will, to that extent, lessen disruption and decay.* But be that so or not so, those of us who are lovers of engineering can now, at Niagara, gratify that taste in the unpretentious place where some of this vast energy is reclaimed for human use, and then, as ever, join with those who, not more than ourselves, love natural beauty, and find with them renewed pleasure and delight in the majestic, organ-toned and eternal cataract.

[The lecture was profusely illustrated with stereopticon views.]

A PRACTICAL PLAN FOR SAND FILTRATION IN PHILADELPHIA.

By Allen Hazen, C.E.

[*A report to the Woman's Health Protective Association of Philadelphia.*]†

In accordance with your instructions I have examined the water-works system of Philadelphia, to determine whether or not it is feasible to purify the water of that city by means of sand filtration as commonly practiced in Europe, and without the use of alum or other coagulants, and if so, to determine as nearly as may be what cost would be thereby involved.

I wish to acknowledge at the outset my very great obligation to Mr. John C. Trautwine, Jr., Chief of the Water Bureau, who has placed the resources of his office at my disposal, and without whose co-operation this report would have been impossible. I am also indebted to Mr. Amasa Ely, his assistant, for personal attention in examining the various grounds mentioned in this report, and to other gentlemen of the Water Bureau for their uniform courtesy and attention in furnishing maps, statistics and data at their disposal.

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* Professor Shaler, of Harvard, has suggested the buttressing of the cavities under the falling sheet of water, with masonry, so as to hold up the superincumbent strata.

† Printed in the *Journal* by permission of the Association.

The question of filtering the water supply of Philadelphia has already been considered at the direction of your Association, by Joseph B. Rider, C.E., who presented a report thereon, dated April 29, 1895. Mr. Rider advocated the adoption of some form of sand filtration, but was inclined to favor a plan somewhat at variance with the most approved European practice.

In the short time available for this examination it has been possible to make but a superficial examination of the problem, sufficient only to determine the feasibility of the general process suggested; and this report, so far as it relates to particulars of arrangement of works, etc., must be considered as suggestive rather than in the nature of definite recommendations.

This is particularly the case, as the whole subject of future water supply for Philadelphia was most exhaustively considered by Mr. Rudolph Hering, an engineer of great eminence and ability, during the years from 1883 to 1886; and as a result of his studies he recommended to the city the introduction of water by gravity from upland sources, supplemented by water pumped from the Delaware River from a point above the most serious points of pollution. Mr. Hering did not consider at length the filtration of the present sources, as he did not consider the then existing evidence as sufficient that filtration would adequately purify such waters. The additions to our knowledge of the nature and results of filtration during the last ten years have materially changed the aspects of the case, and Mr. Hering has himself indicated that if he were reconsidering the subject he would give serious attention to the filtration of the present supply.

The advantages of a gravity supply from upland areas, where the water is not subject to pollution by sewage, are very great, and the project recommended by Mr. Hering is not to be put lightly aside to make room for the latest ideas concerning the purification of polluted waters obtained from sources near at hand, and you will thus readily understand that it is impossible for me at this time to recommend the adoption of any system. I have simply canvassed the ground in a preliminary way to determine the possibilities of filtration.

In case the city should take the matter up, it would be desirable and necessary to have the various suggested localities surveyed and examined by test pits, and to have plans prepared for the various works involved. It would probably be found, upon further study, that the general plans here suggested could be modified with advantage in many important particulars, and a plan could be worked out which could be taken as representing the most favorable system of filtration. This plan should then be compared in all its phases with the plan recommended by Mr. Hering, taking into account changes in the cost of construction and of the interest to be paid for borrowed money, etc., which may have occurred in the ten years since Mr. Hering's report; and it would be only after such a comparison, which is quite beyond the scope of the present report, that a reliable opinion as to the expediency of the introduction of filtration could be given.

PRESENT SOURCES OF SUPPLY.

The city of Philadelphia now derives its water from the Delaware and Schuylkill Rivers, 94 per cent. being taken from the Schuylkill and 6 per cent. from the Delaware. The Schuylkill above the intakes has a drainage area of 1,900 square miles, and the population upon the water-shed above Philadelphia in 1890 was about 350,000, or 185 per square mile. The most important points of pollution are as follows:

Town.	*Population. (Census of 1890.)*	*Distance above intake. Miles. (Queen Lane.)*
Conshohocken	5,470	8
Norristown	19,791	12
Phœnixville	8,514	23
Pottstown	13,285	39
Reading	58,661	60
Pottsville	14,117	103
Total	119,838	

Urban population on water-shed, 63 per square mile.

An effort is now being made to treat and purify the sewage of Reading before its discharge into the river; but there is no assurance that this treatment as yet is adequate. Aside from Reading, all sewage produced upon the watershed is discharged directly into the streams.

The water from the Schuylkill for Philadelphia is pumped from two pools formed in the river by dams within the limits of the city. The sewage from portions of the city was formerly discharged into these pools. An intercepting sewer has been constructed, which takes sewage to a point below a dam below the lowest pumping station. The district served by this intercepting sewer is sewered by what is known as the separate system. That is to say, the rain water and sewage are removed by separate systems of carriers, and I am informed that little, if any, sewage is discharged from the city sewers at any time into the river above the intakes. The river banks above the city limits, and the west side of the river, where the latter forms the boundary, directly opposite the city, are occupied by manufacturing establishments discharging directly into the river.

The use of water from the Schuylkill at the present intakes has been regarded by every competent authority investigating the subject for many years as most objectionable, and the use of water from such a polluted source should be abandoned at the earliest possible moment.

The Delaware River above the water-works intake has a drainage area of 8,100 square miles, with a population in 1890 of about 600,000, or 74 per square mile. The most important places which may pollute the river are as follows:

Town.	*Population.* (*Census of 1890.*)	*Distance above intake. Miles.*
Burlington, N. J.	7,264	11
Bristol, Pa.	6,553	12
Mount Holly, N. J.	5,376	15
Bordentown, N. J.	4,232	21
Trenton, N. J.	57,458	26
Lambertville, N. J.	4,142	41
Point Pleasant, Pa. (Point suggested by Mr. Hering as source of water for Philadelphia)		50

Phillipsburg, N. J.	8,644	75
Easton, Pa.	14,481	75
South Easton, Pa.	5,616	76
Bethlehem, Pa.	6,762	86
South Bethlehem, Pa.	10,302	86
Allentown, Pa.	25,228	91
Mauch Chunk and East Mauch Chunk, Pa.	6,873	121
Hazleton, Pa.	11,872	140
Port Jervis, N. Y.	9,327	140
Total	184,130	
Square miles of water-shed		8,100
Urban population per square mile		23

The Delaware River is tidal as far as Trenton. The rise and fall at the intake is said to be about 6 feet. Most of the city sewage is discharged 4 miles or more below the intake; but Frankford Creek, only 1 mile below, receives a large amount of sewage, which flows with it into the river, and a number of sewers serving local population discharge very near, and even above, the intake. It is thought that at ordinary stages of the river, the flow is sufficient to prevent the tide from carrying sewage matters up stream for any considerable distance, but when the natural flow of the river is small, the up-stream movement of the river must be considerable.

I consider it desirable that the intake should be carried far enough up river to be above the highest point to which considerable quantities of sewage from the Philadelphia sewers may be carried by the tide. Whether the present intake fulfils this condition or not could be determined by numerous float experiments, and particularly by repeated bacterial examinations of the water from various points in the river, particularly at times of spring tide and of minimum flow of the river. Such examinations have not been made, but are desirable at as early a date as practicable, to determine the best location for works.

Aside from this possible tidal pollution, the Delaware River is much less polluted than the Schuylkill; its flow is greater; its water is softer; it is less subject to local pollution, and, in every way, it is more desirable as a source of water supply than the Schuylkill; and the same is equally true whether the waters of each are used in their raw condition, as at present, or if each of them should be filtered by equally good systems of filtration.

SITES FOR FILTERS.

In general topography the land upon which the city of Philadelphia is built rises gradually from the Delaware River. The Schuylkill River cuts through the highland back from the Delaware, and has but a narrow valley. The various pumping stations upon the Schuylkill are surrounded by abrupt hills, and, with but few exceptions, there are no opportunities for the construction of sand filters near them. The exceptions mentioned are not important; for, while considerable quantities of water might be filtered upon land immediately adjoining the Queen Lane and Belmont pumping stations, the areas are inadequate for the filtration of the quantities which will be required for supplying the respective districts, and it will be better to establish filters at other points where all the areas necessary in the respective cases are available at one point.

While the river bottom furnishes no adequate sites for filters, such sites can be found upon the higher and comparatively flat land a short distance back from the river. In utilizing such sites the force mains from the pumping station would be taken to filters constructed upon land above and near the respective reservoirs, and at such elevations as to necessitate as little extra pumping lift as possible. The water would be filtered and then drained from the filters into the respective reservoirs.

At Belmont an area of land a little higher than the reservoir is available, great enough for all possible requirements. A part of this area is park property, while a part is agricultural land and could probably be secured by the city upon reasonable terms.

The Fairmount pumping station, and the Fairmount, Corinthian and Spring Garden reservoirs, are in a closely built-up portion of the city, and are surrounded by lower ground, so that no suitable sites for filters are available in their immediate vicinity.

An area of land between Lehigh Avenue and Clearfield Street, and between Twenty-eighth and Thirty-first Streets, and extending for a little beyond the latter, is owned by the city, having been purchased as a reservoir site. The reservoir, which was to have been called the Cambria reservoir, has not been, and probably will not be, constructed, as the Queen Lane reservoir, in a measure, takes its place. The city owns 45 acres of land in this place, suitable for filter sites, and an additional area immediately adjoining it is now used for agricultural purposes, and could probably be secured. Filters constructed upon this land could be reached from the Spring Garden pumping station, and also, if necessary, from the Queen Lane pumping station, and the effluent would be at a sufficient elevation to drain into the largest of the city reservoirs, the East Park reservoir. The land now owned by the city is sufficient to allow the construction of filters with an effective filtering area of 30 acres with all accessories, and with a maximum filtering capacity of 90,000,000 gallons per day, and with the purchase of other suitable land this capacity could be increased at least one-third.

Another available site for filters is found above the Queen Lane reservoir, where, without going beyond School Lane and Wissahickon Avenue, an area is available sufficient to allow the construction of filters with an effective filtering area of 40 acres, and with a maximum capacity of 120,000,000 gallons per day.

Still another and higher site for filters is available north of the new Roxborough reservoir. I have not maps to show the exact area of this tract, but it is certainly sufficient to meet any reasonable requirements for a long period of years.

Along the Delaware, at the Frankford pumping station, and for many miles above upon the river bank, there are excellent and ample sites for filters. To utilize these sites filters might be constructed in excavation below the level of the river, but it would probably be better to construct filters upon the natural river bank, at an elevation of from 10 to 20 feet above tide water, and to raise the water from the river by means of centrifugal or low-lift pumps. The filtered water would then flow to the present pumping engines, and be pumped by them as at present, and, if additional capacity should be required, by others, to the various reservoirs, or directly into the pumping mains.

SYSTEM OF DISTRIBUTION.

I have not had time to study in detail the system of distribution in Philadelphia, nor is such a study essential to the direct purpose of this report. The following suggestions as to a revised arrangement of districts are based upon the report of the Bureau of Water for 1891, where a proposed future system is outlined.

The first, or Belmont district, comprises that part of the city west of the Schuylkill River, has an area of 21 square miles, and is supplied from the Belmont pumping station upon the Schuylkill River. The estimated population in 1890 was 100,000.

The second, or Roxborough district, is east of the Schuylkill River, and comprises that part of the city above an elevation of 165, city datum. It has an area of 23 square miles, and had a population in 1890 of 70,000, and is supplied from the Roxborough pumping station. At the present time the Roxborough pumping station is supplying a larger area and population because water is let down from it to lower levels; but as this involves pumping of the water to an unnecessary height, it will be desirable to shut off these lower areas and to supply them from the Queen Lane reservoir as soon as the latter is ready for full use.

The third, or Queen Lane district, comprises land on the east side of the Schuylkill, more than 60, but less than 165 feet above city datum, but not including the higher parts of what may be called the Frankford district. This third district, which is in part—and will soon be entirely—supplied from the Queen Lane Reservoir, has an area of 18 square miles, and its population in 1890 was 208,000. The remaining 29 square miles of high land in the city, most of which is agricultural land, and having as yet only a slight population, need not be considered further at the present time.

The fourth district includes all that part of the city below the level of 60 feet, city datum, and is now supplied by the Fairmount and Spring Garden pumping stations, and from the Frankford pumping station (the latter including land up to a level of 90); it covers 38 square miles, and had a population in 1890 of 670,000. This is by far the largest part of the city, and is capable of being supplied either from the Schuylkill or the Delaware, or, as at present, from both. The three first mentioned districts, that is, Belmont, Roxborough and Queen Lane, are much more readily supplied from the Schuylkill than from the Delaware.

The rather numerous high-service districts served by secondary pumpage are not here considered, as securing a pure water at the primary stations involves supplying the same to all secondary systems dependent upon them.

To supply the district below 60, city datum, with filtered water, it will be possible, as mentioned above, to filter the water from Spring Garden station on the site proposed for the Cambria reservoir, and to filter the water pumped at the present Frankford pumping station through filters in its immediate vicinity, or it may be better to go to a point further up the Delaware and construct a new pumping station and filters upon a site particularly adapted to them, and to pump the water from this point into the mains supplying the lower part of the city.

RESERVOIRS.

The city of Philadelphia is supplied with water from elevated reservoirs filled from the rivers by pumping. That is to say, the water pumped is carried direct to reservoirs, and the reservoirs are connected with the system of pipes leading to the consumers. At the present time there is an exception to this arrangement in that water for a small part of the city is pumped directly into the mains from the Spring Garden pumping station; but this is a temporary condition, which will not be continued after the Queen

Lane pumping station and reservoir are ready for full service.

The objects accomplished by these reservoirs are twofold: (1) they assure an abundant quantity of water at all times; and (2) the storage improves the quality of the water supplied. In so far as they relate to quantity, they serve to balance the fluctuations of consumption during the different hours of the day, so that the pumps can be operated at a constant rate while the consumption fluctuates from hour to hour; and they also serve as a reserve to supply the city in case of breakage or other accidents to the pumping machinéry or mains, or for use in case of unusual conflagration or other excessive demands.

In so far as the reservoirs serve to balance the different rates of consumption at different hours of the day (and this is one of their most important functions), the reservoirs at Philadelphia are very much larger than is necessary. The city has eleven considerable reservoirs, with an aggregate nominal capacity of 1,400,000,000 gallons, equivalent to six or seven days' supply at the present rate of consumption. Several of the reservoirs, however, are not in condition for full service, and the actual quantity of water held in reserve does not exceed 1,000,000,000 gallons, or five days' supply, while reservoirs with an available capacity of one-half of one day's supply are ample to balance the hourly fluctuations in consumption.

In regard to the necessity of maintaining so large a quantity of water for emergencies, it might be well to mention that the water-works in many large cities, including such cities as Detroit and Indianapolis, are operated without any reserve whatever of this nature, the water being pumped directly into the mains as required, without storage. It is necessary in such cases to provide a pumping capacity considerably in excess of the actual maximum consumption, to allow for accidents to any part of the machinery, and practical experience has demonstrated that, with reasonable precautions, it is possible at all times to maintain an adequate supply. As a rule, and within certain limits, additional pumping machinery is cheaper than additional reservoirs, and the advisability of maintaining so large reservoir capacity, simply with reference to maintaining the quantity of the supply, may be seriously questioned.

The second function of the reservoirs, perhaps even more important than the first, is that of improving the quality of the water. All the water, with the above-mentioned exception, is pumped to the reservoirs, and it ordinarily remains in them for several days. During these days much of the mud contained in the water is removed by sedimentation; although, after heavy storms, the water supplied from the reservoirs is often very muddy; and, judging from the experience of other cities, and by tests of Dr. Bolton of water from the East Park reservoir, the greater part of the bacteria are also removed, in part by sedimentation, and in part by death, as the conditions in reservoirs are not favorable for the propagation of pathogenic germs, and the larger the reservoir the greater the improvement thus effected. If Philadelphia had reservoirs many times as large as the existing ones, and were able to use them in rotation, it is probable that a reasonably pure, or even an entirely satisfactory, water could be secured from them, even from the present polluted sources; and if the reservoirs had been smaller than they are, the city would have suffered much more severely than it has from the evils of contaminated water. From this standpoint, the ample reservoirs are extremely fortunate and none too large.

In case pure water is furnished, by filtration or otherwise, the conditions with reference to the city's reservoirs will be radically changed. The water will not then be further purified in the reservoirs, and there will be no object in pumping all of the filtered water first to the reservoirs; but it will be quite as satisfactory to pump the water directly into the mains and allow it to go direct to the consumers. By connecting these mains with the present reservoirs it will be possible to operate the pumps at a constant rate, as it is always desirable to do. When more water is pumped than used, as during the night, the excess will go to the reservoirs, gradually filling them; while during the day hours of heavy consumption, when more water is used than is pumped, the excess pumped during the previous night will be available from the reservoirs to supply the deficiency. The reservoir capacity needed to maintain this service need not necessarily exceed one-third or one-half of one day's supply.

Algæ growths, dependent upon sunshine, are much more abundant in pure water than in ordinary river waters, and, in case the supply is filtered, it will be a serious question whether it will not be desirable to cover the reservoirs by roofing or otherwise, so far as they are directly connected with the distributing system. The necessity of covering would be equally great with any system of filtration—with mechanical filtration as much as with sand filtration. Lawrence and Poughkeepsie, supplying filtered water, use open reservoirs, but a certain amount of algæ growths results. This growth is not particularly unhealthy, but it sometimes becomes disagreeable to the senses.

CONSUMPTION OF WATER.

The population in Philadelphia for 1895, assuming that the increase was at the same geometric rate as it was from 1880 to 1890, was 1,164,000; and the quantity of water pumped, as shown by the pumping records, was 77,819,013,-610 gallons or 212,760,673 gallons per day, or 183 gallons daily for every person in the city. In the report of the Water Bureau for 1895 is given a somewhat larger estimate of the population, and a correspondingly lower estimate for the consumption per capita, namely, 162 gallons. Whichever estimate is correct, it is only possible to agree most heartily with the present able Chief of the Water Bureau and with his predecessors, and with every one who has seriously considered the matter in recent years, that this consumption is excessive and entirely beyond the reasonable requirements of the city, and it should and could be reduced at once, by proper measures, to a very much lower figure, probably one-half of the present consumption. It is often alleged that the increased use of baths and other domestic arrangements requiring water largely increases the consumption, and that the rapid increase of manufacturing operations demands large quantities of water, and that the increase in consumption is to be accounted for in these ways.

The most careful studies show, however, that even in the best class of modern houses, with the most liberal number of fixtures, with reasonable use of water, the consumption does not exceed 30 gallons per capita, or one-sixth of the present consumption in Philadelphia. The demands for water for manufacturing purposes, although undoubtedly larger than formerly, are inadequate to account for the alarming increase in consumption. This increase can only be accounted for by the deliberate or careless waste of water due to a wrong method of charging for the same.

Consider, if you please, what would happen to the city gas works if bills were collected according to the size of the house and the number of fixtures, the charge being the same whether gas was used in an economical and modern manner or whether every jet was lighted and allowed to burn all night, and all day long, too, for that matter. You will see that with such a system gas would be deliberately wasted on every hand and the consumption would increase to several or many times the normal and proper amount. As the works would not be operated at a loss the rates would be raised to cover the needless use of gas, and would be much higher than would be necessary under economical conditions. This condition of affairs is so absurd that it is difficult to give it serious consideration; but it is precisely what is being done in the Water Department in spite of the urgent protests and appeals of the present Chief and of his predecessors for the substitution of a more rational and business-like basis.

The remedy for this most unfortunate condition of affairs is simple, and consists in adopting the same principles in the sale of water that are already followed in the sale of gas. Every water service should be metered, and the quantity of water used charged for at a rate sufficient to pay for its collection, purification and distribution; and when this is done I venture to predict that your consumption will be reduced one-half; that everyone will have water in abundance, and that all persons except those who are now drawing water largely in excess of their legitimate demands will be served at a less cost than at the present time. The advantages of this arrangement are so obvious, and will accrue with such uniformity to all parties involved, that it seems incredible that the waste of water has been allowed to go so far without adopting means for preventing it.

NATURE OF FILTRATION PROPOSED.

The filters which I have under consideration are the ordinary sand filters, similar to those in use at London, Hamburg, Altona, Liverpool, Amsterdam, Rotterdam and many other cities. They will consist of water-tight basins, with masonry sides and a water-tight pavement for a bottom, on which will be placed underdrains surrounded by gravel, and upon this a layer of sand. The water is to be brought over the sand by suitable devices and filtered downward through it and afterward collected by the gravel, when it will flow through the underdrains to a suitable regulating apparatus for controlling the rate of filtration and loss of head, and thence to the reservoirs or pumps.

The walls of the filters are to be constructed of solid brick masonry, or a cheaper rubble masonry might be used, lined with brick. The bottoms will require to be water-tight, and can, perhaps, best be made by a thin layer of concrete, with a water-tight asphalt covering above. The pressure sustained will be very much less than in the present reservoirs, and a lighter bottom can thus be used.

Sand and gravel suitable for filtration do not exist upon or near any of the sites proposed for filters, except, possibly, sites upon the Delaware, and these materials will require to be brought in from a distance. Crushed stone can be secured at market rates, and bar or bank sand is also a regular article of commerce in Philadelphia. In the case of the construction of the filters, however, it will, perhaps, be better to have specially equipped boats or barges at the points from which sand is originally secured, provided with the necessary equipments to wash the sand and prepare it for placing in the filters, so that no waste material need be transported to the site of the filters. I examined numerous samples of sand now being brought into the city for building purposes, and I am confident that no difficulty will be experienced in securing an abundance of sand of the quality required.

I consider that the climate in Philadelphia is not severe enough to necessitate the use of covered or vaulted filters, and I have, therefore, made my estimate for open filters. The question as to whether or not sedimentation will be necessary or desirable as a preliminary to filtration cannot be readily settled without a more extended and minute acquaintance with the qualities of the water of the two rivers. From my observations and inquiry, however, I am inclined to think that sedimentation will be unnecessary with the waters of the Delaware, although desirable with the water of the Schuylkill.

In connection with each set of filters for the Schuylkill water provision is made for a receiving basin, into which the water will be pumped and from which it will flow to the filters. These basins will hold one-fourth of a day's supply, and a considerable amount of sedimentation will take place in them, which will probably be sufficient.

The Schuylkill is ordinarily comparatively clear, and could then be filtered without preliminary sedimentation. It is only occasionally when the water is high that very turbid water is pumped, and it should be remembered that these times of turbidity will rarely, if ever, occur at the same time as the maximum consumption, and it will thus be possible to allow the filters to operate at a rate below the maximum when the water is turbid.

I assume that the average daily yield for each acre of effective filtering area for all seasons of the year, including the times when it is out of service for the purpose of being cleaned, will be 2,000,000 gallons. It is further assumed that at times of maximum consumption 50 per cent. more water will be used than the average for the year; and at such times the filters will be operated at a rate of 3,000,000 gallons per acre daily. Draughts of higher rates than this will occur for short periods only, and the deficiency at such times can be made up from the reservoirs.

The rate of filtration is substantially the same as that actually followed in many European cities, even in cases where there is no adequate reservoir capacity and where the rate of filtration varies with the consumption. With the construction proposed such variations will be entirely unnecessary, and filtration can be maintained at a uniform rate for long periods, and under these conditions there is every reason to believe that the best results will be obtained at the rates suggested.

POPULATION AND QUANTITY OF WATER TO BE PROVIDED.

The population of Philadelphia in 1880 was 847,170. In 1890 it had increased to 1,046,946. Assuming that the increase from 1890 to 1900 is at the same rate as for the ten years before 1890, the population in 1900 will be 1,294,000. For the purpose of estimating the quantity of water required I assume that the population will be 1,300,000, and that of this number 800,000 will be resident in the low district; 260,000 will be resident in the district supplied from the Queen Lane reservoir; 100,000 in the Roxborough district, and that 140,000 people will occupy the Belmont district west of the Schuylkill River.

I have further assumed that the average consumption of water for all seasons of the year will have been reduced by the introduction of meters to 100 gallons per capita, but that at times of maximum consumption as much as 150 gallons per capita daily may be required, making a total filtering capacity required of 195,000,000 gallons. This quantity of water is much less than that now being used, but I believe it is ample for all purposes with a reasonable system for the sale of water.

ESTIMATES OF COST.

The following estimate of cost of works required to filter the quantity of water mentioned in connection with the various pumping stations has been made up from approximate data, and while not exact, the figures are upon ample basis, and will be sufficiently close to the truth for your purpose. The estimates are as follows, by pumping stations:

Belmont pumping station, 7 acres of filters; capacity, average, 14,000,000; maximum, 21,000,000 gallons daily.		
Land now owned by the city.		
Receiving basin	$35,000	
Filters	254,000	
Piping and connections	28,000	
Total		$317,000
Roxborough pumping station, 5 acres of filters; capacity, average, 10,000,000; maximum, 15,000,000 gallons daily.		
40 acres of land	$40,000	
Receiving basin	28,000	
Filters	198,000	
Piping and connections	34,000	
Total		$300,000
Queen Lane pumping station, 13 acres of filters; capacity, average, 26,000,000; maximum, 39,000,000 gallons daily.		
40 acres of land	$200,000	
Receiving basin	54,000	
Filters	472,000	
Piping and connections	61,000	
Total		$787,000
Cambria site; Spring Garden pumping station, 30 acres of filters; capacity, average, 60,000,000; maximum, 90,000,000 gallons daily.		
Land now owned by the city.		
Receiving basin	$103,000	
Filters	1,030,000	
Piping and connections	445,000	
Total		$1,578,000
Frankford pumping station, 10 acres of filters; capacity, average, 20,000,000; maximum, 30,000,000 gallons daily.		
20 acres of land	$20,000	
Centrifugal pumps and accessories for lifting water from river to filters	55,000	
Filters	330,000	
Piping and connections	4,000	
Total		$409,000
Total cost of filters with a maximum capacity of 195,000,000 gallons daily in connection with existing pumping stations		$3,391,000

In case the city is unwilling to bring itself to a reasonable use of water, and insists on wasting water as at present, the cost will be increased in proportion to the quantity of water required. The land provided for, however, at Roxborough and Queen Lane is sufficient for the construction of filters with twice the areas of those estimated for, and this item would not, therefore, increase with additional filters on those sites.

The cost of the operation of the filters may be approximately estimated upon a very liberal basis at $3.50 per 1,000,000 gallons of water filtered, or, for the quantity of water estimated for, $166,075 annually. This capitalization at 5 per cent. amounts to $3,321,500.

When additional quantities of water are required the capacity of filters at the Belmont, Roxborough and Queen Lane stations can be increased in connection with those now estimated for, the areas of land being ample for the requirements for a long period of years. The capacity of the filters on the site of the proposed Cambria reservoir, filtering water from the Spring Garden pumping station, can also be increased if desired, although the area of land available is apparently limited, and might not be sufficient for the ultimate requirements. It will, however, be better in many ways to get additional water for the district from the Delaware, instead of from the Schuylkill. Additional filters can be placed on the Delaware at any point selected as most suitable for this purpose.

As mentioned earlier in this report, investigations have not been made to determine the most advantageous point for taking the Delaware water. In case the water should be taken at a point immediately below Torresdale, works for an additional supply of 100,000,000 gallons daily would cost about $3,000,000, of which $1,100,000 would be required for filters, as much more for force mains from the filters to Market Street, connecting at various points with the pipes leading the water to all parts of the city, and $800,000 would be required for pumps, land and various accessories.

The total cost of works for securing water in this way amounts to about $30,000 for every 1,000,000 gallons daily capacity secured, and the works would be of such a nature that any considerable part of them could be installed at nearly the same proportionate cost, and the capacity could be increased as required at the same rate. I do not consider that such a large additional quantity of water will be required in the near future, but the estimate is included that you may know the expense which will be involved in case the city insist upon having so large a quantity of water as 300,000,000 gallons or more per day.

CONCLUSIONS.

The city of Philadelphia is now using water in a most wasteful and extravagant manner, and immediate measures should be taken to check such waste, and to reduce the consumption to a reasonable amount.

It is possible to construct sand filters similar to those in use at London, Hamburg and many other European cities, in connection with the existing pumping stations, of sufficient capacity to furnish water for all reasonable requirements, for the present population, and for that which may be expected in the near future.

When larger quantities of water are required, it will be possible to secure them from the Delaware River by means of filtration, and to use the water so obtained in connection with that from the present pumping stations. The quantity of water which can be secured in this way is practically unlimited, at least 1,000,000,000 gallons being available.

The cost of installing filters with all necessary accessories to filter an average of 100 gallons of water per day for every inhabitant in the city, and with a maximum capacity of 150 gallons per inhabitant per day, amounting to 195,000,000 gallons daily in all, may be approximately estimated at $3,400,000.

85 Water Street, Boston, Mass.,
September 1, 1896.