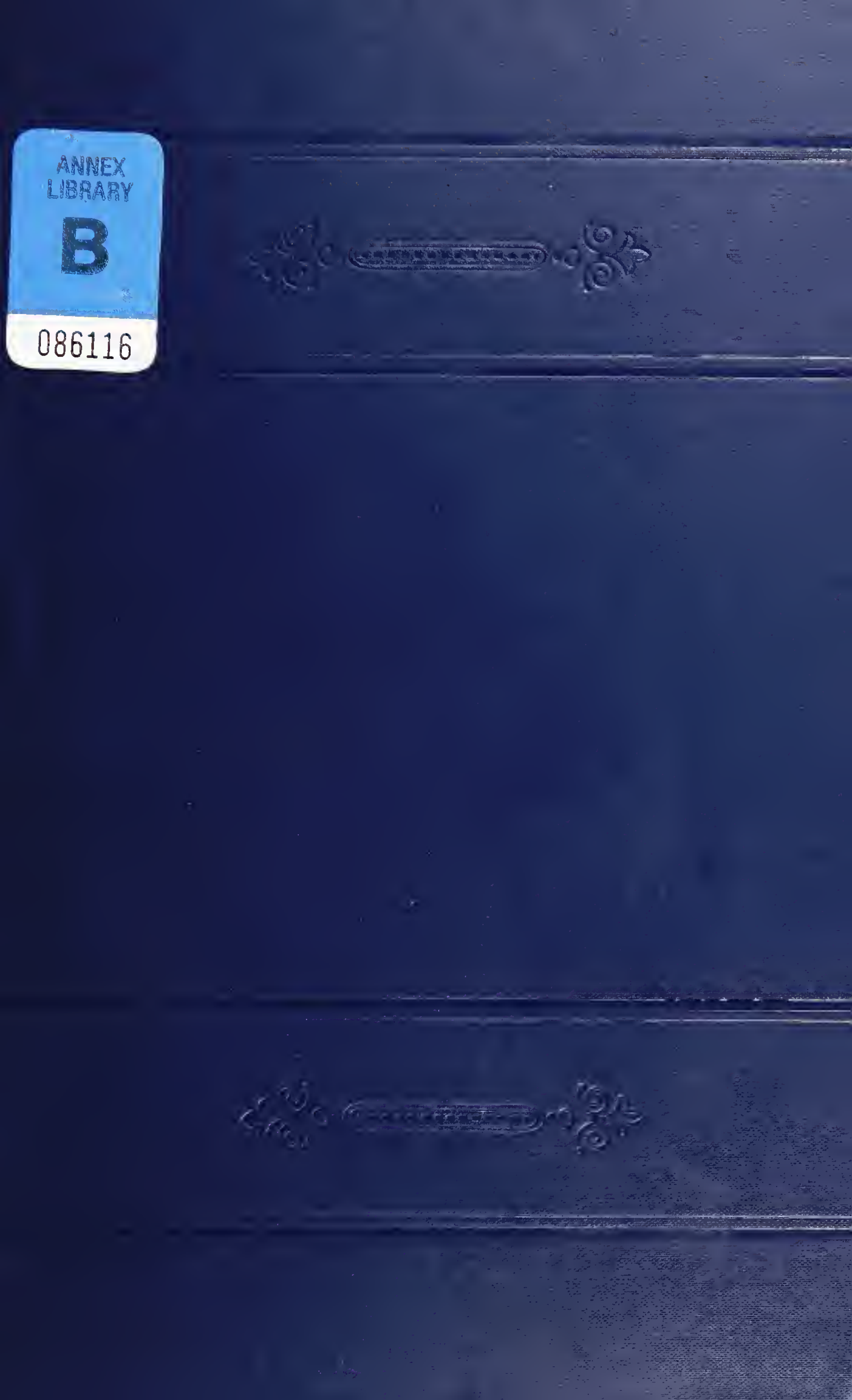

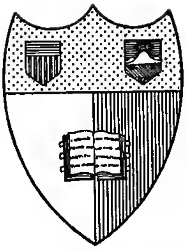

SENATE.

PURIFICATION

OF THE

WASHINGTON WATER SUPPLY.

AN INQUIRY HELD BY DIRECTION OF THE UNITED
STATES SENATE COMMITTEE ON THE
DISTRICT OF COLUMBIA.

EDITED AND COMPILED BY

CHARLES MOORE,

Clerk of the Senate Committee on the District of Columbia.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1901.

CONTENTS.

INTRODUCTION.

Action of the United States Senate on the question of the filtration of the District of Columbia water supply.

CHAPTER I.

Statements made at a hearing held at the Waldorf-Astoria Hotel, New York City, January 4, 1901.

CHAPTER II.

A paper on the Filtration of Public Water Supplies, prepared by Lieut. Col. Charles Smart, deputy colonel surgeon, United States Army, and indorsed by Surgeon-General Sternberg.

CHAPTER III.

A paper on the Filtration of Public Water Supplies, prepared by P. A. Surg. H. D. Geddings, of the Marine-Hospital Service, and indorsed by Supervising Surgeon-General Wyman.

CHAPTER IV.

Letter from Mr. Robert Spurr Weston in regard to the report of the District of Columbia Medical Society.

CHAPTER V.

Extract from the report of the committee on public health of the Washington board of health.

CHAPTER VI.

Historical review of the sanitary efforts to lessen typhoid fever in the District of Columbia.

APPENDIX—PART I.

Report of the investigation on the feasibility and propriety of filtering the water supply of the city of Washington.

APPENDIX—PART 2.

Report made by a special committee of the Medical Society of the District of Columbia upon the relative merits of the slow sand and mechanical filtration.

APPENDIX—PART 3.

A discussion of the filtration of water for public use by the American Society of Civil Engineers, at the London meeting, 1900.

APPENDIX—PART 4.

Daily mean temperatures in the District of Columbia.

Senate Report No. 2380, Fifty-sixth Congress, second session.

THE RELATIVE MERITS OF THE MECHANICAL AND THE SLOW SAND SYSTEMS OF FILTRATION FOR THE WATER SUPPLY OF THE DISTRICT OF COLUMBIA.

FEBRUARY 19, 1901.—Referred to the Committee on Appropriations and ordered to be printed.

Mr. MCMILLAN, from the Committee on the District of Columbia, submitted the following

REPORT.

On December 20, 1900, the Senate, by resolution, directed the Committee on the District of Columbia to make investigation and report as follows:

> *Resolved,* That the Committee on the District of Columbia be, and it is hereby, directed to investigate and report to the Senate, at the earliest practicable date, the relative advantages of the so-called mechanical system and of the slow sand system of water filtration for cities, and the necessary expenses of such investigation shall be paid from the contingent fund of the Senate.

The committee respectfully reports as follows:

The subject of the filtration of the District of Columbia water supply was brought to the attention of Congress in 1894 by Col. George H. Elliot, Corps of Engineers, then in charge of the Washington Aqueduct. The District of Columbia appropriation act approved June 30, 1898, provided that the officer in charge of the Washington Aqueduct should make an investigation of the feasibility and propriety of filtering the water supply of Washington, and submit to Congress a full and detailed report thereon. Three thousand dollars was appropriated for the purpose.

The duty of making this investigation devolved upon Lieut. Col. A. M. Miller, Corps of Engineers, whose report is contained in Senate Doc. No. 259, Fifty-sixth Congress, first session. This report was received while the District appropriation bill for that year was under consideration, and it was decided to appropriate $200,000 to be expended on those portions of a filter plant which would be necessary in either case whether the mechanical system or the slow sand system of filtration should be adopted. This action was taken because more time was desired to decide upon the system to be adopted for the District of Columbia than could properly be given within the limited time then at the disposal of Congress.

After a very long and careful investigation, the report from the War Department, known as Colonel Miller's report, took the ground that the water supply of the District of Columbia contained suspended clay in such fine particles as to make it practically impossible to use the slow sand system of filtration, and he, therefore, recommended the adoption of the rapid, or mechanical, system of filtration.

This report was sharply attacked by the Medical Society of the District of Columbia, and, following the lead of the medical society, by the board of trade and the business men's association. It was argued by those bodies that the use of alum as a coagulant was in itself objectionable, and that the mechanical process was inferior to the slow sand system as a means of removing those forms of pollution that are the cause of typhoid fever.

An inquiry conducted by this committee in New York City on January 4, 1901, was attended by men who have made for themselves the highest reputation in the matter of the construction and operation of filters for public water supplies. No large filter plant, either in existence or projected, was unrepresented at that meeting. The plants at Lawrence, Mass.; Albany, N. Y.; East Providence, R. I.; Norfolk, Va.; Elmira, N. Y., were among those as to which direct testimony was given; and the projects at Philadelphia, Pittsburg, Louisville, Cincinnati, Paterson, and New Orleans were discussed by men who had served or were then serving upon the boards of experts for those cities. No such representative gathering of filtration experts ever before took place in this country. It is true that the discussion of the subject of the filtration of public water supplies held at the meeting of the American Association of Civil Engineers in London, England, in July, 1900, brought together a larger representation of foreign experts; but the leaders of the discussion in London were also present in New York, and at the latter gathering the American problem had its fullest discussion.

The result of this discussion established the fact that the slow sand filter, wherever it had been put into operation, had produced uniformly good results both in clearing the water from turbidity and also in removing bacteria. The theory was maintained, however, that different types of water require different treatment, and that for waters that are simply polluted the slow sand filter is to be preferred; whereas for very turbid waters, containing fine particles of clay, the use of a coagulent is necessary. From this theory but one expert dissented, Mr. John W. Hill, who has had experience in the study of the water supply at Cincinnati, Philadelphia, and other cities. Mr. Hill maintained that he had never found a water for which he would not recommend the slow sand filter, Cincinnati being no exception. With the exception of Mr. Hill, the experts were of the opinion that the mechanical system, when properly operated, was capable of producing superior results as to the clearness of the water and equally good results with the sand filter as to bacterial efficiency. It was admitted that such results had not been uniformly attained; and this was held to be due to a variety of causes which had prevented the mechanical systems from being managed with a view to obtaining the highest efficiency of which they were capable.

There are to-day no cities of the size of Washington using the mechanical system of filtration; but, on the contrary, Lawrence, Mass., and Albany, N. Y., are successfully operating slow sand filters, and Pittsburg is putting in a slow sand system. Philadelphia is about to install a slow sand-filter plant for three-fourths of her water supply and is to construct a mechanical plant for the other fourth, merely for temporary use, the expectation being that the water supply at that particular point will be exhausted within a definite time. At Cincinnati a mechanical system has been recommended; at Louisville, Ky., and Paterson, N. J., also the mechanical system is to be used. The specifications, however, call for a type of filters differing radically from any plant now in operation.

The fact that slow sand filters have been doing highly efficient work for three-quarters of a century, under widely diverse conditions of operation, in the largest cities of the world would make the argument from experience conclusive in favor of the slow sand system, provided the Potomac River water were of the type that can be treated without the use of a coagulant at all times.

The further fact was developed that the cost of the two systems during a series of years is about equal, the first cost of the lands necessary for the slow sand filter being offset by the annual cost of the alum used as a coagulant.

In order to determine first whether the waters of the Potomac are of such a character as to make the use of a coagulant a necessity, and also to obtain the opinions of men who have had large experience in the installation and operation of filter plants, the committee asked for a professional report from Mr. Rudolph Hering, Mr. George W. Fuller, and Mr. Allen Hazen. This report, which has been agreed to by these three experts of conspicuous service and ability, is appended and made a part of the committee's report.

In brief, they recommend the adoption of the slow-sand filter system, modified by the use of coagulation during periods of extreme turbidity in the Potomac water. This combined system has all the advantages that three-quarters of a century have shown slow sand filters to possess, and it also provides for dealing with the peculiarly turbid waters of the Potomac during those exceptional periods when the slow sand system must fail to produce a clear water without materially impairing the filter beds.

The occasional coagulation of Potomac water at times of excessive and continued turbidity, in order to prepare the raw water for the filter beds, is a comparatively small incident in the operation, and the auxiliary works necessary thereto would be of small cost and of easy operation. On an average, during but one month in a year such treatment would be necessary.

Several sites are available for filtration beds, and each has its advantages. The beds might be located along the line of the conduit, where land is cheap; or, if a site near the Howard University reservoir should be selected, the result would be a considerable and highly desirable addition to the park system. At the same time the pumping required to deliver the water to the filter beds would give a very considerable additional head to the gravity supply, thus diminishing the amount of so-called high service required. This additional head for the gravity system is particularly desirable, for the reason that even the completion of the Howard University reservoir will not give an entirely satisfactory head of water on Capitol Hill and in certain other parts of the city that depend on the gravity service.

The committee is under obligations to Mr. Hering, Mr. Fuller, and Mr. Hazen for putting aside other and pressing work and devoting their time continuously to the solution of an intricate and perplexing problem. Colonel Miller very courteously placed at the disposal of the experts all the records and resources of his office that could aid them in the prosecution of their studies, and the engineer officers of the District government did everything in their power to facilitate the investigation.

The committee is also under obligations to Surgeon-General Sternberg, U. S. A., to Lieut. Col. Charles Smart, U. S. A., and to Supervising Surgeon-General Wyman and Dr. Geddings, United States Marine-Hospital Service, for special reports made at the instance of the committee.

In conclusion the committee recommends for use in the District of Columbia the adoption of the slow sand system of water filtration, modified by the use of coagulants whenever the waters of the Potomac are so turbid and turbid for so long a period as to make the use of a coagulant desirable.

REPORT OF MESSRS. RUDOLPH HERING, GEORGE W. FULLER, AND ALLEN HAZEN, ON THE METHODS OF PURIFYING THE WATER SUPPLY OF THE DISTRICT OF COLUMBIA.

WASHINGTON, D. C., *February 18, 1901.*

SIR: In accordance with your request, we present to you herewith a report upon the purification of the Potomac River water for the supply to the District of Columbia.

This subject was investigated by Lieut. Col. A. M. Miller, Corps of Engineers, U. S. A., who, on March 28, 1900, made a report thereon to Gen. J. M. Wilson, Chief of Engineers, U. S. A., which was printed as Senate Doc. No. 259, Fifty-sixth Congress, first session.

In his studies Colonel Miller gave attention to two processes for the purification of the Potomac water. One of these is variously known as American, rapid, or mechanical filtration; the other, as English, slow, or sand filtration. Colonel Miller recommended the adoption of mechanical filtration for the Washington water supply, the plant to be located near the new Howard University reservoir.

Exceptions were taken to this conclusion by a special committee of the Medical Society of the District of Columbia, which made a report dated December 5, 1900, and printed as Senate Doc. No. 27, Fifty-sixth Congress, second session. This committee earnestly recommended the prompt installation of slow sand filters, on the ground that it considered them to be more reliable in purifying the water at all times, and therefore safer from an hygienic standpoint.

By direction of the Senate Committee on the District of Columbia, a hearing was held at the Waldorf-Astoria Hotel in New York City on January 4, 1901, as to the relative merits of the two systems of filtration for the water supply of Washington. At this hearing statements were made by a number of gentlemen familiar with the subject of water filtration.

At your request the undersigned proceeded to the city of Washington, inspected the pertinent parts of the waterworks system and several sites available for filters, secured data bearing upon the problem, and conferred with officers affiliated with this branch of the District service. We beg to express our obligations to all of these gentlemen for the very courteous and efficient assistance which they have rendered us in our investigations.

The character of the raw water is often an element of controlling importance in deciding a question of this kind. Generally speaking, sand filters are best adapted to purifying waters that are not extremely turbid, and mechanical filters have marked advantages in the purification and clarification of waters which for considerable periods are very turbid. It was, therefore, necessary for us to examine all the available evidence regarding the character of the Potomac water.

At those places in this country where observations have been taken on the amount and character of turbidity of different river waters the methods used have not everywhere been the same. To compare the Washington data, which cover a period of twenty-three years, with those concerning other waters which have been studied in detail we have converted them to standards with which we are more familiar and have been able to compare the results with a reasonable degree of confidence. As a result of this study we estimate that a million parts of raw Potomac River water contain, as an annual average, about eighty parts of suspended matter. For the purpose of comparing in general terms the character of this water with the characters of others which have been carefully studied the following table, based on the best evidence now available to us, is presented:

Estimated annual average amount of suspended matter in raw water.

	Parts per million.
Merrimac River, Lawrence	10
Hudson River, Albany	15
Allegheny River, Pittsburg	50
Potomac River, Washington	80
Ohio River, Cincinnati	230
Ohio River, Louisville	350
Mississippi River, New Orleans	560

In the purification of river waters there are other very important factors to be considered besides the average turbidity or the weight of suspended matter. Most prominent among them are the fineness of the suspended matter during flood periods and the duration of periods of turbid water.

With streams where periods of turbidity are of short duration it is often possible at such times to close the intake, thereby avoiding the necessity of treating the most turbid water. The supply in the meantime must be maintained from storage reservoirs. We find that for Washington this procedure would not always be practicable, because the periods of highly turbid water sometimes last much longer than the period during which the supply could be maintained from the existing reservoirs, or from reservoirs which it is practicable to build.

We find that the water of the Potomac River at Great Falls following heavy rains is more turbid than any water which is successfully purified by slow or sand filters in this country. Few exact data regarding the turbidities of European streams are available, but it is certain that none of the waters filtered by the better known European sand filters approach, on an average, the turbidity of the Potomac water.

By subsidence it is possible to reduce materially the excessive turbidity of river waters by passing them through reservoirs. According to the best evidence now available there are times when plain subsidence of this river water for any reasonable period of time would not afford an adequate treatment preparatory to its successful purification by sand filtration. During some years this condition would not obtain, while during others subsidence might be inadequate for periods amounting in the aggregate to ten weeks and on an average to about one month each year.

It is further probable that the bacterial efficiency of the process might sometimes become inadequate, due to the general disarrangement of the filters caused by excessive turbidity. This condition would be less important at Washington than it was at Cincinnati. The water of the Ohio River at Cincinnati was found to be so turbid that it could not be adequately purified even after sedimentation, by sand filtration, for about 35 per cent of the time. On this basis we estimate that at Washington the proportion of the time when sand filters alone would be inadequate would amount to about 8 per cent.

As to the relative merits of the two systems of purification studied by Colonel Miller, namely, the treatment of plain subsided waters by sand and by mechanical filters, his conclusion is correct, namely, that the latter system would be the more efficient and the more judicious one for the city of Washington to adopt.

Since his investigations were instituted, some improvements have been made in the general processes of both slow and rapid filtration. Relative to the former, this progress applies, for very turbid clay-bearing waters, to the use of coagulants when needed. This procedure was studied at length at Cincinnati, and is used at a number of small places in Europe. It is referred to in Colonel Miller's report as the modified English system. It was not investigated by him owing to lack of funds, and in the absence of practical results he did not consider it.

Within the past few months material improvements in mechanical filters have been developed in connection with several municipal water supplies. These departures from former types of filters, in a measure are made possible by the expiration of the Hyatt patent. In our endeavor to solve the Washington problem we have devoted ourselves to a careful consideration of the relative merits of these two methods in their most improved forms.

We have based our consideration of the problem on a daily supply of 75,000,000 gallons of water, which approximates the present carrying capacity of the aqueduct. This amount is sufficient to supply all legitimate needs of a population much greater than the present one. Whenever a new aqueduct becomes necessary the question of purifying the additional supply of water thus obtained will be a part of the new problem. In our opinion it is unnecessary now to consider the purification of more water than can be carried by the existing aqueduct.

In this connection we beg to call your attention to the large waste of water in Washington, and to suggest the advisability of taking measures to limit such waste. One of the most effective means of doing this is by the use of meters; and we recommend that they be placed on all public buildings at once, and on private services, when deemed necessary, as rapidly as practicable.

The question of deciding between the two systems of purification, with the improvements above indicated, is in some respects a difficult one. In character the water for Washington is intermediate between the water for Pittsburg, where sand filters are best adapted to the conditions, and the water for Cincinnati, where American filters are preferable. If the Potomac water were more turpid, or turbid for longer periods than the records show, mechanical filters would unquestionably have the preference. If it were less turbid, or if turbid periods were of shorter duration, the advantage would clearly lie with sand filters.

Practical experience with sand filters is much more extensive and more favorable than that with mechanical filters. Our knowledge of what they will do rests not alone upon experimental investigations, but upon actual use for many years by some of the largest cities of the world. The force of this statement is somewhat reduced, however, by the fact that the raw water at Washington is more turbid than the raw water at the places where sand filters have been generally used.

Our knowledge as to the results that can be obtained by mechanical filters rests more upon experimental evidence than upon results obtained in practice. Nevertheless, these investigations have been made upon such a scale and with such care as to give the greatest confidence in their results.

It appears from consideration of the evidence at our disposal that the average yearly bacterial efficiency of the two systems would be about equal. During the warmer months of the year this efficiency would probably be greatest in the case of sand filters. When the river water is at or near the freezing point, the conditions upon which sand filters depend are less effective, and the efficiency of mechanical filters would probably be a little greater. This deterioration of sand filters would not be materially changed by covering them, as it appears to depend upon the temperature of the water while passing the filters, and this is not materially influenced by covers.

There will apparently be but little difference in the cost of the two systems. The cost of constructing sand filters is larger than the cost of constructing mechanical filters, but the latter are more expensive to operate; and when interest and depreciation charges on the investments are added to the costs of operation, the difference between the total costs is within the limits of accuracy of the two estimates.

After a full consideration of the various aspects of the problem we are of the opinion that the long and favorable experience with sand filters, particularly in the light of the effect which they have had upon the health of the communities using them, should be given greater weight than the present evidence that American filters are able to give substantially equal hygienic efficiency. In view of the fact that there is no available evidence of decided advantage to be gained by adopting the newer method, we prefer in this case to adhere to the one supported by long precedent.

In regard to the exact site for filters, the short time at our disposal has not allowed us to make the necessary surveys and detailed estimates of cost to decide definitely whether a site near the new Howard University reservoir sufficient for the construction of filters to purify all the water that can be gotten through the present aqueduct, or a site beyond the District limits, and near the line of the aqueduct, large enough to allow almost indefinite extension, is to be preferred. The former site has this advantage: That filters constructed upon it would be at such an elevation that the filtered water could be supplied at a greater elevation than that which would be available from the Howard University reservoir. It may be found upon further study that this additional pressure will justify the somewhat greater cost of filters in this vicinity.

In consideration of the full evidence we recommend the construction of a complete system of slow or sand filters, with such auxiliary works as may be necessary for preliminary sedimentation, and the use of a coagulant for a part of the time. There is no reason to believe that the use of this coagulant will in any degree affect the wholesomeness of the water.

Respectfully presented.

RUDOLPH HERING.
GEORGE W. FULLER.
ALLEN HAZEN.

HON. JAMES MCMILLAN,
Chairman Senate Committee on the District of Columbia, Washington, D. C.

PURIFICATION

OF THE

WASHINGTON WATER SUPPLY.

PURIFICATION OF THE WASHINGTON WATER SUPPLY.

CHAPTER I.

STATEMENTS MADE AT A HEARING HELD AT THE WALDORF-ASTORIA HOTEL, NEW YORK CITY, JANUARY 4, 1901.

By direction of the United States Senate Committee on the District of Columbia, an inquiry into the relative merits of the mechanical and the slow sand systems of filtration for the water supply of the District of Columbia was held at the Waldorf-Astoria Hotel, New York City, on Friday, January 4, 1901. The persons present at the request of the committee were:

Lieut. Col. Alexander M. Miller, United States Corps of Engineers, the officer in charge of the Washington Aqueduct.

Dr. William C. Woodward, the health officer of the District of Columbia.

Dr. J. S. Billings, director of the Consolidated Libraries of New York City.

Prof. William P. Mason, professor of chemistry at the Rensselaer Polytechnic Institute, Troy, N. Y.

Mr. Allen Hazen, C. E., St. Paul Building, New York City.

Mr. George W. Fuller, consulting expert in water purification and sewage disposal, No. 220 Broadway, New York City.

Mr. Edmund B. Weston, consulting engineer, Providence, R. I.

Mr. John W. Hill, hydraulic engineer, Cincinnati, Ohio.

Mr. Rudolph Hering, C. E., No. 100 Williams street, New York City.

Mr. John M. Diven, superintendent of the Elmira, N. Y., filtration plant.

Mr. George A. Johnson, bacteriologist, St. Louis, Mo.

The inquiry was informal in character. Senator McMillan, chairman of the Senate Committee on the District of Columbia, having been detained by the delay in the arrival of the western train, Mr. Charles Moore, the clerk of the committee, called the meeting to order, and he also presided at the afternoon session. Colonel Miller, who is charged with the construction of the District filtration plant, and Health Officer Woodward questioned those who testified. The hearing began at 10 o'clock in the morning, and was continued, with two short intermissions, until half after 5 in the afternoon.

The Senate resolution ordering the inquiry is as follows:

In the Senate of the United States,
December 20, 1900.

Resolved, That the Committee on the District of Columbia be, and it is hereby, directed to investigate and report to the Senate, at the earliest practicable date, the relative advantages of the so-called mechanical system and of the slow sand system of water filtration for cities; and the necessary expenses of such investigation shall be paid from the contingent fund of the Senate.

The first person called upon was Dr. J. S. Billings, formerly a surgeon in the United States Army, and now the director of the consolidated Astor, Lenox and Tilden libraries in the city of New York.

STATEMENT OF DR. J. S. BILLINGS.

Dr. Billings. I have seen the operation of the slow sand system of filtration at Hamburg and at several other places in Europe, particularly in England, during my experience in charge of the department of hygiene in the University of Pennsylvania. I have observed the results of some experiments with the Chamberland pressure filters. With the patent mechanical filters I have had no experience. With the general literature on the subject up to four or five years ago I am tolerably familiar. It was part of my work as a teacher of hygiene to lecture on filtration, and I have followed the matter, although not in detail, for the past four or five years. I have glanced over the report of the engineers on the experimental filters at Washington, and have looked over the little pamphlet sent me by Senator McMillan, containing the report of the Medical Society of the District of Columbia on that subject. I have looked over the reports as to the experimental preparatory filters at Pittsburg, just published, and the reports of the filtration of the Massachusetts board of health at Lawrence, Mass. That is the best answer I can give as to my experience, or as to the grounds for forming an opinion. I do not pretend to be an expert in the matter.

Mr. Moore. Have you made up your mind as to the respective merits of the English or slow sand system and the so-called American or mechanical system?

Dr. Billings. I think the question must be settled from special data in the case of each individual city. Neither system has any such marked superiority over the other that it is to be preferred at all hazards and at all costs.

Mr. Moore. Are you satisfied that the mechanical system can produce as good results, under proper care, as the slow sand system?

Dr. Billings. No, sir; but I can not give details or undertake to criticise the mechanical system. As I say, I have not examined that system thoroughly, but the slow sand filter I am familiar with. I would not pretend to pass judgment upon the abstract question. In the particular case of Washington, however, I would, on the whole, from what I know of Washington—and based upon the facts given in these reports—prefer to adopt the slow sand filter.

PRESSURE FILTERS NOT EFFICIENT.

Colonel Miller. You speak of the mechanical or American method, and you speak of pressure filters. Now, I think, as a general rule, it has been agreed that the pressure mechanical filter is not an efficient method for hygienic purposes. The method proposed in my report is not a pressure filter. The report proposes a gravity system, involving the use of coagulants, by which rapid filtration is secured. You stated, in the first part of your remarks, that it depended upon the individual city as to which filter was the best to adopt. What discrimination do you make in that respect?

Dr. Billings. Well, in the first place there would be the procuring of a sufficient area for slow sand filters, which in the case of some cities might be impossible, or possible only at an enormous cost. That should be considered.

Colonel Miller. In the case of the sanitation of a great city that does not enter much into the consideration. Speaking hygienically, what are the reasons why you prefer the American system, or the mechanical method to slow sand filters?

Dr. Billings. I prefer the slow sand filters, because their efficiency has been thoroughly demonstrated, and the efficiency of the mechanical system I do not think has been demonstrated for large cities.

Colonel Miller. Your experience has been gained from the observations at Hamburg, and of some other foreign filters?

Dr. Billings. Yes; and other large systems.

Colonel Miller. The slow sand filter is the only system that is used abroad. Do you consider that the slow sand filter is efficient where the water is continually roily or turbid, and contains finely divided matter?

Dr. Billings. It is satisfactory from a sanitary standpoint, although it may not always give a clear effluent, and it may be more costly by reason of requiring more frequent removals of the deposits from the surface of the sand, and the breaking up of the bacteria deposit on the surface of the sand causes a lower efficiency for a time.

Colonel Miller. Are there any objections to be raised against the American system on the score of the passage of alum through the filters?

Dr. Billings. As to that, I have no positive knowledge. I should judge from the reports that there are not. I think that alum does not appear in the effluent.

Colonel Miller. It depends upon the water?

Dr. Billings. Yes, sir; but I do not think my opinion is very valuable upon that subject.

Colonel Miller. Then you have not formed any very strong opinion on the subject?

Dr. Billings. No; not sufficiently to put myself in the position of an advocate of one system over the other in all cases.

THE FIVE ESSENTIALS IN FILTRATION.

Dr. Woodward. From the standpoint of a general water supply there are, I think, five points to be considered with reference to the effluent. The first is the character of the effluent as shown by the typhoid fever death rate; the second is the character of the effluent as determined by simple bacterial purity; the third is the quality of the water from the standpoint of clearness; the fourth is the quality with reference to the consumption of soap by the community, and the fifth is the effect of the effluent in causing incrustation upon steam boilers. Is not that the proper order of importance?

Dr. Billings. I should think that would be the proper order. The influence upon typhoid fever is the one that will come up most frequently for consideration in this country. The effects relative to cholera should also be considered, and I should perhaps modify that suggestion as to typhoid fever so as to include diseases which may be caused by water-borne organisms, etc.

Dr. Woodward. Of course, in this country we take typhoid fever as the typical water-borne disease. I used it only in that way. With reference to the correspondence between the bacterial efficiency and the probable typhoid-fever death rate, should we expect the death rate from water-borne diseases to vary as the bacterial efficiency of the filter—that is, to vary with the number of organisms taken out; or, we may say, with reference to the bacterial deficiency—I mean the number of organisms that remain in the water.

Dr. Billings. You mean the number of the specific organisms that remain in the water?

Dr. Woodward. The number that remain in the water, rather than the number taken out. You have never, I judge from your statement, gone into the question of the relative efficiency of these two systems in the removal of the colon bacillus.

Dr. Billings. No. I should judge from the Washington reports, from the Pittsburg report, and also from the Massachusetts reports, that the statements given were probably accurate as to that point.

Dr. **Woodward.** Do you know of any standard with reference to the turbidity of the water from a sanitary standpoint—any fixed standard?

Dr. **Billings.** I do not know of any.

Dr. **Woodward.** A slight degree of turbidity, if occasional, would be objectionable or unobjectionable from a sanitary standpoint?

Dr. **Billings.** If the turbidity were due merely to extremely fine particles of alumina or clay, I do not know that there would be.

Dr. **Woodward.** But with a high bacterial efficiency, would you be inclined to regard as important a slight degree of turbidity in the effluent?

Dr. **Billings.** The superior efficiency of a filter in regard to removing infectious forms of organism I should consider of greater importance than its efficiency in removing slight turbidity.

Colonel **Miller.** Is there such a thing as typhoid fever being endemic to localities?

Dr. **Billings.** Well, in one sense, the common sense of the word, yes. The specific organisms appear to be closely connected or identified with certain places and pretty much absent in other places.

Colonel **Miller.** With reference to that, how does Europe, and the Continent generally, compare with this country in that respect?

Dr. **Billings.** I think the statistics show more typhoid in this country than in Europe, as a rule. There are localities in Europe where typhoid is very prevalent; but the conditions for a particular place may change.

Colonel **Miller.** Of course there may be local conditions, but as a general rule do you think this country is more liable to typhoid than Europe?

Dr. **Billings.** As I remember the statistics of the large cities of this country (I have had charge of the compiling of the vital statistics for the last two censuses prior to this), for the cities of 100,000 inhabitants and upward the proportion of typhoid is larger in this country than it is in the European cities.

Colonel **Miller.** I know that in Germany the rules as to the use of water are very strict. Is there a law there requiring the population to use filtered water where such water is furnished?

Dr. **Billings.** I do not know. It would be difficult for the people to use any other water in such places as Berlin or Hamburg.

STATEMENT OF PROF. WILLIAM P. MASON.

Mr. **Moore.** Professor Mason, what has been your experience in regard to water filtration?

Professor **Mason.** Well, I have spent a good many years upon the water question, and have considered generally a great number of questions relative to water filtration by various methods.

Mr. MOORE. You were, I believe, connected with the Albany filter plant?

Professor MASON. No, I never was. I was asked by the board of health in that city to express an opinion with reference to the method of filtering the Albany supply. As early as 1885 I advocated putting in the plant which they now have. If they had put it in sooner, more lives would have been saved.

Mr. MOORE. The Albany plant is a slow sand filter system?

Professor MASON. Yes, sir; the English bed.

Mr. MOORE. At the time the Albany plant was built was the mechanical system much used to filter the water supply of cities?

Professor MASON. Yes; the mechanical system was pretty well known then.

Mr. MOORE. I understand that you have prepared a paper setting forth in some detail your views on the subject.

Professor MASON. Yes; I have. The reason I prepared this paper was that at the time Senator McMillan sent me the Washington reports I did not know exactly what would be the nature of this meeting, so I prepared a statement. I may say that I wrote it without any knowledge of the local conditions at Washington. I have seen the Potomac River from the cars only, and all I know about the situation is what I get from the printed matter furnished.

WHEN THE SLOW SAND FILTER IS PREFERRED.

I have read Senate Doc. No. 259, Fifty-fifth Congress, third session, relative to experiments conducted to determine the feasibility and propriety of filtering the water supply of Washington, and have also read Senate Doc. No. 27, entitled "Relative Merits of Slow Sand and Mechanical Filtration" (both documents having been sent me by Hon. James McMillan, United States Senate), and I beg to offer the following comments thereupon:

After a pretty wide experience in matters connected with the purification of municipal water supplies, I have concluded that, where local conditions do not intervene to affect the choice, the following general rule may be safely followed in selecting the type of a proposed filtration plant: First, I believe in the English bed for great cities using fairly clear raw waters; and secondly, I recommend mechanical filtration for very roily waters, and for small places, irrespective of the character of the raw supply. No hard and fast rule can, however, be laid down, as each case must be judged upon its own local conditions. Thus, not long since, I recommended filtration for two cities using the same raw water, but in one case I proposed the use of an English bed, and in the other I suggested a mechanical plant as best suited to the city's needs.

It must be remembered that roily waters may vary one from the other to a material extent, even when the degree of turbidity is the same; for equality in turbidity does not infer equal fineness in the particles producing such turbidity, nor does it predicate an equal power on the part of such particles to form themselves into larger aggregates. Thus with the same degree of turbidity two waters might give very different filtrates after passage through an English bed.

It is because of such variations in raw waters that experimental filter plants are established with a view of determining whether or not a proposed plan of purification is suited to the water under consideration; for it has been found that the results obtained in one locality may not answer for the conditions existing in another.

Had I been asked to give a snap-shot opinion as to the best form of filter for Washington, my reply would have favored an English sand bed, for I incline to such form of filter for so large a city unless there be special evidence showing some other form better suited to the local conditions.

THE WASHINGTON TESTS.

Of course the best manner in which to arrive at a just decision touching upon the selection of a municipal filter plant is to make practical tests of the forms proposed while they are operating upon the water that the chosen one will be expected to purify.

Such test Washington has made, and I have read with interest the record of results.

I have also read the comments made upon these above-mentioned results by the special committee of the Medical Society of the District of Columbia (as given in Document 27), and I feel that in some respects such comments and criticism almost take the form of special pleading.

For instance, I do not see the wisdom of allowing the public to infer that in some instances mechanical filtration of city water has been a direct cause of a decided increase in typhoid fever. No one who knows anything about filtration believes that to be a fact; and, moreover, so far as two of the cities are concerned where such strange results are claimed, namely, Elmira, N. Y., and Lexington, Ky., I chance to know that the true state of things is quite the reverse of this and that the filters have greatly improved the typhoid death rate. With reference to the remaining town I have no data.

Referring again to the medical society's criticism, I do not think it was well to include the figures on page 41 of Colonel Miller's report when striking the general average for comparison between the filters, for the reason that the mechanical filter was idle a large fraction of that time, and, moreover, because the efficiency of that filter on December 27, 28, and 30 was so poor as to show a manifest and preventable error somewhere. The run from January 6 to March 2 is a fairer period for comparison, omitting from the record, however, the work of the English filter bed for January 8, which is surely an error.

Striking the averages upon this run, we have the efficiency percentages as follows:

	Per cent.
English filter bed	97.64
Mechanical filter	98.60

Placed in graphic form, the "curves" showing the number of bacteria yet remaining in the filtrates from the two filters are given in the accompanying chart.

The relative averages of 88.9 and 86.9 per cent for the entire run of two hundred and sixty-six days are of little value, for such low percentages are entirely inadmissible in any form of plant whatever, except when the actual count is very low.

The continuous running of the English bed and the interrupted working of the mechanical plant is commented upon as unfair to the former. Such a statement is in error. Interruption in operation is of no advantage to a filter, and often may be quite the reverse.

On page 5 of document 27 it is stated that the "percentage of germs which remained in the water from the alum filter was 70 per cent larger than the percentage of germs remaining in the water from the sand filter." This statement is an error, if the calculation be based, as it should be, on the run recorded on page 42 of Colonel Miller's report; but aside from all that it must be remembered that percentages in such form may be very misleading. For instance, on February 17 the percentages of bacterial removal for the two filters were:

	Per cent.
English bed	99.3
Mechanical plant	99.9

Such results are practically perfect, and are consequently to be considered as practically identical. How unfair it would be, therefore, to state that the English bed was passing so many germs as to be 60 per cent inferior to the mechanical plant.

With reference to the question of the use of alum by a mechanical filter and its possible effect upon the health of the community drinking the water, it almost needs an apology at this late day to remind the people that free alum in the filtrate from a municipal plant is an evidence of carelessness on the part of the management not to be tolerated for a moment. It should be as carefully guarded against as the scraping of an English sand bed to undue thinness by successive cleanings.

No alum reaches the consumer, and the aluminum hydrate formed goes to the sewer with the removed dirt.

The change in the chemical composition of the water by the use of alum is a turning of carbonate of lime into sulphate of lime, which is a change without significance from a hygienic point of view, but one which is unpopular with the steam users, because the scale formed by the sulphate attaches itself more firmly to the boiler tubes than does that resulting from the presence of carbonate of lime.

It is, I think, unfortunate to make use of the expression "sulphuric acid" when speaking of the operations of a mechanical filter. It is unnecessary, and, moreover, it frightens the uninitiated. Sulphates are involved in this form of filtration, but no free sulphuric acid.

Would anyone think it wise to refer to the use of "hydrochloric acid" as a part of our daily food, when the real meaning intended was its combined form in the shape of common salt?

CONCLUSIONS.

In conclusion, let me say that although, in the absence of experimental information, I should have favored an English filter bed for Washington, yet now that a practical trial has been made under the direction of reliable and competent men I should consider it great lack of wisdom to attempt to question their findings or to discredit their recommendations.

BACTERIAL EFFICIENCY.

Dr. Woodward. As to the various qualities of the effluent of a filter, stated in the order of their relative importance, will you please specify them, if you recall them.

Professor Mason. I recall them. I should place the passage of disease germs through a filter as of first importance.

Dr. Woodward. In arranging the relative importance of the qualities of the effluent, would you place first the death rate from waterborne diseases?

Professor Mason. That I should place first.

Dr. Woodward. The value of water as indicated by bacterial counts.

Professor Mason. That should be second.

Dr. Woodward. The clearness of the water as indicated by the naked eye. Is that of sanitary importance?

Professor Mason. No, sir; that is not of sanitary importance.

Dr. Woodward. Now, with reference to soap consumption?

Professor Mason. That is an item.

Dr. Woodward. Then, with reference to hard boiler scales?

Professor Mason. That is also an item.

Dr. Woodward. Are those fairly arranged in the order of their importance?

Professor Mason. I should say that that was about as good a list and order as one could make out.

Dr. Woodward. Now, with reference to the statistics furnished by the medical societies of Elmira and Lexington, do you know of any more reliable statistics?

Professor MASON. Yes; I have some myself from Elmira. I was in charge of that plant, running it under an order of the United States court; so I know all about it. I ran that plant for eight days.

Dr. WOODWARD. I mean with reference to the typhoid fever death rates.

Professor MASON. I think you refer to the germ.

Dr. WOODWARD. No; I am referring solely to the number of deaths that occurred from typhoid fever, as obtained from official sources in the two cities. We would be glad to learn better, if we are in error.

Colonel MILLER. Dr. Woodward, you only take one year before and one year after the filter plant was installed, and you then get one death more in the second year, and say there is an increase of 10 per cent in typhoid fever. If that poor devil had died on the 31st of December, you would have changed your percentage to the other side. An increase of 1 death, or from 10 deaths to 11, is hardly fair.

Dr. WOODWARD. That is indicated fairly, I think; the report shows the period covered by the data. Professor Mason, have you any criticism to offer with reference to the relative efficiency of the two systems, as indicated by those figures?

Professor MASON. Now you are asking me to refer to cities like Atlanta and Chattanooga?

Dr. WOODWARD. No; the cities that are compared in the Medical Society's report—Lawrence, Mass.; Ashland, Wis.; Hamilton, N. Y., and Mount Vernon, N. Y.—all using sand filters, with an average reduction in the number of deaths from typhoid fever of 78.5 per cent. Then Macon, Ga.; Atlanta, Ga.; Oakland, Cal.; Reading, Mass., using mechanical filters, showing an average decrease of 26 per cent.

COMPARISON BY CITIES.

Professor MASON. You must bear in mind in comparing those groups of cities, that when you are talking of Ashland, Wis., you are speaking of a really good up-to-date English filter bed. When you speak of Lawrence, Mass., you are speaking of a carefully run filter bed a little different from the English type. But when you speak of cities like Atlanta and Macon, Ga., you are not referring to the kind of filter that has been proposed for the city of Washington. The Atlanta and Macon filters are not very good filters. They are of what is called the pressure type, and it is hardly fair to compare them with the open gravity form of filters such as are used at Elmira, N. Y., and Lorain. I think it would be better to confine the comparison between the English filter bed and the open gravity mechanical plant, which has been referred to in Colonel Miller's report.

Dr. WOODWARD. With reference to that point, is it possible to get water to go through a given amount of filtering material at the rate of 120,000,000 gallons per acre per diem without more pressure than is required to filter water through the same material at the rate of 3,000,000 gallons per acre per diem; is not the pressure in the former case very considerably greater?

Professor Mason. No. If you are at all familiar with open filters, you must know that it is a question of atmospheric pressure. Those are open tanks.

Dr. Woodward. The current goes through at a considerably greater rate than in the other filters?

Professor Mason. No; there is no pressure from the main.

Dr. Woodward. But the amount of force exerted in twenty-four hours, would you regard that as the same?

Professor Mason. It could not be. If you drive a stream of water at the rate of 3,000,000 gallons a day through a sand bed, and another at the rate of 125,000,000 gallons, there is unquestionably a difference in pressure. At the same time I wish to distinguish between the open gravity mechanical and the close pressure mechanical, because I think there is a great deal of difference in the efficiency.

Dr. Woodward. Are there any large cities using the open mechanical filter?

Professor Mason. No, I think not, what you would call a great city; no city of the size of Washington.

Dr. Woodward. What is the largest city you know of?

Professor Mason. I do not know the population of the towns named. Elmira has 36,000 population. That is hardly a large city.

WHAT THE WASHINGTON FIGURES SHOW.

Dr. Woodward. With reference to the figures on page 41 of Colonel Miller's report, I notice that while you disregard certain days for the mechanical filter, you have apparently not disregarded more than one day for the sand filter. Did you notice that the figures for that filter run continuously from December 1 to 31, while as a matter of fact the report shows that "On December 27 the loss of head was 2.30, and the filter began to show signs of breaking through, and it should have been shut down and scraped." The weather was very cold, however, so that the filter was allowed to run until January 5; that is, from December 27 to January 5 before it was cleaned. Would you not disregard the figures from December 27 to January 5, and for a certain length of time after January 5, because of the pollution of the sand by the passage through it of this imperfectly filtered water?

Professor Mason. As I said, I threw that entirely out of consideration.

Dr. Woodward. Then you took the average for the entire period?

Professor Mason. No; I did not. I took the average on page 42. I think that on page 41 the record is so broken that it is hardly wise to take it. I did not take the bottom of page 41. There is something the matter with that mechanical-plant record for that part of the run.

Dr. WOODWARD. Is there not something the matter with the sand plant, as just stated?

Professor MASON. Yes; I think there is; and for that reason I think t is wise to throw it all out and take page 42. I should throw the record out for January 8 for the sand plant, because that is not a fair figure for the sand plant. The sand plant can do vastly better than that.

Dr. WOODWARD. If the sand plant was left to operate from December 27 to January 5, when it should have been shut down, would you not expect to find some effect upon the effluent for some time after it was started again, after simply scraping?

Professor MASON. Yes; there is some inefficiency in the plant just after scraping.

Dr. WOODWARD. Especially if the sand has been polluted by this impure water?

Professor MASON. I do not understand that point.

Dr. WOODWARD. The official report shows that on December 27 the filter should have been thrown out of service; the effluent was bad; the loss of head was great; but it was allowed to run until January 5. Would a simple scraping restore a filter of that sort?

Professor MASON. Yes; I should expect it to.

Dr. WOODWARD. Although it had a crack in it?

Professor MASON. How deep did that crack extend?

Colonel MILLER. What do you mean by having a crack in it?

Dr. WOODWARD. The fissure referred to over the pet-cocks?

Colonel MILLER. That was immediately stopped. There was an effort made, as had been made before, to find out the bacterial efficiency of the filter at different depths in the sand, and in order to obtain that pet-cocks were inserted in such manner that they would not come over one another, but just down to a certain depth; and I think you will find from my report that after the first scraping it brought an undue strain on that side of the filter and made a slight separation there. We shut down in that run because we were unable to stop the filter on account of the severity of the weather. If we had stopped filtering, our filter would have frozen solid; or, if we had drawn the water off and stopped filtering, the sand would have frozen, which would have destroyed the filter for all practical purposes. That was the reason we were obliged to let the filter run during that severe weather. Those tables which appear in the report are not selected at all. They are just exactly as they ran from day to day. The averages were taken without any regard to that point. I think you will find, among the averages taken by Dr. Kober, three or four days that the filter bed was allowed to run without coagulant. I wanted to see exactly what the thing would do without a coagulant, and these days have been lumped in getting the averages there.

Dr. WOODWARD. Mr. Hardy was apparently of a different opinion. He states:

> On draining the filter a very noticeable crack in the *schmutzdecke* was detected, running along the periphery of the tank, just above the pet-cocks. The length of this crack was about 11 feet.

Colonel MILLER. What date is that?

Dr. WOODWARD. It was about January 3. He says:

> It is believed that the bad results from the filter during the latter part of the run, as well as the samples drawn from the pet-cocks, were caused by this crack.

Colonel MILLER. Mr. Johnson, do you remember when we stopped drawing from there?

Mr. JOHNSON. I do not know specifically, but know it occurred immediately after getting those first bad results.

Colonel MILLER. It was before this January arrangement—it was much before that. It was discovered, I think, on the first scraping. As to Mr. Hardy's report, you must remember that although you call him an expert in your report, I do not think any of these gentlemen would admit it. He was merely an assistant for the detail working of the arrangement, and not an expert.

Dr. WOODWARD. Have you any knowledge as to the general bacterial efficiency of these two Washington experimental filters during the entire period? I do not mean the average of the daily samples but taking the total number of bacteria in the samples examined of the influents and effluents.

Professor MASON. Don't you call that 88 per cent and a fraction and 88 per cent and a fraction?

Dr. WOODWARD. That is the average of daily runs given by Colonel Miller in his report, not the percentage of the total possible number of bacteria in the samples of the influent and effluent examined. Do you know what the general showings are with reference to the relative bacterial efficiency of the two systems of filtration?

Professor MASON. In general, I see no difference between them. If I did I would very quickly settle down upon the better one for general recommendation to towns. I see no difference between the mechanical and the English bed in general.

THE CINCINNATI REPORT.

Dr. WOODWARD. I find this in the Cincinnati report, made, I believe, by Mr. Fuller, on page 377:

> In the purification of those classes of water for which the English type of filters is strictly applicable, the available evidence indicates clearly that this method is a satisfactory one when the filters are properly constructed and operated. Further, so

far as our knowledge goes, this method is ordinarily somewhat more efficient and more economical for water for which it is readily applicable than any other process of purification which has received serious attention.

Do you agree with that?

Professor **Mason**. Well, if you have a water that is not too muddy, supplying a large city, I agree with that statement so well as to always advocate an English bed.

Dr. **Woodward**. What do you mean by "too muddy?"

Professor **Mason**. As to that, you will have to let me see a sample of the water.

Dr. **Woodward**. Is there any reliable method of determining that point?

Professor **Mason**. Oh, yes, sir; my method is the reliable method. [Laughter.]

Dr. **Woodward**. Well, knowing your reputation, I am inclined to agree with you, but you might, for the benefit of the record, state it.

TESTS OF TURBIDITY.

Professor **Mason**. I should determine the degree of turbidity by comparing the turbid water with perfectly clear water to which a standard degree of turbidity has been added, and I would state the turbidity as so many parts per 1,000,000. For instance, if I say that the turbidity of the water is 14, I mean that it is so turbid as to exactly match the turbidity of distilled water to which 14 parts per 1,000,000 of clay have been added.

Dr. **Woodward**. Have you examined the method of determining turbidity as followed in the Washington investigation?

Professor **Mason**. I do not know how that method compares with Mr. Hazen's method.

Dr. **Woodward**. I believe it differed from Professor Hazen's method with reference to the accuracy of the readings, using the vernier for that purpose, and also with reference to the use of a strongly turbid water for the dilution of the effluent. Then the result was obtained by a certain formula.

Colonel **Miller**. That is nothing but the grocers' rule, namely, given the prices of different teas to find the price of the mixture.

Dr. **Woodward**. Does the turbidity of the water vary in direct proportion to the number of suspended particles; does the refraction and reflection of light vary directly or in some other proportion?

Professor **Mason**. It does not vary directly; that is, with an absolutely close calculation; but for ordinary purposes I think that the people would better understand the statement that twice the amount of clay being added you will have twice the degree of turbidity.

Dr. **Woodward**. Better than in a sanitary report where you are writing the report in ten-thousandths?

Professor MASON. Yes; there is a discrepancy.

Dr. WOODWARD. And in a calculation of that delicacy would you regard it as necessary to take into consideration the light unit—would that influence the result?

Professor MASON. Yes; it would.

Colonel MILLER. If they are all made under the same light, they are all comparable; there are the same conditions, as far as possible.

Professor MASON. The light will make a difference.

Dr. WOODWARD. Do you know how many companies there are at present controlling the output of alum, and the source from which it is derived, with reference to the possibility of a combine?

Professor MASON. No; I have no idea.

Mr. MOORE. Can you at all times get clear water from a slow sand filter—what you would call a reasonably clear water?

Professor MASON. Oh, yes; there is no doubt about that. Reasonably clear water, however, is a pretty indefinite term.

Mr. MOORE. If a slow sand filter were installed in Washington, is it your opinion that at all times the appearance of the water would be satisfactory to the average consumer?

Professor MASON. I should think likely, although from the report I see that you do not get an absolutely clear water. Of course, the question of what is going to be satisfactory to the consumer is a difficult question to answer. Up in Troy anything short of soup would be satisfactory. [Laughter.] I think that the man who is called on to put in the plant has to solve that question for himself. He sees the water that is being delivered, and, in his judgment, he pronounces it one that the people will be satisfied with. Of course, if it is absolutely clear he knows that they will be absolutely satisfied with it. If it is not absolutely clear, he thinks they will be satisfied with it, and takes his chances.

Mr. MOORE. In Washington during portions of the year we have what might be called clear water.

Dr. WOODWARD. Colonel Miller can probably speak with reference to its absolute clearness.

Colonel MILLER. In my report I have followed the standard used by most experts, namely, the Hazen scale—of twenty-five thousandths; that is, 0.025 is considered satisfactory water.

Mr. HAZEN. There is a difference of opinion as to that. I think in Pittsburg we had 0.02 instead of 0.025.

Colonel MILLER. That difference, as Dr. Mason says, is insignificant. You say two one-hundredths, disregarding the five one-thousandths.

Dr. WOODWARD. Of course the people would accept a water that the expert might not pass, for the reason that people generally use water in small quantities and would not detect what an expert would immediately recognize.

Mr. MOORE. Professor Mason, would you conclude, from the data you have at hand, that the slow sand system in Washington would give an effluent satisfactory in appearance and of undoubted bacterial efficiency?

Professor MASON. Yes. But to repeat the words of that letter which I have read, you have put this matter in charge of reliable men, and when they come to their conclusion, there is no reason why you should not accept it. I believe that the sand filters will do well. They have achieved results which show their efficiency. The mechanical filter appears at least equally good; and for other reasons which they do not state, probably from the general appearance of the water, the men who made the Washington tests seem to incline toward the mechanical filter.

Mr. MOORE. What is the difference in the cost of the two systems? Which is the cheaper system?

Professor MASON. Well, the English bed is more expensive to install and the mechanical plant is the more expensive to manipulate.

Mr. MOORE. So that in a given number of years the expense of the two would be equal.

Professor MASON. They would come pretty near each other. Of course there is this trouble with the mechanical plant, namely, the length of its life. With reference to that we have no data of value. We do not know how long the mechanical filter will live. I see that the allowance of twenty years has been made for the parts called the perishable parts of the mechanical plant. I should put it at about thirty years. I do not know upon what that estimate was based.

THE ELMIRA PLANT.

Mr. MOORE. You spoke about your operation of the Elmira plant for eight days. Will you give some details as to what the results were?

Professor MASON. The Elmira plant at that time was giving a bacteriological efficiency of 97+; I do not know the fraction. The appearance of the water was perfect; it was brilliant and clear, and there was no alum in the filtrate.

Mr. MOORE. What do you regard as the proper figure for efficiency from a bacteriological standpoint?

Professor MASON. I would get as near 99 as I could.

Mr. MOORE. What would you say is permissible? Is there not a limit in Germany? Do not the Germans throw out of operation a filter that does not reach a certain degree of efficiency?

Professor MASON. They have some pretty stiff laws there. I should say we ought to get over 97. I think that is a generous allowance. They are doing better than that at Albany.

Mr. MOORE. Is there any established type of mechanical filter; or would you make a mechanical filter to suit your own ideas, the same as you would draw up specifications for a house, or anything of that kind?

Professor MASON. Under certain circumstances I would make a mechanical filter to suit my own ideas, more particularly when there was an excessive amount of sediment to be removed, on the ground that possibly the arrangement made in a typical plant, as supplied by the companies, might not give sufficient opportunity for sedimentation; but for the average run of water I would take the plant as the makers furnish it. It would hardly pay to go to the expense of a special plant.

Dr. WOODWARD. One more question. Can the efficiency of 97+ for so short a period as eight days be compared fairly with the efficiencies that obtained continuously with the sand-filter beds generally? Does not the efficiency, year in and year out, of a sand-filter bed exceed that figure?

Professor MASON. Yes. The sand-filter bed at Albany at present is running 99.45, which is very good, but I have seen reports from mechanical plants, covering quite considerable periods, that are practically as good.

Dr. WOODWARD. Comparing the figures given, allowing you 97+, or even 98, there remain in the water 2 per cent of the bacteria?

Professor MASON. Yes.

Dr. WOODWARD. The figures from the Albany plant just given by you would leave in the water one-half of 1 per cent of bacteria?

Professor MASON. Yes.

Dr. WOODWARD. So that the number of bacteria in the water would be three times as great in the effluent from the mechanical filter as in the effluent from the sand filter?

Professor MASON. Yes.

COLON BACILLUS.

Dr. WOODWARD. And even supposing that the bacterial efficiency of each filter with reference to the colon bacillus, and therefore presumably with reference to typhoid bacillus, was the same, which is not admitted, the chances of contracting the disease would be three times as great with the effluent from the mechanical filter as with reference to the effluent from the sand filter. Is that not a fair statement?

Professor MASON. Now that is first-rate arithmetic but very poor filtration, for this reason: I have illustrated that. I have taken the run for those two filters that you have in Washington for two days and——

Dr. WOODWARD. Suppose we confine the discussion to the particular cases cited; that is, the two instances. Is there any error in that reasoning?

Professor Mason. Yes; there is a heap of error in that reasoning. I will have to go back to my illustration to show it to you. Where you get a high efficiency—up in the nineties or between 97 and 100—in the shape of percentages, you get a very misleading result. I showed you that in my illustration. I said you have two filters, one is running 99.9 and one is running 99.3. If you reason on those two figures you will have a difference of 60 per cent in the efficiency. That is all wrong. There is no practical difference between 99.9 and 99.3.

Dr. Woodward. That is with regard to the efficiency, but disregarding the bacteria that you have taken out, which we will admit do not hurt anybody, the bacteria that you have left in the water are the dangerous bacteria. Will you not admit that the danger from the bacteria in the water is, so far as we are able to calculate at present from our bacteriological knowledge, in proportion to the number of of bacteria left in it?

Professor Mason. My dear sir, no; not when you get up your numbers as high as that.

Dr. Woodward. Those are low numbers, if you will excuse me, as to the bacteria left in.

Professor Mason. To return one moment to that illustration, if you will pardon me. If you get an efficiency of 99.9 and 99.3 we are dealing with one-tenth and seven-tenths. There is no difference between the figures.

Dr. Woodward. Although one contains seven times as many bacteria as the other?

Professor Mason. Precisely. Although one contains seven times as many bacteria as the other. If you take a filter that runs 99.3 to-day and another which runs 99.9, those figures will reverse in time. Any such figures show perfect filtration and are to be considered identical.

Dr. Woodward. Suppose I give you the figures that have actually resulted from the experiments in Washington during the entire period. Assume, for present purposes, that wherever the number of bacteria per cubic centimeter is given in Colonel Miller's tables, it is the result of the examination of just one cubic centimeter of water. Then the total number of bacteria found in the influent of the slow sand filter was 758,604, and in the effluent, 15,384. The total number found in the influent of the mechanical filter was 729,314, and in the effluent, 19,425. In other words, the effluent from the slow sand filter contained 2.03 per cent of the possible bacteria, and the effluent from the mechanical filter contained 2.66 per cent.

Would you or would you not regard the effluent, containing 2.66 per cent of the bacteria in the raw water as more dangerous than the effluent containing but 2.03?

Professor **Mason**. Is that for the whole run?

Dr. **Woodward**. Yes, regarding, however, December 27 as the end of the fourth run of the slow sand filter, as indicated by page 52 of Colonel Miller's report, but even including the figures for the beginning of the fifth run when the filter was undoubtedly polluted as result of use from December 27 to January 5. Without reference to, or considering the two experimental filters, but simply for the sake of the argument, is it not the number of bacteria in the effluent and not the number left in the filter that indicate the danger in the water?

Professor **Mason**. Yes; as to the general proposition you are right: That if you have more bacteria present in the effluent from filter A than you have in the effluent from filter B, of course the danger will increase with the number of bacteria in the water. There is no doubt about that.

Dr. **Woodward**. And probably in proportion to the two.

Professor **Mason**. Provided you do not get those numbers too small.

STATEMENT OF ALLEN HAZEN.

Mr. **Moore**. Mr. Hazen, with what filtration work have you been connected?

Mr. **Hazen**. I was connected at first with the Lawrence Experiment Station of the Massachusetts State board of health. The Lawrence city filter was built in 1892, and was put in operation in September, 1893. Also I have been connected as engineer with the construction of filter plants at Far Rockaway and at Red Bank, and with the Albany filter plant and with the Superior Water, Light, and Power Company at Superior, Wis., and a plant for the Pennsylvania State Insane Asylum at Harrisburg. I have also designed other filters and have made many investigations and tests of filters in service.

Mr. **Moore**. You are the author of a treatise on the purification of water, the latest edition of which was published in 1900?

Mr. **Hazen**. Yes, sir.

Mr. **Moore**. There have been very rapid advances made in filtration, and of late the knowledge on the subject has increased very largely?

Mr. **Hazen**. Yes, sir. The number of filter plants has increased very largely. The capacity of the filter plants is approximately eight times as great to-day as it was ten years ago. That ratio applies approximately both to sand and mechanical filters in the United States. There have been many very able people who have been studying the problem from different standpoints, and of course much information has accumulated.

Mr. **Moore**. Which is the largest filter plant in the United States, in so far as the amount of water filtered is concerned?

Mr. Hazen. My impression is that the Albany plant is the largest. The nominal capacity of that plant is 15,000,000 gallons per day. It has delivered for short periods up to 20,000,000 gallons.

Mr. Moore. Have you examined the Senate documents that were sent to you in regard to filtration?

Mr. Hazen. I received a copy of Colonel Miller's report when it was issued, and examined it at that time. I have not examined it since hearing from you in connection with this matter.

Mr. Moore. Do you consider that for waters of the New England type the slow sand filter bed is the best?

Mr. Hazen. I thought at Albany the sand filters would be best and recommended them. I think at Lawrence the sand filter is unquestionably the best.

Mr. Moore. The Merrimac River water is a clear water, but is polluted at Lawrence by the sewage from Lowell, Nashua, and Manchester?

Mr. Hazen. Yes; and other cities.

Mr. Moore. Does the sewage from those cities drain into the Merrimac River?

Mr. Hazen. Directly; yes, sir.

Mr. Moore. What were the results that came from the establishment of the filter plant at Lawrence, so far as typhoid fever was concerned?

Mr. Hazen. It has been very largely reduced. The reduction was very large from the start, and it has gradually increased. The efficiency of the filter has increased with age. It is considerably greater than it was the first year.

EFFICIENCY OF FILTERS.

Mr. Moore. Is that due to the filter, or the method of operation?

Mr. Hazen. In part to both, I think. It is generally true that a new sand filter does not give the best results. The processes are largely biological, and it takes a certain time for the organisms to get properly placed on the sand. So the Albany filter, for instance, is doing a great deal better now than it did a year ago.

Mr. Moore. Would you say that it is necessary to treat the Cincinnati water, and the water generally of the Ohio and Mississippi with the coagulant?

Mr. Hazen. It was found to be so at Cincinnati and Louisville. We did not find it to be so at Pittsburg.

Colonel Miller. That was the Allegheny River.

Mr. Hazen. That was the Allegheny, which is the largest part of the Ohio. The water is taken from the river seven or eight miles above Pittsburg. The amount of suspended matter, as it was found at Cincinnati, was about five times as great as we found it at Pittsburg, and was still greater at Louisville. So there is a very great difference in the character of the waters.

Mr. Moore. Is there much pollution in the Allegheny River?

Mr. Hazen. There is quite a good deal at Johnstown, Oil City, Franklin, and Olean, and a number of other towns.

Mr. Moore. Then Pittsburg, as I understand, is putting in the slow sand filter?

Mr. Hazen. It will be put in shortly. The money is appropriated and we are working on the plans now.

Mr. Moore. From your experience, can you get as good results ordinarily with the mechanical filter as with the slow sand filter?

Mr. Hazen. That is with reference to bacterial efficiency?

Mr. Moore. Yes; is there a possibility of it?

Mr. Hazen. I think it is largely a question of construction and operation in both cases. Sand filters can be operated to give high bacterial efficiencies, and the general practice has established certain standards. I think it would be possible to operate filters to give much higher efficiencies than are secured at Lawrence and Albany, if the increased bacterial efficiency would justify the additional expenditure necessary to secure it. And so also with the mechanical filters in even greater measure. It is possible to operate them to give very bad results, or it is possible, by taking great care, and particularly by using large amounts of chemicals, to get very high efficiencies.

Mr. Moore. What advantage has the mechanical filter to recommend its use in preference to the sand filter?

THE NECESSITY OF USING COAGULANTS.

Mr. Hazen. The mechanical filter is always used in connection with a coagulant, and the coagulant is necessary for the treatment of extremely turbid waters.

Mr. Moore. Is necessary?

Mr. Hazen. Yes, is necessary; so that when a water is so turbid that it must be coagulated, it is better, or at least cheaper, to filter it with the mechanical filters.

Mr. Moore. That opens up two questions—better and cheaper.

Mr. Hazen. I think it has usually been decided upon because it is cheaper.

Mr. Moore. Then you would have no hesitation in saying that a mechanical filter, properly constructed, will give satisfactory results from the standpoint of bacterial efficiency.

Mr. Hazen. A mechanical plant can be operated to give a very high bacterial efficiency.

Mr. Moore. Well, have they been so operated?

Mr. Hazen. In plants actually built?

Mr. Moore. Yes.

Mr. Hazen. I do not think so; at least not very often. I have tested some mechanical filter plants and operated them—experimental mechanical filter plants—and plants on a considerable scale, and while it is possible to obtain very good efficiencies, there are a good many things in connection with mechanical filters to cause low degrees in the efficiency. It seems to me that there are greater possibilities of accidents of this kind happening with mechanical filters than with sand filters, where the operations take place more slowly, and, it seems to me, can be more perfectly controlled.

GRAVITY AND PRESSURE FILTERS.

Colonel Miller. In making a comparison between the effects of filtration on typhoid fever, the District Medical Society report which has been read mentions certain cities. Do you know what system is used at Davenport, Iowa?

Mr. Hazen. I have the statistics of all those places at my office. They are published in "The Filtration of Public Water Supplies."

Colonel Miller. I have it from your authority. How do you regard the pressure filter bacteriologically with reference to the gravity filters?

Mr. Hazen. The data in regard to what can be accomplished by pressure filters are much less adequate than the data with reference to the gravity mechanical filters. There are some very recent results that I have seen from pressure filters that seem to correspond very closely with what could have been obtained by gravity filters.

Colonel Miller. Are pressure filters generally adopted for waters where bacterial efficiency is the object sought?

Mr. Hazen. I should say that they had been used to a considerable extent for that purpose.

Colonel Miller. Was that the object in placing pressure filters in Atlanta and Chattanooga?

Mr. Hazen. I do not know.

Colonel Miller. It is claimed that those filters were installed only to remove turbidity. Is not one objection to pressure filters that they are very irregular in their working with reference to velocity?

Mr. Hazen. That depends upon how they are placed. If water is pumped through the filter to a receiving reservoir, the amount of the effluent can be made constant.

Colonel Miller. Are there not some that merely take pressure from gravity?

Mr. Hazen. I presume there may be.

Colonel Miller. In that case the amount of the effluent depends upon the rate of consumption?

Mr. Hazen. Yes, sir.

Colonel **Miller**. So that in such a case they would not work regularly?

Mr. **Hazen**. The pressure filters that I have seen, where the rate fluctuates with the consumption, have usually been designed with quite large filtering areas, so that the maximum draft is not excessive.

Mr. **Moore**. Please define what you mean by pressure filters?

Mr. **Hazen**. A pressure filter is a filter in an inclosed receptacle so that the water can be passed through it at greater pressure than the atmospheric pressure would afford or than could be obtained by gravity.

Colonel **Miller**. I merely ask the question because you have remarked that the bacterial efficiency of pressure filters decreases after they are a year old.

Mr. **Hazen**. I do not think we know much about the bacterial efficiency of the pressure filter.

MECHANICAL FILTERS CAN DO SATISFACTORY WORK.

Mr. **Moore**. Has a type of mechanical filter been developed that could be used with satisfactory results in filtering 60,000,000 gallons of water a day?

Mr. **Hazen**. Oh, I think so.

Mr. **Moore**. You think there are mechanical filters now in use that are capable of doing the work and doing it satisfactorily?

Mr. **Hazen**. That is to say, they could do it on a large scale. There is nothing impossible in that.

Colonel **Miller**. And increase the efficiency?

Mr. **Hazen**. Yes, sir.

Dr. **Woodward**. Do you regard a slight increase of turbidity in water, especially if only occasionally, as in any way diminishing its potability and safety?

Mr. **Hazen**. Not its wholesomeness, but I regard turbidity as objectionable.

Dr. **Woodward**. From an æsthetic standpoint only.

Mr. **Hazen**. Principally from an æsthetic standpoint.

Dr. **Woodward**. From a sanitary standpoint, what are the most reliable guides to the safety of drinking water?

Mr. **Hazen**. Why, the fundamental point—the one that the others all come back to—is the effect of the water on the health of those who use it. The others are indirect, dependent upon our theories of the transmission of disease, though arriving at the same thing.

Dr. **Woodward**. In other words, it depends on the mortality, from water-borne diseases in the first place; or, stated in another form, on the number of bacteria in the water?

Mr. **Hazen**. That is about it; yes, sir.

Dr. **Woodward**. With reference to the experimental plants at Pittsburg, in which I believe Warren and Jewell mechanical filters were compared with sand filters, do you remember the relative bacterial efficiency of the two?

Mr. Hazen. The sand filters gave somewhat better bacterial efficiency.

Dr. Woodward. They did give better results?

Mr. Hazen. Yes, sir.

Dr. Woodward. Are you familiar with the most recent report on those filters, as it appears in the Journal of the Association of Engineering Societies for November?

Mr. Hazen. Yes; I have seen that article, but I have not read it.

Dr. Woodward. You do not know, then, whether the same superiority has continued or not?

Mr. Hazen. I have the records from Pittsburg up to date in official form. I was directly responsible for the original experiments, but I am not responsible for this publication, and do not know as to its accuracy.

BACTERIA IN UNDERDRAINS.

Dr. Woodward. I understand that; but I had the figures and I thought that possibly you were familiar with them. With reference to the origin of bacteria in the effluent of a sand filter, can you give any information for the benefit of the committee with reference to that?

Mr. Hazen. That is, do you mean, as to whether they all come from the raw water?

Dr. Woodward. Yes.

Mr. Hazen. There are usually a certain number of bacteria, or colonies of bacteria, I think, that come from the underdrains that are washed off. The numbers of bacteria coming from that source vary greatly. In some cases the numbers coming from that source would be almost insignificant and in others considerable; in the summer and in certain types of construction growths have taken place which have increased the numbers very much.

Dr. Woodward. In the light of present knowledge do you regard it within the bounds of probability that we should get typhoid bacilli, or colon bacilli—more particularly typhoid bacilli—from colonies in the underdrains?

Mr. Hazen. No, sir.

Dr. Woodward. In other words, the bacteria that are derived from the underdrains are harmless?

Mr. Hazen. They are harmless; yes, sir.

Dr. Woodward. Then the percentage of bacteria which is found in the effluent of a sand filter is increased by certain additions of harmless bacteria which grow in the underdrains?

Mr. Hazen. I believe that is generally the case.

Dr. Woodward. If, then, it were possible to take a sample of water for analysis from the lower strata of the sand filter, and to exclude that from the underdrains, the so-called bacterial efficiency of the filter would be higher?

Mr. HAZEN. Yes, sir; that has been arrived at in another way, particularly by Mr. Clark, now in charge of the Lawrence experiment station. He has found that in some cases the efficiency of the sand filter in removing the colon bacillus from the Merrimac River, which contains them in large numbers, is materially greater than the bacterial efficiency as a whole.

Dr. WOODWARD. That is with a sand filter. We are confining our attention now to the sand filter. The percentage of removal of the colon bacillus is greater than the percentage of the removal of the bacteria as a whole?

Mr. HAZEN. Yes, sir.

Dr. WOODWARD. Then, when we speak of the bacterial efficiency of a slow sand filter, if we would be strictly accurate, we would have to correct it if some of the bacteria we found there got in it from the underdrains.

Mr. HAZEN. That, I think, is a proper thing to take into account.

Dr. WOODWARD. And among the additions from the underdrains there is no probability of typhoid or pathogenic organisms?

Mr. HAZEN. I think not.

Dr. WOODWARD. Then the efficiency with reference to these organisms would be higher than the results show, as you have just stated?

Mr. HAZEN. I believe that it would be higher.

Dr. WOODWARD. Can you give any idea as to the origin of the bacteria in the mechanical filters—that is, the origin of the bacteria in the effluent?

Mr. HAZEN. In mechanical filters, since they have a much higher rate of filtration, if there were corresponding growths in the filters, the numbers of bacteria would be dissipated through very much larger quantities of water and would be proportionally less per unit. In mechanical filters any growths of bacteria in the filter generally I should regard as absolutely unimportant.

Colonel MILLER. The passage of water is so rapid that they would not have time to develop?

Mr. HAZEN. Yes, sir.

COLON BACILLUS.

Dr. WOODWARD. That would probably be the case. Now with reference to the *colon bacillus*, which we have to take as an index to the probability of typhoid bacillus, you have spoken of the results obtained in Lawrence as to their reduction. Are you familiar with the experiments that were made at Cincinnati on this same point with reference to the two types of filters?

Mr. HAZEN. I am not familiar with the details just now.

Dr. WOODWARD. You would expect the typhoid-fever death rate of a community to vary with the number of bacteria in the water, assuming all such bacteria to be derived from the same source?

Mr. HAZEN. I think it would, generally.

Dr. WOODWARD. Then, in studying the probable typhoid-fever mortality of a community supplied by slow sand filters, for the purpose of comparing it with the typhoid-fever mortality of a community having mechanical filters, we would consider, not the relative bacterial efficiency of the two filters, but the bacterial deficiency—if I may so call it—indicating the percentage left in the water?

Mr. HAZEN. I think that your standpoint is correct.

LOCAL CONDITIONS DETERMINE THE TYPE OF PLANT.

Dr. WOODWARD. You stated, I believe, that there is no type of mechanical filter as yet developed and capable of being installed in Washington that has been installed elsewhere with success?

Mr. HAZEN. No, sir; no plant has been installed of that size.

Dr. WOODWARD. Any plant that might be installed would have to be adapted to the local conditions.

Mr. HAZEN. Certainly.

Dr. WOODWARD. And to that extent would be in the nature of an experiment?

Mr. HAZEN. Yes, sir.

Dr. WOODWARD. What would be your estimate as to the life of the working parts, the machinery, etc., of a mechanical filter?

Mr. HAZEN. I think that would depend entirely on the design and the materials of which they were constructed.

Dr. WOODWARD. Would that influence the first cost?

Mr. HAZEN. Necessarily.

Dr. WOODWARD. That would be a matter of engineering theory rather than experience?

Mr. HAZEN. Yes, sir.

Dr. WOODWARD. One man might design a plant and say it would last twenty years, another thirty years, and another fifteen years, and possibly it might last ten, and in actual experience it might last forty?

Mr. HAZEN. I have seen some appliances that would not last even five years.

Dr. WOODWARD. Then when we undertake to calculate the running expenses of a mechanical filter, taking into consideration the duration of the plant, we are dealing, I believe, with a very uncertain factor.

Mr. HAZEN. It is an uncertain factor, and still reasonable estimates can be made, knowing the particular conditions.

Dr. WOODWARD. When you say "reasonable estimates," within what limits of error would you be willing to undertake to make an estimate?

Mr. HAZEN. That would vary with the different items.

Dr. Woodward. There would be a limit of error, though?

Mr. Hazen. Yes; of course.

Dr. Woodward. The only way of determining that would be by running your filter until it wore out. Am I correct?

Mr. Hazen. Yes; that would be one way.

IMPROVEMENTS IN MECHANICAL FILTERS.

Mr. Moore. Has there been any marked advance within the past three or four years in the construction of mechanical filters, or are they substantially the same as they were three or four years ago?

Mr. Hazen. There have been a good many substantial improvements made within three or four years, and quite recently some novel designs have been made. I think there is a chance for very decided improvements in mechanical-filter designs, notwithstanding the facts that a great deal of skill has been put into the present designs, and that they represent many admirable features.

Mr. Moore. Would you say that the future is with the mechanical filter, or with the slow sand filter; do you think that for any reason the mechanical filter will supplement the slow sand filter?

Mr. Hazen. I stated, I think, before the Franklin Institute some time ago in this way: That, apparently, for sewage-polluted and reasonably clear waters the sand filter was the best, while for muddy waters the mechanical filters would be the best. There is, however, a possibility that a type of filter differing somewhat from both the sand and present mechanical filter—perhaps embodying some parts of each—will be an element in the future.

Mr. Moore. Has that probability taken definite form in actual construction? Are you looking forward to the construction of any combination of the two?

Mr. Hazen. That has been contemplated. I do not think anything has been constructed as yet. It has not been possible to do that because of the Hyatt patent, covering the use of the continuous application of coagulant in filtration. The owners of the Hyatt patent have controlled the entire mechanical-filter construction.

STATEMENT AS TO THE HYATT PATENTS.

Mr. Moore. Then there is a certain amount of royalty that enters into the cost of the use of the mechanical filter?

Mr. Hazen. That has been so. I think the patent expires next month.

Mr. Moore. How wide is that patent?

Mr. Hazen. It covers the application of coagulant in a continuous manner in connection with filters.

Mr. Moore. What relations have the various filter companies to the Hyatt patents?

Mr. HAZEN. Other gentlemen present to-day, namely the representatives of the owners of the Hyatt patent, can give you much better information upon that point than I can do.

Mr. MOORE. Is there any person in the room who can tell just exactly what the patent situation is? What is the basis of the patents involving the use of coagulants?

Mr. DENNISON. Just what do you mean by the basis?

Mr. MOORE. You represent the company owning the Hyatt patents, do you not?

Mr. DENNISON. Yes. As Mr. Hazen has stated, that patent involves the continuous application of a coagulant.

Mr. MOORE. Are there several filter companies?

Mr. DENNISON. Yes, sir.

Mr. MOORE. All use a coagulant?

Mr. DENNISON. They do, in some sense; yes.

Mr. MOORE. What are their relations with your company?

Mr. DENNISON. Some of them are down on our companies and some are not. I always thought that the principle of that patent represented practically the number of dollars that it cost to maintain it. It has been in litigation practically ever since the patent was granted.

Mr. MOORE. Then, as I understand it, there are certain companies that are tributary to you, and there are certain companies that are using the coagulant without, as you claim, the right to use it?

Mr. DENNISON. Yes, sir. There are, however, no companies operating under a royalty from us. They have either the right to use it or they have not.

Mr. MOORE. There is no payment to you by them?

Mr. DENNISON. No, sir.

Mr. MOORE. On what do they base their right to use it?

Mr. DENNISON. That they can not get along without it; they must have it. The great contention was as to the use of the word "continuous." In the first place, after the patent was established—that is the mere use of the coagulant continuous process—there were then introduced settling tanks, and it was claimed that that was not an infringement. That was finally decided to be an infringement.

Mr. MOORE. So far as the courts have decided these matters they have sustained the Hyatt patent?

Mr. DENNISON. Yes, sir.

Mr. MOORE. There are some cases still in litigation?

Mr. DENNISON. Yes, sir.

Mr. MOORE. Does the life of that patent expire soon?

Mr. DENNISON. It expires in February; yes, sir.

Mr. MOORE. Are you the largest manufacturers of mechanical filters?

Mr. DENNISON. We are; yes, sir.

Mr. **Moore.** To what cities are you supplying the mechanical filter, and what is the capacity of those cities?

Mr. **Dennison.** About 300,000,000 gallons per diem.

Mr. **Moore.** What is the largest plant that you have in operation now?

Mr. **Dennison.** I think the one at St. Joseph, Mo., is probably the largest. Norfolk is the largest city supply.

COST OF OPERATION.

Dr. **Woodward.** Mr. Hazen, with reference to the cost of operating a mechanical filter, what would be your estimate as to the probable average wastage of water for washing the bed?

Mr. **Hazen.** In my experience with mechanical filters at Pittsburg and Lorain I should say that 4 or 5 per cent would perhaps represent the wash water, but that depends upon the character of the raw water, and is greater as the turbidity increases.

Dr. **Woodward.** Would you regard the water as thus wasted a proper charge against the operating expenses of the plant?

Mr. **Hazen.** Certainly.

Dr. **Woodward.** If the city of Washington has to furnish 2,400,000 gallons of raw water per diem for washing, does that enter into consideration as part of the operating expenses, and as a charge against the filter?

Mr. **Hazen.** Certainly.

Colonel **Miller.** I would like to interrupt Dr. Woodward at this point, as it is important that I defend all these points as they come up. The report of the District medical society intimates that that amount has not been included. You will find that that item is all put in the estimate and is added to the consumption of the city.

Dr. **Woodward.** The cost of filtering is but the value of the raw water, is it not? The value of such water is an item of some importance and is a proper charge, I think, against the operating expenses of a mechanical filter.

Colonel **Miller.** In making the estimate, of course, we calculate the total amount of water necessary to be filtered, but they do not put down raw water as a cost.

Dr. **Woodward.** It costs daily something like 4 per cent of the cost of the entire day's supply.

Colonel **Miller.** Oh, no.

COVERING FOR FILTER BEDS.

Dr. **Woodward.** Mr. Hazen, with reference to the covering of filter beds, are you sufficiently familiar with the climate of Washington to be able to express an opinion as to the necessity for covering them?

Mr. **Hazen.** There may be special considerations in Washington which would make it dangerous for me to express an opinion without going over the matter in detail.

Mr. MOORE. Then that curve in your chart for covered and uncovered filters is simply an approximation?

Mr. HAZEN. It is simply a rough indication. I think in a general way it is substantially correct, but there are local considerations that sometimes make it different.

Dr. WOODWARD. Colonel Miller must pardon me for undertaking to use the reports of Mr. Weston and Mr. Hardy, because I think that is exactly what he did in drawing his conclusions. These gentlemen indicate, or one of them does, that a daily rate of 4,000,000 gallons per acre is permissible in the slow sand filter. But in order to guard against interference with the work of the filter by freezing or otherwise, they estimate the filtering area necessary on the basis of but 3,000,000 gallons per acre per diem. Twenty acres of filtering surface must be in constant operation, and an average of 2 acres of filtering surface, as they calculate, must be out of operation for cleaning. But to guard even further against interference by ice, etc., the total area of effective filtering surface is increased to about 27 acres. Taking the 27 acres thus provided for (thus giving sufficient to allow for the possibility of deterred cleaning made necessary by the presence of ice or from other causes), would you not regard it as possible that the covering of the filters might be dispensed with in a climate like that of Washington? I will give you the exact figures: "A total effective filtering area of 26.92 has been provided in this case, which has been deemed ample." To express it in different terms, if the rate is reduced from a possible 4,000,000 gallons, as indicated by the experiments, to 3,000,000 gallons per acre per diem, and, further, the effective area is increased from 22 acres to 26.92 acres, is it not reasonable to suppose that in Washington we would be safe without covered filters?

Mr. HAZEN. That is a question I would like to look into. I think there is reasonable probability of that being so, but there may be special considerations or conditions there with which I am not familiar.

Dr. WOODWARD. Under the circumstances I have suggested, would you regard it as necessary to proceed to cover the 26.92 acres, or might not the filtering surface be reduced?

Mr. HAZEN. If the filters are covered there is certainly no need of an allowance for deferred cleaning, because they can be cleaned at any time.

EFFECT OF ICE ON FILTER BEDS.

Mr. MOORE. What is the depth of ice that is likely to destroy the efficiency of a sand filter?

Mr. HAZEN. I do not think any depth of ice is likely to form in the United States that would affect a sand filter, because there is usually 4 feet of water, or thereabout, over the sand, and ice would hardly form to that thickness. So long as ice does not hit the sand it does not interfere with filtration. The difficulty comes from freezing the sand when you take the water off for the purpose of cleaning. That interferes with the filtering afterwards.

Mr. **Moore.** If the temperature were above the freezing point at the time of the cleaning, there would be no danger?

Mr. **Hazen.** There is no danger some distance below the freezing point.

Dr. **Woodward.** Have not some of the German filter beds been cleaned under the ice with fairly satisfactory results?

Mr. **Hazen.** They have.

Dr. **Woodward.** Having this allowance then for margin of safety in the low rate at which the filtering beds that are normally operating, having also a margin of safety in the ability to throw extra filter beds into operation, having further a margin of safety in the possibility of cleaning in a fairly satisfactory manner beneath the ice, does it appear probable that in a climate like that of Washington, as at present you believe it to be, it is necessary to cover the filter beds?

Mr. **Hazen.** Your statements seem to be reasonable. I do not know what considerations Colonel Miller may have had in mind in making his report, and I regard the question of covering the filter beds as one dangerous to make definite statements upon without knowing accurately all the facts.

Dr. **Woodward.** In estimating the operating expenses of a slow sand filter what is the probable life of masonry?

Mr. **Hazen.** If masonry is well built, it is permanent; if it is badly built, it is not.

Dr. **Woodward.** But it is practically permanent?

Mr. **Hazen.** Yes, sir.

Colonel **Miller.** The allowance is for seventy-five years.

Dr. **Woodward.** Seventy-five years is the estimate for properly constructed work?

Mr. **Hazen.** Yes, sir.

THE MEASURE OF TURBIDITY.

Dr. **Woodward.** Would you care to express an opinion as to the possibility of calculating turbidity accurately by the method adopted by Colonel Miller in his report?

Mr. **Hazen.** I read the description of Colonel Miller's turbidity method with a great deal of interest, but I made no experiments to inform myself as to its accuracy. In diluting a turbid water with clear water the increased depth at which the wire can be seen is not in proportion to the dilution. It is approximately so, and near enough, so that in diluting a highly turbid water—water that has too high a turbidity to be read directly, and then computing the turbidity of the original water—the difference is probably small. But it occurred to me that in bringing in a water of a higher turbidity the error might be a percentage of the higher turbidity instead of the lower one (which is being determined), and if so, with the method used by Colonel Miller, it might amount to more relatively than in the other case.

Colonel MILLER. As you say, it would depend on whether the water that you are measuring is of greater or less turbidity than what you used as a mixture, but would not that distribute itself so that it would be well enough for the purposes of comparison?

Mr. HAZEN. I could not say as to that without looking the matter up in detail, which I have not done.

Colonel MILLER. In the Washington experiments the turbidity was measured at the same time, on the same day, and under the same circumstances; so that conditions that affected one filter would affect the other just the same. Therefore the comparison would hold good, would it not?

Mr. HAZEN. I should suppose that the relative results would be correct to this extent, that it would show the one that was higher to be the higher; but the ratio between them might not be quite accurate.

Colonel MILLER. Of course it would be in favor of the best filter. On the subject of turbidity, there [indicating map] is the last run of the filters. You see in the count of turbidities there it even went as high as .5 at one time and gradually began to decrease, and in the other two columns you will notice the turbidity of the effluent of the two filters. Now, what portion of that run would you consider as turbid water—from the A filter, for instance? I mean as water that would be condemned by experts, or in experiments, as being beyond the limit of turbidity for filtered water.

Mr. HAZEN. Supposing the figures for turbidity to be exactly comparable with those that we got at Pittsburg, for instance?

Colonel MILLER. Yes. We have allowed even higher than yours.

Mr. HAZEN. Well, the table shows considerable turbidity certainly. The amount that people will stand of course depends upon the people.

Colonel MILLER. Turbidity is a question of the eye, and it has generally been found, and so stated, that when we get in a drinking glass a turbidity of what would be represented in that table as 0.025 it is noticeable to the eye, and that is usually the limit where people begin to object. There are very few people who know anything about the bacterial efficiency of water, and therefore that does not enter into the question. It is only the æsthetic point that enters into the question of turbidity.

Dr. WOODWARD. In view of the statement that on December 27 the sand filter should have been shut down—A is the sand filter, I believe?

Colonel MILLER. A is the English filter.

Dr. Woodward. A is the slow sand filter, then, if you prefer. In view of the fact that on December 27 the official reports showed that the slow sand filter was operating badly and should have been shut down, and in view of the fact that it was not shut down because of freezing weather, but was allowed to operate until January 5, on which day it was scraped and put into use again on the 6th, would you regard it as proper to include in the filtration the turbidity between the 27th of December and a reasonable period after the 6th of January?

Colonel Miller. Not to calculate its efficiency by any means, and that has not been done; but all those experiments have been put there to show what the different filters did under different conditions. That shows what it did when working under the most favorable conditions possible.

Dr. Woodward. It is a well-known fact that there were disturbing factors between December 27 and January 5 which, in my judgment, would influence it not only during that period, but for a certain period afterwards.

(At this point Senator McMillan entered the room and took the chair.)

Mr. Hazen. I think what you want to know is whether the sand filters will remove the turbidity of the Potomac River water so as to make it reasonably satisfactory to the people of the District of Columbia.

Senator McMillan. That is the point.

Mr. Hazen. And the question of what bearing these experimental operations would have on the result. Now, there may have been some differences between these experiments and what you would get on a large scale. It may be, with the large area that you have provided, you could reduce the rate of the filters at times and thereby reduce the turbidity of the effluent very much. It may be that the duration of extremely turbid water in the Potomac is short, as it is in many other rivers, so that you could close your intake at some periods and so help out your filters very much in that way.

Colonel Miller. The average time of turbidity is about one-third of the year. Generally it comes at this period of the year.

Mr. Hazen. Continuously?

Colonel Miller. We generally have it during this time. The remaining turbidity is on account of summer floods.

Dr. Woodward. That is what you term periods of slight turbidity?

Colonel Miller. Yes; it does not last long. Of course in the winter our water is at its maximum density, and that makes a difference as to the sedimentation of these small particles. It is about the same specific gravity of water, and sedimentation does not take place very rapidly.

Mr. Hazen. These questions could only be taken up with the general investigation of the whole subject. They require a great deal of data, which I have not had, and it seems to me that anything that I could say as to these experiments in particular is not directly to the point and may be misleading.

THE COST OF ALUM.

Dr. Woodward. I would like to ask one more question. In Richard P. Rothwell's work on The Mineral Industries of the United States and Other Countries, he makes this statement:

> Alum is, therefore, for all intents and purposes a manufactured product, which is controlled practically by two companies, the Pennsylvania Salt Manufacturing Company and the General Chemical Company, which latter has absorbed the Nichols Chemical Company of New York and the Martin Kalbfleish Chemical Company of New York.

Do you know of any other companies than those engaged in maintaining independent alum plants?

Mr. Hazen. I have bought alum occasionally from the Merrimac Chemical Company, of Boston.

Dr. Woodward. Do you know whether that company is connected with those mentioned?

Mr. Hazen. No; I do not. I should not think it likely that the alum market could be cornered, because the raw materials are very generally distributed and there is no patent on the process.

Dr. Woodward. Do you know what it is made of now?

Mr. Hazen. I think bauxite, but it can be made from other materials.

Senator McMillan. You believe that the sand filter is the most perfect one known now, do you?

Mr. Hazen. For some purposes.

Senator McMillan. For the purpose of getting pure water—it will get rid of everything that we should get rid of and give a clear water?

Mr. Hazen. I have thought that the sand filters were generally more efficient in removing pollution from waters that were not too turbid. The alum filters are more efficient in clarifying very muddy waters.

Senator McMillan. But that is very expensive, and sometimes you taste the alum in the water.

Mr. Hazen. The alum is improperly used at times, but I think the filters can be operated so as to largely reduce that objection, if it is one.

Mr. Moore. Would you not, however, conclude from the investigations that alum does not appear in the effluent?

Mr. Hazen. It ought not to ever appear in the effluent.

Mr. Moore. You can with reasonable care eliminate the alum from the effluent?

Mr. Hazen. I think for many water supplies that is correct. There are some water supplies that have so little lime in them that I do not think alum could be used to coagulate them without using more alum than the amount that would be decomposed.

Senator McMillan. The statement has been made that in Washington it would cost $50,000 a year for alum for the use of mechanical filters. That makes it very expensive?

Mr. Hazen. Yes, sir.

Senator McMillan. And while mechanical filters might cost less at the beginning, yet they would be very much more costly in the end. Colonel Miller's theory is that, having adopted the slow sand process, if some morning the people of Washington should wake up and find that the water was turbid they would say, "What did Miller do for us?" or "What did McMillan do for us. The water is worse than it was before!" So that we want to get the best, the very best, system possible, and yet we do not want to spend too much money to secure it. You have had experience with this sand filter, have you not?

Mr. Hazen. Yes, sir.

Senator McMillan. At Albany?

Mr. Hazen. Yes, sir.

Senator McMillan. Does it work pretty well there?

Mr. Hazen. Yes, sir; it works well.

Senator McMillan. Is it the so-called English system?

Mr. Hazen. It is called the English system by some. I have not used that term.

Senator McMillan. We hear it spoken of as the English system of filtration?

Mr. Hazen. Yes, sir.

Senator McMillan. You do not think it is a perfect system?

Mr. Hazen. I think that improvements are possible. It has done all that was expected of it—all that could reasonably be expected of it, at Albany.

Senator McMillan. Is the mechanical process the same as Colonel Miller expected to use in Washington?

Colonel Miller. The same thing. A great many of my estimates were based upon experience obtained from Mr. Hazen in the construction of these Albany filters. He is diffident or bashful in claiming what they have accomplished. They have exceeded, I think, the best hopes of their friends, and they are making an average now of over 99 per cent—99.45, I think Mr. Hazen said.

THE USE OF ALUM.

Senator McMillan. You have studied the question of alum filters and you prefer the slow sand system?

Mr. Hazen. For certain conditions, but not necessarily for all conditions.

Senator McMillan. If the water should be turbid, as the Potomac water is at times, you think the sand filter would not work well?

Mr. Hazen. There are waters so turbid that filtration through sand would not remove the turbidity sufficiently, and whether the Washington water comes in that class or not I do not know. The turbidity of the raw water, as shown by this statement of Colonel Miller, is not very high. It is not higher than I know can be successfully removed by sand filtration in other cases; but it may be that this Washington turbidity is of a different character, and is caused by finer particles of clay, which go through the filter more easily, as is not the case with the turbidity at Pittsburg, for instance.

Senator McMillan. I have been using an alum filter at my house for ten years and we get very pure water. Once in a while it gets out of order, but as a rule we get very good water from it. Occasionally there is the taste of the alum. We do not use that water for drinking purposes. I presume water filtered by a mechanical filter would taste of alum unless the filter was thoroughly regulated.

Mr. Hazen. It ought to be regulated so that the water would not taste of alum.

Colonel Miller. Alum should not be used in a filter without a great deal of caution, if the water is to be used for drinking purposes.

Senator McMillan. If we should adopt the alum process for Washington, the great majority of the people would drink the water just as it came from the filters.

Colonel Miller. But the filters and the application of alum should be very carefully watched. In domestic filters it has been especially so. You only use yours for bathing purposes, and it is not, I suppose, watched hygienically, so you, of course, get the alum.

Senator McMillan. We have to recognize the fact that the mass of the people in Washington would drink that water just as it comes from the reservoir. So that if alum would injure them at all, we should not use it for drinking purposes.

Colonel Miller. I think that the experience of those who have used the mechanical filter is that they do not get any alum in the effluent. Mr. Hazen has mentioned a case where there is not sufficient alkalinity in the water, and lime has to be used to take up the alum. At Norfolk they put marble dust in the sand because they thought it was not sufficient to take up the two grains of alum used, and it showed that they got more alkalinity in the effluent than they had in the influent, but that is a very bad method, because you have to mix it every time and see that it is there. It ought to be done by regulating the supply of alum, and the alkalinity of the Potomac water has been shown to be large enough to take 3 grains at its lowest point. Theoretically it neutralizes one part about 8 grains, but practically it neutralizes a little more, because there is some of that sulphate of alumina that is decomposed in some other way.

CHEMICAL CHANGES CAUSED BY ALUM.

Dr. Woodward. Mr. Hazen, while the alum itself does not appear in the effluent the effect of it is to bring about chemical changes in the water?

Mr. Hazen. Yes, sir.

Dr. Woodward. Do you know of any careful study as to the effect of these chemical changes on the health of the community?

Mr. Hazen. No, sir; I do not.

Dr. Woodward. There is no definite information to be had as to whether alum will or will not affect, I will not say the death rate, but in general the vigor and length of life and sickness rate of the community?

Mr. Hazen. I do not know that that has ever been investigated, but as a general proposition I should regard that as very improbable that it would have any effect.

STORAGE CAPACITY OF WASHINGTON RESERVOIRS.

Dr. Woodward. The present reservoir capacity of the District of Columbia is 300,850,000 gallons. It is proposed, independently of the filtration scheme, to add to that a new reservoir having a capacity of 300,000,000 gallons, which will be diminished by——

Colonel Miller. No; I beg your pardon. We have abandoned that method of making a fresh-water basin, because it was thought that good foundation for the dam did not exist, and besides there is difficulty of covering. I think Mr. Hazen will agree that the basin for the reception of filtered water should be covered. We keep that capacity still at three-hundredth million.

Dr. Woodward. Then we will increase the storage capacity by 300,000,000 gallons, almost doubling that which exists at present. The estimated daily consumption of water will be 60,000,000 gallons. Do you regard the additional reservoir capacity of 300,000,000 gallons as a factor likely to render the water less turbid?

Mr. Hazen. That is what percentage of the now existing storage?

Dr. Woodward. 300,850,000 gallons. We are going to add 300,000,000 gallons more.

Mr. Hazen. It would not quite double it?

Dr. Woodward. No.

Mr. Hazen. It would be a factor—how large I can not say.

Colonel Miller. You referred to a case where we get our supply by pumping?

Mr. Hazen. Yes, sir.

Colonel Miller. Of course there is a large proportion of the citizens who get water from gravity now; but after adopting either system of filter we would have to pump to the filters to get back to the reservoir level, and we could draw only a certain amount. You do not want to go below 16 feet to get the water anyhow, so you might say it would add five days' extra supply; 300,000,000 would be about five days. I think that would be fair. You could not use it all, of course?

Mr. HAZEN. No, sir.

Mr. MOORE. Is there not a limit of sedimentation—that is to say, where water has been stored for a certain time the sedimentation practically ceases?

Mr. HAZEN. It takes place very, very slowly; the finer particles deposit very slowly, and the action of the wind oftentimes keeps them stirred up.

Mr. MOORE. So by doubling the storage of water it would not necessarily double the precipitation?

Mr. HAZEN. Not by any means.

STATEMENT OF GEORGE W. FULLER.

Senator MCMILLAN. Mr. Fuller, what experience have you had as an expert?

Mr. FULLER. For the past twelve years I have made a special study of this general line of work. For five years I was connected with the Massachusetts State Board of Health, and for the greater part of that time was stationed at Lawrence in connection with investigations as to the best methods of water purification for the Massachusetts waters and the methods of sewage disposal under the Massachusetts conditions. Next, for about three years and a half I was engaged in studying methods of water purification in the Ohio Valley at Louisville and at Cincinnati, and for the past year and a half I have been engaged in private practice. I recently have had occasion to study problems of water purification in the East, and for the last few months at New Orleans, giving a wider range than is required by the usual conditions of the waters found in this country.

Senator MCMILLAN. Have you any financial interest in the manufacture or sale of any device sold in connection with filters?

Mr. FULLER. No, sir.

Senator MCMILLAN. Have you examined Senate Doc. No. 259, Fifty-sixth Congress, first session, relating to the feasibility and propriety of filtering the water supply of Washington, D. C.?

Mr. FULLER. I have looked it over. I have not studied it in all its details.

Senator MCMILLAN. So that you are not able to make any recommendations on that subject?

Mr. FULLER. No, sir; not specifically.

Senator MCMILLAN. You have studied the matter sufficiently to know about our conditions in Washington?

Mr. Fuller. Yes, sir.

Senator McMillan. Please just give us your ideas—what you know and what you think about the system of filtration that should be adopted for the city of Washington.

THE WASHINGTON PROBLEM.

Mr. Fuller. The essential problem which you have before you, as I understand it, is to decide as to which of the two systems of filtration is the better—that is, the American system of purification, involving the use of a coagulant in connection with subsidence and rapid filtration, or the English system, in which sedimentation in the reservoir should be taken advantage of and then the water be filtered slowly through sand beds. That brings up first the question of the specific character of the Potomac water. I consider this to be a fundamental essential to a satisfactory solution of your problem. That is to say, it is not the question of a system of filtration that has got to be considered by itself, but you have to consider the subject with reference to the character of the Potomac water as it leaves the Washington reservoirs.

To make that idea a little plainer, I would say that I have held the view for a good many years, and still hold it, that the waters in New England, which are wholly on the glacial drift formation—waters which contain very little clay, although they are somewhat turbid during the spring freshets (because of the silt and sand)—those waters, as a rule, can be best purified by the English or slow sand filters. There are some exceptions to that rule, but it stands out very clearly in my thoughts as one of the propositions to be borne in mind in looking into this problem at Washington.

Passing to another type of water in this country—that is, the water found in the South, where the glacial drift formation does not exist, where you get clay material, which the water contains in large quantities for a good many months at a time—I am very clearly and firmly of the opinion that sand filtration from present evidence can not be used to advantage. With this class of water, sand filtration would give at times a turbid effluent, for sand filters are unable to hold back for more than a certain number of days—say, less than two to three weeks—an excessive amount of turbidity. After their capacity for retaining the clay has been overtaxed, then they commence to give a turbid effluent, and their general condition is so disarranged that their bacterial efficiency is much interfered with.

I will say that, as a general proposition, a water like the Merrimac or the Hudson or the Connecticut can be best purified by the English system, or by sand filters. But when you have a water like that of the Lower Mississippi, which contains a large amount of clay for three or four months continuously, the English system is not the best. I can imagine how you might build a series of storage reservoirs that would hold so much water that you would not have to take the muddy water from the river during the spring freshets, or how you might reduce the rate of filtration by increasing the area of sand surface, and thus use the sand filters. There are a great many things that could be suggested along the line of possibility, but when you come down to consider the subject practically I think the slow sand method of filtration at present should be ruled out without hesitation for this type of water.

I have now mentioned two extreme types of water. There are between those two extremes a great many waters resembling partly one type and partly the other. The Potomac unquestionably comes in a middle class, resembling, so far as I have been able to learn, the Mississippi water rather than the Hudson or Merrimac. With the data at hand I can not take up and state specifically how that comparison exists and to what degree. It would seem from a reading of Colonel Miller's report that the Potomac water at Washington bears some resemblance in its characteristics to the river waters at Pittsburg and Cincinnati. Apparently it is a water lying between the types of water found at those two cities. It is apparently a water which is turbid for such a long period at a time that it would require considerable careful study to know whether a sand filter could possibly be modified or any adjustments could be arranged to make its use practicable without resorting to coagulation. The results of the experimental studies already made certainly indicate that the conditions are quite unfavorable for the sand filter in Washington on account of the turbidity which the water possesses, due to suspended clay of exceeding fineness.

Now, all of these statements are in general terms. In specific terms, there is not a great deal that I can say, because I have not studied a series of factors which require careful investigation.

Senator McMillan. Your statement is very interesting, and, I think, covers the ground pretty well. Have you had any experience with the other kind of filter—the one using the alum process?

EFFICIENCY OF MECHANICAL FILTERS.

Mr. Fuller. I studied that system on behalf of the city of Louisville—the Louisville Water Company—for nearly two years, and I studied it also in connection with investigations made by the city of Cincinnati, and have tested quite a number of so-called alum filters as operated in practice.

Senator McMillan. What is your opinion as to the use of the mechanical filter? Is that kind of filter in use in Louisville?

Mr. Fuller. They are going to put them in at Louisville. The contract to that end is under way.

Senator McMillan. After very careful and thorough investigation, I presume?

Mr. FULLER. Yes, sir.

Senator McMILLAN. What is your opinion as to the use of that system in connection with the Potomac River water?

Mr. FULLER. I think it would give satisfactory results, without any doubt, if properly operated and constructed.

TYPES OF MECHANICAL FILTERS.

Mr. MOORE. What kind of mechanical filters will be used at Cincinnati—what type has been settled upon, or has any type been settled upon?

Mr. FULLER. No, I do not think that question has been settled upon at either Louisville or at Cincinnati. At the latter place the matter has been in abeyance, I believe, for a year, and will continue so for some time, pending work on new pumping stations, reservoirs, and tunnels. So far as I know, the only work toward adoption of the American system at Cincinnati relates to grading the grounds.

Mr. MOORE. You say it has not yet been settled at Louisville?

Mr. FULLER. No; they are at present advertising for bids on plans and specifications which have been prepared by Mr. Hermany, their chief engineer, but the option has been offered to the bidders to submit their own plans and specifications, provided such shall be recognized as equal to and cheaper than those gotten out by the company.

Mr. MOORE. Do these plans and specifications differ from those of the mechanical filters now in use in other cities?

Mr. FULLER. Essentially. The individual filters or units are very much larger. Instead of having a sand surface of one to four hundred square feet, I think they provide for some 4,000 square feet; that gives you an idea of the difference in size. Then they have quite a number of operating devices that are unique, particularly the mode of agitating the sand layers during washing. There are a great many unique features.

Mr. MOORE. Are any of those points in the specifications covered by patents?

Mr. FULLER. You mean by present patents of filter companies?

Mr. MOORE. Yes.

Mr. FULLER. I do not know in definite terms. I rather imagine there might be a conflict. There are, I understand, some two or three hundred patents which have been issued to the filter companies, covering almost all conceivable types of construction and arrangement. How much value they possess, I do not know. Their value has not been established in court.

Mr. MOORE. But undoubtedly they would infringe the Hyatt patents, or at least an arrangement must be had with the owners of the Hyatt patents to regulate the coagulant.

Mr. FULLER. The Hyatt patent, I think, relates to the manner in which the coagulant shall be applied. I do not think that is a factor for the future. It does not relate to the filter proper; it relates solely to the coagulant.

Mr. MOORE. Are you making plans and specifications for the filter plant for Paterson, N. J.?

Mr. FULLER. Yes, sir; they are being gotten out under my supervision.

Mr. MOORE. They differ from the ordinary mechanical plant in some respects I believe?

Mr. FULLER. Yes, sir; very essentially. They are going to be masonry filters, and a number of short-lived mechanical appliances will be replaced by improved devices.

Mr. MOORE. Then your idea would be that the Washington problem of mechanical filtration, if that system should be adopted, would necessitate plans and specifications particularly drawn for that city?

Mr. FULLER. That probably would be so. I am not prepared to state definitely that it would be so.

Mr. MOORE. At least it has been so at Louisville and Paterson?

Mr. FULLER. It has been considered judicious to look into other types very carefully; and the indications in that direction are certainly promising.

CHEMICAL CHANGES IN EFFLUENT FROM MECHANICAL FILTERS.

Dr. WOODWARD. In your Cincinnati report I find the following statement with reference to the mechanical filters, as to the changes in the water:

> While these changes are undesirable, it can be positively stated that in the quantities required from the treatment of this water they are not injurious to health, and can not be regarded as seriously objectionable.

In what ways are those changes undesirable?

Mr. FULLER. I do not understand the quotation exactly. I think the original report is here. The report is to the effect that directly after cleaning these filters the bacterial contents were somewhat different than at other times.

Dr. WOODWARD. You do not recall in what particular features? I have made the quotation from your report on this paper. So far as I was able to extract it fairly I did so.

Mr. FULLER. Those changes, I should imagine, refer to changes in the mineral constituents of the water, due to the application of coagulant. Those changes consist in a portion of the lime and magnesia being transposed from the form of carbonate to that of sulphate, and a corresponding amount of carbonic acid is displaced and set free. I do not think that comes into the question of effect upon the health of water consumers in any appreciable degree.

Dr. WOODWARD. You say they are undesirable changes?

Mr. FULLER. They are undesirable changes in this way, that the more free carbonic acid the more opportunities for complications of a certain nature. Carbonic acid is just becoming recognized as an explanatory factor in a good many problems, and one which has been given most thought in connection with the corrosion of metal. I do not think that corrosion by carbonic acid is considered to be as much of a factor now as it was a few years ago, as it can be largely obviated by covering the metal with a good protective coating.

BOILER INCRUSTATION.

Dr. WOODWARD. Is the matter of boiler incrustation a matter of any moment?

Mr. FULLER. In a water like the Ohio River I do not think the required amount of combined sulphuric acid going into the water as a coagulant would make much difference. It is on the side of undesirable constituents. Practically, I do not give much, if any, weight to that when the increase in sulphate of lime in the filtered water is only about one-half grain per gallon.

Dr. WOODWARD. Have you noticed the results on the boiler test in Pittsburg recently?

Mr. FULLER. I have seen them, but I have not read Mr. Knowles's paper.

Dr. WOODWARD. You state that "it can be positively stated that these changes are not injurious to health." What are your bases for that opinion?

Mr. FULLER. Well, water treated with a coagulant has been used by many people for a good many years, and if there is any reason to believe that a slightly added amount of sulphate of lime would be a serious factor I have not been able to find it out. I think that it is true that any serious trouble from this cause would have been located definitely in hotels and private residences where coagulants are used, if it occurs. To locate such matters in any of the 165 towns and cities where this type of filter has been adopted is extremely difficult in view of possible complications with other factors which are entitled to equal consideration. I am firmly of the opinion that coagulants should never be applied in such quantities that they appear in undecomposed form in the effluent. Barring out this inexcusable and inadmissible state of affairs, I have never been able to secure any specific testimony to show that the proper use of coagulants was prejudicial to health.

Dr. WOODWARD. Any minor changes would not have been demonstrated?

Mr. FULLER. I do not see how that could be learned in positive terms in view of possible obscuring by other factors. While theoretically such may exist, I know of no reason to consider seriously such a possibility.

Dr. WOODWARD. Then the position is largely a negative one. We do not know of any positive harm that has resulted?

Mr. FULLER. I do not see from my inquiries, both general and specific, how anyone could prove that any harm has resulted from the proper use of coagulants.

Dr. WOODWARD. But do they prove that no harm has resulted?

Mr. FULLER. I do not think that it is possible to prove that any harm has resulted when a coagulant has been properly applied. The logical inference is that no harm has resulted.

BACTERIAL EFFICIENCY.

Dr. WOODWARD. Now, with reference to the value of a filter for filtering a public water supply. Would you determine the value of the filter by reference to the bacterial efficiency of the filter—so called—or with reference to the percentage of bacteria left in the water which has to be consumed by the people?

Mr. FULLER. It is my custom to give weight to both. The extent of the number of bacteria in the effluent, which are not connected at all with the raw water, but are connected with the filter, rather take away the efficiency of the direct comparison between the numbers remaining in the water.

Dr. WOODWARD. But for the present argument, disregarding the bacteria that are derived from the filter proper and regarding simply the number of bacteria in the effluent of two filters, working side by side, on the same water, would you not regard the probability of water-borne diseases occurring in the communities consuming the effluents of these two filters as proportionate to the number of bacteria in the water?

Mr. FULLER. Where the efficiency would be very high I should not be inclined to give weight to that relationship with mathematical accuracy.

Dr. WOODWARD. It would be very closely in that proportion, would it not?

Mr. FULLER. That I do not know. With reference to the numbers of bacteria in water, as throwing light upon the amount of water-borne diseases, of course we have to bear in mind that there are other factors than the public water supply to explain such diseases in part.

Dr. WOODWARD. I understand that, but considering these bacterial counts with reference to bacterial efficiency, should not the bacterial efficiency of the slow sand filter be corrected, if possible, by the subtraction of the bacteria derived from the filter?

Mr. FULLER. If it were possible to do it?

Mr. WOODWARD. Yes.

Mr. Fuller. Yes; I think it would give you information of value if you could do it.

Dr. Woodward. Would it increase the actual bacterial efficiency of the slow sand filter as compared with that of the mechanical system?

Mr. Fuller. Yes, sir.

Dr. Woodward. Even in the absence of such correction, what has been the trend of experiments—not counting, of course, corrections that have been made on theoretical bases, but the actual results obtained by comparison of the two systems—how do the two systems compare in bacterial efficiencies?

Mr. Fuller. You mean as they have been examined in practice?

Dr. Woodward. Yes; in practice.

Mr. Fuller. I think as a rule the degree of efficiency in the operation of the mechanical filters has not been so good as that of the sand filters; but most of the sand filters which we know a great deal about have been operated in Europe, where the conditions are entirely different from what they are here. They have been operated mostly in large cities, whereas in this country most of the mechanical filters have been operated in small cities by water companies and departments who have not been inclined to go to the expense necessary to secure the proper supervision and management, or to the expense of providing a suitable amount of coagulant. I think if you use a sufficient amount of coagulant with a properly constructed mechanical filter, you can equal any efficiency accomplished by a sand filter.

Dr. Woodward. Is not that a matter of opinion, with no facts to justify it?

Mr. Fuller. No; it is substantiated by actual facts observed.

Dr. Woodward. Where were those facts observed?

Mr. Fuller. I made such a test at Hornellsville, N. Y., and at York, Pa.

Dr. Woodward. Have the results been published?

Mr. Fuller. No, sir.

TURBIDITY.

Dr. Woodward. You spoke with reference to the turbidity of water. Is a slight degree of turbidity of water in any degree objectionable from a sanitary point?

Mr. Fuller. No.

Senator McMillan. Do you mean for bathing, or for drinking purposes?

Dr. Woodward. I refer to both. From a purely sanitary standpoint is there any established point at which turbidity becomes objectionable?

Mr. Fuller. Not any that is universally agreed upon. There is this point, however, that I may not have brought out clearly. When the turbidity of the effluent reaches a certain point you lose control of the bacterial efficiency, which then becomes quite uncertain.

Dr. WOODWARD. That is the case with which filter?

Mr. FULLER. The slow sand filter—the English system. There seem to be indications of that in the Washington reports, so far as I can gather.

Dr. WOODWARD. Would you regard the construction of that experimental slow sand filter there as sufficiently typical to yield satisfactory results?

Mr. FULLER. That was my impression. The matter of protecting it from the cold impressed me as being a fact of perhaps some local significance.

COLON BACILLUS.

Dr. WOODWARD. Of course we accept the colon bacillus as an indication of the probable presence of typhoid bacilli. What were the results of your examination of the effluents of these two systems of filters at Pittsburg and Cincinnati on the removal of the colon bacillus?

Mr. FULLER. I do not remember in detail the facts, but the impression in my mind is that there was not a great deal of difference. I am very sure that if there was any difference in favor of the sand filters, an added amount of coagulant in the case of the mechanical filters would have wiped out that difference. At Cincinnati we started in with the idea that with a certain degree of turbidity a certain amount of coagulant was necessary, and we placed that ratio too low. As stated in our reports, the coagulant required was increased from 1.3 to 1.6 grains per gallon on an average, which would make the mechanical filters give as good results as the sand filters, even comparing them with the sand filters where the coagulant was used at times of extreme turbidity.

Dr. WOODWARD. Now, coming to the reasons for the failure of the slow sand filters at Cincinnati; there were several reasons stated in the report in addition to the presence of this finely formed clay. You state among them—

> The comparative absence from the local water of organic matter such as serves readily to form gelatinous films around the grains of sand.

Mr. FULLER. Yes, sir; I attach great importance to that.

Dr. WOODWARD. In the study of our Potomac water, so far as you have examined this report, is there anything to indicate that such organic matter was absent?

Mr. FULLER. I gather that it was absent, but I can not state it specifically.

Dr. WOODWARD. You state further that the slow sand filters failed there because of "the imperfect formation of a gelatinous surface coating upon the top of the sand layer." Is there any indication in the report of Colonel Miller of "an imperfect formation of a gelatinous surface coating upon the top of the sand layer?"

Mr. FULLER. I gathered the impression that there was something abnormal at Washington on that general line. I can not tell you specifically.

Dr. WOODWARD. And the third factor that you mention for the failure of the slow sand filters is "the presence in this water almost uniformly of sufficient air to preclude the use of negative heads." Was there any evidence of the presence of such air in the Potomac water?

Mr. FULLER. That I could not say. That point at Cincinnati related to our ability or inability to use large losses of head there before scraping. That was not bearing directly on the question of efficiency.

RELATIVE COST OF FILTER SYSTEMS.

Dr. WOODWARD. You have heard the statement as to the costs of the two methods of filtration. Would you, from the data at your command, regard it as necessary to cover the filters in Washington?

Mr. FULLER. That is my impression, but it is a matter that I can not state specifically without further study.

Dr. WOODWARD. If the filters were covered, would you regard it as necessary to increase the area and to decrease the rate of filtration in order to allow for possible interference by freezing?

Mr. FULLER. As a general proposition, I should say not. How that applies in this instance I do not know. I think 3,000,000 gallons per acre daily is the net rate generally allowed for covered filters.

Dr. WOODWARD. With reference to the mechanical filters, there is, I believe you stated, no uniform type adapted for all cities, but that each filter must be adapted to the local conditions?

Mr. FULLER. I think that is judicious within certain limits. I think it is unquestionably a wise matter for the large water departments to adopt the type or design most suitable to local conditions; but for very small cities and towns I can see how that would not be very judicious.

Dr. WOODWARD. Then the construction of a plant of that kind in Washington would be to a certain extent experimental?

Mr. FULLER. Well, that does not strike me as hardly a fair statement. It would be experimental in that it would not perhaps have specific precedent for all the exact details and arrangement, but all important factors would be based upon previous experiments and experience. So that should be taken in a relative sense with regard to the experimental aspect, and to no further degree than applies to natural improvements in other lines of construction.

Dr. WOODWARD. Would the particular combinations of those important factors, as they are thrown together in the proposed mechanical filter plant, have precedent?

Mr. FULLER. So far as single units are concerned, I think that is so. On the question of multiplying those units, I do not think it would be true at present.

Dr. WOODWARD. You would adopt a certain point in the design from one city and another point in the design from another city and put them together for the purpose of establishing a satisfactory filter plant for the city of Washington?

Mr. FULLER. I think it should be based upon conclusive evidence as to the best available procedure for every step.

Mr. MOORE. It would, in other words, be individual and not experimental?

Mr. FULLER. Yes; the individuality of quite a number of different methods and types of construction would be taken advantage of to secure a complete plant most applicable to local conditions.

Dr. WOODWARD. Is there any positive information as to the probable life of a mechanical filter?

Mr. FULLER. That depends upon the type of construction.

Dr. WOODWARD. So that, whether you would have to allow for its deterioration in twenty years to a point where it could not be used, or in fifteen or twenty years, would be a matter of estimate and not accurate knowledge?

Mr. FULLER. With this 32,000,000-gallon plant that I am engaged in preparing plans and specifications for at this time at Little Falls, N. J., everything will be masonry except the piping system and the strainer system beneath the sand layer. There is no wood at all.

Dr. WOODWARD. How would the cost of construction of masonry filters for mechanical filtering plants compare with the cost of iron and steel tanks, as estimated for in the estimate here?

Mr. FULLER. I can not state that definitely offhand. I do not think there would be a very great difference—that is to say, I think you can put in a masonry type of construction without increasing the estimates as given for mechanical filters in Colonel Miller's report. That, however, is an impression, and not the result of study of Washington conditions. There would certainly not be a wide difference.

THE M'DOUGALL SYSTEM.

Senator MCMILLAN. Are you acquainted at all with a process devised or patented by a man named McDougall?

Mr. FULLER. Yes, sir. That process was tested under my general direction at Cincinnati in the spring of 1899.

Senator MCMILLAN. They use lime, do they not?

Mr. FULLER. They use lime as a coagulant.

Senator MCMILLAN. How did that process appear to you?

Mr. FULLER. The removal of sediment and bacteria when lime was added in sufficient quantities was very satisfactory indeed. The complication during that test was that they got an excess of lime in the filtered water at times to a degree which you could taste. Shortly before the close of these tests Mr. McDougall and his associates started in to apply carbonic acid to neutralize this free lime, but the test was closed before they got that very well in hand, although he did correct the difficulty for the most part. If it were not for that complication it would be a very desirable thing in many ways. It is a mechanical type of filtration, only a different coagulant is used. The same general type of procedure is used as contemplated by Colonel Miller.

Senator McMillan. So that the expense would be about the same?

Mr. Fuller. The saving that Mr. McDougall had in mind was from the less cost of lime as compared with sulphate of alumina. There would probably be no very great difference in the cost of filters proper in the McDougall system as compared with the one considered by Colonel Miller.

THE FISCHER SYSTEM.

Dr. Woodward. Are there any other processes which, in your judgment, ought to be considered? I ask that because one of the residents of Washington has called attention to the Fischer process used in Worms, Germany.

Mr. Fuller. In answer to that, so far as it relates to the Fischer plate system, I would say that at Berlin this past summer I saw signs of that having been tested with water very much easier to purify than the Potomac water. The tests were brought to a close apparently by the people owning the process, and it was never brought up for official consideration.[1] I do not know of any other process that should be considered in connection with the Potomac water. As to the matter of the adaptation of these two general processes of purification under advisement, it might be possible, upon further study, to evolve some supplementary or auxiliary features, but as to that I can not speak now.

Dr. Woodward. Do I understand that in your studies of the mechanical system of filters you find that they are approaching more nearly the slow sand system by the increase in the size of the filter beds and the increased use of sand?

Mr. Fuller. That is true, in regard to size of single units, of the plans that have been gotten out within a very few days by Mr. Hermany, the chief engineer at Louisville. The chief feature of the Little Falls plans, which resembles the English method, is the use of

---

[1] See Consular Reports, February, 1897, for a description of the Fischer plate system of filtration, by Hon. Frank H. Mason, consul-general, Frankfort, Germany.

masonry rather than steel or wood to contain each individual filter. But for the most part—as to the fundamental principles controlling the efficiency—the Louisville and Little Falls filters would be quite similar to those which have been submitted by Colonel Miller in his report upon the American system for Washington.

STATEMENT OF EDMUND B. WESTON.

Mr. Moore. Kindly tell us what experience you have had in the matter of water filtration.

Mr. Weston. I first began to investigate the subject in about the year 1882. In 1883 I spent some time in England studying the subject of filtration, and upon my return I advocated a slow sand filter plant for Providence, R. I. That, however, was never built. That was before the time that bacteriology was much known about. I found that there had been recently published a report on the Providence water supply to the effect that the Providence water was about as pure a water as there was in America, based upon a chemical analysis. Consequently the matter of filtration was dropped. Later the subject was again taken up in Providence, and I was called upon to supervise some experiments that were made there.

Since then I have had considerable experience in designing plants and looking up the subject, and for the past three or four years I have devoted a great deal of my attention to the subject of the purification of water.

Mr. Moore. What plants have you designed?

Mr. Weston. I designed the East Providence, R. I., plant, a mechanical plant, and the Norfolk, Va., plant, which is also a mechanical plant, and the plant at East Albany, N. Y.; the Rensselaer plant, which is the same kind, and the Norristown, Pa., plant. The two latter are now being constructed.

Mr. Moore. Those are all mechanical filters?

Mr. Weston. Yes. In addition to these I have made designs for a great many filter plants, and have submitted plans, etc., among others, for the plant at Washington, D. C.

RESULTS FROM MECHANICAL FILTERS.

Mr. Moore. Why did you design a mechanical filter plant for a New England water?

Mr. Weston. It was the result of the experiments that were made in Providence. During the test there we conducted slow sand filter experiments as well, though we did not go into that subject as thoroughly as we went into that of mechanical filters, for the reason that after the filters had been in operation for a short time, and from my own knowledge in regard to sand filters, as well as that of the commission in Providence, we felt that it was not necessary to devote any more time to a sand filter. We felt that the mechanical filter was showing surprising results. This was a great surprise to me as well as to the members of the commission. At first I was decidedly opposed to the use of sulphate of alumina or any other chemical in water. I thought the matter should be thoroughly investigated, and I asked the advice of the most eminent experts in this country whom I knew or could communicate with. As the experiments progressed the results continued to be of a superior character, and while there were some adverse elements, as in all cases where experiments have been made, still, upon the whole, at the conclusion of those experiments I felt that the mechanical-filter experiments were very satisfactory.

Mr. Moore. You had no great degree of turbidity to eliminate?

Mr. Weston. No, sir.

Mr. Moore. It was simply from the standpoint of bacterial efficiency that you adopted the mechanical filter?

Mr. Weston. My judgment was principally based upon that.

Mr. Moore. What is the oldest mechanical-filter plant in operation under your direction?

Mr. Weston. The oldest one is the East Providence, R. I., plant.

Mr. Moore. How long has that been in operation?

Mr. Weston. About two years, I think.

Mr. Moore. That has continued down to this time to produce satisfactory results?

Mr. Weston. Yes, sir; very satisfactory results.

Mr. Moore. What is the efficiency from a sanitary standpoint?

Mr. Weston. At the present time examinations are made once a month by the State board of health. The average results have been, for bacterial efficiency, about 99 per cent.

Mr. Moore. Do you use a standard type of filter or have you built the filters upon specifications furnished by yourself?

Mr. Weston. Generally a standard type of filter, for the reason that my experience has been that a standard or certain type of filter is satisfactory.

Mr. Moore. What is the capacity of the plant at East Providence?

Mr. Weston. At the present time it is one-half million gallons for twenty-four hours. The building is arranged for 2,000,000 gallons.

Mr. Moore. To get two millions you would simply increase the number of your mechanical filters.

Mr. Weston. Yes, sir.

Mr. Moore. In any case have you departed from the standard type of filter? Is the filter you use the result of any modifications that you have recommended?

Mr. Weston. So far as the filter itself is concerned I have not modified the standard type. There have been various additions to the filter, such as the method of feeding the alum solutions and the control of the effluent water, but I have not departed from the original design of filter.

Mr. MOORE. You made examinations at Washington. What is the problem there; what points did you feel called upon to take up and consider, and what was the reason for your conclusion?

Mr. WESTON. I really made no conclusion in regard to Washington. I went on to Washington to obtain data for designing a mechanical-filter plant.

Mr. MOORE. You built the filters that were put into operation there?

Mr. WESTON. The Washington experimental filters I had nothing to do with whatever. My work ceased after I made plans, estimates, and designs.

Mr. MOORE. Did you make the plans for the slow sand filters there?

Mr. WESTON. No, sir; I had nothing to do with them.

Mr. MOORE. You simply made the plans for the mechanical filters?

Mr. WESTON. Yes, sir.

Colonel MILLER. Not for the experimental ones?

Mr. WESTON. Not for the experimental but for the mechanical filter plant that is shown in Colonel Miller's report.

Mr. MOORE. You were not called upon to decide the problem as between the two systems?

Mr. WESTON. No, sir.

Mr. MOORE. Were you called upon to decide as to that matter in other plants, at Norfolk, for instance.

Mr. WESTON. No, sir; I was not. The water board there made up their minds that they preferred the mechanical system. Dr. Taylor, who was a member of the board, looked up the matter very thoroughly, and when I was called in it was practically decided to put in the mechanical filters. I talked it over with them and gave them my ideas with regard to the mechanical construction, but I was not called upon to decide the matter.

Mr. MOORE. Do they use the standard filter at Norfolk?

Mr. WESTON. Yes; it has been in operation more than a year; that is, a standard filter of one kind.

Mr. MOORE. What I mean is a filter that is made according to a certain pattern and not an individual filter?

Mr. WESTON. Yes, sir.

Mr. MOORE. Do you know what the bacterial results have been at Norfolk?

Mr. WESTON. Yes. There have been one or two tests made there and the bacterial efficiency, which was determined I think by the bacteriologist of the city during about one month's run, showed that the percentage of removal was about 96 per cent, if I remember correctly; but the number of bacteria in the raw water was very small, and the number in the effluent, if I remember correctly, was from 12 to 14. On one occasion when the number in the applied water reached 3,000 or in the neighborhood of 3,000, the percentage of removal was 99 per cent or more, if I remember correctly. But it certainly showed there, as in other places, that when you consider the percentage of bacteria alone, it is not always fair.

Mr. MOORE. Why do you think that is not fair?

Mr. WESTON. Well, you may take sewage, which may contain millions of bacteria, and you filter it and take out 99.9 per cent of the bacteria, and yet the effluent may contain thousands. Now, I have found in my experience that, taking, for instance, a thousand bacteria in the influent, with the ordinary filter, like that at East Providence, the percentage of removal will reach 99 per cent; whereas if the number of bacteria falls to 200, the percentage may fall off to perhaps 97 or 98 per cent. On the average, though, it keeps up in the neighborhood of 99.

COMPARATIVE COSTS.

Mr. MOORE. What is the comparative cost of the two systems?

Mr. WESTON. That depends somewhat on circumstances. It depends greatly upon the character of the water. Take, for instance, the East Providence water, where it is not necessary to have any preliminary subsidence, except what is obtained in the filters themselves, in round numbers I should say that the cost of sand filtration was about twice as much as that of the mechanical. I was the consulting engineer of the water company and looked up both sides of the question, and I came to that conclusion after careful consideration of the subject.

Mr. MOORE. What elements enter in to make the mechanical system cost so much less than the slow sand system; is it the price of land?

Mr. WESTON. No; at East Providence it was not the price of land. There the filter is in a park, and little extra grading was required than would be the case for the general construction of sand beds themselves. I am an advocate of rather a slow rate for sand filtration, and my experience has been based more upon what I have seen abroad than the results obtained in this country.

Mr. MOORE. What rate an acre would you calculate for a sand filter?

Mr. WESTON. It should not reach more than two and a half millions per acre as a maximum.

Mr. MOORE. That is half a million under the usual estimates.

Mr. WESTON. As I remember, in the Hamburg filters that have been recently built the rate is about 1,700,000 gallons per acre per day. According to the last statistics that I have from England, there the rate is slightly over 2,000,000 gallons per acre, and if I remember the Lawrence filter, which is not really a slow sand filter, the average rate is 1,300,000 gallons.

Mr. MOORE. Why is not the Lawrence filter really a slow sand filter?

Mr. WESTON. As I understand it, a portion of the time the water is drawn off from the filter bed, and it is exposed in the air, whereas the ordinary sand filter is kept covered with water all the time.

Mr. MOORE. You mean to say that part of the cleansing is done by sunlight?

Mr. WESTON. The bacterial action is aided by the sand being exposed to the air.

Mr. MOORE. Then at Lawrence they have a sufficient storage capacity to allow that?

Mr. WESTON. Yes, sir; they have a reservoir.

Mr. MOORE. Do you find that the filtered water deteriorates in the reservoir at Lawrence?

Mr. WESTON. I only know from what I have seen in the reports of the State board of health, and so far as I know it does not.

Mr. MOORE. Is the reservoir covered?

Mr. WESTON. It is not.

Dr. WOODWARD. Are you financially interested in any system of filters?

Mr. WESTON. None whatever.

Dr. WOODWARD. Are you in any way connected with any company or individual that is so interested?

Mr. WESTON. I have been for two or three years consulting engineer of the New York Filter Manufacturing Company, in addition to my other business. I am a general consulting engineer, so to speak.

Dr. WOODWARD. Have you ever designed and superintended the construction of a slow sand filter?

Mr. WESTON. Only in an experimental sense.

Dr. WOODWARD. You state that you designed the East Providence filter?

Mr. WESTON. Yes, sir.

Dr. WOODWARD. For whom did you design that?

Mr. WESTON. For the East Providence Water Company.

Dr. WOODWARD. Do you know anything as as to the terms of the charter of that company, as to its capital stock or the duration of its existence?

Mr. WESTON. I do not.

Dr. WOODWARD. You do not know whether those are factors that entered into the selection of the mechanical system or not?

Mr. WESTON. I do not understand your question.

Dr. WOODWARD. Do you know whether the capital stock of that company is limited so that it could not have laid out the amount of money to put in the system of slow sand filters or that the life of the company is limited by its charter so as to make it undesirable to make a long investment?

Mr. Weston. No. The company is under the control of a wealthy man, who is a very thorough business man. He told me that he wanted the best system put in. He considered the commercial side of the question as well. He thought he would sell more of the water than if it contained a large degree of its original color, and he preferred brilliant, clear water for that reason.

Dr. Woodward. Then, from a commercial standpoint, I think we will have to admit that it would create a brilliant or attractive water rather than a wholesome water.

Mr. Moore. I do not understand that you went into the matter of wholesomeness?

Mr. Weston. Certainly I did.

Dr. Woodward. I mean the man who controlled the company.

Mr. Weston. The man who controlled the company was a man of large means, and he wanted to put in the very best thing. He decided on the mechanical filters himself. I did not recommend them.

Dr. Woodward. What did you mean by the statement that he considered it from a commercial standpoint and thought he would sell more water if it was brilliant and attractive than if it contained a large degree of original color?

Mr. Weston. That was from the esthetic standpoint; that is, an attractive article will appeal to us and we will prefer it to another not so attractive.

Dr. Woodward. You have stated that the capacity of this plant is half a million gallons per day.

Mr. Weston. Yes, sir.

Dr. Woodward. At what capacity is it running?

Mr. Weston. When it runs it is at that rate. The consumption at present is about 300,000 gallons for twenty-four hours.

Dr. Woodward. It does not run the entire twenty-four hours?

Mr. Weston. No; very nearly so. The superintendent told me a few days ago that they would have to add another filter within a few months.

Dr. Woodward. You have seen Dr. Chapin's article, have you not?

Mr. Weston. Yes, sir.

Dr. Woodward. If he stated that it was run at a quarter of a million gallons daily, he is incorrect, is he?

Mr. Weston. My last figures from the superintendent are from 250,000 to 300,000.

Dr. Woodward. Do you know what the problem was that confronted the Norfolk authorities in the matter of improving their water supply?

Mr. WESTON. As I understand, it was mainly the appearance of the water.

Dr. WOODWARD. Was there any claim that Norfolk water was causing disease?

Mr. WESTON. There were no figures that I know of on the subject. There was much complaint in regard to the water, and people objected to drinking it.

Dr. WOODWARD. From its appearance?

Mr. WESTON. Yes, sir.

Dr. WOODWARD. What would be the prime consideration in meeting the demands of the people—the appearance of the water or its bacterial efficiency?

Mr. WESTON. I would suppose the bacterial purity would have the most to do with it.

Dr. WOODWARD. It was the repulsiveness of it that Norfolk people complained of?

Mr. WESTON. So far as I know, that was the main point.

Dr. WOODWARD. Would not the main point of complaint be the main point to be remedied?

Mr. WESTON. The water board was desirous, as I understand, to put in a filter plant that would thoroughly purify the water. They wanted to say that they furnished the best water in the United States at Norfolk. They informed me that a great many people who came there found fault with the water, and they wanted to be able to say that they had the best.

Dr. WOODWARD. As an advertising scheme?

Mr. WESTON. No, sir; I think they were thoroughly sincere.

Dr. WOODWARD. Have you ever designed and had constructed a plant that was not satisfactory, or that has since been abandoned?

Mr. WESTON. No, sir; not in one sense. I do not remember the year. May I ask Mr. Hering if he remembers the year he went over to Wilkesbarre?

Mr. HERING. It was about seven years ago.

Mr. WESTON. Well, about that time I acted as consulting engineer for the Wilkesbarre Water Company, and designed a 10,000,000-gallon plant for that town. It gave very satisfactory results. A number of water companies doing business thereabouts consolidated soon after the Wilkesbarre plant went into operation, and later I understood that the Wilkesbarre plant had been abandoned, and that they took the water elsewhere.

Dr. WOODWARD. Do you remember the reason for abandoning that water plant?

Mr. WESTON. Simply because they went elsewhere and wished to furnish a very much larger supply from another source. The source from which they took water for Wilkesbarre at the time was limited. Another reason was that the water contained a great deal of algæ.

Dr. **Woodward.** Would a mechanical filter remove that?

Mr. **Weston.** Yes.

Dr. **Woodward.** If there was a great deal of algæ in the water which the filter removed, what was the idea of abandoning the plant?

Mr. **Weston.** They felt, as I understand it, that they could go to another source and get a very much larger supply to furnish all the towns in which the consolidated company was furnishing water, so that it was not best to continue to filter a part of the water at Wilkesbarre and go elsewhere for the remainder.

Dr. **Woodward.** You stated that you had prepared the estimates for the proposed mechanical filter at Washington?

Mr. **Weston.** I prepared the original estimates. I think Colonel Miller may have modified them.

Colonel **Miller.** There is very little modification of your original estimate.

Dr. **Woodward.** I notice in the original estimate, as quoted on page 73 of the report, there is this item: "Sixty filters and auxiliaries, $540,000." In the estimate submitted by Colonel Miller we have the item in this shape: "Sixty-four filters and auxiliaries, $540,000." Was that reduction based on any reconsideration of the subject by you?

Mr. **Weston.** Not by me. As I remember, I designed the original building to contain 64 filters, but my estimates were based on 60.

Dr. **Woodward.** The addition of 4 filters would necessitate, then, some increase in the estimate of the original cost?

Mr. **Weston.** In the future, certainly.

Dr. **Woodward.** You could not install 64 filters at the present time at the price estimated for 60?

Mr. **Weston.** I am not so sure about that. I think you could. I based it on 60 filters.

Dr. **Woodward.** But Colonel Miller gives an increase of 4.

Colonel **Miller.** Yes; I beat them down that much.

Dr. **Woodward.** I notice in this estimate of the filters and auxiliaries that there is no item which corresponds with the following item in sand filters: "Engineering and contingencies, 10 per cent." Did you, in making an estimate of the cost of these 60 filters, or 64 filters, and auxiliaries, take all the burden of the engineering and contingencies, or would it be necessary to add 10 per cent for that?

Mr. **Weston.** My estimates, so far as the filters and the building are concerned, included the 10 per cent.

Dr. **Woodward.** You spoke of these filters as having each a capacity of 1,000,000 gallons per acre per diem.

Mr. **Weston.** Yes, sir.

Dr. **Woodward.** Is that the net capacity?

Mr. **Weston.** No, sir; I based it on that.

Dr. WOODWARD. Each filter having a capacity of 1,000,000 gallons per diem—not per acre but per unit. Is that the net capacity of each one of those units?

Mr. WESTON. I simply based the filters on that, on the rate per unit. The capacity of each filter could be increased say up to 1,300,000 gallons.

Dr. WOODWARD. We desire to know the net amount that each of these units would give. What is the net amount in your estimate? Here is the wording as it appears in this report (p. 72):

> Plans and estimates of the cost of a 60,000,000 gallon mechanical filter plant have been furnished by the New York Filter Manufacturing Company, of New York City. The filters proposed consist of 60 units, having a capacity of 1,000,000 gallons per day each.

Does that mean net capacity?

Mr. WESTON. No, sir. When I design a filter plant in a case of that kind I base it upon a certain flow. I considered that those filters could furnish the water at the maximum rate of 128,000,000 gallons per acre. Perhaps six or eight could be thrown out of service; and in addition there would be a certain amount of wash water, so that each one of those filters would be available at the rate of 125,000,000 gallons per acre per twenty-four hours. I do not know just exactly what that would amount to, but I should say perhaps 1,250,000 gallons for each filter.

Dr. WOODWARD. Then the fact remains that the average net amount, delivered by each filter would be 1,000,000 gallons, and you would have to install no additional filters for the supply of wash water, or allow for repairs?

Mr. WESTON. No; you would not. Those 60 filters would furnish easily, with a number of filters out of service, 60,000,000 gallons every twenty-four hours.

BACTERIAL EFFICIENCY.

Dr. WOODWARD. What has been your experience or observation with reference to the death rate from water-borne diseases as an index to the efficiency of any system of filtration? Take a city water supply which is filtered by a slow sand filter, and another city water supply which is filtered by a mechanical filter. Consider first the average number of deaths from typhoid fever before the installation of these filters, and next the number of deaths per annum from typhoid fever after the installation of these filters. Do you regard that as giving any information of value?

Mr. WESTON. I believe that filters of any kind will reduce the typhoid fever death rate. Do you want me to go into that at length? I will say that I have the report of the District Medical Society, that has been handed to me, and I feel that the subject has been handled very unjustly. I have a few notes in my pocket which perhaps bear upon the matter, and if you desire I will read them.

Dr. WOODWARD. I should be glad to hear them, and I am sure we all shall be.

MEDICAL SOCIETY REPORT.

Mr. WESTON. It seems decidedly unfair to make use of the majority of the figures mentioned in the medical society report for the purpose of endeavoring to show that slow sand filters are much more effective in reducing the typhoid-fever death rate than are mechanical filters in the places where they are respectively located.

It is shown in the report that the typhoid fever death rate is excessive in some of the cities where mechanical filters are in service, but this is also the case in some localities where there is no question as to the purity of the water supply.

The comparisons in the report have been made with statistics of 4 of the 20 cities and towns where slow sand-filter plants are located in the United States, having an estimated capacity of about 54,000,000 gallons daily, and with statistics of 8 of the 154 cities or towns where mechanical filter plants are located in the United States, having an estimated capacity of 237,000,000 gallons daily.

It does not appear to have been taken into account that unfavorable sanitary conditions relating to drainage, cesspools, plumbing, etc., may have been the cause of the high death rate due to typhoid fever in some of the places where mechanical filters are in operation, and also that it may have been largely due in some instances to the drinking of other water than that which had been filtered by mechanical filters.

With a lack of precaution and without due discrimination and a thorough knowledge of the whys and wherefores of health statistics, they may sometimes unintentionally be made to appear to prove conditions which are directly contrary to the facts of the case.

An example of an unfair presentation of figures may be seen upon page 3 of the report, in a table showing the death rate due to typhoid fever for the year 1895 in American cities where mechanical filters are used. Among these figures are given 58 as the death rate per 100,000 due to typhoid fever at Quincy, Ill.

In a report dated March 26, 1900, Mr. George Degitz, health officer of Quincy, Ill., gives figures which show that the death rate from typhoid fever for this year, 1895, was 52.2 per 100,000. He also gives figures which show that 45.5 per 100,000 of these deaths occurred where cistern water was used, and that only 6.8 per 100,000 took place where filtered water was used. In other words, only 13 per cent of the total deaths due to typhoid fever occurred where filtered water was used.

The report of Mr. Degitz further shows that at Quincy, during five years, from 1895 to 1899, the total average death rate from typhoid fever was 11.8, but that an average of 9.8 of these 11.8 deaths occurred where cistern water was used, and that only an average of two of the deaths occurred where filtered water was used, or, in other words, 83 per cent of the typhoid-fever deaths occurred where cistern water was used, and only 17 per cent where filtered water was used.

The same report also shows that the total number of deaths due to typhoid fever at Quincy has quite uniformly decreased since 1895, the total number in 1895 being 23 to 6 in 1899.

Careful experiments have demonstrated, with as high a rate of filtration as 2 gallons per square foot of filter bed per minute (128,000,000 gallons per acre per twenty-four hours), that mechanical filters can remove without the aid of an applied chemical 60 per cent of the bacteria.

It has also been demonstrated that mechanical filters are thoroughly efficient in removing typhoid fever germs. This has been shown by the use of *Bacillus prodigiosus.* During the Providence filtration experiments in 1893, it was found that 99.8 per cent of this bacillus could be removed by a mechanical filter. This high percentage of removal has since been corroborated during the filtration experiments at Louisville, Ky. It was determined by a series of investigations at the experiment station at Lawrence, Mass., that the life histories of *Bacillus prodigiosus* and *Bacillus typhi abdominalis* in the Merrimac River at Lawrence are quite similar.

A very strong point in regard to mechanical filtration as a disease preventative is that the filter beds of a mechanical filter plant can be quickly and easily sterilized by the boiling of the filter beds by the aid of steam, which is conveyed to the filters by pipes arranged for the purpose. Consequently if there should be a suspicion of a typhoid-fever germ or germs having gotten into a mechanical filter bed, it could be sterilized in a very short time.

DECEPTIVE FIGURES.

If it were desirous to bring forward an argument that slow sand filters have very little influence in regard to the reduction of the death rate due to typhoid fever and to show that this was brought about by natural causes rather than by filtration, figures can be produced to this end.

For instance, the report of the State Board of Health of Massachusetts for the year 1899 gives the number of deaths per 10,000 of population due to typhoid fever, summed up for periods of about five years, from 1871 to 1899, inclusive. Figures giving the death rate due to typhoid fever at Lawrence, Mass., show that from 1871 to 1890, twenty years, the death rate per 10,000 of population was 9.3, and that for four years, from 1896 to 1899, after the slow sand filter at Lawrence was in operation, the death rate due to typhoid fever was 2.5 per 10,000, showing a reduction of 73 per cent.

It is also shown in the same report that the average death rate due to typhoid fever in four large Massachusetts cities which do not have filters, during the twenty years mentioned above, was 8.1 per 10,000 of population, and that the death rate in these same cities during the four years from 1896 to 1899 (when the Lawrence slow sand filter was in operation) was 2.1 per 10,000. By these figures it can be seen that there was a reduction of 71 per cent in the typhoid-fever death rate without the aid of filtration (only 2 per cent less than at Lawrence), and they also show that the number of deaths per 10,000 during the four years was about 12 per cent less than at Lawrence, where filtered water was used.

The following table gives these figures in more detail:

Place.	Deaths, per 10,000 population, before the Lawrence slow sand filter went into operation, from 1871 to 1890 (20 years).	Deaths, per 10,000 population, after the Lawrence slow sand filter was in operation, from 1896 to 1899 (4 years).	Per cent of reduction.
Lawrence, Mass	9.3	2.5	73
Fall River, Mass	7.3	2.6	64
Springfield, Mass	7.8	2.6	67
Holyoke, Mass	12.7	1.9	85
Worcester, Mass	4.7	1.5	68

As the Lawrence filter first went into operation in 1893, during the period between 1891 and 1895, the figures of this period have not been used, as the data was not in sufficient detail to allow the death rates of the years in which the filter was in operation to be separated from those when it was not.

It is also shown, in the report of the State board of health of Massachusetts referred to, by the typhoid-fever death rate of the entire State that there was a reduction of about 51 per cent in the typhoid-fever death rate of the State (in the cities and towns where there are not any filter plants) during the four years from 1896 to 1899 from what it was during the twenty years from 1871 to 1890.

Of course, I am in no wise a believer of what these figures would seem to show in regard to the little influence that filtration has in connection with the reduction of the typhoid-fever death rate, as my opinion is directly to the contrary, and I have simply called attention to them as an illustration of how figures could be used in a prejudicial manner if they should be handled without due discrimination as to the merits of both sides of the question.

At any rate the figures show conclusively that other sanitary conditions besides the filtration of water may have much to do with the typhoid-fever death rate.

STATISTICS FROM CITIES USING MECHANICAL FILTERS.

Dr. WOODWARD. You have referred to the fact that the statistics from only a few of the cities using mechanical filters have been used. Can you furnish any statistics with reference to those cities not included in this report?

Mr. WESTON. I can not.

Dr. WOODWARD. Can you tell me any means by which those statistics can be procured? The medical society endeavored to get such statistics by corresponding with the mayors of certain cities, but for some reason the statistics have not been forthcoming.

Mr. WESTON. Certainly if the medical society has failed to get them, I should not offer any advice upon the subject.

Dr. WOODWARD. Do you think that furnishes any reasonable ground for not including them in the report if they have not been able to get them?

Mr. WESTON. My opinion is, as expressed, that it is decidedly unfair to take statistics and handle them in the way they have been handled to prove certain points.

Dr. WOODWARD. I think you will have to admit that if we could not get any statistics we could not furnish them. With reference to the matter of the diminution of the number of deaths from typhoid fever having been effected through other sanitary means, is there any reason to believe that other sanitary means have been less effective in the cities in which mechanical filters were installed than they were in the cities where the sand filters are used?

Mr. WESTON. My knowledge on that subject is rather indefinite. I have traveled about this country a great deal—in the South and West, where the mechanical filters are largely located, and I should say that the general sanitary conditions were much more unhealthy there than where the sand filters are located.

Dr. WOODWARD. What would be the ground for this decrease in the prevalence of typhoid fever after the installation of the mechanical filters as compared with the greater decrease after the installation of the slow sand filters?

Mr. WESTON. Have I stated that there was any difference in the improvement? I assume certainly that either system of filters would reduce the typhoid fever death rate.

Dr. WOODWARD. Is it not fair to presume that any diminution in the number of deaths from the prevalence of typhoid fever, which would be affected by sanitary improvements other than the improvement of the water supply, would be equal in the two series of cities from the statistics which have been given?

Mr. WESTON. If you will allow me, I express a disbelief in what the figures tend to show. My impression is that in these Massachusetts cities they have improved their water supply and improved their sewage systems.

Dr. Woodward. I am not referring to your figures, but I am referring to figures here showing the improvement in these two series of cities. Is there any reason to believe that after the installation of the slow sand filter at Ashland, Wis., there was any greater improvement in the sewage system than there was, we will say, at Atlanta, Ga.? You undertook to explain the improvements in the typhoid-fever death rates in the cities having slow sand filters by improvements other than the installation of the filter.

Mr. Weston. No; I have not endeavored to prove that. If you take figures in a general way from statistics and attempt to prove certain things with them, I say that, roughly speaking, you can prove most anything.

Dr. Woodward. Yes, you can; but, on the other hand, if you try to get figures that are as accurate as the figures with which mechanical engineers deal you will find difficulty?

Mr. Weston. I understand that at Lexington, Ky., there is no sewage system. I should suppose from what I know of the locality of Atlanta that, in general terms, it is more unhealthy than at Lawrence, Mass.

Dr. Woodward. You are not prepared to furnish any more accurate figures on that point?

Mr. Weston. No, sir; except in the case of Quincy, Ill.; those are all the figures I have on the subject.

Dr. Woodward. I do not see that Quincy, Ill., plays any part in these figures, at least not in the comparison of reduction of typhoid fever death rate. It is compared with foreign cities. That is a different table. Are you familiar with the results obtained by Mr. Fuller in the examination of specimens of water from his experimental figures in Cincinnati on the reduction of the number and colonies of colon bacilli?

Mr. Weston. I have read Mr. Fuller's report through carefully.

Dr. Woodward. It shows that out of 89 samples from the effluent of the experimental slow sand filters 34 contained colon bacilli; whereas out of the examination of 15 samples of the effluent from mechanical filters 7 contained colon bacilli. Is there any reason to believe that that was due to the difference in the efficiency of the two systems in the removal of such bacilli from the water?

Mr. Weston. As I understood Mr. Fuller to say this morning—if I may answer it in that way—there was no particular difference between the two, as he thought.

Dr. Woodward. I do not understand that he denied the figures.

Mr. Fuller. I do not think the figures refer—if I may interrupt—to the same character of water. The mechanical filter was not examined for the same period as the English filter was. I am very sure that under equal conditions they would equal any English filter.

Mr. WESTON. If I understand you, you have a mechanical filter and take out, say, 99 per cent of bacillus, and from the slow sand filters you take out 99½—is that your question?

Dr. WOODWARD. No. Would you expect, in operating upon the same sample of water, to have the mechanical filter and the slow sand filter remove equal percentages of the colon bacillus?

Mr. WESTON. Well, generally speaking, I would suppose that the results would be about the same. I really know very little about that, because the matter has not been investigated to any very great extent, as I understand it, except during the recent experiments that have been made by Mr. Fuller.

Dr. WOODWARD. What has been your observation as to the relative bacterial efficiency of these two systems in the various experimental plants that have been operated throughout the country—those at Lawrence, Mass., and at Cincinnati, Ohio, and at Pittsburg, Pa.?

Mr. WESTON. I am of the opinion that there is very little choice in the bacterial reduction or efficiency, so far as the removal of bacteria is concerned, between the two systems, if they are both managed well and carefully.

THE MORRISON FILTER.

Dr. WOODWARD. You prepared figures, I think, some years ago on the Morrison filter, did you not?

Mr. WESTON. Yes, sir.

Dr. WOODWARD. In the selection of figures on which the high bacterial efficiency was based, did you not reject a number of days in which the filter was in actual operation?

Mr. WESTON. I rejected quite a number.

Dr. WOODWARD. And in that way brought up the bacterial efficiency?

Mr. WESTON. Not by any means. If I had taken the total figures it would have been more than 98.6 per cent. I am glad to be able to make this explanation, because I have heard criticisms made in regard to the figures. The reason I rejected some of the figures was that I felt the bacterial growths had not been extended long enough and that 15 instead of 10 per cent gelatin had been used. Therefore I felt that I could not use the first figures, which brought it up to more than 98.6 per cent, and I consequently selected the figures that I did.

Dr. WOODWARD. You are quite sure that the examination of figures in every run would have increased the bacterial efficiency?

Mr. WESTON. Yes. For instance, the experiments began in April. I said in my report at the time that from April to October the percentage was about 99.

BACTERIAL EFFICIENCY OF WASHINGTON FILTERS.

Dr. WOODWARD. How do you account for the superior bacterial efficiency of the slow sand filter at Washington over the experimental mechanical filter?

Mr. WESTON. I was under the impression that it was the other way. I have not gone into those figures, but on the train yesterday I made a note in this report. I noticed that there was some criticism in regard to it. I beg your pardon if I am wrong.

Dr. WOODWARD. I think the difference may result from the difference in the method of quoting the efficiency.

Mr. WESTON. I refer to pages 100 and 111 of Colonel Miller's report:

> The average bacterial efficiency of the English filter during these tests was 91.3 and the bacterial efficiency of the system of reservoirs and the filter during the fifty days previous to this report was 98.4.

And as to the American filter it says:

> The average bacterial efficiency of the American filter was 93.7 and the bacterial efficiency of the system of reservoirs and the filter during the last fifty days of these investigations was 99.

Dr. WOODWARD. You say that "the average bacterial efficiency of the American filter was 93.7 and the bacterial efficiency of the system of reservoirs and the filter during the last fifty days of these investigations" was so and so, selecting a period for the comparison which is favorable to the alum filters.

Mr. WESTON. There seems to be a misunderstanding in regard to testing the mechanical filter. It runs from, say, twelve to twenty-four hours, and it is then washed. You can take a mechanical filter one day and put half a grain of alum in it, and the next day add 2 grains and get a high bacterial efficiency. You are simply testing it to get the correct quantity of alum and to get the working result of the filter.

Dr. WOODWARD. Then by selecting the most favorable days for either filter you might do injustice to the other?

Mr. WESTON. You might in this way: You have a slow sand filter, and start it up, and it perhaps runs six weeks. The test of that filter covers the six weeks' operation, whereas with a mechanical filter you might have it run but twenty-four hours, that being an individual test.

Dr. WOODWARD. Do you believe it would be fair to take the average for the entire series of each, allowing the errors to correct themselves as far as possible?

Mr. WESTON. Which, for instance? The sand filter?

Dr. WOODWARD. The sand filter during the entire period of the test, and the mechanical filter for the same period.

Mr. **Weston.** How could you do that—take a six weeks' test and correct an error?

Dr. **Woodward.** The errors, of course, can not be absolutely corrected in either case. It is only a question of disregarding the possible error, allowing the laws of chance to govern it.

Mr. **Moore.** Is it not true that chance does govern in a slow sand filter, whereas chance does not govern in the manufactured product?

Dr. **Woodward.** No; I think you will have to class them both as manufactured products, in one sense of the word. There is a larger element of chance, it seems to me, in the mechanical filter, in determining the amount of alum, than there is in the other. I think the filter company with which you are connected as consulting engineer, Mr. Weston, undertakes in their guaranty of the results to be accomplished by their filters, to furnish an effluent containing an average percentage of not over 100 colonies per cubic centimeter. Am I correct?

Mr. **Weston.** Yes, sir; sometimes they have done that.

Dr. **Woodward.** Do you regard the absolute number of bacteria in the water as a test of its purity?

Mr. **Weston.** No sir; not by any means.

Dr. **Woodward.** Then the fact that the mechanical filter is claimed to have removed a greater percentage of bacteria during the period of greatest turbidity—which is not admitted and not believed to have been proved by these figures—would not show necessarily that it was superior to the slow sand filter, which reduces the percentage during the periods of clear water?

Mr. **Weston.** I do not know that I can answer that question. I can put it in this way: If you should take two filters and test them on a certain day with the same water, and you should find in one filter that the percentage was higher than in the other, I should say that the filter that showed the highest percentage of reduction did the best work.

Dr. **Woodward.** I think that you do not catch the point. It is claimed that during this period in December and January the water was very turbid, that during a certain number of days in that period the effluent from the slow sand filter contained more than 100 colonies of bacteria per cubic centimeter, and that, therefore, during that time the effluent was very unsatisfactory, although the percentage of bacteria remaining in the effluent was small.

Colonel **Miller.** The percentage of efficiency is always lowest when the amount of bacteria in the influent is smallest. For instance, if there are six bacteria in the influent and two in the effluent, you would get a small percentage, but you would have a very good water.

Dr. **Woodward.** Is it not more important to remove the bacteria during the periods when there are comparatively small numbers of bacteria than during the periods when there are enormous numbers—as, for instance, during those periods of great turbidity?

Colonel Miller. I should not say so.

Dr. Woodward. What is your opinion, Mr. Weston?

Mr. Weston. I should say that that would depend upon the character of the bacteria.

Dr. Woodward. Are you familiar with Mr. Theodore Smith's statement as to the bacterial counts of the unfiltered Potomac water?

Mr. Weston. I am not.

Dr. Woodward. I think it is shown by him that the bacterial counts were larger during the months the death rate from typhoid fever was comparatively small than when it was most prevalent. So that if that be a fair criterion it would be more important to get out those germs during the periods of clear water than at other times, would it not? Take the figures for the particular months during the time covered by this observation. In July, 1899, our unfiltered Potomac water contained 66 bacteria per cubic centimeter. During the following month we had 38 deaths from typhoid fever. In January, 1900, the number of bacteria per cubic centimeter in the unfiltered water was 15,873. During the following months we had but six deaths from typhoid fever, showing, it seems to me, the greater importance of high bacterial efficiency during the periods of low bacterial count than at other times.

Mr. Weston. Do I understand that you ask me if I consider that during the seasons or days when the number of disease germs—typhoid-fever germs—in the river are the greatest?

Dr. Woodward. As long as there have been no typhoid-fever germs found in our river, or any other, we can not bring that in.

Mr. Weston. I do not understand your question. You read me some statistics to show that at certain times typhoid fever was more prevalent——

Dr. Woodward. Yes.

Mr. Weston. And they are compared with certain conditions of the water?

Dr. Woodward. Yes.

Mr. Weston. Now what do you wish to ascertain from me?

Dr. Woodward. It is undertaken to show that considering the absolute number of bacteria in the effluent and not the relative number, the mechanical filter is superior to the sand filter. It appears, however, that during this period, that is, during December and January, when these relatively large numbers of bacteria appeared in the effluent, despite the fact that there was a large number in the influent the death rate from typhoid fever was comparatively low, indicating that while the number of germs was large the number of pathogenic organisms was small.

Mr. Weston. Yes.

Dr. **Woodward**. Do you think it is as necessary to filter out all these nonpathogenic organisms as it is to filter out all the others?

Mr. **Weston**. Certainly not, if they are harmless.

Dr. **Woodward**. Then your guaranty of 100 per cubic centimeter, based on bacteria, is not of much importance?

Mr. **Weston**. I think it is.

Dr. **Woodward**. Do you not think it is more important to take into consideration the character of the bacteria?

Mr. **Weston**. Certainly; but you can not do it. There is no designer of a slow sand filter in existence who has guaranteed that his filter will furnish a certain character of effluent water.

Dr. **Woodward**. It is the guaranty offered by the company.

Mr. **Weston**. I know they make certain guaranties. It all originated from the old German rules, which, as I understand, have been modified.

THE WASHINGTON PROBLEM.

Mr. **Moore**. Will you please state what, in your opinion, are the advantages to the city of Washington of the mechanical filter over the slow sand filter?

Mr. **Weston**. Must I base my opinion upon what I read in Colonel Miller's report?

Mr. **Moore**. Certainly. What we want to arrive at is your opinion upon the situation at Washington.

Mr. **Weston**. I should say, in the first place, that the mechanical-filter system would furnish a very much brighter and clearer water, and one that would certainly equal, from a bacteriological standpoint, the slow sand filter.

Mr. **Moore**. Then, as to the cost of the two systems—what would you say about that?

Mr. **Weston**. All I can say is from what I have seen in Colonel Miller's report. He estimates the mechanical at about one-half of the cost of the other.

Mr. **Moore**. That is very largely a matter of the first installation. The use of alum involves a very considerable expense, so that in the long run, perhaps, the mechanical system would be equally, or, perhaps, of greater cost.

Mr. **Weston**. That would depend somewhat upon the conditions; very largely on the amount of chemicals used. I suppose that has been figured out, together with the deterioration, etc. As to that, I can not speak.

Mr. **Moore**. You do not wish to criticise these figures as to the cost of the mechanical filter in Washington, as figured out in Colonel Miller's report?

Mr. **Weston**. The cost of operation; no, sir.

Mr. MOORE. Have you any means of knowing about the cost of alum through a series of years, or the probabilities of the cost of alum for the future?

Mr. WESTON. In 1893 and 1894 I think I used alum at 2 cents per pound. Some figures which I received the other day gave it at about 1.1 cents.

Mr. MOORE. Is the tendency of alum upward or downward in price?

Mr. WESTON. I have not followed that closely, but it seems to me that during the last few years it has been downward. During the Philadelphia investigations I made some estimates and found that it was about 1.2 cents per pound. It is lower at the present time, so that it would seem that it has fallen during the last few years.

Mr. MOORE. I presume we could get that definitely in the report of the Senate Committee on Finance on Wholesale Prices. Do you know why Pittsburg, after experimenting, did not put in the mechanical filter?

Mr. WESTON. Mr. Hazen considered that matter, and his recommendations were adopted.

THE PITTSBURG SLOW SAND FILTER.

Mr. HAZEN. The matter, as stated in the Pittsburg report, came down to about this: The cost of the two systems was practically the same, but taking into consideration the operating expenses, deterioration, etc., the sand filters were considered much better than the mechanical filters. The mechanical filters gave a somewhat brighter effluent than the sand filters. The sewage or pollution of the river was increasing rapidly, and the turbidity we expected to decrease rather than increase, and we thought it was more important, the cost being about equal, to look after the bacterial end than the turbidity end, and we also thought that with the sand filters we could arrange it so that the turbidity would at all times be unobjectionable.

Mr. MILLER. There is one more question that I desire to ask with reference to the efficiency of the filter that you experimented with at Providence, Mr. Weston. How many bacteria, about, did you find in the influent—was it a large or a small number?

Mr. WESTON. I do not remember the averages. At times, I know, it reached 65,000; but I would say on the average, it might have been 3,000 or 4,000, or possibly 5,000, and at times it dropped down in the neighborhood of 100.

Mr. DENNISON. What was the average number at East Providence in the applied water?

Mr. WESTON. During the three months' test, if I remember correctly, it was less than 1,000. The tests that have been made by the State board of health showed less than 600.

Mr. DENNISON. I mean in the applied water.

Mr. WESTON. Well, they went all the way from 150, perhaps, up to 2,000 or 3,000. The test is published.

STATEMENT OF JOHN W. HILL.

Mr. MOORE. Will you please give your residence and experience with water filtration?

Mr. HILL. My legal residence is in Cincinnati; my temporary residence is Philadelphia, Pa. I style myself a hydraulic engineer, and my specialty is works for public water supply and works of sewerage. I have built two or three filters. The first was thirteen years ago, at Findlay, Ohio, where the object of the filter was wholly to clarify the water of the Blanchard River. The chemical analysis made at that time indicated no serious objection to the water from a sanitary standpoint, but the water was at times very turbid, and the filter which I designed and built at that place was intended mainly to change the appearance of the water. During 1890 I designed and had constructed a system of filtration for the city of Oshkosh, using mechanical filters of the Warren type, but operated without a coagulant.

I have made plans for a system of filtration for the city of Ironton, Ohio, of the plain sand-filter type. In the report of the commission, of which I was chairman, on the new plans for the water works for the city of Cincinnati I made plans and reported in favor of plain sand filters. I am now engaged by the city of Philadelphia as consulting and principal engineer in designing, among other things, for the improvement of the water supply of that city, a general system of filtration for all the water supplied to Philadelphia. So far as the investigations at Philadelphia and the plans have proceeded they have been along the line of plain sand filtration, and in view of the fact that the city officials have not taken a decided stand with reference to the use of the water meters, the plans have been based upon the probable treatment of 300,000,000 gallons of water per diem, an amount that is probably considered in excess of what the city needs, but an amount which, in my judgment, they will be required to furnish, unless there is a general introduction of water meters with a view to restricting the use of water.

PER CAPITA USE OF WATER.

Mr. MOORE. What would you say was the proper per capita use of water in a city?

Mr. HILL. From such investigations as I have made latterly at Philadelphia, I should consider 120 or 130 gallons per capita per diem as sufficient in a large city, and a smaller quantity as sufficient in a small city. The character of the city has much to do with the per capita consumption. I believe that in the case of the city of Washington, notwithstanding the fact that it is not a manufacturing city, and therefore does not use large quantities of water for the purposes of the arts, still, in view of the immense amount of greensward and the extent of the asphalt pavements, it would require a larger per capita consumption perhaps than some manufacturing cities. But even there I should assume that 150 gallons per capita per diem would be sufficient.

Mr. MOORE. Is it contemplated in Philadelphia to allow all manufactories to use the filtered water; is there to be no discrimination, no requirements that certain manufactories shall take water from the river, for instance?

Mr. HILL. No, sir. For instance, some manufactories, such as the Cramps' shipyards, largely pump their water from the Delaware River, but there is no theory on the part of the city officials that there should be any restriction in the use of the water in any way. There is a further feeling that the people of Philadelphia will be disposed to crucify those who insist upon the general introduction of meters; but eventually, I think, meters will be used.

THE CINCINNATI SYSTEM.

Mr. MOORE. Has a final result been reached as to the system to be used in Cincinnati?

Mr. HILL. I can not answer that question positively. Mr. Fuller stated in his testimony this morning that the commissioners of water works had decided upon the use of the mechanical filters with a coagulant. I judge that that statement is correct from the fact that the commissioners there are instrumental in opposing the extension of the Hyatt patents by an act of Congress. In fact, I have been personally appealed to by the president of the water commissioners of Cincinnati to say something to some of our Representatives with reference to the matter, but I am not certain that the Cincinnati commissioners will carry out their present intentions. I think I reflect the sentiment of the people of Cincinnati when I say that they are opposed to the use of chemicals in the water supply. That position has been taken by a number of public bodies, and I believe that there is a very strong feelthere that if the Ohio River water can not be purified without the use of chemicals of any description, purification is not desired at all.

COVERED FILTERS.

Mr. MOORE. In your plans for Cincinnati, did you consider the question of covered filters there, or was it necessary to consider that question?

Mr. HILL. They were considered, but no estimate was made of the probable cost of covering the filters. Mention is made in the report that experience might demonstrate that the plain sand filters would require covers. I was somewhat in doubt whether covers were or were not needed, and I am still in doubt about that. Of course, the chief objection to the open filter in a climate like Washington is the probability of having the bed of sand freeze on the surface at times when it was laid bare for the purpose of scraping. I have investigated the devices used at Hamburg for the purpose of scraping the sand bed under a cake of ice, and they are not thoroughly efficient. Still, I am not quite certain but what they would meet the conditions during a period of two months in the year.

I think it is not claimed that they do not get as good an effluent after the bed has been scraped under the cake of ice, but that the filter will not wear as long; its period of duration is considerably lessened. For example, in ordinary scraping where the sand bed is laid dry, the period of operation is thirty days or longer, while the period would be fifteen or twenty days when the filter is scraped in this rough manner under the ice by the Mager sand scraper. But I do not understand from the Hamburg officials that they feel that the quality of the filtrate is less pure by that method of operation, and they decidedly lean to the opinion that in their climate covers are not necessary.

POINTS OF SUPERIORITY OF THE SLOW SAND FILTER.

Mr. MOORE. What were the determining factors in your mind that led you in the case of Cincinnati to recommend the slow sand filter and to pursue your investigations in Philadelphia along that direction rather than along the direction of the mechanical filters?

Mr. HILL. As a general proposition and as the first answer to the question, I believed five years ago that the process of purification by means of a plain bed of sand is superior to purification by a bed of sand plus a chemical, and I believe so still. My first personal knowledge of the influence of filtered water on the health of users was gathered from an investigation that I was called on to make at one of the hotels of Cincinnati, fifteen or more years ago. A curious disease, or perhaps not a disease but a curious series of complaints, was noticed among quite a number of the guests of the Gibson House. One of the guests was an old army acquaintance of mine, Captain Post, then stationed at Cincinnati, in charge of the improvement of some of the rivers tributary to the Ohio.

I visited Captain Post during his illness, and learned from his physician that his trouble was very like that of quite a number of the guests of the hotel, and in conjunction with two of our physicians we sought for a cause. We believed it to be due to the excessive use of alum that was used there in the filter for the purification of the hotel water. It was altogether a bowel trouble, and quite a number manifested the same symptoms. Inquiry showed that alum had been used in the filter without regard to quantity, but solely with a view to furnishing a limpid and sparkling water at all times. The proprietors of the hotel were conferred with and cautioned as to the manner in which the filter was being operated, and by reducing the quantity of alum and applying it with more care the trouble wholly disappeared. At very nearly the same time the same condition developed at the St. Nicholas Hotel in Cincinnati. The guests who were living there were subject to the same bowel trouble or some condition that was unusual, and it was found on investigation of the matter that perhaps alum was being used in that case without regard to whether the quantity was enough or too much.

That perhaps was the first opportunity I had of giving serious thought to the subject of water filtration, although prior to that time I had read the report of Mr. James P. Kirkwood on Filtration, to the city of St. Louis. Since then I have carefully and diligently discussed the matter of mechanical filtration with a gentleman who at one time was manager of one of the large filter companies of the country, and have generally taken the position that I would prefer to see water purified without the use of alum or any other chemical. It is my belief that if there is any way at reasonable cost to purify a polluted water supply by methods which by no chance could make the last condition of that water worse than the first it ought to be adopted. I can not conceive of any type of plain sand filter, no matter how coarse the sand, provided there is a reasonable thickness of bed and a reasonable rate of operation, that will not improve the water somewhat. I can conceive of a condition whereby with the addition of chemicals we can impair the quality of the water. I mean that if the coagulant is injudiciously applied, especially in excessive quantities, undecomposed sulphate of alumina may appear in the filtrate, and I believe such water is not fit for drinking purposes and is calculated to impair the health of at least some individuals by the action of the astringent found in the water on the absorbent vessels of the stomach and the alimentary canal.

Mr. Moore. In your examination of the water at Cincinnati you did not find that it was necessary to use a coagulant in order to get satisfactory results?

Mr. Hill. No experiment on a large scale, such as Mr. Fuller has subsequently conducted, had been made at the time of preparing the plans and submitting a report on the new waterworks at Cincinnati, and I was governed in the recommendation of the plain sand filters very much by my own experiments with sand filters, made in my laboratory, and on the theory that three or four days' subsidence would fit the water to go on a plain sand filter. I realized that we might not be able at all times to furnish an entirely limpid water, but I did not then and I do not now regard a reasonable amount of turbidity as an indication of lack of hygienic quality in a water supply.

Mr. MOORE. Do you recognize a hard and fast line between, say, the New England waters and the waters of the Ohio and Mississippi rivers, so that you would lay down the proposition that the latter should be treated with a coagulant and the former should be filtered by the slow sand system?

A COAGULANT NOT ABSOLUTELY NECESSARY FOR ANY WATER.

Mr. HILL. I recognize a very considerable difference between the waters of the New England cities, the waters of eastern Pennsylvania, and the waters of the Middle West, like the Ohio, Missouri, and Mississippi rivers. I conceive that it is very much easier to purify the waters of the Merrimac River than the waters of the Mississippi River, but I have not reached that point when I am ready to concede that the use of a coagulant is absolutely necessary in any case. I am not quite certain that the natural condition of the water of the Delaware and the Schuylkill rivers is substantially better than that of the Potomac for example; but I do know that it is much better than that of the Ohio River, and if certain experiments that we are conducting at Philadelphia now shall be successful, these experiments may have application to those more turbid waters that we find in the Middle West, and possibly the results may indicate that we will be able to deal with those turbid waters without the use of a chemical.

Mr. MOORE. Can you indicate along what lines your experiments with turbid waters have been conducted?

Mr. HILL. In one set of experiments that we are conducting at Philadelphia we are passing the water through a coarse filter—a rough or preliminary filter, as it may be termed, the intention being to remove as large a percentage as possible of the heavier matter from the water before it passes to the filter proper; and judging by the experience of the past four months this method is calculated to make the filtration of water, in regard to suspended matter, a certain and reasonable problem. Such a filter represents a loss of head that may eventually reach 3 feet. I can not give you any estimate as to the cost of working with that system, because it is too new.

Mr. MOORE. In case the suspended matter is very fine, would the rough filter still do its work?

Mr. HILL. There is a question in my mind whether our preliminary filter is not doing better than it ought to do; whether it leaves the water in a condition to rapidly form what is known as the "Schmutzdecke," or the film of deposited matter on the sand bed, on which the bacterial efficiency of the plain sand filter so largely depends. Our reports indicate that at times this rough filter is furnishing a water entirely free from suspended matter. Now, if that is correct, I think the filter is doing more than it ought to. In other words, we may have built it too well; there should be left in the water enough suspended matter to establish a dirty cover on the surface of the sand filter.

Mr. MOORE. Is not such a film established in the preliminary filter?

Mr. HILL. No, sir; there is no film, strictly speaking, in this rough filter. It is simply an investment of the broken stone, over which the water flows, with a semigelatinous film of mud and other suspended matter in the water, the stones varying in size from 1½ to ¼ inch in dimensions. We merely want to take out what Mr. Hazen termed at one time the "saw logs"—the coarser matter. We only aim to free turbid water from a portion of the suspended matter and make it ready for plain sand filters. We do not expect that the final water will be benefited by this preliminary treatment, but we do expect to prolong the life of a sand filter; and also the gross cost of operation will be less than the cost of a plain sand filter with a settling basin and three or four days' sedimentation of the raw water.

Mr. MOORE. Have you ever considered the proposition of a coagulant in a receiving reservoir before it gets into the mechanical filter?

Mr. HILL. I have given thought to it, but I have had no experience with reference to the efficiency or cost of such an operation.

Colonel MILLER. In the report of the District medical society they quote you as an authority on a great many points. I judge from the tables presented that they have taken their figures on typhoid fever from your very valuable writings, but I think they must have had an old edition. Have you seen their report?

Mr. HILL. The report of the committee of the Medical Society of the District of Columbia; yes, sir.

KNOXVILLE, LEXINGTON, AND ELMIRA FILTERS.

Colonel MILLER. On page 3, Knoxville is given with a rate of 59 per 100,000. That is taken probably from your tables. It is 59 here for 1894—I suppose 1895 is missing—but we have 1896 given also in your table. I presume, therefore, that the medical society had an older edition of your work. In 1896 the population is stated at 45,000. It is divided into two parts, 37,000 living in the city—the urban or city population proper—and 8,000 residing in the suburbs. The typhoid fever death rate for those who belonged in the city proper and who used the filtered water—I presume it is not supplied to the suburbs—is only 32, while that of the 8,000 in the suburbs, whom it is presumed use well water, and very bad well water probably, is 125. So there is a comparison right in the very table here between the use of the mechanical filter and the nonuse of filtered water. In that view of the case I think the question of the 59 there ought to have been rectified.

Mr. HILL. I have never compared those figures, but I do remember, now that you recall it, that there was a division made between the population drawing the water from the water company's supply and those who drew it from other sources, just as it is here given.

Colonel MILLER. You see that the rates there are 32 for the city population and 125 for the other; but that 59 is in all probability taken from that 1894 column. It is given in your column for 1894. So that right in that very table there is shown an exactly opposite effect from what the medical society show in the report.

Mr. HILL. Of course I do not know how the society made its tables.

Colonel MILLER. It agrees exactly with your table, you see—that 59?

Mr. HILL. It does for 1894.

Colonel MILLER. 1895 is vacant, is it not?

Mr. HILL. Yes; it is blank. I can say with reference to these tables that it has been exceedingly difficult to get returns from the cities using mechanical filters.

Colonel MILLER. I have applied to all those who had over a population of 30,000 or 40,000, but without success—I think 43 places; and from those I received answers from only 19. Of those 19 there are only 12 or 13 in a sufficiently concise or definite form to make any tables from. It is difficult to obtain figures. Of course it may be said that no health officer or mayor is willing to admit that there is much typhoid fever in his city, because it is commercially against the city. I do not know whether you have Lexington in your table?

Mr. HILL. I am not quite certain. I remember having a discussion with the superintendent of waterworks at Lexington, about the filters there, but no reliable statistics were to be had.

Colonel MILLER. The reply I received from Lexington was that no typhoid fever could be traced to the filtered water. All typhoid fever was traced to the use of water from wells or cisterns, but in the table there the enormous percentage of 256 increase is given. It is possible but highly improbable that such might be the case. In 1898 there were large camps around there, and typhoid raged among our troops on account of using polluted water. Is it not 256 increase for Lexington?

Mr. HILL. Yes; 256 per cent.

Colonel MILLER. I am merely making this statement because it comes in connection with this typhoid-fever business. At Elmira, my information from the health officer is that for the last ten years there have been cases—all cases, not deaths alone—averaging 133 per annum. Since the adoption of filters the average has been 89—the number of cases, not deaths—which is a reduction of about 33⅓ per cent. In the report of the medical society they take one year before and one year after, and with a difference of 1 death make an increase of 10 per cent. Now, that is not what I find from the report of the health officer, and even in this very report, if they had gone a column further, they would have found, from your information, that there is a direct comparison between filtered and unfiltered water.

PRESSURE FILTERS.

Mr. HILL. The statistics from Davenport are the most reliable of any city within my knowledge where mechanical filters are used. Mr. Charles H. Francis, who resides there and who feels a deep interest in the sanitary aspect of water supply, has for several years gathered the facts in my tables, or, at least, has verified them before they were sent to me.

Colonel MILLER. The system of filters at Davenport I do not consider particularly as bearing upon the point, because they have not used, and do not use, the method which I have recommended in my report. Davenport uses a pressure filter, which is not the method recommended. The method I recommend is the gravity. Davenport, Atlanta, and Chattanooga all have pressure filters.

Mr. HILL. Knoxville uses the gravity filter.

Colonel MILLER. Yes; and Quincy has the gravity.

Mr. HILL. Chattanooga has the pressure filter, I know. I think, too, that at Davenport there is a very general use of the water from the street mains—the public supply.

Dr. WOODWARD. In view of the fact that Colonel Miller has referred to the presumption that certain people in the suburbs of Knoxville did not use city water, it might be well to have appear in the record the facts on which this presumption is based.

Colonel MILLER. The only presumption is that the filtered water is not furnished to the suburban population, and of course if any filtered water is consumed it is consumed by those who live in the city. The probabilities are that a great many of those do not take filtered water.

Dr. WOODWARD. What I am anxious to know is whether that is a presumption founded upon established facts?

Colonel MILLER. It is a presumption founded upon reasoning from possibilities and probabilities. I have never been to Knoxville and only take the published figures as true.

Dr. WOODWARD. It does not appear that there is any more reason to believe that such a presumption holds good at Knoxville than that it holds good for those cities using the slow sand filters which have been cited.

Mr. MOORE. Is the use of the water in the cities using the mechanical filters so general as to make the statistics of real value scientifically?

Mr. HILL. Well, I think so in the case of some cities. At Chattanooga there is a general use of the public water, and at Davenport. I am informed by the superintendent of the waterworks at Quincy that they do not supply the city as a whole, and he has at various times indicated to me about what percentage of the total population draw water from the mains of the water company. The statement has been made by Mr. Wheeler, who owns the waterworks at Knoxville, that a division should be made as between the entire population of the city and those who are drawing from the company's mains. Now, with reference to Atlanta, I have felt that perhaps, with the exception of the colored population, the bulk of the people draw water from the public mains, although I know there are wells in use in that city.

Colonel Miller. Atlanta is one of those cities that of course it is well to speak of as using the mechanical method, but it is the pressure method, which is not the method that I advocate in my report. As I said before, Atlanta, Chattanooga, and Davenport use the pressure system, which is not the method recommended in my report.

Dr. Woodward. Have you any idea as to the relative bacterial efficiency, Mr. Hill, of these two systems, the slow sand system and the mechanical system, when operated experimentally in various places in which such experiments have been adopted?

Mr. Hill. I have only the opinion that is obtained by such reports as that of Mr. Weston at Providence some years ago, the report from Lorain, the report from Elmira, and the report made by Mr. Fuller in his investigations of the Ohio River water.

BACTERIAL EFFICIENCIES.

Dr. Woodward. What are the relative bacterial efficiencies as demonstrated by those experiments?

Mr. Hill. I think during those tests that have been mentioned, care has been taken in the application of the coagulant, and there has not been shown a very great difference in the bacterial efficiency of the two systems of filtration. I rather think the difference is in favor of the slow sand filter.

Dr. Woodward. Would you be willing to state the probable difference in favor of the slow sand filter?

Mr. Hill. I think that a bacterial efficiency of 97 or 98 per cent can be obtained with the mechanical filter and a coagulant, with considerable care in the application of the chemical and in the operation of the filter. I think 97 or 98 per cent can be had from a plain sand filter where it has been in service for a reasonable number of months and the sand bed has ripened, and those preliminary conditions have been overcome, which we know to be necessary in the plain sand filter. I think that this efficiency may be obtained with a plain sand filter without the same care necessary to the successful operation of the mechanical filter. I believe it is possible to have almost any bacterial efficiency desired with either type of filter, but the question is whether we can afford to pay the cost of obtaining it.

Dr. Woodward. What is the general bacterial efficiency of the slow sand filter in places abroad where it has been operated?

Mr. Hill. Ninety-eight, 98½, and 99, and almost 100 per cent in some cases. The latest reports that I have from the filters there—from the East London Water Works, which I receive from time to time—

will show as few as four or six or eight bacteria per cubic centimeter in the filtrate on a four days' incubation of the plates.

Dr. Woodward. In other words, do I express it correctly when I say that with the mechanical filters operated experimentally and with care they have, as a rule, a bacterial efficiency, we will say, of 98 per cent, and the slow sand filters, as used in practice, have a bacterial efficiency of 98½ and 99 per cent?

Mr. Hill. I would assume, if you gave the two types of filter the same care and the same degree of intelligence in operating them, there would be always a reasonable degree of efficiency in either, and the difference would be in favor of the plain sand filter.

Dr. Woodward. The actual bacterial efficiency of a sand filter would have to be corrected by allowing for the growths of organisms in the underdrains.

Mr. Hill. I do not know that that is always to be anticipated. I have some experience that indicates that the bacteria growing in the underdrains have had the effect of largely increasing the count. Investigation will very frequently reveal that they are organisms of a different species from those found in the raw water. I think that condition with any sand filter will be eliminated in time, but I am quite sure that with plain sand filters, where the counts are below 50, we can hardly assume that any portion of that 50 is coming from growths in the underdrains. I should be disposed to charge all of such numbers to the bacteria contained in the raw water which had passed the filter.

Dr. Woodward. Have you studied the relative efficiency of these two systems in the removal of the colon bacillus?

Mr. Hill. Not especially; no, sir.

Dr. Woodward. Would you expect that with a smaller number of germs left in by the slow sand filter we would get a lower typhoid death rate?

Mr. Hill. Well, that of course goes back to the earlier inquiry as to the character of the organisms left in the water. Upon the theory that they are a part of those in the raw water, I should generally infer that the smaller the number of bacteria contained in the filtrate the weaker would be the influence of that water on the typhoid statistics; but that does not necessarily follow unless we couple with the number a differentiation of the species.

Dr. Woodward. Operating on the same water, the resulting typhoid fever death rate would presumably be in favor of the effluent having the lowest number of organisms?

Mr. Hill. As a general proposition, yes.

Dr. Woodward. Have you gone into the question of the possibility of the number of colonies of bacteria observed in the effluent from the mechanical filter being diminished apparently though not in fact, as the result of an inhibiting effect of the alum?

Mr. Hill. By the influence of the alum on the growth of the organisms in the water?

Dr. Woodward. Inhibiting their growth.

Mr. Hill. No; I have not. I should not be surprised if that were found to be true upon experimental investigation.

COVERING OF WASHINGTON FILTER BEDS.

Mr. Moore. I want to go into just one matter with Professor Mason, and that is the question of covering the filter beds in Washington. What would be your idea upon that point?

Professor Mason. If I were asked to give an opinion upon that point I would say do not cover them, but I would suggest that foundations for the piers for future covers should be built and carried up a short distance above the bottom of the filter—not through the sand, of course—so that if at any future time experience showed the necessity for covering, so large a disturbance on the settling plant would not be caused by the construction of such covers. The foundations would not be expensive, and would be a very great improvement in the event of substituting covers at any future time.

Mr. Moore. I understand that the increased cost of filter beds, if they are covered, is about 50 per cent?

Professor Mason. Hardly that, but pretty close to it.

Colonel Miller. Mr. Hazen has a great many figures for such coverings, and I think he figures it at about $15,000 an acre.

Mr. Hazen. Approximately $15,000.

Colonel Miller. On the actual designs at Albany he figured the price at about $15,000 an acre additional to the ordinary uncovered filter.

STATEMENT OF RUDOLPH HERING.

Mr. Moore. What has been your connection, Mr. Hering, with water filtration?

Mr. Hering. In 1880 when in Europe on a mission for our Government upon another subject, I first examined a few of the water filters in Europe, and at that time my interest in this subject began. In 1883 I was engaged by the city of Philadelphia to make studies for a new water supply; this took several years. At that time the subject of water filtration was not so thoroughly developed that it was possible to foretell exactly what would be accomplished by certain constructions and methods. Therefore, it was not then considered wise to recommend systems of filters for the city of Philadelphia; it was preferred to get from the Blue Mountains water unfiltered. At the same time it seemed to me that something might soon develop in the line of purification, and for that reason, at the end of my report, I stated that the

Delaware River water just above the city should still be used until further investigations were made.

Then I have had experience in a number of other cities. The city of Atlanta has been mentioned here. It was I who recommended the Chattahoochee supply for that city, and also recommended the mechanical filters, although my recommendation was for the gravity filters, and I had nothing to do with the subsequent carrying out of the work. I was also connected with the Philadelphia waterworks last year as chairman of a commission to go over the whole subject and recommend what the city should do, which resulted in recommending a system of filters for all the water to be used in the city, both of the Schuylkill and the Delaware water. Our preference was for the slow sand method, for reasons given in the report; but at the same time it was recommended that a mechanical-filter plant of 50,000,000 gallons capacity be installed for a part of the plant.

I have also been connected with an investigation, made for the city of New York, into the question of the future supply of water, and there the question of filtration, likewise, was thoroughly looked into, and purification was recommended. At the present time I am one of the engineers of a board at New Orleans, appointed to consider this question, and we are now making experiments, which Mr. Fuller, who is likewise a member of this board, has already alluded to.

THE ATLANTA PLANT.

Mr. MOORE. What was the determining fact in your mind which led you to recommend for Atlanta the mechanical system?

Mr. HERING. I think it was about ten years ago when that recommendation was made, and the fact which led me to it was the expense of the slow sand method. Sand in that part of the country is expensive. Atlanta is situated about 500 feet above the river. It required an expense which ordinarily did not occur. The river water was not very impure, although very turbid nearly all the time, having a yellowish-brownish color. It seemed to me that the conditions unquestionably indicated the use of mechanical filters. The proper kind of sand was expensive. There was no necessity for a very high bacterial efficiency, which at that time mechanical filters were not always able to give. There was, however, a great turbidity and much suspended clay, which a mechanical filter is often better able to deal with.

Mr. MOORE. Why did Atlanta discard the idea of a gravity system and put in a pressure system?

Mr. HERING. I do not know. I believe that they increased their plant subsequently and then put in pressure filters, but I have not been there for a great many years, and I could not tell you the reasons.

MECHANICAL FILTERS AT PHILADELPHIA.

Mr. Moore. What is the idea in having 50,000,000 gallons a day filtered by a mechanical filter at Philadelphia?

Mr. Hering. The idea is that the station to which this recommendation applies is one which, so to speak, gets the leavings of the Schuylkill River, namely, that quantity of water which the upper stations have not withdrawn from the river. When the city shall have grown larger, then water will cease to be available at this station; and so it was thought that the mechanical filter, being capable of transportation to another point, would be more economical. At the same time, it was considered, although not mentioned in the report, that there was an excellent opportunity for testing the two methods with the same water and at the same time, and that any future work that might be done could be guided by the experience thus gained.

Mr. Moore. From how many points will Philadelphia take water?

Mr. Hering. From four points on the Schuylkill and one on the Delaware. The water will be filtered at five different places. We calculated for 200,000,000 gallons, of which 50,000,000 were to be filtered with mechanical filters and 150,000,000 with the slow sand filters. Is that right, Mr. Hill?

Mr. Hill. That is right; 150,000,000 is what the experts proposed to take from the Schuylkill.

Mr. Hering. The Belmont filter plant was calculated for 27,000,000 at first; the Roxborough for 15,000,000 at first; the Queen Lane for 58,000,000 at first; the East Park filter plant—which was to have the mechanical filters—for 50,000,000 at first; and the Torresdale, which is the Delaware River plant, was to be installed for 50,000,000 gallons at once. The Schuylkill River was exhausted in this way during the driest years, and all future extensions were to be made from the Delaware. In other words, the minimum flow of the Schuylkill River which we considered available for water supply of the city of Philadelphia was taken at 150,000,000 gallons a day, and of course, as you must always have the water, you must consider the least flow that will ever come down the river as being the outside limit for which you build your works.

Mr. Moore. Do we understand that the board looked upon the mechanical system as likely to produce good results if carefully managed?

Mr. Hering. We expected that. The estimates of costs were made, of course, for both methods, and by making the estimate of cost properly in most of these cases you will find that there is not a very great difference in the cost of the two methods. The slow method requires a greater investment of capital and the rapid method requires a greater expense for annual cost of operation. If you capitalize this, allow for the depreciation, and draw your balance, you will find that the two methods do not vary much in point of expense. Of course in some cities the borrowing capacity is limited; then the mechanical filters are sometimes preferable, because it requires less money to be invested at the outset.

Mr. MOORE. Have you gone so far with the investigation for New Orleans as to be able to determine what system you will recommend there?

Mr. HERING. No, sir; the experiments have only begun, and they will continue until next summer.

EFFICIENCY OF FILTERS.

Mr. MOORE. Then I understand your position to be, in regard to these methods, that you treat each water as a separate problem to be investigated, and a system applied as the character of water may determine, being reasonably confident that whichever system is used you will get good results from it?

Mr. HERING. That is correct. That is what I try to do. I am thoroughly convinced that the improvements that have been made with mechanical filters will enable us to get better results than formerly were possible, and also results that may be, under certain circumstances, fully equal to those obtained from slow filtration in Europe, where now that method is exclusively used.

Mr. MOORE. In the case of the city of Washington, whichever system shall be adopted, provided that system is carried out carefully, the result from a sanitary standpoint and from the standpoint of clear water will be good?

Mr. HERING. I feel very confident that that would be the case with the adoption of slow filters, because in Europe we have had very much and varied experience with them; and, on the other hand, from the progress that has been made, and the attention that has been given to the rapid filters during the last few years, I am confident that if proper and intelligent supervision is given to the operation of the works, their results will be so little different from those of the slow filters as to be hardly worth consideration.

THE CLEAR-WATER BASIN.

Mr. MOORE. Are there other essential considerations, such as the size of the clear-water basin? How much filtered water must be stored? Are there limits to the amount that may be stored without deterioration?

Mr. HERING. The clear-water basin should be constructed of a size to hold sufficient water to compensate for the irregular drafts from the city. As the filters should yield a uniform supply constantly, the irregularity in the draft should be made up by storage in this clear-water reservoir.

Mr. MOORE. What is the proportion between the amount of water taken by the city during a day and the size of a clear-water basin?

Mr. HERING. That depends upon the size of the city. The smaller the city, as a rule, the greater is the difference. So that for a very large city you can provide for a fraction of a day with much greater safety than for a small city, because in a large city the uses of the water are very much more diversified. And the time limit also comes in play in a large city. It takes quite a while for the water from the works to reach some of the points where it is used, and there is a sort of equalization going on which causes the fluctuation in the reservoirs to be very much less in a large city than in a small one.

Mr. MOORE. That is to say, the pipes themselves act as a basin?

Mr. HERING. Yes. In New York, for instance, it takes several hours for water to get from, let us say, Central Park reservoir to the Battery. Now if you stop using water—let us say for the purpose of argument—at 10 o'clock in the evening all over the city, then supposing it takes four hours to reach the lower end of New York from the reservoir, the consumption would stop at 10 o'clock near the reservoir, but the water which has gone down to the lower end of New York would have stopped leaving the reservoir four hours before; consequently there is equalization in large cities.

Mr. MOORE. Have you established any ratio?

Mr. HERING. No, sir; I think in Philadelphia—I am sorry that I do not remember it—we assumed a half day's supply for the clear-water reservoir.

Mr. HILL. That is the proportion that we propose to use in the clear-water basin, assuming 50,000,000 gallons daily filtration; then the clear-water basin will carry net 25,000,000 gallons, or in that proportion everywhere.

Mr. HERING. And that, in my opinion, is entirely sufficient for a city the size of Philadelphia.

SLOW FILTERS PREFERRED.

Mr. MOORE. Are there any other factors that enter into a filtration plant?

Mr. HERING. I consider that both methods require intelligent supervision. If such intelligence is not applied either method will be apt to give imperfect results. I think that the slow filters are in that respect better than the rapid filters, because of the very fact that, if anything should happen, less water in an impure condition is likely to escape before a remedy can be found. I would also state that the slightly greater complication of manipulation in a mechanical filter would require more intelligence, but I do not think that financially there would be much difference. The tendency has been in this country, for the last five years, anyway, to give waterworks better supervision. That is in imitation of Europe, where they find it necessary to have experts in charge of every filter plant. I had the pleasure of examining several of them this last summer, and also in 1894 and in 1891, and it impressed me this year that a good deal more intelligence was being put into the supervision of these works than my first examination revealed.

DOUBLE FILTRATION.

What particularly interested me this year was the double filtration in Bremen and a few other places. They prefer the slow method there, and I do not know of any city where the rapid method is used. At the present time experiments are being made in Moscow on a large scale, where both the slow and rapid methods are being tried with the same water and at the same time.

The results, I believe, will not be available for about a year. The double filtration is intended both to secure a better bacterial efficiency and also to get out some of the slight color that the first filters have left.

Mr. MOORE. In the double filters are the two beds the same?

Mr. HERING. They are worked alternately. There must be a larger number of beds. After a filter has been scraped the first water that gets through it is not as good as after the bed has become established and is in working order. This less pure water is again turned on to one of the filter beds which is in good operation and has not been recently cleaned, and is filtered there the second time.

Mr. MOORE. That then removed the last possibility of poor service in the slow filter?

Mr. HERING. No; I should say that added a difficulty, because it requires more careful service. It requires more intelligence and greater watchfulness. The more complications you get in any contrivance the greater intelligence you must have to watch it and operate it.

CLEAR-WATER BASIN.

Colonel MILLER. Mr. Moore has brought up a very important point. It is a point upon which various authorities differ. In looking over all the European plants that I could discover, I find that the question of reservoirs and clear-water basins varies greatly. At some places they have an enormous clear water-basin and at others a much smaller one. Mr. Hazen has a comparatively small one, because they do not confine themselves to filtered water in Albany, but the size depends principally on the variation of the draft. I have here in my hand the measurement of the hourly consumption of water in Washington on the 28th of December, and in Washington we have two additional reservoirs erected. They are now filling the second one, which they fill by pumping from high-pressure supply during the night, so that the consumption is about equalized during the whole of the twenty-four hours. The greatest consumption of this day was two and one-third million gallons per hour, and the lowest ran down as low as one and three-quarters, and if you will examine the table you will see that the hourly consumption is pretty constant. So that in such case would you not infer that so large a reservoir is not necessary.

Measurement of the daily and hourly consumption and waste of water for the twenty-four hours ending at 7 a. m., December 28, 1900.

[City temperature in the shade at 2 p. m., December 27, 42° F, weather clear.]

Hour.	Outflow per hour, December 27 and 28.	Hour.	Outflow per hour, December 27 and 28.
	Gallons.		*Gallons.*
7 to 8 a. m.	2,111,269	9 to 10 p. m	2,210,976
8 to 9 a. m.	2,249,273	10 to 11 p. m	2,345,710
9 to 10 a. m.	2,246,001	11 p. m. to 12 midnight	1,929,272
10 to 11 a. m.	2,102,907	12 midnight to 1 a. m	2,201,766
11 a. m. to 12 noon	2,100,119	1 to 2 a. m	1,924,418
12 noon to 1 p. m.	2,237,155	2 to 3 a. m	2,058,557
1 to 2 p. m.	2,834,124	3 to 4 a. m	2,740,937
2 to 3 p. m.	2,830,852	4 to 5 a. m	2,326,075
3 to 4 p. m.	2,088,849	5 to 6 a. m	1,776,241
4 to 5 p. m.	2,085,819	Rainfall	70,084
5 to 6 p. m.	2,083,395	6 to 7 a. m	1,911,698
6 to 7 p. m.	1,941,754	Rainfall	46,772
7 to 8 p. m.	1,939,574		
8 to 9 p. m.	1,937,149	Total	51,130,746

Mr. Hering. I certainly would infer that it was not necessary to provide for a very large clear-water basin in Washington.

Colonel Miller. Two or three hours' supply is what we have provided for.

Mr. Hering. I would not be able to give any information upon that without looking into it more carefully.

Colonel Miller. Even before pumping was adopted there was such a nightly waste there that it was two and one-half during the hours of daylight and one and nine-tenths during the hours of less consumption, so that there is not much variation there in the hourly draft on the reservoir.

Mr. Hering. In reporting upon the sewerage system in New York some ten years ago, I had occasion to gauge the flow in a large sewer, which is supposed to take all the water supply after it has been used. I erected an automatic self-registering gauge, and kept it going for one year, to estimate the amount of water which was flowing to waste near Fourteenth street. It showed a comparatively slight variation between the minimum and the maximum flows. You can see the diagrams in a late report on the water supply of New York published by the Merchants' Association. That is a very good indication of the water used, because there is not very much underground drainage which gets into these sewers, the surface of the ground being nearly all paved and impervious, so that the rain water runs off rapidly. Very little soaks into the ground thereafter to get into the sewer, and the sewage is a very good index of the water consumption—of its hourly rate in New York City. It agrees very closely with the gaugings that were made directly of the consumption at the Central Park reservoir by Mr. J. R. Freeman last year.

Colonel MILLER. You mean by gauging the reservoir?

Mr. HERING. Yes, sir; in the diagrams referred to the two curves are platted over each other to show how well they correspond, considering the fact that it takes several hours for the water to run from the reservoir down to Fourteenth street.

Dr. WOODWARD. I believe that you were engaged in other engineering work in Washington at one time in connection with our sewerage system?

Mr. HERING. Yes, sir.

Dr. WOODWARD. And had an opportunity of becoming acquainted with local conditions. Would the knowledge obtained in that way, together with the data furnished in Colonel Miller's report, enable you to express an opinion as to the possibility of filtering the water supply of the city of Washington by the slow method?

Mr. HERING. No, sir. I examined into the question of drainage and sewerage in the city of Washington, and that involved merely ascertaining the quantity of water that was likely to be discharged into these sewers, but nothing with reference to its quality. In fact, it was a very large work and we had very little time, and it was impossible to go outside of the actual necessities.

Dr. WOODWARD. You observed the drinking water and the water in the bath tubs during that time. Did that not fix itself in your mind sufficiently to enable you to utilize it by forming an opinion?

Mr. HERING. That opinion would have been absolutely of no utility in our work. Of course I am, in a general way, acquainted with the water in Washington.

WASHINGTON SEWER SYSTEM.

Mr. MOORE. You say that you assisted in planning the sewer system of Washington, and had to work more or less hastily?

Mr. HERING. I did not mean that. The system was very thoroughly worked out, but it simply did not allow any time to do anything else.

Mr. MOORE. I was going to ask if in your experience since that time you had seen any reason to correct any of your work done at that time.

Mr. HERING. No, sir; I am very much pleased to see that the works are being carried out pretty much as they were then recommended.

COVERED FILTERS.

Dr. **Woodward.** Would your residence in Washington, or your visits to Washington during the time that you were engaged in such work, enable you to express an opinion as to the necessity for covering slow sand filters in Washington?

Mr. **Hering.** No, sir; it would not. I would want to know a good deal more than I know now about that to express an opinion. I had a very decided opinion in Philadelphia regarding the covering of filters, but it was especially for Philadelphia. There we decided to cover the filters.

COMPARATIVE MERITS OF SLOW AND RAPID FILTERS.

Dr. **Woodward.** As I understand it, you feel satisfied that if the water of the city of Washington is susceptible of being filtered by slow sand filters, such filters will give satisfactory results, because such results have been accomplished in large cities abroad and are apparently being accomplished at Albany?

Mr. **Hering.** I would say yes, considering the matter from a general standpoint, but the conditions are sometimes such that the reverse may be true; I have in some cases recommended the mechanical filters where, in my opinion, there was absolutely no question regarding the preference. There are a number of questions which combine to lead up to a decision.

Mr. **Moore.** And the burden of proof is with the mechanical system?

Mr. **Hering.** Only because we have not had them so long in operation, and do not feel as sure about all practical complications. As I said before, I have always been of the opinion that for certain conditions in our country only the mechanical filters offered a practical solution, because the slow method would be too expensive as a first cost investment for some of our cities, particularly in the South.

Dr. **Woodward.** Are there other reasons besides that of first cost that would lead you to say that mechanical filters should be adopted in certain sections of the country?

Mr. **Hering.** Well, I consider that where the water is continually turbid, and particularly where it carries clay in suspension, the mechanical filters would, in my opinion, usually be preferable.

Dr. **Woodward.** Do any of the European rivers which are filtered by the slow method carry clay in suspension?

Mr. **Hering.** In western Europe, very little. I have not been in eastern Europe, but I understand that the rivers there do carry clay in suspension.

Dr. **Woodward.** How about the English rivers? Do you include them in your statement—that the rivers of western Europe do not carry clay in suspension, or do some of those carry clay in suspension?

Mr. HERING. In England they carry a little clay. In western Germany some of them carry a little clay.

Dr. WOODWARD. During your investigations of those European filters, did you find any complaints on the part of the people on the score that the filter failed to clarify the water properly?

Mr. HERING. There has been complaint made occasionally that the water was not perfectly clear at times.

Dr. WOODWARD. In what plants, if you can recall?

Mr. HERING. I am thinking particularly of some plants in eastern Europe where complaint was made, namely, in Russia—St. Petersburg and Warsaw, and I think one or two other cities.

Dr. WOODWARD. How long have the mechanical or rapid filters been in use?

Mr. HERING. I think I first became acquainted with them almost twenty years ago.

Dr. WOODWARD. During that period do you know of an European city that has adopted this rapid method of filters, which we have called the mechanical system, or the American system, or the rapid sand filtration?

Mr. HERING. I do not know of any large city where they are using them now.

Dr. WOODWARD. Or any city at all in Europe?

Mr. HERING. I do not know of any city.

Colonel MILLER. Mr. Chairman, there is a gentlemen here from Elmira who has some statistics that he would like to submit for the information of the committee.

Mr. MOORE. We will be glad to hear him.

STATEMENT OF JOHN M. DIVEN, SUPERINTENDENT OF THE WATERWORKS AT ELMIRA, N. Y.

Mr. MOORE. You are superintendent of the waterworks at Elmira, N. Y.?

Mr. DIVEN. Yes, sir.

Mr. MOORE. Who owns the plant?

Mr. DIVEN. It is a water company.

Mr. MOORE. What system is used there?

Mr. DIVEN. The mechanical, gravity.

Mr. MOORE. What particular system?

Mr. DIVEN. The Morrison-Jewell.

Mr. MOORE. What can you say about the efficiency of that plant from a sanitary standpoint?

Mr. Diven. A considerable reduction has been shown by the board of health in the typhoid-fever rate. I have some statistics here which I will read. They give, unfortunately, the number of cases, not the death rate. The cases in 1896, before any filtration system was installed, were 440, and of those 287 were attributed to the users of the city water; 123 to those using well water, and 20 to those using both, more or less. For the next year, part of the time the water was filtered, and the number of cases dropped to 103, of which 53 were attributed to the use of the city water and 32 to the use of well water and 3 to the combined water. In 1898, during which time the filters were in full use, the cases dropped to 75, of which 38 were attributed to the city water and 39 to wells and other sources. In 1899 it was the same. In 1900 there is a slight increase, showing 92 cases, the majority of those being attributed to well water; 42 of the 92 were attributed to the city water, and the balance to the well water.

Mr. Moore. In general terms what reduction has been obtained there?

Mr. Diven. We are getting an average of 98.7.

Colonel Miller. You are speaking of the efficiency of the filter. Is that what you mean?

Mr. Moore. No, that is not what I mean. I mean what reduction has there been in typhoid fever?

Mr. Diven. I have not figured the percentage. You will see from the figures given above that it is very marked—from four hundred and odd cases in 1896 to about 75.

Dr. Woodward. What proportion does the number of reported cases from any one source, say from the filtered water or the unfiltered water, or the well water, during each of those years bear to the entire number of inhabitants consuming that water?

Mr. Diven. The population of Elmira at present is 36,000, and we have 4,000 taps. I should attribute 500 of those to mechanical places—I mean business places.

Dr. Woodward. That of course does not answer the purposes of the vital statistics at all.

Mr. Diven. I was trying to show how many were using well water and how many city water.

Dr. Woodward. We would like to have the number of cases which occured in each class of the population according to water supply used, and the entire number of people in each such class.

Mr. Diven. The well water shows how much was attributed to it.

Dr. Woodward. But it does not show the number of users of well water. Have you that in your table?

Mr. Diven. Yes; 193 in 1895.

Dr. Woodward. How many people in the community were using city water and how many well water?

Mr. Diven. I should say half and half, judging from the proportion of population to the number of taps.

Dr. Woodward. You have no tables on that point?

Mr. Diven. No, sir.

Dr. Woodward. It would seem that that was rather vague information.

Mr. Diven. We could only judge that from the number of taps to the population. Ordinarily there are five people to the tap.

Colonel Miller. Then 60 per cent use filtered water?

Dr. Woodward. Sixty per cent each year.

Colonel Miller. Sixty per cent since filters have been introduced.

Dr. Woodward. Do they not vary from year to year?

Mr. Diven. Not materially.

Dr. Woodward. Under what law are the reports of cases of typhoid fever made?

Mr. Diven. They are made under the State law.

Dr. Woodward. Do you know the terms of it, or the vigor with which it is enforced?

Mr. Diven. Yes, sir; the physicians are called up and fined if they do not make reports.

Dr. Woodward. Will you tell us at what time those particular cases of typhoid fever were attributed to a particular source of water supply?

Mr. Diven. Do you mean what time during the year?

Dr. Woodward. No; when this account was made.

Mr. Diven. I do not understand you.

Dr. Woodward. The cases that were reported, say February 1, 1892. A case was reported by a physician as typhoid fever. Were steps taken at once to determine the origin of that case?

Mr. Diven. As soon as possible; yes,

Dr. Woodward. Every case has been investigated by a duly accredited official of the city government?

Mr. Diven. Not as far back as 1892. I think the first authentic record we have is for September, 1895.

Dr. Woodward. Since that time every case has been duly investigated by a competent and duly accredited official of the city government, having no interest in the water supply, and he has, from sufficient evidence, charged that up there to one system or the other as the case occurred.

Mr. Diven. Yes, sir.

Dr. Woodward. Since 1895?

Mr. Diven. Yes, sir; that is, by the health officer or his inspectors.

Dr. Woodward. Are you interested in any of these systems of filters?

Mr. Diven. No, sir.

Dr. WOODWARD. You are connected with the water company?

Mr. DIVEN. Yes, sir.

Dr. WOODWARD. May I ask who paid your expenses from Elmira to New York City for the purposes of this hearing?

Mr. DIVEN. I paid them myself.

Dr. WOODWARD. What brought you here?

Mr. DIVEN. I was requested to come.

Dr. WOODWARD. By whom?

Mr. MOORE. I can explain that. In the list of gentlemen furnished by Colonel Miller there was the name of Mr. Morrison. I wrote to Mr. Morrison and asked him to be present. I received an answer from the filter company, I think, saying that Mr. Morrison could not be here, but they would be pleased to have present the man in charge of the Elmira filter company, and I wrote back that we would be pleased to hear from him.

Dr. WOOWARD. Then he comes at the instance of the filter company?

Mr. MOORE. Either directly or indirectly, I suppose.

Colonel MILLER. There is a gentleman here who made the bacteriological tests in the laboratory in Washington, and as the methods there are rather brought up in a report of the Medical Society of Washington, and as Mr. Johnson, the gentleman I refer to, is present, I have no doubt he would be glad to answer any questions that Dr. Woodward may desire to ask him.

Dr. WOODWARD. I think the medical society is satisfied with the record as it now stands. I do not desire to ask him any questions.

Colonel MILLER. There were some questions brought up, and I think it was rather intimated that the bacteriological examinations were not satisfactory. We understood that as being one of the points, especially the matter of colon bacillus. It has no weight whatever, because if any other bacilli was passed the coli will too, because it is not considered any more with reference to the efficieney of the filter than anything else. The only thing is to show if the water is dangerous after filtration. If the typhoid bacilli was largely in the water before filtration it would be equally bad in either case after filtration.

Dr. WOODWARD. If Colonel Miller desires it I shall be pleased to question Mr. Johnson.

STATEMENT OF GEORGE A. JOHNSON.

Mr. MOORE. Please state what was your connection with the water investigation at Washington.

Mr. JOHNSON. I was Mr. Weston's representative there, Mr. Weston being in charge of the laboratory work under Colonel Miller.

Mr. MOORE. What has been your training for this work?

Mr. JOHNSON. My first work in this connection was at Louisville in 1895, in September, under Mr. Fuller. I was an assistant in the bacteriological department there for a period of about two years. Then I was in charge of the bacteriological department in the laboratory at Cincinnati—the laboratory of the commissioners of the waterworks—during the filtration experiments that were conducted by them under Mr. Fuller's direction. My training, I may say, has been wholly under his direction in this particular line.

Mr. Moore. So that you have had experience in dealing with different waters, and are generally familiar with the subject?

Mr. Johnson. I think some fifteen different waters, roughly speaking. I will say that perhaps I have made fifty or seventy-five thousand analyses—that is, speaking very roughly. Most of those, it is useless to say, have been for my own edification along the lines of special research work.

Dr. Woodward. Either before or after or during your employment on these investigations have you been connected in any way with any filter company?

Mr. Johnson. No, sir.

Dr. Woodward. With reference to the finding of the colon bacilli in the effluents of these two filters, were the tests directed particularly to that point?

Mr. Johnson. Toward the finding of the *B. coli communis?*

Dr. Woodward. Yes.

Mr. Johnson. Yes, sir.

Dr. Woodward. Continually?

Mr. Johnson. Not continually; those were only subordinate.

Dr. Woodward. What was the total number of analyses in which such bacilli appeared?

Mr. Johnson. I have not those things clearly in my mind. I did not expect to be questioned at this hearing.

Dr. Woodward. You do not remember that?

Mr. Johnson. No, sir; it was not a very large number.

Dr. Woodward. There was no systematic examination made?

Mr. Johnson. No, sir; I do not think there was any made to really base any conclusion upon with regard to the actual superiority of either system. I think it is about an even thing.

Dr. Woodward. Upon what do you base your belief that it is an even thing if there was not enough testimony to base an opinion upon?

Mr. Johnson. So far as the tests went.

Dr. Woodward. At the same time you say there were not enough tests to justify a conclusion.

Mr. Johnson. Well, that is a provisional conclusion; not a final one.

Dr. Woodward. As a bacteriologist you would expect a torrent or a thaw to increase largely the turbidity of a stream and the bacterial count. Would it increase in corresponding ratio the number of pathogenic organisms in it?

Mr. JOHNSON. That would be governed a great deal by local conditions. The question of pollution comes into play there in a great measure. It would depend a great deal upon the initial pollution of the stream, I think.

Dr. WOODWARD. Then in your judgment a torrent or a thaw would cause the amount of infectious excreta to increase in quantity in proportion as it increased the quantity of other ingredients?

Mr. JOHNSON. Yes, sir; it undoubtedly would add to the pollution in a general way.

Dr. WOODWARD. I am speaking of this infectious excreta.

Mr. JOHNSON. I would hardly think so.

Dr. WOODWARD. It would not do that?

Mr. JOHNSON. I would hardly think so.

Dr. WOODWARD. You would think the pollution effected by a torrent or a thaw would rather add an element of safety in diminishing the number of pathogenic organisms per cubic centimeter?

Mr. JOHNSON. It is pretty hard to make a positive statement upon a matter of that sort, although I have always been inclined to look upon water—like the Ohio, for instance—in its lowest stage as the most suspicious in character.

Dr. WOODWARD. At the lowest stage?

Mr. JOHNSON. Yes.

Dr. WOODWARD. Well, in a stream other than the Ohio, which I believe is constantly muddy, you would find the most suspicious water in times of the greatest clearness; the lowest stage of the stream is comparatively the clear stage, I believe.

Mr. JOHNSON. Usually so; yes.

Dr. WOODWARD. Then the clear waters would be more suspicious than the others?

Mr. JOHNSON. I think so, within reasonable limits.

Dr. WOODWARD. That corresponds, I believe, with Prof. Theodolphus Smith's findings, so far as you are familiar with them?

Mr. JOHNSON. Yes, sir; I think so.

Dr. WOODWARD. The importance, then, of diminishing the number of bacteria, from a sanitary standpoint, would be greatest when the water was clearest?

Mr. JOHNSON. I understand what you mean. Yes; I think that argument is all right, but, as I said before, within reasonable limits, and I said it would depend upon circumstances, which might alter the whole complexion of the matter. So far as I know the water in Washington is pretty badly polluted.

Mr. MOORE. And the pollution is constant, is it not, and the turbidity is occasional?

Mr. JOHNSON. Yes.

Mr. MOORE. And when a freshet or thaw comes it simply gives you more water, which would distribute what germs are there?

Mr. **Johnson**. Yes; I am of that opinion. I think it is beneficial rather than deleterious.

Dr. **Woodward**. Have you made any tests to determine the possible effect of alum in inhibiting the growths of these organisms?

Mr. **Johnson**. I can not tell you anything that I have done myself, but what was done by my associate at Louisville, the first assistant in the bacteriological laboratory. He worked that point out and found the results to be negative; he worked with pretty strong swells too—much stronger than in actual practice in water purification.

Dr. **Woodward**. How long were those plates cultivated?

Mr. **Johnson**. I think the standard period of three days.

Dr. **Woodward**. Nothing beyond that?

Mr. **Johnson**. Not necessarily. The gelatine culture is only 20 degrees.

Dr. **Woodward**. He did not go beyond the three days' cultivation of plates?

Mr. **Johnson**. I do not think so.

Dr. **Woodward**. Do you know anything with reference to criticism of the methods used in determining the bacterial efficiency of the East Providence filter?

Mr. **Johnson**. No.

Dr. **Woodward**. Was not that matter discussed in the Albany Medical Annals?

Mr. **Johnson**. I have not those methods clearly in mind. I do not know.

Mr. **Moore**. Gentlemen, this closes to-day's inquiry. The committee is very much obliged to you all for your promptness, and for your courtesy in so responding to the call. I think in no instance has any one invited to attend failed to appear here, except in one case, where it was impossible for the gentleman to come.

CHAPTER II.

A PAPER ON THE FILTRATION OF PUBLIC WATER SUPPLIES, PREPARED BY LIEUT. COL. CHARLES SMART, DEPUTY-SURGEON GENERAL, UNITED STATES ARMY, AND INDORSED BY SURGEON-GENERAL STERNBERG.

War Department, Surgeon-General's Office,
January 3, 1901.

Respectfully returned to Mr. Charles Moore, clerk Committee on District of Columbia, United States Senate. Lieutenant-Colonel Smart is an expert with reference to the subject of this report and his views are entitled to most careful consideration. In my opinion, the so-called "natural method of filtration," properly installed, will secure to the city of Washington a water supply of a satisfactory degree of purity and will greatly reduce the typhoid mortality of this city.

Geo. M. Sternberg,
Surgeon-General United States Army.

War Department, Surgeon-General's Office,
Washington, D. C., December 31, 1900.

Sir: In response to communication of December 21, 1900, from the Senate Committee on the District of Columbia, requesting a paper on the relative merits of the so-called mechanical system of filtration and the slow sand system, I have the honor to submit as follows:

The frequent turbidity of the Potomac water should render any other argument for its purification unnecessary, but there is an argument, not so obvious as this turbidity, which calls imperatively for purification. I refer to the unnecessary prevalence of typhoid fever in the District of Columbia. The report of the health officer for 1899 shows from this disease, per 100,000 of the population, 44 deaths among the white residents and 91 among the colored people. In 1894 a committee of the District Medical Society reported on the causation and prevalence of this fever, recognizing among the prominent causes the use of infected well waters, defective sewerage and drainage, and impurity in the general water supply from the Potomac River, and recommending measures to remedy these sanitary faults. Their recommendations on behalf of the purity of the general water supply embodied the early completion of work then in progress for the sedimentation of the water and the installation of works for filtration, which was stated to be the only proper method of purification. Since then, wells have been examined and closed, sewerage and drainage improved, and the Dalecarlia basin has been reclaimed and utilized for sedimentation, but the prevalence of typhoid continues high, and it will continue to be so until the only proper method of purification has been adopted.

There are other methods by which typhoid fever may be introduced into the city than by the unpurified river water. The infection may be imported from other localities, particularly by those returning from a summer sojourn at the seashore or in the country, and infection may spread from these cases in the absence of the most carefully supervised system of disinfection. But a systematic supply of unpurified river water must be recognized as the main agency by which infection is propagated, for a river contains the surface washings and sewage of the area drained by it, and typhoid fever is so generally distributed that the sewage of every community of any size must be held to be infected. Hence the more sewage in a river the greater the risk of infection to those who drink the water lower down. And this is precisely what we find when we study the prevalence of typhoid fever in relation to sewage-polluted water supplies. On the other hand, when an efficient system of purification is provided for a city having an impure water and a high typhoid rate the improvement is promptly followed by a fall in the death rate. Unfortunately we have to go to Europe for most of our illustrations. We are far behind England and Germany in the care given to the character of public water supplies. We now, in the year 1900, are considering the results produced in the Washington water supply by passing it through a circular sand bed 11 feet in diameter, while seventy years ago filtration was tested by the Chelsea Water Company on the comparatively foul water of the Thames by passing it through an experimental sand bed having an area of one acre. The success which attended this experiment in 1829 led to the general adoption of sand-bed filtration in England and the Continent of Europe for the purification of surface waters.

FILTRATION IN GERMAN CITIES.

Since bacteriological methods have been brought to bear on the quality of filtered waters, this filtration through sand has been shown to be all that could be desired. It was at Berlin that this was first demonstrated. Up to 1856 the only water supply of this city was from wells, one of which was dug in each householder's back yard. These wells had little depth, for the subsoil water of the Valley of the Spree was only a few feet below the surface. In the year mentioned the people felt the need of a general supply to flush their open drains and they brought water in from the Spree, 2½ miles above the city. In 1870, as the city had extended beyond the intake, filter beds after the

English model were built on an expansion of the stream 12 miles up the river. Bacteriological observations were made by M. Piefke, the superintendent of the works, and the results of his experiments were afterwards confirmed by Koch in 1892, and became the basis of legislation for the purification of water in the German Empire: Rate of filtration not to exceed 100 mm. (3⅘ inches) per hour (about 2 gallons per square foot per hour, or 2,000,000 gallons per acre per day); daily bacteriological examinations to be made, and water containing more than 100 colonies per cubic centimeter to be run to waste.

About the same time bacteriological observations were made on unfiltered and filtered waters at the Lawrence experiment station of the State board of health of Massachusetts. The results of these experiments, which were conducted by Professors Sedgwick and Fuller, were that within the limits of 300,000 and 3,000,000 gallons per acre per day variations in the rate of filtration have little influence on the purity of the effluent, provided that the rate for the day be uniform; that the finer the size of the sand between 0.2 and 0.9 mm. the higher the percentage of bacteria removed; that with any moderate rate of filtration whether there is 1 or 5 feet of sand exerts but little influence on the removal of bacteria, and lastly that scraping the surface of the sand does not affect the efficiency of the filter, provided there is no mechanical disturbance of the body of the sand by the scraping or the refilling of the bed with water.

FILTRATION IN THE UNITED STATES.

We know from the extensive and long-continued experience in England and continental Europe that slow filtration of an impure surface water through sand will purify the water and lessen the prevalence of typhoid fever and the death rate from this disease among the people using the water. There is no uncertainty about this. The statistics of every city having sand-bed filters bear witness to the fact. And that we may expect similar results in this country is shown by the experiments conducted under the auspices of the board of health of Massachusetts and by the practical results effected at the few places where this method of filtration has been adopted. Poughkeepsie, on the Hudson, in 1872 was the first city in this country to establish waterworks of this character. Lawrence, Mass., followed in 1893, and shortly afterwards a few small towns in New York, such as Mount Vernon and Auburn, and Ashland, Wis. In all these cases a gratifying reduction in the death rate was effected. Albany, N. Y., began to operate a sand filter, the largest in this country, on August 1, 1899. Mr. Bailey, the superintendent, in a report issued in August, 1900, covering the operation of the filter for three hundred and nineteen days, gave the quantity filtered daily as nearly 12,000,000 gallons. On April 2 and 6, respectively, when the bacteria in the raw water numbered 45,000 and 37,000, respectively, 99.07 per cent of the total was removed. The influence upon the death rate from typhoid fever has been quick and decided. The average number of deaths from typhoid fever in Albany for nine years up to 1899 was 85 in a year. From January, 1899, to August 1, 1899, when the city was using unfiltered water, there were 71 deaths from typhoid fever; and from August 1, 1899, to January 1, 1900, or when filtered water was in use, there were only 7 deaths from this disease. From January 1 of the present year up to July 1 there were only 19 deaths for the six months, or a total of 24 for the year, against 85, the average for the preceding years.

MECHANICAL FILTERS.

Experience with the mechanical filters shows an effluent which is usually perfectly free from inorganic particles, but as operated on the large scale its freedom from typhoid bacteria has yet to be demonstrated. It is an elaboration from the Newark filter, a sample of which I saw for the first time in a hotel in Memphis, Tenn., in 1879. This filter gave a clear water from the reddish-brown clay waters of Wolfe River. It was merely a metal cylinder packed with coke and sand and connected with the water-supply pipes of the city. The head of water in the distributing reservoir forced the water rapidly through the sand, giving a clear effluent, but the suspended clay choked the filter in a short time. The pipes, however, were so arranged that the current could be reversed and all the clay be washed out by the upward rush of water. As soon as the wash water became clear filtration was renewed. The clear water was not improved chemically, and the rapidity of the filtration and frequent disturbance of the sand precluded the idea of a satisfactory removal of bacteria. Sanitary men, therefore, did not give it their confidence. It was made at first in small sizes for hotels, factories, etc., but as it made its way by advertisement before the public under the name of the Hyatt filter, the Jewell filter, etc., larger cylinders were constructed and alum was used to promote the aggregation of the clay particles and facilitate their removal. These filters were introduced into many small towns, particularly in the South, and gave great satisfaction from the clearness of the effluent water. Concerning the 2,000,000-gallon plant established at Atlanta, Ga., it was reported that although the water in the reservoir is generally so muddy from red clay and other suspended matters as to be unfit for bathing and laundry use, yet after it passes into the clear-water basin small objects are plainly seen through it at a depth of 20 feet.

SLOW SAND FILTRATION.

The announcement by Piefke, and afterwards by Koch, of the important part played in slow filtration by the bacterial scum which gathers on the surface of the sand bed led sanitary men to have no faith in the efficiency of the Hyatt filters, as this scum was deliberately washed away at stated intervals by the reversal of the current, and particularly as no bacteriological observations were published to show the amount of bacterial removal accomplished. Recently, however, experiments conducted by Fuller at Cincinnati, Ohio, Schwartz at Providence, R. I., and some others have demonstrated that with due care in the introduction of alum as a "coagulant" to entangle the bacteria and facilitate their removal and in the management of the filtering cylinders very excellent results may be obtained as regards the removal of bacteria.

Meanwhile, however, this is not attended with the beneficial results as regards the lessened prevalence of typhoid fever that years of experience have shown to be a constant sequence of slow filtration through beds of sand.

EXPERIMENTS IN WASHINGTON.

Lieut. Col. A. M. Miller, Corps of Engineers, in his report of an investigation of the feasibility and propriety of filtering the water supply of Washington, D. C., recommends that the mechanical system of filtration be adopted, and bases his recommendation on the bacteriological results obtained under his supervision from the effluent water of two filters, one of which represented the mechanical system while the other was assumed to represent the sand-bed filtration of Europe. A careful study of the filters, the filtration, and the bacteriological results as given in his report leads me, on the contrary, to consider that the method of slow filtration should be adopted. This opinion is reached from the sanitary point of view and without consideration of the relative cost of the two methods.

That the first-mentioned filter was an efficient representative of its system may readily be accepted, as it was erected by the New York Filter Manufacturing Company, and combined all the recent improvements of this method. That the second in its construction and management fairly represented the filtration through a sand bed having an area of an acre or more can not be admitted. This filter was a cylindrical tank 11 feet in diameter, its walls vertical. That imperfectly filtered water passed down these walls to the underdrains seems likely, as when the filter bed was drained to admit of scraping the sand was found to have settled lower around the periphery of the bed than at any other part.

The method of filling the filter after scraping was not such as to give the best results.

The pet-cocks and brass pipes which were inserted November 21 for the purpose of drawing off samples of water at various depths did material damage to the filter bed, which was recognized on November

29, and culminated some time in December in a crack 11 feet long on the surface of the filter just over the line of the cocks (pp. 26, 46, 48).

The experiments with this filter consisted of 5 runs or periods of continuous use in filtering Potomac water as delivered from the sedimenting basins of the city supply.

During the first run, which lasted from June 11 to July 19 at a rate of 1,000,000 to 2,000,000 gallons per acre per day, bacteriological observations were made only on the last seven days. The effluent water showed less than 100 colonies per cubic centimeter on each of these occasions.

During the second run, which lasted from July 21 to September 27, filtration was kept up at a rate of about 3,000,000 gallons per acre. The effluent was below Koch's limit of 100 colonies during this period of 69 days.

During the third run, from September 27 to November 3, a period of 36 days, with a rate of filtration of 4,000,00 gallons, the bacterial limit was exceeded only on the first day, and because, according to Colonel Miller, the filter after having been scraped was filled from below with unfiltered water, a method of filling which would not be used in practical filtration.

The fourth run is interesting. It was begun November 5 and continued to January 5 (pp. 27, 52, 92) at a rate of 3,500,000 gallons per acre, slowed down to 2,000,000 gallons after December 30. On December 27 the filter for the first time gave an effluent having over 100 colonies per cubic centimeter, which was subsequently found to be due to the break in the surface of the filter on its weak line over the pet-cocks and brass tubes inserted into the sand on November 21. During the remaining days of the run the effluent was necessarily of an unsatisfactory character.

During the fifth and last run, which lasted from January 6 to March 2, a period of 56 days, at a rate of 3,000,000 gallons per acre per day, the effluent on 40 of these days was of such a character as would in practice have called for an investigation into the defects of the filter or of its management, but nothing appears to have been done. The filter, notwithstanding that the previous run had demonstrated its specially weak line over the pet-cocks, continued to be accepted as representing the acre filter beds of Europe and no effort appears to have been made to reduce the rapidity of the filtration so as to bring the effluent within the limit of allowable bacterial impurity.

BACTERIAL EFFICIENCY OF MECHANICAL FILTERS.

The work of the mechanical filter as determined by bacteriological experiments during its working days from July 18, 1899, to February 28, 1900, is tabulated on pages 58–64 of Colonel Miller's report. From this I find that during the period corresponding with the second run of the sand filter, that is, from the beginning of the observations to September 27, during which the effluent of the said sand filter was satisfactory, the permissible limit of 100 colonies was reached by the effluent of the mechanical filter on one day and exceeded on four days.

During the period corresponding with the third run of the sand filter, September 27 to November 23, the effluent of the mechanical filter was satisfactory. During the period corresponding with the fourth run of the sand filter, November 5 to December 27, there were three days on which the effluent of the mechanical filter was bacterially impure, and during the period to January 5, 1900, when the sand filter was laboring under the disadvantage of the break on its surface, the mechanical filter also was doing exceedingly poor work. During the period corresponding to the fifth run, January 6 to the end of the experiments, the bacteria in the effluent of the mechanical filter were in excess of the limit on sixteen days. This inefficiency on the part of the mechanical filter was attributed to an insufficiency of the alum coagulant (p. 34), or to the absence of facilities for its proper application (p. 113).

COMPARISONS.

To permit of a comparison of the work of the two filters, Colonel Miller has submitted a tabulation (pp. 41, 42) covering the month of December, 1899, and the period January 6 to March 2, 1900. This is intended to demonstrate "that during the period of greatest turbidity and accompanying bacterial danger the English filter will not furnish a satisfactory effluent; while, on the contrary, during this period the mechanical filter will, with proper attention, furnish an entirely satisfactory effluent, both as to turbidity and sanitary considerations." The period of greatest turbidity began December 27, when the bacteria in the raw water mounted up to 7,900 per cubic centimeter, and continued, with a few exceptional days, to the end of the observations, March 2. The report states that during this period the English filter did not furnish a satisfactory effluent, while that from the mechanical filter was entirely satisfactory as to the numbers of bacteria present. The first statement is readily verified, for from December 27 to the end of the month the sand-bed filter was, as already stated, in a markedly disabled condition, and during its fifth run, January 6 to March 2, the number of bacteria in its effluent was over the limit on forty out of fifty-six days. The second statement does not appear to be so clearly sustained, for the bacterial removal effected by the two filters was practically the same. Sixty-one days of this period of greatest turbidity were tabulated, but the mechanical filter on ten of these days was not in operation. There were, therefore, only fifty-one days on which comparison could be made. During these fifty-one days the sum of the bacteria in the raw water amounted to 674,600; the sum of the bacteria in the effluent of the sand filter was 12,249; of the mechanical filter, 12,494.

The sand filter removed 98.18 per cent of the bacteria, the mechanical filter 98.15 per cent. Hence, so far as concerns the removal of bacteria in times of turbidity and large bacterial content in the raw water there seems to have been no difference in the work of the two filters, but it does not follow from this that in actual practice properly constructed filter beds on the European model and managed by European methods would not have given better bacterial results with the Potomac water than were obtained by the New York Filter Manufacturing Company's filter. Besides the important fact that the experimental sand filter had faults which prevent the acceptance of its work as representative of that of the sand beds of Europe it may be pointed out that while an increased turbidity of the influent was met in the mechanical filter by an increased quantity of alum, no effort was made to improve the character of the effluent from the sand filter. The tubes which had caused a rent 11 feet long during the fourth run were continued in place during the turbidity of the fifth run and even the filtering rate of 3,000,000 gallons per acre was kept up throughout.

THE USE OF ALUM.

It will be seen from the record of the work of the mechanical filter that the essential to its efficiency was the addition of alum to the water prior to its passage through the filtering medium. Without the alum or other coagulant the mechanical filter would have been merely a coarse strainer. The amount of alum to be added varied with the condition of the river water. Alum, when added in proper quantity to a turbid surface water, becomes decomposed. A white gelatinous hydrate of alumina is precipitated, which in subsiding carries with it the clay and other suspended particles constituting the turbidity. The ability of alum to clarify turbid waters was known for many years before it was applied commercially in connection with rapid filtration. The gelatinous aluminum hydrate with the particulate substances, bacteria included, present in the water is removed by the subsequent filtration. The soluble sulphates formed during the decomposition of the alum in the water do not interfere with the potability of the latter, although they may detract from its softness. An excess of alum remaining undecomposed in the water would be exceedingly injurious, but the addition in actual practice could, under expert supervision, easily be regulated.

Nevertheless it must be remembered that the addition of any chemical, which would be harmful if in excess, to the water supply of a city merits consideration only if its addition takes away from the water deleterious qualities which can not be otherwise removed. Colonel Miller's experiments have much value in connection with this proposition. According to my reading of his tables of relative efficiency he has shown that an imperfect model of a sand-bed filter can effect as efficient bacterial purification of the Potomac water in its times of highest turbidity as can be effected by clarification with alum and subsequent rapid filtration by the so-called mechanical filters now before the American public.

CONCLUSION.

I am therefore of the opinion that for the purification of the Potomac water filter beds constructed after the European method should be used rather than rapid filtration subsequent to coagulation by alum. The former we know to be efficient in reducing the number of bacteria to a prescribed limit and in materially lessening the death rate from typhoid fever. Years of experience in many cities have demonstrated these facts. The latter gives a clear water and reduces the number of bacteria, but in none of the American cities in which this system has been adopted do we find such a lessening of the prevalence of typhoid fever as may be found in the sanitary history of those cities which make use of sand-bed filtration. Should it be found in practice that the sand beds fail on certain occasions of high turbidity to give a satisfactory effluent the advisability of promoting sedimentation by alum on these special occasions may be considered and carried into practice with little additional expense and supervision. This, however, is a different matter from instituting a filtration system, the essential of which is the addition of alum to the water supply at all times.

Respectfully,

Ch. Smart,
Lieutenant-Colonel, Deputy Surgeon-General U. S. Army.

Gen. George M. Sternberg,
Surgeon-General United States Army.

CHAPTER III.

PAPER ON THE FILTRATION OF PUBLIC WATER SUPPLIES, PREPARED BY PASSED ASST. SURG. H. D. GEDDINGS, OF THE MARINE HOSPITAL SERVICE, AND INDORSED BY SUPERVISING SURGEON GENERAL WYMAN.

TREASURY DEPARTMENT,
OFFICE SUPERVISING SURGEON-GENERAL
MARINE-HOSPITAL SERVICE,
Washington, January 2, 1901.

SIR: I have to acknowledge the receipt of the request of the Committee on the District of Columbia to present a paper on the relative merits of the so-called mechanical system and of the slow sand filtration system from some person in this Bureau, together with such statement thereon as I may see fit to make.

In reply, I have the honor to inclose herewith a report upon this subject from Passed Asst. Surg. H. D. Geddings, which, it seems to me, in a clear and thorough manner canvasses the relative merits of the two systems mentioned. I think proper to state that a verbal request of this same nature was received some time ago from Mr. Charles Moore, clerk of the committee, and on conferring with Dr. Geddings, I learned that he had been giving this subject close and exhaustive study, particularly during the past two or three months, and the inclosed report, though brief, is the result of a very thorough sifting of the literature upon the subject, as well as of previous practical and scientific research.

I think it proper also to add that I am not prepared, neither is Dr. Geddings, to give an unalterable opinion advocating irrevocably either of the systems under consideration, as I feel that to do this would require on his part and my own somewhat of the same investigation of all the facts, local as well as scientific, which it would seem are now being inquired into by your committee, but I wish to state that, so far as Dr. Geddings's report is concerned and the statements made by him, I have studied the matter, and wish to express my confidence in his conclusions.

I think it due to the committee also to give the following statement concerning the qualifications of Dr. Geddings, whose mature judgment during the thirteen years in which he has been connected with the service has been frequently availed of in scientific matters by the

Bureau. Moreover, Dr. Geddings has given special attention to the matters under consideration throughout his professional life, and has had exceptionable training and opportunities for observation in this particular line of work.

Before entering the Marine-Hospital Service he was adjunct professor of chemistry in the South Carolina Medical College, making at that time water supply and water contamination a specialty. Subsequently he made a special study of bacteriology in New York and continued the same at Johns Hopkins University laboratory, and has been almost continuously engaged since in bacteriological and chemical work demanded by the Marine-Hospital Service, including a detail as technical delegate representing the United States at the international conference with regard to plague, held at Venice, in 1897, immediately thereafter spending the greater part of a year in Koch's laboratory in Berlin and at the Pasteur Institute in Paris.

Dr. Geddings was also a member of the commission appointed by the President for scientific investigation into the cause of yellow fever. Recently he has been giving much attention to the matter of water supply of cities and has been in correspondence with the representatives of the service in France and Belgium, who have been giving like attention to this matter and have forwarded to the Bureau the latest developments with regard to the purification of water supplies in those countries.

Attention is invited to the three inclosures accompanying Dr. Geddings's report.

Respectfully,

WALTER WYMAN,
Surgeon-General Marine-Hospital Service.

Hon. JAMES MCMILLAN,
Chairman Committee on District of Columbia,
United States Senate.

HYGIENIC LABORATORY,
UNITED STATES MARINE-HOSPITAL SERVICE,
Washington, D. C., December 26, 1900.

The SURGEON-GENERAL U. S. MARINE-HOSPITAL SERVICE.

SIR: In compliance with your verbal instructions to me to submit to you a comparative statement of the relative merits of the English or so-called "slow sand filtration method" and the American or "mechanical" system of water purification, with any suggestions which might occur to me, I have the honor to submit the following:

It is deemed expedient for the sake of clearness to take up the systems separately, to then institute the necessary comparisons, and to conclude with my personal impressions and the recommendations derived therefrom.

I.—THE ENGLISH OR SLOW SAND FILTRATION PROCESS.

Inquiry shows that this system was first instituted about 1829, and has changed little from that date to this. The advocates of the system, who are many and of eminent scientific attainments, claim that the process is an application and elaboration simply of natural processes, and that following nature the most perfect results are arrived at.

The process in brief is as follows: Large reservoirs of masonry, concrete, rubble or other material are constructed, and in these reservoirs the filter beds are constructed, the foundation of the beds consisting of cobbles or stones of a uniform diameter (from 4 to 6 inches), which serve to support the layers of gravel and sand, and to form efferent channels for the delivery of the filtered water. This layer is surmounted by one or more layers of gravel, varying in size from 1 to one-fourth inch, and these are in turn surmounted by a layer of sand of uniform size to a depth varying from 36 to 48 inches or more. The size of the grains of sand plays an important part in the process, but more important even than the size of the grains is their uniformity of size and shape.

This method of construction has been departed from in late years by substituting rows or channels of drain tile with open joints for the cobble layer, and in some instances dispensing altogether with the gravel layers. The filter being constructed, the water to be filtered is admitted, preferably from the bottom of the bed, in order to displace all air with a minimum of disturbance, and the water is then allowed to gather on the filter bed in a layer of a thickness equivalent, in general terms, to the depth of the sand layer of the filter. The process of filtration then proceeds. The water is maintained at a uniform depth; the process is at first rapid, but soon shows a falling off in quantity; turbidity is *diminished* and a great diminution is noted in the bacterial content of the effluent water. This last is the most important feature of the process from a hygienic point of view, and must now be described somewhat in detail.

It goes without saying that the layers of sand will arrest all particles in the water which are greater in size than the meshes or interstices of the sand grains; but more than this is needed, otherwise but few if any bacteria would be removed. But an interesting change now takes place in the interstices and upon the surface of the filtering layer. There is a rapid formation of a pellicle or scum upon the surface, consisting of the coarser particles suspended in the water, and these, constantly increasing in size, form a place of lodgment for the bacteria contained in the water, which rapidly aggregate into a continuous surface layer, penetrating to only a very small distance below the surface and into the channels between the particles of sand. To this layer the Germans give the name of "Schmutzdecke" and the English the name of "bacterial-felt."

This layer supplies a constantly increasing resistance to the passage of water, very much diminishes the output of the filter, and is the most important factor in the bacterial purification of the water subjected to the action of the filter beds. In time this layer becomes so resistant that the action of the filter beds is almost entirely arrested, but prior to this another change in the conditions becomes evident, viz, that far from diminishing the number of bacteria found in the affluent water, the effluent contains more bacteria than the crude water. This is not to be wondered at, for it can be laid down as a general axiom that in the life of every filter there comes a time when it gives back to water passed through it the bacteria separated from former affluents. The "Schmutzdecke" or "bacterial felt," then, is at once an important factor of efficiency and a source of retarded action and possible delay in the slow sand process of filtration.

When this time arrives, the filter bed must be cleaned. This operation is performed by draining off the water, and then with sharp shovels removing the upper layer of sand to the depth to which it shows any discoloration. Two to 3 inches is usually sufficient. Fresh sand may or may not be used to replace that removed in scraping; the usual practice is to perform repeated scrapings, and when as much as 6 inches of the original stratum has been removed, to replace this quantity. The sand removed is submitted to washing either by the somewhat crude method of the application of a hose or better in revolving mechanical washers. When thus washed and dried, it may again be used in the filter beds. The sand having been removed, a smooth surface is again produced by the application of the rake or other appliances, which remove the marks of the feet of the workmen employed in the cleaning. Water is again admitted to the beds, and the product is allowed to run to waste until a normal rate of filtration is arrived at, when the whole process is repeated from the beginning.

II.—RATE OF FILTRATION BY THE SLOW SAND METHOD.

The rate varies with many conditions, such as the ordinary practice obtaining in the country or locality, the nature of the water subjected to treatment, the fineness of the sand employed, the loss of head or initial pressure which may be determined upon, and, lastly, the vigilance which is exercised in examining the output. Turbidity in the affluent water will soon clog the filters and lead to a slow output. A fine sand will naturally filter more slowly than a coarse or coarser one, and a plant which is not carefully supervised as to bacterial efficiency will give or be permitted to give a far greater output than one in which everything else is sacrificed to this end.

The output is usually expressed in gallons per square foot of filtering surface, or more generally in gallons per acre of surface per day of twenty-four hours. Expressed in these latter terms the rate reported from European cities varies from 13,895,000 gallons per acre per day in Oporto, Portugal, and 7,500,000 gallons per acre per day at Zurich, Switzerland, to the comparatively low figure of 1,655,000 per acre per day by the West Middlesex Company (London, England). The water at Zurich is derived from a lake of great natural purity and without turbidity; the London water is the turbid water of the Thames, contaminated by surface pollutions and drainage, and also by the discharge of the products of numerous factories and industrial plants. The filters recently constructed at Albany, N. Y., are constructed to give an output of 3,000,000 gallons per acre per day under the best conditions of friction and loss of head.

The regulations of the Imperial German board of health place the maximum at 2,613,525 gallons per acre per day, or 60 gallons per square foot, but as this is accompanied by certain other conditions this output may be considerably reduced, while it may *not* be exceeded. Colonel Miller, in his report to the Secretary of War, bases his estimates for the supply of the city of Washington on the rate of 3,000,000 gallons per acre per day—a seemingly large estimate when the number of days of turbidity of the Potomac water is taken into consideration.

As has already been stated, the filter beds require cleaning at longer or shorter intervals. This renders it necessary to have a reserve filter, the area of which is variously arrived at, but which may be stated in general terms to be equivalent to 20 to 25 per cent of the total area; in other words, the quantity of water desired and the rate of filtration being determined upon in advance, 1.2 to 1.25 acres must be allowed for, instead of 1 acre.

III.—COST OF FILTER BEDS FOR THE SLOW SAND FILTRATION METHOD.

This of course varies with the cost of land, materials, labor, style of construction, and is largely increased if the beds are to be covered or to remain exposed to sun and air. The price is best stated in terms of cost per acre, and is as follows:

	Uncovered.	Covered.
	Per acre.	*Per acre.*
London	$24,000 to $39,000	
Liverpool	do	
Zurich		$98,000
Hamburg	30,500	
Berlin		70,000
Average for all European cities	45,000	68,000
United States:		
Poughkeepsie, N. Y		112,641
Ilion, N. Y		101,900

The filters recently constructed at Albany, N. Y., having an area of about 0.7 acre, are stated to have cost $496,633, including all adjuncts, which are of remarkable completeness. Except in the case of Albany, the prices given do not include sedimentation basins, a very necessary adjunct, and which would materially increase the cost.

Colonel Miller estimates the cost for the city of Washington of a plant having 27 acres of filter beds and 8 acres for other purposes at $2,461,338, allowing for covered filter beds. The necessity for this particular item of expenditure is based upon observation of average January temperature for a term of years, and hydraulic engineers have drawn upon the map of the United States an isothermal line, having one end upon the Pacific coast at a point north of the State of Washington, and sweeping south in a curve to the south of Santa Fe, and thence east to a point on the Atlantic coast, about midway between New York and Atlantic City, N. J., and touching Philadelphia. This being but slightly north of Washington, the provision for covered filters would seem to be a wise one.

IV.—RESULTS OBTAINED FROM USE OF SLOW SAND FILTRATION.

These have been most gratifying from almost all points of view. Turbidity is diminished, but in the case of really turbid waters such a sparkling product is not obtained by this system as may be arrived at by others. It is without beneficial effect upon stained or tinged waters as opposed to turbid waters. Judged from the standard of bacterial efficiency the results are most excellent, and this is after all the most important consideration from a sanitary point of view. Figures are given as follows:

Percentage of bacteria remaining in water when output is—

	Per cent.
500,000 gallons per acre	.010
1,000,000 gallons per acre	.048
1,500,000 gallons per acre	.067
2,000,000 gallons per acre	.088
3,000,000 gallons per acre	.356

(Lawrence, Mass.; water from Merrimac River.)

Other statements give almost as gratifying results. The general bacterial efficiency of the slow sand filtration under efficient supervision may be stated as varying from 98.5 per cent to 99.3 per cent. The filters require cleaning at intervals varying from three to five weeks. Colonel Miller in his report estimates for nine cleanings in the course of the year, or an average of five and seven-ninths weeks of activity. The advantages of the slow sand filtration therefore are: (1) Great bacterial efficiency; (2) that no chemical or other agent is added to the water before or during the filtering process.

The disadvantages are: (1) The very large space needed for the construction of the filter beds; (2) the cost of constructing these beds apart from the cost of the ground upon which they are built; (3) the fact that turbidity is only partially removed and that stained or tinged waters are not improved in appearance; (4) the liability to breakage or disturbance of the "Schmutzdecke" or active filtering agency in the process; (5) the possibility that even with an undisturbed "Schmutzdecke" the cleaning of the filters will be too long delayed, and that the water will come from the effluent with a larger bacterial content than the affluent; (6) the inclination to force the beds beyond their capacity in times of scarcity or unusual consumption of water; (7) the certainty that if the "Schmutzdecke" is broken or cracked in any given filter bed the water from that bed will be contaminated, and, if not recognized at once, that the whole content of the storage reservoirs will be contaminated from the admixture.

II.—MECHANICAL FILTRATION—THE SO-CALLED AMERICAN SYSTEM.

The filtration of large quantities of water through limited areas of sand, and usually under pressure and accompanied by the employment of patented appliances, is a system so entirely confined to this country as to have received the name of the "American" system.

The essential feature of the process consists in the addition to the water to be purified of a charge of alum or other soluble alumina salt and then admitting the water to the filter, which consists of a cylindrical vessel, placed either vertically or horizontally, and filled two-thirds full of fine sand of uniform size.

The alumina compound (a sulphate) unites with the carbonates of lime and magnesia contained in the water, and is precipitated as alumina hydroxide, a magma of gelatinous appearance, and quite insoluble in water.

The reaction may be stated as follows: $K_2Al_2(SO_4)_4+3CaCO_3+3H_2O=3CaSO_4+K_2SO_4+3CO_2+Al_2(OH)_6$.

This material falling to the bottom of the water mechanically entangles all suspended matter and bacteria, and is deposited in a layer upon the surface of the sand filter, from which it is removed at stated intervals by a reversed current of filtered water, thus cleaning and washing the filtering sand.

This washing can be accomplished in about fifteen minutes, and at an expenditure of filtered water which need not exceed 4 per cent.

It will thus be seen that the action of the alum is to form rapidly and artificially a layer or coating upon the surface of the filter to replace the "bacterial felt" layer of the English system. A further action of the precipitated aluminum hydroxide is to unite with the dissolved coloring matters of tinged or stained waters, removing them, and producing a clear and sparkling product, which can not be arrived at by the English system.

It must be distinctly understood that the addition of alum is an essential in this process, as the very rapid passage of the water through the sand layer without it would simply amount to a straining and would not remove the bacteria. It must also be borne in mind that in order to effect a successful sedimentation by the use of alum the water must contain carbonates of lime or magnesia, either in suspension or in solution. The chemical reaction shown above can not take place in their absence, but in the rare cases in which there is a total absence of these ingredients they may be supplied and the alum system employed either by the direct addition of chalk to the water prior to the addition of the alum or by passing the crude water through a preliminary sand strainer in which a portion of the sand is replaced by crushed marble (crystallized calcium carbonate).

In all processes under the American or mechanical system the alum in solution is added to the water by mechanical appliances, in quantity either sufficient to dose the carbonates present, or to react upon such a proportion of the calcic contents as will affect a clarification of the water subjected to the process. Any detailed description of the various forms of filtering apparatus operating under this system would be impossible and undesirable here. The principle has been given, but it may be said in addition that every type possesses mechanical appliances peculiar to itself to break up the deposited bacteria bearing layer and facilitate its removal during the process of washing the filter.

OBJECTIONS URGED AGAINST THE USE OF THE MECHANICAL SYSTEM OF FILTRATION.

These have been numerous, some made in all good faith, and having a certain amount of scientific reasoning behind them; but by far the greater number have arisen from ignorance and prejudice, and should be capable of removal or withdrawal by reasonable explanation.

The prime objection urged is, in the first place, that a germicidal or chemical substance is added to the water in the shape of alum, and that this alum is permanently found in the filtered water and is injurious.

This may be answered that the alum is not added with a view to its bactericidal effect. Indeed, in the quantities in which it is employed (one-fourth grain to 3 grains per gallon), it is a matter of easy demonstration that it is absolutely without such germicidal effect.

That it passes into the filtered water as alum is also denied, and if it is so present it is a proof that it has been added in a perfunctory and injudicious manner. The object of the addition of the alum has been stated. It has been shown that its quantity must never exceed the amount necessary to react with the lime contained in the water. This whole amount may not be needed to effect a perfect product, but may well be held in reserve to be added to the water in times of great or unusual turbidity. The most that can be urged against its use is that a certain quantity of the lime contained in water as carbonate is converted into sulphates, thus changing a portion of the removable into permanent hardness, and while this converted hardness may make a large display in an exposition of percentage proportions, it is in reality a small and almost perfectly negligible quantity.

The process, then, is unobjectionable from a chemical or sanitary standpoint.

EFFICIENCY OF THE MECHANICAL SYSTEM.

This has been very gratifying, and it is believed that the results will bear the closest scrutiny.

A well-known corporation operating a system of rapid or mechanical filtration makes the following guaranty and gives the following standard of purity:

First. All odor, color, and suspended impurities shall be removed.

Second. The free ammonia in the filtered water shall not exceed 0.05 part in 1,000,000.

Third. The albuminoid ammonia in the filtered product shall not exceed 0.1 part per 1,000,000.

Fourth. No measurable amount of the coagulant or other purifying agent used shall be left in the filtered water.

Fifth. The microbes in the filtered water shall not exceed 100 per cubic centimeter.

An examination of these results shows that they are all that could be desired. The removal of turbidity and color could *not* be accomplished by sand filtration; the amounts of free and albuminoid ammonia are entirely unobjectionable and are within the limits given by the best authorities as constituting a good water; the number of bacteria per cubic centimeter is the limit set by Koch, and is the official requirement of the German imperial health board.

Can these promises be maintained?

A series of experiments were made with a set of Jewell filters at Lorain, Ohio. The water was the water of Lake Erie. For the period of one week, with alum to the amount of 2.58 grains per gallon, the bacterial efficiency was 98.9 per cent. For the period of one week, using 2.50 grains per gallon, the bacterial efficiency was 98.4 per cent.

For six weeks the quantity of alum ranging from 0.94 to 2.58 grains per gallon the average rate of output was 1.14 gallons per square foot per minute, and the average of bacterial efficiency 96.4 per cent.

In the Pittsburg experiments during six months the Jewell filter gave an average bacterial efficiency of 97.45 per cent, the raw normal water containing 11,531 bacteria per cubic centimeter. In the same city and for six months the Warren filter, on water containing 11,531 bacteria per cubic centimeter, gave an average bacterial efficiency of 98.26 per cent.

A sand filter receiving the same water for the same period gave a yield containing 105 bacteria per cubic centimeter. It is believed, therefore, that it must be conceded that mechanical filtration is safe and efficient.

Statistics have been given which would seem to show upon their face that the introduction of mechanical filtration in certain cities—as Elmira, N. Y., Newcastle, Pa., and Lexington, Ky.—have caused, or or at least been coincident with, an increase of typhoid mortality. This is hardly fair to the statistics, and is certainly unfair to the mechanical system, for no mention is made of the fact that during the period which is presumably covered by these figures there has been a gradually, but constantly spreading, wave of typhoid over the entire country, reaching its acme in 1898–99 with the aggregation of volunteer troops in large camps of instruction, and which has resulted in the contamination of streams and sources never heretofore suspected of contamination.

Again, it may here be stated once and for all that no filter or system of filters can or will exert any selective elimination of pathogenic bacteria. The pathogenic or sewage bacteria in any given water simply bear a relative proportion to the whole bacterial content, and will be proportionately removed by any system of filtration in direct ratio to its bacterial efficiency—no more and no less. To claim otherwise is not just, and can not be substantiated.

COST OF MECHANICAL FILTRATION.

As has been before stated, the various types of apparatus designed to accomplish rapid or mechanical filtration are all controlled by companies or corporations; are protected by patents, and are either sold outright or operated on a royalty. This being the case, it is obviously impossible to form as close an estimate of cost for this system as is the case in the sand method.

Again referring to the report of Colonel Miller, we note that on the basis of a daily supply of 60,000,000 gallons per diem he estimates the cost of the plant required at $1,081,377, as compared with $2,461,338 for the English or slow sand method.

The most striking point of difference occurs in the amount of ground required, viz, 163,430 square feet, for the mechanical system, as against 1,111,176 square feet for the English.

The comparative cost of operating does not enter into such a communication as the present, and will not be dwelt on. It is interesting, however, to note that Colonel Miller places the average amount of alum coagulant necessary per year at the low figure of 1.3 grains per gallon, a quantity which need excite not the slightest uneasiness. The small area of ground required is easy of explanation when it is remembered that water can be passed through the sand filter at the rate of from 120,000,000 to 150,000,000 gallons per acre per day under the mechanical system, as against the maximum of 3,000,000 per acre per day in the slow sand method.

A COMPARISON OF THE SLOW SAND AND MECHANICAL SYSTEMS OF FILTRATION.

Cost of installation.—As given by most authorities and confirmed in detail by Colonel Miller, the mechanical system is much the cheaper. In the case of the proposed supply for the city of Washington the figures, as already quoted from Colonel Miller, show that the cost of the mechanical system is only about 43.5 per cent that of the slow sand filtration method.

Cost of maintenance.—This is given by Colonel Miller as follows:

Cost of operating per 1,000,000 gallons.

	Including interest charges and deterioration.	Excluding interest charges and deterioration.
English filters	$8.51	$3.44
American filters	8.75	5.61

Efficiency.—The English system can not be counted upon to remove turbidity. It will reduce it to a certain extent, but the filtered product will not be sparkling. It will be without effect on color dependent on dissolved matters, and the report of Mr. Weston to Colonel Miller shows that the Potomac water is slightly tinged. The great turbidity of the Potomac water during certain seasons of the year will reduce the efficiency of the English filters and make more frequent cleaning a necessity. As this turbidity occurs most frequently in winter, the cleaning of the filter beds will subject them to freezing, which has a very deleterious influence on their efficiency. On the other hand, the American system will entirely remove turbidity and color, and the increased seasonal turbidity will have no prejudicial effect upon the filters of the American system, as these are subjected to periodical cleaning or "scrubbing" with a portion of the water filtered, which cleaning water need not exceed 4 to 5 per cent of the total product.

Bacterial efficiency.—As has before been stated, no filter will or can be expected to exert a selective influence in the matter of bacterial separation. A filter will remove a certain percentage of the bacterial content of water, and if pathogenic or sewage bacteria are present these will be removed in direct proportion to their number as compared with the whole bacterial content.

The bacterial efficiency of the slow sand system can not be put higher than 98.5 to 99.3 per cent as a maximum. Immediately after cleaning the efficiency is much less, and when the filters are in need of cleaning they may show an even more decided departure from their normal. As has already been shown, the Pittsburg experiments with the Jewell and Warren filters gave results approximating 98 to 99 per cent, and were within the limit of 100 bacteria per cubic centimeter of filtered water. At the same time a sand filter operating on the same time and presumably under advantageous conditions gave an average of 105 bacteria per cubic centimeter.

The number of bacteria, 100 per cubic centimeter, was fixed upon by Koch as the extreme limit which should be contained in a properly filtered water, and was adopted by the Imperial German board of health as a standard. It therefore seems perfectly fair to say that the mechanical filters have given a satisfactory bacterial result, and the fractional percentage in favor of the sand system should not be held to counterbalance its recognized defects in the matter of slow delivery, opalescent or slightly turbid product, great cost, and liability to accident through the breakage, cracking, or displacement of its layer of "bacterial felt." This last is not an imaginary danger. Instances are on record of serious contamination of storage reservoirs traceable on examination to a slight crack in this layer.

As a result, therefore, of my investigations I would here beg to state to you that I consider the mechanical system, under careful and intelligent supervision, as perfectly capable of furnishing a safe city water supply.

But in this connection I would like to go a step further and to submit to you an additional recommendation, the adoption of which would, I believe, result in a water supply beyond criticism, and perfect from the æsthetic and bacterial points of view.

I refer to the recently exploited system of water purification by the methods of Messrs. Marmier and Abraham, described in No. 44, Vol. XV, of the Public Health Reports of the Marine-Hospital Service, under date of November 2, 1900. The reports therein contained show that the application of ozone to water supplies, under the processes of Marmier and Abraham, give a product practically entirely free from any bacterial contamination, the result being simply about one colony of the *Bacillus subtilis*, or hay bacillus, per 25 cubic centimeters of water treated, with an absolute removal of the bacteria which to the average number of 2,200 per cubic centimeter were present in the water supplied to the city of Lille, France. The experiments were conducted upon quite a large scale, as compared with ordinary laboratory experiments, and a commission composed of such eminent scientists as the bacteriologists Roux and Calmette and the chemists Buisine and Bouriez commend the process in unqualified terms as satisfactory from a bacteriological standpoint in that all bacteria other than a few hay bacilli are removed, and from a chemical standpoint in that organic matter is destroyed, no permanent chemical added to the water, and that organic matter being destroyed the water is less likely to become the seat of subsequent bacterial infection by reason of the removal of the substances upon which bacteria thrive.

Again, the cost of the process can not be definitely entered upon here, but it would seem to be quite reasonable. It is stated that an installation for the treatment of 100,000 cubic meters of water per day (about 21,000,000 gallons approximately), all apparatus being in duplicate, would be about $160,000, and that the cost of treatment would be about $0.0008 to $0.0012 per cubic meter where coal is used to generate the power, and only about one-half this amount where water power can be used for this purpose. Another valuable feature of the process would seem to be that it requires little space for the installation, a building of comparatively small size containing the boilers, engines, dynamos, ozonizing apparatus, etc., and it would seem perfectly feasible to operate the ozonizing method in conjunction with any other system of purification to the end that a more perfect product might be obtained.

I would respectfully submit to those having the matter in charge the adoption of such a combined system for the city of Washington, viz, a system of mechanical filtration, with all its advantages of small required area, comparatively small first cost, perfection of product as to removal of color and turbidity, and the removal of all bacteria save a number not to exceed 100 per cubic centimeter. Add to this the ozonizing process, which would definitely remove these 100 bacteria and render the water as it enters the storage reservoirs unfit for the maintenance of bacterial life, and it would seem that a water supply challenging the world for purity and wholesomeness would be the result.

Another important feature would be that the system being a double one, with both of its component parts of almost absolute perfection, there would be a minimum of danger or embarrassment from a breakdown or derangement of either of these elements. Were the mechanical filters to be temporarily out of order, the ozonizing plant would still furnish a water bacterially pure, but perhaps a little turbid or tinged. Were the ozonizer out of action, the mechanical filters would still furnish a product æsthetically pleasing and safe from a bacterial point of view. I do not pretend to go into the mechanical aspect of the subject or the engineering difficulties which it might present, but these matters might be safely left to the very high talent which now have these features of the problem under consideration.

It is needless, it is believed, in concluding this review, to apologize for its incompleteness and shortcomings. When it is remembered that large volumes have been written specially, not only on the topic of water supplies, but on the single feature of their filtration, and when the differences between authorities of eminence in the matter are remembered, it will be evident that any résumé of this kind must necessarily be incomplete, and savor largely of the personal beliefs and views of the reporter.

Respectfully, H. D. GEDDINGS,
Passed Assistant Surgeon, Marine-Hospital Service,
Acting Director of Laboratory.

CHAPTER IV.

LETTER FROM MR. ROBERT SPURR WESTON IN REGARD TO THE REPORT OF THE DISTRICT OF COLUMBIA MEDICAL SOCIETY.

NEW ORLEANS, LA., *January 2, 1901.*

COLONEL: Your recent letter inclosing a copy of a report made to the Medical Society of the District of Columbia by a committee of physicians is received, and as an interested party I would criticise the report as follows:

It is evident that this report represents the best ideas of the local physicians and therefore of the most intelligent laity in Washington, and the opinions expressed should not go unchallenged, in so far as they were and are refuted by the facts.

I will take up the report under the same headings as were used by the writers, as follows:

"*Need for filtration.*"—The writer is in hearty agreement with the committee.

"*Practical effects of filtration.*"—It is true wherever the English system of filtration has been installed under favorable conditions that there has been a reduction in the mortality from typhoid fever, but the filters at St. Petersburg failed to protect against this disease in 1899, and at Altona and Bremen it is necessary to subject the water to double filtration. Why? Because the sources of supply are silt-bearing streams, and are difficult to handle with the English filters at certain flood seasons.

"*Cost of sand filtration.*"—The writer does not agree with the committee that uncovered filters would be advisable, although at the time his report was written he did think so. In his supplementary report of the 17th of March (not published) he makes the following statement:

> In the previous report the writer advised the present construction of open filters (to be used with coagulant), but now, in view of the high cost of land and the greater reserve filtering area, which must be necessarily provided for in this climate, it would seem, even disregarding construction cost, that the difference in cost between a sufficient area of covered filters and a necessarily larger area of uncovered filters, would be more than offset by the greater convenience in operating the covered filters.

The writer believes that the germicidal effects of sunlight—almost nil when the water is turbid—are more than offset by the ill effects of

---

Simin, Trans. A. S. C. E. 1900.

the sun as influencing obnoxious growth of algæ and other microscopic organisms.

"*Comparative cost of sand and mechanical filters.*"—Believing as he does, namely, that sand filters without coagulation during the turbid seasons would be a costly failure, he can not conscientiously compare their cost. Moreover, if clay gradually penetrates the bed, as it would were English sand filters installed, the renewal of the sand layer would be so costly as to prohibit their use from an operative standpoint.

In the supplementary report (not published) the writer estimated the cost of filtration by the modified English system, using a coagulant 25 per cent of the time, to be $9.15 per million gallons, and the cost of filtration by the American system to be $8.27 per million gallons. Owing to the reduced cost of sulphate of alumina, these estimates can now be somewhat reduced, the American system more in proportion because the cost of coagulant is a more important factor in it.

"*Mechanical filters ineffective, as indicated by typhoid-fever death rates.*"—While agreeing with the committee that the mechanical filter results in practice so far have been unsatisfactory from a public-health standpoint, the writer would call your attention to the fact that nearly, if not all, the mechanical plants mentioned by the committee have been installed for æsthetic reasons, as were the first sand filters by Simpson, in 1839.

The committee in their report ignore the fact that the cities of Louisville and Cincinnati have both decided, after extensive and exhaustive investigations, that the English system is inapplicable in their cases. This work of the last five years has demonstrated beyond a reasonable doubt that the American or mechanical system, when properly designed to meet the required conditions, and well constructed and operated, will give a hygienic efficiency as great as any practicable purification process now known.

The keynote to their efficiency is the proper coagulation of the water prior to filtration, and it is imperative that they should be well managed at all times to attain this result; equally careful management is necessary with any system of purification.

Of the cities mentioned by the committee on page 4, only one, Atlanta, has a typhoid-fever death rate greater than Boston, a city supplied with a fairly pure water. This death rate can be traced to sources other than the water supply. Lexington filters her supply in order to remove algæ growths and odors and Reading, Mass., to remove iron from hygienically pure, deep-well water.

Moreover, none of the filter plants quoted by the committee represent the best practice, as developed during the last five years.

It should also be borne in mind that the mechanical filter as operated at Washington did not represent the best practice, because insufficient time elapsed between the addition of the coagulants and the application of the water to the filter. The water therefore at times missed the keynote of successful treatment by this system, namely, perfect coagulation or aggregation of the suspended matter, considering both submicroscopic clay and bacteria as suspended matter, before filtration. This and the avoidance of its consequences, in practice, is discussed in the writer's report.

"*Superior bacterial efficiency of sand filters.*"—It is under this and the following heading that the writer finds the most to criticise in the committee's report.

First, they fail to make any allowance for the fact that the mechanical filter many times, especially during the summer and early fall, was purposely operated with less than a sufficient amount of coagulant, sometimes with none, in order to determine the minimum effective amount of the same. The English filter, on the other hand, was necessarily operated to obtain the best results.

Granting the committee's contention that absolute numbers of bacteria in drinking water bear but little relation to the prevalence of typhoid fever, the fact still remains that the bacterial efficiencies of the respective systems are best measured by comparing the numbers of bacteria in the effluent with those in the influent. No filter, for example, will completely remove the bacillus coli communis at all times, but its frequency can be diminished to insignificance by carefully operated purification systems. For 25 per cent of the average year this effect could not be secured by the English system at Washington, owing to the high amount of colloidal suspended matter contained in the water.

"*Effects of filtration on turbidity.*"—It is conclusively shown in our reports that high turbidities of effluents were contemporaneous with high numbers of bacteria and low efficiency. To attempt to prove the contrary of this by reference to insignificant chemical determinations is absurd.

The committee did not seem to notice the significant chemical data, which are as follows, expressed as parts per million:

	Potomac water.	English filter effluent.	Mechanical filter effluent.
Color	0.20	0.19	0.06
Oxygen consumed	4.5	3.7	2.05
Albuminoid ammonia	.105	.068	.058
Free ammonia	.013	.003	.005
Nitrites	.002	.000	.000
Incrusting constituents	17	16	29
Alkalinity	75.5	75.2	62.2
Residue on evaporation:			
Dissolved	126	123	126
Suspended	13	3	0
Total	139	126	126
Iron	.88	.29	.05
Carbon dioxid	34	41	43

These results show better chemical purification for the American or mechanical filter. The increase in "incrusting constituents" or "permanent hardness" is counterbalanced by the decrease in the alkalinity; this is the effect of the addition of the coagulant.

The more turbid English-filter effluent contained more organic matter and iron than did the effluent of the American filter.

"*Clarification by sand filter satisfactory.*"—This was not so between December 28, 1899, and March 17, 1900. Were such water supplied to the citizens of Washington, the honorable members of the committee would be the first to complain. Certainly the public has a right to demand clear filtered water, if hygienic results can at the same time be obtained. Especially is this true since the investigation proved that ineffective bacterial purification was contemporaneous with turbid effluents.

"*Addition of 'alum' to Potomac water not warranted.*"—The writer still adheres to his published statement that "the almost unanimous conclusion of experts on water purification is that if the alkalinity of the influent is sufficient to completely decompose the applied chemical its use is in no way prejudicial to health."

That this has not been proved by the experience of the medical profession is stated by the committee. The writer agrees that everything does "depend" upon the nature of the substances into which the applied chemical is decomposed.

Since we know what these products are, we should be able to predict the result to a certainty.

The chemical change would transform at the maximum 25 parts per million of "alkalinity" or carbonates of lime and magnesia into an equivalent number of parts of "permanent hardness," or sulphates of lime and magnesia, and would set free about 10 parts per million of carbonic-acid gas. That this change would be apparent on the inside of a steam boiler is quite possible, but the fact that waters containing ten times the above amounts of sulphates are drunk daily by many hundred thousands of Englishmen is, in the writer's opinion, a refutation of the committee's statement, even from a medical standpoint. Physicians are daily recommending American mineral waters, which contain similar amounts of the above constituents, as especially beneficial. The writer, too, believes that coagulants should not be used except when necessary. He would call your attention to the whole paragraph of the report of the Committee on the Pollution of Public Water Supplies of the American Public Health Association, instead of the excerpt:

> For those waters, which for long periods at a time contain excessive quantities of finely divided clay, there is no practicable method of purification without the use of a coagulant and subsidence basins. It is the consensus of opinion, however, that coagulants should not be employed where it is practicable to secure satisfactory results without them.

While coagulants can be successfully used in connection with the English system of water purification, in those cases where coagulants are imperative, the American method, as a rule, yields a somewhat more efficient and economical effluent.

Many of the purification plants now in operation in this country have not shown as high efficiency as is reached in a few of the better ones and as may be expected from those now to be built. This is due in part to their construction and in part to their management, the latter point applying particularly to mechanical filters.

This opinion probably represents the best existing thought on the subject in hand, since it is the composite report of a committee composed of physicians, engineers, chemists, and sanitarians, each member being especially trained along water-purification lines.

"*Reasons why experimental sand filter did not accomplish even more striking results.*"—(*a*) It is usual to construct English filters with vertical walls. It is probably true that the current along the walls of the filter was slightly increased. This is not, however, indicated by the depression at the periphery of the sand layer, since all bodies of sand in round filters compact toward the centers of the same when water is drawn away. This is due to the capillary adhesion between the sand grains. This disappears when the voids of the sand are refilled.

Our English filter now in operation at New Orleans shows the same depression at the periphery as did your Washington filter, although our filter has grooves cut around the sides only six (6) inches apart. Increased rates along the sides of English municipal filters are usually due to cracks in the masonry. Wet sand conforms to all inequalities of the filter walls.

If it were true that the proportionately large periphery militated against the efficiency of the sand filter, would it not have influenced the results of the mechanical filter to a greater degree since the ratio of periphery to sand surface was much greater in the case of the latter smaller filter?

Experimental English filters of the same size at Lawrence have given better results than those obtained in practice.

(*b*) That the filter was always refilled with unfiltered water is true, but only once from below, then with clear water containing few bacteria. This was a disadvantage from an operative standpoint chiefly, as the water had to stand on top of the filter a longer time before starting the filter in order to allow all of the entrapped air to pass out before beginning filtration.

This had little or nothing to do with the working of sediment into the bed. That was because of the peculiar composition of the applied water.

In a clay-bearing stream the zoogleal masses of organic matter are attached to the silt particles. Therefore, the formation of a biologic film around the sand grains of the filter is a matter of extreme difficulty or impossibility, and upon the formation of this film the efficiency of the process hangs.

The filters were not shut down and scraped December 28, because the surface of the sand would have frozen. This would happen in practice with uncovered filters, and would produce the same ill effects.

(*c*) The sand, though somewhat coarser than recommended for the modified English system, was not too coarse for good efficiency, under other conditions, with the plain English system, using no coagulant.

Sand of from 0.19 to 0.22 mm. effective size was recommended for the filters *to be used with coagulant.* Much coarser sands are in use in English filters, in practice, for example:

City.	Effective size of sand.	City.	Effective size of sand.
	mm.		*mm.*
London, average	0.37	Zurich	0.30
Antwerp	.38	Liverpool, Rivington	.43
Berlin, average	.35	Liverpool, Owesty	.31
Magdeburg	.40	Albany	.36
Breslau	.39		

Comment on the above is unnecessary.

"*Sand filtration a natural process.*"—The writer has nothing to say to the committee's quotations beyond what he has said above, namely, that this biologic action, so essential to the operation of sand filters, does not occur at Washington, since nearly all of the organic film-forming material is absorbed by the particles of silt during the turbid seasons, leaving none to form a film on the sand grains.

"*Mechanical filtration a chemical process requiring utmost care.*"—This is a truth well stated and granting good design, care, and experience, the process is satisfactory.

The committee seems to misunderstand the action between a coagulant and the water. When sulphate of alumina (or alum even) is introduced into Potomac water in proper amounts it ceases to exist as such, but is changed immediately into bacterially inert sulphate and the insoluble hydrate, the latter the sine qua non of coagulation. Therefore there can be no bactericidal action and the bacterial counts can not be affected by the addition.

"*Results of mechanical filtration unsatisfactory.*"—Also quoting Mr. Fuller:[1]

> It is not many years since nearly everyone interested in water purification, including the speaker, was inclined to regard English filters as being readily adaptable to the satisfactory treatment of practically all waters.
>
> At Cincinnati it was learned that after the flood water was subsided, for three days and afterwards, applied to English filters, at a normal rate, the effluent would be of a satisfactory quality for one or two weeks; then it would become turbid, and toward the end of long freshets the effluent would be more turbid than the unfiltered water, due to the washing out of the clay that was stored in the sand layer from the earlier part of the flood.

---

[1] Kings Co. Med. Soc., Brooklyn, September 18, 1900.

> Concerning the successful purification of those highly colored or turbid waters for which English filters, either alone or in connection with settling basins, have such marked limitations, it may be stated that as far as is now known it is necessary to make use of coagulation as one of the steps in the process.

Sulphate of alumina has been used repeatedly to aid in the purification of Holland water supplies at Groningen, Gouda, Schiedam, Leewarden, Delft, Alkmaar, and Vlaardingen.

Mr. Fuller says again in the same paper:

> Coagulation by itself is not a complete process for purifying water. It is simply an aid. * * * Bacterial purification is only facilitated by it, due to the aggregation of the bacteria into relatively large masses, which can be removed more easily than the individual members.
>
> When the applied coagulant is completely decomposed, it may be stated in unqualified terms that no ill effects will be met in the treated waters.
>
> This is based on the most careful tests afforded by chemical science, and by the experience of years of from one to two million water consumers.
>
> In cases where coagulation must be employed in purification it is optional whether it be used in connection with English or American (mechanical) filters.
>
> When American (mechanical) filters are well designed, constructed, and operated, it may be said that they will give a hygienic efficiency as great as by any practicable purification process now known.

"*Sand filters recommended.*"—In view of the above facts it seems to the writer that the committee are flying in the face of the data which has been accumulated since the beginning of the Louisville experiments in 1895 when they recommend uncovered English filters *without coagulants* for the purification of the Washington water supply.

At St. Petersburg the bacterial efficiency of the filters drops to 60 per cent during the Neva floods, and the writer would fear a similar, though less marked, diminution in the efficiency of the Washington filters should the English system be adopted.

The writer realizes that the work of the committee has been a labor of love, and their interest and time have been freely given and with that fine public spirit which has usually characterized the medical profession, which plays a most important rôle in molding public opinion to a degree which allows improvements in the sanitary condition of water supplies.

It seems unfortunate, therefore, that the committee, representing the most influential body of professional laymen in Washington, do not seem ready to accept the conclusions of various professional experts on water purification, nearly all of whom would agree to the general conclusions of your and our reports.

At present the writer is engaged in an investigation into the feasibility of purifying the Mississippi River water at New Orleans, and feels sure that the data will force the same conclusions as at Washington, namely, that coagulation as a preliminary step to filtration will be a necessity. Our English filter, even with water subsided for six days, has yet failed to give a passable effluent, either from a hygienic or an æsthetic standpoint. This filter is much more refined in construction than could be expected in practice, and its failure up to this time is a confirmation of what goes above.

Yours, respectfully,

ROBERT SPURR WESTON,
Resident Expert, Sewerage and Water Board of New Orleans, La.

Lieut. Col. A. M. MILLER,
Corps of Engineers, Washington, D. C.

CHAPTER V.

EXTRACT FROM ANNUAL REPORT OF THE COMMITTEE ON PUBLIC HEALTH, PRESENTED TO THE BOARD OF TRADE NOVEMBER, 1900. REFERRED TO THE COMMITTEE ON THE DISTRICT OF COLUMBIA, UNITED STATES SENATE, BY THE WASHINGTON BOARD OF TRADE.

The number of deaths during the past year from typhoid fever was 221 as compared with 169 in 1898–99, or an increase of 52 deaths. This difference is to be explained in part by the increase of population and in part by the general spread of the disease in most of the Atlantic cities. The number of deaths from this cause is very great, and yet in 1890, with a population of 230,000, there were 208 deaths, and in 1895, with an estimated population of 268,000, there were 221 deaths.

If the number of cases is estimated from the number of deaths, the average mortality being known, it is seen that there were during the past year from 1,500 to 2,000 cases of typhoid fever, with an average duration of four weeks, entailing great suffering and loss of time and money by those so afflicted.

At the present time the city is well sewered, and with two exceptions is in a better sanitary condition than heretofore, but the regularly recurring death list from typhoid fever makes it an important duty upon every citizen to work for the removal of the causes that produce and maintain this fatal disease. The following table gives the annual number of deaths from typhoid fever from 1881, when records of deaths began to be kept, to the present time:

TABLE I.

Years.	Population.	Deaths from typhoid fever.	Ratio of deaths from typhoid fever to 1,000 deaths from other causes.	Ratio of deaths from typhoid fever to each 10,000 population.
1881	183,000	67	16.2	3.6
1882	188,653	120	26.2	6.3
1883	191,980	92	21.4	4.8
1884	200,000	76	16	3.8
1885	200,000	124	25	6.2
1886	205,000	125	27.2	6.2
1887	210,000	116	25	5.5
1888	225,000	168	33.6	7.4
1889	250,000	170	33.3	6.8
1890	250,000	208	37.7	8.3
1891	250,000	208	36.6	8.3
1892	260,000	183	30.4	7
1893	263,000	186	28.8	7.1
1894	265,000	210	34.7	7.9
1895	268,000	221	37.9	8.2
1896	274,180	133	22.8	4.85
1897	[a]276,963	132	24.06	4.76
1898	[a]280,250	130	....	4.63
1899	[a]287,462	169	....	5.88
1900	[b]278,718	221	....	7.9

[a] Erroneous estimates of population made in these years.
[b] Census of 1900.

FILTRATION OF THE POTOMAC WATER.

The following conclusions are based upon such oft-repeated and positive testimony that we may assume them to be true without again presenting the facts from which they are derived.

1. The introduction of an abundant water supply and the sewering of a city improve public health, but do not remove certain sources of disease.

2. There is a close relationship between the organic impurity of water used for drinking purposes and the prevalence of typhoid fever and other diseases. Typhoid fever is more prevalent where the water is impure, and less so when the impurities are absent or when they are removed by filtration.

3. The filtration of a city's water supply has quickly been followed by a lessening of the number of cases of typhoid fever and of the typhoid death rate, and in many cities, as in Munich and Frankfort, Germany, and in Lawrence, Mass., and Ashland, Wis., typhoid fever has in consequence of water filtration ceased to be the scourge that it is in cities supplied with impure and unfiltered water. In the city of Lawrence, Mass., the mortality of typhoid fever since the filtration of the water supply was begun has been reduced 73.5 per cent, and in Ashland, Wis., the reduction was 88.5 per cent.

4. The drinking water furnished to Washington, although more pure than that of the Allegheny, Ohio, Missouri, and other rivers, contains organic impurities that render it unhealthful and productive of disease. In the examination made under the direction of Colonel Miller, U. S. A., it was found that 50 per cent of the specimens of Potomac water examined on 200 different days contained undoubted evidence of pollution with fecal matter.

5. With every year, as the population of cities and towns on the Potomac River above Washington grows, the contamination of the water supply must correspondingly increase. There is, then, in view of the continued prevalence and fatality of typhoid fever in this city, an urgent need of filtration of the water supply.

THE NATURAL AND MECHANICAL METHODS OF FILTRATION.

The question of filtration of the Potomac water supply is being considered by Congress, and it should receive the attention of every citizen of the District. In Europe, where every effort has been made to discover the best mode of filtration, the natural method by sand and gravel beds has been generally adopted. Filter beds purify the water supply of Berlin, Breslau, Hamburg, Amsterdam, Rotterdam, The Hague, Warsaw, Zurich, Birmingham, Leeds, Liverpool, Dublin, Edinburgh, London, Antwerp, and other cities of the Netherlands, Germany, and England. In this country sand filter beds are used in Lawrence, Mass.;

Ashland, Wis.; Hamilton and Mount Vernon, N. Y. The effect of water filtration by the natural method on the typhoid-fever death rate in these cities has been uniform; in all, the mortality has fallen so decidedly as to leave no doubt as to the efficiency of the method employed. In Hamburg the death rate from typhoid fever in 1890 was 28 per 100,000 inhabitants, in 1891 it was 23, and in 1892 it was 34 per 100,000 population. The new sand filter was started in May, 1893; the immediate result was a reduction of mortality to 18 per 100,000. In the following two years it fell to 6 and 9, respectively. The difference between 34 and 6 represents the difference of effect between polluted water and sand-filtered water in producing typhoid fever. The same argument is repeated in the experiences of every one of the cities mentioned, both in Europe and the United States. The following table gives the relative effect of unfiltered water and of water filtered by mechanical method and by the natural process upon the typhoid death rate:

TABLE II.—*Percentage of deaths from typhoid fever to 10,000 population in cities of Europe and the United States.*

Cities supplied with unfiltered water:	
New York	2.0
Chicago	*a*3.2
Buffalo	3.9
Providence	3.9
San Francisco	4.0
Minneapolis	4.0
Baltimore	4.5
Newark	4.5
St. Louis	4.7
Newport	4.7
Philadelphia	4.8
Denver	4.8
Cleveland	4.9
Cincinnati	5.2
Washington	6.9
Jersey City	7.5
Louisville	7.9
Chattanooga	8.0
Chicago	*b*8.4
Pittsburg	9.1
Lowell	9.2
Indianapolis	9.7
Turin, Italy	9.5
Palermo, Sicily	13.1
Alexandria, Egypt	16.2
Cairo	18.9
Catania, Sicily	19.0
Average	7.5

---

a After change in water intake.

b Before change in water intake.

Cities supplied with water filtered by the mechanical (American) process:

Atlanta	9.2
Quincy, Ill	5.8
Knoxville, Tenn	5.9
Chattanooga	5.8
Davenport, Iowa	2.6
Average	5.8

Cities supplied with water filtered by the natural (English) process:

The Hague	.49
Rotterdam	.52
Dresden	.69
Christiana	.70
Dantzic	1.5
Edinburg	1.5
Breslau	1.1
Frankfort	1.4
London	1.4
Hamburg	2.1
St. Petersburg	5.2
Dublin	5.8
Average	1.86

It may be urged that mechanical filtration is equally efficient in preventing disease, and is preferable to the natural method because less expensive and more easily operated. So far, experience with mechanical methods is not very great, but where comparison of the two methods has been made the result is greatly in favor of natural filtration.

Dr. Kober, of Washington, has collected figures based upon the typhoid-fever death rate in different cities using natural and mechanical plans of filtration, and as his tables are so instructive I reproduce them here:

TABLE III.—*Comparison of typhoid-fever death rate in European cities using sand filtration and in American cities with mechanical filtration to 10,000 population.*

EUROPE (SAND FILTRATION).

	Before filtration.	After filtration.
Berlin	10.0	.5
Breslau	11.3	.9
London	10.2	1.4
Hamburg	2.8	.9
Rotterdam	....	.2
The Hague	....	.5
St. Petersburg	9.9	5.2
Average	8.8	1.3

UNITED STATES (MECHANICAL FILTRATION).

Davenport	2.6
Atlanta	4.3
Chattanooga	4.8
Quincy, Ill	5.8
Knoxville	5.9
Average	5.9

Dr. Kober adds: "Lest this comparison between foreign and domestic cities be considered unfair, I have prepared Table No. IV, showing the average number of deaths from typhoid fever in several American cities before and after filtration. From this table we learn that while sand filtration accomplished a reduction of 78.5 per cent in the number of deaths from typhoid fever, the mechanical filters actually produced an increase of 20.43 per cent;[1] and even if we eliminate from our consideration Elmira, Lexington, and Newcastle, where an increase was noted, the reduction of typhoid fever in consequence of mechanical filtration amounts to only 26 per cent, as compared with 78.5 per cent as by the process of filtration."

TABLE IV.—*Showing the average number of deaths from typhoid fever per annum after filtration to 10,000 population.*

SAND FILTERS.

Name of town.	Average number of deaths from typhoid fever per annum before filtration.	Average number of deaths from typhoid fever after filtration.	Reduction.	Number of years upon which statistics are based before and after filtration.	Remarks.
			Per cent.		
Lawrence, Mass	5.2	1.3	73.5	5	Filter established September, 1893.
Ashland, Wis	3.9	.4	88.5	2	Filter established September, 1895.
Hamilton, N. Y	.06	.03	50	3	Filter established in 1896.
Mount Vernon, N. Y.	.3	.1	47	5	Filter established in 1894.
Average	2.36	.45	78.5	....	

MECHANICAL FILTERS.

			Per cent.		
Macon, Ga	1	.7	33	4	Filter established in 1893.
Atlanta, Ga	6.1	4.6	25	3	Filter established in 1881.
Oakland, Cal	1.9	1.7	11	5	Filter established (Hyatt) 1892.
Reading, Mass	.4	.1	75	1	Filter established (Warren) July, 1896.
Terre Haute, Ind	2.1	1.5	31	5	Filter established (natural filter) July, 1890.
Elmira, N. Y	[a]1	[a]1.1	[a]10	1	Filter established April, 1896.
Newcastle, Pa	[a]1.3	[a]2.8	[a]115	1	Filter established (New York) April, 1897.
Lexington, Ky	[a]1.8	[a]6.4	[a]256	4	Filter established June, 1895.
Average	1.9	2.3	[a]20.43	....	

[a] Increase.

According to the report of Colonel Miller, as a result of experiments conducted under his direction, both methods, under average conditions, are equally successful in clearing the water and eliminating bacteria in the laboratory tests made. In seasons when the Potomac

---

[1] It can not justly be said that mechanical filtration was the cause of the increase of the typhoid death rate; such increase must have been due to considerations having no relation to the method of filtration. The table has its value in showing the inefficiency of the mechanical filter in preventing a large mortality from typhoid fever in these cities.

water is turbid, this being especially the case in winter, by increasing the quantity of the alum coagulant the resulting effluent was clearer and had fewer bacteria than from the experimental sand filter. The average for the year, however, was in favor of the natural filter, as by this process 97.3 of the contained bacteria was eliminated, the mechanical filter giving a bacterial reduction of 95.7.

In the opinion of the committee, the installation of filter beds constructed in accordance with the so-called natural (English) method would insure to the city of Washington a supply of water of a satisfactory degree of purity and would greatly reduce the typhoid death rate in this city. This system has in its favor the fact that it has been tested in a practical way in numerous cities of Europe and in several in this country with excellent results. As regards the so-called mechanical (American) system, which depends upon the use of alum as a coagulant, the committee is not prepared at the present time to give a positive opinion. The experiments made by Colonel Miller under the direction of the Chief of Engineers show that it is capable of giving satisfactory results, when properly managed, in reducing the number of bacteria and in clarifying the water. In our opinion it should not be adopted without a fuller investigation as to its practical working on a large scale, and the results attained in lessening the typhoid death rate in cities where it has already been installed.

CHAPTER VI.

HISTORICAL REVIEW OF SANITARY EFFORTS TO LESSEN TYPHOID FEVER IN THE CITY OF WASHINGTON.

WASHINGTON, D. C., *January 23, 1901.*

Hon. JAMES MCMILLAN,
Chairman of the United States Senate Committee on Inquiry into the Purification of the Washington Water Supply.

SIR: The committee on water filtration of the Medical Society of the District of Columbia begs leave to submit the following supplementary report:

The purification of the Potomac River water supply of the city of Washington has been under discussion for many years. Much money has been expended in efforts at purification by sedimentation, but now, although the capacity of the sedimenting basins amounts to an eight-days' supply for the city, the water delivered for use is turbid during one-third of the year; and so great is this turbidity at times that it renders the water absolutely unfit for either laundry or bathing purposes. Moreover, some seven or eight years ago the medical society of the District of Columbia became alive to the fact that typhoid fever was endemic in the District to an extent that indicated grave faults in the sanitary management. Faulty sewerage was blamed and remedied, suspected wells were closed, and the milk supply was carefully regulated, but the mortality from this fever continued high. During the year ended June 30, 1900, there were 221 deaths from this disease, and probably not less than 2,200 cases, which, at a conservative estimate, represent a financial loss to the community of over $1,000,000 per annum. In view of our knowledge of the propagation of typhoid fever by water supplies, the purification of the Potomac River water was imperatively demanded, and filtration was regarded as the only proper method of purification.

APPROPRIATION FOR EXPERIMENTAL FILTERS.

Urged by the representations of the society, an appropriation was made two years ago by Congress to determine the best means for the purification of the water supply. This was placed at the disposition of the Engineer Department of the Army, and experiments were conducted by Lieut. Col. A. M. Miller, United States Engineers, from

June 11, 1899, to March 2, 1900, to carry out the views of Congress. Two methods of filtration were tested in these experiments—slow sand-bed filtration as conducted in England and in the cities of Continental Europe, and rapid or mechanical filtration as installed in some of the smaller cities of the United States. A small circular tank, 11 feet in diameter, was constructed to represent the sand beds of Europe, and a mechanical filter with all the latest improvements, built, tested, and installed by the manufacturing company interested in its success, was used in comparison.

RESULTS OF COLONEL MILLER'S EXPERIMENTS.

From his experience with these two filters Colonel Miller concluded that the mechanical system should be adopted for the Potomac water, basing his recommendation chiefly upon the bacteriological results obtained from the effluents of the two filters. Fortunately, in his report, he gave day by day statements of the work accomplished, from which the most careful study is unable to elicit the grounds of his decidedly expressed partiality. During the period of greatest turbidity of the river water the sand-filter tank, which was assumed, notwithstanding its acknowledged faults, to represent slow filtration through beds of sand as conducted in Europe, gave an effluent with no more bacteria per cubic centimeter than that of the carefully built and regulated mechanical filter. The medical society thereupon took exception to his recommendation and urged the adoption of slow filtration through sand beds.

HEARING OF EXPERTS ON WATER PURIFICATION IN NEW YORK CITY JANUARY 4, 1901.

Beset by these contending views the Senate Committee on the District of Columbia gathered the opinions of the men who have had the largest experience of the subjects under discussion, and since the report of the committee of the medical society has been made the basis for criticism we beg leave to submit a general review of the evidence.

The committee professes to be fairly familiar with the scientific aspects of filtration on a large scale, because hygiene and bacteriology have furnished any amount of data by which the two systems can be compared, and as the committee was appointed at the invitation of General Wilson, Chief of Engineers, to visit the experimental filter plant, we deemed ourselves both competent and authorized to criticise the experiments conducted under Colonel Miller. If after a careful consideration of all the facts we arrived at an adverse conclusion, we did so in the face of the overwhelming evidence in favor of slow sand filtration, and had hoped to present our recommendations in the interests of public health without being charged with bias or unfairness.

REVIEW OF THE TESTIMONY.

We will now proceed to consider in how far the statements of the committee are sustained by the evidence presented at the hearing.

Dr. John S. Billings, of New York; Mr. John W. Hill, consulting engineer for a sand-bed filter at Philadelphia, Pa., and Mr. Allen Hazen, who constructed the sand-filter beds now in successful operation at Albany, N. Y., were in favor of slow sand filtration. "In the particular case of Washington," said Dr. Billings, "I would, on the whole, from what I know of Washington, and based on the facts given in these reports (Colonel Miller's), prefer to adopt the slow sand filter."

Lieut. Col. Charles Smart, United States Army Medical Department, after a most exhaustive and able presentation of the facts, concludes:

> I am therefore of the opinion that for the purification of the Potomac water filter beds constructed after the European method should be used rather than rapid filtration subsequent to coagulation by alum. * * *

Surgeon-General Sternberg, of the Army, in forwarding this report, says:

> Lieutenant-Colonel Smart is an expert with reference to the subject of this report, and his views are entitled to most careful consideration. In my opinion the so-called natural method of filtration properly installed will secure to the city of Washington a water supply of a satisfactory degree of purity and will greatly reduce the typhoid mortality of this city.

Others were less decided in their expressions of preference, acknowledging the value of slow filtration in clear waters polluted with sewage, but suggesting that mechanical filtration might be more suitable for the treatment of the frequently turbid waters of the Potomac River. Among these were W. P. Mason, of the Rensselaer Polytechnic Institute, Troy, N. Y.; George W. Fuller, who conducted experiments on filtration for the State board of health of Massachusetts and for the water companies of Louisville, Ky., and Cincinnati, Ohio; Rudolph Hering, editor of the Engineering Record, and Dr. H. D. Geddings, passed assistant surgeon, United States Marine-Hospital Service. But even by these the expressions of doubt as to the relative efficiency of slow sand and mechanical filtration in the treatment of Washington water was based on an experience with other waters and not on a knowledge of or a familiarity with the conditions of the Potomac River.

TURBIDITY AS A FACTOR IN THE PURIFICATION OF POTOMAC WATER.

The committee of the medical society had very carefully considered the question of turbidity as a factor in the filtration of the Potomac water, and felt convinced that whatever objections on the ground of submicroscopic particles of clay might be adduced elsewhere they did not apply to the Potomac water, for the bacterial results obtained by Colonel Miller during the period of greatest turbidity with an imperfectly constructed sand filter are sufficient to dispel every vestige of doubt. The committee realizes also that after the completion of the new reservoir, which will add five more days to the period of sedimentation, the amount of suspended clay particles will be no more than sufficient for the proper functioning of a sand filter. This is of special importance, since C. Piefke, of Berlin,[1] has shown that a certain amount of clay particles are of importance for the formation of an effective "schmutzdecke." He tells us that the principal streams of north Germany, the Elbe, Oder, and Vistula, carry mostly a clay-colored water, while the sluggish subordinate streams like the Spree, Havel, and Elde do not, and that the latter rather favor the formation of algæ. His experiments demonstrated that a "schlammdecke" composed largely of fine particles of clay reduced the number of the bacillus violaceus in the ratio of 1:3224, while a "schlammdecke" composed largely of organic matter (algæ and bacteria) eliminated the germs in the ratio of 1:1403.

Professor Mason, on being asked, after considering the data in Colonel Miller's report, whether the slow sand filter would give a satisfactory effluent, replied: "I believe that the sand filters will do well. They have achieved results which show their efficiency." Assistant Surgeon Geddings stated that, "judged from the standard of bacterial efficiency, the results are most excellent, and this is after all the most important consideration from a sanitary point of view. * * * The advantages of the slow sand filtration are, first, great bacterial efficiency, and, second, that no chemical or other agent is added to the water before, during, or after the filtering process." Even Mr. E. B. Weston, who has designed mechanical filter plants for a number of cities, avowed himself at the hearing an advocate of slow sand filtration, specifying the rate at two and a half million gallons per acre daily.

EFFICIENCY OF SAND-BED FILTRATION IN LESSENING THE PREVALENCE OF TYPHOID FEVER PROVEN.

There is, in fact, in the testimony no question as to the efficiency of slow sand-bed filtration in lessening the prevalence of typhoid fever among the communities using the filtered water. There is, on the contrary, a question as to the efficiency of mechanical filtration, for the installation of mechanical filtration plants in cities has not been followed by that marked diminution in the mortality from this disease

---

[1] Aphorism uber Wasserversorgung vom hygienisch technischen Standpunkt ausbeobachted, Zeitschft. für Hygiene, 1889. 7 Band, p. 115.

which has been recorded in communities which have adopted sand-bed filters. In other words, the mechanical filter is still in the experimental stage so far as concerns typhoid fever.

TYPHOID-FEVER STATISTICS.

A tabulation was presented by us showing the average number of deaths from typhoid fever per annum in four towns in this country where sand filtration is used and in eight towns where mechanical filters are in operation. The average annual number of deaths in the former was 95.06 before filtration and 20.43 after filtration; and this lessened mortality after sand filtration is sustained and strengthened by the excellent results in this line furnished by the history of sand filtration in European cities. The average number of deaths from typhoid fever in five of the eight towns in which mechanical filters were established was 116 before and 86 after filtration, and in three of the eight there was an actual increase in the number of deaths after filtration, showing that the small amount of benefit derived from filtering a certain percentage of the water supply used was insufficient to overcome the ordinary fluctuations in the death rate that are always to be found in towns where typhoid fever is endemic. It is to be observed that these are not selected statistics, but include all that could be obtained by a careful canvas of the towns in which mechanical filters have been installed.

ATTEMPTS TO DISCREDIT THE TYPHOID-FEVER STATISTICS OF THE MEDICAL SOCIETY UNSUCCESSFUL.

Professor Mason and Mr. Weston both attempted to discredit these statistics. The committee, in discussing this subject, said:

> From this table we learn that while sand filters accomplished a reduction of 78.5 per cent in the number of deaths from typhoid fever, the establishment and use of mechanical filters have coincided with an increase of 20.43 per cent; and even if we eliminate from our consideration Elmira, Lexington, and Newcastle, where an increase was noted, the reduction of typhoid fever in consequence of mechanical filtration amounts to only 26 per cent as compared with 78.5 per cent by the process of sand filtration.

If the intelligent public, in spite of our language, should be led to infer that in some instances the mechanical filters have been a direct cause of a decided increase in typhoid fever we are not responsible, but "en passant" we would remind Professor Mason that the possibility of such an occurrence is by no means excluded. Colonel Miller's report shows that at least on two occasions the effluent contained more germs than the influent, and every text-book on hygiene points out the fact that badly managed domestic filters may actually afford breeding places for germs, and Plagge[1] is strongly of the opinion that disease germs may multiply in badly managed filters.

---

[1] Untersuchungen über Wasserfilter; Veröffentl. aus dem Gebiete des Militär-Sanitätswesens. Med. Abth. des Königl. preuss. Kriegsministerium, pt. 7. Heft. Berlin, 1895.

In answer to Dr. Geddings's criticism of these statistics, the committee offers him the same opportunity accorded to the other gentlemen to adduce evidence which would disprove our figures. In the meantime, however, the committee does not deem it a fair assumption that the "gradually but constantly spreading wave of typhoid fever over the entire country," and other etiological factors, should have shown a special predilection for towns and places supplied with mechanical filters. Mr. R. S. Weston, one of Colonel Miller's laboratory assistants, and, excluding Colonel Miller, the only one of the experts who testified to the undoubted superiority of mechanical filtration, acknowledged the accuracy and value of these statistics by stating that nearly all of the mechanical plants cited by us as failing to reduce the typhoid rate were installed for æsthetic reasons, i. e., to give a crystalline clear water. The superiority of the slow filtration in the suppression of typhoid fever may therefore be accepted as acknowledged.

A LESSENED DEATH RATE FROM TYPHOID FEVER THE MAIN OBJECT OF FILTRATION.

The following statement of the committee has been subjected to criticism:

> It has been suggested that the superiority of sand filters depends upon a combination of mechanical and biological action; that is to say, that apart from the felt-like growth of the organisms themselves, which develops upon the top of the filter and increases the fineness of the strainer, the ordinary harmless water bacteria and bacteria of nitrification decompose much of the organic matter and even kill the disease germs.

Our authority for this statement will be found in Egbert's Hygiene and Sanitation, page 168, edition 1900, and appears to find support in the Treatises of Hygiene, by Parker, Notter, and Firth, 1896, pages 47 and 48, and Stevenson and Murphy, Vol. I, page 253. Moreover, the experiments of Meade Bolton, F. Hueppe, Kraus, Karlinski, Uffelmann, and others, on the behavior of pathogenic microorganisms in water, conclusively show that the ordinary water bacteria hasten the death of the typhoid and cholera bacilli. It does not follow that there is a struggle between them; it is perhaps simply a question of suitable food, or the presence of products evolved by one species which acts as a poison to the other. Just exactly how this is accomplished is a mystery on which science merely speaks as yet to tell us that the fact must be accepted. Whatever the explanation may be, we believe that the action of sand filter beds is precisely the method adopted by nature in the purification of surface waters, and we have no disposition to improve upon her simple and perfect methods.

The committee has not claimed that the sand filter exerts any selective elimination of pathogenic bacteria. We have simply offered the only explanation at hand for its superior efficiency in reducing typhoid-fever death rates. But disregarding all theories on this question, it will be conceded that from the hygienic standpoint the main object of filtration is a lessened death rate from typhoid fever. Now, since it may be assumed that typhoid germs will be removed by a filter from a water containing them in the same proportion as other bacteria in the water are removed, the bacterial efficiency of a filter has been taken as an expression of its probable influence on the typhoid death rate. Perhaps a better expression is the number of bacteria in the effluent. Ninety-eight per cent removal means only 2 bacteria per cubic centimeter of effluent when the raw water contains 100 per cubic centimeter, but it means 1,000 in the effluent when the raw water is charged with 50,000. Koch evidently recognized this when he made 100 bacterial colonies per cubic centimeter the limit of bacterial impurity in the effluent of an efficient sand-bed filter. Parenthetically we may remark that an ignorant or careless use of these two modes of expression may be made to throw disparagement on a system, as is illustrated in the report of Passed Assist. Surg. H. D. Geddings, United States Marine Hospital, since he has stated that "in the Pittsburg experiments during six months the Jewell filter gave an average bacterial efficiency of 97.45 per cent, the raw normal water containing 11,531 bacteria per cubic centimeter. In the same city and for six months the Warren filter on water containing 11,531 bacteria per cubic centimeter gave an average bacterial efficiency of 98.26 per cent. A sand filter receiving the same water for the same period gave a yield containing 105 bacteria per cubic centimeter. It is believed, therefore, that it must be conceded that mechanical filtration is safe and efficient." We would have looked upon these statements as unworthy of criticism, but that they are repeated in a subsequent part of Dr. Geddings's, paper and in fact constitute the basis of his predilection for mechanical filtration. This basis calculated from his own statements is as follows, where our figures are given in italics:

Experience of six months at Pittsburg, Pa.

	Bacteria in raw water per cubic centimeter.	Percentage of bacteria removed.	Number of bacteria per cubic centimeter of effluent.
Jewell filter	11,531	97.45	*294*
Warren filter	11,531	98.26	*200*
Sand filter	11,531	*99.09*	105

If typhoid germs are proportioned to the colonies of bacteria found in the effluent of a filter, can anyone deny that the prevalence of typhoid fever among the users of each of the three waters, as deduced from the above figures, would be in the proportions of 105, 200, and

274, or nearly 1.2 and 3, the advantage being in favor of slow sand filtration? And yet the stated facts were presented by Dr. Geddings as an argument on behalf of mechanical filtration. From the testimony received, there appears to be no doubt that sand filtration in practice has given better results than mechanical filtration, the contention of those who hesitatingly advocate mechanical filtration being that this system when properly and carefully carried into practice, not as it has been but as it should be, would give just as good results as slow sand filtration. Mechanical filtration on a large scale is therefore, as we have already stated, an experiment from the hygienic standpoint; that is, as bearing on the prevalence of typhoid fever.

SUPERIOR BACTERIAL EFFICIENCY OF COLONEL MILLER'S SAND FILTER DEMONSTRATED IN COLONEL SMART'S REPORT.

But descending from these generalities, what do we find in the carefully recorded experiments in Colonel Miller's report? Here let us call to mind another possibility of error in dealing with figures representing bacterial removal. There is something definite in the statement that on a certain day a filter removed a stated percentage of the bacteria present in a water; but the average of a series of daily percentage may give erroneous ideas of the actual removal during the period covered by the series. With 98 per cent on one of two days and 97 per cent on the other, the removal for the two days is 97.5 per cent only when the number of bacteria in the influent is the same on both days. If the number in the raw water on the 98 per cent day was 1,000 and on the 97 per cent day 10,000, the percentage for the two days would be 96.9 and not the mean of the two percentages, 97.5. On this account confusion has arisen in considering the results of the work of Colonel Miller's two filters. Lieutenant-Colonel Smart is correct in his calculation of their work during the period of greatest turbidity of the Potomac water.

"The period of greatest turbidity began December 27, when the bacteria in the raw water mounted up to 7,900 per cubic centimeter and continued, with a few exceptional days, to the end of the observations, March 2. The report states that during this period the English filter did not furnish a satisfactory effluent, while that from the mechanical filter was entirely satisfactory as to the numbers of bacteria present. The first statement is readily verified, for from December 27 to the end of the month the sand-bed filter was, as already stated, in a markedly disabled condition, and during its fifth run, January 6 to March 2, the number of bacteria in its effluent was over the limit on forty out of fifty-six days. The second statement does not appear to be so clearly sustained, for the bacterial removal effected by the two filters was practically the same. Sixty-one days of this period of greatest turbidity were tabulated, but the mechanical filter on ten of these days was not in operation. There were, therefore, only fifty-one days on which comparison could be made. During these fifty-one days the sum of the bacteria in the raw water amounted to 674,600; the sum of the bacteria in the effluent of the sand filter was 12,249; of the mechanical filter, 12,494. The sand filter removed 98.18 per cent of the bacteria; the mechanical filter, 98.15 per cent. Hence, so far as concerns the removal of bacteria in times of turbidity and large bacterial content in the raw water, there seems to have been no difference in the work of the two filters; but it does not follow from this that in actual practice properly constructed filter beds on the European model and managed by European methods would not have given better bacterial results with the Potomac water than were obtained by the New York Filter Manufacturing Company's filter. Besides, the important fact that the experimental sand filter had faults which prevent the acceptance of its work as representative of that of the sand beds of Europe, it may be pointed out that while an increased turbidity of the influent was met in the mechanical filter by an increased quantity of alum, no effort was made to improve the character of the effluent from the sand filter. The tubes which had caused a rent of 11 feet long during the fourth run were continued in place during the turbidity of the fifth run, and even the filtering rate of 3,000,000 gallons per acre was kept up throughout."

If we examine the various runs of the two filters prior to this period of greatest turbidity the result is found to be decidedly favorable to the slow sand filter.

During the first run of this filter, which lasted from June 11 to July 19, bacterial examinations were made only during the last seven days. The effluent showed less than 100 bacteria on each of these occasions. The mechanical filter was not running during this period.

During the second run, from July 21 to September 27, a period of sixty-nine days, the effluent contained less than 100 colonies on each of these days while the permissible limit of 100 colonies was reached by the effluent of the mechanical filter on one day and exceeded on four days.

During the third run the effluents of both filters were below Koch's limit.

During the fourth run the sand filter gave a satisfactory effluent until December 27, while on three of the days of this period the effluent of the mechanical filter was above Koch's limit.

After December 27 came the "period of greatest turbidity," during which the sand filter, laboring under disabilities which in practice would have called for inquiry and rectification, did as good work in the matter of bacterial removal as the carefully regulated mechanical filter.

We must conclude, therefore, that from June 11 to December 27 slow filtration, as conducted by Colonel Miller on the Potomac water, gave results which would have been accepted by European experts, while mechanical filtration under his observation failed on several occasions to keep up to this high standard, and that subsequent to the latter date and during the period of greatest annual trial the slow sand filter, although disabled and uncared for, did at least as good work as the mechanical filter carefully alumed to meet existing turbidity.

DANGER FROM TYPHOID GERMS NOT SO GREAT IN PERIODS OF GREATEST TURBIDITY.

It is to be observed with regard to a river like the Potomac that the danger from typhoid germs is not proportioned to the number of bacteria in the raw water. The amount of sewage and of consequent danger of typhoid infection draining into the stream may be regarded as a fixed quantity. Winter thaws and spring freshets bring down from the drainage area a greatly increased volume of water turbid from clay and other matters and containing immense numbers of nonpathogenic bacteria to dilute this dangerous sewage. Owing to this dilution, the danger from typhoid fever is less than during periods of low water, clear flow, and relatively small bacterial counts. It is therefore claimed, and with justice, that in periods of continued flood and turbidity the Potomac effluent of a sand filter does not have a typhoid danger corresponding to its want of absolute transparency or to an associated increase in the bacterial count.

The clearness and transparency of water clarified by alum and run through a mechanical filter is well known. It has indeed been acknowledged that in many towns this clearness of the filtered water has been the main factor in determining the system of filtration to be adopted, a clear crystal water being desired as a commercial advantage for the money invested. (Testimony of Mr. E. B. Weston.) The question of wholesomeness was not considered. In fact, in most—we may say with truth in all—cities in which mechanical plants have been recommended the recommendation has been based on other than sanitary grounds. Thus, Mr. Hering has shown that at Atlanta, Ga., the expense of sand was the main factor in determining in favor of mechanical filters, and he explained the 50,000,000-gallon plant recommended for Philadelphia as a temporary utilization of water which will be thrown out of the water system after a certain growth of the city. In other cases a limitation on the borrowing capacity of a town determines in favor of the mechanical system, which costs less for installment.

COST OF THE TWO METHODS COMPARED BY MR. HERING.

This brings us to the question of cost. Much testimony was submitted on this point, but Mr. Hering summed up the whole subject in a very few words, which we quote:

> There is not a great difference in the cost. The slow method requires a greater investment of capital and the rapid method a greater expense for cost of operation. If you capitalize that, allow for the depreciation and draw your balance, you will find that the two methods do not vary much in point of expense.

The committee of the Medical Society suggested that "the cost of the sand-filter plant may be safely reduced by $530,310 by omitting the covering of the filter beds, as recommended by both of the experts employed by the War Department, and that apart from this saving it is believed that the germicidal effects of sunlight operating on the open filters will render them far more efficient than if they were covered."

This recommendation, in spite of Mr. Weston's opinion, finds ample support in the experiments of Kruse, Arloing, Roux, Palermo, and Buchner and Mink.[1] The latter have shown that after two and one-half hours' exposure in water to direct sunlight typhoid bacilli were reduced from 30,140 to 0, cholera bacilli from 7,000 to 15, colon bacilli from 165,000 to 0, diphtheria bacilli, after seven hours' exposure, from 2,425,000 to 150, and it is believed that the blue-violet and ultra-violet rays of sunlight exert a destructive influence upon the living, colorless protoplasm of these organisms.

Mr. Weston's statement of the ill effects of the sunlight as influencing obnoxious growth of algæ and other microscopic organisms is not sustained by Piefke's observations, who in 1889, in Zeitschft. für Hygiene, made a plea for more light in covered filters, as the algæ formation in covered filters usually takes place on the surface of the water, while in uncovered filters they develop at the bottom of the water.

Cost, however, should not enter as a factor into the consideration of the purification of the Washington water supply unless from the sanitary point of view one system of filtration is as good as the other, and this we have shown to be not the case.

THE EFFECTS OF ALUM AS A COAGULANT.

There is another argument against the installation of mechanical filters which require the use of alum to effect purification of the water. Mr. John W. Hill, from a knowledge of harmful effects produced by

---

[1] Buchner and Mink, Ueber den Einfluss des Lichtes auf Bacterien. Centralbl. für Bacteriologie, etc., 1891, II B, p. 781. See also Loeffler, Das Wasser und die Mikroorganism, p. 600. Handb. der Hygiene, 24 Lieferung.

alum in filtered water, stated: "I believed five years ago that the process of purification by means of a plain bed of sand is superior to purification by a bed of sand plus a chemical, and I believe so still." Colonel Miller's experiments showed, on the one hand, slow filtration in continuous and satisfactory progress for sixty-nine days in one run, while rapid filtration necessitated, on the other hand, a constant but daily varying addition of alum to the water. It is acknowledged that this addition of alum would tend to lessen the value of the water for certain manufacturing and laundry purposes, but it is claimed that with proper supervision no free alum would be found in the filtered water.

The following extract from an editorial in the Journal of the American Medical Association, January 19, 1901, expresses our views on this subject:

> The efficiency of the sand bed depends on a slow and regulated filtration; that of the mechanical filter on the addition of alum to the water to clarify it. Carbonates in the water decompose the alum, precipitating the gelatinous aluminum hydrate, which entangles clay and other particles constituting the turbidity, together with the bacteria which may be present. These are strained off by the passage of the water through the mechanical filter. It is the alum, not the filtration, which is actively concerned in the removal of the bacteria. If enough alum is added the effluent is clear and gives satisfactory results on bacteriological examination. If an insufficient quantity is added the effluent may be turbid and charged with bacteria. If too much is added, or more than can be decomposed by the carbonates present, alum will remain in solution in the effluent as a most undesirable accidental constituent. With care at the waterworks alum may no doubt be added to effect its purpose without a trace of it appearing in the effluent, but it will be conceded by all medical men that chemicals which would be injurious in excess should not be added to a water supply if a satisfactory purification can be effected without their use; and the experiments of the engineer department on turbid Potomac River water have shown that such purification can be accomplished by slow sand-bed filtration.

THE IMPORTANCE OF HYGIENICALLY PURE WATER INDORSED BY THE LAITY OF WASHINGTON.

The committee of the Medical Society believes that Colonel Miller, in his desire to give the people of Washington a clear, brilliant water, naturally underrated the hygienic importance of the question. This is plainly shown in his statement before the board of trade, when he declared: "I do not believe the people of this city will be satisfied with any system of filtration that does not give them a perfectly clear water, even though every germ is removed." The intelligent laity in Washington, as represented by the board of trade and the Business Men's Association, have voiced their answer in unmistakable terms by unanimously recommending in public meetings the installation of sand filters.

The committee reiterates the statement that we have observed the result of sand filtration on the Potomac water, and, while the product may not be always as clear or sparkling as the product of the alum filter, regards it as entirely free from objections either from an æsthetic or a sanitary standpoint.

In conclusion it appears to us that the question before the Senate committee is, from the hygienic standpoint, not difficult of solution. Slow sand-bed filtration properly conducted on the large scale will certainly give better results than those obtained from the imperfect model, and therefore better than those from the mechanical filter. Another year should not be wasted in further experiments to prove the efficiency of sand-bed filtration. Purification is needful to prevent disease and death, and it should be effected without delay. In the interest of the people we would urge speedy action on the part of Congress to supply the city of Washington with water purified by natural or slow filtration through suitable sand beds.

Respectfully submitted.

Samuel C. Busey,
G. Wythe Cook,
Geo. M. Kober,
Z. T. Sowers,
W. C. Woodward,
Committee.

APPENDIX.

PURIFICATION OF THE WASHINGTON WATER SUPPLY.

PART I.

[Senate Doc. No. 259, Fifty-sixth Congress, first session.]

LETTER FROM THE SECRETARY OF WAR, TRANSMITTING COPY OF A COMMUNICATION FROM THE CHIEF OF ENGINEERS, UNITED STATES ARMY, SUBMITTING REPORT OF AN INVESTIGATION OF THE FEASIBILITY AND PROPRIETY OF FILTERING THE WATER SUPPLY OF THE CITY OF WASHINGTON.

War Department,
Washington, March 31, 1900.

Sir: I have the honor to transmit herewith copy of a letter from the Chief of Engineers, United States Army, of this date, submitting report of an investigation of the feasibility and propriety of filtering the water supply of the city of Washington, together with detailed estimate of the cost of the work required.

Very respectfully,

Elihu Root,
Secretary of War.

The President pro tempore of the United States Senate.

Office of the Chief of Engineers,
United States Army,
Washington, March 31, 1900.

Sir: I have the honor to transmit herewith, in duplicate, a report of an investigation of the feasibility and propriety of filtering the water supply of the city of Washington, and a detailed estimate of the cost of the work required.

The investigation and report were made in accordance with existing law (vol. 30, U. S. Stat. L., pp. 533 and 1054) by Lieut. Col. A. M.

Miller, Corps of Engineers, in local charge of the Washington Aqueduct and of increasing the water supply of Washington.

I concur in the general conclusions reached by Lieutenant-Colonel Miller, and have therefore to report that in my opinion it is feasible to satisfactorily filter the water supply of Washington, and that it is not only proper but eminently necessary for the public health that the said filtration be undertaken as soon as practicable.

Should Congress decide that the work shall proceed, it is suggested that the legislation enacted to that end should permit such changes in details to be made as may be found necessary from time to time during the progress of the work.

Very respectfully, your obedient servant,

John M. Wilson,
Brig. Gen., Chief of Engineers,
U. S. Army.

Hon. Elihu Root,
Secretary of War.

REPORT OF AN INVESTIGATION OF THE FEASIBILITY AND PROPRIETY OF FILTERING THE WATER SUPPLY OF WASHINGTON, D. C., WITH DETAILED ESTIMATE OF THE COST OF THE WORK REQUIRED.

Office of the Washington Aqueduct,
Washington, D. C., March 28, 1900.

General: "An act making appropriations to provide for the expenses of the government of the District of Columbia for the fiscal year ending June thirtieth, eighteen hundred and ninety-nine, and for other purposes," approved June 30, 1898, contains the following clause under the head "Washington Aqueduct:"

> To enable the proper officer of the Government having charge of the Washington Aqueduct and water supply of the city of Washington to make an investigation of the feasibility and propriety of filtering the water supply of Washington and to submit to Congress a full and detailed report thereon, and to meet all necessary expenses of said investigation, three thousand dollars. Said report shall be accompanied by a detailed estimate of the cost of the work required; and in making the investigation and in the preparation of this report the Chief of Engineers, United States Army, shall be associated with the proper officer of the Government in charge of the Aqueduct as consulting engineer.

"An act making appropriations to provide for the expenses of the government of the District of Columbia for the fiscal year ending June thirtieth, nineteen hundred, and for other purposes," approved March 3, 1899, contains the following clause:

> For additional amount to enable the proper officer of the Government having charge of the Washington Aqueduct and water supply to the city of Washington to make an investigation of the feasibility and propriety of filtering the water supply of Washington, and to submit to Congress a full and detailed report thereon, and to meet all necessary expenses of said investigation, five thousand dollars, to be immediately available.

By the two acts—Public No. 170, approved June 30, 1898, and Public No. 187, approved March 3, 1899—there has been appropriated for this investigation $8,000.

By virtue of Special Order No. 151, dated Headquarters of the Army, Adjutant-General's Office, Washington, D. C., June 28, 1898, I was directed to report to Washington, D. C., not later than July 11, 1898, and relieve Col. Theodore A. Bingham, United States Army, captain, Corps of Engineers, of the charge of the Washington Aqueduct and of the increase of the water supply of the city of Washington. Having relieved Colonel Bingham and assumed charge of the above-mentioned works on July 11, 1898, the duty of making the investigation of the feasibility of the filtration of the water supply of Washington and submitting the report mentioned in the above-quoted acts devolved upon me.

I have therefore the honor to submit through you the following report on the investigation of the feasibility and propriety of filtering the water supply of Washington, and a detailed estimate of the cost of the work required:

I.—Investigation of the Feasibility and Propriety of Filtering the Water Supply of Washington.

WATER SUPPLY OF WASHINGTON.

The water supply of Washington has received attention and consideration contemporaneously with the original laying out of the city. At that early period the Potomac above Great Falls, Rock Creek, and the Eastern Branch of the Potomac, the numerous springs within the city limits, and the smaller springs in the vicinity were all contemplated as sources of supply.

Numerous surveys were made by Major L'Enfant, under the direction of General Washington, to ascertain the practicability and feasibility of obtaining a full and good supply of water for the Federal capital.

The immense volume of water discharged over the Great Falls of the Potomac indicated this as the point whence a certain and abundant supply could be obtained; the only argument against it was the expense of bringing the water to the city.

In 1850 the Thirty-first Congress, by "An act making appropriation for the civil and diplomatic expenses of the Government for the year ending the thirtieth of June, eighteen hundred and fifty-one, and for other purposes," approved September 30, 1850, appropriated the sum of $500 "to enable the War Department to make such examinations and surveys as may be necessary to determine the best and most available mode of supplying the city of Washington with pure water, and to prepare a plan and estimate of the probable cost of the same, to be reported to Congress at its next session."

In accordance with the above act, on January 25, 1851, Mr. C. M. Conrad, then Secretary of War, submitted to Congress the report of Brevet Lieut. Col. Geo. W. Hughes, Corps of Topographical Engineers.

The report considers and discusses two sources of supply, the Potomac at Great Falls, and Rock Creek.

Owing to insufficient data in respect to the Great Falls supply, due to the small amount of the appropriation ($1,500), the city of Washington having added $1,000 to the funds available, the Great Falls project was not gone into, but the survey and investigation was confined to the

Rock Creek project. Colonel Hughes proposed, by building a dam, to obtain from Rock Creek a possible supply of 8,000,000 gallons per diem, and this was considered adequate to supply the city for the following forty years.

Washington at the time (1851) contained, by the recent census, 40,027 inhabitants. It was proposed to supply 1,500,000 gallons daily; this was considered at the time ample, being more than 30 gallons per capita per diem. Colonel Hughes says:

> This is the highest calculation I have seen, and is, no doubt, ample for uses for a city, except for manufacturing purposes.

In the above project a sedimentation reservoir was proposed, located on Meridian Hill, with a distributing reservoir "to be established just back of Franklin road, the highest ground within the city;" this location was Eleventh and N streets northwest. The surface of the water in the distributing reservoir was to be 147 feet above ordinary low tide, or 57 feet above the eastern base of the Capitol. The level of water in the sedimentation reservoir was to be 160 feet above low tide, and the water for fountains and a "great jet d'eaux" was to be drawn directly from this level. The estimated cost of this project was $500,000.

The water supply of Washington (see Pl. I) is now derived from the Potomac River, taken at Great Falls, 14 miles above Washington. The project and estimate for delivering this water to the city of Washington originated with Capt. M. C. Meigs, Corps of Engineers, United States Army.

In 1852 the Thirty-second Congress, at its first session, appropriated $5,000 to enable the President of the United States to cause to be made the necessary surveys, projects, and estimates for determining the best means of affording to the cities of Washington and Georgetown an unfailing and abundant supply of good and wholesome water.

Under this order of Congress the surveys were made in the winter of 1852–53, and the report of Lieutenant Meigs, dated February 12, 1853, was, on February 22, ordered to be printed, and will be found in Senate Ex. Doc. No. 48, Thirty-second Congress, second session. Projects with careful estimates and elaborate details were prepared, showing the best mode of procuring this water supply.

Congress, after a full discussion and consideration of the project, agreed to a provision in the general appropriation bill approved March 3, 1853, appropriating—

> For bringing water into Washington, upon such plan as the President of the United States may approve, one hundred thousand dollars: *Provided*, That if the water shall be taken from any place within the limits of Maryland, the consent of the State shall first be obtained.

The President of the United States, acting under the requirements of this law, adopted the project described in the report and estimate of Lieutenant Meigs—that is, the aqueduct from the Great Falls of the Potomac, with a conduit 9 feet in diameter. The State of Maryland passed an act granting her consent, ceding jurisdiction over the lands to be acquired for the aqueduct, and authorizing the appraisement and condemnation of lands in case the owners would not agree to sell them on reasonable terms.

The project contemplated a dam at Great Falls to hold the water at a proper level, whence it was to be conducted by a circular conduit of brick 9 feet in diameter, having a fall of 9½ inches to the mile. The level of the comb of the dam was to be 145 feet above high tide at Washington.

The project contemplated two reservoirs, a receiving reservoir and a distributing reservoir. The receiving reservoir was formed by damming Little Falls Branch, a tributary of the Potomac situated along the line of the conduit, about 4½ miles from Washington. Its area is 50.651 acres and its capacity, above the level of 140 feet above tide, is 82,521,500 gallons. This reservoir acts not only as a storage reservoir, but also as a sedimentation basin. As originally constructed it also added to the water supply by gathering the surface water from its watershed, which was considerable. The water enters this reservoir by a tunnel at a distance of half a mile from the point at which it leaves it. The reservoir naturally shortens the conduit and saves the expense of an aqueduct bridge over Little Falls Branch.

The distributing reservoir, situated about 2 miles from Washington on the heights beyond Georgetown and connected with the receiving reservoir by a continuation of the conduit, is formed by an embankment of earth surrounding a favorable site. The area of its water surface is 36¾ acres, its level when full was 145 feet above tide, its contents, above 140 feet, is 59,783,000 gallons, and its total contents 167,530,000 gallons.

The two reservoirs are designed to afford, should the conduit be obstructed by floods or interrupted by accident, or during the periodical examinations necessary for repair, 142,530,000 gallons without reducing the head below 140 feet; and in case the level be lowered to 131 they would yield 250,000,000 gallons, besides what would be supplied from the watershed of the receiving reservoir on Little Falls Branch.

The mains which led the water to the city from the distributing reservoir were two, one 30 inches in diameter and one 12 inches in diameter. The size adopted was considered ample for the supply for some years after the completion of the aqueduct; the distribution of the water to the several parts of Washington was by smaller distributing mains laid by the city. As the demand for water increased with the growth of Washington, two other mains were added, a 36-inch main in 1873 and a 48-inch main in 1890, so that at present the supply is received through four mains—one 48-inch, one 36-inch, one 30-inch, and one 12-inch main.

A part of Georgetown, being too high to take water by gravity alone, was supplied from a high-service reservoir filled by pumping machinery.

The estimated daily capacity of the aqueduct was 67,560,400 gallons, and its estimated cost, including distributing mains to the various public buildings, which were also to be used for the city supply, $2,271,244.

The estimated population of Washington in 1852 was 49,339. Georgetown, by the census of 1850, contained 8,366 inhabitants, making a total to be supplied by the water system of 58,000.

The aqueduct, according to the above project, was so far completed in 1859 that the water from the receiving reservoir was available and turned into the mains. This supply was independent of the Potomac and was furnished by the watershed of Little Falls Branch. The conduit was completed and water supplied from the Potomac December 5, 1863, and since that date the system has been in successful operation.

It was found that the receiving reservoir was frequently rendered very turbid from sudden rises in Little Falls Branch and from surface drainage, thus making the water supply objectionable. To avoid this trouble a by-conduit was built carrying the Potomac water around the receiving reservoir, and it was intended to use the reservoir only when in a suitable condition as to turbidity or otherwise in case of emergency.

The constant turbidity and impurity introduced by the watershed draining into the receiving reservoir was finally remedied in 1895 by collecting this surface water and draining it into Little Falls Creek below the reservoir.

At the time of the first introduction of the Potomac water, the dam at Great Falls was a riprap dam and extended across the Maryland channel only. At low water in the Potomac constant difficulty was encountered in obtaining a sufficient supply of water. This was partially obviated by extending temporary dams above Conns Island, which was on the west side of the Maryland channel, and clearing out this channel by the removal of rock from its bottom. The riprap dam required constant repair after the damage caused by spring freshets and the run out of the ice.

In 1886 this dam was replaced by a masonry structure which was extended to the Virginia bank of the Potomac at a level of 148 feet above mean tide water at Washington and was finally, in 1896, raised to the level of 150.5 above the same level.

The capacity of the conduit after the raising of the dam was 76,500,000 gallons per diem when the water in the distributing reservoir was held at a level of 144.

This last amount may be considered as the present capacity of the Washington water system, as a lower height in the reservoir than 144 would so materially decrease the pressure in the mains that a marked lowering of the gravity supply would result.

With the present head a large part of the city can not be supplied by gravity. This portion is supplied by direct pumping and by a high-service reservoir at Fort Reno, to which water is pumped by the District Commissioners.

To recapitulate, the following is a concise description of the present Washington Aqueduct system:

The water supply is taken from the Potomac River at Great Falls, about 14 miles above the city.

At this point a masonry dam extends across the river from the Maryland to the Virginia shore. Its total length is 2,877 feet, and the width of its crest in the Virginia channel and across Conns Island is 8 feet 3 inches and in the Maryland channel 7 feet 9 inches. In 1895–96 the crest of the dam was raised from a reference of 148 feet above mean tide at the Washington Navy-Yard to 150.5 feet above the same datum plane.

The top of the mouth of the feeder of the conduit at Great Falls is at a reference of 149 feet and the bottom at a reference of 139.5 feet.

The water passes from the feeder through the gatehouse and into the conduit, which at this point has a reference of 152 feet at the interior surface of the crown of the arch.

The slope of the conduit is uniform between the gatehouse at Great Falls and the distributing reservoir and is 9 inches in 5,000 feet.

The conduit is circular in cross section, and for the greater part of its entire length is 9 feet in diameter and composed either of rubble masonry plastered or of 3 rings of brick, but where the soil in which it was built was considered particularly good the inner ring of brick was omitted and the diameter is 9 feet 9 inches. Where the conduit passes as an unlined tunnel through rock the excavation was sufficient to contain an inscribed circle 11 feet in diameter.

The lengths of the conduit and its connections are as follows:

Length of feeder at Great Falls, 256 feet.

Area of cross section at mouth, 157.45 square feet.

Length of conduit between gatehouse at Great Falls and north connection of Dalecarlia Reservoir, 47,896.5 feet; least diameter, 9 feet.

Length of by-conduit around Dalecarlia Reservoir, 2,730.5 feet; diameter for 625 feet, 8 feet; for rest of distance, 9 feet.

Length of conduit between south connection of the Dalecarlia Reservoir and north connection of the distributing reservoir, 10,149.87 feet; diameter of conduit, 9 feet.

Length of by-conduit around the distributing reservoir, 2,274.35 feet; diameter 7 feet.

At the distributing reservoir the water passes into four cast-iron mains, 48 inches, 36 inches, 30 inches, and 12 inches in diameter, respectively.

The Dalecarlia Reservoir has a storage capacity of about 150,000,000 gallons; is practically without paved slope wall, is perfectly protected against pollution from the drainage of the surrounding country, and is provided with a spillway, the reference of the bottom of which is 146.5 feet. The reference of the interior surface of the crown of the arch of the conduit at the north connection of this reservoir is 143.77 feet and at the south connection 143.39 feet. The distance between these points, measured along the line of flow of the water across the reservoir, is about 3,550 feet.

The distributing reservoir has a storage capacity of about 150,850,000 gallons and is divided by a puddled and paved wall, through which is a passageway which can be closed with stop planks, into two sections containing 97,600,000 and 53,250,000 gallons, respectively.

The interior surface of the crown of the arch of the conduit at the north connection of this reservoir has a reference of 141.87 feet.

In addition to the three reservoirs already mentioned, which form a part of the aqueduct system, there is another reservoir, built and controlled by the Commissioners of the District of Columbia, called the Fort Reno Reservoir, with a capacity of about 4,500,000 gallons, the reference of its water surface, when the reservoir is full, being about 420 feet.

This reservoir, like the high-service reservoir in Georgetown, is supplied with water taken from the 36-inch main by the U street pumping station.

The Dalecarlia and distributing reservoirs supply this station and that part of the District which lies below 100 feet above datum. The areas lying between the levels of 100 and 210 feet above datum are supplied by pumping from the U street station directly into the distributing mains. The areas having a greater elevation than 210 feet above datum are supplied from the Fort Reno Reservoir.

It will be observed, therefore, that the total present storage capacity of all reservoirs is a little over 305,000,000 gallons, or about six days' normal supply.

There is now under construction, for increasing the water supply of Washington, a tunnel from the present distributing reservoir to a new reservoir situated near the Howard University.

The new reservoir has a capacity of 300,000,000 gallons, thus raising the capacity of storage to 605,000,000 gallons.

The new reservoir, being situated about 4 miles east of the present distributing reservoir, will occupy a more central distribution point, and thus somewhat reduce the loss of head now obtaining at Capitol Hill and east thereof. The level of water in this reservoir will be 144, and it is estimated will add about 15 feet additional height to the water delivered at Capitol Hill.

Until the average daily consumption of water becomes considerably greater than at present, the reference of the surface of the water at the lowest stage of the Potomac will be about 151 feet at the mouth of the feeder at Great Falls; about 146.75 feet at the Dalecarlia Reservoir, and 146 feet at the distributing reservoir.

The following table gives the daily consumption of water by the District of Columbia as furnished by the Washington Aqueduct for the last twenty-six years:

Date.	Daily consumption.	Population.	Amount per capita per diem.
	Gallons.		*Gallons.*
1874	17,554,848	[1]130,182	134
1875	21,000,000	[1]138,091	152
1876	24,177,797	[1]146,000	165
1877	23,252,932	[1]153,909	151
1878	24,885,945	[1]161,818	154
1879	25,947,642	[1]169,727	153
1880	25,740,138	[2]177,638	145
1881	26,525,991	[1]182,893	145
1882	29,727,864	[1]187,968	158
1883	24,314,715	[1]193,133	126
1884	24,827,113	[1]198,198	125
1885	25,219,194	[3]203,459	124
1886	25,542,476	[1]208,358	123
1887	26,878,424	[1]213,357	126
1888	29,115,774	[1]218,157	133
1889	27,708,779	[1]225,309	123
1890	35,541,845	[2]232,460	153
1891	38,594,743	[1]248,539	155
1892	41,161,780	[3]264,618	156
1893	46,727,108	[1]267,569	171
1894	49,162,357	[3]270,519	182
1895	47,182,681	[1]272,667	173
1896	44,113,574	[1]274,815	161
1897	45,267,047	[3]276,963	163
1898	47,288,733	[1]279,432	169
1899	50,079,855	[1]281,901	178

[1] Estimated. [2] United States census. [3] Police census.

THE POTOMAC RIVER WATER.

The Potomac River, formed by the junction of its north and south branches, rises in the Allegheny Mountains, the north branch in the western part of Maryland, near the head waters of the Monongahela River, and the south branch in the State of West Virginia. These two branches, draining narrow and precipitous valleys in the mountainous regions, unite at Cumberland, Md., to form the main river, thence in a southeasterly direction, normal to its previous course and to the direction of the mountain range, the river flows to the sea through one of the great estuaries of the Atlantic—Chesapeake Bay.

Owing to the narrow and steep-sided valleys in which it has its source, and to the fact that there are no lakes throughout its basin, the Potomac is subject to sudden and heavy freshets.

The principal tributary is the Shenandoah River, joining from the south at Harpers Ferry. Many small streams, generally from the Maryland side, are also tributary, the principal one being the Monocacy River, upon which the city of Frederick is situated. These tributaries flow through a rolling and cultivated country quite in contrast to that above Harpers Ferry.

The drainage area of the Potomac River above the Great Falls, whence is taken the Washington water supply, is 11,043 square miles. The minimum flow of the river at the Great Falls is 1,065 cubic feet per second, or 700,000,000 gallons per diem, the average flow 6,500,000,000 gallons per diem, and the estimated flow during the flood of 1889 305,650,000,000 gallons. The estimated population for 1900 of the watershed is 491,813, or about 44.5 per square mile.

The towns in the drainage basin of the Potomac are not sewered, so that very little direct sewage is emptied into the stream, the main source of contamination being from surface drainage, whence may be expected pollution due to decaying vegetable and animal matter, the surface wash from fertilized fields, the excreta from man and animals, the waste from factories, and whatever salts may be held in solution derived from the natural geological formation of the basin.

From the figures given above it will be seen that the Potomac River affords an abundant supply for the District of Columbia. The present consumption—50,000,000 gallons per diem—is only about 7 per cent of the minimum discharge of 700,000,000. The present population of the District of Columbia is estimated as 280,000, and will, according to estimate (see report upon the sewerage of the District of Columbia, House Ex. Doc. No. 445, Fifty-first Congress, first session), probably reach 500,000 in 1930. At the present rate of consumption this population would require a per diem supply of about 100,000,000 gallons, about 15 per cent of the minimum discharge.

Pure water does not exist in nature. The rain that falls from the clouds becomes contaminated before reaching the earth. It absorbs ammonia, carbonic acid, sulphuretted hydrogen, and other gases from the atmosphere, especially in the vicinity of cities and towns. It takes up and holds in suspension floating particles of the minute dust always present in the atmosphere—carbon in the form of smoke or floating soot. After falling to earth and before it again appears at the surface as springs it has, although having undergone a natural filtration, dissolved from the soil and strata through which it has passed various soluble salts, which are sometimes so noticeable as to give a medicinal quality to the water. From the spring or fountain head the water, again starting on its journey to the ocean whence it came in vapor, is joined by other springs and surface drainage, becoming more or less polluted as the character of the districts through which it passes varies, till at last, receiving the enormous sewage discharge of large cities, it becomes dangerous as a domestic supply.

The spread of many zymotic diseases is attributed by modern authorities to polluted water. It is almost universally admitted that typhoid fever, Asiatic cholera, anthrax, and even tetanus are water-borne diseases, whose germs have been carried in the water contaminated by surface drainage or sewage.

The science of bacteriology has so far advanced that careful examination of suspected water can differentiate these disease bacilli, and no source of supply should, under present conditions of civilization, be adopted for domestic purposes until this examination be made.

The bacteriological examination of a source of supply, if a running stream, subject to the various changing conditions of the seasons, should be continuous for at least a year to give perfectly satisfactory results, as the stage of stream, the temperature, and seasons of the year all affect its condition.

In addition to the bacteriological examination, a water supply should also be submitted to a chemical analysis. By such analysis may be determined the probable source of pollution, if any exists.

The chemical analysis of potable water consists in determining the parts per million of ammonia, nitrogen as nitrites and nitrates, chlorine, alkalinity, required oxygen, total solids, turbidity, color, odor, and taste.

Ammonia.—The presence of ammonia in abnormal or suspicious quantity indicates pollution by animal matter, decayed or decaying.

Nitrogen as nitrites and nitrates.—The presence of nitrites is always to be looked upon with suspicion as indicating contamination. Nitrates indicate the former presence of nitrites more fully oxidized.

Chlorine.—The presence of chlorine above the normal is very suspicious. Chlorine is nearly always present in the water used for domestic purposes, due to common salt, and an excess is a positive indication of sewage contamination.

Alkalinity.—The determination of alkalinity is important as an indication of hardness. Very hard water is expensive as wasting soap, and "scales" in cooking utensils and steam boilers, and frequently renders the water disagreeable to the taste.

Required oxygen.—This determination gives a means of judging the amount of organic carbon present in water.

Turbidity.—This is determined chemically by ascertaining the total amount of solids in suspension.

Color.—This is determined ocularly by comparison with standards.

Odor.—This is obtained by smell.

Taste.—This is determined by physical test.

No absolute standards can be established by which a water may be condemned as unfit for domestic purposes, as the source of supply must always enter into consideration, and an excess in any item of determination may be traced to harmless causes.

The following are some of the standards quoted from Prof. William P. Mason's treatise on "Water supply:"

Ammonia.—Professor Mallet gives from an analysis of 15 drinking waters believed to be wholesome, for albuminoid ammonia, 0.125 parts per million. Dr. Leeds gives as the highest limits as a standard for American waters, free ammonia 0.01 to 0.12 per million.

Nitrites.—Mallet gives 0.0135 per million. Leeds gives (American rivers) 0.003 per million.

Nitrates.—Mallet gives as an average of 13 samples 0.42 per million. Extremes, 0 to 1.04.

Chlorine.—Leeds gives 3 to 10 per million. Ordinary sewage contains 110 to 160 per million. Human urine contains 5,872 per million.

Hardness.—Leeds gives, in parts per million, 50 for soft and 150 for hard waters.

Total solids.—Dr. Smart, National Board of Health, 1880, gives as a safe limit 300 parts per million; to be condemned, 1,000 parts per million. Leeds gives, as a standard for American rivers, 150 to 200 parts per million.

Required oxygen.—Leeds gives 5 to 7 parts per million.

These standards are shown below in tabular form:

Total solids	150 –300
Free ammonia	0.01 – 0.12
Albumin. ammonia	.10 – .28
Nitrites	.0135– .003
Nitrates	.0 – 1.04
Chlorine	3 – 10
Required oxygen	5 – 7

RESULTS OF CHEMICAL ANALYSIS OF THE WASHINGTON WATER SUPPLY.

The chemical analysis of the water as taken from the faucet has been made weekly at the health office of the District Commissioners for several years.

Col. Charles Smart, Assistant Surgeon-General, United States Army, kindly furnished analyses made by Dr. William M. Mew, Army Medical Museum.

Analyses were also made during the experiments by Mr. Robert Spurr Weston, who had charge of this subject, as well as the bacteriological and physical examinations.

The results of the analyses by the District health office and Dr. William M. Mew are given below.

The details of Mr. Weston's analyses can be examined by reference to his valuable report, which is submitted as an appendix.

Statement of the results of various analyses of Potomac water as delivered from the faucet in the laboratory of the health office, Washington, D. C., since July 22, 1897.

[Parts per million.]

No.	Date.	Total solids.	Loss on ignition.	Free ammonia.	Albuminoid ammonia.	Nitrites.	Nitrates.	Chlorine.	Oxygen consumed.
	1897.								
1	July 22	145	48	0.002	0.175	Trace.	0.45	3.5	2.52
2	July 29	137	61	.006	.220	0.002	.47	3.5	2.74
3	Aug. 5	128	45	.000	.135	.000	.47	3.6	2.56
4	Aug. 12	142	60	Trace.	.140	.000	.60	3.5	2.60
5	Aug. 19	131	39	.004	.128	.000	.50	3.5	2.40
6	Aug. 26	125	54	.000	.130	.000	.50	3.5	2,36
7	Sept. 2	140	62	.000	.130	.000	.52	3.5	2.30
8	Sept. 9	136	48	.000	.130	.000	.50	3.5	2.32
9	Sept. 16	125	51	.000	.110	.000	.54	3.5	2.16
10	Sept. 23	117	60	.000	.096	.000	.51	3.5	1.96
11	Sept. 30	130	54	.000	.105	.000	.52	3.5	2.04
12	Oct. 7	135	60	Trace.	.115	.000	.52	3.5	2.11
13	Oct. 14	145	60	.000	.110	.000	.35	5.0	2.00
14	Oct. 21	140	50	.000	.105	.000	.50	4.0	1.96
15	Oct. 28	142	51	.000	.115	.000	.65	4.0	2.04
16	Nov. 4	136	48	.000	.100	.000	.60	4.0	1.95
17	Nov. 11	139	56	.000	.120	.000	.60	4.0	2.00
18	Nov. 18	135	54	.000	.145	.000	.70	4.5	2.12
19	Nov. 23	140	56	.000	.140	.000	.70	4.5	2.10
20	Dec. 1	168	63	.0066	.197	.000	.70	4.5	3.08
21	Dec. 9	140	47	.004	.100	.000	.60	4.0	1.90
22	Dec. 16	131	42	.000	.098	.000	.60	4.0	1.84
23	Dec. 23	119	41	Trace.	.096	.000	.60	4.0	1.72
24	Dec. 30	116	40	.001	.098	.000	.65	4.0	2.11
	1898.								
25	Jan. 6	121	38	.000	.098	.000	.65	4.0	1.84
26	Jan. 13	105	38	.000	.074	.000	.60	4.5	1.76
27	Jan. 20	116	42	Trace.	.089	.000	.60	4.0	1.84
28	Jan. 27	140	44	.000	.110	.000	.60	4.0	2.06
29	Feb. 3	103	37	.001	.064	.000	.65	4.0	1.66
30	Feb. 10	100	35	.000	.084	.000	.60	4.0	1.72
31	Feb. 17	94	32	.000	.090	.000	.60	4.0	1.76
32	Feb. 24	100	41	.000	.074	.000	.75	3.5	1.56
33	Mar. 3	96	35	.000	.068	.000	.80	3.5	1.52
34	Mar. 10	95	38	.000	.060	.000	.85	3.5	1.42
35	Mar. 17	92	37	.000	.045	.000	.85	3.5	1.32
36	Mar. 24	96	36	.000	.050	.000	.80	3.5	1.36
37	Mar. 31	101	40	.000	.056	.000	.80	3.5	1.52
38	Apr. 7	108	38	.000	.089	.000	.75	3.5	2.12
39	Apr. 14	110	46	.000	.086	.000	.70	4.0	2.00
40	Apr. 21	98	39	.000	.097	.000	.70	3.5	2.16
41	Apr. 28	92	41	.000	.079	.000	.70	3.5	1.91
42	May 5	95	39	.000	.072	.000	.70	3.5	1.79
43	May 12	97	40	.000	.084	.000	.70	3.5	1.60
44	May 19	106	42	.000	.100	.000	.70	3.5	1.84
45	May 26	112	45	.000	.130	.000	.60	3.5	1.98
46	June 2	116	40	.000	.140	.000	.60	3.5	2.00
47	June 9	120	42	.000	.145	.000	.60	3.0	2.11
48	June 16	125	42	.000	.128	.000	.55	3.5	2.00
49	June 23	128	46	.000	.116	.000	.60	3.0	1.90
60	June 30	122	41	.000	.120	.000	.50	3.0	1.96
51	July 7	125	44	.000	.135	.000	.50	3.0	1.90
52	July 14	132	48	.000	.110	.000	.50	3.0	1.80
	1899.								
53	Aug. 28	128	61	.000	.130	.000	.80	4.0	2.60
54	Sept. 5	130	52	.000	.150	.000	.80	4.0	3.60
55	Sept. 21	131	45	.000	.165	.000	.70	4.0	2.36
56	Sept. 28	137	44	.000	.134	.000	.70	4.0	3.00
57	Oct. 4	144	43	.000	.110	.000	.70	4.0	3.20
58	Oct. 18	151	58	.000	.060	.000	.70	4.0	3.60
59	Oct. 24	157	45	.000	.125	.000	.70	4.0	4.00
60	Nov. 1	144	44	.000	.150	.000	.70	4.0	3.40
61	Nov. 9	156	42	.000	.140	.000	.70	4.0	3.60
62	Nov. 16	148	56	.000	.110	.000	.70	4.0	4.00
63	Nov. 22	125	44	.000	.105	.000	.70	4.0	3.60
64	Dec. 5	144	46	.000	.110	.000	.70	4.0	4.00
65	Dec. 6	137	48	.000	.065	.000	.70	4.0	5.60
66	Dec. 14	138	51	.000	.070	.000	.70	4.0	4.00
67	Dec. 28	145	48	.000	.097	.000	.70	4.0	4.20
	1900.								
68	Jan. 4	154	52	.005	.120	.000	.72	4.0	6.00
69	Jan. 11	161	51	.004	.156	.000	.72	4.0	4.60
70	Jan. 18	132	35	.010	.110	.000	.72	4.0	5.60
71	Jan. 25	129	37	.010	.135	.000	.72	4.0	5.40
72	Jan. 31	145	40	.006	.140	.000	.70	4.0	4.50
	Average.	126.7	45.6	.0008	.111	....	.637	3.78	2.55

Statement of results of analyses of Potomac water from April 25 to October 25, 1899, inclusive.

[The results are given in parts per 100,000 of the water.]

Date.	Chlorine.	Nitrites.	Nitrogen in nitrates.	Free ammonia.	Albuminoid ammonia.	Oxygen used.	Total solids.	Loss on ignition.
April 25	0.4	None.	0.10	Trace.	0.008	0.144	9.4	4.5
May 3	.4	None.	.15	Trace.	.008	.150	9.7	4.1
May 11	.4	None.	.15	Trace.	.005	.152	13.0	*2.5
May 17	.4	None.	Trace.	Trace.	.008	.232	14.0	*3.0
June 1	.4	None.	Trace.	Trace.	.006	*.250	11.0	*2.0
June 14	.4	Trace.	0.15	Trace.	.012	*.264	15.0	*3.5
June 23	.4	None.	.10	Trace.	.008	.150	9.7	4.0
June 28	.4	Trace.	.05	Trace.	.10	.192	14.5	5.5
July 6	.4	None.	.10	Trace.	.006	.188	12.0	4.0
July 19	.4	None.	.07	Trace.	.006	.164	11.2	4.2
August 2	.4	Trace.	.10	Trace.	.012	.180	12.1	4.0
August 16	.4	None.	.10	Trace.	.014	.220	12.5	4.1
August 30	.4	None.	.11	Trace.	.015	.256	12.6	5.4
October 4	.4	None.	.15	Trace.	.012	.262	13.9	4.7
October 18	.4	Trace.	.12	Trace.	.007	.268	14.5	5.4
October 25	.4	None.	.11	Trace.	.012	.284	15.1	4.8
Averages	.4	Trace.	.11	Trace.	.015	.210	12.5	4.1

NOTE.—The asterisks point to experiments made to ascertain the loss on ignition after total removal of suspended matter by means of the centrifugal machine. Also, in two cases, the effect of this on the estimation of "oxygen used." That of June 1 had required, before the removal of suspended matter, 0.264, and that of June 14 0.280 parts.

In the nitrite column, where traces are reported, the reaction, never more than faint, became apparent in fifteen minutes.

Experiments were made to ascertain the amount of suspended matter in turbid water on May 17 and on June 14. It amounted to 5 parts and 6 parts, respectively. All the "oxygen used" estimations given above were made upon water free from suspended matter.

The albuminoid ammonia estimations on July 6 and 19, being unusually low, were repeated and found correct.

The nitrogen in nitrates was estimated by the picric-acid method.

W. M. MEW,
Chemist, Surgeon-General's Office.

DECEMBER 15, 1899.

The following are the results tabulated for comparison, by averages:

	Total solids.	Free ammonia.	Albumin. ammonia.	Nitrites.	Nitrates.	Chlorine.	Required oxygen.
Health office, District of Columbia	126.7	0.0008	0.111	Trace.	0.639	3.78	2.56
Dr. William M. Mew	125.0	Trace.	.150	Trace.	1.100	4.00	2.10
Mr. Robert Spurr Weston	139.0	.013	.105	0.002	.73	2.60	4.50
Mason's safe limit	150–300	.01–.12	.10–.28	.0135–.003	.42	3–10	5–7

Turbidity in a water supply is objectionable more from an æsthetic point of view than hygienically; this is also true generally in respect to color.

Turbidity is caused by insoluble matter held in suspension, generally finely divided clay, and may largely be removed by sedimentation when receiving reservoirs or sedimentation basins are available. The water of the Missouri River is constantly very turbid, but may be regarded as very good water from a sanitary point of view. The water from the Dismal Swamp, the supply of Norfolk and Portsmouth, Va., is distinctly colored, but is not thereby rendered sanitarily impure. Both these waters—the Missouri, which is the Mississippi at New Orleans, and the water at Portsmouth, Va.—were considered so good in the time of sailing vessels that ships at these ports usually laid in a full supply for voyages. But, as turbidity and color are decidedly objectionable to consumers, these defects should be removed from a municipal supply.

There are various methods of measuring the turbidity of water; none in use, however, have given quite satisfactory results.

Daily observations of the turbidity of the Washington water supply have been taken since the year 1880. The method employed was the determination of the distance in inches at which a sphere of copper 1 inch in diameter could be seen with the naked eye through the water placed in a rectangular tube. The length of the tube used enabled distances to be reached up to 36 inches. An arbitrary scale was adopted as follows:

When the sphere was visible from 36 to 22 inches—clear.
When the sphere was visible from 21 to 15 inches—slightly turbid.
When the sphere was visible from 14 to 8 inches—turbid.
When the sphere was visible from 7 to 0 inches—very turbid.

Experience has proved that when the water is reported clear, or when the sphere is visible through 22 inches of water, no objection is made to the water on the score of turbidity. Thirty-six being the limit of the scale, all water clearer than this is reported as 36. The following table exhibits the turbidity of the Potomac water by this scale:

Turbidity of Potomac water.

Fiscal year	Great Falls.				Receiving reservoir.			
	Clear.	Slightly turbid.	Turbid.	Very turbid.	Clear.	Slightly turbid.	Turbid.	Very turbid.
1880	188	44	40	94	251	28	41	46
1881	189	21	32	123	234	27	41	63
1882	186	21	29	129	228	19	42	76
1883	161	30	38	136	232	37	53	43
1884	134	30	29	173	189	46	24	107
1885	173	14	52	126	180	46	40	72
1886	127	36	51	151	Reservoir out of service.			
1887	164	29	61	121	187	37	52	19
1888	194	15	26	131	18	8	56	87
1889	147	33	50	135	Reservoir out of service.			
1890	159	27	57	122				
1891	144	30	61	130				
1892	140	41	46	139				
1893	186	14	51	114				
1894	165	32	59	109				
1895	205	26	52	82				
1896	195	28	25	118	191	8	32	87
1897	192	18	36	119	200	20	34	111
1898	168	16	44	137	184	12	33	136
1899	151	17	46	151	162	25	42	136
	3,368	522	875	2,540	2,256	313	490	933
		3,937=53.8 per cent.				1,736=43.5 per cent.		

NOTE.—The receiving reservoir was out of service from June 3, 1885, to July 28, 1886; from April 6, 1887, to May 7, 1887; from June 21, 1887, to December 23, 1887; from April 20, 1888, to August 17, 1895, and from August 27 to 28, 1895.

Distributing reservoir.

Fiscal year.	Receiving reservoir in service, showing effect of two sedimentations.				Receiving reservoir out of service, showing effect of one sedimentation.			
	Clear.	Slightly turbid.	Turbid.	Very turbid.	Clear.	Slightly turbid.	Turbid.	Very turbid.
1880	290	27	31	18	....	....	....	....
1881	281	9	17	58	....	....	....	....
1882	261	16	28	60	....	....	....	....
1883	293	13	25	34	....	....	....	....
1884	244	21	8	93	....	....	....	....
1885	184	20	53	81	27	....	....	....
1886	Receiving reservoir out of service.				147	35	72	111
1887	221	35	29	38	35	4	3	....
1888	15	7	40	67	225	9	12	1
1889	Receiving reservoir out of service.				193	24	64	84
1890					124	29	26	16
1891					188	35	84	58
1892					178	34	70	84
1893					205	30	43	87
1894					213	34	63	55
1896					249	17	38	61
1896	195	12	24	87	28	3	2	15
1897	226	23	49	67	....	....	....	....
1898	221	28	33	83	....	....	....	....
1899	180	41	47	97	....	....	....	....
	2,611	252	384	773	1,812	254	477	572
		1,409=35 per cent.				1,303=45 per cent.		

These tables show continuous observations of turbidity at Great Falls for twenty years, and that during that period the water was turbid for 53.8 per cent of the time. The record at the receiving reservoir shows the effect of sedimentation at that place, and that during the period it was in service the water was turbid for 43.5 per cent of the time. During the period of nonservice of the receiving reservoir the distributing reservoir was turbid 45 per cent of the time. Or, in other words, the effect of one sedimentation reduced the period of turbidity from 53.8 per cent at the Great Falls to 43.5 per cent and 45 per cent. During the period when both reservoirs were in service, thus giving two sedimentations, the first in the receiving reservoir and the second in the distributing reservoir, turbidity was indicated for 35 per cent of the time. In other words, one sedimentation reduced the turbidity period from 53 per cent to a percentage of 45, while the effect of two sedimentations was to reduce the period from 53 per cent to 35 per cent of the term observed.

The Washington water supply, therefore, is objectionable by reason of turbidity at present for 35 per cent of the time. The Howard Reservoir, when completed, will add one more sedimentation; therefore, with the present system complete as contemplated, it may be estimated that the Washington water supply will be objectionable, owing to turbidity, for one-third of the year, or for one hundred and twenty-two days.

The only practical remedy for this turbidity is filtration.

For the purpose of making an expert examination of the water supply the services of Mr. Robert Spurr Weston, of Boston, Mass., were secured. He was placed in charge of the chemical and bacteriological examination of the water on September 11, 1899. Between June 22, 1899, and September 10, 1899, Mr. James M. Caird had charge of this work, but resigned, on account of ill health, September 10, 1899.

The bacteriological results obtained show that the Potomac water as delivered from the mains is, in times of turbidity and low temperature, dangerous to health by reason of the quantity of bacteria present.

The number of bacteria present in 1 cubic centimeter of raw water has varied from 48 to 51,000.

The table below gives the results of bacterial counts:

Date.	Maximum.	Minimum.	Average.
1899.			
July (19 days)	790	48	154
August	685	67	269
September	556	90	196
October	500	80	138
November	1,200	70	401
December	31,000	135	3,281
1900.			
January	51,000	3,500	15,700
February	26,200	2,500	9,950

The above results are only quantitative—that is, showing the number of bacteria present per cubic centimeter. A further examination as to the nature of the bacteria is necessary to decide on the hygienic quality of the water. This examination is the qualitative or method by differentiation. In other words, a method to ascertain whether pathogenic or disease-bearing bacteria are present. As an indication of sewage pollution or contamination from excreta, the presence of the bacillus coli communis, the ordinary intestinal bacteria, is a positive test. Other bacilli are capable of differentiation, but generally in water examinations the tests are confined to the coli communis, as the presence of this species would suggest the probable presence of the intestinal bacilli, and among them the typhus bacilli, so much dreaded in city supplies.

The bacteriological examination of the influent water was principally conducted for the purpose of ascertaining the quantitative results or number of bacteria, without regard to classification, present in the raw water. Qualitative examinations were made only to ascertain the presence of the bacillus coli communis. This is the bacillus of excreta, and its presence indicates sewage contamination, or contamination of like character from surface drainage.

Of the specimens examined, 50 per cent, or one-half, indicated the presence of this germ, and it may be concluded that the water supply of Washington is dangerous to health and requires filtration.

The relative pollution of the water is judged by the number of bacteria present per cubic centimeter. Professor Koch, the acknowledged German authority, states that a potable filtered water should contain no more than 100 bacteria per cubic centimeter, and this criterion has been established in Germany by law, and under Government supervision all water supplies from filters which contain more than this quantity are condemned as unfit for domestic use in times of epidemics.

From what has preceded it may be stated that Washington is now supplied with water of a quality as good as that of most American cities where filtration has not been adopted. The principal objection urged against it is occasional turbidity. But all surface water obtained from the drainage of large watersheds is liable to pollution from increasing population, the sewage of cities and towns, and epidemics, which are liable at any time to give the water the faculty of spreading disease. In the present state of civilization and advancement in science the means are at hand to render a river supply harmless. Washington, the capital of the country, should be provided with every hygienic precaution against disease, and the purification of its water supply is one of the most important. Experiment and experience have demonstrated that this purification can be accomplished.

In this country the purification of the water supplies of large cities has within the last decade become a matter of serious and careful consideration, and exhaustive experiments have been made at Louisville, Ky., Cincinnati, Ohio, and Pittsburg, Pa., as to the feasibility, method, and cost of works for this purpose. Many smaller cities and towns have adopted systems of filtration, but the largest cities, owing, possibly, to the financial aspect of the question, have not, up to the present, installed any large plants.

If Washington is to be supplied at all times with an unobjectionable water, the only recourse is the adoption of a system of filtration.

FILTRATION.

The word filtration has for its root felt, and its meaning is taken from the fact that felt was first used as a strainer for the clearing of water, and filtration, as originally understood, had for its object the removal from water or liquids of suspended matter, or turbidity, by straining.

No positive indications of filtration on a large scale can be found among the ancient ruins whose object was the supplying of water to communities, but remains are in existence which indicate that an attempt at clarification by sedimentation was adopted.

It was not until the year 1829 that any attempt was made to filter water on a large scale. At this time an experimental sand filter one acre in extent was constructed in London by the Chelsea Water Company, on the recommendation of a royal commission.

Since this date numerous and large filters have been erected in London for the filtration of a daily supply of 200,000,000 gallons.

From this beginning the practice of filtration has been carried forward on the English system until most of the large cities of England and the continent of Europe have adopted this system. The English method, which has changed little during the last seventy years, consists in passing the water to be purified through a stratum of sand overlying gravel and collecting the filtrate by means of underdrains properly constructed.

In the English system the water usually after sedimentation is passed to a depth of 4 to 5 feet on to the sand layer having a thickness varying from 4 to 8 feet, and allowed to pass through the sand at a rate of about 1,700,000 gallons per diem per acre. This rate is about the average rate, but the actual rate of filtration depends upon the condition of the water delivered to the filter. In some cases, as at Zurich in Switzerland, where the water is taken from the lake, a rate of 7,000,000 gallons per acre per diem is often attained with good results.

As this method of filtration has been developed the science of public hygiene has greatly advanced, and examination of the filtered and unfiltered waters has disclosed the fact that this method not only removes the coarser materials to which turbidity is due, but also removes the bacteria and germs of water-borne diseases, which are generally plentiful in water requiring filtration. The study of this subject, more especially in Germany, has led to the adoption of certain criteria to be attained by the filtered water, and all public water supplies which are filtered are required by law to reach this standard.

The following are the latest regulations adopted by the German Empire:

SECTION 1. In judging the quality of a filtered surface water attention is to be paid to the following points: (*a*) The operation of the filter is to be regarded as satisfactory if the number of bacteria in the effluent does not exceed that limit which experiment has shown to be attained by good sand filtration at the waterworks in question. A satisfactory effluent shall, as a rule, not contain more than about 100 bacteria per cubic centimeter when it leaves the filter. (*b*) The filtrate must be clear as possible, and must not be inferior in color, taste, temperature, and chemical character to the water before filtration.

SEC. 2. In order to control a waterworks continuously in its bacteriological relations, it is advisable to examine the effluent of each filter daily, where the conditions permit. Such a daily examination is particularly important (*a*) after the construction of a new filter until it assumes its regular working conditions; (*b*) whenever a filter is put in operation after cleaning and for at least two days after that time, until the effluent has a satisfactory character; (*c*) after the filtration head becomes more than two-thirds of the maximum for the works in question; (*d*) when the filtration head suddenly decreases; (*e*) during all unusual conditions, especially at times of high water.

SEC. 3. In order to be able to conduct bacteriological investigations according to section 1 (*a*) the effluent of each filter must be accessible, that samples may be taken at any desired time.

SEC. 4. In order to assure a uniform system of bacteriological investigations the method given below is recommended for general use.

SEC. 5. The persons intrusted with the conduct of the bacteriological investigations must furnish proof that they possess the qualifications necessary for the work. They should belong to the official operating staff itself whenever possible.

SEC. 6. If a filter furnishes water which does not meet the hygienic requirements, it is to be cut out of service, provided the cause of the deficient character has not already been removed during the course of the bacteriological investigations. In case a filter furnishes an unsatisfactory effluent oftener than occasionally, it is to be placed out of service and the defects sought out and remedied.

SEC. 7. In order to be able to waste poor water which does not meet the requirements, each filter must be arranged so that it can be cut off from the filtered water mains, and the effluent allowed to flow away. This waste is to take place regularly, so far as the details of management permit, (*a*) immediately after the complete cleaning of the filter, and (*b*) after completely renewing the bed of sand. The superintendent in charge must determine, from his experience with the continuous bacteriological investigations, whether a waste of the effluent is necessary in each individual case after the completion of this cleaning or renewal, and the length of time that must elapse before the effluent attains the required degree of purity.

SEC. 8. It is necessary for satisfactory sand filtration for the surface of the filters to have ample dimensions and provide sufficient reserve to assure the velocity of filtration suitable for the local conditions and the character of the raw water.

SEC. 9. Each filter bed must be controllable as respects quantity of effluent, excess pressure, and character of effluent. It must also be arranged so that it can be completely emptied, and also be filled from below with filtered water after each cleaning.

SEC. 10. The speed of filtration in each filter bed must be capable of adaptation to the most favorable conditions for filtration at any time, and be as regular and free from sudden fluctuations or interruptions as possible. To this end the usual fluctuations, caused by the varying demand for water during different portions of the day are to be equalized, as far as possible, by reservoirs.

SEC. 11. The filter beds are to be so arranged that their operation will not be influenced by varying levels of the water surface in the clear-water reservoir.

SEC. 12. The excess filtration head must never be so great that breakage of the filtering top layer can occur. The limit to which the excess pressure may rise without influencing the effluent is to be determined for each plant by bacteriological investigations.

SEC. 13. The filters shall be constructed in such a manner that every portion of the surface of each bed shall work as uniformly as possible.

SEC. 14. The walls and bottom of a filter are to be water-tight, and particularly must there be no danger of an immediate connection or passage through which raw water may pass from the filter into the filtered-water main. For this purpose special attention is to be paid to water-tight construction and maintenance of the air shafts of the filtered water mains.

SEC. 15. The thickness of the bed of sand shall be at least so great that the cleaning will never reduce it to less than 30 centimeters (12 inches) where the conditions permit. Nevertheless, it is recommended that this minimum limit be raised to 40 centimeters (16 inches) where the conditions permit.

SEC. 16. It is desired that annual reports be made from all the sand filtration works in the German Empire to the Imperial Board of Health, giving the results of operation, and particularly the bacteriological character of the water before and after filtration.

It will appear by the above description that the English system of filtration is a method following the processes by which ground waters attain their purity; that is, the passage of the water through finely-divided insoluble mineral material. Many materials have been proposed and experimented with as substitutes for sand, but none have been found which could be economically used in its place.

The successful operation of the English filters has established their efficiency in other countries. In this country, up to this date, only a few of these filters have been erected and operated, and these on only a rather small scale. The largest in operation are those recently completed at Albany, N. Y., for the filtration of the Hudson River water. They have been in operation but a short time and have given good results both as regards economy of operation and efficiency of results as to the removal of turbidity and bacteria.

The theory of the English system is as follows: The water, when first allowed to flow on the sand bed, sinks slowly through the sand, leaving behind on the sand surface the material and bacteria which are too large to pass the interstices in the sand, and this accumulation gradually forms a layer, or blanket, or felt on the surface of the sand, called by the Germans "schmutz decke," which is really the filtering film, although it is claimed that some of the bacteria which pass into the sand bed, by forming a gelatinous film adhering to the sand, add to the efficiency of the filter by decreasing the size of the interstices in the sand.

After a certain period, depending upon the conditions of the raw water, the "schmutz decke" becomes so compact and offers so great a resistance to the passage of the water that it becomes necessary to remove it. This is done by drawing the water off the surface and scraping the top of the sand. It is found usually that it is necessary to remove from one-half to three-fourths of an inch in thickness to restore the filter to proper condition. The filter is then ready for use and the water is again turned on. This removal of the sand, after a certain period, would render the thickness of the sand layer too small to filter properly, and new sand must be placed in the filter to take the place of that removed by scraping. The removal and replacing of this sand is the principal item of expense in the operation of the English system. Experience has shown that the thickness of the sand should never be reduced below 12 inches, and it is best never to reach this limit. It is the practice in some filters, after a certain time, to renew the sand bed entirely, but the general practice is to renew, from time to time, as the filter is scraped, for instance, after 6 inches have been removed to replace with clean sand.

It has been found that in general the English filter improves with age.

Another method of filtration has been adopted in this country, sometimes called the American or mechanical system.

In this system a great rapidity of filtration is obtained, the rate being about 120,000,000 gallons per acre per diem.

In order to attain this high rate it is necessary that the sand used must be much coarser than that used in the English system. Also, owing to the coarseness of the sand and the consequent comparatively large interstices, the suspended matter must be collected into particles or masses too large to pass these interstices. This is attained by the use of a coagulant—generally sulphate of alumina.

This coagulant is applied to the water before it flows upon the sand and in quantities as called for by the condition of the water to be filtered.

In this method, owing to the great rapidity of filtration, the schmutz decke formed by the aluminum hydrate and the coagulated sediment soon becomes so impervious as to require removal. This removal is accomplished by sending a current of filtered water through the sand in a reverse direction and at the same time stirring the sand by machinery. After the turbid water, the result of washing, is removed, filtration is again started. It requires about fifteen minutes to perform this washing, and under favorable conditions the filters of this system will run twelve hours without washing—under unfavorable conditions about eight hours.

The amount of coagulant used depends upon the condition of the applied water. It may vary between 1 and 6 grains per gallon filtered.

The principal expense involved in the operation of this system of filtration is the cost of sulphate of alumina used and the running and repair of machinery.

Results which have been obtained from the use of this system of filtration are highly satisfactory in respect to the condition of the filtered water, both as to the removal of bacteria and clearness and brilliancy of the effluent. The expense of manipulation and coagulant are somewhat higher than in the English system, although the first cost of plant is less. The period between washings may be sometimes prolonged by agitating or trailing the surface, but this is not very efficient.

The results of experimenting with the two systems, with the Potomac water, will be given further on.

EXPERIMENTAL FILTERS.

In order to ascertain practically the efficiency of filtration as applied to the Washington water supply, it was decided to erect two experimental filters, one of the English type and one embracing the most recent improvements in the American system.

ENGLISH OR SLOW SAND FILTER, "A."

This filter was constructed as follows (see Pl. II): The filter consisted of a cylindrical white-pine tank, 11 feet in diameter, horizontal inside area 95,033 square feet, containing the filtering materials, with the necessary pipes, valves, meter, etc., to admit the raw water, control its velocity through the filter, or rate of filtration, and dispose of the filtered water.

The supply of raw water was taken from the 30 and 36 inch mains which supply the aqueduct office, through a three-fourths-inch galvanized-iron pipe, to the influent box of the filter.

The filtering material was as follows: The lower layer of large gravel or cobblestones, to serve as underdrains, was 8 inches deep and composed of gravel 4 inches in diameter. Above this were placed three layers of smaller gravel to support the sand. The lower layer was composed of 1-inch gravel of a depth of 4 inches; the next layer above consisted of one-fourth-inch gravel having a depth of 3 inches, and above this was a layer of one-sixteenth-inch gravel with a depth of 3 inches. The whole gravel layer, therefore, was 10 inches thick, and rested on the larger cobblestones, which served the purpose of underdrains.

Upon the top of this gravel was placed a layer of washed Potomac River sand 3 feet in thickness. The sand had an effective size of 0.25 mm., and a uniformity coefficient of 1.8.

Upon this bed of filtering material the water to be filtered was admitted to a depth of 3 feet.

The filtered water from the underdrains was admitted to a clear-water well, and thence passed through a meter to the effluent pipe. A vertical scale was erected on the exterior of the tank, on which pointers, connected by floats with the surface of the water in the filter and with the surface of the water in the clear-water well, served to indicate the level of these two surfaces. The water in the filter was kept at a constant head or level, the difference of the reading of the two pointers serving to measure the loss of head due to friction in passing through the filter.

The construction of the filter and the various arrangements are shown plainly on Pl. II, and a more detailed description is given in Appendix I.

THE AMERICAN OR MECHANICAL FILTER, "B."

The filter used in experiments was erected by the New York Filter Manufacturing Company, and combines all the recent improvements in this method. (See Pls. III and IV.)

It consists of a cylindrical steel tank, set up vertically and divided by a horizontal diaphragm into two compartments, the lower compartment serving as a preliminary sedimentation basin, and receiving the raw water and coagulant. The influent is so arranged that a centrifugal motion is given to the water on entering. From this lower compartment the water passes to the second or upper compartment, in which is situated the filtering device.

The filtering device consists of a cylindrical steel vessel, smaller in diameter than the outer cylinder, resting on the horizontal diaphragm. In the bottom of this interior vessel are placed, set in cement, the strainers, which collect the filtered water and pass it to a main drain, whence it is passed through a regulator to the effluent of the filter. In this filtering chamber, above the strainers, is placed about 42 inches in depth of sand of an effective size of 0.40 millimeter and a coefficient of uniformity of 1.9.

The raw water is delivered on to this sand by a central influent pipe, which fills the filter, including the spaces between the inner and outer cylinders, to a depth of 18 inches above the sand; an automatic float valve keeps the water at a constant level, the regulator above mentioned automatically controlling the rate of filtration. A number of valves regulate the working and cleaning of the filter. There is an influent valve, an effluent valve, a wash valve, and a draining valve to pass off the wash water, a valve to empty the settling basin, and a manhole to enter this basin for the purpose of cleaning.

The machinery consists of the rakes, with necessary shafting and pulleys to rotate them, with the engine to furnish power, and a pump to supply water for washing purposes.

The washing of the sand in the filter is accomplished by opening and closing the proper valves and pumping filtered water up through the sand in a reverse direction to that of filtration and drawing off the wash water from the space between the inner and outer cylinders.

Attached to the filter is a device consisting of a cylindrical well connected with the effluent pipe, which indicates by a pointer actuated by a float the difference in head between the water in the effluent pipe and the water in the filter above the sand. All these different attachments can be studied by a reference to Plates III and IV. The diameter of the sand tank or filter proper was 6 feet, giving a filtering surface of 28.14 square feet. The normal rate of filtration, with the regulator as set by the manufacturers, was 130,000,000 gallons per acre per diem.

METHOD OF CONDUCTING TESTS OF FILTERS.

The object of the investigation was to ascertain whether the Potomac water, as delivered to the consumer at Washington at present, could be rendered by filtration, with either method, acceptable in appearance and hygienically fit for a domestic supply.

An acceptable appearance of the water requires the removal of the turbidity to an extent which will render the water unobjectionable. Hygienic requirements are satisfied by the reduction of the number of bacteria to an acceptable quantity.

TURBIDITY.

Turbidity is a condition of a water supply which renders it objectionable by reason of suspended matter. This suspended matter renders the water more or less opaque and more or less disagreeable in appearance and to the taste, according to the amount and color of the matter in suspension. Several methods have been adopted for determining the turbidity of water. Among them are:

1. A determination of the parts per million by weight of the matter in suspension.
2. By comparison with standards containing certain parts per million of kaolin in distilled water.
3. By photometry, or the determination of the loss of light in passing through the turbid water.
4. By determining the distance at which certain well-defined objects may be seen through the water by the naked eye.

In this investigation two methods were employed:

1. The determination of the parts by weight per million of suspended matter, and
2. The determination of the distance a certain object could be seen in the water under examination.

The first method was employed by Mr. Weston and is discussed in his report. (Appendix II.)

Various means have been employed for turbidity measurement by the second method. A method commonly used was to determine at what depth in a metal tube a mark on the transparent bottom disappeared. Mr. Allen Hazen, who has had large experience in the examination of water supplies, uses what he calls the "wire method." This consists in determining at what depth a platinum wire an inch in length and a millimeter in diameter can be seen in the water under examination by the naked eye. This method has been applied by Mr. Hazen principally to water of considerable turbidity. His instrument consists of a rod graduated to inches and fractions, at one extremity of which the wire was fixed. By lowering the rod vertically in the water to be measured the distance in inches at which the wire disappeared was noted. The reciprocal of this distance was taken as the measure of turbidity.

For example: If the wire disappeared at a distance of 1 inch the turbidity is recorded as 1; if it became invisible at 2 inches the turbidity was 0.5, etc. With this method slight turbidity can not be measured without a modification of the operation. When the turbidity is very slight and approaches absolute clearness or the turbidity of distilled water, the distance at which the wire could be theoretically seen would be so great as to be beyond the limit of vision. In such cases a modification of the method is required. The measurement can then be obtained within the proper limits by mixing the water to be measured with water of a known turbidity and measuring the turbidity of this mixture. By a simple calculation the turbidity required can be deduced from this measurement.

In this investigation, to simplify the calculation, equal parts of the water whose turbidity was to be determined and the water whose turbidity was known were used for the mixture. The known turbidity was obtained by adding clay in suspension to water until a turbidity in the vicinity of 0.5 was obtained, and then determining the turbidity of a mixture in equal parts of this standard and the water whose turbidity was to be determined. The standard mixture was prepared each day and used for determining the turbidity of the influent and effluent of each filter.

The calculation to determine the required turbidity, when equal parts of the standard and water of the turbidity to be determined were used, was as follows:

Let T_s represent the turbidity of the standard.

Let T_m represent the turbidity of the mixture.

Let T_x represent the turbidity to be determined.

Then, the mixture being of equal parts of T_s and T_x

$$T_m = \frac{T_s + T_x}{2} \text{ and } T_x = 2T_m - T_s.$$

From the above we see that if $T_m = \frac{1}{2}T_s$ we have $T_x = 0$.

In other words, if the turbidity of the mixture of equal parts be equal to one-half the turbidity of the standard, our required turbidity is 0. This is as it should be, for by mixing equal parts of water with a turbidity of T_s with water with a turbidity of 0 we obtain a mixture with the same amount of suspended matter distributed through twice the amount of water, and the turbidity of the mixture has been reduced one-half. If $T_m = T_s$, then $T_x = T_s$; that is, if the turbidity of the mixture be the same as the turbidity of the standard, the required turbidity is also the same.

As the turbidities to be determined in this investigation were sometimes very small, approaching the limit, it was necessary to have an instrument which would measure small differences in distance in determining the depths of disappearance of the platinum wire. An instrument was devised for this purpose, which is shown on Pl. XIV.

The instrument consisted of a metallic rod graduated to read, by means of a vernier, to one five-hundredth of an inch. The end of the rod terminates in a hook, and at right angles to this, at the same distance from the zero of the scale, is attached to the rod a platinum wire 1 inch in length and 1 millimeter in diameter. By means of a tangent screw and ratchet the rod may be moved vertically past the zero of the vernier, which remains stationary.

To use this instrument the vernier is placed at zero of the scale, then the vessel containing the water whose turbidity is to be determined is moved vertically by a suitable appliance until the point of the hook is at the surface of the water; the wire will then be also at the same level. By means of the tangent screw the rod is then lowered until the wire disappears. The reading is then taken by means of the vernier. The reciprocal of this reading represents the turbidity of the water tested.

During the investigation the turbidity of the influent water was determined every day, as well as the turbidity of the effluents for each filter. At the distributing reservoir the turbidity was determined by the method used at the Washington Aqueduct Office during the last twenty years. The instrument consists of a rectangular water-tight box, with a sphere 1 inch in diameter so arranged as to slide in the direction of the length of the box through a distance of 36 inches. The ends of the box are closed by glass.

To determine turbidity by this method the observer, placing his eye at one end of the box, moves the sphere horizontally and determines the distance at which it disappears. This instrument was limited in its measurement to 36 inches.

An arbitrary scale has been adopted for this method, taken from the experience of twenty years. It has been found from experience that when the sphere is seen a distance of 22 inches the water is unobjectionable to consumers on the score of turbidity, and therefore all measurements between this limit and 36 inches are recorded as "clear." When the sphere disappears between 21 and 15 inches the record is by this scale "slightly turbid." When seen between 14 and 18 inches the record is "turbid." When between 7 and 1 inches the water is called "very turbid," or as follows:

Scale of turbidity for the distributing reservoir.

When sphere is seen from 1 to 7 inches, "very turbid."
When sphere is seen from 8 to 14 inches, "turbid."
When sphere is seen from 15 to 21 inches, "slightly turbid."
When sphere is seen from 22 to 36 inches, "clear."

These two methods of determining turbidity differ in two essentials. In the first place, the objects observed are quite different in size and shape, one being a platinum wire and the other a metallic sphere; in the second place, the observation with the wire is made with diffused light from all directions, while the light for the second method is only admitted at the ends of the tube. Thus far, as might be expected, the results do not agree exactly by the two methods. The wire method generally, for the same water with small turbidities, shows a greater turbidity by reciprocals than the other method, probably owing to the diffused light. In taking the turbidity by the wire method the water was placed in a glass jar which stood upon a wire frame, thus allowing the admission of light from all directions. For the purpose of manipulation the instrument was erected on an ordinary drill press, the water being adjusted to the proper position by the vertical movement of the table.

The determination of turbidity by ascertaining the amount of matter in suspension in parts per million was made in the laboratory by the usual methods.

1. THE ENGLISH OR SLOW SAND FILTER, "A."

This filter, as above described, was completed and started work on June 11, 1899, and was continued in constant operation until the writing of this report, a period of about eight months.

The data to be determined were—

1. The proper rate of filtration to obtain the required results.
2. The period or length of time the filter could be advantageously run before scraping was necessary.
3. The amount of sand necessary to remove at each scraping.
4. The amount of water filtered between scrapings.
5. The proper loss of head under which to operate the filter.
6. The efficiency of the filter under the various conditions.

1. RATE OF FILTRATION.

First run.—The filter was started on June 11, 1899, at a rate of 1,000,000 gallons per acre per diem, or as near as practicable to this rate, and the rate gradually increased until a rate of 2,500,000 gallons per acre per diem was reached on the 19th. This rate was continued until July 19, the entire period of duration of the run being thirty-eight days.

This was the initial run of the filter, and as filters of this system require a certain period of time before they reach a proper working efficiency, the first effluents showed that good results were obtained as to the appearance of the water on the fourth day. No bacteriological examinations were made until July 13, and during the last seven days of the run the bacteria in the influent varied from 790 to 57 per cubic centimeter, and the corresponding number in the effluent varied from 70 to 8 per cubic centimeter.

Second run.—The filter was shut down on July 19, the surface of the sand scraped, and the filter started operations again on the 21st. On this run the rate was increased to 3,000,000 gallons per acre per diem. This run was continued until September 27, a period of sixty-nine days. During this run the turbidity of the effluent was satisfactory. The bacteria in the influent varied from a maximum of 556 to a minimum of 71 per cubic centimeter, and in the effluent varied from a maximum of 79 to a minimum of 5 bacteria per cubic centimeter. This rate showed a satisfactory result with the applied water.

Third run.—The filter was shut down and scraped on September 27 and started again on the 29th. On this run the rate was increased to 4,000,000 gallons per acre per diem and the run continued at this rate until November 3, when the filter was shut down. This was a period of thirty-six days. The results as to turbidity were good. The bacteria in the influent varied from a maximum of 460 per cubic centimeter to a minimum of 80 per cubic centimeter; the bacteria found in the effluent from a maximum of 65 per cc., on the second day, to a minimum of 15 per cc. On the first day the number of bacteria in the effluent was 160, but as the filter had been filled from the bottom with unfiltered water, this observation did not fairly show the bacterial efficiency.

Fourth run.—The filter was shut down on November 3, scraped, and started in operation again on November 5. The rate of filtration for this run was 3,000,000 gallons per acre per diem until November 22, when the rate was increased to 3,500,000 gallons per acre per diem. The run was continued until January 5, 1900. It was intended to end this run on December 30, 1899, but owing to the severity of the weather, the thermometer reaching 11° F., it was continued until January 5, when, the temperature being above the freezing point, the filter was shut down and scraped. This run produced satisfactory results up to December 26, or for a period of forty-three days. During this period of forty-three days the effluent was satisfactory as regards turbidity. The number of bacteria in the influent varied from a maximum of 4,900 to a minimum of 70 per cc., the bacteria in the effluent varying during the same period from a maximum of 47 to a minimum of 3 per cc.

On December 27 the effluent began to show poor results, as the following table shows:

	Bacteria per cubic centimeter in—	
	Influent.	Effluent.
Dec. 27	7,900	130
Dec. 28	12,000	310
Dec. 29	16,000	550
Dec. 30	11,300	420
Dec. 31	31,000	450
Jan. 1	9,600	1,600
Jan. 2	12,300	1,400
Jan. 3	15,400	1,000
Jan. 4	13,600	900
Jan. 5	16,900	200

On drawing off the filter for scraping on January 5 it was found that a crack had occurred in the filter film, or schmutz decke, on the east side of the filter. The evident cause of this break was as follows: In order to take samples of water from different depths in the filter sand, small pet cocks, connecting with one-fourth-inch pipes, were inserted in the side of the filter 8 inches into the sand. The ends of the pipes were perforated and covered with wire gauze to prevent drawing off any sand with the water. They were placed at depths below the surface of the sand of 6, 12, 18, 24, 30, and 36 inches. In using these faucets to obtain samples it was frequently found that some sand passed through, and in order to obtain proper samples the faucets were allowed to run for about five minutes when used. The faucets were inserted in such a manner that no two were in the same vertical plane, but the space measured on the circumference occupied was about 8 feet. In using these cocks a strain was brought on the schmutz decke in this particular vicinity by a sudden local increase of rate of filtration, and a break occured along the edge of the filter immediately over the cocks. The result of this break is shown by reference to the above table.

Fifth run.—The filter was scraped on January 5 and started at 7.55 p. m., and shut down again for scraping on March 3, the length of run being fifty-six days. The rate during this run was 3,000,000 gallons per acre per diem. The influent during this run, as well as the latter part of the fourth run, was very turbid, with larger numbers of bacteria present, varying from 51,000 to 2,500 per cc. The number of bacteria in the effluent varied from 1,200 to 50 per cc.

It will be seen from the above that the filter was operated at rates varying from 2,500,000 to 4,000,000 gallons per acre, and during the worst condition of the influent water was run for a part of the time at a rate of 3,500,000 gallons per acre per diem.

During the first, second, and third runs, with rates varying from 2,500,000 to 4,000,000 gallons per acre per diem, the results were satisfactory both as to the removal of the turbidity and reduction of bacteria, demonstrating the fact that with water of this quality, as to turbidity and bacteria, this method of filtration at the rates above mentioned will furnish a satisfactory effluent.

During the fourth run, with a filtration rate of 3,500,000 gallons per acre per diem, the results were not so satisfactory toward the latter part of the run. Although the breaking through of the filter film occurred during the latter part of the run, thus causing a defective filtration, the turbidity and number of bacteria in the applied water also greatly increased, and the results would point to the conclusion that the rate of filtration might have been too high for the conditions that obtained.

In the fifth or last run, the rate of filtration was 3,000,000 gallons per acre per diem, and the condition as to turbidity and bacteria of the influent remained about the same as in the last days of the previous run. The effluent discharge was, as a rule, not satisfactory as to turbidity or number of bacteria present.

2. THE PERIOD OR LENGTH OF TIME THE FILTER COULD BE ADVANTAGEOUSLY RUN BEFORE SCRAPING.

The lengths of the different runs were as follows:

First run, thirty-eight days, with 2,500,000 gallons per acre per diem.
Second run, sixty-nine days, with 3,000,000 gallons per acre per diem.
Third run, thirty-six days, with 4,000,000 gallons per acre per diem.
Fourth run, forty-three days, with 3,500,000 gallons per acre per diem.
Fifth run, fifty-six days, with 3,000,000 gallons per acre per diem.

If an average were taken it would give fifty-eight days for the length of run or time between scrapings. As, however, during the second run of sixty-nine days the water was comparatively free from turbidity, this period should not be given so great weight in estimating. It will be safe to estimate that the filter would average a period of forty-three days between scrapings, or require about nine scrapings per annum.

3. THE AMOUNT OF SAND NECESSARY TO REMOVE BETWEEN SCRAPINGS.

It was found that the sand required to be removed between scrapings varied from one-half to 1 inch in depth. This would be, for an acre of filter surface, from 67.06 to 134.12 cubic yards.

4. THE AMOUNT OF WATER FILTERED BETWEEN SCRAPINGS.

As a rate of 3,000,000 gallons per acre per diem is the normal rate to be adopted, it is only necessary to consider what amount of water is passed between scrapings under this condition.

During the second run, which lasted sixty-nine days, 204,201,000 gallons per acre passed the filter. If the filter had worked regularly at the rate of 3,000,000 gallons, the amount should have been 69 multiplied by 3 or 207,000,000 gallons per acre, but owing to the necessary adjustments to control the rate and the variation of rate, the amount passed was somewhat less.

The fifth run, which was at the rate of 3,000,000 gallons per acre per day, lasted fifty-six days, and the amount of water passed was 168,050,000 gallons, or at the rate of 3,000,000 gallons per diem without appreciable change.

This demonstrates that the rate of filtration may be kept constant by ordinary attention.

5. THE PROPER LOSS OF HEAD UNDER WHICH TO OPERATE THE FILTER.

The loss of head in this filter is the difference between the level of the water surface on the filter bed and that in the clear water or effluent well. Experience in other experiments with this form of filter has shown that a loss of head or difference of level, greater than the depth of water on the filter bed is inadvisable; in other words, the level of the surface of the water in the effluent well should never be allowed to go below the level of the surface of the sand in the filter. When this occurs the filter is working under what is known as a negative head. The limit then for loss of head in the case of the experimental filter was 3 feet, equal to the depth of water on the sand. This loss of head only obtains when the filter is in operation, for if the effluent pipe be closed the water in the effluent well rises to the same level as the surface of the water on the filter bed.

On first starting the filter there was a loss of head of three one-hundredths of a foot; at the beginning of the second run, sixteen one-hundredths of a foot; the third run, fifteen one-hundredths of a foot; on the fourth run, nineteen one-hundredths of a foot, and at the beginning of the last or fifth run it was twelve one-hundredths of a foot.

The corresponding losses of head at the ends of these runs were, respectively, first, 2.94; second, 2.87; third, 2.91; fourth, 2.50; fifth, 2.73. The increase in loss of head as the run proceeds, is due to the accumulating thickness and impermeability of the filter film. At first the loss of head increases very slowly, but when it reaches 2 feet the increase is quite rapid and reaches 3 feet, or the limit, in from three to four days. This last rapid increase applies equally to whatever rate of filtration is considered.

Three feet has been adopted as the limit of loss of head for this filter, as a loss of head beyond this brings undue strain on the filter film and renders it liable to break through and also draws air into the sand, causing a disturbance of the filter bed. As but little time is gained by pushing the limit of loss of head to the extreme, only three or four days in time, with this filter, it is best to establish the limit of loss of head at 2½ feet, or 6 inches less than the depth of water above the sand bed.

During the fourth run it was impracticable to stop the filter when the loss of head had reached the limit of 3 feet, owing to the danger of freezing, and the filter was forced to run to a loss of head of 3.35 feet. The poor results mentioned above in connection with this run were probably partially due to this strain on the filter film.

With a limit of loss of head of 2½ feet and a rate of filtration of 3,000,000 gallons per acre per diem, the filter can be run at an average of forty days between scrapings.

EFFICIENCY OF THE FILTER UNDER THE VARIOUS CONDITIONS.

Turbidity.—During the experiments with this filter the condition of the influent water has varied from clear to very turbid, or from the best to the most objectionable condition as to turbidity. A turbidity of 0.02 by the wire gauge is unobjectionable; when the turbidity became greater than this it is noticeable and objectionable. During the fifth or last run, which continued from January 6 to March 3, the turbidity of the influent varied from 0.249 to 0.071 and the turbidity of the effluent from 0.123 to 0.009, and for twelve days only was it up to the standard, 0.02; that is, for forty-four days of the fifty-six days of the run the effluent was objectionable on the score of turbidity. Therefore the experiments show that while the Potomac water was in the condition obtaining during the fifth run the filter would not produce a proper effluent as to turbidity.

Bacterial efficiency.—It has been customary in most investigations of filtration to measure the bacterial efficiency of a filter by the percentage of bacteria removed from the influent. This method is not quite satisfactory. The filtration of sewage gives an enormous efficiency measured by this method, but the effluent would hardly be a potable water. In other words, when the influent of a good filter is quite abundant in bacteria its efficiency by the percentage scale would be high, while the contrary would obtain were the influent comparatively poor in bacteria. This was prominently brought out in these experiments. With small numbers of bacteria present in the influent—95 to 120—the English filter gave percentages of removal of only 28.6 to 50 per cent, while the number of bacteria per cubic centimeter were 50 to 75 in the effluent. Although here there was a low efficiency, the effluent was perfectly unobjectionable bacteriologically. Again, with bacteria in the influent varying from 2,500 to 51,000, the efficiency percentage varied from 85.7 to 99.7 and the bacteria in the effluent from 1,200 to 50 per cubic centimeter.

It would seem from the above that a certain number of bacteria pass out of the filter under all circumstances.

Koch's criterion, as applied to the filtration of German river waters, is that a good filtrate should not contain more than 100 bacteria per cubic centimeter. The regulations of the German imperial board of health require that—

> A satisfactory effluent shall, as a rule, not contain more than about 100 bacteria per cubic centimeter when it leaves the filter. The filtrate should be as clear as possible, and must not be inferior in color, taste, temperature, and chemical character to the water before filtration.

Professor Koch states:

> The opinion that filtered water containing more than 100 germs is not sufficiently cleansed has been completely justified by the experience of the Altona waterworks, which is confirmed by that of other works. Of course this statement is not to be

> understood to mean that water containing 101 or 105 germs is to be rejected without more ado. Each case must be intelligently judged of by itself, and the number 100 is merely intended to afford those called upon to form such judgments a basis founded on experience.

He also states that the rate of filtration for German river water should not exceed 100 millimeters per hour, or 2.56 million gallons per diem per acre.

Sternberg states:

> We conclude from the experimental data recorded that water containing less than 100 bacteria to the cubic centimeter is presumably from a deep source and uncontaminated by surface drainage, and that it will usually be safe to recommend such water for drinking purposes, unless it contains injurious mineral substances. Water that contains more than 500 bacteria to the cubic centimeter, although it may in many cases be harmless, is to be looked upon with some suspicion, and water containing 1,000 or more bacteria is presumably contaminated by sewage or surface drainage, and should be rejected or filtered before it is used for drinking purposes. But, as heretofore stated, the danger does not depend directly upon the number of bacteria present, but upon contamination with pathogenic species which are liable to be present in surface water and sewage. In swallowing a glassful of pure spring water a number of bacteria from the buccal cavity are washed away and carried into the stomach, which if enumerated would doubtless far exceed in numbers those found in the most impure river water.

These two authorities differ somewhat as to the number of bacteria admissible in potable water, but it must be borne in mind that Professor Koch's requirements apply to filtered water, while General Sternberg refers to surface or river water.

In adapting filtration to the Washington water supply, the condition of the influent will be better than during the experiments. The new reservoir will have been completed, which will add five days more to the period of sedimentation. This will result in a reduction of turbidity and bacteria and render the influent water less objectionable and requiring therefore a less reduction in turbidity and bacteria in the effluent.

The greatest bacterial efficiency of the filter, with the large number of bacteria present in the effluent was 99.7 per cent. If the filter worked constantly at this efficiency and were required to deliver an effluent with not more than 100 bacteria per cubic centimeter, it would not produce this result when the number of bacteria in the influent exceeded 33,000 per cubic centimeter. During the operation of the filter there were only two occasions when the influent contained more than this number. They occurred on January 22 and 23, 1900, when the influent contained, respectively, 51,000 and 36,000 bacteria per cc. On these occasions the effluent contained 210 and 180 per cc., a percentage of bacterial reduction, respectively, of 99.6 and 99.5. The average bacterial efficiency during the run now in progress, which has continued for thirty-seven days, has been 98.2 per cent. A bacterial efficiency of 98.2 per cent would, with an influent containing 5,555 bacteria per cc., give an effluent containing 100 bacteria per cc., which is, by Koch's criterion, acceptable.

The following table shows the number of bacteria per cc. in the influent which may be successfully filtered at different pencentages of efficiency, applying Koch's criterion:

Percentage of efficiency required to filter water containing varying numbers of bacteria to produce an effluent containing 100 bacteria per c. c.

[Bacteria per c. c.]

Influent.	Per cent of reduction.	Influent.	Per cent of reduction.	Influent.	Per cent of reduction.	Influent.	Per cent of reduction.	Influent.	Per cent of reduction.
100,000	99.9	1,266	92.1	637	84.3	426	76.5	319	68.7
50,000	99.8	1,250	92.0	633	84.2	424	76.4	318	68.6
33,333	99.7	1,235	91.9	629	84.1	422	76.3	317	68.5
25,000	99.6	1,220	91.8	625	84.0	420	76.2	316	68.4
20,000	99.5	1,205	91.7	621	83.9	418	76.1	315	68.3
16,666	99.4	1,190	91.6	617	83.8	417	76.0	314	68.2
14,286	99.3	1,176	91.5	613	83.7	415	75.9	313	68.1
12,500	99.2	1,163	91.4	610	83.6	413	75.8	312	68.0
11,111	99.1	1,149	91.3	606	83.5	412	75.7	312	67.9
10,000	99.0	1,136	91.2	602	83.4	410	75.6	311	67.8
9,090	98.9	1,124	91.1	599	83.3	408	75.5	310	67.7
8,333	98.8	1,111	91.0	595	83.2	406	75.4	309	67.6
7,692	98.7	1,099	90.9	592	83.1	405	75.3	308	67.5
7,143	98.6	1,087	90.8	588	83.0	403	75.2	307	67.4
6,667	98.5	1,075	90.7	585	82.9	402	75.1	306	67.3
6,250	98.4	1,064	90.6	581	82.8	400	75.0	305	67.2
5,882	98.3	1,053	90.5	578	82.7	398	74.9	304	67.1
5,565	98.2	1,042	90.4	575	82.6	397	74.8	303	67.0
5,263	98.1	1,031	90.3	571	82.5	395	74.7	302	66.9
5,000	98.0	1,020	90.2	568	82.4	394	74.6	301	66.8
4,762	97.9	1,010	90.1	565	82.3	392	74.5	300	66.7
4,546	97.8	1,000	90.0	562	82.2	390	74.4	299	66.6
4,348	97.7	991	89.9	559	82.1	389	74.3	299	66.5
4,167	97.6	980	89.8	556	82.0	388	74.2	298	66.4
4,000	97.5	971	89.7	552	81.9	386	74.1	297	66.3
3,846	97.4	962	89.6	549	81.8	385	74.0	296	66.2
3,704	97.3	952	89.5	546	81.7	383	73.9	295	66.1
3,571	97.2	943	89.4	543	81.6	382	73.8	294	66.0
3,448	97.1	935	89.3	541	81.5	380	73.7	293	65.9
3,333	97.0	926	89.2	538	81.4	379	73.6	292	65.8
3,226	96.9	917	89.1	535	81.3	377	73.5	291	65.7
3,125	96.8	909	89.0	532	81.2	376	73.4	291	65.6
3,030	96.7	901	88.9	529	81.1	375	73.3	290	65.5
2,941	96.6	893	88.8	526	81.0	373	73.2	289	65.4
2,857	96.5	885	88.7	524	80.9	372	73.1	288	65.3
2,778	96.4	877	88.6	521	80.8	370	73 0	287	65.2
2,703	96.3	870	88.5	518	80.7	369	72.9	286	65.1
2,642	96.2	862	88.4	515	80.6	368	72.8	286	65.0
2,564	96.1	855	88.3	513	80.5	366	72.7	285	64.9
2,500	96.0	847	88.2	610	80.4	365	72.6	284	64.8
2,439	95.9	840	88.1	508	80.3	364	72.5	283	64.7
2,381	95.8	833	88.0	505	80.2	362	72.4	282	64.6
2,326	95.7	826	87.9	503	80.1	361	72.3	282	64.5
2,273	95.6	820	87.8	500	80.0	360	72.2	281	64.4
2,222	95.5	813	87.7	498	79.9	358	72.1	280	64.3
2,174	95.4	806	87.6	495	79.8	357	72.0	279	64.2
2,128	95.3	800	87.5	493	79.7	356	71.9	279	64.1
2,083	95.2	794	87.4	490	79.6	355	71.8	278	64.0
2,041	95.1	787	87.3	488	79.5	353	71.7	277	63.9
2,000	95.0	781	87.2	485	79.4	352	71.6	276	63.6
1,961	94.9	775	87.1	483	79.3	351	71.5	275	63.8
1,923	94.8	769	87.0	481	79.2	350	71.4	275	63.7
1,887	94.7	763	86.9	478	79.1	348	71.3	274	63.5
1,852	94.6	757	86.8	476	79.0	347	71.2	273	63.4
1,818	94.5	752	86.7	474	78.9	346	71.1	272	63.3
1,786	94.4	746	86.6	472	78.8	345	71.0	272	63.2
1,754	94.3	741	86.5	469	78.7	344	70.9	271	63.1
1,724	94.2	735	86.4	467	78.6	342	70.8	270	63.0
1,696	94.1	730	86.3	465	78.5	341	70.7	270	62.9
1,667	94.0	725	86.2	463	78.4	340	70.6	269	62.8
1,639	93.9	719	86.1	461	78.3	339	70.5	268	62.7
1,613	93.8	714	86.0	459	78.2	338	70.4	267	62.6
1,687	93.7	709	85.9	457	78.1	337	70.3	267	62.5
1,562	93.6	704	85.8	465	78.0	336	70.2	266	62.4
1,638	93.5	699	85.7	452	77.9	334	70.1	265	62.3
1,515	93.4	694	85.6	450	77.8	333	70.0	265	62.2
1,493	93.3	690	85.5	448	77.7	332	69.9	264	62.1
1,471	93.2	685	85.4	446	77.6	331	69.8	263	62.0
1,449	93.1	680	85.3	444	77.5	330	69.7	262	61.9
1,429	93.0	676	85.2	442	77.4	329	69.6	262	61.8
1,408	92.9	671	85.1	441	77.3	328	69.5	261	61.7
1,389	92.8	667	85.0	439	77.2	327	69.4	260	61.6
1,370	92.7	662	84.9	437	77.1	326	69.3	260	61.5
1,351	92.6	668	84.8	435	77.0	325	69.2	259	61.4
1,333	92.5	654	84.7	433	76.9	324	69.1	258	61.3
1,316	92.4	659	84.6	431	76.8	323	69.0	258	61.2
1,299	92.3	646	84.5	429	76.7	322	68.9	257	61.1
1,282	92.2	641	84.4	427	76.6	321	68.8	256	61.0

Percentage of efficiency required to filter water containing varying numbers of bacteria to produce an effluent containing 100 bacteria per c. c.—Continued.

[Bacteria per c. c.]

Influent.	Per cent of reduction.	Influent.	Per cent of reduction.	Influent.	Per cent of reduction.	Influent.	Per cent of reduction.	Influent.	Per cent of reduction.
256	60.9	242	58.7	230	56.5	219	54.3	209	52.1
255	60.8	242	58.6	229	56.4	219	54.2	208	52.0
254	60.7	241	58.5	229	56.3	218	54.1	208	51.9
254	60.6	240	58.4	228	56.2	217	54.0	207	51.8
253	60.5	240	58.3	228	56.1	217	53.9	207	51.7
253	60.4	239	58.2	227	56.0	216	53.8	207	51.6
252	60.3	239	58.1	227	55.9	216	53.7	206	51.5
251	60.2	238	58.0	226	55.8	216	53.6	206	51.4
251	60.1	238	57.9	226	55.7	215	53.5	205	51.3
250	60.0	237	57.8	225	55.6	215	53.4	205	51.2
249	59.9	236	57.7	225	55.5	214	53.3	205	51.1
249	59.8	236	57.6	224	55.4	214	53.2	204	51.0
248	59.7	235	57.5	224	55.3	213	53.1	204	50.9
248	59.6	235	57.4	223	55.2	213	53.0	203	50.8
247	59.5	234	57.3	223	55.1	212	52.9	203	50.7
246	59.4	234	57.2	222	55.0	212	52.8	202	50.6
246	59.3	233	57.1	222	54.9	211	52.7	202	50.5
245	59.2	233	57.0	221	54.8	211	52.6	202	50.4
244	59.1	232	56.9	221	54.7	211	52.5	201	50.3
244	59.0	231	56.8	220	54.6	210	52.4	201	50.2
243	58.9	231	56.7	220	54.5	210	52.3	200	50.1
243	58.8	230	56.6	220	54.4	210	52.2	200	50.0

It may be concluded from the results obtained with the English or slow sand filter that a bacterial efficiency of 97.8 per cent may be obtained. This percentage (97.8) will produce an effluent containing but 100 bacteria per cubic centimeter when the bacteria in the influent do not exceed 4,549 per cubic centimeter. During the times of greatest turbidity this number of bacteria is largely exceeded in the raw water; in fact, turbidity and quantity of bacteria increase together, and when the bacteria exceed 4,549 per cubic centimeter the English filter would fail to give an effluent which would be satisfactory from a bacteriological point of view.

Colon.—The bacillus coli communis was found in the effluent in 25 per cent of the specimens examined. As above mentioned, this bacillus was found in 50 per cent of the influent specimens. This would indicate that 50 per cent of this disease germ was removed.

The quantitative results of bacterial tests may be examined by referring to the table giving the various results for each run of the English filter ("A"), as set forth in Mr. Hardy's report, Appendix I.

Color.—The amount of dissolved color in the water, both filtered and unfiltered, was determined by the platinum-cobalt method. In this method an arbitrary scale has been adopted for comparison. When by this scale the color is recorded as 0.5 it is quite perceptible.

The color of the influent during the experiments has varied from 0.35 to 0.10. As the English system has no effect in the reduction of this color, the effluent has passed through the same limits. This color, however, is not objectionable hygienically and can hardly be perceived in an ordinary tumbler unless it be compared with colorless water.

AMERICAN OR MECHANICAL FILTER, "B".

The objects of the experiments with this filter were to determine—

1. The proper rate of filtration.
2. The amount of water required to waste and wash.

3. The loss of head.
4. Frequency and duration of washing.
5. The amount of coagulant required.
6. The efficiency of the filter under the various conditions.

The filter was erected by the New York Filter Manufacturing Company, and turned over in operating order July 18, 1899, when the experimental runs were begun. The filter was kept in constant operation until February 28, 1900, except between the 6th and 20th of December, 1899, when it was shut down in order to erect a house around it for the purpose of protection from freezing weather.

1. RATE OF FILTRATION.

The filter as delivered and set up included the "regulator," which determined the rate of filtration for the experiment. The regulator was set, as near as possible, at a rate of 130,000,000 gallons per acre per diem. This rate was practically maintained during the investigation. The rate above mentioned may be called the gross rate.

2. THE AMOUNT OF WATER REQUIRED FOR WASHING AND WASTE.

The results of the investigation show that the amount of water used in washing the filter between runs was 3.7 per cent of the amount filtered during the previous run. The investigation as to the necessity of wasting water would indicate that this factor is inconsiderable, as in a system of filtration by this method the proportion of filters being washed to those working would be so small that a slight decrease in bacteriological efficiency would not be appreciable in a large plant. The amount of wash water reduces the net rate of filtration thus 3.7 per cent, or reduces it to 125,000,000 gallons per acre per diem.

3. THE LOSS OF HEAD.

The investigation with this filter demonstrated that the filter should be shut down for washing when the loss of head was between 13 and 14 feet. This limit was indicated by a clogging of the sand and a tendency to break through, as shown by an increase in the turbidity of the effluent.

4. THE FREQUENCY AND DURATION OF WASHING.

This element depended on the condition of the influent water. At times it was necessary to wash every eight hours; at other times the filter could be run twelve hours without washing. Several runs of twenty-four hours between washings were made, but not with very satisfactory results. It would appear that this system with the water experimented with would require washing from two to three times in twenty-four hours. This duration of washing would average about thirty-seven and one-half minutes, or 2.6 per cent of a day, and, added to the reduction for wash water, gives a rate of 121,810,000 gallons per acre per diem.

5. THE AMOUNT OF COAGULANT REQUIRED.

The coagulant used in this investigation was furnished by the New York Filter Manufacturing Company, and was in powdered or ground form. The analyses of the specimens were as follows:

	Lot 1.	Lot 2.
Insoluble in water	0.02	0.07
Alumina (Al_2O_3)	23.14	23.44
Sulphuric acid (SO_3)	48.79	49.16
Iron (Fe_2O_3)	0.00	0.00
Water	28.05	27.33
	100.00	100.00

No free sulphuric acid in either sample.

The sulphate of alumina heretofore used in practice usually contained but 17.5 per cent of alumina.

In order to apply this to the influent water, solutions of certain known strength were prepared and fed at a known rate to the influent pipe as it entered the sedimentation basin. The amount was regulated as the appearance and bacteriological efficiency of the effluent seemed to demand, and varied from 0.6 to 5.84 grains per gallon of applied water.

6. THE EFFICIENCY OF THE FILTER.

Removal of turbidity.—At times, when a sudden increase in the turbidity of the influent took place, the effluent showed an appreciable deterioration. This was owing to the fact that the supply of coagulant had not been correspondingly increased. When this was done and the proper amount supplied the effluent returned to its original excellent condition.

It may be concluded from these investigations that the Washington water supply may be filtered by this method so as to give at all times a clear, brilliant, and colorless effluent. These results require, however, constant and very careful attendance in order to regulate the frequency of washing and the proper supply of coagulant. This coagulant should vary from 0.6 to 3 grains per gallon, according to experience and the condition of the influent.

On no occasion during the investigation was it indicated that any coagulant was present in the effluent. This would also be indicated by the alkalinity of the influent, which varied from 24 to 100 parts per million. This amount of alkalinity neutralizes from 3 to 12 grains of sulphate of alumina per gallon.

At no time during the investigation were more than 6 grains per gallon applied. As above stated, in practical operation the maximum quantity would be about 3 grains per gallon, and was wholly neutralized by the minimum alkalinity, 24 parts per million, found in the influent.

Removal of bacteria.—The bacteriological efficiency obtained with the American filter closely followed the removal of turbidity. On the occasions when the turbidity of the influent and the number of bacteria in the same increased quite suddenly, the results were unsatisfactory, but this can not be taken as evidence against the efficiency of the filter, as subsequently, when the same conditions obtained, a satisfactory result bacteriologically was obtained by proper attention to washing and regulating the supply of coagulant.

The detailed description of operation and tabulated results of the investigation of the American filter will be found in the reports appended of Mr. Hardy and Mr. Weston.

The question of the cost of operation of this method of filtration will be treated further on.

DETAILED ESTIMATE OF COST OF FILTRATION OF THE WASHINGTON WATER SUPPLY.

The present consumption of water in the city of Washington, including a portion of the District of Columbia outside the city, is 50,000,000 gallons per day. It is estimated that this demand will increase, if the present rate of consumption is considered, to 60,000,000 gallons per diem in 1910, with an estimated population of 337,000.

If the consumption per capita be reduced, as is feasible, desirable, and abundant, to 100 gallons per diem per capita, this amount of water—60,000,000 gallons per diem—would supply a population of 600,000, which is the estimated population of Washington in 1945.

The estimates submitted are for a filter plant to supply 60,000,000 gallons per diem, which would, at the present rate of consumption, be ample for the next ten years, and would furnish an abundant supply for forty-five years were wastage properly controlled, and the consumption reduced to 100 gallons per capita per diem.

ENGLISH FILTERS.

ESTIMATE OF COST OF 60,000,000-GALLON FILTER PLANT.

Land.—As shown by experience in other investigations and those carried on as described in this report on the Washington water supply, it has been decided to adopt in this estimate a rate of filtration for the English method of 3,000,000 gallons per acre per diem. In order to supply 60,000,000 gallons at this rate a constant filtering area of 20 acres must be in operation, and there must also be acreage to be placed in use during the period of cleaning of any filters, and also in case of accident to the same, or on any occasion when a part of the plant is out of use. For this purpose a reserve of about 33 per cent of the acreage in active operation is desirable. In other words, when three-quarters of the whole plant is in active operation one-quarter will be out of use undergoing scraping, refilling, or any of the necessary operations to keep the plant in an efficient condition.

To operate under these conditions there will be required 27 acres of filtering surface. This is merely the actual surface of the sand in the filter beds; the necessary buildings, the masonry of the filters, the space occupied by communications, and sand washers, etc., will add about 8 acres to the required area. Altogether, then, about 35 acres of land will be required to erect such a plant.

The location of the plant should be as near the new reservoir, located near the Soldiers' Home grounds, as possible. The site selected lies adjacent to the reservoir and is bounded on the north by the Soldiers' Home grounds, on the east by North Capitol street, on the south by Detroit street, and on the west by the new reservoir. This plot contains, exclusive of First street west, 35.68 acres, or 1,554,156 square feet. Excluding Michigan avenue, Frankfort and Emporia streets, containing 442,980 square feet, there are 1,111,176 square feet laid out in building lots. As the area for the streets has been dedicated, the land to be occupied would therefore be 1,111,176 square feet. It is estimated that this land could be purchased for 50 cents per square foot, or at a cost of $555,588.

Grading.—In order to prepare this site for the construction of the filters the grading of 731,000 yards, at 30 cents, or $219,300, will be necessary.

Pumping plant.—The Washington water supply is partly a gravity supply, and any system of filtration adopted should be so arranged that no loss of head be permitted. This requires that the filter beds must be above the delivery level and that the filtered water be delivered at this same level. To accomplish this it will be necessary to raise the water to the filter beds by pumping. The pumping plant must be able to deliver 60,000,000 gallons of water per diem with a maximum lift of 30 feet. It case of accident to this plant, which would be a very serious matter and stop the supply of filtered water, and for necessary repairs, etc., there should be a reserve. A reserve of 50 per cent has been adopted and the plant divided into three units of 30,000,000 gallons each, two in constant use and one in reserve. The cost of the pumping plant complete is estimated at $90,000.

Filters.—The filters estimated for are located as shown on Pl. V on land in the immediate vicinity of the Howard or new reservoir. The filters are laid out to agree with the plat of the ground, and average, as near as may be, 1.6 acres in extent each. The filters are designed as large as practicable in order to save masonry. They are rectangular or trapezoidal in plan, according to location, contain sand to a depth of 3 feet supported on 1 foot of gravel, with the proper underdrains, collecting conduits, influent and effluent pipes and regulating apparatus. They are shown in detail on Pls. VI, VII, and VIII.

The plates show designs for both covered and open filters.

It is usually considered safe to erect open filters in latitudes where the average January temperature is not below 32° F., and although Washington is located below the 32° January curve, there are occasions when the temperature falls much below this point and occasionally for quite a time, sufficiently long enough to render the scraping of open filters extremely difficult and expensive on acconnt of the ice. In order to avoid risk and difficulties from this cause, which occur at times when the Potomac water is especially turbid and bacteriologically impure, it is deemed best that covered filters should be erected for Washington.

Dam for filtered water reservoir.—As the filters should be worked at a constant rate, it is necessary to provide for the varying hourly demand. This necessitates a filtered water reservoir. It is provided by setting apart, by a masonry dam with proper gatehouse and valves, a portion of the Howard reservoir. The filtered water reservoir will contain 30,000,000 gallons at the normal elevation of 144 feet above mean tide. The dam is given such a height as to allow an excess over this quantity as a compensation for the varying demand. The cost of the dam is estimated at $80,000.

Itemized cost of installation of covered English filters with a capacity of 60,000,000 gallons per diem.

Land, 1,111,176 square feet, at 50 cents	$555, 588
Grading, 731,000 cubic yards, at 30 cents	219, 300
Sand for filter beds, 139,000 yards, at $2	278, 000
Gravel for filter beds, 43,500 yards, at $2	87, 000
Concrete in walls, 23,200 cubic yards, at $5.50	127, 600
Concrete in floor and drains, 23,700 cubic yards, at $6	142, 200
Flagging for main drains, 5,400 square yards, at $2	10, 800
Tile for lateral drains, 85,000 feet, at 10 cents	8, 500
Iron piping, 2,900 tons, at $30	87, 000
Laying same	20, 000
Influent and effluent houses	66, 000
Dam for clear-water reservoir	80, 000
Pumping plant complete	90, 000
Electric-light plant	10, 000
Laboratory and office	6, 000
Sand washers and piping	8, 000
Cleaning up	10, 000
For covering filter beds	482, 100
Engineering and contingencies, 10 per cent	173, 250
Total	2, 461, 338

COST OF OPERATING FOR 60,000,000 GALLONS PER DIEM, ENGLISH FILTER.

The operating expenses consist—

1. In scraping the filter beds, in moving out the scraped sand, in washing this sand, and in replacing the same.
2. Pumping water to filter beds.
3. Superintendence.
4. Interest on original cost of plant.
5. Deterioration of plant.

1. Scraping filter beds, moving out, washing, and replacing sand.—This can be best estimated by the acre. From experience gained with the filters at Albany, N. Y., it has been found that an acre of filter bed can be scraped in 67 man hours. Estimating the depth to be scraped at 1 inch, this would give $\frac{43,560}{12\times 27}=134.54$ cubic yards per acre.

With a total average haul of 600 feet going and coming, one man will wheel out 0.38 of a cubic yard per hour.

One man will wash 0.41 cubic yard of sand per hour.

In wheeling back or refilling one man will handle 0.52 of a cubic yard in one hour.

The work, then, would be as follows:

	Hours.
Scraping 134.54 cubic yards	67
Wheeling out 134.54 cubic yards	354
Washing 134. 54 cubic yards	328. 1
Refilling 134. 54 cubic yards	258. 7
	1, 007. 8

The cost of above, then, per acre would be 1,007.8, at 18¾ cents= $188.96.

There would be continually in operation 20 acres of filter bed, therefore the cost of one scraping would be $188.96×20=$3,779.20.

The results of investigation indicate that there would be required nine scrapings per annum, so that the cost of scraping per annum would be $3,779.20×9=$34,012.80.

2. *Pumping water to filter beds.*—It is estimated that the cost of pumping would be for pay roll, $8,940; for coal and waste, $22,000; in all, $30,940.

3. *Superintendence*, including bacteriologist, watchmen, clerk, and foremen, $10,320.

4. *Interest on original cost of plant* $2,461,338, at 3 per cent= $73,840.14.

5. *Deterioration of plant.*—For estimating this amount the plant is divided into two classes—

(*a*) Machinery, piping, valves, and sand, as it is estimated that the sand would require renewal in twenty years.

This class is supposed to have a life of twenty years, or to deteriorate 5 per cent per annum. It consists of the following:

Cast-iron piping in place	$107,000
Valves and sluice gates	39,000
Pumps and boilers	60,000
Electric-light plant	10,000
Sand washers and piping	8,000
Sand (renewal in twenty years)	278,000
Total	502,000

Interest on above at 5 per cent, $25,100.

(*b*) The second class consists of the masonry, which amounts to a total value of $914,200, which at 1⅓ per cent per annum = $12,189.33.

The above may be itemized as follows:

Operating expenses per annum.

Scraping, washing, and replacing sand		$34,012.80
Pumping water to filter		30,940.00
Superintendence, etc		10,320.00
Interest on cost of plant		73,840.14
Deterioration of plant	(*a*)	25,100.00
	(*b*)	12,189.33
Total		186,402.27

The total amount of water filtered per annum would be 60 by 365 = 21,900 million gallons, which, at $186,402.27, would be a cost of $8.51 per million gallons.

Of the above cost the actual operating expenses, exclusive of interest and deterioration of plant, are $75,272.80, which would give $3.44 as the cost per million gallons.

ITEMIZED COST OF INSTALLATION OF AMERICAN FILTER PLANT WITH A CAPACITY OF 60,000,000 GALLONS PER DIEM.

This plant consists of 64 unit filters, each capable of filtering one million gallons per diem. See Plates IX, X, XI, XII, and XIII.

The plant is located on land adjoining the new reservoir. It consists of the pumping plant, as in the English system, the mechanical filters, filter house, and laboratory.

Land.—The land required contains 163,430 square feet, which at 50 cents per square foot amounts to $81,715.

Grading.—The grading is 83,500 cubic yards, which, at 30 cents per cubic yard, amounts to $25,050.

Land	$81,715
Grading	25,050
Plant:	
Sixty-four filters and auxiliaries	540,000
Steam pump for washing	6,000
Boilers	9,000
Engines	1,600
Steam heating	5,240
Electric-light plant	6,497
Equipment of engine room	925
Filter building	178,400
Conduit	4,100
Engineering and contingencies on above, 10 per cent (on cost of filter building and conduit)	18,250
Pumping plant	90,000
Piping	10,000
Dam for clear-water reservoir	80,000
Laboratory and office	6,000
Engineering and contingencies on $186,000—10 per cent	18,600
Total	1,081,377

COST OF OPERATING FOR 60,000,000 GALLONS PER DIEM, AMERICAN FILTER.

1. *Interest* on $1,081,377 at 3 per cent = $32,441.31.
2. *Deterioration of plant.*—

(*a*)	Filters	$540,000
	Pumps	6,000
	Boilers	9,000
	Engines	1,600
	Steam heating	5,240
	Electric lights	6,497
	Piping	10,000
	Main pump and boilers	60,000
	Valves	10,000
	Equipment for engine room	925
	Total	649,262

at 5 per cent = $32,463.10.

(*b*)	Dam for clear water reservoir	70,000
	Building for pumping station	30,000
	Filter house	178,400
	Conduit	4,100
	Laboratory and office	6,000
	Total	$288,500

at 1⅓ per cent = $3,846.67.

3. *Pumping.*—The expense for pumping the influent for this plant will be equal to that for the English system, or per annum $30,940.

Pumping for wash water and expenses of steam heating, lighting, and machinery $15,000, making a total of $45,940.

4. *Coagulant.*—It is estimated that there will be required for the year an average of 1.3 grains per gallon of sulphate of alumina. The amount of water to be filtered is 21,900 million gallons per annum, but the filters must also supply a further amount of 4 per cent for wash water, or a total of 21,900 + 876=22,776 million gallons.

The amount of coagulant then required in pounds would be 22,776 million multiplied by 1.3 and divided by 7,000 or 4,229,828 pounds; this amount of coagulant at $1.20 per 100 pounds, amounts to $50,757.94.

5. *Pay roll*—

1 superintendent	$2,400.00
1 assistant superintendent	1,800.00
1 bacteriologist	1,500.00
1 clerk	900.00
3 janitors, at $600	1,800.00
3 filter foremen, at $900	2,700.00
6 filtermen, at $600	3,600.00
1 machinist	1,200.00
1 assistant machinist	600.00
6 engine men, at $900	5,400.00
6 firemen, at $720	4,320.00
Total	26,220.00

Summary of operating expenses.

1. Interest on cost of plant	$32,441.31
2. Deterioration of plant	36,309.77
3. Pumping and machinery	45,940.00
4. Coagulant	50,757.94
5. Superintendence and labor	26,220.00
Total	191,669.02

This gives a cost of $191,669.02, divided by 21,900=$8.75 per million gallons.

Deducting interest charges and deterioration of plant, this will be $122,917.94, divided by 21,900=$5.61 per million gallons.

The above estimates may be compared as follows:

Cost of plant.	Cost of operating per million gallons.	
	Including interest charges and deterioration.	Excluding interest charges and deterioration.
English filters, $2,461,338	$8.51	$3.44
American filters, $1,081,377	8.75	5.61

In the investigation of the Cincinnati water supply experiments were made with a view to the investigation of a so-called modified English system. This system consisted essentially in adding, during certain conditions of the raw water, a coagulant to the water and allowing a certain time for this to produce its effect in coagulating basins. This system has never been operated in practice on a large scale. It adds to the cost of the English system the price of coagulant and the preparation of coagulating basins.

Mr. Weston in his report, Appendix 2, states that the amount of coagulant required would be for the Potomac water 0.325 grains per gallon.

There would be for this system an additional expenditure for arranging a coagulating basin and a plant for handling the coagulant; this latter would cost $20,000.

This would add to the expense for operating the English system as described, 56 cents per million gallons for coagulant alone, and with the extra attendance and machinery—estimated at about 23 cents—would amount to a charge of 79 cents per million gallons.

As the funds available for investigation did not allow an experimental study of this method, and as no practical experience is available, the method has not been considered in this report.

CONCLUSIONS AND RECOMMENDATIONS.

These investigations have continued during a period of nine months. During this period the Potomac water has passed through extreme stages, from clear to very turbid. With the exception of a few days the water has been very turbid from December 28, 1899, to March 13, 1900.

During this period the English filter "A" has not furnished a satisfactory effluent, either as to turbidity or bacterial efficiency.

During the same period the American or mechanical filter "B" has furnished an effluent which was entirely satisfactory, both as to turbidity and numbers of bacteria present.

At no time has there been any indication of sulphate of alumina present in the effluent of the mechanical filter.[1]

It is therefore demonstrated that during the period of greatest turbidity and accompanying bacterial danger the English filter will not furnish a satisfactory effluent; while, on the contrary, during this period the mechanical filter will, with proper attention, furnish an entirely satisfactory effluent both as to turbidity and sanitary considerations.

The following table shows the work of the two filters compared during the period of greatest turbidity. The table shows the turbidity of the applied water and effluents of the English filter (A) and mechanical filter (B); also the number of bacteria present per cubic centimeter in the same, with the bacterial efficiency and amount of coagulant used:

Date.	Turbidity.			Bacteria per cubic centimeter.					Sulphate of alumina, grains per gallon.
	Raw water.	Effluent.		Raw water.	Effluent.		Per cent removed.		
		A.	B.		A.	B.	A.	B.	
1899.									
Dec. 1	0.054	0.004	0.009	170	6	50	96.5	81.8	0.56
2	.054	.000	.005	170	9	33	94.7	80.1	.58
3	.058	.004		200	6		97.9		
4	.054	.002	.008	220	10	27	91.4	97.7	.57
5	.054	.002	.009	250	3	36	98.8	85.6	.57
6	.056	.004	.006	180	8	14	95.6	92.2	.77
7	.056	.002		160	8	39	95.0	75.6	.77
8	.057	.004		210	8		96.2		
9	.048	.000		180	12		93.3		
10	.050	.000		150	4		97.3		
11	.049	.004		135	4		97.0		
12	.051	.000		200	11		94.6		
13	.053	.001		220	6		97.3		
14	.047	.000		190	4		97.9		
15	.054	.001		300	4		98.7		
16	.055	.004		600	6		99.0		
17	.058	.005		450	4		99.1		
18	.057	.004		700	9		98.7		
19	.060	.002		Lost.	Lost.		Lost.		
20	.057	.002	.001	1,900	47	70	97.6	96.3	.78
21	.052	.000	.002	1,500	10	85	99.3	94.3	.70
22	.055	.002	.005	950	10	130	99.0	86.3	.63
23	.059	.005	.004	1,100	9	200	99.2	81.8	.83
24	.063	.004		1,400	16		98.9		
25	.062	.004		3,800	50		98.7		
26	.073	.008		4,900	50		99.1		.60
27	.063	.002	[2].053	7,900	130	[2]1,800	98.4	77.2	.94
28	.043	.008	.009	12,000	310	1,600	97.4	86.7	1.23
29	.246	.022	.008	16,000	650	800	96.6	95.0	1.23
30	.252	.038	.065	11,300	420	1,600	96.3	85.8	1.25
31	.249	.029		31,000	450	750	98.6	97.6	2.53

---

[1] See letter from Dr. William M. Mew appended hereto.

[2] Washed settling basin of Filter B on 26th.

Date.	Turbidity.			Bacteria per cubic centimeter.					Sulphate of alumina, grains per gallon.
	Raw water.	Effluent.		Raw water.	Effluent.		Per cent removed.		
		A.	B.		A.	B.	A.	B.	
1900.									
Jan. 6[1]	0.238	0.073	0.024	13,800	600	80	96.4	99.5	4.99
7	.249	.076	....	13,500	500	....	96.3	....	....
8	.214	.078	.034	8,400	1,200	90	85.7	98.9	2.29
9	.121	.093	.008	8,000	660	115	91.9	98.9	1.66
10	.116	.086	.024	5,700	800	300	86.0	94.3	1.03
11	.132	.074	.019	5,000	460	270	90.8	94.6	.96
12	.131	.073	.018	5,100	340	180	93.3	96.5	1.07
13	.120	.065	.007	4,300	270	210	93.7	95.1	1.09
14	.113	.054	....	5,200	220	....	95.9	....	....
15	.111	.058	.009	4,100	180	170	95.6	95.9	1.06
16	.089	.053	.009	3,500	180	91	95.0	97.4	1.42
17	.104	.057	.011	4,800	112	160	97.6	96.7	1.07
18	.185	.051	.009	11,600	160	460	98.6	96.0	1.38
19	.178	.042	.008	31,400	370	800	98.8	97.5	1.34
20	.206	.044	.001	31,300	305	700	99.0	97.8	1.35
21	.201	.033	....	26,000	220	....	99.1	....	....
22	.184	.025	.009	51,000	210	550	99.6	98.9	1.54
23	.191	.022	.010	36,000	180	320	99.5	99.1	1.92
24	.171	.012	.005	33,000	98	100	99.7	99.7	2.03
25	.188	.021	.005	28,800	95	160	99.7	99.4	1.95
26	.207	.026	.006	26,000	90	55	99.7	99.8	1.97
27	.187	.025	.007	18,300	160	75	99.2	99.6	1.98
28	.238	.026	....	12,500	180	....	98.6	....	....
29	.202	.021	.005	11,100	180	32	98.6	99.7	2.11
30	.174	.024	.006	10,300	125	23	98.8	99.8	1.88
31	.179	.023	.005	10,300	155	33	98.5	99.7	1.89
Feb. 1	.116	.024	....	6,500	125	....	98.1	....	....
2	.132	.026	.002	7,300	135	14	98.1	99.8	1.84
3	.120	.022	.005	5,400	100	7	98.1	99.9	1.64
4	.117	.018	....	8,900	85	....	99.0	....	....
5	.083	.020	.002	16,600	165	75	99.0	99.5	1.35
6	.085	.021	.005	5,500	110	23	98.0	99.6	1.52
7	.075	.014	.004	2,600	62	35	97.6	98.6	1.42
8	.071	.009	.002	2,800	60	47	97.9	98.3	1.44
9	.076	.015	.002	2,700	55	36	98.0	98.7	1.42
10	.073	.011	.002	3,000	55	23	98.2	99.2	1.35
11	.071	.010	....	3,000	65	....	97.8	....	....
12	.088	.008	.002	2,500	56	21	97.8	99.2	1.57
13	.107	.013	.005	2,500	55	23	97.8	99.1	1.80
14	.145	.017	.008	4,000	55	150	98.6	96.3	2.03
15	.172	.014	.009	7,200	50	33	99.5	99.5	2.94
16	.191	.021	.010	13,100	60	10	99.5	99.9	3.04
17	.290	.050	.010	13,800	97	11	99.3	99.9	3.50
18	.370	.056	....	23,000	160	....	99.3	....	....
19	.422	.057	.014	26,200	225	31	99.1	99.9	2.76
20	.500	.068	.011	21,200	300	42	98.6	99.7	2.26
21	.495	.123	.017	16,100	230	80	98.6	99.6	3.55
22	.500	.117	....	12,000	200	....	98.3	....	....
23	.394	.117	.012	11,400	240	12	97.9	99.9	8.59
24	.322	.080	.005	7,100	135	7	97.7	99.9	2.49
25	.338	.065	....	22,000	200	....	99.1	....	....
26	.341	.092	.011	11,400	260	42	97.7	99.6	2.91
27	.453	.093	.029	10,000	260	120	97.4	98.8	3.42
28	.417	.089	.017	10,000	180	80	98.2	99.2	3.51
Mar. 1	.410	.086	.009	17,700	415	24	97.7	99.9	3.59
2	.313	.072	.009	14,500	220	24	98.5	99.8	2.48

[1] Started run.

In view of the above facts it is recommended that for the filtration of the Washington water supply the American or mechanical system of filtration be adopted.

If Congress should conclude to adopt any system of filtration it is absolutely necessary that an immediate appropriation be made for the construction of the dam for the clear-water reservoir. Whatever system be adopted this clear-water reservoir would be absolutely necessary.

The dam should be constructed before the new reservoir is placed in operation, and it is urgently recommended that an appropriation for this purpose be made.

By the act of Congress directing this investigation the Chief of

Engineers, United States Army, was associated with the proper officer of the Government in charge of the aqueduct as consulting engineer.

During the investigation the Chief of Engineers, United States Army, has, by frequent and personal inspection and examination of the results, as well as by valuable and timely advice and counsel, greatly promoted the work.

The actual manipulation of the filters and the daily reports on rate, turbidity, etc., have been under the immediate charge Mr. E. D. Hardy, of this office.

The bacteriological and chemical examinations have been conducted by Mr. Robert Spurr Weston, of Boston, Mass., assisted by Mr. George A. Johnson, under his supervision.

To these gentlemen for intelligent, constant, and punctual work the value of the investigation is due.

The Medical Department, United States Army, has greatly assisted by bacteriological and chemical examinations, as well as by the use of books of reference from the library.

The following books of reference, furnished by the library of the Medical Department, United States Army, and of the engineer school at Willetts Point, N. Y., have been largely consulted:

The Filtration of Public Water Supplies, Allen Hazen.
The Purification of Public Water Supplies, John W. Hill.
Water Supply, William P. Mason.
Examination of Water, William P. Mason.
Water and Public Health, James H. Fuertes.
Purification of Sewage and Water, W. J. Dibdin.
Water Supply and Distribution, International Health Exhibit.
The Microscopy of Drinking Water, George Chandler Whipple, 1899.
Annual Reports, National Board of Health.
Annual Reports, State Board of Health, Massachusetts.
Water Supply, Chemical and Sanitary, Wm. Ripley Nichols.
Water Purification at Louisville, George W. Fuller.
Report of the Filtration Commission, Pittsburg, 1899.
Report on Water Purification, Cincinnati, 1899.
Report on the Extension and Improvement of the Water Supply of Philadelphia, 1899.
Manual of Bacteriology, Sternberg.
Koch on Cholera.
The Engineering News.
The Engineering Record.
Proceedings of the American Society of Civil Engineers and of the Franklin Institute.
Various reports on the filtration of public water supplies in England and on the Continent of Europe.

Respectfully submitted.

A. M. Miller,
Lieutenant-Colonel, Corps of Engineers.

Brig. Gen. John M. Wilson,
Chief of Engineers, U. S. A.

LETTER OF DR. W. M. MEW.

War Department,
Surgeon-General's Office,
Washington, March 9, 1900.

Dear Colonel: I have carefully tested the water you sent me yesterday, both for sulphuric acid and alumina. I have also estimated the total solids. The latter gave as a mean of two weighings 9.7 parts per 100,000 parts, a pretty close agreement with the amount found last summer when the water was quite clear—9.5 parts. Alumina was tested for in the usual way in a concentrated solution and became visible some ten minutes after the addition of the precipitant. It was a trace only. Sulphuric acid was present, but not in larger amount than that found in filtered tap water with which it was compared. It is safe to say, then, that sulphate of alumina is not present in the sample.

Very respectfully, your obedient servant,

W. M. Mew,
Chemist in Charge of Laboratory.

Lieut. Col. A. M. Miller,
United States Army.

Report of weekly examinations of Potomac River water drawn from the hydrant in the laboratory of the Army Medical Museum, Washington, D. C.

Date.	Number of colonies per c. c. agar-plate cultures.	Inoculation of glucose bouillon fermentation tubes—2 c. c. of water in each.		Gas production.		General group to which the gas-producing organisms isolated belong.
		Number of tubes inoculated.	Number showing gas production.	Minimum.	Maximum.	
1899.				*cm.*	*cm.*	
May 10	[1]106	12	12	2.30	13.00	Colon.
17	[1]326	6	6	4.75	11.00	Do.
24	[1]106	6	6	2.75	14.00	Do.
31	[1]223	6	6	2.75	9.25	Colon atypical.
June 7	[1]149	6	6	1.50	7.50	Not easily classified.
14	[1]233	6	6	5.00	13.75	Colon.
21	[1]346	6	6	3.00	12.00	Do.
27	[1]488	6	6	3.75	9.50	Colon and lactis ærogenes.
July 5	[1]336	6	6	2.00	13.00	Do.
12	[1]387	6	6	2.75	9.50	Colon.
19	[1]332	6	6	2.50	9.50	Do.
26	[1]251	6	6	2.50	9.00	Do.
Aug. 2	[1]223	6	6	2.25	12.50	Do.
9	[1]66	6	6	2.50	10.50	Do.
16	[1]218	6	6	3.50	13.00	Do.
23	[1]103	6	6	9.00	11.50	Lactis ærogenes and atypical colon.
30	[2]136	6	6	8.00	13.50	Atypical colon.
Sept. 6	[2]257	6	6	2.75	11.00	Colon.
13	[2]88	6	6	8.50	13.00	Do.
20	[2]100	6	6	4.50	8.50	Colon and hog cholera.
27	[2]139	6	6	3.50	10.50	Colon.
Oct. 4	[2]265	6	6	2.50	9.00	Lactis ærogenes.
11	[2]195	6	6	1.50	9.00	Colon.
18	[2]101	6	6	3.00	13.00	Not easily classified.
25	[2]86	6	6	3.50	11.00	Do.
Nov. 1	[2]113	6	6	2.00	11.00	Colon and hog cholera.
8	[2]741	6	6	3.50	5.00	Lactis ærogenes.
15	[2]486	6	6	5.50	11.00	Lactis ærogenes and hog cholera.
22	[2]259	6	5	.50	10.00	Atypical colon.
29	[2]219	6	5	2.00	12.50	Do.
Dec. 6	[3]180	6	4	2.00	12.00	Colon.
13	[4]319	6	5	2.00	8.50	Colon and lactis ærogenes.

[1] Grown twenty-four hours at 35° C. and twenty-four hours at room temperature.
[2] Grown five days at 10° C. and one day at 35° C.
[3] Grown one day at 35° C. and two days at room temperature.
[4] Grown five days at 10° C. and one day at 35° C.

Laboratory of the Army Medical Museum,
Washington, D. C., January 12, 1900.

Respectfully submitted.

James Carroll,
Acting Assistant Surgeon, United States Army.

APPENDIX—PART II.

[Senate Doc. No. 27, Fifty-sixth Congress, second session.]

REPORT MADE BY A SPECIAL COMMITTEE OF THE MEDICAL SOCIETY OF THE DISTRICT OF COLUMBIA UPON THE RELATIVE MERITS OF SLOW SAND AND MECHANICAL FILTRATION.

MEDICAL SOCIETY OF THE DISTRICT OF COLUMBIA,
Washington, D. C., December 7, 1900.

DEAR SIR: I have been directed by the Medical Society of the District of Columbia to transmit the inclosed copy of a report made by a special committee appointed to investigate the relative merits of slow sand and mechanical filtration. This report was adopted by the society by a unanimous vote.

Respectfully,
THOMAS C. SMITH, M. D.,
Secretary.

Hon. JAMES MCMILLAN,
Chairman Committee on the District of Columbia,
United States Senate.

WASHINGTON, D. C., *December 5, 1900.*

To the Medical Society of the District of Columbia:

Your committee appointed to inquire into the relative merits of natural or slow sand filtration and mechanical filtration in their relation to the public water supply of this District respectfully submits the following report:

NEED FOR FILTRATION.

Filtration of the Potomac water on a large scale is imperatively called for in order to diminish the excessive typhoid-fever death rate in the national capital. During the year ended June 30, 1900, there were 221 deaths from this disease, and probably not less than 2,200 cases, which, at a conservative estimate, represent a financial loss to the community of over $1,000,000 per annum. The number of deaths which have occurred in the District during each of the past ten years is as follows:

Year ended June 30—	Typhoid.	Typhoid malarial.	Total.
1891	208	20	228
1892	183	23	206
1893	187	19	206
1894	191	27	218
1895	187	13	200
1896	228	12	240
1897	147	6	153
1898	130	5	135
1899	169	11	180
1900	216	5	221
Total	1,846	141	1,987

PRACTICAL EFFECTS OF FILTRATION.

Wherever a proper system of slow sand filtration of the water supply has been installed the mortality from typhoid fever has been reduced from 50 to 75 per cent, and there is every reason to assume that the same result can be accomplished in this city. If we reduce the mortality only one-half, every year over 100 lives will be spared, the number of cases will be reduced from upward of 2,000 to about 1,000, and the community will save over $500,000 and an incalculable amount of human suffering and distress. That this may be accomplished is indicated by the fact that the experimental sand filter eliminated 50 per cent of the colon bacilli, which are an accurate index of the presence of disease germs and by many classed as such.

COST OF SAND FILTRATION.

This result may be accomplished by the expenditure of $2,461,338 for the installation of the sand filters, with an annual operating expense, including interest on cost of plant and deterioration, of $186,402.27. Indeed, the first cost of the plant may be safely reduced by $530,310 by omitting the covering of the filter beds, as suggested by both of the experts employed by the War Department to investigate the subject. And this reduction in the first cost would effect a reduction of about $22,980.10 per annum in the operating expenses by diminishing the amount to be charged against "Interest on original cost of plant" and "Deterioration of plant." Moreover, apart from the saving effected by constructing open instead of closed filters, it is believed by your committee that the germicidal effects of sunlight operating on the open filters will render them far more efficient than if they were covered.

COMPARATIVE COST OF SAND AND MECHANICAL FILTRATION.

While the first cost of the mechanical system of filtration, on account of the limited amount of land required, is approximately only $1,081,377, it has been found in general that the sand filters improve with age, and that the operating expenses (which, not including the value of 876,000,000 gallons of water delivered to the filter for washing, amount to $191,669.02 per annum) and deterioration of the plant of the mechanical system are very much greater than the operating expenses and deterioration of the sand filters; for instance, according to the report of Lieut. Col. A. M. Miller, in charge of the Washington Aqueduct (Senate Document No. 259, Fifty-sixth Congress, first session, page 40[1]), the cost of operating in this city, exclusive of interest charges and deterioration, would be for slow sand filtration $3.44 and for mechanical filtration $5.61 per million gallons. The additional amount of land required for the sand filters may itself be regarded as a sanitary factor, as it will increase the breathing space for the city by over 1,000,000 square feet, and if debited against the cost of slow sand filtration should be offset by a corresponding and sufficient credit.

MECHANICAL FILTERS INEFFECTIVE, AS INDICATED BY TYPHOID-FEVER DEATH RATES.

While not ignoring the economic side of the question, your committee considers that the most important aspect from which the two methods of filtration shall be compared is in their relation to public health, and, more particularly, in relation to what they have accomplished in the reduction of typhoid-fever mortality in cities where they have been employed. Viewed from this standpoint it appears that the mechanical filters, as first pointed out by Mr. Hill, have accomplished relatively very little in the reduction of typhoid-fever death rates. In the subjoined table five American cities using the mechanical devices are compared with five cities in Europe using water from sand filters, with an average for the year 1895 for the American cities of 46.8 typhoid-fever deaths per 100,000 of the population, against 6 deaths per 100,000 for the foreign cities; that is to say, the American rate was almost eight times as great as the foreign rate:

Europe (sand filtration):	
Berlin	5
Breslau	9
Hamburg	9
Rotterdam	2
The Hague	5
Average	6
United States (mechanical filters):	
Davenport	26
Atlanta	43
Chattanooga	48
Quincy, Ill	58
Knoxville	59
Average	46.8

Lest this comparison between foreign and domestic cities be considered unfair, the committee has prepared the following table, showing the average number of deaths from typhoid fever in several American cities before and after filtration. From this table we learn that while sand filters accomplished a reduction of 78.5 per cent in the number of deaths from typhoid fever, the establishment and use of mechanical filters have coincided with an increase of 20.43 per cent; and even if we eliminate from our consideration Elmira, Lexington, and Newcastle, where an increase was noted, the reduction of typhoid fever in consequence of mechanical filtration amounts to only 26 per cent, as compared with 78.5 per cent by the process of sand filtration.

---

[1] All page numbers throughout this report refer to this document.

Average number of deaths from typhoid fever per annum before and after filtration.

SAND FILTERS.

Name of town.	Before filtration.	After filtration.	Reduction.	Number of years before and after filtration upon which statistics are based.	Filter established.
			Per cent.		
Lawrence, Mass	52	13.8	73.5	5	September, 1893.
Ashland, Wis	39	4.5	88.5	2	September, 1895.
Hamilton, N. Y	0.66	0.33	50	3	1896.
Mt. Vernon, N. Y	3.4	1.8	47	5	1894.
	95.06	20.43	78.5	....	

MECHANICAL FILTERS.

Name of town.	Before filtration.	After filtration.	Reduction.	Number of years before and after filtration upon which statistics are based.	Filter established.
Macon, Ga	10.5	7	33	4	1893.
Atlanta, Ga	61	46	25	3	1881.
Oakland, Cal	19	17	11	5	1892 (Hyatt).
Reading, Mass	4	1	75	1	July, 1896 (Warren).
Terre Haute, Ind	21.6	15	31	5	July, 1890 (National).
Elmira, N. Y	10	11	[a]10	1	April, 1898.
Newcastle, Pa	13	28	[a]115	1	April, 1897 (New York).
Lexington, Ky	18	64.2	[a]256	4	June, 1895.
	157.1	189.2	[a]20.43	....	

[a] Increase.

SUPERIOR BACTERIAL EFFICIENCY OF SAND FILTERS.

Your committee is mindful of the statement contained in Colonel Miller's report (page 41) that during a certain period (whether the entire nine months covered by the investigations or the period from December 28, 1899, to March 13, 1900, is not clear) the sand filter did not furnish a satisfactory effluent, either as to turbidity or bacterial efficiency, while the mechanical filter furnished an effluent which was extremely satisfactory both as to turbidity and numbers of bacteria present. So far as the bacterial efficiency is concerned, however—and this is the criterion by which the sanitary properties of the effluent are to be judged, rather than by its turbidity—your committee is unable to discover the figures to sustain this conclusion. The average bacterial efficiency of the sand filter during the period of greatest turbidity, as shown by the table submitted by Colonel Miller on pages 41 and 42, was 97.6, while during the same period the average bacterial efficiency of the mechanical filter was but 95.9.

Disregarding the results obtained from the sand filter on the days during which the mechanical filter was not in operation—that is, taking the results during the period when the two filters were operating upon precisely the same character of influent—the relative bacterial efficiency of the two systems was as follows: Sand filter, 97.2; mechanical filter, 95.9. If we compare the average bacterial results of the two filters during the entire time during which they were in operation and during which such results were observed, we find that between July 13, 1899, and February 28, 1900, the sand filter was operated almost continuously for two hundred and sixty-six days, with an average bacterial efficiency of 88.9 (pages 49 to 53). The mechanical filter, how ever, was operated between July 18, 1899, and February 28, 1900, on one hundred and seventy-three days. It was shut down at night and on Sundays and legal holidays and once for repairs and once to allow a house to be built over it to protect it from the cold, yet its bacterial efficiency was but 86.9 (pages 58 to 64).

The importance to be attached to the difference in bacterial efficiency in favor of the sand filter, indicated above, is increased when it is borne in mind that in construction it differed in several important particulars likely unfavorably to affect its operation from sand filters as constructed for municipal service, and that its operation practically during the entire period of service was experimental, while the mechanical filter was constructed by a company having experience in such matters and deeply interested in its success, differed apparently from the municipal filter proposed by that company in nothing but size, and was not turned over to the Government to be tested until "after being tested by actual service until it was deemed by them (its builders) to be in a satisfactory condition for representing good practice in mechanical filtration" (page 56).

SUPERIORITY OF SAND FILTERS IN BACTERIAL EFFICIENCY AND SUPERIORITY IN REDUCTION OF TYPHOID FEVER HARMONIOUS.

Difficulty has been experienced by some in reconciling the comparatively slight failure of the mechanical filter in bacterial efficiency with its marked failure in diminishing the prevalence of typhoid fever. Your committee believes, however, that the difficulty is apparent rather than real. During the period of greatest turbidity, from December 1, 1899, to March 2, 1900, the bacterial efficiency of the sand filter was, as we have seen, 97.6, and that of the mechanical filter 95.9. Expressed differently, the water filtered by the mechanical filter contained 4.1 per cent of the germs in the influent, while that filtered by the sand filter contained but 2.8 per cent; that is, the percentage of germs which remained in the water from the alum filter was 70 per cent greater than the percentage of germs remaining in the water from the sand filter.

During the entire series of experiments the sand filter removed 88.9 per cent of the germs and the mechanical filter 86.9. The percentage of germs remaining in the water filtered by the sand filter was therefore 11.1, while the percentage remaining in the water filtered by the mechanical filter was 13.1, or 18 per cent more than in the sand-filtered water. When it is remembered that the experimental sand filter was all this time operating at a disadvantage, while the experimental mechanical filter was not, there should be no difficulty in understanding why sand filters generally should have resulted in a reduction of 78.5 per cent in the typhoid-fever death rates of those cities in which they have been introduced, while mechanical filters have effected a decrease of but 26 per cent.

In considering this matter your committee does not ignore the fact that a different conclusion might possibly be obtained by adopting an arbitrary standard for the bacterial purity of water based on numbers and disregarding the character of the bacteria (pages 29 to 32). Neither in practice nor in theory, however, is this permissible. How completely the number of bacteria, if considered without reference to their origin, fails to indicate the degree of danger is shown by the following statement. In view of the fact that deaths resulting from infection by typhoid fever will probably occur a month or more after such infection, comparison should be made between the number of bacteria in our drinking water during one month with the number of deaths from typhoid fever reported during the month following:

Date.	Number of bacteria per cubic centimeter in Potomac River water.[1]	Number of deaths in District of Columbia.		Date.
		Typhoid.	Typho-malarial.	
July, 1899	66.8	38	1	Aug., 1899.
August, 1899	268.8	30	....	Sept., 1899.
September, 1899	221.2	28	....	Oct., 1899.
October, 1899	137.1	27	2	Nov., 1899.
November, 1899	430.6	26	....	Dec., 1899.
December, 1899	5,969.3	17	....	Jan., 1900.
January, 1900	15,873.1	6	....	Feb., 1900.
February, 1900	9,231.8	8	....	Mar., 1900.

[1] Result of analyses of influent of experimental mechanical filter.

Practically, as shown above, the number of bacteria in drinking water do not bear a constant relation with the prevalence of typhoid fever, which is a typical water-borne disease; nor theoretically should we expect such a relation to exist. Germs of diseases peculiar to man and the lower animals are propagated almost exclusively in the bodies of such animals and are given off with the excrement, as urine, fæces, etc. A heavy rain or a sudden thaw does not, therefore, materially increase the number of disease-producing germs, since the amount of excrement from which such germs are derived remains practically constant, although it may wash into the water courses enormous numbers of harmless bacteria such as are found everywhere and thus swell the number of bacteria in the stream when considered altogether.

Even if there be any slight increase in the amount of excrement carried into the river by reason of the scouring of the earth's surface resulting from rains and thaws, it is more than offset by the large increase of the volume of water flowing into the water courses at such times. The volume of water is increased, but the absolute quantity of infective matter suspended in it is practically constant. The quantity of infective matter, therefore, which is suspended in any given amount of water is diminished, and the number of cases of typhoid fever, the chief infective disease depending on impure water, also diminish. The fact that the amount of dead matter and the number of harmless bacteria suspended in the water increases does not influence this result.

It is, moreover, a matter of common medical knowledge that the typhoid-fever death rate is largest during years of but little rainfall, and therefore during years when there is little or no turbidity and comparatively few bacteria, for the simple reason that while the amount of excrement finding its way into the sources from which our drinking water is derived remains the same, the amount of water is diminished, and therefore there is a greater proportionate amount of infective material found in the water as delivered to the consumer.

In order for the number of bacteria in drinking water at any given time to be of value as an index to the safety of such water, it must be considered in connection with the varieties of such bacteria and with their origin. Your committee can not, therefore, admit that a sand filter would, from a bacteriological standpoint, be unsatisfactory simply because it might fail at times to yield an effluent containing more than 100 bacteria per cubic centimeter. Yet such seems to have been the basis, without reference to the nature or origin of such bacteria, on which Colonel Miller reports that a sand filter would fail at times to give an effluent which would be satisfactory from a bacteriological point of view (pages 32 and 41).

EFFECTS OF FILTRATION ON TURBIDITY.

A moderate degree of turbidity in drinking water is not in itself an element of danger, and in the face of superior bacterial purity should certainly be disregarded. In respect to turbidity, however, it may be stated, as pointed out by Colonel Miller, that when the new reservoir has been completed it will add five days to the period of sedimentation, and so result in a reduction of turbidity and bacteria in the influent. The amount of turbidity to be removed by any proposed filter will then be less than has existed during the recent experiments, and the effluent of a sand filter would be even superior to that yielded by the experimental sand filter during the recent tests.

If evidence be desired that slight degrees of turbidity do not afford safe guides to the purity of water, it appears in the results of the chemical analyses of the effluents of the experimental sand and mechanical filters constructed and operated under Colonel Miller's direction. The average amount of residue on evaporation was in each case the same, viz, 126 parts per million; the effluent from the sand filter was, however, slightly turbid, because three parts of this residue per million were in suspension (page 95), and the effluent of the mechanical filter was clear because the corresponding three parts of the residue were in solution (page 103). That the clear water from the alum filter was any purer than the water from the sand filter is certainly not demonstrated by such figures as these.

CLARIFICATION BY SAND FILTER SATISFACTORY.

Your committee has observed the result of sand filtration on the Potomac River water, and while the product may not be always as clear or sparkling as the product of the alum filter, regards it as entirely free from objection either from an æsthetic or a sanitary standpoint.

ADDITION OF ALUM TO POTOMAC WATER NOT WARRANTED.

An important consideration with reference to the use of the mechanical filters arises in connection with the effect of the chemical used as a coagulant on the health of the consumers of the filtered water. Mr. Weston's statement (page 111) that "the almost unanimous conclusion is that if the alkalinity of the influent is sufficient to completely decompose the applied chemical its use is in no way prejudicial to health" has certainly not been proved by the experience of the medical profession, and, as stated, at least is incorrect. Everything will depend upon the nature of the substances into which the "applied chemical" is decomposed.

The most that can be said is that it has not yet been demonstrated that alum as used in mechanical filters is prejudicial to health, and in the opinion of your committee the people of this community should not be made use of to determine this question. Neither is Mr. Weston's statement supported by the very recently expressed opinion of certain experts "that coagulants should not be employed where it is practicable to secure satisfactory results without them" (Engineering Record, November 3, 1900,) for if there is no danger in the use of coagulants why should they be employed only in cases of necessity and not in cases when it would be merely more convenient to use them.

Much is said in Colonel Miller's report about the failure of any undecomposed sulphate of alum to find its way into the effluent of the mechanical filter, but little appears, however, with reference to the substances resulting from the decomposition of this chemical. It is admitted that in order to obtain satisfactory results by the use of alum there must be "constant and very careful attendance in order to regulate the frequency of washing and the proper supply of the coagulant" (page 34). But even with the care devoted to the experimental mechanical filter under Colonel Miller's supervision and control, it did not at times give a brilliant effluent, because, in Mr. Weston's opinion, particles of aluminum hydrate broke through the filter and appeared in the filtered water even in sufficient quantities to give it a peculiar opalescence (page 110).

The chemical analyses of water filtered by the experimental mechanical filter showed, too, an average increase of almost 50 per cent in the amount of sulphuric acid. Potomac water contained before filtration 13 parts per million, after filtration by sand 12 parts per million, and after filtration by mechanical filters 19 parts per million. Indeed, one sample taken from the mechanical filter contained as much as 40 parts of sulphuric acid per million, about three times as much as was found in a sample of unfiltered water collected on the same day (pages 86, 95, and 103). Another noticeable change in the chemical composition of water which resulted from the use of the alum filter was the increase in the "incrusting constituents;" unfiltered water contained 17 parts per million, water filtered by the sand filter 16 parts per million, and water filtered by the mechanical filter 29 parts per million, or an excess of about 70 per cent (ibid).

The constituents just referred to do not, possibly, afford any indication as to the wholesomeness of the water, but the changes occurring in them help to emphasize the fact that chemical changes are effected by the alum used in the mechanical filter, which should not be dismissed with the statement that "at no time has there been any indication of sulphate of alumina present in the effluent of the mechanical filter" (page 41).

REASONS WHY EXPERIMENTAL SAND FILTER DID NOT ACCOMPLISH EVEN MORE STRIKING RESULTS.

Reference has already been made in a general way to the disadvantage under which the experimental sand filter operated. Lest, however, there should be any misunderstanding on this point, your committee deems it advisable to indicate the following particulars in which this disadvantage appears most conspicuously:

(*a*) The walls of this filter were practically vertical, and no effort appears to have been made to prevent water percolating into the under drains between the wall and the sand, except the construction of a narrow ledge along the inner wall of the tank 2 feet below the upper surface of the sand. That this might prevent water percolating between the wall and the filtering medium below this point may possibly be conceded, but it appears improbable that it interfered with the percolation above; in other words, a part of the water found its way into the effluent by percolating along the wall and passing through but 1 foot of sand and 18 inches of gravel. That there was an increased current along the wall of the filter, as might have been expected, is indicated by the fact that when the filter was first drained the sand around the periphery of the tank had settled more than at any other point (page 48). In an ordinary municipal filter this factor, although of some importance, might possibly be disregarded; but in an experimental tank, where the ratio of the periphery to the filtering area is so great, this can not be done.

(*b*) The filter was always refilled with unfiltered water, a thing which would not be allowed in practice. At no time after the first filling was it refilled from below. These objections were recognized by Mr. Hardy, one of the experts employed by the War Department to investigate the subject, who says (p. 54): "That the results obtained from the filter just after scraping would probably have been more satisfactory if it could have been refilled with filtered water through the under drains instead of from above with raw water, as was always the practice. When the raw water was very turbid for several days at a time, the sediment gradually worked its way down through the bed and appeared in the effluent." This, of course, worked a positive disadvantage to the sand filter, both as to clearness and the number of germs contained in the water. A similar disadvantage resulted from allowing the sand filter to operate from December 27, when "it should have been shut down and scraped" (p. 48), until January 3. Even if the results as to bacterial efficiency and turbidity during this period be disregarded, it must be remembered that the passage of improperly filtered water through the sand and gravel during all of this time tended to contaminate them and to interfere with their efficiency as filtering media during the fifth run.

(*c*) The sand used was apparently too coarse. Its effective size was 0.25 millimeter, while the effective size recommended by Mr. Weston was "not more than 0.22 millimeter" (page 114).

SAND FILTRATION A NATURAL PROCESS.

It should be remembered that notwithstanding these positive disadvantages in construction and operation, the sand filter has made the best average record, even during the experimental period, removing during the entire test 88.9 per cent of the bacteria present, even without proper sedimentation, while the mechanical filter removed but 86.9 per cent. It is, of course, an easy matter to argue that because the mechanical filter eliminated 86.9 per cent of the bacteria present it will remove a corresponding number of disease germs, and therefore be nearly as efficient and less expensive in first cost than the sand filter, and that the increased operating expenses are of no importance. There are, however, a number of points which have yet to be solved. One of these is the question of what becomes of the bacteria which appear to have been removed by the filter.

It has been suggested that the superiority of sand filters depends upon a combination of mechanical and biological action—that is to say, that, apart from the felt-like growth of the organisms themselves which develops upon the top of the filter and increases the fineness of the strainer, the ordinary harmless water bacteria and bacteria of nitrification decompose much of the organic matter and even kill the disease germs. In an informal discussion on filtration of water for public use, held at the annual convention of the American Society of Civil Engineers July 3 and 5, 1900, Dr. Ad. Kemna (Antwerp, Belium) said in part:

> The action of sand filtration is essentially a biological one. The mechanical action of straining is obvious; but as microbes are much smaller than the interstices between the grains, this action alone does not account for their retention, and it is absolutely inadequate for the reduction of the dissolved organic matter. Various theories have been proposed. The one which considers reduction as a fermentation is consistent with the greatest number and the greatest variety of facts. * * * The fact should be emphasized that sand filtration is not an artificial or a theoretical process; that it is a natural process, especially because that process is exactly like what goes on in the purification of springs, which invalidates the sentimental argument against purified river water.

Mr. H. Alfred Roechling, at the same meeting, writing on the merits of sand filters, said:

> When Simpson first introduced sand filtration at the Chelsea works on a large scale, about the year 1839, he had no idea in what manner the purification of water was brought about in this process; he imitated nature, and, as nature's own processes are generally simplicity and perfection, he succeeded.

Mr. Walter Hunter, M. Inst. C. E., engineering director of Grand Junction Water Works Company, of London, operating sand filters, who personally attended the convention, said in part:

> After all, the greatest testimony as to the quality of any water is found in the statistics in regard to the health of the community supplied. The admirable way in which the water supply of London is conducted, for instance, can be so shown. When the death rate in the metropolis is, as it was a week or two ago, something between 12 and 13[1] per 1,000, and when the average for the year continues from year to year to be something between 17 and 19, and when, too, the very small amount of typhoid fever which we have in this enormous city is noticed, the inference that the filtration of the water is carried out in a very admirable way and that the community has no need to fear in regard to the quality of that water seems fully justified. * * * We are able to deal with it absolutely well by filtration, taking out something like from 98.99 per cent or 99.999 per cent of the microbes, and the chemical analyses as made by Sir William Crookes and Professor Denar, and also by the Government analyst, Dr. Thorpe, are most satisfactory.

Dr. MacHarg, vice-president of the medical society of the county of Albany, N. Y., referring recently to the sand filters in operation at Albany, N. Y., said:

> The immediate and quick returns in the decrease of typhoid fever is as unusual as it is gratifying. There have been fewer cases of typhoid fever than there were deaths from this cause before. * * * From January, 1899, to August 1, when the city was using unfiltered water, there were 71 deaths from typhoid fever, and from August 1, 1899, to January 1, 1900, or when filtered water was in use, there were only 7 deaths from this disease. From January 1 of the present year up to July 1 there were only 19 deaths for the six months, or a total of 24 for the year, against 85, the average for the preceding nine years. It seems to me that the Albany filtration plant, as a means of diminishing the death rate from typhoid fever, has been a grand success.

Your committee calls attention to the fact that this plant is the largest system of sand filters so far constructed in America.

---

[1] The death rate in Washington during the same period was between 20 and 21 per 1,000.

MECHANICAL FILTRATION A CHEMICAL PROCESS REQUIRING UTMOST CARE.

Another question to be solved is whether alum in the quantities employed as a coagulant in the mechanical filter may not exert an inhibitory effect upon the micro-organisms. While alum in large quantities is a positive germicide, it is possible that in dilute solutions it may retard the growth and development of the germs for a day or two, and thus by the bacterial count, made in the ordinary manner, give rise to a false sense of security.

Mr. George W. Fuller, in speaking of the mechanical filters at the meeting already referred to, said:

> It is well known that they are proprietary devices of comparative recent origin. The more important patents, however, will expire shortly. * * * Up to 1895 very little was known of the hygienic efficiency or cost of operation of these filters. Naturally they were not looked upon with favor by the great majority of engineers. During the last five years there has been a great increase in our knowledge of the leading features connected with these filters. This is particularly so in the detailed knowledge of coagulating processes, which are such a vital matter in this type of filter. Without coagulation one can expect from them no hygienic efficiency. As already stated, the proper degree of coagulation of the water as it enters the sand layer is the keynote to their successful work. * * * At one time it was quite universally feared that the use of such coagulants as sulphate of alumina might result prejudicially to the health of those using water purified in this manner. As a result of most careful studies upon this point it may now be stated that *when the coagulant is applied in proper quantities in the presence of proper quantities of alkaline constituents of the water there need be no fear of undecomposed chemicals in the effluent. With this process it is imperative that the supervision should be such that at no time should the inadmissible result be met of applying more coagulant than can be completely decomposed.* (The italics are ours.)

RESULTS OF MECHANICAL FILTRATION UNSATISFACTORY.

Mr. Fuller, speaking further, said:

> If the merits of filters of this type were to be judged from the general knowledge as to their efficiency as now obtained in practice in the majority of cases the indications are that it would not receive a rating of the highest grade. This seems to be due in part to a lack of the necessary skilled supervision at small plants and in part to a desire to avoid the expense of applying a sufficient quantity of coagulant.

Mr. Fuller is a pronounced advocate of filtration by the mechanical system, especially of those waters which are either so highly colored or so highly charged with submicroscopic clay particles that it is impossible to obtain satisfactory results without the use of coagulants, and his remarks on the keynote to their successful work are of special significance.

INSTALLATION OF SAND FILTERS URGENTLY RECOMMENDED.

Whatever the merits of the mechanical system of water purification may be, the burden of proof as to its capability of diminishing typhoid fever clearly rests with this method, which, we regret to say, has so far failed to sustain this claim, and your committee, in view of the evidence in favor of sand filtration, which has stood the test with increasingly good results for over a half century, furnishing now the daily supply of water to more than twenty million of people, would deem it an unwise experiment to resort to mechanical filtration of our city's water supply.

Quite recently other methods for the sterilization of water by chloric peroxide and by ozone have been proposed by French scientists, which from a sanitary point of view promise most excellent results. But since the needs of the national capital for pure water are so very urgent, and as within the past ten years 1,187 persons have perished from typhoid and typhomalarial fever alone in this city, which from our standpoint means a needless sacrifice of at least 1,993 lives and 9,930 cases of sickness, with a financial loss to the community of over $5,000,000, we appreciate that the gravity of the situation admits of no further delay and experiments, and therefore earnestly and unhesitatingly recommend the prompt installation of the natural sand filters.

Respectfully submitted.

SAMUEL C. BUSEY,
G. WYTHE COOK,
GEO. M. KOBER,
Z. T. SOWERS,
WM. C. WOODWARD,
Committee.

APPENDIX—PART III.

A DISCUSSION OF THE FILTRATION OF WATER FOR PUBLIC USE, AT THE LONDON, ENGLAND, MEETING OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS.

At the meeting of the American Society of Civil Engineers held in London, England, in July, 1900, an informal discussion on the subject of "The filtration of water for public use" took place. This discussion so clearly and comprehensively, and yet so briefly, covers the subject that the essential portions of it are given below.

REMARKS OF RUDOLPH HERING, OF NEW YORK.

When continually growing centers of population reach a point when their water supplies can no longer be obtained from springs or wells, it becomes necessary to utilize larger sources, such as rivers. Open streams, however, are often turbid and polluted, at least by the surface washing of rain water, and it becomes desirable to purify such water before use. Thus originated the practice of filtering public water supplies. The first large filters for this purpose were constructed by Mr. James Simpson, in the year 1829, for the Chelsea Water Company.

In the early days the aim was to get a clear and palatable water. Since the discovery of the bacterial origin of many diseases, and the further discovery that such pathogenic bacteria may be introduced into our bodies through the use of water, a further and most important requisite is the elimination of disease germs also.

Filtration has, therefore, a triple duty to perform. It must render the water healthful, clear, and pleasant to taste.

As might be expected, different lines of practice have been followed in different countries, and even in the same country, in the endeavor to obtain the most effective and most economical means of water purification. The result has been the development of several distinct processes.

At the last international gathering of engineers interested in this subject, during the World's Fair at Chicago, in 1893, the results of studies pursued at the experiment station of the Massachusetts State board of health were made known to the world. These results contributed much to the knowledge of removing bacterial germs from water and elevated the practice of filtration from an empirical to a scientific basis.

Since then further substantial progress has been made on both sides of the Atlantic, but particularly through the extensive experiments made on a large scale at Louisville, Cincinnati, and Pittsburg, which covered the conditions of water highly charged with suspended matter as well as polluted by sewage. These experiments included also a test of filters of another order than those previously investigated in Massachusetts.

Experience has not yet brought about a general agreement regarding the relative merits of these several filters and methods of purification now in use. It was hoped, therefore, that a discussion at this second international gathering of engineers might contribute greater clearness as to the controlling elements, and thus lead to a more rapid progress toward the desired end.

METHODS OF PURIFICATION.

We may divide the methods of water purification now practiced substantially into two classes: One requires a large bed of fine sand through which the water is allowed to percolate, at the rate of, roughly, from 5 to 10 cubic feet per day on 1 square foot of filter surface, or a column 2½ to 5 inches in depth, per hour. The other, with a much smaller bed of sand or similar material, requires from, say, 200 to 400 cubic feet per day to pass through 1 square foot of filter surface, or a column of water of from 8 to 16 feet in depth per hour, which is, on the average, a rate 40 times faster than in the first case.

As the chief difference is this rate of speed, the two systems have been called, respectively, slow and rapid filtration. The appliances have also been called "sand" and "mechanical" filters, because sand is the chief element in the first case, while mechanical contrivances form the chief element in the latter case. They have also been distinguished, respectively, as the English and American filters, from the countries where they were first developed.

For filtering public water supplies there are still other appliances, of which the Fischer or Worms system and the Maignen system have been most prominent.

The Worms system requires the use of artificial tiles, through which the water is made to percolate. Experience, however, has shown that with a reasonably large yield of water the purity may be insufficient, or vice versa, the expense being rather great for any other than originally clear waters.

The Maignen system requires the use of asbestus pulp, which is caused to gradually form a layer or cover over the sand beds of slow filters and collect the sediment and bacteria. It is claimed that it greatly increases the safe rate of filtration per square foot. The cleansing is effected by simply rolling up this cover, which separates readily from the sand. With this contrivance no experience on a large scale has yet been had.

The slow or sand filters have been used almost exclusively in Europe. The principle upon which they act is a double one. First, there is a straining action, in keeping out of the passing water all coarse suspended matter and many of the bacteria by the slimy sediment layer which forms upon the surface of the sand; and, secondly, there is a further disappearance of the bacteria caused by an organic process going on while the water is percolating through the sand.

EFFICIENCY OF SAND FILTERS.

The efficiency of such a filter depends upon a number of conditions, the most important of which are:

1. The size of the sand grains.—It is found that fine sand of uniform size, several feet in depth, gives the best results. It is further found that the number of bacteria in the effluent water increases with a decreasing thickness of sand bed and with an increasing size of sand grains.

2. The rate of filtration.—A rate of from 2,000,000 to 3,000,000 United States gallons per acre per day, or a column of water about 3 to 4½ inches in depth per hour, is found most satisfactory, as a rule. The number of bacteria passing through the filter increases rapidly with the rate, which should, in any case, be kept uniform to get the best results, and to accomplish which requires the use of controlling devices.

3. Drainage.—The free withdrawal of the water from the underdrains, to secure the same rate in all parts of the filter.

4. Temperature.—The temperature of the water should not vary greatly, because it controls the pressure required to effect a given rate of filtration, and because the bacterial efficiency decreases with the temperature.

5. The age of the filter bed.—New or freshly scraped filter beds give higher numbers of bacteria in the effluent water than old and well-compacted sand layers.

CONTINUOUS AND INTERMITTENT FILTRATION.

The slow system of filtration has been practiced according to two methods—the continuous and the intermittent. When the amount of dissolved oxygen contained in the water is sufficient for the necessary bacterial action, the continuous method is preferable, because it is simpler and cheaper. It is therefore the more common one. When the water is highly polluted, requiring a large amount of oxygen for the proper bacterial action, the intermittent system may be preferable, as in Lawrence, Mass., where the sand beds must be given a frequent aeration, and thereby receive a new supply of oxygen, or when the water is highly polluted a double continuous filtration may be practiced, as in several cities of Europe. Still another variation is practiced in Bremen, where the first filtrate coming from the filter just after it has been cleaned, and therefore generally not sufficiently pure, is passed through another filter, which has not been recently cleaned, before it enters the city's mains.

FILTER COVERS.

In climates where water freezes frequently during the winter, and to a depth of at least several inches, it is customary to cover the filters in order to obtain the best results. Where it is impracticable to do so, as was the case in Hamburg, special allowance must be made for the decreased bacterial activity in the colder water and for the mechanical difficulties resulting from the ice.

SETTLING BASINS.

When the water to be filtered has a high degree of turbidity, economy demands that it be allowed to deposit most of its suspended matter before it is run upon the filters. Settling basins are therefore a necessary adjunct to almost all filters for river water. When this contains finely divided clay, the particles of which are smaller than bacteria, it is necessary to add a coagulant to the water before it enters the settling basins. Unless there is a prior removal of this fine clay, the filter may allow the water to pass through without giving it a thorough clarification.

One day's settling is usually sufficient for the purpose, as by far the largest proportion of suspended matter, and all the coarser matter, is removed within that period. While the custom to provide for about one day's settling prevails in America and Germany, it has been preferred in England to build storage reservoirs sufficient in size to hold water for a much longer period, the idea being that, for economical reasons, enough water should be stored for use during the time when a storm makes the river water very turbid.

CLEANING SLOW FILTERS.

A slow filter is cleaned by removing a thin layer of sand, ½ to 1 inch in thickness. This upper layer contains not only the suspended matter deposited from the water, but also most of the bacteria.

MECHANICAL FILTERS.

The second class of filters, the so-called rapid or mechanical filters, were first introduced in America and are extensively used there. They act on the principle of straining, by which the suspended matter and the bacteria are kept substantially on the surface of the filter material. The rapid rate of the passing water does not allow of much organic action below the surface, and requires also a rather coarse filtering material.

In order to hold back the fine matter held in suspension, such as clay particles and bacteria, coagulating substances are added to the water in definite quantities, depending chiefly upon the amount of lime and organic matter contained in the raw water. The resulting flocculent matter settles upon the surface of the filter bed, and then acts chiefly as a strainer, sufficiently fine to hold back the minute particles, including a percentage of bacteria, which, under favorable conditions, may be as large as that removed by the slow filters.

Through the investigations chiefly of George W. Fuller, associate member American Society of Civil Engineers, the conditions for the successful operation of such filters are understood now much better than formerly. It is possible now to arrange their operation, so that from a water of a given quality fairly definite results can be obtained. The efficiency depends mainly upon the size and character of the grains, upon the rate of filtration, the constancy of this rate, the proper admixture of the necessary coagulants varying with the quality of the water, and upon the arrangements for properly withdrawing the filtered water.

PRESSURE FILTERS.

Two kinds of rapid or mechanical filters have been used—those acting under the slight pressure of the water contained in an open filter, and those acting under a high pressure in a closed filter. Although it is in many cases convenient and economical, the high-pressure filter can not give equally good bacterial results, because the delicate film of coagulant may be more readily ruptured. High-pressure filters, therefore, should be used only for waters which are not seriously polluted.

CLEANING MECHANICAL FILTERS.

A rapid filter is cleaned by reversing the current and washing the entire mass of sand thoroughly with filtered water, for which numerous and more or less efficient mechanical devices have been used. This washing process requires from 3 to 5 per cent of the filtered water, and an opportunity of disposing of the waste water in an unobjectionable manner.

In case the water is very turbid a preliminary settling is of advantage also with this class of filters.

BOTH SYSTEMS GIVE GOOD RESULTS.

From the foregoing necessarily very brief review of the chief characteristics of the two principal methods of filtration now in use it will be gathered that they may both satisfactorily purify water under many ordinary conditions.

The criteria which should guide in the selection of one or the other method for a particular case are their relative sanitary effects under expected conditions, the reliability of their operation, and their cost.

SANITARY EFFECTS.

The sanitary effect of a filtered water will be judged by the prevailing death and sick rates. We have abundant evidence that a well constructed and faithfully operated filter of the slow type can materially reduce typhoid fever and diarrheal diseases. There is hardly a question that it will also remove the contagion of cholera. A similarly strong statement regarding the sanitary effect of rapid filters can, from lack of experience, hardly yet be made, though we know that the bacterial efficiency of both classes of filters can be made almost equally high, the slow filters being probably slightly more efficient.

RELIABILITY OF OPERATION.

As to the reliability of operation, it seems to the speaker that the slow filters should be given the preference. The great difference in the rate of filtration furnishes the reason for this conclusion. When there is a rupture in the coagulated material covering the filter—and such a rupture is likely to be produced by some irregularity—the amount of unpurified water passing through the filter is many times greater than in the case of a slow filter, where such a rupture, even when it does occur, can not produce as harmful results.

Regarding the other chances of mishaps, they are less serious and may result equally in both cases. The skill necessary to operate the two kinds of filters may also be considered as equal, if the best results are reached.

CONCLUSIONS.

We may conclude, therefore, that, as regards efficiency and reliability, both methods can render satisfactory service, depending on the special conditions of the raw water, the degree of purity to be obtained, and the care exercised in the operation.

If the raw water is highly polluted, slow filtration, or a double filtration, is to be preferred. In other cases the decision will generally depend upon the cost.

Regarding the cost, it has been found that often the two methods are about equally expensive. The required investment is usually greater for slow filters, but the cost of operation is correspondingly less, and vice versa.

We may expect, therefore, that both the slow and rapid filters will be used in the future with good results in their respective spheres, and that the peculiar conditions of each locality will enable the engineer to decide as to which will give the greater satisfaction at the lower cost.

REMARKS OF GEORGE F. DEACON, FORMERLY ENGINEER OF THE VYRNWY WATERWORKS, LIVERPOOL.

In England sand filtration has been carried on to a larger extent than in any other country, and it might be said here to be practically the universal system for potable water. On the Continent some special tests and experiments have been made, but the speaker thinks that they are all eclipsed by the very complete series of experiments conducted by the Massachusetts State board of health, by the Pittsburg commission, and by certain other authorities in the United States, and which are now referred to as among the most important investigations which have been made on the subject. Only within the last few years has it been discovered what sand filtration really means, and there is still one element which is not completely settled or defined in the minds of all engineers concerned in the subject, viz, the part which the sand really plays in the process. This much is known: That the sand is not much more than a strainer, and that it serves as a support to a gelatinous film which forms on its surface, and which really constitutes the filtering medium. Opinions differ as to whether, when this filtering medium is doing its legitimate work, the sand beneath it is or is not giving anything more than a supporting assistance.

The speaker's view is that the sand does little or nothing in the way of actual filtration, but that it is nevertheless necessary in considerable thickeness to insure complete filtration by the film resting upon it.

Of so-called mechanical filters, the class without coagulants is of little use, except for straining purposes. With coagulants used from day to day under intelligent direction, mechanical filters will, when in the best working condition, produce results nearly equal to those of sand filtration. But in practical working the speaker does not believe that this can be so. The proportioning of the coagulants can not be automatically done in a perfect manner. The work has to be put into the hands of much more intelligent men than those required for sand filtration, and he knows of no means of securing anything like the same uniformly efficient conditions as those so readily obtained from properly constructed sand filters, provided with apparatus for recording automatically all the changes, whether prescribed or irregular.

Sand filters are nothing if not sure defenses against the passage of bacteria. In nine cases out of ten this is their principal object; and where it is so, the speaker is satisfied that for public supplies sand filtration, properly conducted, is better than any other known device.

REMARKS OF GEORGE W. FULLER.

For the engineer who has to consider water filtration problems in different parts of America, the speaker thinks there is no point more deeply impressed on his mind than that the waters from different sections of the country possess to a large degree a distinct individuality in reference to their purification. Having listened to the excellent résumé of this topic by Mr. Hering and the discussion on English practice by Mr. Deacon, it is thought that it would be of interest to look at the subject for a few moments from the standpoint of the applicability of different methods of purification to different types of water.

One of the fundamental principles of water purification, as viewed from experience in America, is that the quality and the composition of the water to be filtered are factors of prime importance. This is particularly so with American surface waters, where there are wide ranges in character. In this discussion consideration is given only to surface waters, and not to ground waters which may need treatment for the removal of iron. With the surface waters from different sections of the country, the most variable features, from the purification standpoint, are with reference to turbidity and color. By turbidity is meant the sand, silt, clay, and those matters of an amorphous and organic nature which are contained in the water in suspension; and by color is meant the vegetable matter which is dissolved in the water, and which gives what is called by many a vegetable stain.

In the original application of water purification, improvement in the appearance of the water was, of course, the object sought. Within the last fifteen or twenty years the problem has changed, as is well known, and, fundamentally, the object now to be secured is the removal of those bacteria which are associated with the causation of disease. In looking at the problem from that point of view, it may be of interest to point out a difference which occurs between conditions in America and in Europe.

HOW FOREIGN AND AMERICAN PROBLEMS DIFFER.

In Europe, particularly in England and in the western portion of the Continent, or, more accurately, with those filtered waters with which American engineers are more familiar, the speaker understands that it is generally true that if the water is filtered so as to eliminate the bacteria, the appearance of the water is satisfactory. That is to say, if the effluent is satisfactory from a hygienic standpoint, it is not necessary to give attention to the appearance of the filtered water. But in America the reverse of this would be true in numerous instances. In many places—not in the Northeastern portion of the country, but in the South and central West—the character of the waters is such that if the water after filtration is satisfactory in appearance it is also substantially free from bacteria. This shows, in a general way, a difference, which perhaps is seldom appreciated, in the conditions in America and Europe. The reason for this, of course, is that the clay particles found in the Southern and Western waters of America are much smaller in size than the bacteria. It is a fact that many of the clay particles in these waters are not more than 0.00001 inch in average diameter, or about one-tenth the size of the ordinary bacterium. Some of the clay particles are still smaller, and, without doubt, our estimates of their size are much limited by the present facilities for measurement under the microscope.

While a filtered water, of course, should primarily be as free of bacteria as is practicable, it appears to the speaker that the appearance of the water should also be satisfactory in order to fulfill requirements as found in many cases. In this connection it is to be borne in mind that many water consumers judge the character of a water by its appearance, and, regardless of the hygienic side of the question, do not look with especial favor upon a water which is either turbid or colored to a considerable degree. Public opinion in America appears to be undergoing a gradual but distinct change in this respect. Colored and turbid waters which seemed to be acceptable a few years ago are now complained of in many instances, and, in the opinion of the speaker, the development of the "spring-water" trade and of house filters is suggestive of conditions which water-works engineers must consider in the near future.

TURBID WATERS.

When turbid waters in America are to be purified for hygienic reasons, it seems to be the consensus of opinion that the purification works should yield an effluent which is also practically free from turbidity at all times. With waters containing much vegetable stain opinion varies widely. In fact, in America it would seem that the amount of permissible (dissolved) color in a first-class water is one of the most unsettled points at present in connection with water supply and water purification. The permissible limit depends, of course, to a large degree upon the point of view of the observer. Perhaps the most critical observers at present in America are the water consumers themselves, who judge the appearance of the water in bulk with a white background as they see it on their tables and in porcelain-lined bath tubs.

To decide, in a conservative and reasonable manner, upon the permissible amount of dissolved color in water for the future requirements in America is a task which is as difficult as it is desirable. So far as the speaker has been able to form a judgment upon this matter, he would be inclined to place the limit at 0.30 part of dissolved color by the platinum-cobalt standard. This amount of color is about half of that frequently seen in many waters in the eastern part of America, and about double the amount found in the Southern and Western waters after the removal of the suspended silt and clay.

THREE TYPES OF WATERS.

Returning now to the character of the American waters, it may be said, in a general way, that there are three types, as viewed from the present standpoint of purification. There is, first, the water from those comparatively short rivers, and from lakes and ponds, which lie within the glacial-drift formation; that is, the waters best known to us as those of New England and the northern Atlantic States. There is also another very distinct type of water which lies south of the glacial-drift formation almost entirely, that is, the large rivers lying south of and including the Potomac, the Ohio, the Missouri, and extending from the Atlantic Ocean west to the Rocky Mountains. Between these types there is an intermediate class resembling in a measure the two; such waters as are found in the Delaware, the Susquehanna, the Allegheny, and rivers which lie along the dividing line between the drift formation and the section of country where the drift is absent.

To attempt to make specific comparisons of these types of water is a very difficult matter at the present time. In the first place, the amount of analytical evidence, with few exceptions, is very meager indeed, and especially with reference to results from samples which represent the normal and maximum conditions which the engineeer must consider in the design of purification works. There is also another reason why these data are somewhat wanting in the significance they carry, and that is the lack of uniformity in the analytical methods used in obtaining the results. This latter point is becoming realized more and more clearly by engineers, and also by the analysts themselves. In passing, it may be of interest to state that an effort is being made to correct this state of affairs. At the last meeting of the American Public Health Association a section of chemistry and bacteriology was formed, and there was appointed under that section a standing committee to consider the question of standard uniform methods of water analysis. Ultimately it is hoped that some good may come of this.

WATERS OF THE GLACIAL-DRIFT REGION.

Comparing with each other these general types of American surface waters in regard to the turbidity, or suspended matters which they contain, it may be said that those bodies of water lying wholly in the area of the glacial-drift formation, such waters as that of the Merrimac, Connecticut, Hudson, and Passaic Rivers, carry from about 5 to 15 parts per million of suspended matters as an annual average. This quantity is greatly exceeded at times of heavy floods, and in the case of the Merrimac River the amount of suspended matter has been known to exceed 1,000 parts per million. The conditions of the spring freshet in this instance, however, were abnormal. With regard to the character of the turbidity in this type of water, it may be stated that, comparatively speaking, it is caused by fine silt, and not by clay. Accordingly it is a type of water which is not very troublesome in its purification, as the silt can be removed quite readily by subsidence.

WATERS OF THE SOUTH AND WEST.

The waters of the second class, those of the South and West, contain very large amounts of suspended matter. The annual average amounts in the Ohio River water have been found to be 230 and 350 parts per million at Cincinnati and Louisville, respectively. In the case of the Mississippi River water, there are records showing the annual average amount of suspended matter at St. Louis to be about 1,000 parts per million, and about 560 parts at New Orleans. These records cover information obtained at different times during the past fifty years, and are by no means strictly comparable with each other. They are sufficient, however, to show that this general type of water contains roughly from twenty-five to fifty times as much suspended matter, on an average, as do the waters of the northern Atlantic seaboard in America, and also the English river waters as the latter are known to American engineers. From a practical purification standpoint the comparative difficulty in handling the very turbid river waters of the South and West is by no means adequately shown by the annual average amounts of suspended matter. There are several reasons for this. In the first place, the flood periods continue uninterruptedly for many weeks, and, in some instances, extend over several months, during which time the suspended matters vary very rapidly and continue normally in excess of the annual average, reaching at times more than 5,000 parts per million. Another feature of great importance in explaining the difficulty in purifying these very turbid waters is the fact that a considerable proportion, say about one-fourth, of the suspended matters consists of minute clay particles. The submicroscopic nature of these particles has already been referred to by the speaker, and it may be further added that it is practically impossible to remove them by subsidence.

WATERS OF THE DELAWARE, SUSQUEHANNA, AND ALLEGHENY.

The third, or intermediate, class of water, such as found in the Delaware, Susquehanna, and Allegheny, etc., contains suspended matters ranging apparently from about 25 to 75 parts per million, on an average. In duration of flood periods, proportion of clay particles, and in the size of clay particles, this class of water stands intermediate between the two previously described. The evidence, however, shows that in some instances there are decided complications from coal dust and mine drainage.

With regard to the amount of dissolved color or vegetable stain contained in these general types of water, it may be said that many, but by no means all, waters of the first class contain more color than is considered by some to be satisfactory. To this class of waters of the glacial drift area there must be added swamp waters from all sections of the country. No attempt will be made to show in detail the general evidence as to the color of this type of water, partly because of lack of available comparable records and partly because of the unsettled condition of the problem of what amount of color is permissible in a first-class public water supply.

The dissolved color in the waters of the second and third types is not a factor of practical significance, so far as the speaker has been able to learn. Undoubtedly, organic matter capable of producing a vegetable stain reaches these turbid waters, but it seems to be removed in the streams and settling basins. Apparently, it becomes united to the silt and clay particles (hydrosilicate of aluminum) and settles to the bottom with them. In a measure, this may be called filtration of silt and clay through water.

From this account of the conditions met with in America, it will be seen that the method of purification to be adopted in any instance must be adjusted to the requirements of the water under consideration. Further, the character of many surface waters in America is such that in the design of purification works which shall successfully meet the requirements of the future, careful attention must be given, not only to the question of bacterial removal, but also to the decolorization and clarification of the water.

AMERICAN METHODS.

Of the methods of purification now considered in America, there are two important ones, as has been very clearly shown by Mr. Hering, who has described and compared their leading characteristics. The nomenclature used in this line of work in America is in quite a transitional and unsettled state. The term "filtration of water" was satisfactory so long as it was applied to waters which were not excessively colored or turbid. Since the subject has grown and included the consideration of the more complicated types of water, the term "purification of water" is considered by many to be more logical and comprehensive. For many waters, filtration by itself is inadequate, and there are required in connection therewith plain subsidence, coagulation, and supplementary subsidence. In some places the expression "method of filtration" has been replaced by "method" or "systems of purification." With regard to the two methods of filtration proper, they are variously spoken of as sand, or English, or slow filters, and as mechanical, or American, or rapid filters, respectively. Upon comparing the two methods of filtration when each is operating at a high degree of efficiency, it is found that there is a long series of differential features, of which the most important is the physical condition of the water as it enters the sand layer. To many it seems desirable to avoid a nomenclature which gives undue prominence to one superficial feature, and to use a name which implies a series of conditions requisite for first-class work. By these engineers the two methods are called English and American filters, respectively, from the countries where they are first developed.

Water purification on a practical scale in America is in its infancy. Ten years ago its application was almost nominal. During the past decade, however, considerable progress has been made in the small cities and towns. At present it may be said in general terms that there are about 20 English sand filters in service in America, having an area of about 17 acres and yielding about 25,000,000 gallons of water as a daily average. There are also in service about 160 American or mechanical filter plants, having a nominal capacity of about 250,000,000 gallons daily, but actually supplying a consumption of only about half this quantity.

AMERICAN EXPERIMENTS.

With few exceptions these purification plants by both methods are very small, and there is comparatively little information available, showing continuously in detail the efficiency and the cost of operation. Under these circumstances American engineers are obliged to base their detailed knowledge of water purification in a large measure upon the results of European experience and of the careful investigations made on an experimental scale at Lawrence, Providence, Louisville, Pittsburg, and Cincinnati. The European experience in connection with the purification of waters comparable to those now filtered abroad, has been carefully followed in America for many years, beginning with the classical report made by the late James P. Kirkwood, member American Society Civil Engineers for the city of St. Louis. For the purification of the more difficult types of water, due to their excessive color or turbidity, dependence is now placed on the laws of purification as deducted by the special studies in the cities just named. Upon the more important points it is considered that this evidence is substantially correct for the types of water actually studied, and it is now being used as a guide in the design and construction of purification works for a number of the larger American cities.

Concerning the relative merits of the two leading methods of purification, the experience of the speaker has led him to the opinion that English sand filters, as a rule, are most satisfactory in point of efficiency and economy for those waters for which they are strictly applicable. Such waters may be defined as the nonclay-bearing waters, which are only slightly or moderately discolored by vegetable stain, and which are found in the first type of waters mentioned in this discussion. Although it is well known that these filters have decided limitations in the successful treatment of very colored and very turbid waters, it is a difficult matter at present to define satisfactorily the dividing line between those waters for which this method of purification is applicable or nonapplicable. There are some cases in which this method is strictly applicable for the local water where it is probable that its adoption would be inadvisable on the ground of cost, owing to the area which it requires, thus necessitating an isolated location and an extra pumping of the water. Notwithstanding the fact that English sand filters are applicable for a far smaller proportion of the American water supplies than was generally considered to be the case a few years ago, it is the opinion of the speaker that they have a large field of usefulness in America and that they will be adopted in many places within the next few years.

ENGLISH SAND FILTERS IN AMERICA.

Referring to the construction and operation of English sand filters in America, it may be fairly said that the recently completed purification works at Albany, N. Y., designed by Allen Hazen, member American Society Civil Engineers, may be taken as representative of the best current knowledge in this line, based both on European experience and American investigations. These filters differ much from the older filters of Europe, but do not differ very materially in the more vital points, when compared with the best modern filters abroad. Nevertheless, they have an individuality of their own. Among the more interesting and important features of the Albany filters, from the standpoint of efficiency and economy, are the arrangement of the floor with the thin layers of gravel to support the sand, and the means taken to prevent the passage of water between the walls and the sand.

The recent estimates made for English sand filters at a number of American cities are on the basis of an average capacity of 3,000,000 gallons (United States) per acre daily. In view of the fact that the maximum consumption in some places ranges from 25 to 50 per cent above the average during very hot and very cold weather, the rate would at times reach between 4,000,000 and 5,000,000 gallons per acre daily, even with moderately large distributing and compensating reservoirs. From present evidence this seems reasonably safe for very short periods, unless the raw water should be excessively polluted. In fact, it appeared from experimental evidence obtained several years ago at Lawrence and elsewhere that, with some kinds of water, rates of 5,000,000 and even 7,500,000 gallons per acre could be safely used. More recently, however, the very careful studies made at Lawrence with reference to the passage of bacillus coli communis, the leading intestinal bacterium, indicate that these rates are too high for such waters as that of the Merrimac River. In the event that rates of filtration have to be increased materially to meet unusual conditions of consumption, experience indicates that the changes should be made gradually and not suddenly. In fact, proper regulation of the rate of filtration is now universally recognized as an essential feature of successful filtration, and the introduction of devices to secure this end shows one of the most marked improvements in the new over the older filters.

COVERS FOR FILTERS.

There is some difference of opinion in America concerning the conditions under which covers should be provided for English sand filters. A few years ago it was thought that this could be settled by the mean January temperature, on the basis that covers would be required where this temperature was at or below the freezing point. More detailed studies of temperature conditions, however, show that every few years there are exceptionally cold winters during which there are so many days in succession when it would not be practicable to scrape open filters that the foregoing rule seems to be questionable. According to the opinion of many engineers, experience will ultimately show that covers are an advantage at nearly all points on and north of the Potomac and Ohio rivers. If this should prove true, it would necessitate covers in nearly all the American territory where English sand filters now appear to be applicable. With regard to the effect which covers produce upon the bacterial efficiency of the filter in connection with vegetable growths, etc., this is a point upon which there is very little or no evidence in America.

MECHANICAL FILTERS.

With regard to the American or mechanical filters, it is well known that they are proprietary devices of comparatively recent origin. The more important patents, however, will expire shortly. Prior to 1885 these filters were used exclusively in the treatment of water for industrial purposes for the removal of vegetable stain and turbidity. Since that date they have been introduced for the purification of many public water supplies, and during the last few years progress has been very rapid. For the most part they have been installed for small works, not so much because they were necessarily the most applicable process for each water, but rather, perhaps, on account of the filter companies guaranteeing certain results with devices of fairly low first cost.

THE QUESTION OF COAGULATION.

Up to 1895 very little was known of the hygienic efficiency or cost of operation of these filters. Naturally they were not looked upon with favor by the great majority of engineers. During the last five years there has been a great increase in our knowledge of the leading features connected with these filters. This is particularly so in the detailed knowledge of coagulating processes, which are such a vital matter in this type of filter. Without coagulation one can expect from them no hygienic efficiency. As already stated, the proper degree of coagulation of the water as it enters the sand layer is the keynote to their successful work. When this is satisfactory such factors as rate of filtration, size of sand grain, thickness of sand layer, and detailed method of cleaning the sand layer appear, within reasonable limits, to drop into comparative insignificance. At one time it was quite universally feared that the use of such coagulants as sulphate of alumina might result prejudicially to the health of those using water purified in this manner. As a result of most careful studies upon this point, it may now be stated that when the coagulant is applied in proper quantities in the presence of proper quantities of alkaline constituents of the water there need be no fear of undecomposed chemical in the effluent. With this process it is imperative that the supervision should be such that at no time should the inadmissible result be met of applying more coagulant than can be completely decomposed. In this decomposition there is a conversion of the carbonates of lime and magnesia into the sulphates of these bases, with the liberation of a corresponding quantity of carbonic acid. The alumina itself is, of course, removed as a flocculent precipitate.

If the merits of filters of this type were to be judged from the general knowledge as to their efficiency, as now obtained in practice in the majority of cases, the indications are that it would not receive a rating of the highest grade. This seems to be due, in part, to a lack of the necessary skilled supervision at small plants, and, in part, to a desire to avoid the expense of applying a sufficient quantity of coagulant. From the results of extended investigations upon the subject, however, it is considered that sufficient knowledge is available to design and operate by this method plants which will give first-class results, when judged practically from the highest plane of excellence. From the added knowledge of tests of short duration upon recently constructed plants in practice, it is felt by the speaker that the laws of this process, so far as they have been formulated, are substantially sound and accurate.

Concerning the applicability of this method of purification, it is the judgment of the speaker that for the nonclay-bearing waters which are low in amount of dissolved color it is, as a rule, less suitable than English sand filters. This is based on the present general evidence that for this type of water the English filters can give a thoroughly satisfactory effluent, and at a total cost equal to or slightly less than that of American filters; that the use of coagulants is to be avoided where not imperative, and that the use of coagulants for these waters is especially undesirable and exacting in the control of their application, due to their low alkalinity. There are, of course, exceptions to this general rule, such, for instance, as cases where the compact form of the American filters would permit of a location where extra pumping would be avoided, and where this could not be done with English filters.

The especial field of usefulness for the American filter is in connection with the purification of those waters which are either so highly colored or so highly charged with submicroscopic clay particles that it is impossible to obtain satisfactory results without the use of coagulants. With waters which require a coagulant, either constantly or for the great majority of the time, the present evidence shows that as a rule the American system of purification is the better. For very turbid waters this system consists of plain subsidence, coagulation and supplementary subsidence, and mechanical filters. For such waters the use of English sand filters would increase the total cost somewhat; they would give normally no higher grade of purification; they would be more difficult to operate, and for the latter reason there would be a tendency for them to yield a less satisfactory effluent at times when the river water would be most variable in character.

DIFFICULTY OF OPERATING SAND FILTERS WHERE WATERS ARE TURBID.

In explanation of the point that, with English filters, purification plants for very turbid waters would be more difficult to operate, it may be said that the great rapidity with which the character of the water changes makes it very difficult, and in a measure impossible, to apply at all times just the proper quantity of coagulant at the inlet to the coagulating basin. Obviously, this would be kept as low as consistent with good efficiency for the sake of economy. If it should be found that the application of coagulant was too small, it is possible with American filters to correct this by adding more coagulant as the water reaches the filters, thus maintaining the efficiency of the plant. With English filters this is not possible, because, if the coagulant were applied at the outlet of the coagulating basin, it would clog the surface of the sand very quickly, and put the entire plant out of service for some little time. From a practical standpoint, the speaker attaches great importance to this feature, which was repeatedly noted during the investigations at Cincinnati.

There has as yet been very little experience in the purification of waters containing large amounts of dissolved color. Judging from experience with the recently completed works at Norfolk, Va., it appears that the American method with mechanical filters is the better, for reasons similar to those stated for the clay-bearing waters.

Concerning the purification of those intermediate types of water, which for short periods are moderately colored or turbid, there are not sufficient data to draw any well-defined lines. A careful study of local conditions, with reference to the characteristics of the two methods of purification, can alone settle the matter properly for the present.

REMARKS OF SAMUEL RIDEAL, OF LONDON, ENGLAND.

The remarks on the American practice with mechanical filters have greatly interested the speaker. Speaking as an English chemist and bacteriologist, he thought that the lesson to be learned from this discussion was that English engineers should give these mechanical filters a trial in this country, parallel to the trials that American engineers were giving to the English method of sand filtration. Mr. Fuller's remarks seem to show that there is a future for mechanical filters in England, where recent practice has been to do away with the sand-filtered water supplies from rivers, and to go to the mountain and upland surface waters, many of which, containing vegetable coloring matter, would seem to be very amenable to this mechanical filtration. These waters frequently give rise to plumbism. With a mechanical filter using alum (and lime, if the water is not sufficiently hard from carbonate of lime), the coagulant would correct that evil; so that with mechanical filtration, using alum with or without lime, we should effect the removal of the vegetable coloring matter and prevent plumbism at the same time. That our method of sand filtration seems generally to give a better bacterial purity than the mechanical filters may be due to the fact that the latter have been worked at a much greater rate, and perhaps with the minimum quantity of coagulant, without due regard to the reduction of bacteria—a difference that doubtless could be removed.

Neither method of filtration can, however, be regarded as a satisfactory means for preventing the appearance of pathogenic germs in water. No matter how small the fraction of the organisms left, there might be among them some which might be injurious to health. Therefore, although either sand filtration or mechanical filtration is a very good line of defense, it is not the only line of defense upon which one should rely.

The speaker believes that the question of sterilizing water will soon become prominent, and that the removal of pathogenic organisms can only be effected satisfactorily and economically by heat sterilizing. He used the term "heat sterilizing" (a somewhat misleading phrase) purposely, because he wished to accentuate before a body of engineers that it is not a question of heat sterilization at all, but a temperature condition. The organisms are killed when they reach a certain temperature and a maintenance of this condition does not necessarily involve the expenditure of any energy.

The problem of bringing a body of water to a high temperature, and keeping it at that temperature sufficiently long to insure the death of the organisms present, is one which he believes would be worth while for engineers in this country and in the States to pay special attention to. The cost of bringing very small quantities of water—perhaps 2 or 3 pints per head of the population, instead of the 65 or 75 gallons—to a temperature which will insure the killing off of the pathogenic organisms, can not be very large. By a proper system of incoming and outcoming of the water, and possibly by a vacuum jacket such as is used for maintaining a very low temperature, the expenditure of the heat or energy, either gas or electric heating, which would be required for bringing about such local sterilization of water for potable purposes would be very small indeed. Probably in the States as well as in this country legislation could be brought to bear in the same way that we now have by-laws for limiting the quantity of waste in flushing closets. In this way it would be possible for the municipalities to supply to every consumer a machine for producing sufficient sterilized water for potable purposes, while leaving the supplies and mains in their present condition.

REMARKS OF HENRY DAVEY, ENGINEER OF THE BIRMINGHAM, ENGLAND, WATERWORKS.

The speaker thinks that a high tribute is due to Mr. Hering for his discussion, in which the case is stated very clearly, and in which opinions are expressed which seem perfectly in accordance with the facts of practice. On this question, and referring only to the English practice, or what has been termed the sand filter, the speaker, who for many years has had charge of very large filter beds dealing with large quantities of very impure river water which it is necessary to filter and bring into a proper state for domestic use, has very little to say, because the general principles have been so thoroughly stated that he could only repeat what has been already said, or go into minute questions of detail which would not be profitable.

He would, however, like to emphasize what has already been said. The question of sedimentation is a highly important one. If storage reservoirs can be made sufficiently capacious, the quality of the water may be so improved that the work on the filters is reduced. In the sand filter, as has been pointed out already, it is only the thin layer of the surface that does the work, and the object is to maintain that thin stratum in a quiescent state in order that the bacteriological effects may properly take place. The rate of filtration, then, is an important point, because time must be given for these bacteriological operations. Four inches per hour has been named, and that, according to the speaker's experience, is good practice in England; but, as Mr. Deacon has intimated, the longer the filter works the less will be the rate. If an average of 4 inches is taken, it may be too rapid to begin with. We know that when the water is put on the filter immediately after the filter has been cleansed that there is very little effect—the water goes through. The filter should be worked for the first two or three days at an exceedingly low rate in order to produce the film that is necessary without letting many bacteria go through. When the filters are newly made they should be worked very slowly indeed to get the best results. Much depends on the class of water, but, from the speaker's experience, 4 inches per hour should be the maximum with waters that are high in bacteria.

Although a thin layer of sand is all that is necessary to maintain the surface film, yet a considerable thickness is desirable, for the reasons which have been mentioned by Mr. Deacon. The speaker has found that in a section of the filter bed having a depth of sand of, say, 4 feet, there are streaks of pollution through the sand, showing that if that had been very much thinner much polluted matter would have gone through. He thinks it is a safe thing to have a great depth of sand, but, as has already been pointed out, it should be sand and not pebbles and gravel, which are only useful as a support. An important point which has given the speaker considerable trouble is that unless the inlet to the filter is properly constructed the current of water around it disturbs the sand and the water at once finds its way down through without the surface film being formed. It is not necessary to go into the actual construction, but merely to mention that the distribution of the water over the filter and on the filter in such a way that the surface is not disturbed is an important point to be taken into consideration.

REMARKS OF DR. AD. KEMNA, OF ANTWERP, BELGIUM.

The action of sand filtration is essentially a biological one. The mechanical action of straining is obvious, but as microbes are much smaller than the interstices between the grains this action alone does not account for their retention, and it is absolutely inadequate for the reduction of the dissolved organic matter. Various theories have been proposed; the one which considers reduction as a fermentation is consistent with the greatest number and the greatest variety of facts.

So, for example, an apparent contradiction can be easily explained. Animal pollution is easily reduced by filtration, while we have it on the authority of Mr. Fuller that vegetable color is extremely hard to remove. Now, we know from our school chemistry that vegetable organic compounds are much more stable than animal nitrogenous contamination; the filter masters the one and fails with the other. Besides, microbes do not act on all substances; in racemic acid the tartrate will be destroyed and the right remains unaltered; similar cases are likely to occur with the mixture we call organic matter in water.

Negative proofs can be given of that biological action. In moderate climates the bacterial efficiency of sand filtration is over 99 per cent, but in colder climates, like Warsaw and Odessa, only 96 per cent is reached, and, according to Simin (Moscow), the reduction is as low as 60 per cent.

There was a spell of sharp frost over western Europe in December, 1899. The cold had not set in three days before the filters of Antwerp gave insufficient bacterial and chemical purification. The size of a pin's head of the slimy upper layer gives in the field of the microscope generally over 200 living organisms, chiefly diatoms; during the cold there were 4 or 5, and it seems reasonable to admit that their vital activity also is greatly diminished. A chemical process (iron and marble) was applied with good results to insure the quality of the supply.

Another proof is the interesting fact that at Louisville, according to Mr. Fuller, ordinary sand filtration does not work; the high turbidity of the Ohio water shuts out the light, which is essential to the development of diatoms.

The sand filter has been, and is still, in many places, a very simple thing; it is a heap of sand; water is poured on the top and extracted from underneath; it is worked by a foreman, who knows, of course, how much water he pumps on the filters, but he can not always tell how much each particular filter is doing, its speed, etc. Generally the filters are left to settle that between themselves. This is the acme of simplicity.

The thickness of the sand is a much-discussed question; the small size of the grain is all-important for the mechanical action of straining; the thickness of the bed is all-important with the physical theory of surface action, very popular some decades ago, when chemistry told that dissolved matter was abstracted from the water. But it is an undisputed fact that quartz has only a very limited power of adhesion, quite unlike that which is so marked with aluminum compounds. In the light of the biological theory the sand is something like the gravel—a support to the superficial living layer. The well-ascertained fact that thick filters give an effluent of more constant bacteriological composition has received a simple mechanical explanation from Allen Hazen. If the superficial layer is broken in some places, a thick bed of sand allows of only a small direct flow, and contamination is kept down to a minimum.

As the reduction of dissolved organic matter is a fermentation, some time must be allowed for it. The retention of the microbes is a sort of compromise between the erosive mechanical action of running water and the stickiness of the stuff coating the sand grains. For these two reasons the rate of filtration must be kept within certain limits. The 4 inches per hour, or about 2.5 meters per day, is the limit fixed by the German imperial health office. It is a limit, and, as the engineer of

Birmingham has very well pointed out, that speed can not always be given. The pace of a man walking is, say, 1 meter, but that can not be expected from a child. When a filter has just been scraped it is in its infancy, and must be worked very gently at first. As soon as the filtering layer has been formed the speed may be increased, and, according to experience at Antwerp, may be much more than the 4 inches per hour and still give good results.

The suggestion of Dr. Rideal to sterilize the water is based on the fact that some epidemic diseases are caused by water-borne microbes. It is obvious that absolute security can only be obtained by complete sterilization, but the practice of fifty years' filtration proves that the risk of contamination is an exceedingly small one. A heating apparatus for thousands of cubic meters means a large expense; a special canalization for a few liters of water a day is another big item. It is a question whether that very small increase of security is worth the extra expense, the more so as the temperature of 70° C., mentioned by Dr. Rideal, will certainly not kill all the spores, some of which are very resistant.

The discussion has wavered between English and American filters. In both cases sand is applied, but that is the only point they have in common. In both cases this point is unimportant, the sand being only a support—in the ordinary filter a support to a layer of algæ and clay in which biological actions are prominent, in the mechanical filter merely for straining out the coagulum. Ordinary sand filtration is not at all an artificial process. We can not order life to multiply and the microbes and algæ to work in a special way; we are completely at their mercy. In the mechanical filter a chemical compound of known composition and predetermined reactions is used which can be adequately dosed. The comparison between the two processes is really an antithetic one.

REMARKS OF WALKER HUNTER, ENGINEERING DIRECTOR GRAND JUNCTION WATERWORKS, LONDON, ENGLAND.

After all, the great testimony as to the quality of any water is found in the statistics in regard to the health of the community supplied. The admirable way in which the water supply of London is conducted, for instance, can be so shown. When the death rate in the metropolis is, as it was a week or two ago, something between 12 and 13 per thousand, and when the average for the year continues from year to year to be something between 17 and 19, and when, too, the very small amount of enteric fever which we have in this enormous city is noticed, the inference that the filtration of the water is carried out in a very admirable way, and that the community has no need to fear in regard to the quality of that water, seems fully justified. The Thames has been wonderfully improved by the action of the Thames conservancy during the past few years. The raw water taken from the river is at least 33 per cent better than it was. We are able to deal with it absolutely well by filtration, taking out something like from 98 to 99 per cent, or 99.999 per cent of the microbes, and the chemical analyses, as made by Sir William Crookes and Professor Dewar, and also by the Government analyst, Doctor Thorpe, are most satisfactory.

REPORT OF NICHOLAS SIMIN, CHIEF ENGINEER OF THE MOSCOW WATERWORKS.

Moscow will soon have to decide upon the method of filtering daily 45,000,000 United States gallons of river water, the quantity necessary for its municipal water supply. This circumstance was the cause of the writer's journey from Moscow to the United States of America in the autumn of 1897, when the so-called "American method of water purification" or "the rapid sand filtration with coagulation" had just begun to receive a scientific sanction in America.

The purification of water by subsidence and with the aid of coagulation by alum has been practiced since ancient times, and its good results in making the most turbid waters clear as crystal are well known. The modern "American method of water purification" is but an improvement of the older one by changing the process from a slow to a rapid one.

During the first ten years of its development in the United States it was not under scientific control, and was advocated merely on commercial grounds. The great advantage, however, of a method of rapid filtration with coagulation caused several series of well-arranged scientific investigations to be made, and their results led to material improvements.

The first of these investigations was made in the year 1893 by Edmund B. Weston in the city of Providence, R. I. In 1896 and 1897 more extensive investigations were undertaken in Louisville, through the initiative of Charles Hermany, and directed by G. W. Fuller, who gave to the science of water purification a great literary work without equal. At the same time independent scientific tests of mechanical filters were made in Lorain, Ohio, by the State board of health, under the direction of Allen Hazen.

At the close of his work in Louisville in 1898 Mr. Fuller made further studies in Cincinnati, Ohio, where the importance of subsidence, with and without coagulation before filtration, was especially well demonstrated. In 1897 the city of Pittsburg, Pa., made parallel experiments with slow and rapid filters, under the general direction of Mr. Hazen. In 1899 Mr. Weston again experimented in East Providence, R. I., and in Norfolk, Va., and in March, 1900, Colonel Miller terminated a comparative test of slow and rapid filters in Washington, D. C., resulting in a recommendation to adopt the rapid method of water purification for 60,000,000 gallons daily.

All these scientific investigations combine to prove that "rapid or mechanical filters" are able to give good results; and although Mr. Hazen recommended slow filters for Pittsburg, Pa., this did not prevent him from stating that the rapid filters were also able to purify water and to remove its coloring matter to a greater extent than possible with slow sand filters.

At the time, when the writer was still under the inspiration of his inspection of mechanical filter plants in the United States, when he was familiar only with Mr. Weston's work in Providence, and could have had but a superficial idea of Mr. Fuller's work in Louisville, he expressed his opinion that no obstacle would be able to stop the spread of the "American rapid method of water purification." Now, since all the above-mentioned scientific investigations are in public possession, the writer can not do otherwise than reaffirm that opinion.

The writer now wishes to glance at the matter from a Russian standpoint.

The method of water purification with slow filters has been used in Europe about seventy years, and it has proven that good results can be obtained by it. At the same time they are not always obtained. In Russia not a single case of slow sand filters can be considered as being wholly successful. The best filters of this kind were built in Warsaw by the talented Mr. Lindley, and they left the water turbid during the session of the second convention of the Russian Waterworks Association, held in 1895. The slow sand filters in Odessa, also very well constructed by English engineers, work at the rate of only 3 inches per hour, and yet cases of unsatisfactory effluent occur often. In St. Petersburg the slow sand filters work with too great a velocity, and their average bacterial efficiency does not amount to 60 per cent. In several other Russian cities slow sand filters are also made to work at too great velocities, on account of their insufficient size, and therefore give bad results. The writer believes that such cases of lack of success occur also in Western Europe, were English slow filters are used at many city waterworks.

American mechanical filters are almost unknown in municipal waterworks in Europe, and many superstitions exist regarding them. Systematic scientific investigations of the "American method of filtration with coagulation and sedimentation" have not as yet been made here. The investigations now undertaken by the Moscow municipality, after the example of Louisville and Pittsburg, should therefore be considered as the first made in Europe.

The water is taken from the Moscow River, within the city, where it is considerably polluted by sewage and factory refuse, and has a very changeable character. Many special investigations, already made at the Moscow experimental filter plant, have cleared the subject, and the results in general agree with those obtained in America. Last March and April, when the stage of the river was high, and when the water was very turbid, the mechanical "Jewell" gravity filter removed 97 to 99.8 per cent of the bacteria, and the filtered water during the whole time was quite clear. Sulphate of alumina, in quantities of from 4 to 6 grains per gallon, was used as the coagulant, such large quantities being necessary to obtain satisfactory bacterial results.

Although these investigations are intended to extend over one whole year, they can not be considered as final, because they do not indicate the results which would be obtained if the water is taken at the proposed new intake for the city water supply, to be located 30 miles above the city. The water there contains but about 400 bacteria per cubic centimeter, and therefore will require much less coagulant for its purification. On that account it is proposed to continue the investigations at the place where the water for the future supply will actually be taken, and to make parallel experiments with mechanical and slow sand filters.

If the experiments should be limited to those now being made in Moscow, the writer is not sure that they would secure the adoption of mechanical filters for the Moscow water supply. The citizens are not yet accustomed to the idea that it is possible to dispense with slow sand filters for water purification. If the writer continues the experiments for another year he will have more data, and believes it will then be easier to remove the prejudice against the American method of water purification.

The writer feels certain in his conclusion that the most reliable, the most comfortable, the easiest and cheapest method, and the one best adapted to control scientifically the purification of the Moscow city water supply is the American method of rapid filtration with coagulation of organic matter.

The reasons are as follows: In the daily practice of water purification one should certainly give preference to a plant, the sanitary operation of which can be more easily subjected to scientific control. Such a control is more readily obtained by the American rapid filters than by the English filters, for the following reasons:

1. If the normal operation of an American plant is somewhat disturbed, it is very easy to restore it by washing and coagulation. After a ten-minute washing it is possible in three minutes to receive a good effluent, while the effluent of the English slow filters can not be quite satisfactory until three or five days after cleaning, during which time the filtered water must be allowed to run to waste. In case the effluent suddenly appears turbid, the filtered water must also run to waste until it clears itself. In this sense it is not possible to control a slow sand filter.

2. In countries having severe winters the American method of water purification costs much less than the method requiring covered slow sand filters. (The cost of filtration by means of rapid filters and of open slow filters is about the same.)

3. By the American method it is possible, not only to make the water clear and to remove the bacteria from it, but also to remove the color caused by vegetable pigments and other organic matter. Slow filtration removes such coloring matter to a much smaller extent, which is an important and insurmountable defect of that system.

4. In the case of American filters an increase in the rate of filtration does not cause such a noticeable depreciation in the quality of the effluent, as in the case of English filters. At the Moscow experimental plant a satisfactory effluent is obtained with a rate of 150 inches per hour, and it remains practically the same up to a rate of 250 inches per hour.

5. Occupying over fifty times as much horizontal area as American filters of the same capacity, the English filters meet with serious difficulties when there are no suitable pieces of ground upon which to locate them.

6. The method of cleaning the English filters is complicated and inconvenient. The sand has to be removed by hand and periodically restored by hand. The washing of the sand by machines presents difficulties during freezing weather. The washing of mechanical filters is easy and quick, and obviates taking the sand out of the filters. The rapidity of washing obviates also the large reserve filtering areas of the slow method.

7. The existing English slow filters make it too easy to increase the quantity of filtered water, and thus to avoid the erection of new filters. To do this it is only necessary to increase the velocity or rate of filtration and to dispense with the wasting of the first effluent. Such a practice, however, is detrimental to the quality of the effluent water. With the use of mechanical filters an increase of the quantity of the

filtered water is much more easily and cheaply obtained by adding a small supplementary rapid filter than a large English filter. Nor is it necessary to waste such great quantities of the first effluent. Furthermore, the increase of velocity of filtration does not affect the quality of the effluent to the same extent as in the case of English filters.

8. In many cases American filters offer a possibility of uniting the process of filtration with that of softening the water or of freeing it from iron. With the English filters this double effect is not attainable.

The greatest hindrance to the adoption of the American method is the fact that it requires a coagulation, that is to say, the introduction of chemicals into water. It is often said that the public is afraid of the sanitary effects of a chemical treatment of the water which it is obliged to drink. The writer sees no justification in such fears. Mankind often uses chemical processes for various purposes, and to a great extent, so that the micro-chemical process of coagulation, when the water is subsequently to be filtered, must not be regarded as anything out of the way. The writer thinks that the spread of the American method at city waterworks, when subjected to a good sanitary control, may be considered even as a sign of an increasing public culture and public reliance upon a triumphant science.

During the last few years America has made many scientific and practical investigations of rapid water purification. Not a single one of them has undermined its reputation, on the contrary, all of them have strengthened it.

America has investigated also the English or slow method of filtration, and has proved that it also may give good results.

The science of water purification is much indebted to America and to its literature for the studies made of both the English and American methods. Europe did not do as much for the English method alone as America did for both.

The writer thinks, however, that the American investigations on slow filtration can not wholly serve as a basis, as regards its daily practical working, because during the investigations the filters are always placed in a more favorable condition than that which they are likely to get in practice. Only when made on large filter plants in daily use, and when free from idealization, are such experiments able to show clearly all the merits and defects in their true light. Our present waterworks literature hardly yet contains a record of any such investigations as regards English filters. The writer feels sure that such investigations, if systematic and thorough, would clear the way for the further spread of the American method. Therefore, although insisting on the use of this method for purifying the new Moscow water supply, the writer recommended that one filter with a daily capacity of 500,000 verdo (1,625,000 United States gallons) should be arranged according to the English method with all its improvements, and that such a filter should work under the best practical conditions simultaneously with the mechanical filters.

If the writer succeeds in having an American filter plant of 45,000,000 United States gallons daily capacity, adopted for the Moscow water supply, he would take care that the English filter plant, which it is proposed to build for 1,625,000 gallons per twenty-four hours, should remain for permanent use, so that investigations of both systems could be made under permanent scientific control and on an equal footing.

The investigations made in the United States of America have thrown much light upon the method of rapid water purification. Let us hope that a similar light may be thrown upon the English method of slow filtration, which, almost exclusively for seventy years, has served in European water works practice.

RÉSUMÉ BY RUDOLPH HERING.

In reviewing the discussion on the subject of the filtration of water for public use, for the first time presented for international discussion, it is gratifying to observe so little diversity of opinion on so important a matter, and that the positions taken in the opening remarks have been quite generally sustained.

Mr. Fuller's reminder that, when speaking of the entire process, the expression "water purification" should be used instead of "water filtration" is rational and proper, because the word filtration does not always comprise the whole process. The chief point made in his discussion refers to the necessity of applying different methods to different types of water, because these greatly vary, particularly in America, as regards suspended matter causing turbidity and as regards dissolved vegetal matter causing color. This fact the more closely it is analyzed will, the writer believes, gradually brush aside the remaining differences of opinion regarding the relative merits of the slow and rapid processes.

It is unfortunate that the opinions are not unanimous regarding the proper names by which these two processes are distinguished. Besides "slow and rapid," we say "English and American," and we also say "sand and mechanical" filters.

The latter pair of names seems to be the least descriptive, because sand is the chief material in both systems, and both have now mechanical contrivances to regulate the flow and also to clean the sand. Further, the writer does not think that the nationality of the first of its kind is sufficiently descriptive for a true and permanent distinction. We are not sure but that some essential improvements will be made in some other country than that in which the process originated, and the name will then have but little meaning. The writer has, therefore, used the terms "slow and rapid," because the quantity of water passing through a unit of area in the two classes shows decidedly the most distinctive of all the characteristic features of the two processes, and one which is inherent to the process, and will of necessity be permanent. The cost per million gallons filtered, for the average case, is about the same in both processes. The means adopted for retaining the bacteria are essentially different, and are more expensive in rapid than in slow filters, while, in balancing this greater expense, the former permit the water to pass with a correspondingly greater speed. As yet, we seem to have no single word to characterize these different means for retaining the bacteria, the only other essential distinguishing feature between the two systems.

Mr. Fuller makes an important distinction between the waters of western Europe, which resemble the waters of New England, and those chiefly of the Mississippi Basin. In the former the principal object is to remove bacteria, because, after such removal, the water is generally clear—the other chief requirement. In the latter case the principal object is to remove the fine particles of suspended clay, and thus to clarify the water, because then the bacteria, which are much larger, will of necessity also be removed.

The vegetal stain is independent of these considerations, and, with our present knowledge, seems to be a matter of æsthetics rather than sanitation. It, therefore, represents a question of finance rather than hygiene, and the removal of this color seems to be governed by the question as to whether or not the community is willing to pay for it much as the individual decides whether he will drink champagne or claret.

The character of the finest suspended matter may be so different, as Mr. Fuller points out, as to radically affect the method of treatment. If it is silt, it consists largely of silicates and vegetal matter, most of which is readily removed by subsidence; if it is clay, subsidence removes only the grosser particles, while the finer ones can be removed only by coagulants.

The use of coagulants is still much objected to by the medical profession, but it seems to be largely due to a lack of knowledge of the details of the process. The coagulating material need not pass through the filter. Its main object is to retain the bacteria and suspended matter and to remove color. In doing this it changes its chemical constitution. Only when the quantity added is unnecessarily great, or when the alkalinity of the water is insufficient, both of which contingencies may be avoided or corrected, does it escape into the filtered water, and then probably only in harmless quantities. At other and normal times the coagulant is retained on top of the filter medium.

Coagulants have been used in both rapid and slow filters. In the former they are always essential; in the latter only when the water contains fine clay. After scraping the slow filters a single dose of coagulant may quickly reestablish the normal condition, and thus avoid the otherwise necessary waste of water for several days.

In the case of slow filters, Mr. Fuller attaches great importance to the difficulty of adding the proper amount of coagulants at the inlet to the settling basin, which difficulty is removed in the case of rapid filters by the possibility of readily changing the amount as the water enters upon them. This, however, is not a serious question. An examination of the water is, or should be, made at the inlet to the basin as well as at the filter. Experience at the works will soon indicate the proper allowance of coagulant for every condition of the water on those comparatively infrequent occasions when a quick variation in the composition of the water takes place. In any case, this difficulty seems to be of less importance than securing the most perfect mingling of the slight quantity of coagulant with the large quantity of water to be affected.

Mr. Deacon prefers the slow filters because the quantity of coagulants, necessary in rapid filters, can not be perfectly proportioned by an automatic apparatus. This disadvantage, he says, requires the employment of more intelligent men. Yet such a disadvantage is surely not serious, and may be measured by the cost element, which is generally the deciding one.

Regarding the duty performed by the sand grains, he adheres to the view that the sand is substantially but a support to the film on the surface of the bed, a view not originally held by the Massachusetts State board of health. By making the sand bed several feet thick we therefore merely add a factor of safety, so as to secure the desired action in the face of the natural irregularities found in the sand grains. This view is supported by Mr. Deacon, who calls attention to the fact observed by him that the water does not go down vertically, but in erratic lines, as a piece of paper falling through the air.

To obviate a number of the troubles with filters, Mr. Deacon uses automatic contrivances, not only to regulate the flow of water, as usually done, but also to immediately record and measure it on a diagram by a differentiating meter, a practice which is to be most highly commended as a means of knowing and of controlling the actual condition of the filter at any time.

Mr. Simin mentions the failures of slow filters in several of the larger Russian cities, and anticipates better results from the rapid process. These failures, in the writer's opinion, were probably due either to an impossibility of removing suspended clay particles of extreme fineness, or to bad management, or to both—causes which have appeared also elsewhere. Mr. Simin's eight reasons for preferring rapid to slow filtration form, however, the most complete short presentation of the merits of the former which the writer has seen. While some of the reasons may yet be too sanguine, and while nothing is said concerning the comparative demerits, they nevertheless indicate that a large field of profitable application for rapid filters may exist in some parts of Europe, as there does exist in some parts of America. The experiments with filters of both systems now being conducted side by side near Moscow will, it is hoped, throw some new light upon the subject from a European point of view.

Mr. Johnston makes a strong plea for the use of polarite instead of sand when filtering water, claiming that the degree of purification is higher and that the rate of filtration may therefore be more rapid. This substance has been known in America for ten years, and has been examined and tested. The chief disadvantage lies in the limited life of the material, so far as its purifying effect is concerned. When fresh it does better work than sand, but it does not permanently continue this ratio. Its greater first cost and the necessity of replacing it at intervals, would, in the long run, usually increase the entire cost of filtration above that of sand filters.

To overcome some of the difficulties met with in European slow filters, in getting pure as well as clear water at economical rates, the practice of double filtration was introduced, and is to-day practiced in Zurich, Schiedam, Bremen, and Altona. In the last-named city this practice is not found to be of great advantage, and was not adopted for the adjoining new Hamburg filters. In Bremen it gives very satisfactory results. In Schiedam the advantage is questioned. The method of operation differs in each of these instances.

Professor Hilgard, in his discussion, describes the double-filtration plant at Zurich, where the lake water is given a rapid preliminary filtration before it is passed through the regular filters, for the purpose of removing chiefly the large number of minute organisms which had decreased the effectiveness of the single filters to about one-fourth of what it had been originally. The chief advantage of forcing air through the sand when washing the preliminary filters in Zurich should be sought in its mechanical and not in any biological effects. The bacterial results in Professor Hilgard's table confirm the belief that many bacteria get into the water after it has left the filter and before it is taken for use in the buildings—a matter which is often lost sight of in other cities when pronouncing upon the work of filters.

When drinking water is highly charged with iron, Mr. Palmer advocates the use of polarite for preliminary and rapid filtration, prior to turning the water upon the ordinary filter bed. No details are given as to the durability of this material and the cost of the process as compared with other means of removing iron. The experience gained with aeration seems to indicate that for equally good results the polarite could remove the iron as a permanent process only at a greater cost than the more common aerating process.

The removal of iron, the softening of water, and the Zurich case substantiate the suggestion that economy will often result from a differentiation of the process, by a separate removal of each group of matter, similarly to what has been found advantageous in sewage purification.

Mr. Roechling believes that the methods of filtering drinking water and sewage are "totally different," "that the conditions of work in them are reversed." The writer does not understand the two processes quite in that way. In both cases we have water as the main substance, and in it are, suspended or in solution, dead organic and mineral matter, living organic matter, such as bacteria or other minute self-reproducing organisms; and we have in both cases a loss of oxygen in the water. The difference in the cases of raw water and sewage is merely one of degree, and the process of purification varies with the amount of organic matter, its stability and the amount of oxygen present. In raw water selected for drinking there is sufficient oxygen to enable the bacteria to nitrify or convert the dead organic matter into mineral salts by the single process of oxidation; in sewage the oxygen present is not sufficient, and an intermediate process of putrefaction takes place, succeeded, however, by a process of oxidation, for which putrefaction is sometimes but a necessary preparation.

Dr. Kemna sees great advantages in the slow method of filtration, and recognizes it as the process of nature when converting surface rain water into spring water by percolation.

Dr. Rideal has indicated to us a new advantage in the use of alum by indirectly preventing plumbism. The sterilization of water by heat appears to him to be "the coming question." While it is not clear to engineers how the maintenance of a temperature sufficient to kill the pathogenic organisms "does not necessarily involve the expenditure of any energy." it may be well to call attention to what is the most economic method known to raise the temperature of water to the boiling point for a few moments at least. By a simple contrivance, arranged by Mr. John Forbes, 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. The water is thus actually boiled, with a very small expenditure of heat, only enough to raise its temperature from 2 to 5 degrees.

Mr. Hunter does not place much weight upon bacterial analysis; yet, with all its shortcomings and uncertainties, such an analysis gives us to-day the best known index for the sanitary condition of the water, and has brought about the late development and true understanding of the essentials and nonessentials of filtration. Without it we would have no measure of the sanitary value of a particular filter except the sick and death rates, which are affected also by other causes.

From the entire discussion it appears that no strong reasons have been brought out in favor of one and against the other of the two methods of water purification. Both methods have merits and a field of application, and their efficiency and cost do not differ very greatly in any case. In formulating their relative advantages, substantially as Mr. Fuller has done, we may say that the slow method generally has advantages for waters which are non-clay bearing and low in color, which are cases where the rapid method is generally less efficient and greater in cost. On the other hand, the rapid method, with obligatory use of a coagulant, has advantages for waters highly charged with submicroscopic particles of clay or which are highly colored, in both of which cases the slow method is less efficient.

As there is sometimes only a slight difference in the cost of the processes, or in the results of purification, the rapid method may sometimes be preferable solely because it requires a smaller investment of money at the outset, although a larger annual charge for operation, which in some cities, limited in their borrowing capacity, is an essential condition for the introduction of water-purification works.

APPENDIX—PART IV.

DAILY MEAN TEMPERATURES IN THE DISTRICT OF COLUMBIA.

U. S. Department of Agriculture,
Weather Bureau,
Washington, D. C., January 5, 1901.

Dear Sir: I beg to inclose herewith inclosed tables of daily mean temperature in this city during the months of December, January, February, and March for the last ten years.

This in answer to your request of the 3d instant.

Very respectfully,

H. E. Williams,
Acting Chief United States Weather Bureau.

Mr. Charles Moore,
Clerk to Committee on the District of Columbia,
United States Senate.

Mean monthly and daily temperature (degrees Fahrenheit) at Washington, D. C., during the months of January, February, March, and December for the last ten years.

Day.	1891.				1892.				1893.			
	Jan.	Feb.	Mar.	Dec.	Jan.	Feb.	Mar.	Dec.	Jan.	Feb.	Mar.	Dec.
1	36	52	24	32	41	40	36	40	41	44	40	40
2	47	46	24	38	47	48	30	44	38	39	40	28
3	32	48	30	42	24	44	35	42	26	48	42	40
4	24	22	35	56	24	39	47	41	20	26	28	32
5	27	26	29	46	29	27	40	34	22	24	26	25
6	29	40	27	46	32	20	39	33	22	32	36	28
7	28	44	32	49	30	30	44	50	22	40	41	34
8	32	44	36	38	29	49	43	68	22	28	44	32
9	32	36	42	43	31	37	47	40	22	30	52	32
10	37	40	40	42	27	35	42	38	12	46	43	45
11	44	34	41	43	28	40	26	32	12	36	38	39
12	40	35	45	44	34	24	44	30	21	34	46	49
13	34	41	47	44	39	25	36	34	14	32	45	30
14	38	37	30	45	51	36	30	42	8	40	48	26
15	36	37	28	51	30	45	31	40	16	52	32	47
16	38	54	46	50	21	30	28	38	8	52	28	56
17	33	68	32	31	19	26	26	38	14	27	30	35
18	32	60	42	25	30	37	28	37	8	28	32	34
19	32	36	48	32	33	44	31	33	22	36	40	39
20	38	37	40	37	17	46	34	31	20	17	40	30
21	42	48	40	38	24	39	30	28	18	22	60	36
22	50	43	42	45	30	45	29	25	17	28	46	44
23	42	37	52	60	40	41	62	25	36	36	39	48
24	37	44	52	62	37	36	42	20	30	40	50	48
25	36	58	48	50	45	38	44	24	42	42	56	50
26	37	36	38	54	22	44	44	18	38	35	49	38
27	47	26	36	35	21	42	42	18	44	36	42	34
28	43	32	35	34	32	29	44	24	32	34	38	42
29	46	......	42	44	41	36	45	22	40	......	34	56
30	48	......	48	42	36	......	41	23	36	......	45	36
31	38	......	44	38	38	......	40	24	38	......	51	38
Sums	1,155	1,161	1,195	1,336	982	1,071	1,170	1,026	761	984	1,271	1,191
Means	37.3	41.5	38.5	43.1	31.7	36.9	37.7	33.1	24.5	35.1	41.0	38.4

Mean monthly and daily temperature (degrees Fahrenheit) at Washington, D. C., during the months of January, February, March, and December for the last ten years—Cont'd.

Day.	1894.				1895.				1896.			
	Jan.	Feb.	Mar.	Dec.	Jan.	Feb.	Mar.	Dec.	Jan.	Feb.	Mar.	Dec.
1	36	38	42	42	24	24	61	38	32	46	45	24
2	34	32	46	44	22	30	36	51	34	46	36	24
3	37	40	46	39	28	12	41	30	36	36	32	24
4	46	34	45	39	28	25	46	25	14	36	32	26
5	50	22	54	34	19	10	30	31	14	38	36	38
6	42	34	61	38	36	6	42	28	15	46	39	46
7	41	38	56	40	53	8	44	37	24	44	50	48
8	33	44	52	44	41	6	47	42	30	38	38	50
9	31	45	47	44	30	10	38	36	30	40	40	50
10	33	50	52	38	40	18	52	26	33	39	42	51
11	38	44	57	42	44	18	36	28	32	36	34	42
12	30	32	52	46	38	20	35	24	36	36	26	40
13	34	32	49	44	9	22	44	20	36	44	24	52
14	44	28	47	44	24	24	43	24	30	38	26	46
15	42	33	36	43	34	28	31	34	29	46	32	34
16	50	28	53	45	36	28	34	39	30	33	34	35
17	38	33	49	45	36	36	34	33	35	14	33	37
18	38	52	57	36	30	30	43	42	39	20	36	36
19	45	60	68	40	40	37	44	50	34	31	50	38
20	32	43	58	40	30	34	36	58	34	13	35	32
21	39	37	51	40	40	41	38	56	36	18	36	31
22	43	30	67	45	39	32	36	48	36	28	50	31
23	47	30	56	34	34	30	38	52	38	45	37	29
24	45	18	43	32	26	28	42	56	48	50	26	20
25	26	17	42	44	22	43	54	52	43	34	35	24
26	24	31	30	28	34	38	46	56	43	38	49	30
27	30	35	27	29	33	42	45	39	36	38	36	27
28	28	36	32	17	32	54	45	36	36	42	39	24
29	36	......	40	14	26	......	44	36	38	50	54	30
30	35	......	42	22	26	......	45	38	44	......	62	44
31	41	......	50	28	25	......	46	36	38	......	52	42
Sums	1,168	986	1,507	1,160	979	734	1,296	1,201	1,033	1,063	1,196	1,105
Means	37.7	35.2	48.6	37.4	31.6	26.2	41.8	38.7	33.3	36.7	38.6	35.6

Day.	1897.				1898.				1899.			
	Jan.	Feb.	Mar.	Dec.	Jan.	Feb.	Mar.	Dec.	Jan.	Feb.	Mar.	Dec.
1	39	25	36	36	26	19	34	40	14	13	47	50
2	42	35	52	36	22	18	33	36	12	21	44	48
3	48	36	55	34	30	16	36	40	34	28	38	46
4	58	32	40	37	32	19	36	45	48	40	42	40
5	44	29	42	39	38	31	40	38	50	28	52	34
6	28	44	44	39	32	33	38	37	36	26	37	36
7	30	44	35	42	40	34	44	38	30	28	26	30
8	29	36	35	40	48	36	42	29	30	18	31	40
9	32	34	42	46	40	41	46	26	38	2	34	39
10	39	30	56	50	39	46	53	32	30	−2	38	42
11	34	32	46	58	36	51	56	38	19	−2	45	54
12	28	32	52	46	46	56	62	32	24	8	62	56
13	22	37	44	39	52	38	61	26	32	8	50	48
14	26	44	44	46	42	44	49	20	43	14	40	40
15	30	44	42	46	44	42	46	26	46	14	39	38
16	32	39	40	42	42	27	48	32	40	24	42	28
17	38	47	36	44	32	32	60	34	42	42	40	34
18	40	46	44	41	35	36	50	40	34	37	46	41
19	28	38	46	28	32	39	63	33	27	40	50	48
20	30	32	58	30	41	42	64	38	30	47	40	38
21	40	42	60	38	44	38	50	42	38	49	35	38
22	42	40	63	36	36	35	48	40	45	52	42	40
23	34	42	60	28	48	34	55	40	40	42	43	36
24	24	38	48	20	36	40	47	34	40	34	38	43
25	12	37	40	24	32	36	48	32	36	33	37	28
26	16	34	39	36	39	31	45	31	42	42	46	23
27	20	24	37	32	36	32	55	36	32	42	40	22
28	14	28	42	28	30	32	61	30	22	40	39	20
29	20	......	44	31	33	......	53	44	26	......	37	16
30	20	......	51	48	26	......	50	56	30	......	48	12
31	23	......	52	41	29	......	43	38	25	......	58	13
Sums	962	1,021	1,425	1,181	1,137	978	1,516	1,103	1,035	768	1,306	1,121
Means	31.0	36.5	46.0	38.1	36.7	34.9	48.9	35.6	33.4	27.4	42.1	36.2

Mean monthly and daily temperature (degrees Fahrenheit) at Washington, D. C., during the months of January, February, March, and December for the last ten years—Cont'd.

Day.	1900.			
	Jan.	Feb.	Mar.	Dec.
1	19	12	47	38
2	20	20	36	40
3	28	29	37	38
4	22	42	42	48
5	32	37	44	44
6	40	42	50	38
7	39	42	50	38
8	40	54	34	40
9	30	48	42	38
10	41	34	46	30
11	37	38	34	28
12	38	42	20	32
13	30	52	38	46
14	42	38	40	32
15	45	48	28	23
16	46	30	28	24
17	38	22	19	26
18	42	18	29	38
19	48	20	48	44
20	54	26	45	40
21	40	36	33	31
22	40	49	40	29
23	48	41	50	42
24	41	40	46	52
25	42	14	35	42
26	28	19	35	34
27	26	17	45	32
28	30	34	42	39
29	23	......	39	32
30	22	......	40	32
31	20	......	39	40
Sums	1,091	944	1,201	1,130
Means	35.2	33.7	38.7	36.5

INDEX.

O