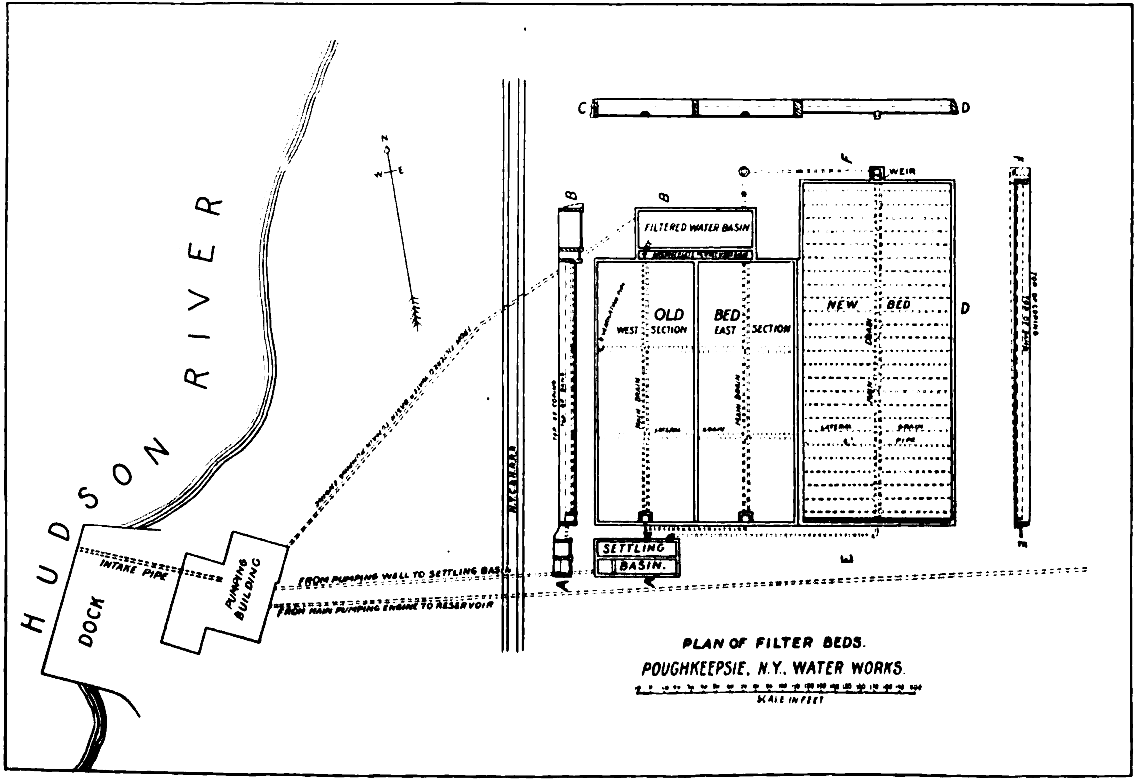

HUDSON RIVER
DOCK
INTAKE PIPE
PUMPING BUILDING
FROM PUMPING WELL TO SETTLING BASIN
FROM MAIN PUMPING ENGINE TO RESERVOIR
RAILROAD
FILTERED WATER BASIN
WEIR
OLD BED
WEST SECTION
EAST SECTION
NEW BED
SETTLING BASIN.
PLAN OF FILTER BEDS.
POUGHKEEPSIE, N.Y., WATER WORKS.
SCALE IN FEET

NEW ENGLAND WATER WORKS ASSOCIATION.

ORGANIZED 1882.

Vol. XII. June, 1898. No. 4.

THE OPERATION OF A SLOW SAND FILTER.

BY CHARLES E. FOWLER, SUPERINTENDENT AND ENGINEER OF PUBLIC WORKS, POUGHKEEPSIE, N. Y.

[*Read March 9, 1898.*]

Mr. President and Members of the New England Water Works Association: Having been honored with a request to present before you a paper on the "Operation of a Sand Filter" I will endeavor to comply by narrating some of the experiences met in the effort, during the past seventeen years, to render the water of a sewage polluted river fit for domestic use by means of such an appliance.

The sand filter of my experience is located at Poughkeepsie, N. Y., a city of about 23,000 inhabitants, situated on the east bank of the Hudson River, about midway between its mouth and the head of navigation.

The construction of its system of water works was commenced in 1869 and completed in 1872. The commission entrusted with the work investigated every probable source of supply and arrived at the conclusion, which subsequent years have fully justified, that the Hudson River afforded the only assurance of an ample volume within the limits of reasonable cost. Their consulting engineer was the late James P. Kirkwood, of Brooklyn, N. Y., who had but recently investigated the filtration systems of Europe in the interest of the city of St. Louis, Mo. The city of St. Louis did not adopt the filtration system, but it was applied to the water supply of Poughkeepsie under Mr. Kirkwood's supervision and in accordance with his plans.

The Hudson River, at Poughkeepsie, has a drainage area of about 11,500 square miles. Within this area is a total population of about 1,000,000 and an urban population of about 500,000. Fifteen miles above Poughkeepsie, on the west shore, is the city of Kingston containing about 23,000 inhabitants. Forty miles above, on the east shore, is the city of Hudson, containing about 10,000 inhabitants. Seventy miles above, on the west shore, is the city of Albany with about 96,000 inhabitants and, above Albany, a total urban population of about 300,000. A short distance above Poughkeepsie, on the same side of the river, is located one of the New York State Hospitals for the Insane. The patients and attendants make a population of about 1,500 or upwards. The institution is completely sewered and the outfall is in the Hudson River 2,797 feet above the intake of the Poughkeepsie water works. The ebb tidal currents flow directly from this outfall past the intake. The central sewer outfall of the Poughkeepsie system discharges into the river 6,124 feet south of the water works intake, and the flood tidal currents, from the outfall, pass far above the intake but nearer the center of the river. The width of the river at the water works intake is about 2,400 feet with a nearly uniform depth of 50 feet, the shores being quite bold.

The pumping plant is located at the edge of the river. The filtration plant, as originally constructed, is located about 500 feet easterly and about 28 feet above mean high water in the river. This plant consists of a settling basin 25 feet by 60 feet in plan and 12 feet deep. The bed is 200 feet long by 150 feet wide, divided longitudinally into two sections by a wall in the center. The walls are vertical, of rubble masonry, and 12 feet in height from coping to top of concrete bottom.

The filtering materials occupy one half the depth, comprising, beginning at the bottom, 24 inches of coarse broken stones, 6 inches two-inch gravel, 6 inches one-inch gravel, 6 inches one-half-inch gravel, 6 inches one-quarter-inch gravel and 24 inches of sand. A main drain, of dry rubble 2 feet by 2 feet in cross section, extends longitudinally through the center of each section and two lateral drains of same dimensions traverse each section at right angles to the main drain.

A gate is placed at the outlet of each main drain, opening into an intermediate chamber 6 feet wide by 88 feet long and 16 feet deep, from which the filtered water passes, over a weir, into a filtered water basin 88 feet long by 28 feet wide and 17 feet deep. From this basin the filtered water passes to the main pumping engine and thence to the distributing reservoir.

The distributing reservoir has a capacity of 12,000,000 gallons or a practical maximum supply of seven days.

The filter bed was put in operation in 1872. In 1874 an attempt was made to substitute subsidence in the distributing reservoir for filtration and the annual report for that year states that "The use of these beds has been abandoned except as may be occasionally required, when from the stage of the river the water may be unusually turbid." In the year 1875 the bed was in use about six months. In the year 1876 the annual report states they "Were in almost constant use." In the report for 1877 it is stated "The entire supply for this year was filtered." In the report for 1878 the volume filtered is the entire volume pumped, and it is added "The consumers accustomed to drink filtered water will accept nothing else, nor will they consider any circumstance, or complication of circumstances as offering any excuse for their nonuse." In the report for 1879 and 1880 the volumes filtered are the entire volumes pumped. The attempt to abandon the filter bed was not successful.

When I assumed charge of the works, in January, 1881, I found the bed not in use owing to a heavy coating of ice which rendered cleaning difficult. I at once caused the ice to be removed and the bed cleaned and put in operation. From that day I have not at any time seen the water of the river, judging from appearance alone, in fit condition for domestic use without some effort at purification. At that time bacteriological examinations of water supplies were unknown and but few chemical examinations had been made of the Poughkeepsie water; nevertheless I was impressed with the belief that that filter bed, in its best possible condition, was essential to the satisfactory quality of the water supplied to the city and upon that principle have based all action relative thereto, and have allowed no water to be supplied to the city without passing through it.

From various causes the river water has been much more heavily charged with mud and silt at all seasons, during the past eight or ten years, than previously. The normal rate of filtration, that is, the water pumped from the clear water basin, prior to 1893, was 4,500,000 gallons per acre per twenty-four hours. Since 1893 the rate has been 5,000,000 gallons, or over, per twenty-four hours, per acre. The head, or difference of level between the surface of the water on the bed and that in the intermediate filtered water chamber, required to obtain this rate varied according to conditions, from 1 foot to 6 feet and, in extreme cases, it has increased to 7 feet or even 8 feet or more. During the last six or eight years the endeavor has been to make 4 feet the maximum.

The word "conditions" has a very broad significance to one who has been obliged to meet them. To understand this it must be borne in mind that there was on the one hand, among the consumers of water, a lingering impression, occasionally expressed, that the filter was not in use, and, on the other hand, my firm conviction that the constant use of the filter was a sanitary necessity and a firm determination that no unfiltered water should be pumped to the city.

A feature of this bed was a set of six 6-inch cast iron pipes, in each section, one being set vertically over each end of the main drain and the outer end of each lateral. They were open at each end and extended from the top of the drain nearly to the top of the side walls. The purpose of these pipes, evidently, was to provide an exit for the air in the lower portion of the bed when it was being filled by water flowing on the top and thereby prevent disturbance of the sand. I discovered after a time, however, that a practical use was made of them not altogether intended by the designer. I noticed that after reaching nearly the limit of head the bed would sometimes seem to run for a disproportionate time without material increase.

Upon examination and inquiry I found that the night engineer, and not infrequently the day engineer, would, in order to delay the cleaning of the bed, allow the water to rise and overflow these ventilators thus admitting an appreciable volume of unfiltered water to the drains below and relieving the bed. This practice was prohibited at once and a close watch maintained to prevent its recurrence.

During the years 1881 to 1883 the water of the river was much clearer than I have seen it since and, consequently, the work of the bed was less. It was the practice to "clean" the bed by removing from the surface of the sand the silt left by the water in passing through. This was done whenever the bed failed to pass enough water under the given limit of head. The work was done by men with square pointed shovels who "skimmed" the slimy coat from the sand and deposited it in wheelbarrows which were wheeled by other men and deposited at the side of the bed. Still other men threw the deposit to the bank above. When the bed was new this was sufficient, but when I assumed charge it was not sufficient and it was the practice, after skimming, to loosen the sand with garden forks and then rake the surface over. This would not be done at every cleaning, but it soon became necessary to do it at every cleaning; and, after a time, even this was insufficient to enable the water to pass through readily but it would require from twelve hours to forty-eight hours after cleaning, for the bed to deliver the normal rate. In the construction of this bed no provision was made for drawing the water from above the surface of the sand when it became necessary to clean it. It was necessary, therefore, for the water to filter through before the work of cleaning could be commenced. In 1885 the condition of the filtering material had become such that forty-eight hours were required, after pumping ceased, to drain the sand so that cleaning could begin.

Prior to this time it had been the practice to replace the sand on the bed when a depth of about 6 inches had been removed in cleaning. Once only a depth of 10 inches had been removed. Below this depth the filtering material had not been disturbed since construction. Under the conditions mentioned it will be observed that a period of five days would be required from the time pumping on the bed ceased, in order to prepare for cleaning, to the time of obtaining normal flow from the bed after cleaning, namely, two days for draining, one day for cleaning and two days for obtaining normal flow.

At such a time if a storm, lasting two or three days, should occur to prevent cleaning the effect will be readily understood.

On the fourth day of January, 1886, a severe storm occurred as the bed was being cleaned and stopped the work when about two-thirds done. The rain was succeded by a muddy state of the river water previously unknown. In addition to this a period of severe cold set in which caused a large increase of consumption amounting in some days to nine-tenths of the full capacity of the pumping engine. The bed was filled to the coping and forced to its utmost, but was unable to filter the full amount of daily consumption and the balance overflowed through the ventilating pipes, before mentioned, unfiltered, rendering the water delivered to the city very roily and causing great complaint. By constant pumping it required nearly three weeks to store sufficient water in the reservoir to permit the pumps to stop long enough to clean the bed and, when it was again cleaned its efficiency was but little improved. The sand pores had become so filled as to render it, under the water pressure necessary, like a mass of compact loam and almost as impervious to water. It thus became necessary, at once, either to remove the sand entirely and replace it with new, or after removing the old sand to wash and replace it. The latter course was decided upon and, accordingly, the entire body of sand was removed, to the gravel, and washed and replaced. The work was commenced in the latter part of March and completed the latter part of October, the bed being in continuous use meanwhile. A thickness of from 1 inch to 2 inches of sand was removed at a time and washed and placed in a pile. Then another, equal thickness, and so on. When the sand had been removed to within about 3 inches of the gravel the east section of the bed was shut off, the remainder of the sand removed from it, and washed, and the full depth of the washed sand replaced on this section.

During this time all the water pumped to the city was filtered through the west section. The west section was then shut off and the process repeated there. When the work of replacing was completed on both sections the bed was, apparently, in as good condition as a new bed. From this time the sand removed in cleaning, and washed, was not replaced as frequently as heretofore.

No sand was replaced until 1890 when, the sand remaining on the bed, about 6 inches in depth, was removed and washed and all was replaced as before. In 1893 the sand removed and washed during the previous three years was replaced on the bed together with about 400 cubic yards of new sand. In 1894 about 300 cubic yards of new sand was added and about the same quantity of old sand replaced making a depth of about 7 inches. In 1897 all of the sand on the bed was removed and wasted and new sand to the depth of 30 inches put on the bed.

One of the worst experiences occurred during the month of April, 1895. A heavy rain, on the 8th and 9th, brought down a charge of red mud and silt which stopped filtration. The pumps were stopped on Thursday morning, the 11th, with nearly 14 feet of water in the reservoir. Allowing forty-eight hours for draining the bed we expected to clean on Saturday. On Saturday, however, it rained heavily; also a part of Sunday, so that no cleaning could be done until Monday, the 15th; but, even then, the bed was not sufficiently drained, owing to the rains of Saturday and Sunday. A force of men was put on and urged to their utmost and the bed cleaned and pumping to the reservoir started at seven o'clock in the evening, with less than 4 feet in the reservoir. Since it is impracticable to draw from the reservoir below 3 feet we had but 1 foot available, or twelve hours supply, when pumping began. The river being still very muddy we were compelled to stop pumping on Saturday morning, the 20th, after running four and one-half days. The bed was cleaned on Monday, the 22nd, and pumping began with less than 3 feet available in the reservoir. We were again obliged to stop on Saturday morning, the 27th, after running four and one-half days and clean on Monday, the 29th, starting the pumps with less than 3 feet available in the reservoir, so that three times during that month, we were in such condition that a rain storm of twenty-four hours would have compelled us to pump unfiltered water. We were obliged to clean the bed again on the 6th of May, making four times in five successive weeks, an experience unequaled before or since.

One of the great hindrances to the operation of this bed has been the growth of a species of green, filamentous, algæ on the surface of the sand. It does not develop in every year nor at the same time in the year. It sometimes begins in the latter part of May and sometimes not until September. It usually disappears with heavy frost. Its development begins in small round patches on the surface of the sand and continues with greater or less rapidity, according to temperature and condition of the water, until the entire surface is covered as with a blanket and the passage of water is entirely stopped. It has been known to develop on the clean sand and entirely stop filtration within seven days from cleaning. An essential condition for its rapid growth is clear sunlight. It will not develop in the dark and very little in the shadow of any object. All the basins, as constructed, were open to the sunlight. Much trouble was experienced from the growth of the same species of algæ in the clear water basin. In 1891 this basin was covered so as to exclude the light and no trace of algæ has been seen in it since. When filtration is stopped from this cause there is no alternative but to drain the bed and clean in the usual way. The algæ cannot be removed under water. When the bed is drained and the algæ is allowed to dry it will cohere and roll up like a piece of paper. But touched with a shovel or other appliance for its removal, under water, it instantly flies in all directions in minute particles which immediately settle upon the sand and commence development vigorously on their own account. It has sometimes happened that the delivery of the bed has commenced to decrease, from algæ growth, within forty-eight hours after its removal. These extreme cases are, however, of rare occurrence. As this development always occurs during one of the seasons of greatest consumption of water it has sometimes taxed us to the utmost to maintain the supply of filtered water. I have never observed that its presence imparted either odor or taste to the filtered water.

During the last eight or ten years the frosts of winter have greatly hindered the maintenance of the bed in proper working condition. As before mentioned the river water has been much more turbid during this later period and it has seemed much more difficult to catch a thaw at the right time, and of sufficient duration, to enable the bed to be properly cleaned. In order to clean in the winter the first operation is to remove the ice. This will vary from 10 to 20 inches in thickness and we have removed some 28 inches thick, though that thickness is very seldom attained and then does not extend over the entire surface. In removing the ice the bed is filled to the coping, and the ice cut in pieces and hauled out by men. The operation requires about a week, more or less, depending upon the thickness of ice and the number of men employed. When the ice has been removed, pumping is stopped and the bed drained. If we have struck a favorable thaw, and, if during the forty-eight hours or more required to drain the bed no frost occurs and none occurs until the bed is cleaned, all is well and the bed will probably be in good order. It, however, more frequently occurs that 2 or 3 inches of ice forms while the bed is being drained.

We have sometimes removed the ice and drained the bed without frost, and early in the morning of the day of cleaning, a sudden drop in temperature occur that would freeze the sand and stop the work before it was completed. It sometimes happens that we are unable to foresee the failure of the bed in time to remove the ice owing to a sudden change in the character of the river water. In such cases an effort is made to clean by lowering the ice on the sand, breaking it up, turning over the pieces and cleaning underneath. This is very unsatisfactory and only undertaken in emergencies. A sudden drop of temperature will sometimes stop even this operation before it is completed. In February, 1893, the bed suddenly failed with about 10 or 12 inches of ice on the surface and low water in the reservoir. It was impossible to continue and the bed was drained and the ice lowered to the sand. As much ice as possible was removed from one section while the bed was being drained. The work of cleaning was commenced, but before two-thirds of the section from which the ice had been removed, had been cleaned, the sand froze to such an extent that the work was stopped. There were but 5 feet of water in the reservoir and I decided to turn on the water and get what we could from the bed, fully expecting to be compelled to pump direct from the river within the next twenty-four hours. To my surprise, on going to the bed the next morning, I found it delivering its normal flow. The ice, on the section from which none had been removed, had settled evenly upon the sand and the severe cold had frozen the sand to the under side so that when the ice arose with the inflowing water it carried about one inch of sand from the entire surface of that section with it. It is not a method of cleaning to be recommended but it delivered us at the only time in my experience that the elements were in complete mastery. It is very rare, however, that all the conditions would be favorable to such action.

The under surface of the ice must be even, the surface of the sand even, the thickness of the ice sufficient to lift the sand and not enough to protect the sand from cold and the cold intense enough to freeze the sand under the ice. All of these conditions must occur together, which is very seldom the case.

In cleaning the bed, as before described, from one-quarter inch to one-half inch of sand was removed under normal conditions. In cases of frost the depth would be increased, sometimes to 2 inches or more. The labor required, under normal conditions, was one man for each 150 square feet of surface cleaned per hour, including wheeling and elevating to bank. As the sand is in use it becomes, in time, coated with a gelatinous film, throughout its depth. The finer silt also extends, in continually decreasing quantity, for a considerable depth below that removed by cleaning. The pressure to maintain a given flow, with the surface clean, gradually in creases. Consequently, the pressure throughout increases, until, after a sufficient time, the water will not pass through even after cleaning and it becomes necessary to loosen the sand. This is done by the use of garden forks, as before mentioned, which are pressed into the sand a sufficient depth, vertically, and the top of the handle drawn backward sufficiently to loosen the sand in front of it.

At first the forks need enter but 3 or 4 inches but the necessary depth gradually increases until the full length of the fork is used and even this is not sufficient and the entire body of sand must be removed and washed or renewed as was the case in 1886. After the sand is loosened the surface is raked over evenly with a garden rake. Forking and raking requires about one man to each 500 square feet of surface per hour.

Under the foregoing conditions of sand and pressure, the sand will sometimes become so compact and hard that a considerable force is required to press the fork into it, and the tramping of men on the surface makes no impression. The time required for a filter to attain the condition referred to as occurring in 1886 would, of course, depend upon the rate of filtration and the character of the applied water. The period of constant use had been about ten years previous to 1886. Subsequent to that the sand was all removed and replaced at the end of four years, in 1890, before such condition had attained. Subsequent to that the entire body was not removed until 1897, a period of seven years, when the same conditions occurred and it would have been impossible to complete the year. The most favorable conditions for cleaning are fair, mild weather, not cold or hot, with the sand slightly moist. In the heat of summer, under a glaring sun, the sand sometimes becomes baked to a depth of nearly an inch compelling the removal of a depth greater than would be necessary, were this not the case, thus increasing the expense. Greater care is required in cleaning as the bed grows older. The shovels should be lifted on the return stroke and not drawn backward on the sand, particularly, if the sand is moist. When the bed is to be forked and raked this is not essential. When the bed is new the only effect of a shower of rain, during cleaning, is to delay the work while the shower lasts, but if the bed has become clogged to any extent, even if it has not been necessary to loosen with forks, a heavy shower will so compact the surface as to necessitate recleaning the portion that has been cleaned or loosening it with rakes. If heavy rain falls upon a portion that has been forked and raked it will be necessary to repeat both the forking and raking before the delivery will be satisfactory. The effect of a fall of snow, during cleaning, is to increase the labor and expense and, if the snow is moist or melting, and the sand at all clogged, will require the removal of a greater thickness of sand.

In 1886 two bridges were constructed, one spanning each section of the bed. These bridges were movable, laterally, lengthwise of the bed, upon rails laid upon the coping. From the bridges platforms were suspended a little above the surface of the sand. In cleaning the men stood upon the platforms, scraped the surface of the sand and deposited the scrapings upon the platforms.

When about one-third of the bed had been cleaned the bridge, with its load, was moved to one end of the bed and the load thrown upon the bank. By this method there was no wheeling or tramping, whatever, upon the sand. One man, by this process, would clean 240 square feet of surface per hour, under normal conditions. For two or more years all the cleaning was done by two men. One section of the bed being used while the other was being cleaned.

The two men would clean one section in three days. This method was abandoned chiefly because it was impracticable to so regulate the draft upon the section in use as to avoid overworking it and hastening its clogging. There was a material saving in cost of cleaning by the use of these bridges, but in the construction of the new bed, in 1896, owing to the increased cost of construction necessary for their use, this feature was omitted. In 1897, the timber work of the bridges having decayed to such an extent as to require renewal, their use was discontinued for the sake of uniformity of operation and a better appearance of the plant.

We have now returned to the original method of cleaning.

Several methods have been used for washing sand. The one in use when I assumed charge was to cause the sand to pass over two inclined troughs, each about 12 feet long.

Near the upper end of the first trough the sand was met by small streams of water issuing from a perforated pipe under a pressure of about 100 pounds per square inch. The inclination of the troughs was such that the water carried the sand down and the force of the small jets, with the attrition of the particles during the flow, separated the silt from the sand. The water and sand were discharged into a box or tank, the sand settling to the bottom and the water flowing off at the top carrying the silt with it. Between the lower end of the upper trough and the upper end of the lower one, was a screen through which all the sand passed on its way down. Four men were employed who washed less than 3 cubic yards per day at an average cost of about $2.38 per cubic yard. The washing was very efficient. This system was changed by increasing the number of troughs and dispensing with the services of two men thereby reducing the cost to about $1.47 per cubic yard. The work was carried on from April to December. In 1886 a trough 240 feet long was constructed and an additional supply of water taken from the settling basin. Five or six men were employed and about 2,000 cubic yards washed from March to September, at a cost of about 61 cents per cubic yard.

This method was continued, with a less number of men, depending upon the quantity to be washed, for several years. The work done by this arrangement was not altogether satisfactory, and, in 1892, a machine was put in operation consisting of a circular tank in which was a vertical, hollow shaft with perforated arms projecting horizontally from the bottom. This shaft was made to revolve slowly by means of a water motor, the water from which passed down through the hollow shaft and out through the perforated arms. The sand was placed in the tank and agitated by the revolving arms while the water flowed up through the sand and off at the top of the tank carrying away the sand and silt. The sand, when sufficiently washed, was discharged through a valve at the bottom of the tank. The work done by this machine was very satisfactory except that it was difficult to separate the leaves and algæ, particularly the latter. The cost, by this method, was about 64 cents per cubic yard. In 1895 and 1896 a single jet washer was used. By this plan the cost was reduced to about 54 cents per cubic yard. For several years the work has been done mainly by two regular employees, together with other work, and the quantity washed in a given time, with a given quantity of water, would depend upon the diligence of the men. The figures given are for ordinary work. In November, 1897, in washing and replacing the sand removed from the new bed, since it was put in operation in December, 1896, a double jet of much greater capacity was used. The sand and water from the first jet was discharged into a tank from which the water and silt flowed off at the top while the sand passed through a valve in the bottom into the second jet. From this jet the water and sand were transported about 130 feet to a tank over one corner of the bed. The water and remaining silt flowed off from the top of this tank and the sand discharged through a valve in the bottom on the bed.

A little over five cubic yards of sand were washed and delivered on the bed, per hour, by this means. The total cost of labor at eighteen cents per hour, for washing and delivering on the bed, was 24 cents per cubic yard. Cost of water three cents per cubic yard. Total 27 cents per cubic yard. The quantity of water used was eighteen times the quantity of sand. The work was well done.

The water used was filtered water taken from the force main.

The total quantity of sand washed was 325 cubic yards. The number of hours worked was sixty.

No examinations, chemical or otherwise, for the determination of the efficiency of the bed, were made for several years after its construction. In November, 1877, an analysis was made by the late Prof. W. R. Nichols of the Massachusetts Institute of Technology. Twelve years later, in November, 1889, an analysis was made by Dr. T. M. Drown, then of the above mentioned institute; also one in 1891. The results of these three analyses, in parts per 100,000 of albuminoid ammonia, before and after filtration, also the percentage of reduction of albuminoid ammonia, of free ammonia and total solids, are as follows:

Date.	Albuminoid Ammonia. Parts in 100,000. Unfiltered Water.	Filtered Water.	Percentage of Reduction. Alb. Am.	Free Am.	Tot. Sol.
November, 1877	.0197	.0139	29	30	24
November, 1889	.0198	.0130	34	68	22
November, 1891	.0153	.0100	35	100	28

During the fourteen years from November, 1877, to November, 1891, the materials composing the bed had not been disturbed except by washing and replacing the sand. No new sand had been added. These analyses show no deterioration in efficiency, but rather, a material increase, during that period.

The results of a series of six analyses, made by Dr. Drown in June, 1893, showed a percentage of reduction by filtration, as follows:

Albuminoid ammonia	38.2	per cent.
Free ammonia	97.	"
Nitrogen, as nitrites	96.	"
Oxygen consumed	29.	"
Nitrogen, as nitrates (increased)	40.	"

Ordinarily, little or no effect is produced upon the color of the river water by passing through this filter, though one analysis by Dr. Drown, showed a reduction of discoloration as great as 60 per cent as the result of filtration.

Bacteriological examinations, three in number, made by Dr. Drown in November and December, 1891, showed percentages of removal, highest 97.7 per cent, lowest 92.4 per cent, average 94.9 per cent. An examination by Dr. Drown in January, 1892, showed percentage of removal 82.1 per cent; and in December, 1892, 91.8 per cent.

In 1895 eight bacteriological examinations were made by D. B. Ward, M. D., of Poughkeepsie, from April to December, showing an average removal of 93.8 per cent, with maximum of 98.6 per cent in June and minimum of 85.9 per cent in October. On February 14, 1896, an examination by Dr. Ward showed only 31 per cent removed; and in February 24th, but 37 per cent removed.

The death rate from typhoid fever has varied materially during the past 18 years, as will appear from the following table showing the population, in each year, from 1880 to 1897, both inclusive, as estimated from the ratio of increase in the census returns of 1890 over those of 1880, together with the number of deaths, from that cause in each year, and the number per 10,000:

Year.	Estimated Population.	No. of Deaths from Typhoid Fever.	No. of Deaths per 10,000.
1880	20,200	12	5.9
1881	20,400	10	4.9
1882	20,600	22	10.6
1883	20,800	9	4.3
1884	21,000	11	5.2
1885	21,200	11	5.1
1886	21,400	4	1.8
1887	21,600	5	2.3
1888	21,800	5	2.2
1889	22,000	6	2.7
1890	22,200	6	2.7
1891	22,400	9	4.
1892	22,600	13	5.7
1893	22,800	22	9.6
1894	23,000	15	6.5
1895	23,200	10	4.8
1896	23,400	5	2.1
1897	23,600	11	4.6
			Average. 4.72

There appears to be no definite relation between the condition of the filter bed and the death rate from typhoid fever, except that the greatest number of deaths, from this cause, occur from January to April, when the efficiency of the bed is the lowest. In 1886 the condition of the bed was, certainly, the worst of any year of the eighteen under consideration, yet, the rate, 1.8 per 10,000, was the lowest of any year in that period. It is probable that the bed was not in as good order in February, 1893, when the rate was 9.6 per 10,000, as in 1892 or 1894, when the rate was much lower; it was certainly, however, in no better condition in 1886 than in 1892 and 1894. Of course the want of frequent bacteriological examinations deprives us of accurate knowledge, but these are the facts so far as they can be known without them. During the last six or eight years a higher rate of filtration has prevailed owing to increased leakage in the filter basin and the introduction of a pumping engine of greater capacity.

In 1896 an additional filter bed was constructed having an area equal to the old bed, thus doubling the filtering area. This bed consists of a single basin having a length, inside of walls, of 260 feet and width of 114 feet. Total area 29,640 square feet. The clear depth of the basin from the top of the coping to the surface of the concrete bottom, is 10.3 feet. This bed adjoins the old bed on the east and the side walls consist of rubble masonry laid in Rosendale cement mortar, faced with a brick wall laid in Portland cement mortar. The inner faces of the walls are vertical. The bottom is of concrete.

A main drain, of brick masonry, sunken below the surface of the concrete, extends longitudinally through the center of the basin. Lateral drains of 6-inch tile pipes are laid on the concrete bottom at right angles to the main drain, and 10 feet and 3 inches apart between centers. These lateral drains are covered with 2-inch broken stone. The spaces between the laterals are filled, to a depth of 10 inches, with 2-inch broken stone and 1-inch gravel. Above this is a layer of one-half inch gravel 8 inches thick, and above this, a layer of one-quarter inch gravel 6 inches thick; the total thickness of the gravel layers being 24 inches. Above the gravel is the filtering sand 31 inches in thickness. The water for this bed is taken from the settling basin of the old bed. The main drain discharges into a delivery well, 6 feet by 8 feet, on the outside of the north wall of the basin. In this well is a weir of cast iron, sliding in vertical grooves, by means of which the working head may be regulated. From this well the filtered water is conducted to the filtered water basin of the old bed.

The supply and delivery are controlled by gates so that the bed may be cut off at will. The sand and gravel, for this bed, were obtained from a bank at Hempstead Harbor, on Long Island.

They were screened and washed at the bank and delivered along side our dock on scows from which they were delivered to the bed by carts. Water was let on this bed on December 17th, 1896. From the beginning of 1897, nearly all the work devolved upon this bed owing to the clogging of the old one.

About the first of June, 1897, the old bed was shut off and the work of repair commenced. The sand remaining thereon was entirely removed and wasted. The gravel and broken stones, forming the lower portion of the bed, originally 4 feet in depth, was excavated around the outer wall, to the bottom, of sufficient width to permit working. The joints of the rubble masonry composing the side walls were cut out and filled with mortar composed of Trinidad asphalt and sand, applied hot and driven in with hammers. A trench about 3 inches wide and 4 inches deep was cut in the concrete bottom, next the wall, which was filled with the same mortar rammed solid. The surface of this trench, and the bottom for about 2 feet from the side walls, also the side walls, were covered with a thin coat of melted asphalt.

Rainy weather in July and August greatly hindered the work, not only by loss of time during the storms but by the time required, after the storms, to render the joints sufficiently dry to receive the asphalt mortar. This was, in large measure, overcome by the use of pulverized quick lime, which absorbed the moisture and imparted sufficient warmth to the joint to enable the mortar to adhere. After the side walls were completed the broken stones and gravel were replaced. New sand was then placed on the entire bed to the depth of 2½ feet. It was found that the stones and gravel had settled about 6 inches.

The different grades of gravel had become mixed to a considerable extent. Sand was found among the broken stones at the bottom.

Whether this intermingling was due to carelessness in the original placing of the materials or to the operation of the bed is not known.

The sand placed on the new bed, before described, although screened and washed at the bank, still contained a sufficient quantity of loam to impart turbidity to the filtered water, in greater or less degree, for nearly six months after it was put in service. The new sand placed on the old bed came from the same bank and was screened and washed in the same manner. In order to avoid the difficulty experienced with the new bed the sand was transported from the scow to the bed by means of a hydraulic jet. An ejector was so placed at the dock as to reach the center of the scows and to raise and lower with the tide.

The ejector was supplied with water from the force main at the engine house. A line of 4-inch cast iron pipe extended from the ejector to the top of a tank on the division wall at the center of the old bed. The sand was shoveled into a hopper attached to the ejector on the scow and the water and sand delivered into the tank on the wall. The water, carrying with it the loam and silt, flowed off from the top of the tank and the sand was discharged, through a valve in the bottom, on the bed, perfectly clean, having been thoroughly rinsed in the transfer. The length of the 4-inch pipe, from the ejector to the tank, was 630 feet. Total lift, from scow to top of tank, 30 feet. Diameter of jet 1 inch. Diameter of nozzle 1½ inches. Water pressure at jet about 110 pounds per square inch. Quantity of sand discharged 8 cubic yards per hour. This bed was put in service about the first of October, 1897, and its operation has been most satisfactory from the first.

The sand used in the original construction of the old bed was in two grades, the coarser having been obtained on the bank of the Hudson river at Roa Hook, about 30 miles south of Poughkeepsie. The finer was obtained in New Jersey. In the years of use these two grades have become intermingled somewhat with each other, and with additional sand purchased.

The following table shows approximately the mean diameters of the grains of sand comprising:

First, the lower portion of the old bed, which was removed in 1897.

Second, the upper portion of the old bed, which had been previously removed.

Third, the new sand placed on the old bed in 1897.

Fourth, the sand used in constructing the new bed in 1896.

	1 m. m. and above. Per cent.	.5 m. m. to 1 m. m. Per cent.	.25 m. m. to .5 m. m. Per cent.	.05 m. m. to .25 m. m. Per cent.
Old sand removed from old bed in 1897	37	19	41	3
Sand from upper portion of old bed	12	13	53	22
Sand placed on old bed in 1897	25	19	50	6
Sand used in new bed in 1896	24	18	44	14

The old sand removed in 1897 was considerably worn, the grains apparently rounded by the sharp corners having been broken off.

The difference in size between the sand placed on the old bed in 1897 and that used in the new bed in 1896, is due to the washing of the former which removed a considerable portion of the finer sand. The coarser grade of the old sand was very irregular in size; some grains being 6 m. m. or 8 m. m. in diameter, showing that gravel had become mixed with it. The coarser grade of the other sands was quite uniform.

Since December, 1897, both beds have been in operation. Six bacteriological examinations have been made by Dr. Ward of Poughkeepsie showing the following results :

Date.	Source of Water.	Colonies per cubic c. m.	Per cent. removed.
Dec. 23, 1897	Settling basin,	14,160	
"	Effluent, old bed,	166	98.8
"	" new bed,	872	93.
Jan. 6, 1898	Settling basin,	17,850	
"	Effluent, old bed,	132	99.26
"	" new bed,	348	98.02
Jan. 19, 1898	Settling basin,	27,000	
"	Effluent, old bed,	480	98.2
"	" new bed,	900	96.6
Jan. 27, 1898.	Settling basin,	17,850	
"	Effluent, old bed,	52	99.70
"	" new bed,	60	99.66
Feb. 4, 1898	Settling basin,	13,950	
"	Effluent, old bed,	144	98.96
"	" new bed,	88	99.36
Feb. 24, 1898	Settling basin,	19,600	
"	Effluent, old basin,	690	96.47
"	" new basin,	298	98.47

Average old, 98.56 per cent; average new, 97.52 per cent; average all, 98.04 per cent.

The old bed was cleaned on November 13th, and from that date until December 1st, all the water was filtered through it, the river water, meanwhile, being very roily. Since December 1st more water has been drawn from the new bed than from the old. The next cleaning of the old bed was on March 1st, 1898. The new bed has not been cleaned since December 1st, 1897.

The total cost of the original plant, as given in the reports of the department, including land, pumping plant, wells, etc., was $75,-694.82. Deducting the cost of land, pumping engine, pumping well and supply and delivery pipes leaves the cost of the bed proper with settling and clear water basins, about $62,000.00.

The cost of the new bed, exclusive of land, was $28,898.70.

For 20 years, from 1877 to 1896 both inclusive, the total volume filtered, exclusive of leakage, was 11,848,600,000 gallons. The total expenditures, in connection with the bed, during that period, was $35,468.37, which gives for the average cost of maintenance and operation, for a period of 20 years, $2.99 per million gallons.

DISCUSSION.

MR. HAZEN. I think that we are all greatly indebted to Mr. Fowler for his paper and the information which it contains. I was fortunate enough to find out several years ago that Mr. Fowler had a remarkable fund of experience and observation upon the subject which he has treated in his paper, and that he was disposed to give others the benefit of his experience. I am particularly glad that he has been able to present some of this material to the Association, and to put on record facts in regard to the first sand filter plant in America, which will be of the greatest value to all interested in the purification of public water supplies.

Mr. Fowler has been operating sand filters for a much longer period than anyone else in America. He has filtered, I think. a larger amount of water than anyone else in America, and the results that he has gotten are certainly very valuable and instructive to us, and the work of the plant as a whole is very suggestive. Mr. Fowler has labored under numerous difficulties. His filtering area has been at times inadequate; the filters were constructed a long time ago, on filled ground, and unequal settlement has resulted in cracks and in a loss of water and also in the flow of the water from one side to the other, which has seriously interfered with the operation of the plant; but in spite of all these difficulties, he has been supplying filtered water for all these years and with admirable results.

He has given you some statistics as to typhoid fever in Poughkeepsie, but to fully appreciate the significance of those statistics one needs to compare them with the corresponding statistics for other cities up and down the river, which have been using the water without filtration, and these other cities have had rates right along several times as high as Poughkeepsie has had, and when there have been epidemics in these other cities Poughkeepsie has remained pretty nearly free from typhoid fever.

I have a tabular statement of the operation of some sand filter plants giving the amount of water filtered for a year, the areas of the filters, the average rates, the area of filter surface cleaned, and the water filtered per acre between scrapings. It is the data one likes to have when one is figuring on the area of filters to be provided, and the cost of operation.

RECENT FILTER STATISTCS.

Place.	Year ending in	Quantity filtered Million gallons.		Area of filters. Acres.	Av'r'ge daily yield. Million gals. per acre.	Filter area cleaned acres. One year.	Million gallons per acre filtered between scrapings.
		For year	Daily Average				
Altona	Mar. 1896	1,730	4.75	3.08	1.55	48.5	
Amsterdam	Dec. 1894	3,720	10.20	10.37	0.98	139.0	27
Ashland	Feb. 1897	398	1.09	0.50	2.18	4.83	83
Berlin	Mar. 1896	13,000	35.60	25.10	1.42		
Bremen	Mar. 1896	1,220	3.34	3.21	1.04	32.5	38
Breslau	Mar. 1896	2,960	8.10	5.12	1.58	40.0	74
Brunswick	Mar. 1896	840	2.30	1.48	1.56	13.3	63
Copenhagen	Dec. 1895	2,330	6.40	2.88	2.22	44.7	52
Dordrech	Dec. 1894	365	1.00	0.56	1.79		
Frankfort on Oder	Dec. 1895	310	0.85	0.37	2.38	2.9	107
Hamburg	Dec. 1895	11,700	32.10	34.00	0.94	275.0	43
Hudson	Dec. 1895	535	1.46	0.74	1.98		
Konigsburg	Mar. 1896	1,085	2.97	2.70	1.10	35.0	31
Lawrence	Dec. 1896	1,101	3.02	2.50	1.20	30.0	37
Liverpool—							
Oswestry	Dec. 1896	4,460	12.30	4.90	2.52	100.0	45
Rivington	Dec. 1896	4,060	11.10	6.02	1.84	58.0	70
Total	Dec. 1896	8,520	23.40	10.92	2.14	158.0	54
London (rivers only)	Dec. 1896	72,482	198.00	123.75	1.60		
Lubeck	Mar. 1896	1,600	4.38	1.40	3.13	24.4	66
Magdeburg	Mar. 1896	1,950	5.35	3.76	1.42	65.0	20
Mt. Vernon	Dec. 1896	608	1.66	1.10	1.51	9.2	66
Posen	Mar. 1896	346	0.94	0.70	1.35	10.4	33
Poughkeepsie	Dec. 1896	664	1.82	0.68	2.68	9.0	73
Stettin	Mar. 1896	1,030	2.83	2.26	1.25	15.5	66
Stockholm	Dec. 1895	2,375	6.50	2.78	2.33	70.0	34
Stuttgart	Mar. 1896	1,220	3.34	1.66	2.04	17.7	69
Zurich	Dec. 1896	2,360	6.45	1.66	3.88	30.0	79

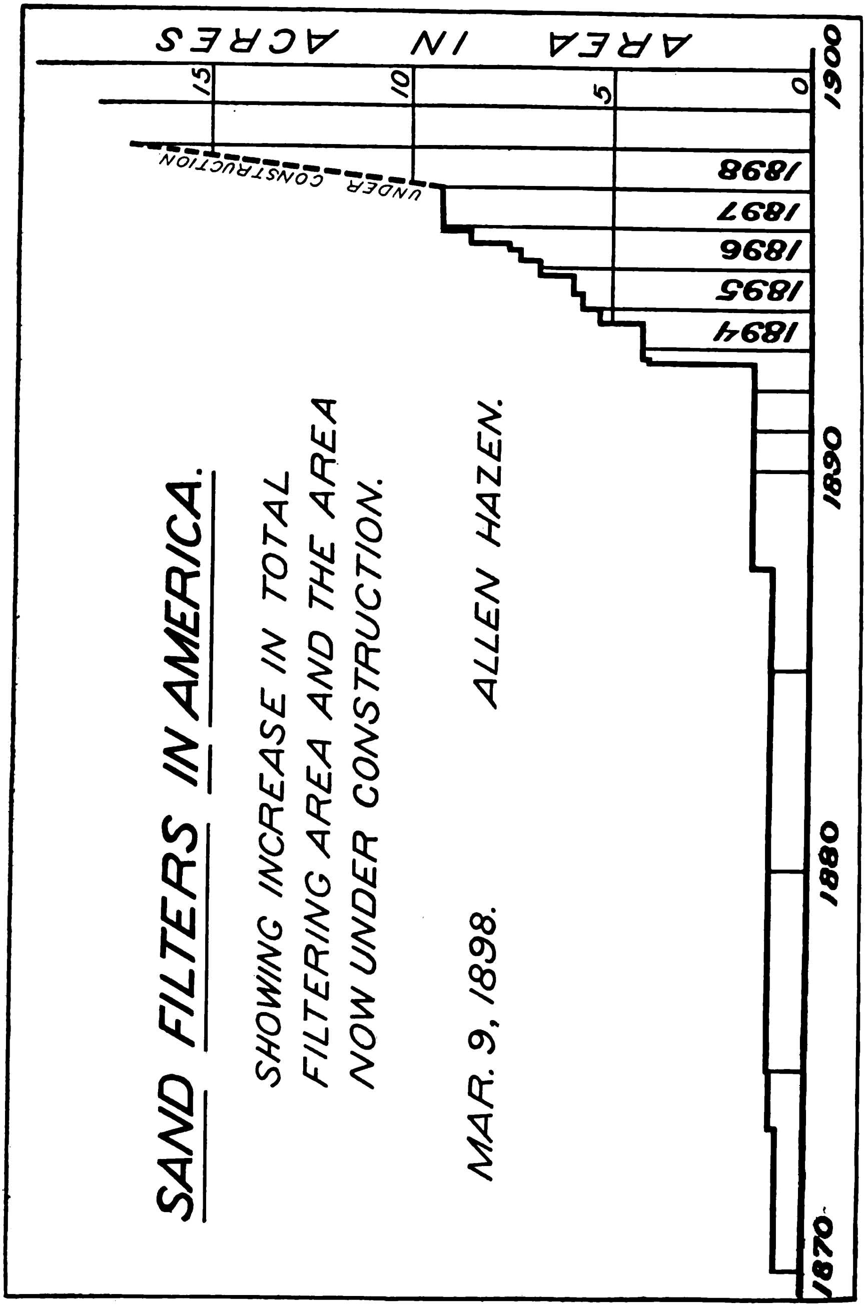
I have also a table of sand filters now in use in the United States and Canada, with their approximate areas, and the dates when they were built, and a list of filters under construction.

SAND FILTERS IN AMERICA.

Place.	Area, Acres.	Built.	In Operation.	Total Area to Date.
Poughkeepsie N.Y., (original)	0.68	1872		0.68
Hudson, N, Y., (original)....	0.21	1874		0.89
St. Johnsbury, Vt...........	0.05	1875(?)		0.94
Hudson, addition...........	0.53	1888		1.47
Nantucket, Mass............	0.11	1892	Aug. 8, 1893	1.58
Lawrence, Mass.............	2.50	1892-3	Sept. 20, 1893	4.08
Ilion, N. Y	0.14	1893	Sept. 30, 1893	4.22
Mt. Vernon, N. Y............	1.10	1894	Aug. 1, 1894	5.32
Grand Forks, N. D	0.42	1894	Jan. 4, 1895	5.74
Milford, Mass...............	0.25		1895	5.99
Victoria, B. C...	0.83		1895	6.82
Ashland, Wis................	0.50	1895	Feb. 5, 1896	7.32
Lambertsville, N. J	0.28		May 4, 1896	7.60
Far Rockaway, N. Y....	0.92	1896	July 1, 1896	8.52
Poughkeepsie, addition.....	0.68	1896	Dec. 17, 1896	9.20
Red Bank, N. J........... .	0.03	1897	June 5, 1897	9.23
Under Construction.				
Somersworth, N. H.....	0.50			
Nyack, N. Y	0.39			
Albany, N. Y..	5.70			
Rock Island, Ill............	1.20			

A diagram herewith presented shows the aggregate filter area up to the various dates mentioned, starting with the Poughkeepsie plant back in 1872, followed by the original plant at Hudson, built in 1874, and the little plant at St. Johnsbury, and by the others. The first great increase came with the Lawrence filter and since that time the increase has been rapid. There are something over nine acres of sand filters in use in North America at the present time, and enough more filters are under construction to bring the total area up to something over seventeen acres. The increase has practically all been in the last five years.

I want to ask Mr. Fowler, as to the behavior of the filtered water in his open distributing reservoir. With surface waters open distributing reservoirs are generally considered as good or better than covered reservoirs. With ground water supplies it is considered necessary to exclude the light, to prevent objectionable vegetable


SAND FILTERS IN AMERICA.
SHOWING INCREASE IN TOTAL FILTERING AREA AND THE AREA NOW UNDER CONSTRUCTION.
MAR. 9, 1898.
ALLEN HAZEN.
AREA IN ACRES
0
5
10
15
UNDER CONSTRUCTION.
1898
1897
1896
1895
1894
1870
1880
1890
1900

growths. Now filtered river water in its characteristics comes between ground water and surface water, and it has been pretty commonly thought in some places that it was necessary to store filtered water in covered reservoirs. I would like to have Mr. Fowler state, if he will, whether he has observed any objectionable tastes or odors from the growth of organisms in his distributing reservoirs; and, if there is anyone here from Lawrence, who knows about the Lawrence conditions I wish we could have some information in regard to Lawrence in that connection, and, also, as to whether there is any difference between the new high service reservoir at Lawrence, which is covered, and the old reservoir, which is open?

MR. CLARK. In regard to that matter I will say that at Lawrence they have had in the open reservoir a growth, one or two summers since the filter was put in, of fresh water sponge, which has caused a slight taste and odor in the water, but the sponge grew there before the water was filtered. That is the only thing we have noticed at all. In the stand-pipe the past year there has, of course, been no growth, so far as we could observe, and there was only a very slight growth in the reservoir last summer, nothing that anybody noticed except in a few houses.

There is one thing Mr. Fowler spoke of I should like to mention, and that is the growth of this algæ on the surface of the filter. His filter, I understand, is a continuous filter, and is covered with water except at times of scraping. At the experiment station we have had in operation for some years both continuous and intermittent filters. They were both uncovered until the fall of 1895. During the summer of each year that we operated these filters before covering, there was a growth, generally in September, I think, of this spirogyra, on the surface of the uncovered continuous filter, but it did not grow on the surface of the intermittent filter; neither has it occurred to any extent at the Lawrence city filter. There has been a slight growth in patches here and there from time to time, but nothing that has caused any trouble. Since the fall of 1895 the experimental filters at the station have been covered, that is, we have a board covering over them about three feet above their surface, and there has been no growth of this spirogyra on the filters since that time.

Mr. Fowler also says that the filtration of the river water at Poughkeepsie has not affected the color to any extent. With our filters at Lawrence we remove about from 30 to 50 per cent of the color at different seasons of the year. In the fall sometimes, when the river water is high and very highly colored with the washings from swamps or woodlands up the river, we do not remove more than 25 to 30 per cent; in other portions of the year we remove 50 per cent. It is different with the Lawrence city filter, of course. As you know, that is built upon a mud bottom, and we have coming into it ground water containing considerable iron, which colors the entire water from the filter to a certain extent. That is to say, the ground water with the iron gets in with the filtered water, and causes an increase of color over what the real filtered water has, but as a general thing, as an average for the year, we have removed 30 per cent of the color from the river water, even after the addition of this iron water.

Now, in regard to the death rate at Lawrence before and since filtration, I presume it is pretty familiar to most of you that for a number of years before we had the filter, typhoid fever was epidemic in Lawrence each year, and we had death rates ranging from 10 to 12 or 13, I believe, per 10,000 inhabitants. The year the filter was built, 1893—it was put in operation the 20th of September—the death rate was a little over 8 per 10,000; in 1894 it was 5 per 10,000; in 1895 it was 3.07 per 10,000; in 1896 1.86 per 10,000; and in 1897 1.62 per 10,000. The death rate from typhoid has certainly gone down. I may say that a little while ago I heard two doctors and one of the undertakers in the city complaining bitterly of dull times in Lawrence. They stated that their occupation was practically gone in the months of the year when they were formerly very busy. [Laughter.] I was talking with a stablekeeper the other day also who has in his stable the wagons and horses of two undertakers, and he said that they had been in about every day for the past two weeks, saying that nobody was dying, and they didn't know whether they should be able to pay their bills; in fact, I think he said they hadn't paid their bills. [Laughter.]

I don't think I have anything further to say in regard to filtered water, except that the death rate and the disease records of the city show that apparently other diseases beside typhoid fever have been lessened. We sometimes have complaints of the appearance of the water and the taste of the water as it is delivered to the consumer. Generally those complaints are from people who live near the ends of pipes, dead ends, so-called; and there is an accumulation of iron there and stagnant water. But the people who complain the most bitterly, and whose cases we look up by going to their houses to take samples, always say when we get there that the water has no odor that day. [Applause.]

MR. FOWLER. Mr. President, just briefly to answer the questions asked, I will say, first, with reference to odor in our reservoir water, that since I have been in charge there has been no difficulty experienced whatever. I am told that previous to that time there was an occasional odor, that is, this fishy odor which is very common, and it has occurred once or twice since in the dead ends, as was referred to by Mr. Clark; but during my administration no trouble has occurred in the reservoir.

With reference to our filter being continuous, it is continuous in that most of the time the basin is covered, particularly in the winter; but our pumping is not continuous. We pump generally 3½ to 4 days in the week, and the filter works during that time, though we aim to keep the water on the filter. But in the summer time we have sometimes allowed the water to go off the filter and drain dry, hoping that the rays of the sun would kill the alga growth, but it does not do so with us. As soon as we turn the water on it begins to develop again.

With reference to typhoid fever, you notice two instances in my table of very high rates. Now, it is a fact that a number of the cases of typhoid fever in our city originate outside, because we have quite a large number of transient students in our college, and typhoid fever occurs frequently among those, and perhaps the variation in the rate may be due to some such fact as that.

MR. CLARK. There is one thing I should like to add to what I said before, and that is that we still have canal water piped into some of the mills, and a number of the deaths that go to make this record of typhoid fever are of people who have acknowledged drinking the canal water. We have had two deaths from typhoid fever thus far this year, one in January and one in February, and in one case the man acknowledged that he had been in the habit of drinking canal water at the mill.

MR. HASKELL. I would like to ask Mr. Clark if it is not probable that there is less danger from typhoid fever from the use of the filtered water in Lawrence, water taken from the Merrimac and filtered in their filters, than there would be from an ordinary surface water supply unfiltered?

MR. CLARK. I don't know just what an ordinary surface water supply is. You can have a surface water supply that is perfectly pure, I suppose, from a pond that is not contaminated at all. There are a number of surface supplies in Massachusetts that are contaminated to a certain extent and used without filtration, that is, they are liable to contamination, and I think by using such a water there is more liability of typhoid fever occurring, certainly, than with a filtered water.

Mr. Fowler made some statements in regard to the bacteriological efficiency of the filter. Our filter at Lawrence does better work than his, better bacteriological work. We make analyses of its effluent every day for the largest portion of the year, and I can say that for the past three months, while the average number of bacteria in the river water has been towards 6,000 or 7,000 bacteria per centimetre, I don't think there has been but one or two days when the numbers in the filtered water have averaged over 50, generally down to 25 or 30. We are making a good many additional tests this year. We test the filtered water every day for the presence of coli, the characteristic sewage bacteria; and, while I am not ready to make any statements in regard to those results, I will say that they certainly show an efficiency in that respect that can hardly be shown by percentages. There is a practical elimination of sewage bacteria. And if we do find any, we have generally found a cause for it. There has been something going on in the pumping station, the testing of the pump, and the water allowed to flow back over the floor of the station into the pump well, or something of that sort.

MR. HASKELL. Will Mr. Fowler explain the algæ growth on the bed of this filter?

MR. FOWLER. The algæ growth to which I referred is simply the growth of the plant. It does not affect the water in any way I am aware of, either by odor or taste. It simply grows on the top of the sand and stops filtration, that is the only way it affects us; and the only way we can get rid of it is to stop filtering, drain the bed, and take it off with shovels. It develops on the bed, it is not in the water and taken out on the bed, but it grows on the sand. Perhaps the germs may be in the water, but the algæ, the plant itself, grows on the sand. It will start in a little bit of a speck and grow in a circle like a dollar until the whole bed is covered as with a blanket.

MR. THOMAS. I would like to inquire of Mr. Fowler if the filtration of the water has increased the hardness to any appreciable extent?

MR. FOWLER. So far as chemical examinations have been made there is no difference, I believe, between the hardness of the unfiltered and the hardness of the filtered water. The total solids are reduced, of course, but I think there is little if any difference in the hardness.

THE PRESIDENT. Professor Sedgwick, will you say something on this subject?

PROF. SEDGWICK. Mr. President, and gentlemen of the Association, I have suggested to your secretary that this paper is so valuable and so full of material that it ought to be thoroughly discussed by all the members present, who ought to embrace this as a rare opportunity; and that to that end I should be very glad to defer what remarks I was going to make in the form of an informal talk to another occasion. And with that in view, I should like to say one or two things about Mr. Fowler's paper.

This is really a rare occasion. Here is the one man in the United States who has had a long experience with sand filtration of a highly polluted water, in a northern winter, with the ordinary American community to deal with and get his money from—a longer experience, as Mr. Hazen very truly says, than any other man in the United States. He has used a filter built by the eminent Mr. Kirkwood, and one which, so far as I can judge, has on the whole efficiently protected the citizens of Poughkeepsie from typhoid fever.

One or two questions which have been asked suggest the idea that should always be kept in mind, viz:—that typhoid fever does not come entirely from water, so that when the typhoid rate is reduced to a low point, as it has been in Poughkeepsie, and as it has been in Lawrence, we may say that there is no more typhoid fever in a city of that kind with these low figures than there is in many cities having absolutely unobjectionable water supplies, derived from very pure sources. It is necessary to make this statment very squarely and flat-footedly, because one or two engineers in particular have from time to time insisted that as long as there was any typhoid fever in a city, the filter, or water supply, whatever it might be, must be at fault, and that the only remedy is to use distilled water.

Well, that is absolutely false. The right test in these cases is to see whether the amount of typhoid fever remaining after the introduction of the new system, whatever it may be, is any greater than would be found in a similar city supplied with water drawn from perfectly unobjectionable sources.

Now, in the case of the Merrimac river water it is easy to get at that, because there are cities above and below Lawrence that have remarkably good water supplies. They are of the same climatic situation, they have the same late winters and early falls; and they are under the same Divine Providence, which some people still think is responsible for typhoid fever; they are occupied in the same or similar industries, they have just about the same surroundings, the people in the different cities are of similar classes; and with the rate in such cities the rate, for instance in Lawrence, should be compared, and not with the figure zero. There is not a city in the country that hasn't some typhoid fever, and there are many cities in the country that have water supplies which cannot be conceived of as polluted.

It seems to me that the results given here, especially these results in more recent years, when Mr. Fowler has had the advantage of modern sanitary science, are figures which are highly noteworthy; and even the earlier figures, when the filter was run without the modern knowledge of filtration, are also very helpful. The paper is not only full of practical value, but as I look at it has an historic importance; and I for one, sir, am very glad you have consented to read it before this Association, in order that it may go into our JOURNAL and be accessible to all the members of the New England Water Works Association; because we, who are members, believe that this Association does not yield the first place to any such association in the world. We are glad to get papers of this kind, and we appreciate them when we do get them. They are genuine contributions to sanitary science, as well as to the science of water works engineering and management.

I should say that the city of Poughkeepsie had been fortunate in its superintendent. And, while that may seem an empty compliment, let me assure you that it is not so, for there is in all these water supplies the human element. Mr. Fowler discovered it when he found his engineers letting the water run over into the waste-pipe to avoid cleaning the filters. There will always be a human element in the management of everything. Locomotive engineers will once in a while disregard signals and have collisions, rear-end collisions and the like. Admirals, like the English Admiral on the warship Victoria, will once in a while give directions to turn when there is not room to turn, with the result that they and their ships go to the bottom. There is a human element in all these things, and that water supply is to be esteemed fortunate which has for its administrative officer a man who is persevering, watchful, intelligent and faithful; and such, I believe, most of the water works in New England do have, and all over the country, for that matter. They have to have them, or the people will come to grief.

With regard to the question raised by Mr. Haskell, I had come with considerable talk bottled up on that subject. I am proud that more than a year ago I was able to read a paper before this Association, and that it is printed in our reports, on the Protection of Surface Waters from Pollution. It was the first thing of the kind, so far as I know, that has gone into print, but it is not going to be the last. There have been very serious epidemics in England, particularly within the last six or eight months, three above all others—Maidstone, Lynn, King's Lynn, I believe the full name of it is, and Horsley; where in at least two, and perhaps in all of the cases, a surface water, which had previously been supposed to be pretty pure, that is it was by some, although it had been condemned by others has been the source of very serious damage indeed, and I had come prepared to speak on that subject. But I came with this distinct understanding—it was possible Mr. Fowler might not turn up, and I offered to come only as a stop-gap. I do not propose, therefore, to distract attention, if I could distract it, which I very much doubt, and which I certainly do not want to do, from this very valuable paper. I think an afternoon where we have had reported an experience of seventeen years from a man like Mr. Fowler, on a subject which is certainly the coming subject of water supply all over the world, is an afternoon which has been amply filled, and I do not propose to bring in any other subject at this time.

I do wish to say. however, that Mr. Haskell's question is very well raised. There is no doubt whatever that a surface water which has some little brook sneaking into it, over which privies are hanging, and into which typhoid dejecta are dropping, is a more serious menace to the people using that water than is any rather badly regulated filter. I would rather take my chances with sewage polluted water filtered intelligently and well, than with a surface water I knew nothing about. And if the time should come when I could give you some extended talk on that subject in amplification of my paper of a year or more ago, I should be very glad to do it, because we are learning every day how serious, as population increases, are the dangers from surface waters not properly watched. It is the watching of the watershed that is our salvation in these cases, and the cleaning of it up. These recent epidemics have set all England in an uproar. I am not exaggerating it one bit. The people are more stirred up in regard to water supply there than they have been for probably twenty-five years.

I happened to be over there this summer, but, unfortunately, the Maidstone epidemic did not occur until just after I reached home. I should have been very glad to have been there and brought you a report of what I could have found on the spot. Since then there have been that great epidemic and two more. It really seems today as though American sanitation in water works affairs was far superior to the English system and practice. The fact is England has been lying on her oars in this matter while America has been forging ahead. And it is a matter of national congratulation, I think, that our water supplies are, as I believe they really are on the whole, our surface water supplies, in better repair and in better condition today, than the average English surface water supplies, for several reasons, which I will not go into now. I wish personally to thank Mr. Fowler for the trouble and time he has taken to prepare and to put this paper on record. It is a matter of congratulation that we have his experiences, and I hope he will come often and give us further chapters from his experience.

Mr. Haskell. There is one other point I wanted to develop to a certain extent in relation to Mr. Fowler's paper, and it is something that ought to seem perfectly surprising, and that is the cost of operating a sand filter. When we think of the vast amount of money individuals are spending in trying to operate some of their filters—I know where they are changing the materials in their filters every three or four weeks, and purchasing quartz in large quantities, —here we find a man who has operated a filter for a long period of years, who has succeeded in getting 97 per cent bacterial efficiency from the use of his filter for a long period, whenever there have been examinations made, and he has done it all at an expense of less than $3 per million gallons.

Now you all know that the bacteria are the dangerous things in the water. The disagreeable things may not be so fully eliminated, but the dangerous ones have been eliminated by Mr. Fowler to the extent of 97 per cent. And there is hardly any city that could not afford to add $3 a million gallons to the cost of its water, when very likely it costs $85 or $90 a million gallons for maintenance and operation. Calling it $85, it wouldn't add but a small per cent to filter the water. And when we know how easy it is for a camp of gypsies or somebody else to catch around on the edge of a water supply, and stop there, and perhaps send typhoid fever down into the service, or for some of these Italian camps to be located around on a water supply, and that one or two cases of typhoid fever there can produce an epidemic in a city, it does seem as though the attention of everyone ought to be fully brought to the importance of these filters, and also to the cheapness with which they can be supplied and operated.

PROF. SEDGWICK. There is one point which Mr. Haskell's remarks remind me of, and which I think ought to be borne in mind when we speak of the efficiency of filtration. We speak, Mr. Fowler has spoken, and Mr. Clark has, and we all do, of the reduction of bacteria as 97, 98 or 99 per cent, and so on. Now what does that mean? It means that there are so many bacteria to a cubic centimetre in the water before filtration, and so many after filtration, and we speak of that as a reduction of so many, or so much per cent. But it ought always to be borne in mind that the real reduction of applied bacteria may be very much greater than that, and for this reason: It often happens that a natural filter is a place where bacteria, fed as they are by a constantly passing stream of water, may somewhat multiply. Those, of course, will only be the harmless water bacteria, at least that is a fair assumption. And I know it has been tried at Lawrence to find a term which should express the thing a little more exactly than to say there was a reduction of 97 or 98 per cent. It is a difficult thing to do, because if you try it, you will find that any expression which really states all the facts is rather long and cumbrous.

There are a great many house filters, for example, which actually give out more bacteria than they take in, but they are perfectly harmless bacteria, so far as we can judge, from the fact that the people drinking the water seem to be in excellent health and to have no trouble from them at all. But if there are 1 or 2 per cent of bacteria still found in the effluent water, I do not think there is any doubt at all that a certain proportion of those have got to be charged up to the natural development of the bacteria in a filter to which food is coming all the time. It is a place where bacteria reside, and if they reside there they will multiply more or less, so that the real efficiency is higher than the apparent efficiency in all these cases.

And then you will remember that you are dealing with a germ like the typhoid germ, which is all covered over, as it were, with whiskers, it has cilia all over it, and to pass that through sand is very much like trying to pass, for example, a hair brush which has bristles not merely on one side, but all around it. That is a kind of thing that tangles up there far more than the bacteria which are not covered with these lashes, or, as I have roughly called them, whiskers, which cause entanglement. And I haven't the slightest doubt in the world that the real efficiency of these sand filters is far greater than the apparent efficiency. So when it comes up to 99 per cent., for instance, the figure very likely is 100 per cent. of the bacteria actually put on, and especially of bacteria like the typhoid germ. Unfortunately it is not easy to state that.

Everybody assumes that if we put on 100 bacteria, 99 of those bacteria stay there and one of them slips through. Well, sometimes undoubtedly they do slip through, and sometimes undoubtedly they do not slip through, but those which come out below are really those which were raised, perhaps, on the underdrain or in some such place as that. So that the real efficiency of these filters on the whole, in my judgment, is a good deal higher than the apparent efficiency, and for good reasons.

MR. HASKELL. There is one matter, which is very important, connected with the construction of these filters, about which I would like to get some information from Mr. Clark or Prof. Sedgwick. There was a time when we did not consider there could be more than 750,000 gallons of water per acre properly filtered with a good bacterial efficiency. Now, as I read the reports of the State Board of Health, I find that they are increasing in their bacterial efficiency. I really think they have got nearly to ten million gallons per acre per 24 hours, and I think they have maintained for the year continuous work as good as 99.70 to 99.73 per cent. Now that means a good deal in the construction of a filter, and if we can get that fine work through a continuous filter, I should like to know it, and I didn't know but Mr. Clark or Prof. Sedgwick could tell us.

MR. CLARK. We have never operated any filters at so high a rate as 10,000,000 gallons except for a few weeks at a time, and then we have got apparently very good results. But, taking the filters which we have been operating for a number of years at the experiment station, the average rate of filtration has been rather less than 4,000,000, three million six or seven hundred thousand, with our largest and best sand filters. I myself believe that with careful handling of a small plant, with intelligent direction, you can perhaps filter a water, something nearly as badly polluted as the Merrimac river water, at a rate approximating 4,000,000 gallons per acre daily, but I think that a safe rate is 3,000,000 gallons, with the care which the filters on a large scale would generally receive. I, certainly, if I was building filters, or recommending filters for any municipality, should not advise that the rate be over 3,000,000 gallons per acre daily. I think that the economy in running a filter at the rate of 3,000,000 gallons is greater than at the rate of 5,000,000; that is, I think there will be more scraping, more washing of sand and changing of sand at the rate of 5,000,000 than at the rate of 3,000,000, that is, a greater cost per million gallons of water filtered. This whole question depends, however, upon the character of the water to be filtered.

MR. FOWLER. Mr. President, may I be allowed one word with reference to that point. I think that in examining the paper, which the gentlemen have been so kind as to speak so favorably of here, one thing will be prominent, and that is that a larger area is necessary in constructing filters than just the area sufficient to do good work when everything is in perfect order. Therefore, if 3,000,000 gallons, which I fully agree with Mr. Clark ought not to be exceeded, is the quantity wanted per day, we should have a certain amount in excess, in order that we may always have our area for 3,000,000 gallons per day in perfect order. I find that the great trouble with my work. I worked for 16 years with one filter of the size I gave you, two-thirds of an acre in extent. Now we have just built a new filter equal in area to that, giving us one and one-third acres. If we were to operate an uncovered filter, I should not consider the plant perfect for use until we had one more filter of one-third of an acre in area, that is in order that it might be in perfect order at all times. Of course that is something I don't expect to get, probably, during my administration; but I shall not say that our plant is perfect for our city until we have a little more surface, so I may always have the two I now have in perfect order.

MR. HASKELL. It seems to me that perhaps Mr. Clark is a little too modest about telling us of the final results they have secured up there in Lawrence in some of their experiments. My memory is not as good as it was once, but I have read the reports each year, and if I remember correctly, filter A, I forget the number now, it may be 58, has been operated for 11 years. They operated it in different ways and they did very good work with it, and they finally thought they would construct a filter as near as they could under the conditions which would apply to an ordinary water supply, and they have operated that now, I should think, about six years. It was run at the rate of over 4,000,000 per day of 24 hours, and practically run continuously for the term of four years. And I think by the report for 1896, it appears that for the three years run at that rapid rate continuously the percentages were 99.70, 99.73 and 99.50. Now it did do nearly as good work as that, didn't it, Mr. Clark, although you wouldn't fully recommend it, and it did it under conditions copying as near as possible a practical filter!

MR. CLARK. I said, Mr. President, that I thought small filters, with careful watching hour by hour, with intelligent management, could be operated at these high rates. When I said "small filters," I meant filters such as we are running at the Lawrence experiment station. I have no doubt however that a filter with a surface area of an acre or half an acre, receiving water like the Merrimac river water, can be operated, if extreme care is given to it, at a rate approximating 4,000,000 gallons per acre daily; but I believe a safer rate is a little lower than that, and I do not think, with my present knowledge of the subject and my present experience in operating filters, I should ever advise a rate as high as 4,000,000 gallons, with such water as the Merrimac river water. Still we have got for the past four years extremely good results with an experimental filter, 17 feet in diameter, running at a rate approximating four millions; I don't think the average has been four millions. I think it has been about 3,600,000 for the four years.

MR. HAZEN. I have come to the conclusion that different waters can be filtered at different rates, and that it is perfectly possible to filter some waters with high bacterial efficiency, at rates at least twice as high as can be successfully used with other waters. I am not going to tell you all the conditions which influence or control the possible rate of filtration, principally because I do not fully understand them myself, although we are learning something about them. In regard to the efficiency that is secured by the operation of filters, there is the efficiency which is gotten when the filter is in perfect condition, and there is the efficiency which is gotten when the filter is in a defective condition. And I think that the lower bacterial efficiencies resulting from defective conditions have been a good deal more common than has been generally supposed.

One of the commonest defects of a filter plant is for the unfiltered water in some way or other to get around the sand into the under drains. Mr. Fowler told you how it went through his ventilator pipes. Filters have been built without any ventilator pipes, and they work just as well without them, and this danger is avoided. Sometimes the sand will cake a little, and it will draw away from the wall, and the unfiltered water will run down the wall. We have corrected that by putting some little ledges or jogs in the wall, and the sand makes a better joint on a horizontal surface than on a vertical surface. That was a good idea as far as it went, but even with those jogs the masonry may sometimes crack, and the water leak into a crack above the sand line and come out of a crack below the sand line. Now we are building filters keeping the gravel back from the outside walls all the way around. It perhaps reduces the area of the filter a little theoretically, but if the water comes down the wall in some way, it has to pass along the bottom through the sand before it gets into the underdrains. We keep finding out such things as that. Mr. Haskell asked me today if we were ready to build a perfect filter. I told him no, we didn't expect to build a perfect filter for a long time yet, but we are building as good filters as we can, and are learning more about how to do it all the time, and are building filters which will do very good work, even if they are not perfect.