FILTRATION

OF

POTABLE WATER

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ON THE

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BY

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FILTRATION OF POTABLE WATER.

INTRODUCTION.

PROMINENT among the requirements of various commissions which have been busied in different places with the matter of water-supply, is the statement which needs no commission to establish; namely, that a good drinking-water should be free from all suspended matter, and as far as possible free from color.

Comparatively few towns can congratulate themselves on having in their possession, or even within their reach, a supply of water which shall correspond in all points to the ideal drinking-water. Often the question must be decided between an extravagant expenditure of money, and a water which is of inferior quality although not actually unwholesome. In theory, financial considerations stand behind sanitary considerations; yet in practice there is always a limit which cannot reasonably be exceeded.

It is not proposed at this time to enter into any discussion as to what may be, theoretically, the best source from which the supply of water for town or city use should if possible be taken: in actual practice it is often found necessary to choose as a source of supply a river or pond, which, although it may not have become unfit for use by reason of pollution, is of inferior quality owing to the presence of suspended particles of vegetable or mineral matter, or to excessive hardness, or to coloring matter of vegetable origin in solution. In such cases it is possible to improve the quality of water which in its natural condition is not well suited for use. It may, however, be regarded as a principle in sanitary science, that a water which is *polluted* by admixture of substances known or generally suspected to be injurious, to such an extent as to require actual *purification*, should be rejected at once as a source of domestic supply; but a water too *hard* for use may be softened by Clark's process, which is applicable on the large scale;[1] and a water containing matter in suspension may be clarified by some process of filtration, to be preceded as a rule, in the case of running streams, by subsidence. It is the purpose of the present paper to consider, in the light of American and foreign experience, *artificial filtration* on the large scale, especially with reference to the conditions which obtain in our own State; and, on account of its intimate connection with the same subject, we shall also consider the so-called *natural filtration* method of water-supply, and the filtration of water in the household.

Before beginning upon the subject proper, attention is called to certain definitions, which to some will seem, no doubt, very elementary. There is, however, a great deal of confusion in the minds of even well-educated people, as to the use of the terms *in solution*, and *in suspension*, as referred to waters; a great deal of confusion, also, with reference to the distinction between *clear* and *colorless*, ideas which are by no means synonymous. The accurate use of the terms can probably best be made plain by illustrations. If, for instance, we put some common salt into a quantity of water, after a time the salt disappears, the ultimate particles being distributed through the water so that they are no longer distinguishable by the eye, even aided by the most powerful microscope: the salt cannot be removed by simple filtration; and, although the solution is somewhat less mobile than water, it is still transparent. This is a case of solution. Suppose instead of the salt we take a quantity of blue vitriol (sulphate of copper). The phenomena would be similar, but the blue color of the compound would show itself in the solution. If the solution were saturated, i.e., if the water had dissolved

[1] The so-called hardness of water is due in the main to the presence of compounds of lime and magnesia in solution. These compounds are generally the sulphates and bicarbonates. When the hardness is due to the bicarbonates of lime and magnesia, the water becomes softer on boiling, because the bicarbonates are decomposed into carbonic-acid gas, which escapes, and the carbonates of lime and of magnesia, which are insoluble in water. Practically the same effect as that produced by boiling may be brought about by the addition of a proper amount of milk of lime. The lime unites with the bicarbonates to form simple carbonates, which are deposited as a white powder, incidentally removing at the same time most of the suspended matter which the water originally contained, and often removing more or less coloring matter. There is no serious difficulty in applying this process on a very large scale.

as much as it could, the transparency of the liquid would be diminished on account of the depth of color: it would be easy, however, to take a very thin layer of the solution, and satisfy one's self of its transparency. Such a liquid is colored, but is also clear.

Suppose, now, we take some clay, shake it with water, and then allow it to settle. The grosser particles will subside to the bottom of the vessel, but the finer particles will remain in suspension. Very finely divided clay will refuse to settle for weeks, and sometimes even for months. In such cases the liquid appears somewhat turbid and opaque; and although the individual particles are too fine to be readily removed by ordinary filters, and too small to be distinguished as particles by the eye, still the clay has not dissolved, and the very turbidity or opacity of the liquid shows the presence of solid particles, although they are extremely minute. Such an appearance is not to be described as "being colored," although finely divided clay and other material may be suspended in a liquid which does of itself possess a distinct color. One often meets with the expression, and that too in standard works, "the water is discolored by clay," when really it is a question of a colorless water carrying particles in suspension. The water in many of our New-England streams is at seasons highly colored by vegetable extractive matter in solution, while the water may at the same time be perfectly clear and transparent. On the other hand, our pond waters are often decidedly green; but simple filtration gives a colorless water, and shows the green color to have been due to particles of green (vegetable) matter which were suspended in the liquid.

I. — Artificial Filtration on the Large Scale.

The filtration of water on the large scale has been practised in England and on the Continent of Europe for many years, and has become very general in cases where the supply is taken from streams or ponds. From statistics which were laid before the Düsseldorf meeting of the German Public Health Association (in 1876) by Engineer Grahn[1], it would seem that in Germany since 1858 there has been no town of

[1] See the Deutsche Vierteljahrsschr. für öffentl. Gesundheitspflege, ix. (1877), p. 108.

considerable size supplied with unfiltered river water, while the increase with reference to other sources of supply may be seen from the following data:—

Total Number of Inhabitants in 80 Towns of Germany, German-Austria, and Switzerland,

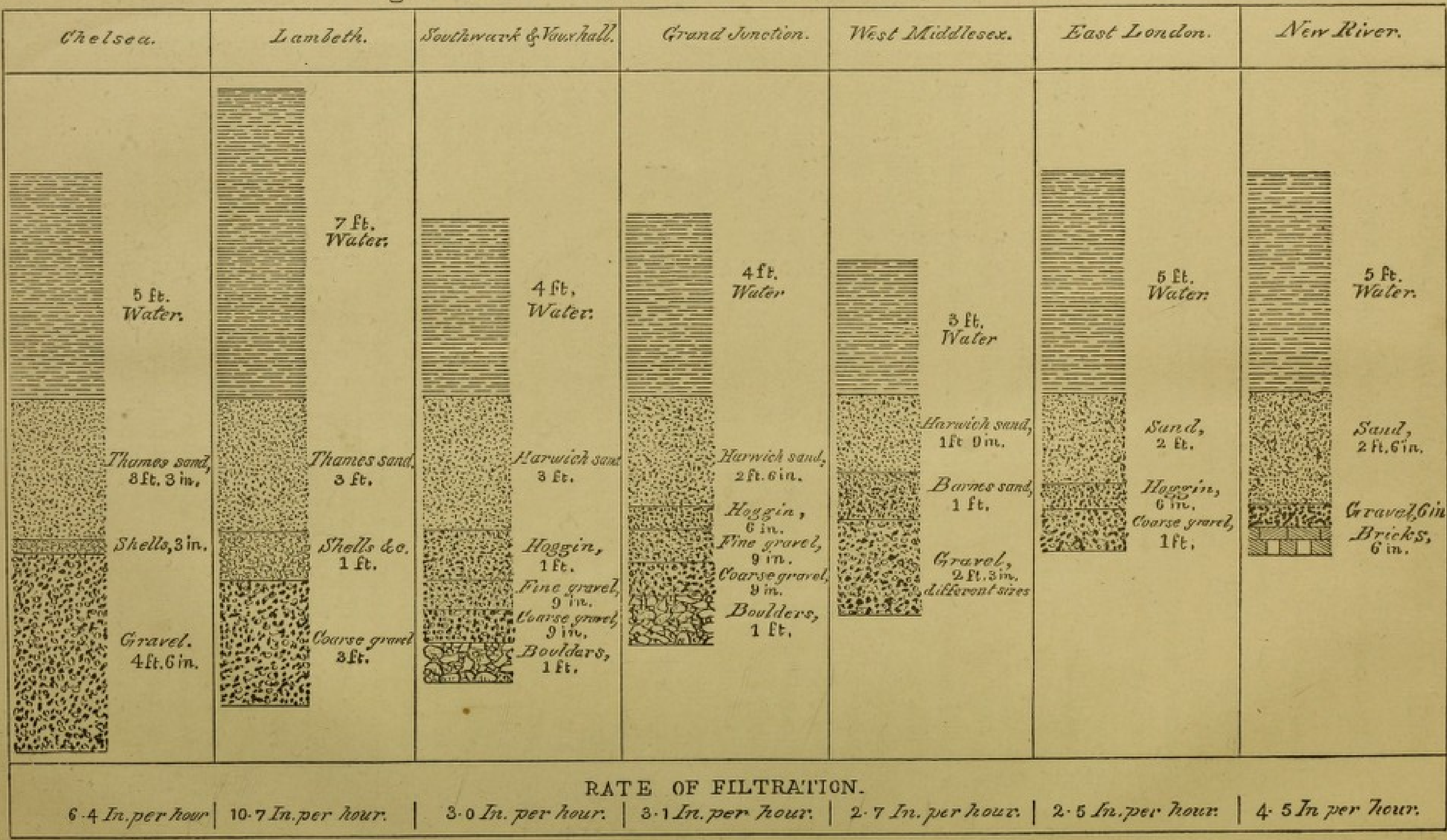
SUPPLIED WITH—	1858.	1876.
Unfiltered river water, ...	460,000	460,000
Filtered river water, ...	1,060,000	1,697,000
Spring and ground water (by gravitation), ...	25,000	1,519,000
Spring and ground water (by pumping),	45,000	1,719,000

In the United States the practice of the filtration of water on the large scale is but just beginning to come into use. In the year 1866, James P. Kirkwood, C.E., went to Europe in the interests of the city of St. Louis, to study the clarification of river waters used for the supply of cities; and his elaborate report[1] on the subject of filtration in general is almost the only book on the subject which is at all comprehensive. Full details of European practice are there given, as well as plans and suggestions for filtering-beds for St. Louis. St. Louis has not yet adopted any system of filtration, but several other cities of smaller size have done so with more or less success: namely, Poughkeepsie, N.Y., in 1871; Hudson, N.Y., in 1874; Columbus, O., in 1874; Toledo, O., in 1875. The necessity of filtration is, however, in many places felt, and would no doubt have been long since undertaken were it not for the additional outlay required for subsiding-basins and filter-beds, and the expense of maintenance.

It may be well, in the first place, to describe the general features of filtration as practised abroad and at home, to study the results obtained, and to see how far the necessity for such a process exists in our own State, and how far and under what conditions it is to be recommended. Up to the present time no filtering-material has proved practically available on the large scale, except sand, although various attempts have been made to use other substances. (See page 172.)

[1] Kirkwood. Filtration of River Waters. New York, 1869.

Fig. I.—FILTER BEDS OF THE LONDON WATER COMPANIES.



Filter-beds, as usually constructed, are water-tight basins some ten feet or more in depth, the sides built of masonry, and the bottom puddled or made of concrete, or paved with brick and cemented. The area may be from 20,000 to 50,000, or in some cases even 150,000 square feet. In building up the filtering-bed, provision is first made for the ready collection of the water by constructing upon the floor of the basin drains or channel-ways of stone or brick laid dry; then follows a layer of broken stone, the fragments being three or four inches in diameter. This is succeeded by gravel screened so as to be of uniform size, a layer of coarse being followed by one or more layers of finer material; upon the gravel rests sand likewise separated into layers of uniform size. The exact thickness of the different layers, and the extent to which the separation into the different sizes is carried, are subject, of course, to considerable variation; the accompanying cut (opp. 143) from Humber[1] will show the prevailing practice in England as represented by the various London works.

The water stands several feet deep over the surface of the sand, and is allowed to flow down through the filter at such rate as experience shows to be most advantageous. Naturally, when the sand is clean, a greater quantity of water will pass in a given time than when the sand has become clogged; practice differs as to the maximum rate; but it is seldom over six inches, vertically, per hour, and often less. At the rate mentioned, each square foot of surface would deliver 12 cubic feet (or 89¾ United-States gallons) per day.

When the beds become clogged so as no longer to filter with sufficient rapidity, the water is drawn down to from 12 to 24 inches below the upper surface of the filtering-beds, and the upper layer of sand, for a depth of one-half or three-quarters of an inch, is removed. When by successive parings the thickness of the sand has been considerably reduced, that which has been removed is washed and replaced so as to restore the original thickness, the waste of washing being made up with fresh sand. In the worst stages of the English rivers a filter-bed has to be cleaned once a week, rarely oftener. When the rivers are free from turbidity, cleansing may not be necessary more than once a month, or in some cases once in two months.

[1] Humber. Treatise on Water-Supply. London, 1877.

While it is, in general, true that the upper layer of sand does most of the work in intercepting the various floating matters in the water, it does not do the whole under the conditions which occur in ordinary practice. Examination shows that the sand is somewhat affected to a greater depth, and it may occasionally be necessary to renew all the sand. The very fact, which will appear presently, that in all actual works there are times when the water is imperfectly clarified, shows that the interior of a sand filter must become more or less fouled. The depth to which the sand becomes sensibly fouled depends upon several conditions, and mainly, in the case of any given water, upon the rate of flow, upon the *head* under which filtration takes place, and upon the frequency with which the beds are cleansed.

The *head* under which the water is filtered varies at any works according to the condition of the sand. The clear-water well is generally so arranged that the height of water in it can be lowered at pleasure; and the head under which the water is filtered is the difference between the level in the bed and in the clear-water well, as may be seen in the accompanying cut, where the head is measured by the distance between *a* and *b*. While the beds are clean, a difference of from 9 to 12 inches suffices to cause a proper rate of flow; when they become clogged a much greater pressure is required. There is a limit, however, beyond which it becomes undesirable to increase the head.

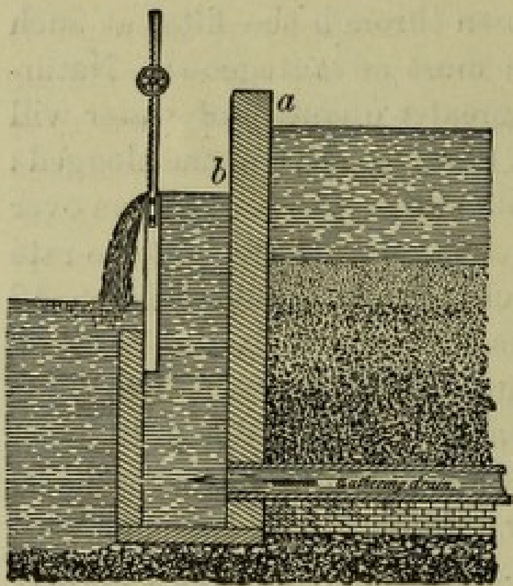


Fig. 2.

The greater the pressure, the more densely does the sand become packed; and in cleaning the beds, after scraping off the very top of the sand, the remainder is usually loosened several inches deep; but the best authorities do not advise this. The increase of pressure, too, drives the impurities to a greater depth into the sand: there is liability also, in filtering under too great a head when the bed has become somewhat clogged, especially if the water in the clear-water well is allowed to fall below the level of the sand, that the water will force its way through the sand where the clogging material offers the least resistance, and thus pass downward irregularly and in actual streamlets.

It may perhaps be asked, why, if the work is practically done by the first few inches of sand, it is necessary to bestow such care on the construction of the beds, and on the arrangement of the materials employed.

In the first place, it is a well-recognized fact, that the worst possible filter is one in which the portions of material of different sizes are indiscriminately mixed. "The different degrees of fineness in the materials beneath the sand, and their several thicknesses, were intended first to prevent the fine sand from following the water downward into the drains, and next to insure the presence of such a body of clean water below the surface of the filter, as would penetrate the numerous joints and openings of the drains, and keep them full, without creating anywhere currents or veins of water of any perceptible difference of velocity.

"With the drains much nearer to the body of the sand, it will be understood that the tendency of the water would be to flow through the filtering-material more rapidly just over the pipe than at five feet on either side of it. The distance through which it had to travel might be so short as to induce its concentration. The low velocity at which the water flows through the filter, the uniformity of fineness in the sand, and the distance of the collecting drains from its surface, all work together to produce that regularity of action over the entire filter-bed upon which its perfection depends."[1]

While the preceding description covers essentially the greater number of existing filter-beds, there have been modifications introduced, to one of which allusion may be made. The plan adopted in some of the more recently constructed beds of the New River Company, London, is to lay bricks upon the floor of the filter-basin, end to end, with spaces between the rows. A second course of bricks laid closely together, and in the opposite direction, covers the spaces below, which thus serve as drains to carry the filtered water. Upon the upper course of bricks, is placed a thin layer of gravel, and upon this, the sand as usual. (See the cut op. page 143.)

[1] Kirkwood, page 10.

Description of American Filter-Beds.

Poughkeepsie, on the Hudson River, in the State of New York, was the first city in the Union to adopt a scheme for the artificial filtration of the entire water supply.[1] The works were constructed by Mr. J. B. G. Rand, Mr. Kirkwood himself serving as consulting engineer; and the filtering-beds are built upon the English model. The filtering-works consist[2] of a settling-basin 25 × 60 feet in plan and 12 feet deep, in three compartments, arranged with reference to the deposition of the heavier particles of mud before the water passes on to the beds. The two filter-beds are each 200 × 73½ feet in plan, and 12 feet deep, built with vertical walls: each has, therefore, 14,700 square feet of filtering-area. The six feet of filtering-materials, beginning at the top of the bed, are disposed as follows: —

24	inches	of	sand.
6	"	"	¼ inch gravel.
6	"	"	½ " "
6	"	"	1 " "
6	"	"	2 " broken stone.
24	"	"	4 to 8 in. " "

Total, 72 inches.

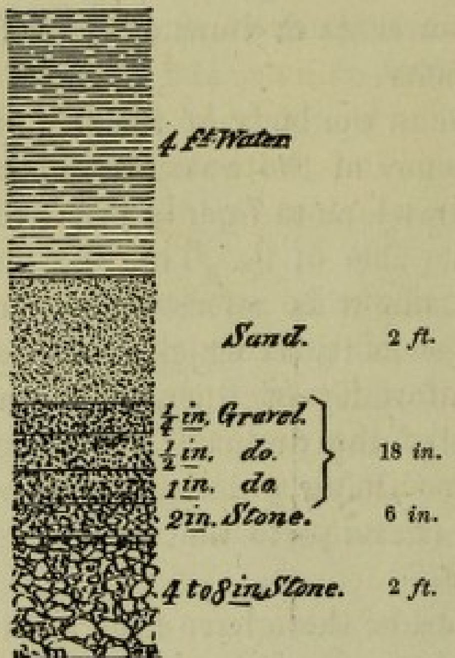


Fig. 3.
Section of Poughkeepsie Filter-Bed.

The beds have a concrete bottom or floor 12 inches in thickness, upon which are arranged open stone culverts to conduct the filtered water to the intermediate basin. The flow of water from each bed to this intermediate basin is controlled by a gate, so that while one bed is being cleaned the other may be used.

The intermediate filtered-water basin is 6×85 feet in plan, and 16 feet deep. This retains the filtered water until it is allowed to pass into the filtered-water reservoir. This reservoir is 28×88 feet in plan, and 17 feet deep; and from it the

[1] See, however, a statement on page 152 to follow.

[2] See Fourth Annual Report of the Water Commissioners of the City of Poughkeepsie, for the year ending Dec. 31, 1872.

water is pumped to the uncovered distributing reservoir from which the service-pipes are fed. Sluice-gates and drain-pipes permit the lowering of the water on the beds or in any or all of the basins.

The filtration is conducted as has been described in a previous part of this paper. When the filter becomes clogged the water is drawn down to some distance below the surface, and the top layer of sand to the depth of about one inch is carefully removed: water is again let on to the beds; and, after several cleanings have diminished the thickness of sand as much as it is thought advisable, the sand is washed and replaced.

The works at Poughkeepsie are particularly instructive, because a very careful account has been kept of the expense involved in filtering the water. The original cost of the beds was a little less than $54,000. According to figures kindly furnished me by the superintendent, Mr. The. W. Davis, the entire amount of water filtered during the year 1876 was 590,927,452 United-States gallons, and the cost of maintenance was $2,084.41. This would make the cost of filtration about $3.50 per million gallons, without including the interest on the plant ($54,000), which at 7 per cent would be $3,780.

I have also been furnished details with reference to the year 1877, during which the cost of filtering per million gallons was about $2.55. The cost of filtration thus appears smaller than in 1876: the excess of the previous year may be in part explained by the fact that an unusual quantity of sand was purchased in 1876 (namely, to an amount of $267.70 in 1876, against $72 in 1877).

As this is the only similar record of American experience which is accessible, the details are given in full as furnished by the superintendent: —

MONTH.	Cost of cleaning filter-beds.	Cost of washing sand.	Amount of water filtered, — U. S. gallons.
January, ...	Not cleaned,	No sand washed,	63,340,939
February, ...	$70 80	" "	47,637,216
March, ...	67 50	" "	49,886,240
April, ...	Not cleaned,	" "	43,868,334
May, ...	$35 63	$60 00	51,122,732
June,[1]	60 79	37 50	43,292,800
July, ...	29 50	130 00	49,112,912
August, ...	Not cleaned,	135 00	48,824,052
September,[2]	$129 75	125 00	45,174,068
October, ...	22 47	135 00	47,502,603
November, ...	30 75	130 00	42,298,567
December, ...	26 90	65 00	– –
	$474 09	$817 50	532,060,463

[1] In addition to cleaning, 2″ of sand was put on.
[2] In addition to cleaning, 4″ of sand was put on.

The expense, then, for 532,000,000 gallons, was: —

For cleaning, ...	$474 09
For washing sand, ...	817 50
For sand (60 tons), ...	72 00
	$1,363 59

It may be remarked in this place, that the cleaning of the filter-beds in winter is attended with considerable inconvenience. The European practice, in locations where the ice freezes to any thickness, may be learned by the following quotation from Kirkwood's account of the Berlin works: "The long and severe winters here made especial care and precaution necessary in the use of filters during the months of severe frost. The filter-beds cannot be laid bare in mid-winter; for the frost would in that case penetrate the body of the filter, and render it useless. All the filters are, in consequence, during the winter months, kept constantly covered with their maximum depth of water, — four feet. Luckily the river-water during the winter months is in its best state as regards freedom from turbidity, and also as regards freedom from vegetable discoloration or impurity. The filters, therefore, have comparatively little to intercept, and the river-water is flowed continuously upon them, and passes through them without very sensibly impairing their efficiency. To make provision, however, for an unusually long winter, or for an exceptional condition of the river then, which may occasionally occur, it is evident that a larger filtering surface is desirable than would be necessary in a milder climate.

"The ice forms upon the filter-beds 15 inches thick, and sometimes, though rarely, 24 inches thick. To protect the enclosing walls of each filter from damage, the ice is kept separated from the walls, 6 to 12 inches, by attendants appointed to that duty; and, so long as the cake of ice is kept floating in this way, the masonry is safe from any danger by its thrust. That this service has been well performed, is demonstrated by the condition of the walls, which are in the best of order, and nowhere out of line, or abraded, that I could perceive."

At Poughkeepsie (and at Hudson, as will presently be described) the filtering-area is not sufficient to deliver the water throughout the winter without occasional cleaning. The ice has therefore to be broken up, and thrown or rather dragged out.

Description of Filtering-Works at Hudson, N.Y.

The city of Hudson, N.Y., is supplied from the Hudson River. The works were constructed, as were those of Poughkeepsie, by Mr. J. B. G. Rand. The river-water is pumped to the summit of a hill overlooking the town, on which are situated the filter-bed and the distributing reservoir. The filter-basin[1] is 13½ feet in depth, is built with sloping sides, and has an area, at the surface of the sand, of 9,081 feet.

The filtering-material is six feet deep, and is arranged precisely as in the Poughkeepsie works which have been already described. The fragments of broken stone rest upon a concrete floor six inches in thickness, having a slight inclination towards the middle or axial line, and this line towards the outlet. Along this line runs an openly-laid stone culvert 18×24 inches, which is connected by a cast-iron pipe under the division embankment with the clear-water well. From the clear-water well the filtered water passes over a gate or weir, where it is measured and its flow regulat-

[1] See Third Report of the Water Commissioners of the City of Hudson (1875).

ed, to the clear-water basin or distributing reservoir. Thence it passes ordinarily into the effluent chamber through fine copper-wire screens to the 18-inch supply pipe; but the clear-water well can be connected directly with the supply-main, so that the city may be supplied from the bed without passing the water through the basin or distributing reservoir. The distributing reservoir is 20 feet deep; its capacity is 3,200,000 gallons. The engineer who constructed the works, Mr. J. B. G. Rand, recommended that the basins be covered, and prepared plans for covering them. He says in the report alluded to, "The length and severity of the winter in this latitude on this part of the continent renders it necessary either to cover filter-beds to prevent the formation of thick coats of ice, and to enable us to reach the sand and clean it, or to have areas of sand sufficient to filter all the water required from December till April without drawing off the water for cleaning. Last winter the ice formed to the depth of 24 inches on the bed, and to a thickness of 40 inches on the clear-water basin."

He further states that "the covering would be about as useful during the warm season in checking the growth of aquatic plants, and reducing the number of cleanings at that season." I am inclined to think, that, in many places, the covering would be of *greater* advantage in the summer, but have not been able to ascertain from the superintendent or from water-takers in the town that there has ever been any complaint about the quality of the water, or that there had ever been any trouble such as has been experienced at Poughkeepsie from the growth of algæ, and which will be alluded to later (see page 165). The Hudson River contains in summer large quantities of confervoid growth, and the same sort of plants grow quite abundantly in the filtered water; but these plants, except in decay, produce no unpleasant effects.

At Hudson the sand is washed by a machine, which is rather ingeniously devised for the purpose, and is said to reduce the cost of washing considerably. The additional expense of filtering the water is considered trifling; but no separate account is kept which can give data for comparison.

Filtering-Works at Columbus, Ohio.

Columbus, Ohio, at the junction of the Scioto and Olentangy Rivers, is supplied in part with water which has been passed through an artificial sand filter similar in construction to those already described, except that the depth of sand is much less, being in fact only seven inches. The entire thickness of sand, gravel, and broken stone, is 54 inches. The basin is constructed with sloping sides, and has a filtering-surface of 8,742 square feet. The water is admitted directly to the filter-bed, but is taken from a portion of the river which, on account of a dam below, is practically a settling-basin. The usual height of water upon the sand is 30 inches, and the amount filtered when the bed is clean is about 500,000 gallons per day. The cleaning of the beds is conducted as usual; but when by successive parings the thickness of the sand has been reduced to five inches, the whole of the sand is renewed.

Filtering-Works at Toledo, Ohio.

The water of the Maumee River supplies the city of Toledo; and a single filter-bed of 20,000 feet area was for a time in use, having been constructed, or rather being ready for use, in the spring of 1875. This area proved altogether inadequate for the needs of the city, and the use of the bed was afterwards abandoned. (See page 173.)

Other American Localities.

It is not unlikely that there are other places beside those mentioned where a similar scheme of sand filtration is in use, but I have been unable to obtain details of such. The same principle is also occasionally made use of in procuring clear water for manufacturing purposes, although, as a rule, less care is exercised in the selection and sorting of the material of the bed. A very good example of such application is to be found in a paper-mill on the Agawam River near Springfield, Mass. The bed is under cover, being, in fact, in a low building with brick walls. The basin is cement-lined; and the filter is constructed by laying joists lengthwise of the building, placing slabs across, and covering with gravel, the first layer coarse, the second fine, and this covered with several inches of sand. The sand is washed as often as the filter shows signs of clogging.

In speaking of the American localities above mentioned as being the only ones, and in speaking of there being no works established previous to 1871, I am not ignorant of the fact that a number of towns and water companies undertake to "filter" their water by passing it through broken stone, gravel, or gravel and charcoal, or even through sand and gravel. As far, however, as I have examined such arrangements, the most that can be said of them is that they act with greater or less efficiency as *strainers*, removing some of the coarser matters; the infrequency of the cleansing showing that the work done cannot be very great. This will be more evident when we consider the action of filters of sand and other material; but, to illustrate the method in which some so-called filtration is conducted in this country, I will in this place give the details furnished me in a certain instance by the superintendent of the water-works. The filter-beds were built in 1853. They are constructed with sloping sides, and measure 50 × 60 feet. The filtering-material, which consists of sand, gravel, and pebble-stones, has an entire thickness of 24 inches; and filtration is carried on under a head of from 10 to 15 feet. The beds are not used in winter, but when in use the amount of water filtered daily is 1,500,000 gallons. The beds are cleaned not oftener than once a year. This is an extreme case; but inadequate area and infrequent cleansing are the common faults of many so-called filters. Of course, occasionally, the character of the suspended matter which is to be removed is such that a very simple straining process, combined with sedimentation, is all sufficient.

I might also allude to a filter-bed which was constructed in 1876, in Lowell, Mass.[1] The bed is rectangular in plan, with a bottom area of 11,400 square feet. It has sloping sides; and the arrangement of the gathering drains and the filtering-material is substantially as in the English beds already described, except that the bottom is of pervious gravel, and below the level of the water in the river. The bed is situated directly on the bank of the river, and nearly a third of the sand surface (2,850 feet) is covered except when the river

[1] Fourth Annual Report of the Lowell Water Board, Jan. 1, 1877.

is very low; the remainder of the area (about 7,150 feet) is separated from the river by a wooden trestle-work, planked so as to form a platform, to which are fastened folding flash-board frames. In winter the frames are folded down on account of the ice; but in summer they can be raised so as to shut off the inner portion of the beds, which thus may be made accessible for cleaning. As the Merrimack carries in time of freshet a great deal of silt, which would quickly clog any filter, the outer portion of the bed would become practically useless almost at once, and the inner portion would for the same reason be useless for a considerable portion of the year. In reality the freshets of the first winter not only deposited silt on the surface of the sand, but washed in from the banks a quantity of the material which had been excavated in making the bed; and this had not been removed in the early summer when I visited the works. No doubt a considerable amount of water is obtained through the gravelly bottom of the bed by the process of natural filtration. (See page 179.)

These instances which I have mentioned show that systematic filtration as practised in Europe is not yet appreciated in this country, or that we are not yet ready to make the outlay necessary for the proper carrying-on of such a scheme.

Object and Results of Filtration on the Large Scale.

Having considered the method of filtration in common use, we may now profitably inquire more closely into the object which it aims to accomplish, and the results which are actually obtained.

Although, as we shall see later, something more is incidentally accomplished, filtration in its strict sense is simply a mechanical operation, and consists in causing a liquid containing suspended particles of solid matter to pass through some material, the pores of which, although large enough to permit the passage of liquids, are still too small for the passage of the solid particles suspended in the liquid. The suspended matter which by its presence in our water-supplies makes filtration desirable is somewhat various in character. Most rivers are liable, particularly at times of freshet, to carry a greater or smaller quantity of mineral matters in suspension; this may be, first, of such a character as to settle quite readily by virtue of the comparatively high specific gravity of the particles, as will be the case of the mineral matter consisting of sand, mica, &c. Such material as this is readily removed by filtration; but it is generally more economical to subject the water to a process of sedimentation first, and settling-basins are quite universally regarded as a necessary preliminary to successful filtration. It is evident that without sedimentation a slower rate of filtration must be employed, and the sand must be cleaned more frequently.

The suspended matter may obstinately refuse to settle, as is the case of rivers rendered turbid by the presence of clay in suspension;[1] in which case it is almost impossible as a rule to filter the water slowly enough to obtain good results if the turbid water without previous sedimentation is put directly upon the filter-beds. Even with sedimentation the result is not always as good as might be desired. The following table, taken from the Sixth Report of the Rivers Pollution Commission (p. 215), will give an idea of the efficiency of the filtration as practised by the various London companies. The observations being made on monthly samples, the statements of the table will perhaps hardly give a just idea of the results obtained day by day; but they will serve to indicate the fact that the mere possession of filter-beds does not secure perfectly clear water at all times.[2]

[1] See, for instance, an examination of the suspended matter of the Merrimack River water in the Report of the Joint Special Committee on a Supply of Water for the City of Lowell, September, 1869, p. 76. I may also refer in this connection to the report of Professor M. B. Hardin, of the Virginia Military Institute, on the turbidity of the James River water which is supplied to the city of Richmond, Va. See the Annual Report of the Engineer for 1875. It is also stated by Mr. W. E. Cutshaw, Engineer of the Richmond Water Works, that experiments on filtering the James River water through sand have not proved successful, owing to the exceeding fineness of a portion of the matter to which the turbidity is due: he estimates that if beds were constructed they could not deliver more than twenty-five gallons to the square foot per day.

[2] These estimates of the turbidity are made by the eye alone. Recently there have been attempts to measure more exactly the amount of turbidity by means of a photometric apparatus. The general principle consists in placing a layer of the water of given thickness in front of a light of known intensity, and measuring the amount of light absorbed. See account of the Seventeenth Jahresversammlung des Vereins von Gas- und Wasserfachmännern Deutschlands, in the Journal für Gasbeleuchtung und Wasserversorgung, 1877, p. 543 and following.

TABLE I. — *Thames and Lee Water. Comparative Efficiency of different Rates of Filtration during the years* 1868 *to* 1873, *inclusive.*

NAME OF COMPANY.	Maximum rate of Filtration expressed in inches per hour.	NUMBER OF MONTHLY OCCASIONS WHEN—			
		Clear.	Slightly Turbid.	Turbid.	Very Turbid.
THAMES.					
Chelsea, ...	7.27	49	15	5	6
West Middlesex, . . .	4.71	75	0	0	0
Southwark and Vauxhall, .	6.00	41	24	5	4
Grand Junction, . . .	6.97	55	14	7	0
Lambeth, ...	12.00	42	11	12	10
LEE.					
New River, ...	5.00	70	4	0	0
East London, ...	3.85	51	18	3	2

In speaking of suspended matters it is hardly necessary to allude to fish and small animals, or to chips and sawdust and other such substances, intentionally thrown into running streams, or to leaves and other fragments of vegetable matter which have fallen from the trees and forests along their banks. Most of such floating matter can be arrested by suitable screens, which would be without effect as far as removing the finer particles is concerned.

We have spoken of the turbidity of many streams: ponds are less liable to be turbid from the causes alluded to, being, in fact, settling reservoirs; and in the case of old ponds with sandy or gravelly sides and bottom there is seldom any thing to complain of or to necessitate filtration. Ponds are, however, particularly liable to other sorts of suspended matters; namely, to growths of minute vegetable organisms. This trouble concerns so intimately the water-supplies of this region, where the water is quite commonly taken from natural or artificial ponds, that we may dwell upon it somewhat in detail.

No natural water which is exposed to the air and light, whether in pond or river, is ever entirely free from vegetable growth.

The non-professional and non-botanical observer might very likely divide the various plants found growing in the water into three classes: 1st, and most readily recognized as plants, are those commonly known as eel-grass, pond-weed, pickerel-weed, lilies, &c., which have roots and leaves, and also, at the proper season, flowers; 2d, and less readily recognized as plants, are the confervoid growths,[1] as they are often called, of filamentous structure, grass-green or in some cases bluish-green in color, forming tangled masses readily removed from the water, and, when so removed, shrinking enormously in apparent bulk, and drying away to a grayish or colorless mass, in some cases looking almost like coarse paper. Plants of this character grow in almost all reservoirs, or other bodies of water exposed to the light and air, both in still and running water: they either float in masses in the water, or grow attached more or less firmly to the rocks and stones of the bottom of the pond or reservoir. By their growth they do no harm to the water in which they flourish; and as they are readily arrested by ordinary wire screens, or easily removed by rakes or scoop-nets, their presence causes no serious inconvenience in water used for town-supply.

The third division of the non-professional would include, if indeed they were recognized as plants, those minute organisms which appear as greenish specks, or minute straight or curved threads, diffused through the water, visible enough if a large quantity of water be looked at, but perhaps almost escaping notice in the small quantity which would be taken up in a single glass. It is true that the individual plants are in some cases distinguishable by the naked eye, but their form and structure can be made out only by use of the microscope. If collected together as a scum, which often happens, especially on the windward shore of a pond, the scum is not coherent, is easily broken up, either by a wind setting in the opposite direction, by a shower of rain, or by artificial agitation. The appearance has been sometimes described as that of meal or of fine dust scattered through the

[1] These, as well as those mentioned below, belong to the class of cryptogamous (non-flowering) plants, which the botanists call *algæ*, — plants which grow in the water, or in moist places, and usually contain chlorophyll (green coloring matter), or some allied substance. To their number and variety there is almost no end.

water. The number of individuals is almost infinite, and under favorable conditions they increase with great rapidity. Their presence gives a decidedly green or greenish-yellow tinge to large bodies of water; and their death and decay often cause considerable offence to the sense of smell of those sojourning in the neighborhood, and to the sense of taste of those obliged to drink the water.

While very many species of the minute *algæ* present this general appearance, as far as my own observation and information extend, the number of species which are known to increase to such a great extent as to completely fill the waters of ponds of many acres area, and to cause sensible inconvenience, is comparatively small; the most common in this neighborhood (New England) seeming to be the *Clathrocystis æruginosa*, but certain plants referable to the *Nostochineæ* are not uncommon alone, or in company with the *Clathrocystis*.[1]

The inconvenience caused by the presence of the plant is felt first by those who use the water for town-supply, and, secondly, by those who cut ice upon the pond. While the plant is alive and growing, there is little taste or odor given to the water, hardly noticeable if the water is iced. When the plants enter into the first stage of decay, the water acquires a peculiar taste and odor. Light and a certain degree of temperature are requisite for the normal growth of these algæ, and the decay often takes place in the mains and service-pipes: it will not unfrequently happen that the water in a reservoir or pond will have almost no taste, while the water as delivered to consumers will have a decided taste. By the settling of the green growth to the bottom in a more or less decayed state, the ponds are generally (?) cleared before the cold weather sets in; but, in several cases which have come under my observation, the material floats up to the under surface of the ice, and is frozen into the ice, making it unmarketable.

[1] It may be interesting to note, with reference to the chemical effect of the presence of these algæ, that they are highly nitrogeneous. A sample collected in the Ludlow Reservoir was dried, and was found to contain 11.18 per cent of nitrogen. The sample consisted mainly of the Clathrocystis, but of course it was impossible to separate the microscopic animal organisms from the vegetable.

Among the various questions which are often propounded with reference to the matter, are the following: —

1. What is the cause of the trouble?
2. Is it injurious to health?
3. Can any thing be done to prevent it?

1. *The Cause of the Trouble.* — Although there is no doubt that the trouble is caused by minute vegetable organisms, of whose life-history a good deal is known to botanists, various suggestions have been made as to the cause of its appearance. By many it has been supposed to be a sort of fermentation, a process of purification.[1] In some cases, this abundant appearance of the green matter has seemed to follow the apparent increase of sewage and other impurities discharged into the pond. I have within the last few years examined a great many ponds affected in this way, and cannot satisfy myself that there is any connection between such discharge of sewage and the growth of these algæ: the amount of soluble nitrogeneous matter, of ammoniacal salts, of phosphates, and of other mineral compounds necessary for their growth, are everywhere present; and it would be unsafe to prophecy the security therefrom of any pond. Although it would seem that ponds recently made by flowing marshy or cultivated land were peculiarly liable to the trouble, especially if shallow, my observations have led me to make even this statement less emphatic than I was at first inclined.

Although these plants are not all killed by a considerable degree of cold, still they *thrive* only in warm weather. Observations on this point are incomplete; but such as I have been able to collect would seem to point to a temperature of 70° F., or thereabout, below which the trouble is not likely to begin. Extended observations on this point are much needed.

I have been unable to satisfy myself that the presence of aquatic plants at the margins of the ponds has other effect than that of entangling and holding masses of scum, which if then exposed to a hot summer sun rapidly enter into decay.

[1] I have often found that residents (farmers and others) on the banks of large ponds are familiar with what they call a "fomentation" in the pond, taking place with some regularity at certain seasons of the year, which phenomenon is, in some cases at least, a growth of these minute algæ.

2. *Is the Matter Injurious to Health?* — The observations as to the effect on the human organism, of water containing these algæ, are not, of course, very definite or complete. In some places, however, where the only source of supply is thus affected, opportunity for observation is afforded. I have not been able to obtain any evidence of the unwholesomeness of the water from a supply which is in other respects of good quality. When the algæ are alive and fresh, horses and cattle drink the water readily, in preference to spring water: when decay has taken place, the water sometimes becomes so offensive that they refuse to drink it. In this condition it is manifestly unsuited for domestic use.

3. *Can Any Thing be done to prevent the Trouble?* — As far as our present knowledge extends, nothing.

Various plans of local applicability are pursued in different places, by which the annoyance is lessened. Sometimes while the vegetable matter is a scum, water may be wasted from the surface of the reservoir, at a point where the material has collected; and sometimes the pond may be left to itself, and an alternate supply made use of.

There is no difficulty in removing the vegetable matter completely by sand filtration, although of course the filters become rapidly clogged. This clogging is aided also by the development upon the beds themselves of confervoid growth, which in uncovered beds becomes so abundant and vigorous as to form a sort of carpet on the surface of the sand, which can be raked off in coherent sheets, or rolled up. If the vegetable matter in the water, or that which grows in the beds, enters into decay, and communicates an unpleasant taste to the water, the filtration may be unable to remove the taste completely.[1]

[1] I would be distinctly understood as not asserting that all bad tastes and odors to which water-supplies are subject are due to the presence of these or other algæ. They are the real cause of a real trouble. The occurrence of a *fishy*, *musty*, *cucumber*, *green corn*, or other peculiar odor or taste, may be due to the presence or decomposition of certain algæ; but it may be produced by the decay of more highly organized plants, or by causes of which we are ignorant. For instance, the cucumber taste which affected the Chestnut Hill Reservoir of the Boston Water-Works in 1875 was traceable to no such cause, nor, indeed, to any assignable cause, although careful examinations were made from a chemical, from a botanical, and from a zoölogical standpoint. Other cases also have come under my observation, where no algæ, fresh or decomposed, could be found in sufficient quantity to account for the unpleasant taste, which was very noticeable.

It also seems that filtration through sand does not remove the germs or spores of the plants; so that if the filtered water be stored in open reservoirs, exposed to light, it is again liable to vegetable growth. For this reason, such water, when once filtered, should be delivered at once into the distribution-pipes; or, if storage is necessary, it should be stored in covered reservoirs, preferably of such size as to be readily emptied and cleaned if occasion require.

We are come now to consider more particularly the action of a sand filter. On the suspended matter, the action, although simple, is twofold. In the first place, particles too large to pass into the interstices of the filter are arrested at the very outside; in the second place, and with regard to finer particles, the process is one of sedimentation and adhesion. It is well known that a turbid liquid will deposit sediment, not simply on the bottom of the vessel in which it is contained, but also upon the sides. In a sand filter, as the water passes slowly downwards, not in veins, but by percolation, the minute particles of suspended matter are attracted to and deposited upon the walls of the numerous vessels which are formed by the void spaces between the grains of sand. This is true even when the material of the filter is very coarse. If muddy water be passed *slowly* through a bed of shingle or broken stone, it will clear much more rapidly than if the subsidence takes place in an unobstructed basin.

It has already been said, that in addition to the clarification of the water, some effect is produced upon matter actually in solution. This effect has been very much exaggerated; and yet there is no doubt, that, if properly managed, sand filtration is competent to remove an appreciable amount of dissolved organic matter. The action may be explained in two ways. In the first place, most porous substances possess the power of removing certain kinds of organic matter by something which may be called *adhesion*. The absorptive power for any substance is limited and soon reached, and the substance thus removed may by appropriate means be again brought into solution. Quartz sand, as we should infer, possesses the power to a slight degree only. The second method by which dissolved organic matter is removed in the sand filter is by oxidation. The substance is actually burned more or less completely, in part by the oxygen held in solution in the water, and in part by the air entangled in the interstices of the sand. Although in filling the beds with water, great care is taken to displace the air gradually, and as completely as possible, there must always some remain in the concavities of the individual grains of sand and otherwise entangled. The extent of the action of a sand filter in this direction depends not only on the thickness of the filtering medium, and the rate at which the filtration takes place, but also and in considerable measure upon the frequency with which the filter is cleansed. The cleansing of the filter not only removes the accumulation of organic matter, which if allowed to remain would tend to injure the water, but also involves the aëration of the sand, at least to a considerable depth.

The effect of filtration on the water of the Thames and Lee has been made the subject of experiment by the Rivers Pollution Commission and others. The following table includes some of the results obtained:—

TABLE II. — *Observations on the Water of the various London Companies.*

(From the Sixth Report of the Rivers Pollution Commission, p. 217.)

COMPANY.	Date.	Unfiltered or Filtered.	Total Solid Residue at 120°–130° C.	Organic Carbon.	Organic Nitrogen.	Ammonia.
NEW RIVER.						
New River, at Stoke Newington,	Jan. 25, 1873,	Unfiltered,	31.98	0.350	0.084	0.004
		Filtered,	30.16	0.246	0.042	0
New River, at New River Head,	Jan. 27, 1873,	Unfiltered,	31.96	0.330	0.061	0.004
		Filtered,	31.56	0.242	0.043	0
THAMES RIVER.						
Southwark, at Hampton,	Jan. 31, 1873,	Unfiltered,	32.00	0.321	0.063	0.001
		Filtered,	31.56	0.273	0.042	0
Chelsea,	Jan. 31, 1873,	Unfiltered,	31.36	0.325	0.046	0.003
		Filtered,	31.10	0.258	0.032	0
Lambeth,	Jan. 31, 1873,	Unfiltered.	32.96	0.273	0.067	0.004
		Filtered,	32.74	0.258	0.038	0.001
Grand Junction,	Feb. 3, 1873,	Unfiltered,	31.42	0.262	0.042	0.004
		Filtered,	30.68	0.231	0.032	0.001
Southwark, at Battersea,	Feb. 5, 1873,	Unfiltered,	31.80	0.239	0.047	0.005
		Filtered,	30.90	0.226	0.035	0.001
West Middlesex,	Feb. 7, 1873,	Unfiltered	31.22	0.209	0.071	0.005
		Filtered,	30.56	0.198	0.043	0.001
RIVER LEE.						
East London,	Feb. 1, 1873,	Unfiltered,	34.68	0.363	0.082	0.004
		Filtered,	34.70	0.305	0.041	0.001

It is true that it is difficult, if not impossible, to take samples which shall represent the *same water* before and after its passage through the beds; and samples of water taken at different times of the same day, from the same locality in the river, would vary somewhat. Still, making due allowance for this fact, it is evident that in some cases there is a considerable decrease in the amount of organic matter, as indicated by the carbon and nitrogen which enter into its composition. It is also evident that sometimes this action is quite small, and that it is subject to considerable variation. As far as removing dissolved mineral matters, the action of a sand filter is practically nothing. I am aware of statements that pure quartz sand can remove saline matters, such, for instance, as common salt from salt water. I believe most of the statements rest on imperfect experiments, the results of which may be explained in other ways. I propose at another time to repeat and criticise some of these experiments. There are some, however, which seem to show that even pure quartz sand does possess to a very slight degree the power of absorbing from solution, and retaining, small quantities of mineral salts. I am convinced, however, from the latest recorded experiments on the subject, and from such as I have made myself, that, for all practical purposes, we may say that sand filtration has no effect on the dissolved mineral matter, unless there is opportunity for a chemical change to take place. Thus it seems to be well attested, that a hard water containing bicarbonate of lime may deposit carbonate of lime in the filter, owing to the escape of carbonic acid.[1] Sometimes the amount of mineral matter may be greater in the filtered than in the unfiltered water, if the material of the bed, the gravel and stones, contain, as they often do, soluble ingredients.

I have made several examinations of water from American filter-beds. The results of the examination of two sets of waters from Poughkeepsie, N.Y., are included in the accompanying table.

[1] See, for example, Lefort, Chimie Hydrologique, pp. 165, 200. It has also been shown by Schloesing (see Assainissement de la Seine, 2ième partie, Enquête, p. 191), that at some depth in soil which had been irrigated with sewage, there were formed crystals of carbonate of lime, owing to the escape of carbonic acid from the sewage-water which contained a small proportion of bicarbonate of lime in solution.

TABLE III. — *Examination of Water from Poughkeepsie, N.Y.*

[Results expressed in parts in 100,000.]

Number.	Date received.	LOCALITY.	Water as Received.		Water after Filtration through Paper.		Solid Residue.			Total Solids after filtration through paper.	Chlorine.	
			Ammonia.	"Albuminoid Ammonia."	Ammonia.	"Albuminoid Ammonia."	Inorganic.	"Organic and Volatile."	Total at 212° Fahrenheit.			
	1877.											
408	Nov. 13,	River, . . .	0.0109	0.0197	0.0109	0.0184	10.4	1.7	12.1	10.1	0.32	Very turbid.
409	Nov. 13,	Clear-water basin,	0.0077	0.0139	0.0077	0.0139	8.9	1.1	9.1	9.0	0.30	Clear.
428	Nov. 19,	River, . . .	0.0104	0.0157	0.0104	0.0157	9.0	1.5	10.5	8.6	0.32	Very turbid.
427	Nov. 19,	Clear-water basin,	0.0112	0.0155	0.0112	0.0149	8.1	1.3	9.4	9.0	0.33	Slightly turbid.

Remarks on the Table.

In the case of the Hudson River, the river-water, besides being more or less strongly colored in the fall, is often quite turbid. A part of the matter which causes the turbidity settles somewhat readily, and a part remains suspended for a long time. I kept a specimen of the water, taken in October, for a number of weeks, without any considerable improvement in appearance after the grosser particles had once subsided. Both of the specimens of river-water submitted to examination were very turbid. The specimen numbered 409 was taken just previous to the cleansing of the filter-beds, and was filtered at the rate of about 6¾ inches per hour (i.e., about 100 gallons per square foot per hour). It was quite clear. The specimen numbered 427 was a portion of the first water pumped after the cleansing of the beds, and was slightly turbid.

In connection with the examination of the water, I may refer to the examination of several specimens of sand. A sample of washed sand (received Nov. 13), as it is put upon the beds, was found to lose on ignition 0.25 per cent. Two samples of dirty sand, as it comes from the beds, were examined, and found to lose respectively 0.74 per cent (specimen received Nov. 13), and 0.64 per cent (specimen received Nov. 14). The sand was in each case dried at 212° F. before ignition, so that the difference in the loss on ignition may be taken to represent quite closely the amount of organic matter retained. Taking the mean of these results, it would appear that every ton of sand retained mechanically about nine pounds of organic (mainly vegetable) matter. The Rivers Pollution Commission [1] found, in a case which they examined, that one ton of dry sand, washed after previous use, was capable of removing from water, and retaining, 16.1 pounds of peaty matter.

There is one matter worth mentioning in connection with the Poughkeepsie filter-beds, which strengthens the conclusion one cannot fail to arrive at in studying this subject; namely, that in our climate the filter-beds and all reservoirs used for subsequent storage of the filtered water should be *covered*. In the early summer, when the temperature of the river

[1] See the Sixth Report before alluded to, p. 215.

reaches 70° F., or a few degrees higher, the exposure of the water to the sun in a comparatively thin layer on the filter-beds causes the development of a large number of minute algæ, which by their decay in the service-pipes communicate a very disagreeable odor and taste to the water. When this growth begins, it is the practice of the superintendent to pump the greater part of the water used directly from the river into the pipes, and in this way the trouble is entirely overcome. The liability to this annoyance lasts only a short time, and it is generally only through the month of June that the beds are thrown out of use on this account. I am of the opinion that if the beds were covered, and if the water after filtration were kept in covered reservoirs, there would probably be little or no trouble from this source. It is true that there is plant-life almost everywhere, even in closed conduits and in covered reservoirs: this, however, is a different matter from the growth of algæ alluded to, and is less likely to cause annoyance. I am convinced that the best way of all is *not to store* the water after filtration, but to deliver it at once to the consumers.

I have examined also specimens of filtered and unfiltered water from the Hudson Water-Works, which were furnished me by the superintendent, Capt. John S. Ray.

TABLE IV.—*Examination of Water from Hudson, N.Y.*

[Results expressed in parts in 100,000.]

Number.	Date received.	LOCALITY.	Water as Received.		Water Filtered through Paper.		Solid Residue.			Total Solids after filtration through paper.	Chlorine.	
			Ammonia.	"Albuminoid Ammonia."	Ammonia.	"Albuminoid Ammonia."	Inorganic.	"Organic and Volatile."	Total at 212° Fahrenheit.			
	1877.											
447	Nov. 27,	River, . . .	0.0059	0.0152	0.0059	0.0139	7.08	1.13	8.21	–	–	Turbid.
446	Nov. 27,	Filtered water, .	0.0040	0.0123	–	–	–	–	–	–	–	Slightly turbid.
464	Dec. 10,	River, . . .	0.0051	0.0152	0.0051	0.0120	7.68	0.72	8.40	–	0.30	Turbid.
463	Dec. 10,	Filtered water, .	0.0056	0.0131	0.0056	0.0123	7.12	1.02	8.14	–	0.32	Slightly turbid.
	1878.											
2	Jan. 18,	Top of filter-bed, i.e., unfiltered.	0.0123	0.0133	0.0123	0.0128	9.52	1.12	10.64	10.00	0.33	Turbid.
3	Jan. 18,	Filtered water, .	0.0237	0.0163	0.0237	0.0160	10.20	0.92	11.12	10.60	0.32	Slightly turbid.

NOTE.—In the first set of specimens, the demijohn containing No. 446 was broken in transit, and almost all the water was lost. The bed was cleaned on November 13, and on December 10.

In explanation of these results, I would say that the filtered water was sensibly clearer than the river-water, but that very little effect seems to be produced upon the matter in solution. It is exceedingly difficult, in the case of the Hudson-river water, to obtain any thing like constant results in determining the so-called "organic and volatile matter;" so that I should lay no stress upon the difference observed in this column. In the samples received in November and December, 1877, the close agreement of the "albuminoid ammonia" in the two waters, after being passed through filter-paper, shows that practically no appreciable quantity of soluble nitrogeneous organic matter was removed by the passage through the sand. The same thing was found to be true by a comparative test with permanganate of potash.

In the waters received in January, 1878, the filtered water, while less turbid than the unfiltered water, showed a positive increase in the soluble nitrogeneous matter, making it evident that for some reason the bed was not working properly.

Experiments at Springfield, Mass.

Among other experiments which I have made on the subject, I may here detail the results obtained on the water-supply of Springfield, Mass., in an experimental filter constructed under my direction. The experiment was carried on by Mr. J. C. Hancock, Superintendent of the Springfield Water-Works, who sent me, from time to time, specimens of water for analysis. The experiment was conducted in the joint interest of the Springfield Water Commissioners and of the Board of Health; and the results will appear also in the Report of the Water Commissioners of the City of Springfield, for the year 1877.

The filter was made by standing a cement-lined,[1] twenty-

[1] I should here state that I am perfectly familiar from my own experience with the objections to experiments conducted on such a small scale, owing to the tendency of the water to flow along the sides of the containing vessel, rather than uniformly through the material with which it is filled. This was in great measure obviated in the present case, by using a cement-lined pipe. I may add that there was some difficulty in regulating the flow to a sufficiently small amount, and at the same time causing it to be registered by the meter, so that the rate of flow was in several instances in excess of what would be recommended on a large scale.

four-inch main on end, and filling with material arranged as follows from the top downward:—

12	inches	fine sand.
12	"	coarse sand.
6	"	fine gravel.
6	"	medium gravel.
6	"	coarse gravel.
12	"	broken stone.
54	"	in all.

This material rested on a cement bottom six inches or so in thickness. Although the work is mainly done by the very upper portion of the sand, it was thought best, in the construction of the filter, to imitate, as far as possible, the conditions which occur in filtration of the large scale. The depth of water above the sand was about two and one-half feet, and the area of filtering-surface was about three square feet. The filter stood in a building connected with the Water Commissioners' Office, and the water was taken from the street-main by an independent pipe. The deposit in the main was occasionally purposely disturbed by the opening of a hydrant. The water began to flow on Aug. 1, and at the beginning was allowed to run slowly, afterwards more rapidly, as is evident from the readings of the meter which was attached.

DATE.	Reading of Meter.	Average rate of flow, cubic feet per hour.
August 21,	0 feet,	–
September 1,	52 "	–
" 3,	375 "	6.73
" 4,	524 "	6.20
" 5,	673 "	6.20
" 7,	943 "	5.63
" 10,	1,268 "	4.51
" 11,	1,320 "	2.17
October 4,	2,132 "	–

The filter began to clog so as to perceptibly affect the flow about Sept. 25. On Oct. 4 the flow was stopped, the water lowered in the filter, and the upper portion of sand to the depth of an inch taken for examination. The water was then allowed to flow freely through the filter: it flowed at the rate indicated by the meter-readings as follows:—

DATE.	Reading of Meter.	Average rate of flow.
October 9,	2,133 feet,	–
" 10,	2,228 "	3.95
" 19,	3,067 "	3.88
" 24,	3,392 "	2.71
November 5 (clogged),	3,489 "	–

The results of the chemical examination of water taken before and after filtration are given in the accompanying table. In collecting specimens for examination the unfiltered water was first taken; and, after a sufficient time had elapsed for the water then flowing upon the filter to pass completely through, the filtered water was secured. Before the specimens Nos. 312 and 313 were taken, the water in the main had been disturbed, and the unfiltered water was quite turbid, and possessed of unpleasant odor and taste, which also accompanied the filtered water. Probably a better effect would have been obtained if the water had passed more slowly; but still other experiments have convinced me of the impossibility of completely removing this taste by simple filtration through sand. Before Nos. 328 and 329 were taken, the pipes were also disturbed, but the amount of sediment was then much less than before.

TABLE V.—*Examination of Water from Springfield, Mass.*

(Results expressed in parts per 100,000.)

Number.	Date.	LOCALITY.	Water as Received.					After Filtration through Paper.				
			Ammonia.	"Albuminoid Ammonia."	Solid Residue.			Ammonia.	"Albuminoid Ammonia."	Solid Residue.		
					Inorganic.	"Organic and Volatile."	Total at 212° Fahrenheit.			Inorganic.	"Organic and Volatile."	Total at 212° Fahrenheit.
304	Aug. 30,	Unfiltered, ...	0.0064	0.0261	–	–	–	0.0069	0.0235	3.08	2.40	5.48
303	Aug. 30,	Filtered, ...	0.0061	0.0235	–	–	–	0.0061	0.0189	4.12	2.88	7.00
312	Sept. 3,	Unfiltered, ...	0.0139	0.0392	4.20	2.68	6.88	0.0139	0.0323	4.04	2.20	6.24
313	Sept. 3,	Filtered, ...	0.0179	0.0275	4.52	1.92	6.44	0.0179	0.0245	4.60	1.72	6.32
319	Sept. 5,	Unfiltered, ...	0.0083	0.0229	–	–	–	0.0083	0.0227	2.72	2.60	5.32
320	Sept. 5,	Filtered, ...	0.0048	0.0248	–	–	–	0.0048	0.0235	3.40	1.84	5.24
326	Sept. 12,	Unfiltered, ...	0.0087	0.0264	3.60	2.36	5.96	0.0087	0.0264	3.48	2.36	5.84
327	Sept. 12,	Filtered, ...	0.0048	0.0219	4.00	2.44	6.44	0.0048	0.0219	3.88	2.40	6.28
328	Sept. 12,	Unfiltered, ...	0.0088	0.0459	3.40	3.32	6.72	0.0088	0.0240	2.80	2.84	5.64
329	Sept. 12,	Filtered, ...	0.0040	0.0216	3.84	2.48	6.32	0.0040	0.0216	4.08	2.16	6.24
353	Oct. 5,	Unfiltered, ...	0.0104	0.0520	4.16	2.00	6.16	0.0109	0.0403	–	–	–
354	Oct. 5,	Filtered, ...	0.0056	0.0299	4.36	1.52	5.88	0.0056	0.0299	–	–	–
Average of unfiltered water, . . .			0.0094	0.0354	3.84	2.59	6.43	0.0096	0.0282	3.22	2.48	5.70
Average of filtered water, . . .			0.0072	0.0249	4.18	2.09	6.27	0.0072	0.0234	4.02	2.20	6.22

The sand taken from the top of the filter, after drying at 212° F., was found to lose, when ignited, 0.91 per cent of its weight; after being washed, and brought into condition to be replaced, it lost only 0.46 per cent, showing that it had removed from the water filtered through it a considerable amount of organic matter, about the same as was found to be the case with the sand from Poughkeepsie (see page 165).

As a result of the experiment it was evident that there was no difficulty in removing completely all matter in suspension, provided the flow was not too rapid. The water after filtration was generally bright and clear. At first there was a trifling increase of the inorganic matter, due, no doubt, to the action of the water on the material of the filter. It was further evident that there was a slight decrease in the organic matter which was in a state of solution in the water, as may be seen by comparing the amounts of "albuminoid ammonia" obtained from the respective waters after filtration through paper. This "albuminoid ammonia" may be taken as an index of the relative amounts of nitrogeneous matter.

Other Substances beside Sand.

Many other substances have been proposed from time to time as suitable to replace the sand wholly or in part, and to accomplish more than sand can in the chemical action on the impurities of the water filtered. The only one, however, which has met with practical success on any thing like a large scale, is the so-called carbide of iron, of Mr. Thomas Spencer, which is used by several towns in England. The carbide of iron is prepared by roasting a mixture of hematite iron-ore and sawdust, and is no doubt very efficient as a purifying agent. It is, however, expensive, and could hardly be prepared for less than $20 or $25 per ton, and for the best effect should be preceded by a rough sand filtration. At Wakefield, England, where, to be sure, the water is extremely filthy, and the bed confessedly overworked, the Rivers Pollution Commission found that "the water, owing in part to putrescent fermentation and subsidence, and in part to filtration, was chemically less contaminated than might be expected, yet on both occasions it contained a large proportion of nitrogeneous organic matter. It was of a greenish-yellow color, and on one occasion very turbid."

Wood-charcoal is often used in filters of small size, mixed with sand. Practically, however, it adds nothing to the efficiency of a properly managed sand filter. One way in which charcoal is used is illustrated by the works of Marshalltown, Iowa. Here a filter-basin, 32×16 feet, was built of masonry; and a filter-floor of two-inch plank was supported on joists laid crosswise. The floor was pierced with three-fourth-inch holes, and covered with wire gauze. On this there is a layer of charcoal four inches thick, and above this 14 inches of clean gravel and sand.

I am informed of a method of filtration in use by the Water-Works Company of Clinton, Iowa, where a number of boxes, 16 in fact, filled with charcoal, gravel, and sharp sand, rest upon the conduit. The water flows on to the boxes, and through the material into the conduit. The boxes can be raised one at a time for cleaning. In case of fire, however, the water is taken into the conduit without filtration.

I should perhaps also allude to a system of filtration devised by Mr. J. D. Cook, chief engineer of the Toledo Water-Works. This consists of a series of settling and filter chambers, the filtration being upward through sand, gravel, and charcoal: any one of the chambers can be cleaned independently of the others. It is stated that an experimental filter tested with the turbid water of the Maumee River gave excellent results: the filter has not, however, as yet been put into actual operation on a scale sufficient to judge decisively as to its availability for use in supplying a town of considerable size.

Conclusions.

I will here bring together the general conclusions reached from a study of the practice and results at home and abroad, and from my own experiments.

1. No material has yet been brought into practical use for artificial filtration on the large scale, except sand.

2. With our present knowledge we have no evidence that sand filtration can be regarded as an efficient means of purification of *polluted* water; although it may, if properly carried out, lessen the liability of ill effects.

[1] See Annual Report of the Toledo Water-Works, for the year ending Jan. 1, 1877.

3. All visible suspended particles, and an appreciable proportion of organic matter actually in solution, may be removed by properly conducted filtration through sand.

4. For the present, at any rate, it will be best to regard artificial filtration mainly as a means for the removal of *suspended* matters, although under the management of a person of intelligence, education, and experience, the simple sand filter is capable of producing sensible improvement in respect to the organic matter which is dissolved in the water. In ordinary practice, however, it is quite certain that sufficient care will not be taken to secure such results; and, in view of what is actually accomplished in existing works, it seems to be best to regard the removal of color and unpleasant taste as incidental, and likely to vary very much according to the condition of the filter.

As the public mind becomes educated in the matter, a higher standard of efficiency may be exacted; but for the present it should not be held out to towns and water-boards as a result which will follow filtration through sand, that a water which is naturally strongly colored by vegetable extractive matter will be rendered colorless in ordinary practice, although it is true, that, starting with an entirely new filter, the first portions of water filtered may be deprived of color, and such an experiment has often led into error.

5. It not worth while to introduce a system of sand filtration in the case of any town-supply unless there is the willingness to make such outlay for construction and maintenance as shall render the scheme thorough and efficient. This will involve properly constructed filter-beds and generally settling-basins of sufficient size; it will involve intelligent supervision, and frequent cleansing and renewing of the material of the filter. It should also involve, in the construction, the covering of the filter-beds; and for the best effect the filtered water should be delivered at once to the consumers. There should be at least duplicate beds, so that there can always be one in use. If on account of lack of duplicate beds, or for other reasons, it seems necessary to store the filtered water, this should be done in covered reservoirs of small size, which can be readily emptied and cleaned if occasion require. It cannot be said too emphatically, that sand filters, or indeed filters of any description, are not auto-

matic, and that the effect obtained depends not only on the construction of the filters, but also, and even more, upon the care with which they are managed. I believe that money expended on a scheme for filtration is practically wasted unless a sufficient outlay is made to secure certain efficiency. It is possible to store the filtered water under such conditions that it shall become as bad as before filtration. A desire for economy in original outlay may lead to a scanty area of settling-basins and filter-beds; but a subsequent larger demand than the plant can meet will necessitate either too rapid filtration, by which imperfectly filtered water will be obtained, and the beds fouled throughout; or an admixture of unfiltered water, which, even if necessary for a short time only, will foul the pipes, and undo the subsequent work of the filter.

I should not recommend any town to undertake the artificial filtration of their water unless they were willing to face the probability of its costing from $2.50 to $3.00 per million gallons in addition to the original outlay for the works.

II. — Natural Filtration.

The so-called *natural filtration* has already been described to a certain extent in the Fifth Annual Report of the State Board of Health in connection with the water-supplies of Lowell and Waltham. As, however, each year witnesses an increase of the number of towns thus supplied, and as it is important that the principles on which the process depends should be clearly understood, it will be appropriate to briefly discuss the matter in connection with the artificial filtration which has just been considered.

In the first place, it is necessary to obtain some clear idea of what is meant by the "ground-water;" for this is the source of the water obtained by this method. Most rivers of any size flow for a portion of their course through beds of sand and gravel of greater or less extent, which have been deposited by the river itself at an earlier stage of its history. Many ponds and lakes are situated in a similar deposit. In any such case, near the banks of the river or pond, the water stands in the gravel at approximately the level of the river or pond; and, as we recede from the banks, the water-level is found to rise more or less regularly according to the character of the deposit. In fact, in any deposit of sand or gravel resting on an impervious stratum of rock or clay, water will usually be found. This is often spoken of as the ground-water, or by engineers as the water-table.[1] Although subject to fluctuation, the ground-water often maintains a very uniform relative level over large areas: its height and fluctuations are important factors in the sanitary condition of any locality.

The water obtained by sinking a well into a stratum of sand or gravel which has not been artificially disturbed is, as a rule, bright and clear, and free, or nearly free, from organic matter. Although originally coming from the atmosphere, in its slow passage into and through the ground the water has been subjected to a long process of sedimentation and filtration, combined with processes of oxidation. In this sense, the water may be said to have been purified by *natural* filtration: the process, however, is not brought about by the means taken to collect and utilize the water, but has been practically completed before the demand is made upon it.

We will consider first the principal methods by which this underground supply is made available, and then discuss its proximate source and the effect of such taking upon the ground-water itself.

The most simple method, and the one earliest adopted, is to sink a well, covered or open, into the water-bearing stratum, and to pump therefrom. Such a well, which draws its supply from the ground-water proper, is generally called a shallow well, in distinction from a deep well, which may extend into a rocky stratum, and obtain its supply from a water-bearing fissure; and in distinction also from an artesian well sunk to a considerable depth into underlying strata which have no connection with the ground-water of the particular locality. This method of shallow wells has been employed from time immemorial on the small scale requisite for supplying the water for a single family or group of families: it has also been and is frequently used in supplying a portion or the whole of the amount needed by large communities. A good and accessible example of such a well is that situated in Prospect Park, Brooklyn, N.Y., which

[1] Or as the water-spring or water-basin. The water-table might more strictly designate the surface of the ground-water, but there is no consistency in the use of the term.

is some thirty-five feet in diameter, and supplies 700,000 gallons daily. The water, although suitable, is not used for domestic supply.

Attleborough, Mass., is supplied by a similar well, although in this case a portion of the water is derived from a lower stratum by means of iron pipes driven into the bottom of the well, and the well itself is dug in a gravelly intervale, about seventy-five feet from the river. This method of procuring a supply of water is also quite common in the Western States. Many industrial establishments, especially bleacheries and paper-mills, are supplied with water in this way, the wells being generally located near the banks of a stream.[1]

In some places the well from its dimensions may more properly be called a basin, and this form of construction is of long standing abroad. The works of some of the towns and cities in Europe where such basins are in use are described by Kirkwood; and for details of others reference may be made to the books, the title of which appear at the end of this article. In our own country the pioneer basins are said to be those of Newark, N.J., which were constructed in 1869. There are now many others in the United States, and several in Canada. In Massachusetts the cities of Newton and Taunton are supplied from uncovered basins on the banks of rivers. The town of Waltham is provided with a filter-basin

[1] In order to obtain some definite idea of the extent to which the various methods of filtration were employed in furnishing water for manufacturing purposes in this State, the Secretary of the Board addressed a circular to various manufacturers of the finer grades of paper, the names being obtained from a trade directory. Fifty-one circulars were sent, and twenty-seven replies received. The circular was as follows: —

COMMONWEALTH OF MASSACHUSETTS.

OFFICE OF STATE BOARD OF HEALTH.

STATE HOUSE, BOSTON, Sept. 1, 1877.

DEAR SIR, — It is expected that the next Annual Report of the State Board of Health will contain a paper by Professor Nichols, of the Massachusetts Institute of Technology, on the subject of filtration of water both on the large and on a household scale.

Although the subject will be considered primarily from a sanitary point of view, it is desired not to neglect the question of the filtration of water for industrial purposes. We are aware of the necessity of clear and colorless water in the manufacture of the better grades of paper, and are also acquainted with some of the many devices which have been adopted for obtaining water suitable for this use. In order, however, that we may make the matter more of somewhat similar construction, to which more particular allusion will be made hereafter.

The second method of collecting the ground-water is by means of a covered gallery or tunnel constructed in part of porous material; often the top and sides are built of tolerably impervious masonry or brickwork, while the bottom is of an open character, so that the water which rises into the gallery shall come mainly from beneath. An example of this now quite common mode of collection is at Lowell, Mass. A description of the works was given in the Fifth Annual Report of the Board of Health. The "filtering-gallery" is situated about 1,500 feet above Pawtucket Bridge, on the northerly shore of the Merrimack River and parallel with it, about 100 feet from the water's edge. Its length is 1,300 feet, width 8 feet, and height (inside) 8 feet. The side-walls have an average thickness of 2¾ feet and a height of 5 feet, and are constructed of heavy rubble-masonry, laid water-tight in hydraulic mortar. The walls support a semicircular brick arch, one foot thick, made water-tight. Along the bottom, stone braces, one foot square and eight feet long, are placed, ten feet from centre to centre, between the walls, to

complete, by having data from the experience in our own State, we should esteem it a favor if you would be willing to answer the enclosed questions.

Please address replies, as early as you may find it convenient, to Professor Nichols.

In behalf of the State Board of Health,

Very respectfully yours,

CHARLES F. FOLSOM, M.D., *Secretary.*

1. Name of mill.
2. Owners.
3. Location,— town? On what stream?
4. Source from which water is taken for manufacturing purposes.
5. If the water is subject to any process of purification, please indicate the process, and the results obtained.
6. If the process be one of *filtration*, please indicate—

(*a*) The material employed; or the maker of the filter, if a patented filter is employed.

(*b*) The amount of water filtered daily.

The number of replies was too small to furnish data from which to make accurate particular statements. The general facts ascertained are as follows: The greater number of the mills from which replies were obtained either use spring, river, or pond water as drawn, or else, and more often, subject it to simple straining through wire screens, excelsior, flannel, &c., or pass it through sponge filters. Of the rest, a few have some such systematic arrangements for artificial filtration as have already been described on page 151, but a larger number rely upon shallow wells sunk near the banks of a running stream.

keep them in position. The bottom is covered with coarse-screened gravel, one foot thick, to the level of the brace-stones.[1]

This description will be made somewhat clearer by the accompanying cut, taken by permission from Fanning's "Water Supply Engineering."

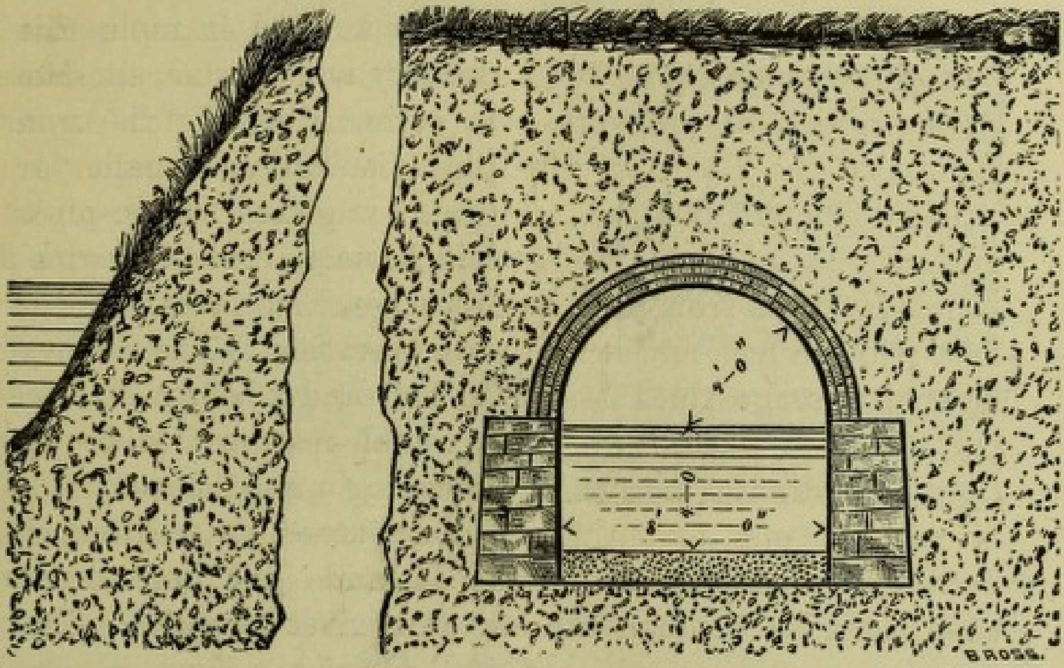


FIG. 4.
Filter-gallery, Lowell, Mass.

It may be remarked that the quantity of water which can be obtained has proved inadequate to the wants of the city, and some water is taken directly from the river. The bottom area of the gallery has more recently been increased by the construction of what purports to be a filter-bed, as already described on page 153.

A third method, which as far as I know has not been employed in this country, is to substitute for the collecting-gallery a line of iron pipes, i.e., practically water-mains, cast with a great number of narrow longitudinal slits, and laid with loose joints. These pipes collect the water, and conduct it to receiving-wells from which the supply is pumped. In filling the trench in which the pipes are laid, the pipes are surrounded on all sides with coarse material, of too large a size to fall into or through the slits, and the trench is then filled with screened material of decreasing size. Works of

[1] Third Annual Report of the Water Commissioners of the City of Lowell, January, 1873.

this character are in operation in various places in Germany, as for instance in Dresden and in Halle. Full details may be found in the reports of these cities, the titles of which are given farther on. The figure No. 5 will give some idea of this method. A somewhat similar method, in use in this country and abroad, consists in substituting for the iron pipes ordinary cement or other unglazed drain-pipes laid loosely. At Arlington, Mass., such an arrangement is in operation, the pipes being laid in the gravelly bed of an artificial reservoir made by damming a small brook.

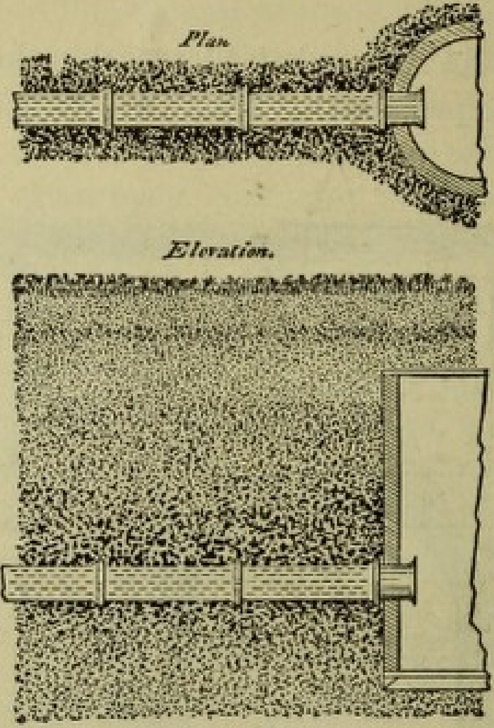


FIG. 5.

Sometimes the collecting-galleries or pipes are, as in the instance just mentioned, placed actually beneath the bed of a river or pond. The following is a description of the filtering-gallery in use, with very satisfactory results, at a paper-mill on the Westfield River, the details of which were furnished me by one of the proprietors, C. O. Chapin, Esq.: —

" The water used for washing and cleansing purposes is obtained from a gravel or sand bed or bar about 1,200 feet up the stream from the mill, and on the opposite side. This bar lies within the bed of the river when the water is high, although not covered with water for the greater part of the year. In this gravel-bed, a trench of 250 feet long was dug, of such depth as to bring the bottom of it as low as, or lower than, the bottom of the river at its deepest part, and of six feet or more in width. The trench was then filled to the depth of a foot with stones of various sizes, from small cobble to coarsest gravel stones, making the surface as even as possible, though with a slight grade down stream.

" On this foundation a line of timbers six by six inches is laid on each side of the trench, four feet apart. Across these are placed and firmly nailed on, three feet apart, square frames four feet wide by three feet high, made of timber six by six inches, each frame strengthened in the centre by a standard two and one-half by six inches from the top to the bottom. The top and two sides of this row of frames are covered with hemlock plank two and one-half inches thick; and thus a filtering-gallery 250 feet long, three

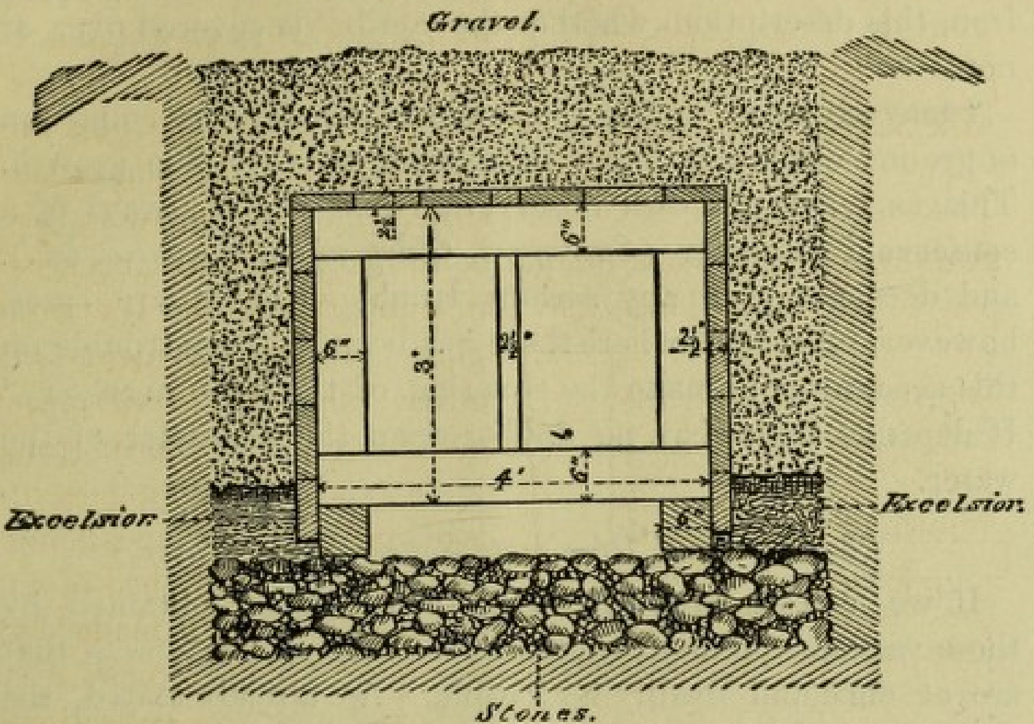


FIG. 6.

feet high, and four feet wide, is made. On the outside of this gallery, at the bottom, a filling of eight inches of excelsior is lightly tramped down; and then the trench is filled up with the gravel, and the filter is complete. From this filter 600 gallons per minute of the clearest water are obtained. The filtration is upward and through the stone bottom: the gallery is kept full in low water by taking water through canals over the filter from a point in the river above."

The account of this gallery has been given with some detail, to show that at a comparatively small expense it might often be possible for a village or small town to procure a supply of water of superior quality, although some modifications might be suggested if the water were to be used for domestic purposes. The possibility in any given case, of obtaining conditions sufficiently favorable for the adoption of such a scheme, would be necessarily a matter of experiment. The town of Decatur, Ill., is actually supplied by a similar gallery, which is thus described by the superintendent: "We filter by a natural process by sinking a crib measuring 10 feet × 110 feet, and 50 feet from and parallel with the river, into a stratum of gravel, the bottom of crib being about three feet below bed of river, and seven feet below low-water mark. The crib is not large enough, and we are going to enlarge it next season." It is not perfectly clear, from this description, whether the "crib" is covered over or not.

I may say at this point that open basins for the collection of ground-water are liable in summer to vegetable growth. This, as far as my own observation extends, is always of a confervoid character (*Spirogyra*, *Œdogonium*, *Zygnema*, &c.), and does not give any serious trouble. There are cases, however, on record, where there has been so much trouble on this account as to make the covering of the basin necessary.[1] It depends somewhat, no doubt, upon the character of the water.

Character and Proximate Source of the Water.

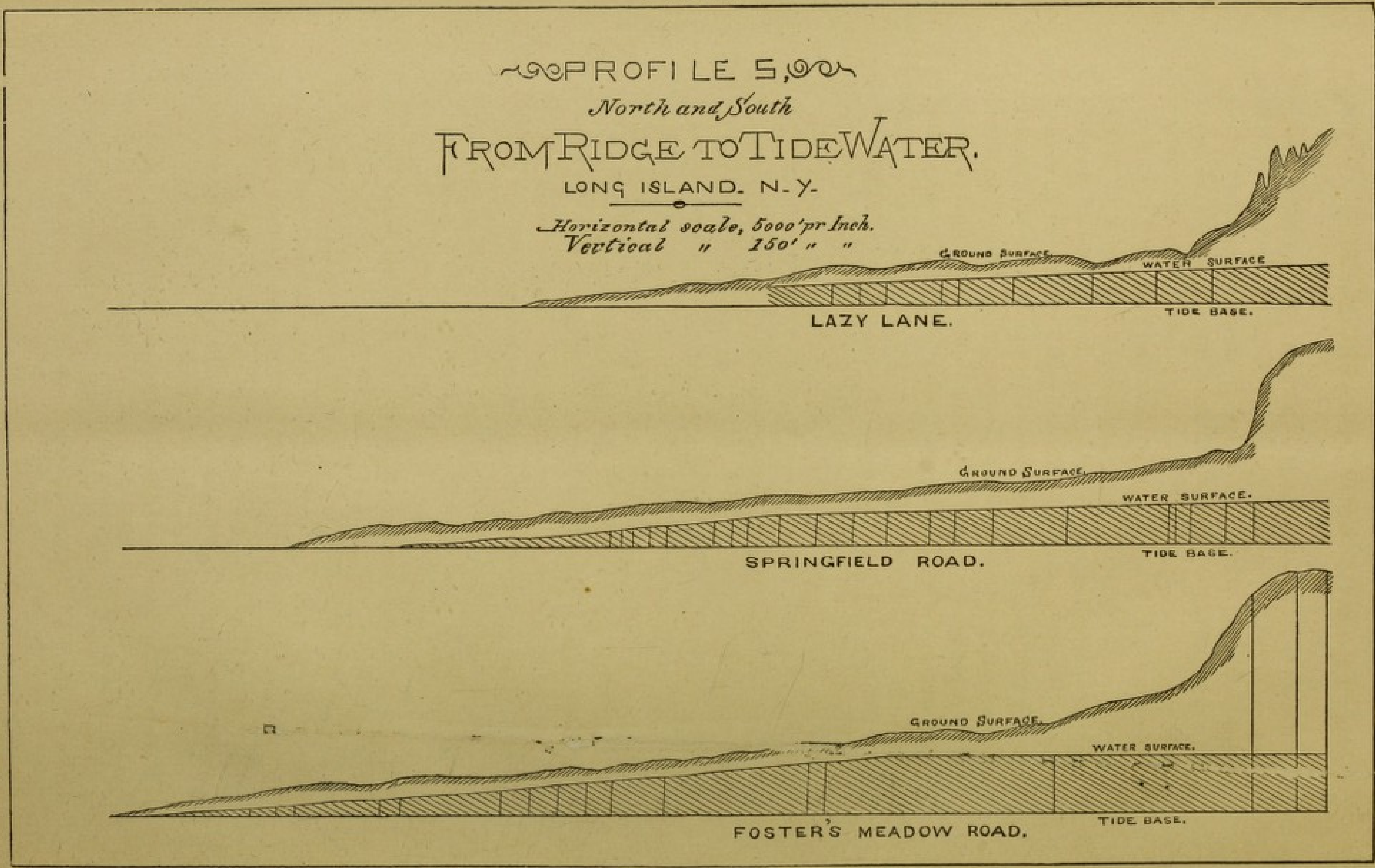
If we consider the character of the water obtained by these various methods, there are certain general facts that are at once and readily noticeable. As already stated, the water thus obtained is generally clear and colorless: it is of a quite uniform temperature, cool therefore in summer, and in winter much warmer than the water of neighboring ponds and rivers, which, of course, approach in temperature very close to the freezing-point. The water also differs in chemical character from that of neighboring streams or ponds, generally being somewhat harder.

[1] This was the case in the "filtering-gallery" of Toulouse. "Le premier filtre donna d'abord de fort bonne eau; mais, dès la deuxième année, une végétation de plantes aquatiques commença à s'y établir, et à altérer la qualité de ses produits. L'année suivante, le mal empira : les rayons du soleil traversant sans obstacle une couche d'eau mince et transparente, atteignaient le fond dans toute leur intensité; ils y développaient une forte chaleur, laquelle était encore augmentée pas l'effet et la réverbération des bords et des digues. Par suite, la végétation y acquit une vigueur extrême ; les divers moyens employés pour la détruire furent sans effet; des reptiles s'y joignirent. Ces plantes et ces animaux, en mourant et se putréfiant dans une eau tiède, la rendaient très mauvaise.

"Il fallut se presser de porter un remède au mal ; encore un an, et il eût été absolument intolérable. L'eau était très bonne en entrant dans le filtre, et vicieuse lorsqu'elle en sortait. La forte chaleur et la lumière en étaient la cause manifeste; il fallait l'attaquer. On ne le pouvait qu'en couvrant le filtre; j'en émis l'idée: on remplit le fond avec des cailloux et puis on le combla.

"Depuis que le filtre a été ainsi disposé, la qualité des eaux s'est non seulement rétablie, mais améliorée." . . . — D'Aubisson, *Annales des Ponts et Chaussées*, 1838; also quoted in Dupuit, de la Distribution des Eaux, p. 122, and in Dupasquier, des Eaux de Source, etc., p. 144.

FIG. VII.


PROFILE 5,
North and South
FROM RIDGE TO TIDE WATER.
LONG ISLAND. N.Y.
Horizontal scale, 5000' pr Inch.
Vertical " 150' " "
GROUND SURFACE.
WATER SURFACE
TIDE BASE.
LAZY LANE.
GROUND SURFACE.
WATER SURFACE.
TIDE BASE.
SPRINGFIELD ROAD.
GROUND SURFACE.
WATER SURFACE.
TIDE BASE.
FOSTER'S MEADOW ROAD.

Although for many practical purposes it is sufficient to know that the water procured is of good quality, it will be interesting and perhaps profitable to inquire somewhat into the proximate source of the water thus obtained. I say proximate source, for of course the rainfall is the ultimate source from which all our available water comes.

Over limited areas the upper surface of the ground-water may be nearly horizontal: there is, however, almost always an inclination and a more or less sluggish movement towards a lower level, a river, or a lake. Although there do occur actual underground streams flowing with greater or less velocity, especially in rock formations which abound in fissures, in sandy or gravelly deposits, which are tolerably homogeneous, it is seldom strictly correct to characterize the movement of the water as a *flow* in the sense in which we apply the term to streams above ground. The term is, however, so convenient that it may be used if it be not misinterpreted.

The inclination of the ground-water depends mainly upon the character of the water-bearing stratum itself: where this is thin, the configuration of the underlying impervious stratum exerts some influence, especially in determining the direction of the flow; configuration of the surface has very little influence in the matter, and can seldom give any reliable indications of the water-level beneath it.

A number of careful observations have been made on the level of the ground-water in different places, and its variations, together with its relation to neighboring streams or ponds. To American readers, the most extensive of such as are readily accessible are in the Report of the Brooklyn Water Commissioners on the Brooklyn Water-Works and Sewers: New York, 1867.

Where the character of the water-bearing stratum is tolerably uniform, and the underlying impervious stratum is at a considerable distance from the surface, there is generally a more or less uniform increase in the height of the ground-water as we recede from the shore. This is well marked in the case of Long Island, where there is a quite uniform slant from the central ridge to the ocean or to Long Island Sound. The average inclination is about seven feet to the mile. From the many profiles in the Brooklyn Report alluded to, a few for the sake of illustration appear in Fig. 7, opposite.

In some localities the inclination is much greater than this for limited distances; thus, in the neighborhood of the Taunton Water-Works there is a fall, in what seems to be a continuous water-table, of about 14 feet in 1,000.[1]

Now, what happens when a well is sunk into the ground-water? We will first take the case of a well like that in the Prospect Park, Brooklyn, N.Y. This well is nearly two miles from tide-water, and the level of the water in the well is 13 feet above tide. It is, therefore, far removed from any large body of water which could be supposed to influence it. In such a case as this, of course the mere opening of the well makes no difference in the natural level of the water in the same stratum; but when water is pumped from the well the level of the ground-water is lowered for a certain distance in every direction. If the water-level in the well be kept for a sufficiently long time at a certain fixed point, by pumping as much as may be necessary, the ground-water around the well in every direction also assumes a constant level. The form of the water surface will be understood from Fig. 8, which represents a section through the well; the water-level being indicated by the curved line which lies above the straight line joining the two points *a* and *b*. The exact shape of this curve, its distance above the straight line,

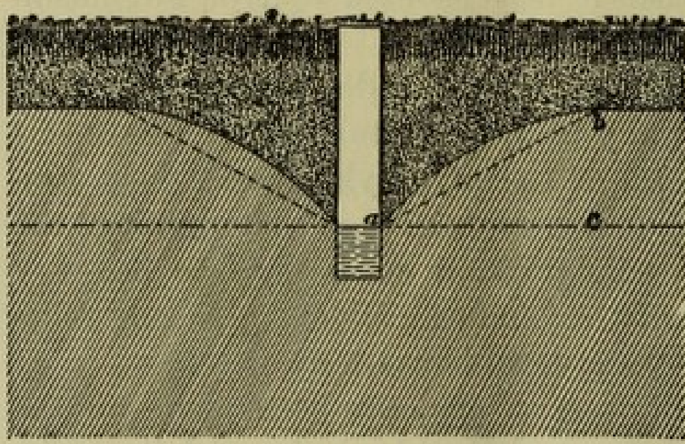


FIG. 8.

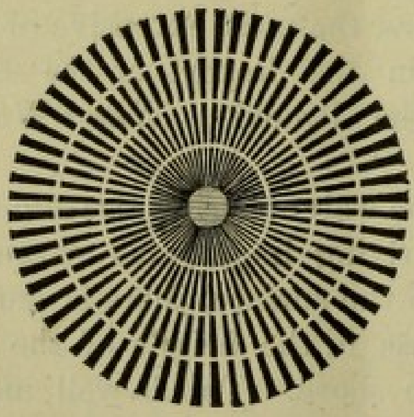


FIG. 9.

[1] A great many profiles resulting from actual measurements, and showing the inclination of the ground-water, may be found in the Berlin and Munich reports, the titles of which appear on pages 224–226. In the latter the profiles include the surface levels, the level of the ground-water, and the level of the underlying impervious stratum, and are very instructive.

will depend mainly upon the nature of the ground, as will also the quantity of water which must be pumped in order to maintain a constant level in the well, and also the point *b*, which is the outer limit of the measurable influence on the ground-water. Of course this influence is in every direction as shown in the plan, Fig. 9.

Although perhaps somewhat difficult at first to obtain a clear idea of the matter, this taking of water from the ground-water differs in almost nothing from taking water from a lake or pond. Suppose that we have a lake or pond, as there are many, generally situated in valleys, with no considerable visible inlet, and yet from which experience has shown that a certain number of gallons daily can be withdrawn without affecting its level. If this lake be now filled with sand and gravel, we can still pump the same daily *quantum* (even more, owing to lessened evaporation) ; but, owing to the resistance of the material, the level of the water does not equalize itself at once, and for a certain limited distance the water forms a curved surface of the same general character as would be formed by water flowing through a bank of sand or gravel if the water-levels on the two sides of the bank were different but constant. The character of that curve, as ascertained by experiment, I shall speak of later. (See page 195.) To return now to our well. If the demand made upon the well be increased, — that is, if the level of the water in the well is kept constantly at a lower point, — the circle of influence is extended, but not in proportion to the increased supply. Theoretically, in a perfectly homogeneous material, if the ground-water were lowered through a double distance, the influence would be felt twice as far ; i.e., the circle of influence would be four times as great. Practically, these theoretical conditions would be only partially realized, as it would be impossible to have a perfectly homogeneous deposit. Of course, in order that the well should give a uniform supply, the amount of rainfall received over the region drained, and over the region which contributes to the underground supply, should be uniform. The level of the ground-water is subject naturally to some variations, according as the season is wet or dry. If there were no rainfall, the ground-water would be lowered eventually throughout the entire water-bearing stratum, practically to very nearly the level of the water in the well; or, to refer to the Figure 8, the point *b* would recede farther and farther until for some distance the curve *a b*, the straight line *a b*, and the straight line *a c* would all three practically coincide. That is to say, if the lake which we took for comparison were no lake, but a cistern, it would be eventually pumped dry, or to the level of the suction-main.

The general principles relative to the effect of pumping upon the ground-water in the same tolerably homogeneous stratum are not matters of conjecture or theory, but have been determined by experiment. I may refer to Salbach's Report on the Dresden Water-Works, from which figures Nos. 9 and 10 are taken. In the experiments which were there very carefully conducted in the alluvial deposit on the banks of the Elbe, from which the water has been taken for the supply of the city, it was found that when the water in an experimental well was, by pumping, kept constantly 2.5 meters below its normal level, the height of the ground-water was affected in every direction for a distance of 60 meters (about 200 feet), and that the curve which the level of the ground-water assumed was the same as represented in the Figure 8. (If the figure is to apply to this particular case, the vertical scale is to the horizontal as 10 to 1, and the diameter of the circle is 120 meters.) Beyond this point the effect was inappreciable. The Figure 10 represents what

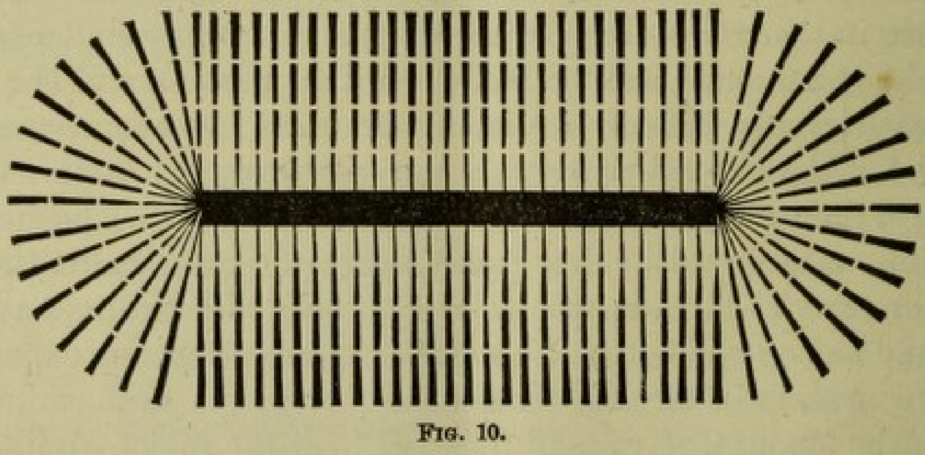


FIG. 10.

would be the effect of a series of such wells connected together, or, what amounts to the same thing, a pervious gallery in which the water was kept at the same constant level. It is to be borne in mind, that in the case referred to, the gravel was extremely porous, and the well was located very near the bank of the river. The amount of water necessarily pumped, in order to keep the level at the point indicated, was 1.56 cubic meters per minute (about 600,000 United-States gallons per day).

In comparing the ground-water to a lake, we overlook one important point, namely, the movement of the ground-water. A more just comparison in many cases would be to compare it to a pond formed by the enlargement of a stream, where there is a continual inflow and discharge, although the current is hardly noticeable.

The most favorable situation for a gathering well, basin, or gallery, is therefore in the neighborhood of a lake or river, for two reasons; first, because at such a place there is almost certain to be a decided movement of the ground-water towards the stream; and, in the second place, the water from the river can make up any deficiency caused by removal of the ground-water.[1]

It was formerly supposed, and is so even now by many persons who have not made a study of the subject, that in such cases the water is derived directly from the river, and filtered by passing through the intervening sand and gravel. While I would not deny that in some cases even a considerable amount of water comes from the stream, I believe that as a rule the smaller proportion of the water is thus derived, and in many cases none at all.

That it is not necessary in all cases to call upon the stream directly to explain the source of the water, is evident, if the above explanation of wells sunk at a considerable distance from any stream is correct. Suppose, for the moment, that the bank of the river is actually water-tight: it is manifest, that, instead of a "circle of influence," we have now to deal with a "semicircle;" otherwise things are as before.[2] The bank is not, however, as a rule, even practically water-tight; but in the natural condition there is, at least where

[1] Hereafter, in speaking of "collecting-wells near the banks of a stream or river," it will be understood that the term "well" shall include also open or covered galleries or basins, and that the term "stream" or "river" shall also include "ponds" or "lakes." The essential points are the same in any of these cases.

[2] If the level of the water in the well were kept below the bottom of the river, the circle of influence might then be completed on the other side of the stream: if by so doing the tendency was to lower the level of the ground-water, and leave a vacuous space under the bed of the river, the river-water would work its way down to fill the gaps, and in that way water would be obtained from the stream.

the ground is sandy or gravelly, a continual passage of the ground-water into the stream. It is well known that a river passing through an alluvial deposit of sand and gravel generally increases in size as it flows, even when no visible streams add to its volume. The observation has also been made again and again, that the water in shallow wells situated at some distance from a river stands at a higher level than in the river itself. This was clearly shown by measurements made for a considerable period in Berlin, Germany, on a large number of ordinary and bored wells all over the city, and at different distances from the Spree. Here it was supposed that the impurities of the river were fouling the wells of the city; but these experiments showed that the ground-water in the region lying about the river was really at a higher level, and that the movement was towards the river; and many experiments since that time have shown the same thing.

It is well known that wells may often be sunk very near to tide-water, may rise and fall with the tide, and yet yield fresh water; in the same way the level of the ground-water along any stream is determined by the height of water in the stream. Let us consider the explanation of this fact. Suppose the tide falls, or the water in the river is lowered. The ground-water level also falls, but more slowly, on account of the resistance of the ground, and continues to fall after the tide or stream begins to rise. The rising water, however, reaches the point to which the ground-water has fallen; and, as it continues to rise, it causes the setting-back of the ground-water, or at least interrupts its flow. The level of the water in the ground then rises somewhat as is represented in Fig. 11, No. 2 (op. p. 195). Here the several curves may represent the successive levels of the ground-water, as the stream or tide successively reaches the points indicated by the right-hand extremities of the lines. If the ground is very porous, and there is little flow to the ground-water, the water from the outside may work into the bank, but the distance will be a limited one. Sometimes, in the case of a sudden flood, the water may for a time stand considerably higher in the river than in the ground in the immediate vicinity. Other things being equal, the passage of water from the ground, into the bed of a river, is much more easy than its passage from the river into the ground; for the particles of silt deposited on the bed of the river, choke the passages between the grains of sand and gravel, and become, as it were, wedged in. Pressure from the outside tends to make the mass more compact and less pervious; but, if pressure be applied from the inside, the particles of silt are forced out or lifted as valves from their seats. If the condition of things be as just stated, it must be ordinarily possible to intercept and appropriate a certain amount of water by means of a well or gallery, without drawing water from the river itself, although it would be extremely difficult to estimate what this amount might be in any given case except by inference from gaugings of the stream above and below the point in question.

It is not strange that the river or pond should be assigned as the source of the water which is actually obtained; for, in the first place, it seems to the ordinary mind hard to believe that such a large amount of water can be drawn day after day from no visible source, even if the fact of a general natural flow towards the river be admitted. It also sometimes happens that wells which are situated in very porous deposits near tide-water, and from which considerable quantities of water are taken, become brackish, indicating that the sea-water does sometimes find its way through the gravel. On the other hand, there are many facts which tend to show the contrary, and which I will mention in a general way, and then proceed to describe certain particular instances where observations have been made. The yield of course varies in different localities; but it is generally true that while increasing the bottom area of the basin, or its length in the direction of the stream, increases the amount of water obtained, this increase is not in proportion to the area or length. It is almost invariably found that the temperature of the water thus obtained is nearly uniform from season to season, while that of the river is subject to considerable variation. Often also the water differs very much in particular respects; such, for instance, as in hardness, which will make itself evident by its effect when the water is employed for washing, or in steam-boilers. In this neighborhood the difference in hardness is not great, although in time it shows itself by the formation of boiler-scale. Belgrand gives a number of examples from French localities, from which I may cite the following:[1] —

Water of Rhone, at Lyons,	16°
Water of filtering-gallery at Lyons,	17.94
Water of Loire, at Nevers,	4.96
Water of collecting-well,	20.70
Water of Loire, at Blois,	7.76
Water of the gallery (which is beneath the bed of the river),	14.45

Sharples has found[2] that the water in the filter-gallery near Little Pond, Cambridge, contains nearly twice as much lime as that of the pond, and instances might be multiplied indefinitely. In the case of the Dresden water-supply before alluded to, the river-water is harder than that obtained from the collecting-wells.[3]

Even when the gallery or well is sunk directly in the bed of the river, or in an island surrounded on all sides by the river or pond, the ground-water still contributes largely or wholly to the supply. Many experiments have shown that the water in a gravel-deposit directly beneath a river differs essentially from that of the stream itself.

I now proceed to give a few instances of observations which have been made in particular cases. The city of Toulouse, in France, is supplied by a number of filtering-galleries in a gravel-deposit on the banks of the Garonne. The original gallery was built in 182– at a distance of about 60 meters (200 feet) from the river. This furnished water acceptable in quality, but deficient in quantity; an increase of the length of the gallery failed to furnish a corresponding increase in quantity of water obtained. A second filtering-gallery, or rather series of connected wells, was constructed nearer to the river, at a distance, in fact, of only 10 meters. In this case, the water obtained manifestly did come, in part at any rate, from the river: the river was somewhat turbid, and, what is very instructive, the passage through a bank of thirty feet, and admixture of course with some ground-water, failed to bring the water to any thing like the uniform temperature of the other galleries. The temperature fell in winter to 2° C.

1 La Seine, &c. pp. 463 and following.

2 Twelfth Annual Report of the Cambridge Water Board, for the year 1876. Boston, 1877; page 30.

3 Salbach. Das Wasserwerk der Stadt Dresden; 3 Theil, page 7.

(36° F.), and in summer rose above 21° C. (70° F.).[1] This gallery was therefore abandoned, and others constructed at a greater distance from the stream. These furnish water which is satisfactory, except when in time of flood the river covers the whole territory in which the galleries are built.

Lowell, Mass. — In the Fifth Annual Report of the Board of Health may be found an account of the examination of the water in the filtering-gallery at Lowell, as compared with the water in the river; and it is not necessary to enter into any further discussion at this place. The conclusion reached was, that the river could not be regarded as supplying directly the whole of the water obtained. Since that time the supply has proved inadequate to the demand, and it has been necessary to use unfiltered river-water.

Waltham, Mass. — The case of Waltham was also mentioned in the report alluded to, and chemical examinations of the water of river and filter-basin were made: I have had occasion to study the question somewhat further since the date of that report.

The water-supply of Waltham is pumped from a so called "filter-basin" on the banks of the Charles River. This basin was constructed at the side of the stream, partly by making an excavation into the knoll at the foot of which the basin is situated; and partly, on three sides in fact, by enclosing a portion of the river by a gravel embankment some fifty or sixty feet wide. This embankment slopes outward on the river side, but is walled perpendicularly on the side towards the basin. The idea at first was, that the river-water should *filter through* this gravel embankment, and the filtered water should then be pumped into the reservoir, and distributed for domestic use. Practically, it seems, however, that the basin draws the main portion of its supply, not from the river, but in part from the ground-water proper, and in part from actual springs rising from a lower level, — from what we might call an *under*-ground water. Even casual observation would lead to this conclusion. In the first place, it was noticed, before the construction of the basin, that in winter there was generally open water at this point in the river, or,

[1] "Se trouvant trop près de la rivière, elle en conserva trop la temperature; dans l' hiver dernier, sa chaleur a diminué, jusqu' à n'être qu' à 2° du thermomètre, et, dans l'été, elle va a plus de 21°." — D'Aubisson, *Ann. des Ponts et Chaussées*, 1838.

when ice did form in extreme cold weather, that it was thinner than on the river itself, indicating the entrance of warmer water from the land. Further, during the construction of the basin it was found that water came into it so rapidly from springs, that it was necessary to pump at the rate of 4,000 gallons per minute in order to remove the water that the work might go on: moreover, the water sometimes stands higher in the basin than in the river, and the temperature is quite uniformly 49° or 50° F. The pumps do not work on Sunday; and on Monday morning, when the weather is cold, the water which has then stood in the basin some thirty-six-hours is found to be skimmed over with ice, having acquired at the surface a low temperature; but during the week, as the water is constantly renewed and constantly supplied, it is found that the temperature varies but slightly.

It has been also observed, that, while the Charles-river water has no effect on steam-boilers, the water from the basins causes a slight incrustation after some time, although the basin-water is itself very soft.

I was requested in the year 1876, by the Water Commissioners of Waltham, to make some examinations which might lead to an opinion as to the source from which the bulk of the water came. The experiments as planned were never fully carried out, but the investigation proceeded far enough to confirm the view above expressed. The report containing the results of my observations was never printed; but, by permission of the Water Commissioners, I can quote somewhat freely from it in this place, avoiding, as far as possible, repeating what has been already stated in the Fifth Annual Report of the Board already alluded to.

Many examinations have shown that the basin-water contains much less ammonia and "albuminoid ammonia" than the water of the river, that the total dissolved matter is somewhat greater, and that it consists in a larger proportion of mineral matter. See Table VI. Owing to the smaller proportion of vegetable matter, the water in the basin is clear and colorless.

TABLE VI. — *Examination of Water from Waltham, Mass.*

[Results expressed in parts per 100,000.]

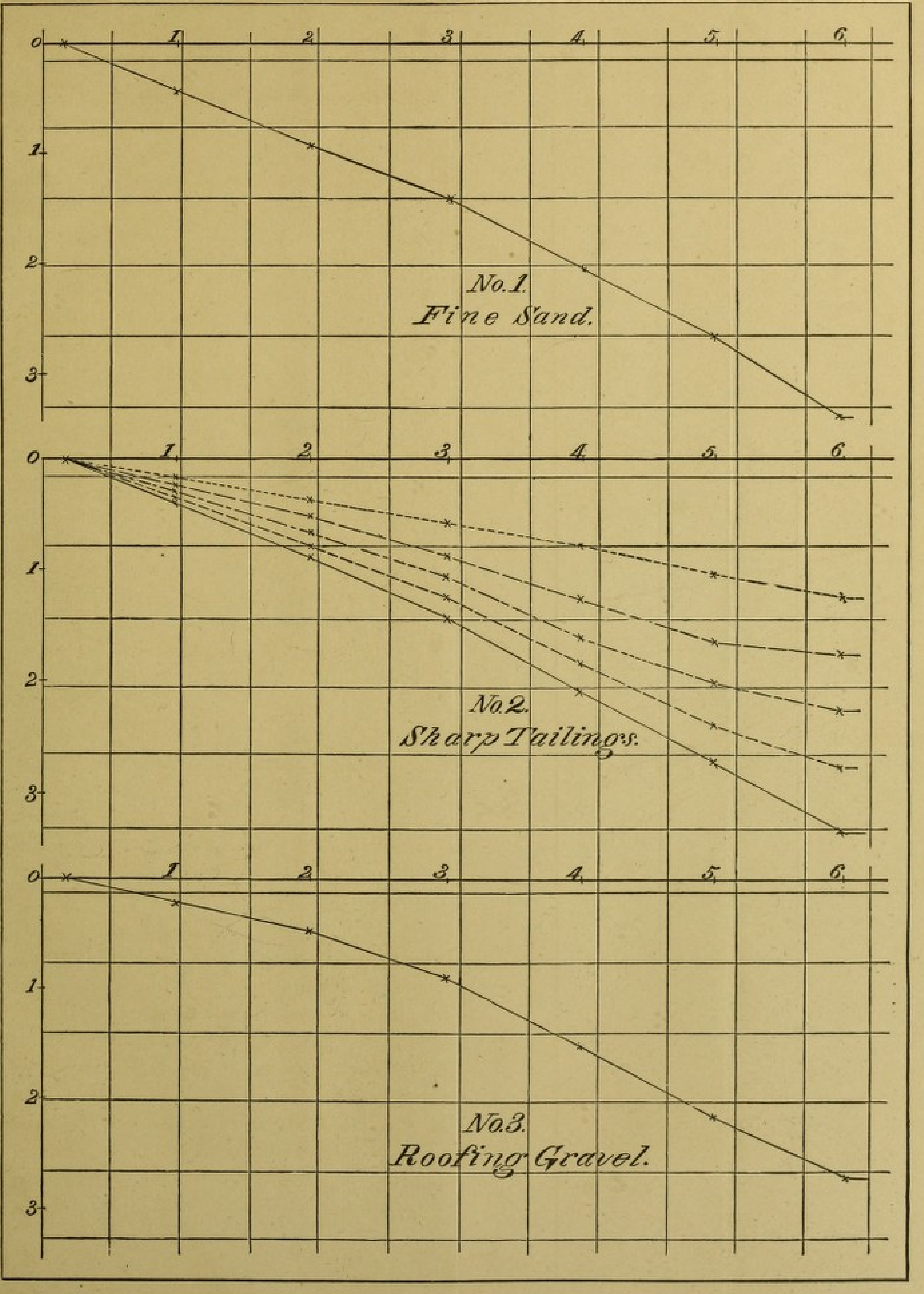
Number.	Date.	LOCALITY.	Ammonia.	"Albuminoid Ammonia."	Solid Residue. Inorganic.	Solid Residue. "Organic and Volatile."	Solid Residue. Total at 212° Fahrenheit.	Chlorine.	Silica.	Sulphuric Acid (SO_3).	Lime.	Height of Water in River.	Height of Water in Basin.
	1876.												
1	Aug. 1,	River, . .	0.0107	0.0259	3.08	1.84	4.92	-	0.48	0.27	0.68	3.01	0.90
4	Aug. 12,	River, . .	-	-	2.90	1.68	4.58	0.38	0.47	-	0.65	1.45	-
8	Aug. 23,	River, . .	0.0069	0.0253	2.60	2.36	4.96	0.33	0.77	0.33	0.66	2.02	0.60
2	Aug. 1,	Basin, . .	0.0016	0.0075	4.84	0.80	5.64	-	0.95	0.31	1.15	3.01	0.90
3	Aug. 12,	Basin, . .	-	-	5.44	1.02	6.46	0.42	1.01	-	1.14	1.45	-
7	Aug. 23,	Basin, . .	0.0016	0.0067	5.34	0.80	6.14	0.30	1.57	0.32	1.08	2.02	0.60
16	Aug. 26,	Basin, . .	-	-	5.40	0.42	5.82	0.19	1.29	-	1.42	1.89	— 0.48

The first question which would naturally arise is, whether it would be possible for the water of the river, in passing through the bank of gravel some 50 or 60 feet thick, to become changed so as to be similar to the water in the basin.

I answer that it is not *impossible;* and, to determine the probability in this case, I have made a variety of experiments. In the first place, I examined the gravel of which the bank is made, and found that it is not destitute of soluble matter. In fact, a portion treated for a number of hours with boiling water gave up to the water 0.02% (two one-hundredths of one per cent) of its weight of soluble matter. In order to judge of the probability of the solution of mineral matter by the percolation of the river-water at ordinary temperatures, some gravel taken from the bank (and which had been screened through a sieve of three meshes to the inch) was packed in several lengths of four-inch lead pipe connected together so as to form a column about 22½ feet in length, and supported in an inclined position. Through this gravel I allowed to flow slowly (with a single interruption when it was necessary to alter slightly the situation of the pipe), for a number of weeks, a constant stream of Cochituate water, — a water very similar to that of Charles River. The water as it flowed from the end of the pipe was examined chemically at several different times. It was found that the water lost a large proportion of the vegetable matter dissolved in it, and that it became brighter and less colored. At first there seemed to be also a slight loss of mineral matter; but after a time there was practically no difference between the amount of mineral matter in the water before and after filtration.

Observations of the Relative Levels of Water. — While the level of the water in the basin would naturally be slightly above that of the river, and is indeed so when the pumping is interrupted for a sufficient length of time, ordinarily the river level is higher. Pumping is always discontinued at night; and then the water in the basin rises, at first rapidly, afterwards more slowly, but does not, as a rule, rise as high as the water in the river before pumping begins again. The question may be asked: If the water comes *through the bank*, as it was at first supposed that it would, what level would the water in the bank assume? In order to obtain an answer to this question by actual experiment, I had constructed a

Fig. XI.



box six feet long, four inches wide, and six inches deep, so arranged that when it was filled with sand or gravel I could keep a constant level of water at either end. This box was filled on different occasions with a variety of materials; and by means of glass tubes properly arranged, I was able to determine the level of the water in the sand at different points.[1]

Fig. 11 represents several of the curves obtained: in each case the difference of level was about three inches; in one case (No. 1) was used fine Berkshire sand, through which the water flowed with considerable difficulty; and in No. 3 common roofing-gravel was used. Whatever material was experimented with, — whether fine sand well compacted, through which the water passed very slowly, or roofing-gravel through which the water ran rapidly, — the general character of the curve was the same.[2] Fig. 11, No. 2, shows the effect of the gradual rise of water such as occurs in the basin when filling up. The lower curve represents the condition of things in the experimental bank when there was three inches difference of level: the outflow was then stopped, and as the water rose in the sand its height at different stages was noted. It will be noticed that the water-level rises throughout its whole extent, although not uniformly. It was therefore evident, that, if there was *free* passage of water through the bank, water would be found in the centre of the bank at a level nearly midway between that of the river and that of the basin. I then had driven into the centre of the bank, at two different points, iron pipes, such as are used in driven wells, terminating just below the bottom of the basin. These pipes we will call A and B. Several sets of observations were made on the relative levels of the water in these tubes; two of these

[1] Without going fully into all the precautions taken to insure accurate results, I may say, in reply to questions which would certainly arise in the minds of any who have made such experiments, that, in order to avoid the passage of water at an unequal rate along the sides and bottom of the trough, the box was painted inside and well sanded: also there was always a depth of about two inches of sand, or rather of dead water, below the point of outflow. Of course, for measuring the delivery of any particular material, such an experiment would be worthless; but the general character of the curve, which I wished to ascertain, could be reached accurately enough.

[2] In these diagrams, the vertical scale is ten times as great as the horizontal. It is evident that the curve lies in each case somewhat above the straight line joining the points which indicate the level of the water on the two sides of the bank; but for all practical purposes this curve may be taken as a straight line.

sets are given in the accompanying tables. The second set of measurements here recorded I made myself, and with very great care.

TABLE VII. — *Observations on Water Levels, Waltham Water-Works.*

Measurements made by T. W. ROBINSON.

[Heights stated in feet above zero of gauge in basin.]

Date.	Hour.	River.	Pipe A.	Pipe B.	Basin.	REMARKS.
1876.						
Aug. 23,	6 A.M.,	2.10	1.76	1.76	1.88	
23,	9 A.M.,	2.05	0.80	0.78	0.84	
23,	12 M.,	2.00	0.39	0.48	0.35	
23,	3 P.M.,	1.99	−0.04	0.06	−0.16 [1]	
23,	6 P.M.,	1.94	−0.27	−0.17	−0.46 [1]	
23,	9 P.M.,	1.97	0.29	0.36	0.25	Pumping stopped at 7 P.M.
24,	6 A.M.,	1.99	0.96	1.03	1.00	Pumping began at 5½ A.M.
24,	9 A.M.,	1.94	0.33	0.41	0.32	
24,	12 M.,	1.88	0.06	0.06	−0.21 [1]	
24,	3 P.M.,	1.85	−0.24	−0.24	−0.51 [1]	
24,	6 P.M.,	1.79	−0.54	−0.44	−0.71 [1]	
24,	9 P.M.,	1.82	0.11	0.16	0.19	Pumping stopped at 7 P.M.
25,	8 A.M.,	1.88	1.31	1.32	1.31	No pumping Aug. 25.
25,	11 A.M.,	1.83	1.40	1.41	1.42	
25,	7½ P.M.,	1.80	1.51	1.56	1.59	
26,	8 A.M.,	1.91	0.76	0.86	0.79	Pumping began at 5½ A.M.
26,	11 A.M.,	1.89	0.21	0.31	0.21	
26,	2 P.M.,	1.90	0.06	−0.12	−0.36	
26,	5 P.M.,	1.89	−0.24	−0.33	−0.61	

[1] In the case of these (5) observations, the measurements were not made with as great accuracy as the others, and they may vary 0.1 foot from the truth. In the other cases the limit of error may be 0.05.

TABLE VIII. — *Observations on Water Levels, Waltham Water-Works.*

Measurements made by W. R. NICHOLS.

[Heights stated in feet above zero of gauge in basin.]

Date.	Hour.	Pipe A.	Pipe B.	Basin.
1877. Feb. 9,	6.45 P.M., ...	1.76	–	1.73
9,	6.55 P.M., ...	1.86	–	1.81
9,	7 P.M., ...	1.885	–	1.86
9,	7.15 P.M., ...	2.01	–	1.975
9,	7.30 P.M., ...	2.10	–	2.095
9,	7.45 P.M., ...	2.18	–	2.18
9,	8 P.M., ...	–	2.275	2.26
9,	8.30 P.M., ...	2.41	–	2.39
9,	9 P.M., ...	–	2.56	2.525
9,	9.30 P.M., ...	2.63	–	2.63
9,	10 P.M., ...	–	2.75	2.735
9,	10.30 P.M., ...	2.82	–	2.82
9,	11 P.M., ...	–	2.91	2.91
9,	11.30 P.M., ...	2.98	–	2.99
9,	12 P.M., ...	–	3.07	3.06
10,	12.30 A.M., ...	3.12	–	3.12
10,	1 A.M., ...	–	3.19	3.185
10,	1.30 A.M., ...	3.23	–	3.24
10,	2 A.M., ...	–	3.29	3.30
10,	2.30 A.M., ...	3.33	–	3.345
10,	3 A.M., ...	–	3.39	3.395
10,	3.30 A.M., ...	3.41	–	3.43
10,	4 A.M., ...	–	3.47	3.47
10,	4.30 A.M., ...	3.48	–	3.51
10,	5 A.M., ...	–	3.54	3.555
10,	5.30 A.M., ...	3.55	–	3.58

These observations show that the water in the middle of the bank follows very closely that of the basin. When the water in the basin is considerably lower than that of the river, and still falling, the water in the basin is somewhat lower than in the bank. This may indicate that with the head which then exists there is passage of a small amount of water through the bank. The difference of level is not, however, so marked except when the river is very low: at such times when the basin is pumped down the shelving bottom is exposed, and this practically makes the bank many feet thicker. When the basin begins to fill, the level rises a trifle more rapidly in the basin than in the bank at first, but afterwards at nearly the same rate; before, however, the water in the basin reaches that of the river, the level in the basin is slightly above that in the bank. It thus would appear that although the bank is not perfectly water-tight, for practical purposes it may be regarded as quite impervious and as forming a part of the basin.

Observations on the Temperature.

Observations show that while the temperature of the basin at different points differs, and while in some instances at the same point the temperature is subject to variation, the water as drawn from the conduit is tolerably uniform. The basin being quite shallow, and having a sandy bottom, if the water were supplied mainly from the river and exposed in this basin to a summer's sun, the water would naturally become heated to a temperature higher than that of the river. Continuous observations made from Aug. 23 to Aug. 26 showed for the river an average temperature of 74° F., and for the basin an average temperature of 62.8° F. In the basin the variation from morning to noon was found to be, as we should expect, much greater than in the river; and it seems to me necessary, in order to account for the observed facts, that the temperature of the water entering the basin should be considerably below the temperature observed in the basin.

TABLE IX. — *Observations on Temperature, Waltham. (In degrees Fahrenheit.)*

Date.	Hour.	10 INCHES BELOW SURFACE.		Pipe B.	Pipe A.	Basin at efflux 10'' below surface.
		River at Gauge.	River at Pipe C.			
1876.						
Aug. 23,	6 A.M., ...	69.9	70.2	68.2	72.3	59.0
23,	9 A.M., ...	72.5	71.1	68.4	72.3	59.9
23,	12 M., ...	73.4	73.9	66.2	71.5	65.3
23,	3 P.M., ...	75.2	77.0	68.0	71.5	67.9
23,	6 P.M., ...	75.2	74.7	68.0	70.5	60.8
23,	9 P.M., ...	73.4	73.4	67.4	70.1	56.3
24,	6 A.M., ...	71.2	71.2	67.8	71.4	55.4
24,	9 A.M., ...	71.4	70.7	65.8	71.4	58.1
24,	12 M., ...	72.5	72.5	68.0	71.1	63.0
24,	3 P.M., ...	74.3	75.2	67.8	71.1	63.5
24,	6 P.M., ...	75.2	75.2	67.6	70.4	57.6
24,	9 P.M., ...	73.4	73.6	67.8	70.0	55.4
25,	8 A.M., ...	72.5	72.5	68.6	71.1	60.4
25,	11 A.M., ...	74.2	75.8	68.7	71.4	64.4
25,	7½ P.M., ...	77.0	76.0	68.2	71.6	69.8
26,	8 A.M., ...	74.8	73.7	68.6	71.4	68.4
26,	11 A.M., ...	76.3	75.0	68.0	70.7	70.2
26,	2 P.M., ...	77.4	77.7	68.4	70.5	71.6
26,	5 P.M., ...	78.3	77.6	68.0	70.5	66.2
		74.1	74.0	67.9	71.1	62.8

NOTE. — The pipe B was situated nearer to the natural bank, and at a less exposed part of the embankment.

I have on various other occasions observed the difference in temperature between river and basin, which is as marked in winter as in summer. For instance,

	Temperature of Air.	Temperature in River.	Temperature in Basin.
Feb. 7, 1874 (day), ...	19° Fah.,	36° Fah.,	44–45° Fah.
Feb. 9, 1877 (night), ...	14° Fah.,	32° Fah.,	48° Fah.

On the last occasion the temperature in the middle of the bank was about 39°. There is, it is true, considerable difference between the temperature of the water in the basin in winter and in summer, owing to the fact that the surface exposed to the air is great compared with the depth of water. If the basin were covered over, this difference would no doubt be much less.

It may also be said that the river in the neighborhood of the filtering-works is very sluggish, being practically a long mill-pond, and would naturally deposit silt on the banks so as to prevent even an artificially constructed bank from being long pervious to water. Although the river may contribute somewhat to the supply, it seems to me that in this case the larger portion of the water is intercepted and not derived. On one occasion when the river had been purposely drawn down for some weeks, I noted the height of the water in the ground at a point some 500 feet from the basin and about 100 feet from the nearest point of the river. The water was found to be several tenths of a foot below that of the river, showing that at that time the influence of the pumping was felt on the ground-water for the distance of 500 feet. On a subsequent occasion when the river was high, the level was practically the same at this point and in the river.

Taunton, Mass. — Taunton is supplied from an uncovered basin situated near the Taunton River, which at this point feels the tide although the water is not brackish.

"The filter basin or canal was constructed 400 feet in length, with side slopes of two feet horizontal to one foot perpendicular, both on the inside of the canal, also on the face or river side, the bottom of the canal being 8 feet below mean low-water mark, and the top or embankment 13 feet above, or a total depth of 21 feet from the top of embankment, which on the river side is 15 feet in width on top and 100 feet at bottom. The width of canal at bottom is 17, at top 101 feet, paved with stone on each slope for a distance of 18 feet from the bottom: the balance is sodded."[1]

There is also a pump-well some 28 feet deep. The idea in the construction was, as I am informed, that the river-water should filter through the bank into the basin, and the possible yield of the basin was anticipated to be one and one-half

[1] First Annual Report of the Water Commissioners of the City of Taunton, Dec. 1, 1876.

million gallons per day; the nature of the bank, however, which is artificial, and is composed of a mixture of gravel and clay, is such that it would soon become impervious to water, and would make a better dam than filter. It would be safe to say that practically no water is obtained directly from the river. Owing to the depth of the pump-well, and to the fact that the deposits of clay are here very irregularly distributed, it is impossible to say whether the water all comes from the same stratum or not, or how far the stream may contribute to the ground-water. The ground rises back of the basin; and the level of the ground-water, in what seems to be a continuous stratum between two layers of clay, has been found to rise some 14 feet in 1,000, beyond which point the water-level is more nearly horizontal.

Some observations on the water-levels of the basin and in the neighboring region were made last fall by Mr. A. H. Martine, civil engineer, from whose results I make the following statements. The highest tide observed by Mr. Martine caused the water in the river to stand at 9.28 feet above a certain zero, and the lowest tide 4.29 feet. What the level of the water near the river was before the basin was opened, we have no means of knowing, but it was probably somewhat below the point reached by the highest tide; and as the ground is not very pervious it was probably considerably above the point lying midway between high and low tide, perhaps at 8½ feet above the zero referred to. The water ordinarily stands in the basin at 6½ or 7 feet, and the amount of water pumped daily is estimated at 250,000 gallons. It seems that the pumping of this amount does not require the lowering of the natural level of the ground-water more than two feet. At the time referred to last fall, it was found that to keep the level some five feet lower than this, about 600,000 gallons daily were pumped. The water in the basin was kept at this lower level for five days; and during that time the level of the ground-water was not affected at a distance of 320 feet, although it was affected at a distance of 80 feet from the basin. The exact limit of measurable influence could not be ascertained without continuing the experiments for a longer time. Chemical examination of the water in the river and in the basin was made last August: the results are included in the following table.

TABLE X. — *Examination of Water from Taunton.*

[Results expressed in parts in 100,000.]

Date.	LOCALITY.	Water as Received.		Water after Filtration through Paper.		Solid Residue.			
		Ammonia.	"Albuminoid Ammonia."	Ammonia.	"Albuminoid Ammonia."	Inorganic.	"Organic and Volatile."	Total at 212° Fahrenheit.	
1877. Aug. 14,	Reservoir, ...	0.0088	0.0099	-	-	3.80	1.80	5.60	Unfiltered.
		-	-	0.0088	0.0091	3.48	1.76	5.24	Filtered through paper.
Aug. 14,	River, ...	0.0051	0.0211	-	-	2.64	3.20	5.84	Unfiltered.
		-	-	0.0051	0.0165	2.64	2.08	4.72	Filtered through paper.

We might consider other localities where the so-called natural filtration is in operation; but these examples will probably suffice to show the main features of the method.

CONCLUSIONS.

The so-called method of natural filtration consists in drawing the supply required or obtained from what is known as the ground-water, and is practicable only in localities where the ground-water is of good quality, free from possibility of pollution, and of sufficient depth and extent. The yield of any well, basin, or collecting-gallery is limited, although it may not be possible, by experiments continued for a long time, to fix the exact limit. Although something may be judged from the general lay of the land, yet correct evidence as to the possibility of obtaining a supply of sufficient abundance and of satisfactory quality can be reached only as the result of direct experiment.

The most favorable location of such a well, basin, or gallery is in the neighborhood of a running stream or of a pond or lake. The proportion of water obtained from the land side and from the river or pond near which the collecting-works are situated, varies with the circumstances of each particular situation. Sometimes the amount drawn directly from the stream is practically nothing, and the stream cannot be relied on alone to furnish the necessary supply, unless in exceptional cases where the ground is very pervious, and the current sufficiently rapid to prevent clogging of the bank surface. As far as the character of the water is concerned, it is in New England generally good when sufficiently abundant: it is almost always harder than the river-water, but in most localities in our State this difference in hardness is small although appreciable. In limestone regions, however, the ground-water is often so hard as to be unsuited for use; and sometimes the presence of streaks or beds of clay makes it impossible to obtain clear water. Other substances which are present in the ground may render the water inferior, so that, as a rule, it is necessary to submit it to chemical examination. Wherever experiment shows that this method can furnish a supply of water suitable in respect to quality and quantity, it is to be recommended in preference to artificial filtration.

Further, although there is less liability to pollution than in the case of small shallow wells sunk near dwellings, slaughter-houses, factories, or stables, it must be remembered that the ground-water is fed by the percolation into it of the atmospheric water, and that it is possible to pollute even a large body of water. This fact should be taken into account in choosing a locality for the collecting-wells.

In matters of this kind there is great liability of drawing hasty conclusions from incomplete data, especially in our country where we are in such haste to carry out a work when once actually decided upon, and where there is a disinclination to spend money in investigation before the decision is made. Any such preliminary examination with reference to a future water-supply should involve a careful study of the extent and character of the stratum containing the ground-water which is to be utilized, and the effect of the pumping upon its level. This is readily done by driving iron pipes with perforated "points" at regular distances, preferably in two lines at right angles to each other, intersecting in the experimental well. Observations should be made on the natural level of the ground-water before pumping is begun; and the pumping is best conducted by keeping the level of the water in the well at a certain measured distance below the natural level of the ground-water, or below the level of the water in the pond or stream. Although absolute equilibrium cannot be established for a considerable time, unless the water comes very freely, sufficient indications can be obtained to form judgment, within limits, as to the probable yield of the well. To obtain information as to the character of the water to be obtained, it is much more important to examine the ground-water than the water of the river, although examination of the latter should not be neglected.

It is also important to obtain information as to whether the supply must be drawn mainly from the rain-fall over the region drained by the gathering well, or whether there is sufficient movement to the underground water to practically increase this area. Where the level of the well is not below that of neighboring ponds or streams, it is generally the rain-fall alone over the drainage area of the well which furnishes the supply. This admits of being calculated with some degree of accuracy, if the general character of the land is known. Sometimes higher land, even at a considerable distance, may cause the yield to be greater than calculation would ascribe to the apparent drainage area. In all cases the preliminary examinations should be made by those conversant with the matter, as there is great liability to over-estimate. As a rule, the amount obtained from any such well is greater at first, as it requires time to drain out the water naturally occupying the territory which hereafter is to flow into the well, and in some cases it may be years before the well falls to what may be considered its normal delivery.

III. — Household Filtration.

In localities where there is a public water-supply, it should be the duty of the water board or company to deliver the water to consumers in a condition fit for domestic use.[1] If the source which is, on the whole, the most available for the water-supply is such that filtration is absolutely necessary, the water should be filtered on the large scale by the authority controlling the works. Even taking into account the large amount of water used for extinguishing fires, flushing sewers, watering streets, etc., it would no doubt be cheaper in any given case to filter the entire supply on the large scale than for each consumer to filter with equal thoroughness his individual portion. Even if the expense were equal, or if the filtration on the large scale were more expensive, there would still be objection on sanitary grounds to intrusting the matter to individuals, unless indeed the filters could be arranged in the line of the service-pipes, as gas or water meters are introduced, and be under the control of the water-board. This, in our country, would scarcely be practicable.

While, therefore, a water which needs filtration *ought* not to be regarded in its natural condition as suitable for a general supply, every one knows that few water-supplies come up to the theoretical standard. In the large majority of towns supplied from rivers, the condition of things is as tersely expressed by a superintendent of water-works, in

[1] An exception may be made in respect to the temperature. In our climate it would be too much, at present at any rate, to insist that the water in summer should be as cool as might be desired. Ice is comparatively cheap, and the habit of drinking iced-water is almost universal, and would probably be so still if the water were furnished at any temperature above 45° F.

answer to a circular of inquiry, "When the river is clear we have clear water: when the river is muddy we have muddy water." In such cases, whatever may be the feeling as to the proper authority to effect the filtration, under the existing conditions those who can afford to filter their own supply will be likely to do so if practicable. Another and greater demand for household filtration arises in the cases of detached houses and smaller towns where there is no general supply, and where it is necessary to rely upon wells and cisterns.

For effecting filtration on the household scale, numerous devices have been employed. The records of the Patent Office contain a very great number of filters which have been patented, although to one who is not an adept at discrimination it is difficult in many cases to see any thing but adaptations of old ideas. It would be a hopeless task to undertake any enumeration of the various forms proposed, nor would such an enumeration be of practical value. The materials employed in filtration are also very numerous: many sorts of porous stone, sand, powdered glass, bricks, iron in turnings and other forms, vegetable and animal charcoal, sponge, wool, flannel, cotton, straw, sawdust, excelsior, and wire-gauze, — these are some of the substances which are used. There are certain fundamental and necessary requirements which must be met by a filter suitable for household use. In the first place, the filter must be made of a material which cannot communicate any injurious or offensive quality to the water which passes through it; second, the filter must remove from the water all suspended particles, so as to render the water bright and clear; third, the filter must either be readily cleaned, or the filtering-material must be such as to be readily renewed. In addition to these *requirements*, it is of great advantage if the filter is able to remove a noticeable amount of the dissolved organic matter which most waters contain.

As we have already seen in an earlier portion of this paper, the action of a filter is either mechanical or chemical. There is a mechanical action by virtue of which solid particles which are too large to pass the pores of the filter are arrested: other particles are drawn by a force of adhesion to the surface of the particles of the filter, and are thus removed. This property of adhesion, if it may be so called, is sometimes exerted to such an extent as to remove substances which seem to be completely dissolved, without, however, producing any apparent chemical change in them. The substances so removed may be again by proper means recovered and brought into solution. There is also an unmistakable chemical action, by virtue of which certain substances are destroyed, or rather converted into new compounds. This action is mainly due to processes of oxidation which take place, in part at the expense of the oxygen which is contained in the solution, and in part at the expense of the oxygen mechanically entangled in the pores of the porous substance employed. Different porous substances differ very much in this respect. While, as we have already seen, clean quartz sand possesses the property to a slight degree, other substances, such as animal charcoal (bone charcoal), possess it to a very great degree.

We may divide the various filters into three classes: first, those of small size, intended to be attached to the faucet, where the water is brought in pipes either from the service-mains of a general supply, or from a tank in the building; second, the portable filters intended to occupy a more or less permanent position, and to be filled with water, either by some ball-cock or other similar arrangement, or by means of smaller supplies continually renewed; third, the more permanent and fixed devices which are inserted or built into underground or other cisterns.

It may be stated on general principles, with reference to the smaller sorts of filters, that, considering the volume of water which must flow through an extremely limited amount of material, no filter capable of being screwed on to an ordinary water-tap can act in any other way than as a strainer. It is not difficult to construct a filter which can be attached to the faucet without very seriously obstructing the flow, and which shall for a limited time remove all floating objects, and render the water clear and free from turbidity.[1] It is safe to say, however, that no such filter has been devised, or is likely to be devised, which can do more than this, — which can in any case free the water from impurities held in

[1] Except in the case of finely divided clay, as already seen: this is difficult to remove even by the carefully conducted filtration of the laboratory.

solution. Moreover, the success of such a filter in the accomplishment of its legitimate work depends upon the frequency with which it is cleaned. No filter can be self-cleaning. Attention on the part of some individual is necessary; and in the household, where such matters are generally left to the care or neglect of servants, the filters are more likely to be neglected than to be cared for. It is true that in the case of some of them the actual clogging of the filter, and the consequent interruption of the usual supply, may enforce attention; but before this happens the accumulated organic matter, vegetable and animal, has begun to decay, and most likely causes the water passing through to become of poorer quality than it would be if left without filtration. In many cases a filter once screwed upon the faucet remains for month after month without being cleansed, so that its presence is simply a delusion and a snare.

Of all the patent contrivances which have been proposed, there is probably, after all, none better than the form which has been in use for many years, which is filled with clean quartz sand, and is capable of being readily reversed and thus cleansed. Even a cotton-flannel bag, primitive and uncouth as it may seem, is very efficient, provided the pressure is not too great: it may be often renewed at a trifling expense, and in summer the odor of the vegetable matter entangled will probably call attention to it, and lead to its frequent washing or renewal. Sponge is very efficient as a strainer, and admits of being compressed into small compass. There are several forms of sponge filters which may be screwed upon a common tap. If the sponge be removed and washed with hot water every few days (every day, in fact, in hot weather), these filters serve a good purpose: left to themselves, however, they do more harm than good. Of course with such a filter the flow of water is more or less obstructed; and, if the arrangement is such as to facilitate removal for cleaning, the temptation is always before the servant to remove the filter altogether in order to obtain the water more freely.[1]

[1] Sponge is much used in filtering water for manufacturing operations, such as paper-making; and has been used to a limited extent in connection with sand and gravel, even on the larger scale of a town supply. Alton, Ill., pumps from the Mississippi River; and the water is, as I am informed by the superintendent, filtered through sponge contained in a cast-iron filter-box of

We come now to the larger forms of filters, to those which are portable, but which are intended to occupy a permanent position in the room, or in some cases to be placed in the tank from which the supply is drawn. The material which, next to simple sand, has probably been used as long as any thing for the purpose, is stone. Some varieties of sandstone are particularly porous, sufficiently so to allow of the use of slabs of the stone as filters: other similar substances, such as pumice-stone or unglazed earthenware, have been employed; the most common arrangement being to insert the stone as a horizontal partition in a small tank or vessel. Here we have to deal in the main with simple mechanical action. As far as I know, these filters are not in common use in this country, although found occasionally.

Without entering into a detailed consideration of the various other materials which have been and are used, we may notice that one of the most common, one which is used and has been used for a long time, is animal charcoal. All varieties of carbon formed by the destructive distillation of vegetable or animal matter possess the property of removing organic matter from solution, but to a very different extent: that prepared by the distillation of bones, by subjecting bones to a high heat in retorts to which the air does not have access, is one of the most powerful, and is on this account produced on a large scale. One of the familiar uses to which it is put in the industrial arts is in the refining of sugar, where it is employed to remove the coloring matter from the crude sirups. There are a great many forms of filter for using animal charcoal, and the material is one which has often been the subject of experiment. In order to ascertain its effect on such waters as Cochituate, which may be regarded as a fair example of the kind of water most used in New England, a number of experiments have been made, most of them with a filter much employed in England, manufactured by the London and General Water Purifying Company. A sectional view and an elevation of one of these filters is

54 cubic feet capacity: this box fits into a tight chamber in the aqueduct leading from the river to the pump-well, and can be raised by machinery. The box can be raised, the sponges renewed, and the box replaced, in three hours. The amount of water filtered is at present only 150,000 gallons a day. When the river is muddy the sponges are cleaned every three or four weeks: sometimes, when the river is clear, not oftener than once in three months.

given in the accompanying illustrations, Figures 12 *a* and 12 *b*. The earthenware filter-box is filled with animal charcoal, in the form of charred bones, broken into small pieces, and freed from dust. There is no chamber for storing filtered water: the water is filtered at the time it is drawn off for use. The filter is readily cleansed and the charcoal renewed. The water passes *upwards* through the filtering-material, in order that matters spontaneously settling down may not be deposited upon the filtering-material, and may not, therefore, help to clog its pores; and, further, that the suspended matters strained from the water, being separated as they always are, mainly at the surface of the filtering-material, may fall away from it and deposit elsewhere; the consequence of this is, that the filtering-material requires less frequent cleansing. This filter may be taken as a type of the better class of filters which contain the charcoal in fragments rather than compressed into blocks. No attempt was made to institute a comparison between this and any other form of filter using the same material: the general arrangement is, however, as good as in any one that has come under my observation.

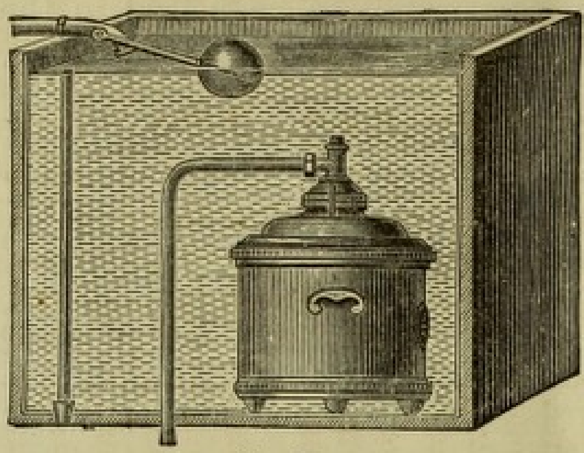


Fig. 12 *a*.

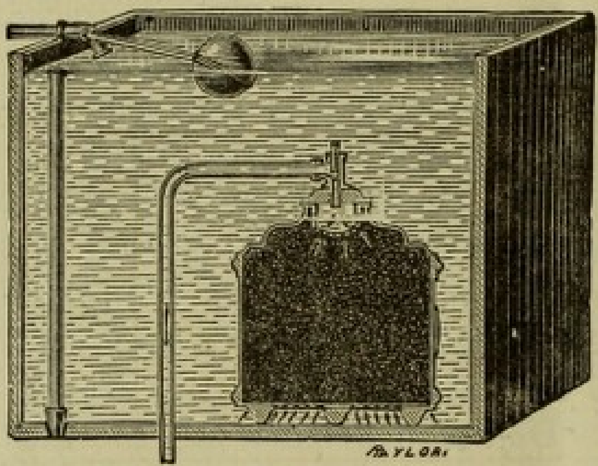


Fig. 12 *b*.

For the present experiments, one of these filters of small size, No. 0, was placed in a tank which is supplied by Cochituate water, and a stream of water was allowed to flow through it at various rates. The results appear in the following table: —

TABLE XI. — *Examination of Filter of Animal Charcoal.*

[Results expressed in parts per 100,000.]

DATE.	TANK WATER.		AFTER FILTRATION THROUGH PAPER.		AFTER FILTRATION THROUGH ANIMAL CHARCOAL.		Rate of flow. No. of minutes required for one liter.	Total number of liters passed through filter.
	Ammonia.	"Albuminoid Ammonia."	Ammonia.	"Albuminoid Ammonia."	Ammonia.	"Albuminoid Ammonia."		
1877.								
November 17,[1]	0.0181	0.0363	0.0173	0.0192	0.0384	0.0176	15	12
19, ...	0.0043	0.0144	0.0043	0.0139	0.0176	0.0104	45	102
21, ...	–	–	–	–	0.0040	0.0101	30	196
23, ...	–	–	–	–	0.0053	0.0088	17	340
24, ...	–	–	–	–	0.0035	0.0099	7	510
December 8, ...	0.0040	0.0163	–	–	0.0048	0.0091	9	1,334
18, ...	0.0053	0.0163	–	–	0.0059	0.0104	17	3,396
29, ...	0.0045	0.0133	–	–	0.0043	0.0107	5	5,470
1878.								
January 11, ...	0.0048	0.0149	–	–	0.0048	0.0133	4	9,173
12, ...	0.0051	0.0157	–	–	0.0037	0.0117	7	9,470
22, ...	0.0053	0.0139	–	–	0.0053	0.0117	2	10,136
Average of last six, ...	0.0048	0.0151	–	–	0.0048	0.0111	–	–

[1] Tank disturbed by insertion of filter.

After the examination of Nov. 24, the filter was put into a smaller tank containing water which was strongly colored with extract of peat; after the water had passed for a sufficient length of time through the filter, a sample was subjected to examination with the following results: —

	Amomnia.	"Albuminoid Ammonia."
Water before filtration, ...	0.0416	0.0389
Water after filtration, ...	0.0232	0.0136

The water after filtration was entirely destitute of color. The filter was then replaced in the tank as before; and, a constant stream being allowed to pass through it, the water was examined from time to time with the results indicated in the table, from Dec. 8, 1877, to Jan. 22, 1878.

It thus appears that the bone-charcoal is able to remove a considerable portion of the nitrogeneous organic matter from the water; and these, of course, are but confirmations of the experiments of others. Frankland at one time proposed to filter the whole water-supply of London by this method. Although this would be expensive, it is not altogether impracticable. In large works it would be possible to wash and re-burn the coal from time to time, and the dust and waste would have a certain value as a fertilizer.

I have also made some experiments with bone-coal which had been compressed into blocks. The results were, as a whole, not as favorable as when the charcoal is in lumps. With Cochituate water the effect was about the same, as appears from the results of a number of experiments, the average of which was as follows: —

	Ammonia.	"Albuminoid Ammonia."
Water before filtration, ...	0.0043	0.0144
Water after filtration, ...	0.0033	0.0108

With a strongly colored peaty water, the results were not as satisfactory.

The action of bone-coal in the removal of *mineral* matters in solution is, on the whole, slight, although at first it is appreciable on certain salts: thus a hard water is slightly softened at first. This action, however, soon ceases.

Another material which has lately come into use to a considerable extent in England is what is known as "spongy iron." It was observed a long time ago, that metallic iron possessed the property of removing considerable quantities of organic matter from solutions containing it; and iron in turnings, and in other forms, has been proposed and used to a very limited extent as a means of purifying water. The material at present alluded to, and which forms the essential part of Bischof's Patent Spongy Iron Filter, is an iron which has been reduced from a hematite ore without fusion, and is consequently in a porous and finely-divided condition, and in its effects resembles the carbide of iron before referred to.

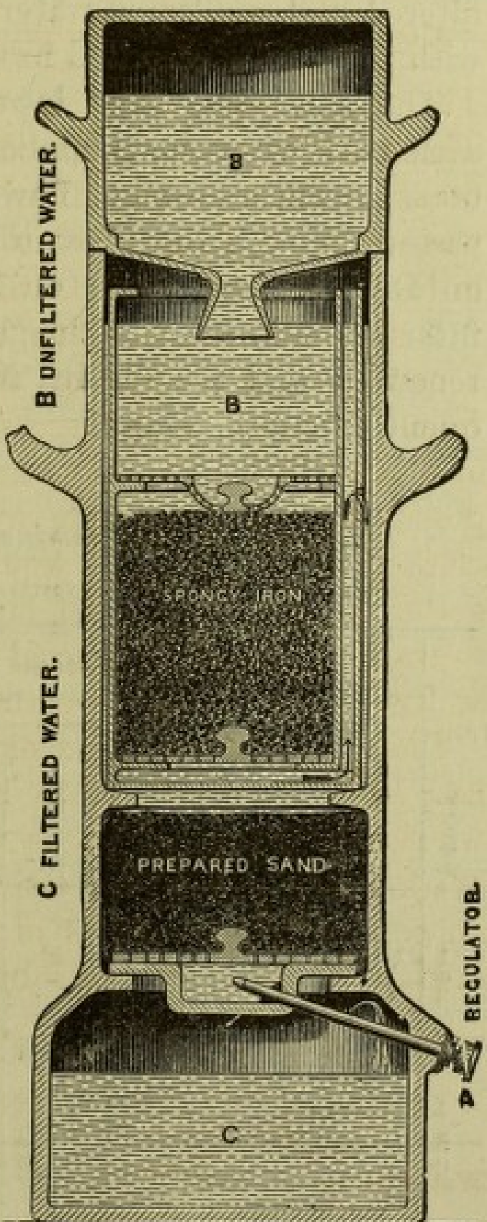


FIG. 13.

The filters are constructed in various forms, but on the same general plan. Fig. 13 represents one form, where the water is supplied from an inverted bottle, which must be refilled as often as empty. In other forms the reservoir of unfiltered water is kept full by being connected with the service-pipe by means of a ball-cock attachment. The material of all the vessels is earthenware.

To ascertain the effect of filtration through spongy iron on one of our soft waters, a small-sized filter of the pattern shown in Fig. 13 was procured, and the filter connected with the Cochituate service-pipe in my laboratory. After running a constant stream of water through the filter for several days, the water still showed by its color and taste that it carried considerable iron in solution. The water, examined as to the effect produced on the organic matter, gave the results indicated in the accompanying table, Nos. 1, 2, and 3.

After these determinations, the connection with the service-pipe was interrupted, and the filter supplied with a somewhat strongly colored peat-water; after this had passed through the filter sufficiently long to displace all the water which had previously filled the apparatus, specimens of the filtered and unfiltered water were subjected to examination, with the results recorded in the table, as No. 4.

The filter was now brought into connection with the same tank which had supplied the carbon filter, and a continuous stream allowed to flow. When some 1,500 liters had passed through the filter, the water was examined; namely, on Dec. 18, and again on Dec. 29 (Nos. 5 and 6). The filter had now become clogged. The material was after this renewed; and the results, Nos. 7, 8, and 9, represent subsequent determinations.

TABLE XII.—*Examination of Spongy Iron Filter.*

[Results expressed in parts per 100,000.]

Number.	Date.	Before Filtration. Ammonia.	Before Filtration. "Albuminoid Ammonia."	After Filtration. Ammonia.	After Filtration. "Albuminoid Ammonia."	Rate of flow. No. of minutes required for 1 liter.	Total No. of liters passed through filter since renewal of material.
	1877.						
1	November 23, A.M., .	–	–	0.0064	0.0107		
2	23, P.M., .	–	–	0.0051	0.0112		
3	24, . .	–	–	0.0056	0.0117		
	Average, . . .	0.0050	0.0150	0.0057	0.0112		
4	November 26, . .	0.0381	0.0363	0.0179	0.0171		
5	December 18, . .	0.0053	0.0163	0.0059	0.0109	85	
6	29, . .	0.0045	0.0133	0.0040	0.0115	40	
	1878.						
7	January 11, . .	0.0048	0.0149	0.0064	0.0139	4	576
8	12, . .	0.0051	0.0157	0.0056	0.0115	6	833
9	22, . .	0.0053	0.0139	0.0056	0.0117	16	2,614
	Average of last three,	0.0051	0.0148	0.0059	0.0124		

In judging of the effect produced, it is to be noticed as generally true in the case of this and other filters, that from a water containing a small amount of organic matter, a less *proportion* is removed than from one which is more impure. This is plainly seen in comparing the action of the spongy iron on Cochituate water, and on the peaty water. There is no question but that the spongy iron has a marked action on organic matter, but I found considerable difficulty in obtaining the filtered water free from iron. After a very large amount of water had been passed through the filter, it still retained the color due to the presence of iron. The filters are constructed with a view to the removal of the iron by the subsequent passage of the water through fragments of flint and quartz-sand, with which has been mixed pyrolusite, the native oxide of manganese. My experience seemed to show, that, in order to obtain water reasonably free from iron, it was necessary to fill the reservoir so many times, that, unless it were possible to make connection with some tank or service-pipe, no ordinary individual would have the patience to follow the directions, which are to "fill the filter, and let the water run off until bright and free from taste." As other experimenters have not mentioned this as giving difficulty, I am inclined to think that the cause of the trouble is, that, as is well known, the Cochituate water, like other soft waters, acts violently on iron. Hard water, such as has been used mainly by the Rivers Pollution Commission and by others who have experimented on this material, has probably much less action. I found, on renewing the iron after some six weeks' use, that it was considerably rusted throughout the entire mass: I finally succeeded in obtaining better results, by renewing the iron first, and allowing the water to run for a number of days before renewing the sand; in this way I obtained finally a water nearly free from iron. While the material is certainly one that commends itself to a chemist, and when properly used is capable of exercising a marked effect upon dissolved organic matter, it should be said, that, considering the capacity of the filters, they are quite expensive. Thus the filter experimented with was calculated to yield only nine gallons in 24 hours; the retail price is £1. 10*s.* (about $7.50), and the material for re-charging 2*s.* 9*d.*; while one capable of yielding 24 gallons per day costs £2. 15*s*., i.e., about $13, and is somewhat bulky withal. There are also tank-filters on the same principle, and a larger size would probably give somewhat better results than the small-sized one on which my experiments were made.

I have also experimented with the so-called Silicated Carbon filters. The material of these filters is compressed into blocks, and consists of the residue of the distillation of a certain variety of bituminous shale. Thus it is a coke mixed with mineral matter. In the common form of household filters of this make, the block is cemented as a partition into an earthen jar, and is not readily cleaned. Some experiments with an ordinary filter of small size gave the following results: —

	Ammonia.	"Albuminoid Ammonia."
Water before filtration, ...	0.0043	0.0144
Water after filtration, ...	0.0035	0.0115
" "	0.0045	0.0120
Water before filtration, ...	0.0181	0.0363
Water after filtration, ...	0.0080	0.0128

These results show a considerable action on organic matter; and there is no doubt that the material is effective as a means of purifying water. I find, however, that with the water used, the filter clogged rather rapidly: it would, no doubt, give better results if the water were first passed through sand or other material which could intercept the floating particles. It is true of this as well as of the "Spongy Iron" and other filters, that the smaller sizes would hardly find favor with an American public. The larger sizes which are arranged for automatic supply from a tank, although of course more expensive, would give much greater satisfaction.

As a result of my own examinations and the published results of other experimenters, I am led to the belief that there is no substance, on the whole, better than animal charcoal for household filtration. There are, however, certain points which are to be taken into consideration. The charcoal should be renewed from time to time; how often, will depend upon the character of the water, and the amount passed through the filter. If the coal be in blocks, the clogging of the pores will indicate the necessity for cleaning; if in granules (which on many accounts is preferable), it may be well to renew the charcoal once in six or twelve months according to the amount of water used. In the case of a filter fixed with some permanence, it would be worth while to have a simple chemical examination if the efficiency of the filter were suspected: this would indicate whether the work was still being properly performed. It is true in the case of these as of filters in general, that unless attention is paid to them, and they are cleaned at proper intervals, their presence is worse than useless.[1]

We come now to the discussion of filters suitable for cisterns or for tanks of considerable size. There is an exaggerated idea, in the minds of many, of the purity and wholesomeness of rain-water. As ordinarily collected from the roofs, and stored in cisterns, rain-water is far from being superior to good spring-water in regions where the natural spring-waters are not too hard. It is a disputed point, whether very soft water is as wholesome as water which by its passage through the earth has taken up some mineral matter. Be this as it may, the collection of water from the roofs of houses involves the collection of dust and dirt more or less objectionable in character, especially in places where soft coal is burned. Although it is possible by automatic contrivances to avoid the collection of the first portions of the water coming at any time from the roof, yet these do not perfectly accomplish their intended object, and are not at all commonly employed. Moreover, the construction of ordinary cisterns is such that after the water is once collected it is liable to deterioration and to contamination by various foreign matters which fall into it. However, even in its ordinary condition cistern-water is apt to be better than well-water, as it is seldom contaminated by sewage in any form: still cistern-water

[1] When water is filtered through animal charcoal, it is better that the filtration should be made as the water is needed for use. I have found the filtered water to keep bright and clear even when exposed to sunlight; but if it be mixed with sugar or some such other organic substance, and exposed to light, it will gradually become turbid: this is explained by the fact that the water in filtering takes up some *phosphates*, and is rendered the more capable of supporting the growth of the lower vegetable organisms if the conditions otherwise be favorable.

should, as a rule, be subjected to filtration before being used for drinking. Most of the materials in common use as filters can be obtained in forms suitable for insertion in ordinary tanks or cisterns, from which the filtered water can be delivered by gravity; and it is not uncommon to construct underground cisterns so that the water is not pumped directly from the cistern, but from a sort of pump-well, to enter which the water must pass through a porous partition-wall made of bricks.[1] These walls are constructed in various ways: one form is represented in the accompanying cut, taken from "Scribner's Monthly Magazine" for September, 1877.

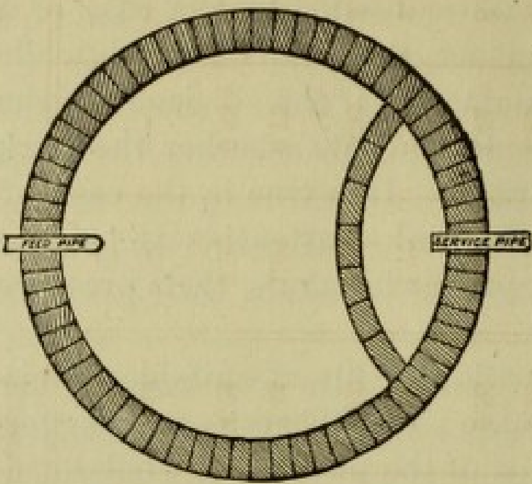


FIG. 14.

When the brick partition is new, it is undoubtedly of good service; but it soon becomes clogged, and covered on the outside with a deposit of organic matter, so that after a time the water which passes through the brick wall must first have an opportunity to leach out what it can from this mass of decaying matter. Fortunately in many cases this clogging so interferes with the passage of water through the wall, that attention is called to the fact, the cistern is cleaned, and the filtering-wall is cleaned or renewed; but where the filtering-surface is large, and the filtered-water chamber of considerable size, the water may be in many cases supplied in sufficient amount long after the process of filtration is an injury rather than a benefit. I have had occasion to examine samples of water from several such cisterns: the results obtained appear in the following table: —

[1] An attempt was made to filter the supply of the village of Malone, N.Y., through a filter of soft brick, but it was not found practicable to filter with sufficient rapidity.

TABLE XIII. — *Examination of Cistern Water filtered through Brick Walls.*

[Results expressed in parts in 100,000.]

Number.	Date.	Description.	Water as Received.		Water after Passing through Paper.		Solid Residue of Water as Received.			Solid Residue of Water after Passing through Paper.			Chlorine.
			Ammonia.	"Albuminoid Ammonia."	Ammonia.	"Albuminoid Ammonia."	Inorganic.	"Organic and Volatile."	Total at 212° Fahrenheit.	Inorganic.	"Organic and Volatile."	Total at 212° Fahrenheit.	
	1877. April 17,	Unfiltered, .	0.0131	0.0080	0.0131	0.0080	3.96	1.32	5.28	2.68	1.44	4.12	0.32
	April 17,	Filtered, .	0.0125	0.0072	0.0125	0.0064	5.24	1.32	6.56	4.64	1.44	6.08	0.36
323	Sept. 11,	Unfiltered, .	0.0048	0.0115	0.0048	0.0091	2.56	0.68	3.24	1.72	0.52	2.24	0.10
324	Sept. 11.	Filtered, .	0.0243	0.0165	0.0243	0.0123	3.20	1.60	4.80	3.10	1.30	4.40	0.12
340[1]	Sept. 18,	Unfiltered, .	0.0037	0.0117	0.0037	0.0104	-	-	2.44	1.68	0.72	2.40	-
341[1]	Sept. 18,	Filtered, .	0.0083	0.0141	0.0083	0.0126	-	-	4.24	2.92	0.88	3.80	-
460	Dec. 10,	Unfiltered, .	0.0213	0.0067	-	-	3.20	0.28	3.48	-	-	-	0.69
459	Dec. 10,	Filtered, .	0.0072	0.0069	-	-	4.80	0.40	5.20	-	-	-	0.70

[1] Nos. 340 and 341 were from the same cistern as Nos. 323 and 324.

I have also had occasion to examine some of the deposit taken from the surface of such a filtering-wall as has been described. I found it to contain a considerable amount of animal matter in the remains of various insects, worms, etc. Chemical examination showed that it contained 19.8 per cent of organic matter (i.e., loss on ignition), and that it contained 1.11 per cent of nitrogen.

The objection made to the arrangement which has been described is not to the material; for porous brick is efficient in removing suspended matters from water passed through it, and communicates nothing that could be or become injurious. The trouble lies in the fact that the wall soon becomes clogged, and as a rule is not readily accessible. Moreover, when the cistern is relied upon as the sole or as a principal supply for the household, it is impossible to renew frequently the filtering-wall, or even to thoroughly clean the outer surface. The best that can be done under ordinary circumstances is to clean the outer surface of the wall as thoroughly as may be with a stiff brush every few months, and to renew the wall whenever the probability of a rainy season allows.

The filtration in the cistern may, however, be better accomplished in other ways, two of which I will indicate. In the first place, instead of the wall, the filtering-material may be placed in a frame capable of sliding in a groove and of being readily lifted from its place. The filtering-material may consist of porous tiles or of blocks of animal charcoal; and, if duplicate frames are provided, the grooves may be so arranged that a fresh frame can be lowered into place before the old one is taken away. The Figure 15[1] represents a cistern constructed with such frames containing blocks of animal charcoal, as prepared by Atkins & Co., London. These blocks can be readily cleaned by scraping the outer surface (at some expense, to be sure, of the material of the blocks), and they can be renewed when necessary. They are made of various densities; the most dense permitting the passage of 30 to 40 gallons per square foot per day, while the most porous pass some 250 to 300 gallons. For use in ordinary cisterns tolerably porous blocks would probably answer well enough, and for such use as this the charcoal is

[1] Taken by permission from Fanning's Water-Supply Engineering.

more conveniently employed in this form of blocks than as fragments.

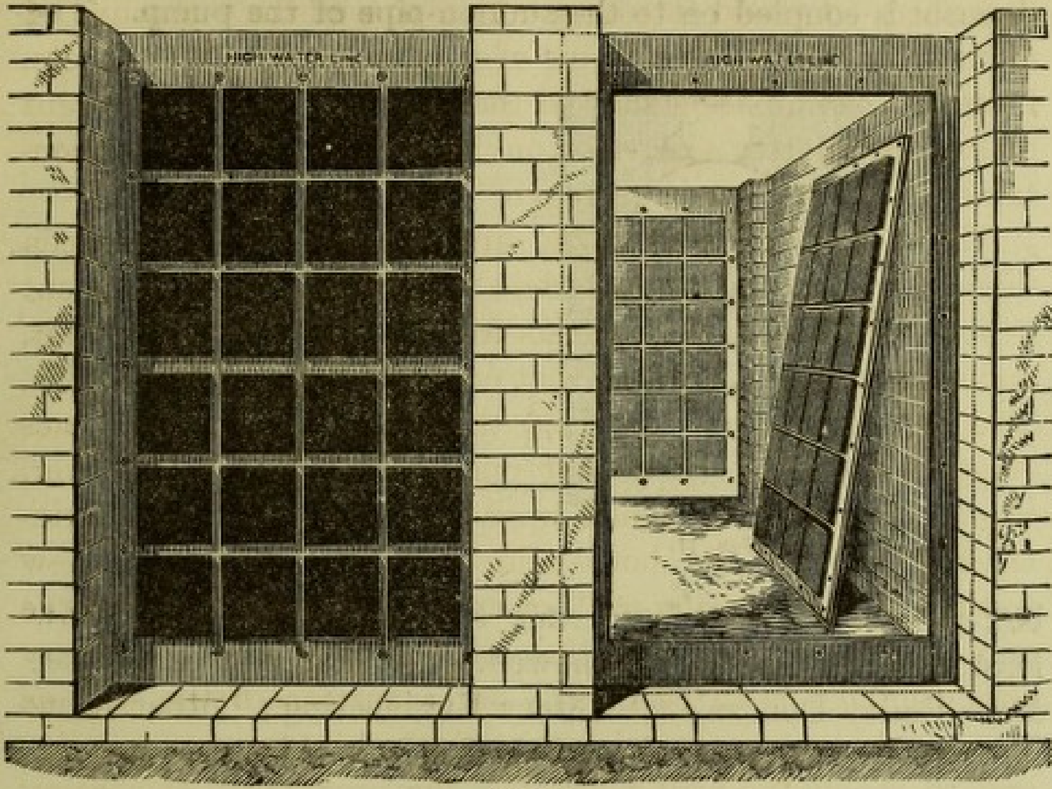


FIG. 15.

The arrangement which has been described is rather expensive for common use; although, if the necessary provision were made in the original plan for the construction of the cistern, it would, on the whole, be more satisfactory than other plans which involve less outlay at the start. Various other methods are in use for employing animal charcoal in cisterns, one of which is represented in the woodcut.[1]

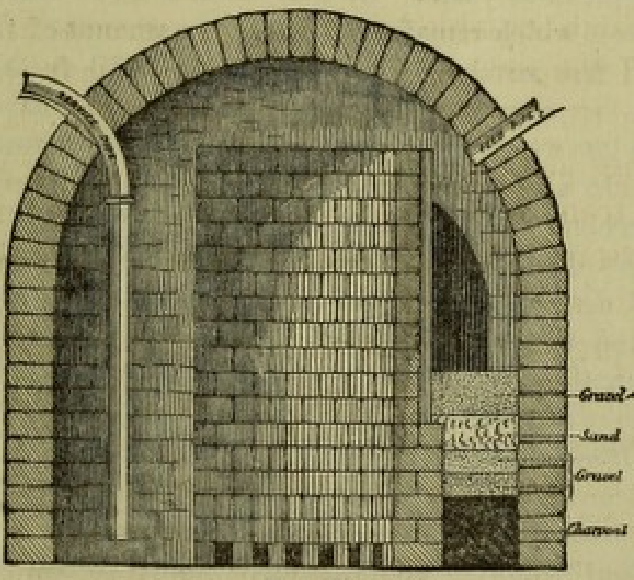


FIG. 16.

This arrangement is open to the common objection, that the difficulty of access throws an obstacle in the way of the renewal of the material as frequently as

[1] This cut is taken from Scribner's Magazine. The writer there speaks of using wood-charcoal: animal charcoal would be more effective.

necessary. A better plan on many accounts is represented in Figs. 17 and 18. Here the box which contains the sand and charcoal is coupled on to the suction-pipe of the pump. The

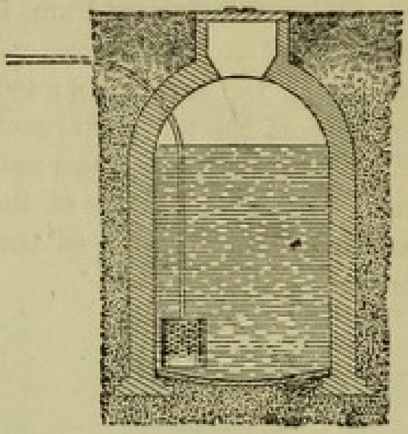


Fig. 17.

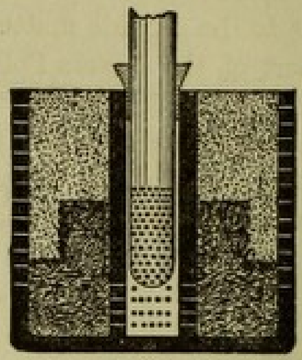


Fig. 18.

box can be removed from time to time, say once a year at least, and the contents renewed. These figures are taken from Bailey Denton's "Sanitary Engineering;" other forms have been devised to accomplish the same object.

Note with Reference to the Methods of Analysis.

The methods of analysis which have been employed in the examinations of the various samples of water, the results of which are recorded in this report, are the same as in previous years. By the "total solid residue," is understood the solid matter which remains when a given amount of the water is evaporated, and the residue dried at 212° F. until further drying causes no further loss of weight. By the "organic and volatile matter," is understood the loss which this residue is found to have suffered where, after being exposed to a low red heat, it is subsequently moistened with water containing carbonic acid, and again dried at 212° F. It is but fair to say that this determination is far from possessing great accuracy. In the case of certain soft waters, like Cochituate, constant results can be obtained, and the loss is nearly all due to the destruction of organic matter; but, in the case of waters containing a considerable quantity of nitrates and chlorides, the loss may be due in great measure to the alteration and volatilization of mineral matter.

The "ammonia" is determined by distilling a measured quantity of the water with carbonate of soda; and the "albuminoid ammonia" is determined by the method of Wanklyn and Chapman, which consists in subjecting the water, which has been freed from ammonia, to distillation in the presence of a strongly alkaline solution of permanganate of potash. Most nitrogeneous substances, under such treatment, give off a portion of their nitrogen, as ammonia. This amount is constant for any one substance, but different organic substances disengage different amounts of ammonia. The term "albuminoid ammonia" is used because albumen acts in this way, and the substances in ordinary water, which give off ammonia under these conditions, may be regarded in some sense as allied to albumen.

In the experiments on filtration, the determination of "albuminoid ammonia," before and after passage through the filtering medium, affords a ready means of comparing the filtered and unfiltered water, with reference to the organic matter in solution. In the analysis quoted from the Report of the Rivers Pollution Commission, the terms "organic carbon" and "organic nitrogen" are used. These determinations are made by Frankland's method, and are obtained by the combustion of the residue of the evaporation of the water and the determination of the total carbon and nitrogen contained in the organic matter present.

BIBLIOGRAPHY.

The following list contains the titles of the various works alluded to in the preceding pages. It does not claim to be exhaustive, and makes no attempt to include local American reports: —

Belgrand, M. — Les Travaux souterrains de Paris. Études préliminaires. La Seine. Régime de la Pluie, des Sources, des Eaux courantes. Applications à l'Agriculture. 8vo, pp. 612, with atlas. Paris, Dunod, 1875. [Especially chap. vii., Des nappes d'eau souterrains, and chap. xxvi., Du filtrage des eaux, etc.]

Berlin. — Vorarbeiten zu einer zukünftigen Wasserversorgung der Stadt Berlin. Ausgeführt in den Jahren 1868 und 1869 von L. A. Veitmeyer. 8vo, pp. 368, with atlas. Berlin, Reimer, 1871. [Especially pp. 109–130, — experiments on the ground-water in the neighborhood of the Tegeler See.]

Berlin. — Reinigung und Entwässerung Berlins. Berichte über mehrere auf Veranlassung des Magistrats der königl. Haupt- und Residenzstadt Berlin Versuche und Untersuchungen. 12 Hefte, with 3 Anhänge. 8vo. Berlin, Hirschwald, 1870–76. [Especially Heft v., "über die Grundwasserverhältnisse," with a great number of profiles.]

Brooklyn, N. Y. — The Brooklyn Water-Works and Sewers. Prepared and printed by order of the Board of Water Commissioners. 4to, pp. 159, with 59 lith. plates. New York, Van Nostrand, 1867.

Darcy, Henry. — Les fontaines publiques de la ville de Dijon. 4to, pp. 647, with atlas. [Especially Appendix D, Filtrage.]

Denton, J. Bailey. — Sanitary Engineering. 8vo, pp. 429, with many plates. London, Spon, 1877.

Dresden. — Das Wasserwerk der Stadt Dresden erbaut in den Jahren 1871–1874, von B. Salbach. 8vo. In three parts, with atlases containing many plates. Halle, Knapp, 1874–76.

Dupasquier, A. — Des Eaux de Source et des Eaux d'Rivière comparées, etc. 12mo, pp. 414. Paris et Lyon, 1840.

Dupuit, J. — Traité de la Conduite et de la Distribution des Eaux, etc. Suivi de la Description des Filtres naturelles de Toulouse par D'Aubisson. 4to, with atlas. Paris, 1854.

Fanning, J. T. — A Practical Treatise on Water-Supply Engineering, etc. 8vo, pp. 650. New York, Van Nostrand, 1877.

Grahn and Meyer. — Reisebericht einer von Hamburg nach Paris und London ausgesandten Commission über künstliche centrale Sandfiltration zur Wasserversorgung von Städten, und über Filtration in kleinen

Massstabe. Von E. Grahn und F. Andreas Meyer. 8vo, pp. 153. Hamburg, Meissner, 1877. [Especially Anlage 3, "Historische Notizen über künstliche Filtration im kleineren Massstabe."]

Grahn, E. — Die städtische Wasserversorgung. 3 vols. 8vo. Vol i. Oldenbourg, München, 1877. [Vol i. contains Statistik der städtischen Wasserversorgungen; Beschreibung der Anlagen in Bau und Betrieb. Vols ii. and iii. are not yet published.]

Great Britain. — Sixth Report of the Commissioners appointed in 1868 to inquire into the best Means of Preventing the Pollution of Rivers. Domestic Water-Supply of Great Britain (Parliamentary Document). London, 1874. [Especially Part iii. 6, "On the improvement of potable water by filtration," pp. 216–221.]

Grimaud, de Caux. — Des Eaux publiques, etc. 8vo, pp. 348. Paris. Dezobry, 1863. [Especially chap. xiv., "de la clarification des eaux publiques."]

Halle. — Das Wasserwerk der Stadt Halle, erbaut in den Jahren 1867 und 1868. Von B. Salbach. Folio, with atlas. Halle, Knapp, 1871.

Humber, William. — A Comprehensive Treatise on the Water-Supply of Cities and Towns, etc. Folio, pp. 378, and many plates. London, Crosby, Lockwood, & Co., 1877.

Kirkwood, J. P. — Report on the Filtration of River Waters for the Supply of Cities, as practised in Europe. 4to, pp. 178, with 30 plates. New York, Van Nostrand, 1869.

Munich. — Berichte über die Verhandlungen und die Arbeiten der Commission für Wasserversorgung, Canalisation, und Abfuhr. Erster Bericht, 1874-75; Zweiter Bericht, 1876, und Anhänge, 1877. 4to, with plans and profiles. München, Mühlthaler, 1876, 1877.

Paris. — Assainissement de la Seine. Épuration et Utilisation des Eaux d'Egout. Documents administratifs; Enquête; Annexes. 3 vols. 8vo, with plates. Paris, Gauthier-Villars, 1876.

Schorer, Th. — Lübeck's Trinkwasser, 8vo, pp. 284. Lübeck, Seelig, 1877. [Especially pp. 248-257, describing the deterioration of water by vegetable growth and decay, etc.]

Ward, F. O. — Moyens de créer des sources artificielles d'eau pure pour Bruxelles. 8vo, pp. 106. Bruxelles, Decq, 1853.

Wiebel, Dr. F. — Die Fluss- und Bodenwässer Hamburgs. Chemische Beitrage zur Analyse gewöhnlicher Lauf- Nutz- und Trinkwässer sowie zu der Frage der Wasserversorgung grosser Städte von sanitärem und gewerblichem Standpunkte. 4to, pp. 152. Hamburg, Meissner, 1876.

Reference may be made also to the following papers: —

d'Avigdor, E. H. — Water-works, ancient and modern. Engineering, 1876 and 1877. [Especially vol. xxii. (1876) p. 101.]

Byrne, E. — Experiments on the Removal of Organic and Inorganic Substances in Water. Proceedings Institution of Civil Engineers, xxv. (1867), pp. 544–555, with supplement and discussion xxvii. (1868), p. 1 and folio.

Dresden. — Ground-water. Proc. Inst. Civ. Eng. xxxix. (1874–5) p. 369

Abstract of a paper by Manck in the Protokolle d. Sächs. Ingenieur-Verein, Sept. 7, 1874.

Dresden Water-works. — Proc. Inst. Civ. Eng. xxxix. (1874–5), p. 383. Abstract of a paper of Salbach's in the Protokolle d. Sächs. Ingenieur-Verein, May 10, 1874.

Grahn. — Zur Wasserversorgung Prags. Journ. für Gasbeleuchtung und Wasserversorgung, xx. (1877), pp. 162 and 299.

Grahn. — Über Klärung und Filtration von Flusswasser. Journ. für Gasbeleuchtung, etc. xx. (1877), pp. 543 and 723.

Kümmel. — Zur Frage der Klärung und Filtration des Wassers. Journ. für Gasb., etc. xx. (1877), pp. 453 and 522.

Salbach. — Apparat zum Messen der Klärung des Wassers. Journ. für Gasb., etc. xx. (1877), p. 545.

v. Weise. — Beitrag zur Kenntniss der Grundwasserströmungen und der Brunnenwasser bei Bonn. Niederrhein. Correspondenzblatt, ii., p. 16.

ERRATA.

Page 7, line 17 from top,— *for* (opp. 143) *read* Fig. 1.
" 9, last line, — *for* 143 *read* 7.
" 14, line 9 from bottom,— *for* 165 *read* 29.
" 15, line 15 from bottom,— *for* 173 *read* 37.
" 17, line 19 from top,— *for* 179 *read* 43.
" 36, line 7 from top,— *for* 165 *read* 29.
" 43, line 11 from bottom,—*for* 153 *read* 17.
" 49, line 18 from bottom,—*for* 195 *read* 59.
" 52, line 11 from bottom,—*for* 195 *read* 59.
" 65, line 2, *for* "which is artificial" *read* "which is in part artificial."
" 89, near bottom,—*for* "Wiebel" *read* "Wibel."
" 89, bottom,—*for* "and folio" *read* "and foll."

ADDITIONAL NOTES.

Page 7, last paragraph. It is perhaps the more general custom to drain the beds *completely* before removing the sand. This aerates the entire mass of the filtering material and is found necessary, or at least especially advisable, where the water is affected by the peculiar taste given by the microscopic algae.

At Zurich, in Switzerland, it is the custom to clean the beds by forcing the water in a reverse direction through the filters. Workmen, clad in rubber clothing, then stir up the upper surface of the sand with forks, and the collected slime is washed off and floated away. This requires an abundance of water, and the ability to command the requisite pressure. One would suppose also that it would involve some danger of disturbing the arrangement of the filtering material. It may be said that the Zurich filter beds are covered and the water which is filtered carries little vegetable matter, the suspended matter being mainly clay.

Page 12, last paragraph. Since Kirkwood's report was written additional *covered* beds have been built. I am informed that the uncovered beds are not cleaned during the winter, the burden of the work being thrown upon the covered beds.

Page 24, top. Further investigation and inquiry makes it quite certain to my mind that properly filtered water stored in *covered* reservoirs is not again subject to vegetable growth ; the cause of such growths in filtered water stored in open reservoirs is not necessarily due to imperfect filtration as the spores may come through the air ; it is true, however, that water filtered through sand still shows suspended particles when viewed with the electric light, although the water may not appear turbid when viewed under ordinary conditions.

Page 34, end. It is possible that this statement is a trifle too strong. I found last summer that the condition of things at Berlin resembles those at Springfield, quite closely. The algae, " wasserblüthe," which grow in the river-water and on the filter-beds are almost the same, if not the same, as those which grow in the Ludlow reservoir. There was formerly trouble with the filtered water but I could not learn that there was any trouble at present. The filter-beds are cleaned with sufficient frequency, and are thoroughly aerated in the process ; the filtered water is stored under cover. It is possible that extended inquiries among the consumers would reveal occasional difficulties but such have not come to my notice.

Page 80, bottom. Since this report was written I have had made in my laboratory further examinations of the spongy-iron and the animal charcoal filters, the water being examined by Frankland's method. The results have corroborated those previously obtained by Wanklyn's method. A recent German experimenter (Dr. L. Lewin, Zeitschrift für Biologie, XIV (1878), page 483) has expressed the belief that the spongy-iron is worthless as a material for the destruction or removal of organic matter from water. I cannot agree with this view and think that the experiments were unfair to the filter, as the organic liquids employed were quite concentrated. The material claims to be efficient in the case of waters which contain no such considerable amount of organic matter, and the filters are regulated so that only a small amount of water passes in a given time, so small, indeed, as to interfere seriously with the general use of the filters (see page 79, bottom).

I have had recent occasion to examine an American filter which is much used in certain sections of the country, and in which the filtering medium is wood-charcoal with clean quartz pebbles. The filtering material is arranged in an oak tub and the water is placed in a zinc pan at the top, and passes first through a handful of sponge and then downward through the pebbles and charcoal. The experiments extended over several months and the water was examined both by Frankland's and by Wanklyn's method. I found that in the case of the Boston water, when the filter was in constant use, absolutely no effect was produced on the water, — the water which issued from the filter containing exactly the same amount of organic matter as when it entered. If the sponge were taken out, thoroughly washed and replaced, there was for a short time a slight difference between the filtered and unfiltered water, but the effect was temporary and soon ceased. In spite of the bulk and weight of this filter (the smallest size of which weighs about 150 lbs.), the entire work seems to be done by the handful of sponge at the top. I do not name the filter, but it is one of a class which claim to be chemical in their action, but which cannot do more than remove suspended matter; this end is very desirable to be sure, but it can be reached in a much simpler way.

Page 88. Add to the "Bibliography"

Fischer, Dr. Ferdinand. — Die chemische Technologie des Wassers. Braunschweig, 1878. [Especially pp. 148 *et seq.*, "Reinigung von Trinkwasser.]

Page 89. Note that an American edition of Humber is publishing in Chicago, by Geo. H. Frost. Also that there is a German edition of Kirkwood which contains additional matter, especially with reference to Hamburg, by Arnold Samuelson, Ingenieur der Stadtwasserkunst in Hamburg.

Page 90. Add

Bischof. — On putrescent organic matter in potable water. Proc. Royal Society, 1877.

Fleck. — Ueber dem Einfluss des Elbstromes auf die Zusammensetzung des Grundwassers von Dresden. Jahresbericht d. chem Centralstelle in Dresden. VI. and VII, 1878, pp. 62–71.

Lewin, Dr. L. — Untersuchungen über den Eisenschwamm und die Thierkohle als Reinigungsmittel für Wasser. Zeitschrift für Biologie, XIV (1878), pp. 483-505.