Double-track tramway, cars and equipment	54,800 00
Residence for superintendent	5,000 00
Proportional part of cost of bacteriological laboratory	32,300 00
Office and store-room	30,000 00
Shelter, lunch-room, and conveniences	100,000 00
Fencing	15,000 00
Sidetrack from Pennsylvania Railroad	8,000 00
Cleaning up, etc	30,000 00
	$11,851,850 90
15 per cent	1,777,777 63
Total	$13,629,628 53

MOUNTAIN WATER SUPPLY.

Cost of Construction.

Storage.

Reservoirs, Intake-dams, Connecting Pipes and Accessory Works.

Perkiomen watershed.. $8,330,000 00

Lehigh watershed:

Above Big creek 10,650,000 00

Big and Aquanchicola creeks 8,370,000 00

Delaware watershed.. 14,850,000 00

20 per cent. of the area of each reservoir is assumed to be stripped 12 inches deep.

Perkiomen High-Level Aqueduct.

Green Lane to Queen Lane Reservoir.

Diameter, 12 feet. Capacity, 225,000,000 gallons daily.

	Miles.	Total cost.	Cost per foot.	Description.
Aqueduct....	14.00	$3,105,000	$42 20	Slope, .000167.
Tunnel.	6.30	2,170,000	65 30	Slope, .000167.
Steel Pipe...	7.80	4,215,000	101 40	4 sections of four 80-inch pipes; slope, .0003. 5th section—three 72-inch pipes; slope, .001.
Totals.........	28.10	$9,490,000		

Average cost per foot, $64 00

Perkiomen Low-Level Aqueduct.

Green Lane to East Park Reservoir.

Diameter, 12 feet. Capacity, 225,000,000 gallons daily.

From	To	Miles.	Total cost.	Cost per foot	Description.
Green Lane...	Frederic	4.89	$1,225,000	$47 50	Two 72-inch pipes; slope, .0025.
Frederic	Wissahickon	18.73	4,845,000	49 00	Aqueduct, 12-foot diameter; slope, .000167.
Frederic	Wissahickon	4.83	1,600,000	62 80	Tunnel, 12-foot diameter; slope, .000167.
Frederic	Wissahickon	1.08	755,000	132 50	Three steel pipes, 72-inch diameter; slope, .001.
Wissahickon creek..........	East Park reservoir ...	2.37	625,000	50 00	One 72-inch steel pipe, one 60-inch steel pipe; slope, .0035.
Totals.........	....	31.9	$9,050,000		

Average cost per foot, $53.80.

Lehigh Aqueduct.

Big Creek to Treichlersville.

Diameter, 8 feet. Capacity, 120,000,000 gallons daily.

	Length.		Cost.		
	Feet.	Miles.	Total.	Per foot.	Per mile.
Aqueduct..................	129,600	24.54	$4,120,000	$31.80	$168,000
Tunnel.....................	26,900	5.09	900,000	33.50	177,000
Syphon.....................	20,300	3.81	1,440,000	71.00	375.000
	176,800	33 47	$6,460,000	$36.60 (Average)	$193,000 (Average)
Open Channel..........	5,000	0.95	90,000	18.00	95,000
	181,800	34.42	$6,550,000	$36.00 (Average)	$190,000 (Average)

Lehigh Aqueduct.

White Haven to Aquanchicola Creek.

Section.	From	To	Miles.	Total cost.	Cost per foot.
I.	White Haven...	Muddy Run.....	8.24	$1,660,000	$38.20
II.	Muddy Run.....	Bear Creek......	6.91	2,050,000	56.10
III.	Bear Creek......	Big Creek........	8.33	2,860,000	65.00
IV.	Big Creek......	Aquanchicola...	6.35	2,830,000	84.50
			29.83	$9,400,000	$59.70 (Average)

Aquanchicola Creek to Reservoir near Treichlersville.

Section V.	Miles.	Total cost.	Cost per foot.	Description.
Masonry Aqueduct........	20.2	$5,345,000	$50.10	12-foot aqueduct; slope, .00045.
Tunnel.........................	5.09	1,605,000	59.60	12-foot aqueduct; slope, .00045.
Steel Pipe......................	3.39	2,230,000	124.50	Four 80-inch pipes; slope, .001.
Open Channel...............	0.95	120,000	24.00	20-foot channel.
	29.63	$9,300.000	$59.40 (Average)	

NOTES.

Section I: Capacity, 200,000,000 gallons daily. 14 300 feet, two 5-foot pipes; slope, .0055. 29 200 feet, one 10-foot aqueduct; slope, .0005.

Section II: Capacity, 250,000,000 gallons daily. 25 100 feet, two 5-foot pipes; slope, .008. 700 feet, two 6-foot pipes; slope, .004. 10 700 feet, 8-foot tunnel; slope, .002.

Section III: Capacity, 300,000,000 gallons daily. 34 800 feet, two 6-foot pipes; slope, .005. 9 200 feet, 10-foot tunnel; slope, .001.

Section IV: Capacity, 350,000,000 gallons daily. Three 80-inch pipes; slope, .002.

Section V: Capacity, 350,000,000 gallons daily.

Delaware Aqueduct.

Water Gap to Portland.

Diameter, 12 feet. Slope, .0003.
Capacity, 260,000,000 gallons daily.
Length, 5.86 miles.
Cost, complete, $2,112,540.

Portland to Point Pleasant.

Diameter, 14 feet. Slope, .000167. Capacity, 260,000,-000 gallons daily.

	Total cost.	Length.		Cost.	
		Feet.	Miles.	Per Foot.	Per Mile.
Aqueduct	$14,220,000	208,200	39.43	$68 30	$360,000
Tunnel	2,200,000	29,500	5.59	74 60	394,000
Steel pipe	1,730,000	11,200	2.12	154 00	816,000
	$18,150,000	248,900	47.14	$72 90 (Average.)	$385,000 (Average.)

Point Pleasant to Philadelphia.

Diameter, 14 feet. Slope, .000167. Capacity, 260,000,-000 gallons daily.

	Total cost.	Length.		Cost.	
		Feet.	Miles.	Per Foot.	Per Mile.
Aqueduct	$7,990,000	130,600	24.73	$61 20	$323.000
Tunnel	2,695,000	38,400	7.27	70 20	370,000
Steel pipe	745,000	4,700	0.89	158 50	837,000
	$11,430,000	173,700	32.89	$65 80 (Average.)	$347,000 (Average.)

Expenditures Necessary to Put the Present Works into Proper Condition.

Fairmount Pumping Station.

River wall at Fairmount forebay	$16,500 00
Roof and improvements to Fairmount western pump house..	20,000 00

Spring Garden Pumping Station.

Repairs to Cramp pumping engine No. 7	5,000 00
Repairs to Holly pumping engines Nos. 2 and 3	16,500 00
Repairs to Gaskill pumping engine No. 11	5,000 00
Building conduits and filling forebay	25,000 00

Belmont Pumping Station.

House for Worthington pumping engine No. 4 and for housing additional pumping engines	25,000 00
Repairs to Worthington pumping engines Nos. 1, 2 and 3	3,000 00
Additional pumping machinery	75,000 00

Queen Lane Pumping Station.

Relaying suction mains and building new pump well	35,000 00
Tunnel and coal shed	36,000 00

Roxborough Pumping Station.

Repairs to Worthington pumping engines	1,500 00
Total	$263,500 00

As the labor at the stations will be furnished by the Department, it is not included in the above estimates of cost.

Fairmount and Flat Rock Dams.

Without more knowledge of the interior condition of the dams at Fairmount and Flat Rock, it is not possible to approximate the cost of repairing them, and, therefore, no amount is allowed in the above estimate of cost for this work.

Additional Mains for the Distribution System.

Belmont district	$372,000 00
Roxborough district	535,000 00
Queen Lane district	440,000 00
East Park district	770,000 00
Frankford district	650,000 00
	$2,767,000 00
Mains to connect Fairmount pumping station with East Park reservoir, and alterations in pumps (approximately)	260,000 00

Meters.

Repair shop and testing plant	$15,000 00
Tools, etc.	5,000 00
Purchase of meters	80,000 00
Total	$100,000 00

APPENDIX V.

Mechanical Analysis of Sands.

	Effective Size, m. m.	Uniformity Coefficient.
Cape May beach sand	.38	1.9
Delaware bar sand	.35	2.1
Gloucester sand—fine	.33	2.1
Bar sand	.30	2.5
Bank sand—Rancocas creek	.27	2.3
Cape May beach sand—fine	.24	1.5
White Jersey sand	.23	2.8
White sand—Gloucester	.24	3.0
Delaware bar sand—fine	.20	1.8
Gloucester sand—rough	.35	9.0
Jersey gravel—Rancocas creek	.16	4.4

"Effective size" designates the diameter of a grain of sand, 10 per cent. by weight of all the grains of the sample being smaller and 90 per cent. being larger than itself.

"Uniformity coefficient" designates the ratio of the size of a grain which has 60 per cent. of all the grains finer than itself to the size which has 10 per cent. finer than itself; if all grains were of equal size this coefficient would be unity.

All the above sands would require washing before being used in filter beds—the Cape May beach sands, to remove the salt; the bar sands, to remove the fragments of bark and finely-divided organic matter; and the bank sands, to remove the loam and clay mixed through them.

The Cape May sand is the best, but most expensive sand. The Delaware bar sand can be secured at a reasonable price, and, with proper selection and washing, would prove well adapted for purposes of filtration in the slow filters. The rough Gloucester sand, with screening and washing, would be valuable both for filter sand and for making concrete.

...om 1889 to 1898 inclusive.

Total.	"1" Extensions.	Total Expenditure.	Net Earnings, or Excess of Gross Earnings over Expenses. Amount.	Per Cent. of Earnings.
1 $708,847 53	$605,658 57	$1,314,506 10	$927,493 75	41.37
1 712,497 37	280,866 92	993,364 29	1,387,673 41	58.30
1 781,227 83	749,066 21	1,530,294 04	970,408 69	38.82
1 814,332 89	558,124 42	1,372,457 31	1,261,998 71	47.91
1 1,121,555 91	1,471,834 90	2,593,390 81	80,884 43	3.02
1 1,677,081 03	1,235,775 01	2,912,856 04	—153,225 45	—5.55
1 1,509,902 97	387,322 23	1,897,225 20	932,631 97	32.97
1 1,311,338 57	514,272 32	1,825,610 89	1,053,522 37	36.58
1 1,354,642 90	310,510 31	1,665,153 21	1,306,204 31	43.96
1 1,360,220 19	135,776 65	1,495,996 84	1,569,669 02	51.22

...ary supply and service mains; meters of all kinds, large valves, stops and ...enses of purveyors' offices, and lead service pipes laid by the City from main to

..." Expenditures for construction and repair shop include salaries of Superin... machinists, blacksmiths and all employees at shop; shop castings, including ...for fire hydrants, small stops, stop-box frames and covers, and grate bars; ...hine and miscellaneous castings, brass castings used in connection with the ..., wrought iron and steel, other materials, and expenses of pattern shop.

..." Expenditures for office include salaries of Chief and assistants, Chief Clerk ...tants, Chief Inspectors and nineteen inspectors, four draughtsmen, assistant in ...distribution, and all other office employees; also office expenses, stationery and ...' supplies.

..." Expenditures for extensions include new work for which special appropria... made; including, in general, new pumping stations or engines, boilers, reser... ...akes, mains, etc.