against the disease in sheep and apparently also in human beings. He refers to about twenty cases of human anthrax treated with this serum in various parts of Italy, and states that most of the patients recover.

Cholera. Working in the epidemic of 1894 at Calcutta, Haffkine inoculated with an emulsion of living cholera vibrios some 40,000 of the inhabitants. In one town, of 340 uninoculated, 45 got cholera and 39 died; of 181 inoculated, 4 got cholera and 4 died. Among 18 people living in one house, 11 were inoculated and no cholera occurred in any of them. Seven were not inoculated, 4 of them took the cholera, and 3 died. The inoculations cause a rise of 1° to 2° C., lasting with some constitutional symptoms for twenty-four hours.

Scarlet Fever. That the serum of patients convalescent from scarlet fever seems to exercise a favorable influence on the course of active cases has been noted by many observers (*e.g.*, Huber and Blumenthal, *Berl. klin. Woch.*, 1897, No. 31, and Leyden, *Münch. med. Woch.*, January 18th, 1902).

More recently sera prepared from streptococci isolated from the organs of scarlet fever cases have been used especially by Baginsky (using Aronson's serum) and by Moser, using a serum of his own manufacture. Each reports good results.

Richard C. Cabot.

SEVEN SPRINGS.—Washington County, Virginia. These springs are located two miles from the Glade Springs. Depôt, on the Norfolk and Western Railroad. They have been known for many years, but no accommodations have as yet been provided for visitors. The waters are used commercially in the form of Seven Springs Iron and Alum Mass, an evaporated residue. An analysis of this mass by Prof. J. W. Mallet, of the University of Virginia, showed the presence of a large proportion of aluminum sulphate and iron persulphate, besides a considerable quantity of magnesium and calcium sulphate, and numerous other ingredients in smaller proportion. This substance is highly recommended as a general tonic and reconstructive, and is said to possess special merits in such affections as cholera morbus and dysentery, and in various hepatic and intestinal disorders.

James K. Crook.

SEWERAGE AND SEWAGE DISPOSAL.—A system of sewerage is the network of pipes, conduits, etc., constructed for the purpose of collecting and carrying away from a city, town or village, the wastes of human life other than that portion of the wastes which are known collectively under the term garbage. The wastes entering the sewers may come from houses, stores, stables, factories, etc., and, if the sewerage system is constructed upon the so-called combined plan, the sewers will also carry street wash. If the system is constructed upon the so-called separate plan, street wash will be excluded, to be cared for by means of drains built for that purpose. The volume of sewage flowing in the sewers of a town or city of a given population depends mainly upon three things: (1) The consumption of water; (2) the tightness of the sewers, that is, their ability to prevent the entrance of ground water; and (3) whether the sewers are on the so-called separate or on the combined system. In England and upon the Continent, where the consumption of water does not average much more than thirty gallons per capita per day, the average volume of sewage produced by a given population must necessarily be less than in America, where the consumption of water in our largest cities and towns varies from seventy-five to two hundred and fifty gallons per capita per day. Upon the tightness of the joints of the pipes of the sewer system rests a great deal of responsibility in regard to the volume of liquid entering these sewers. By careful construction of the sewers and in some soils the ground water may be almost entirely excluded, but faulty construction in porous soils will often allow the entrance of a volume of ground water sometimes fully as great or greater than the volume of true sewage. In the combined system of sewage the volume of sewage flowing in the sewers is very much augmented at times of storm by the addition of street wash.

After collection in sewers some satisfactory method for the disposal of sewage is necessary. Formerly it was considered sufficient to empty this sewage into some body of water or flowing stream, which would either dilute it sufficiently to prevent visible nuisance, or carry it away from the vicinity of the town or city producing it. This method can still be carried out without offence by fortunately located cities and in sparsely settled countries with large rivers, lakes, and streams. As a country becomes more thickly settled, however, it is not sufficient simply to pass the sewage from its source to a point where it will not cause a nuisance to those producing it, but it must also be cared for in such a way as to prevent it from becoming a nuisance or a source of danger to other communities. On this account and coincidently with the great increase of urban life in civilized countries during the past twenty-five years, the question of sewage disposal has become a most pressing one. So general had the nuisance caused by sewage entering streams become in England as early as 1876, that the Rivers Pollution Prevention Act was passed—a law providing that no rivers or streams should be polluted because of the admission of crude sewage. In the twenty-seven years elapsing since that time there has been a constant agitation in England upon the subject, with an idea to bettering the condition of the rivers and streams, but even now the Act is very imperfectly carried out.

Practically the first agitation of this question in America was in the State of Massachusetts. The report of the State Board of Health for 1876 contained an article by the then secretary of the board, in regard to sewage disposal systems in England and on the Continent, and the same volume contained a report by an engineer of an examination in regard to the condition, on account of sewage pollution, of certain rivers and streams of Massachusetts. Since that date more important investigations upon sewage disposal and purification have been accomplished than during any previous period. An outline of this work, however, with descriptions of the most important methods, is all that can be given here. It is also well to state at this place that in this article little mention can be made of methods of dry disposal of wastes. These methods do not properly come under the head of sewage disposal, but they are methods in vogue in towns, dwellings, public buildings, etc., by means of which the wastes are collected in such manner as to render them more or less valuable for fertilizing purposes; that is, either without having been diluted or mixed with water, or only to a very slight extent. Besides the common middens, privies, etc., many patent processes for the accomplishment of the same result are in vogue in different places, and many processes by which by some means the solid matter of these wastes is, even when mixed with water, separated more or less efficiently from it before the main body of liquid enters the sewers

The demands made upon modern engineering in complex and difficult sewerage construction are very great, and as a result methods of construction are constantly improving. Sewerage works are increasing enormously, in number, in the area covered by a single system, and in the volume of sewage collected at a single point. The volume of sewage thus collected for disposal by a single city or metropolitan district now often reaches into the hundreds of millions of gallons daily.

Direct Disposal into Bodies of Water, or Disposal by Dilution.—Fortunately located cities and towns can satisfactorily discharge their sewage unpurified into large bodies of water. Where such communities are in close proximity to the seacoast or upon a very large river, the discharge of unpurified sewage into tidal waters or swift currents is still resorted to successfully. The method is practically without expense after the sewerage system is once complete, other than that, in some instances, of pumping. It is efficient if the tidal or other currents are strong and the sewage is prevented in this manner from reaching adjoining shores, and if the volume of water

into which the sewage is discharged is large compared with the volume of entering sewage. In some instances, however, even in such locations, some attempt at partial purification is made by collecting the sewage in basins and allowing sedimentation to occur before the discharge of the supernatant liquid; this sedimentation often being aided by the use of chemical precipitants.

Beginning in 1852 the straggling sewers of the city of London were given more definite form, and the sewage of this city was collected and carried by means of sewers to Barking Creek and Crossness, twelve miles below London Bridge. This enormous work was made necessary by the polluted condition of the Thames River. Before this date the sewage was discharged through many sewers directly into the Thames, as the river passed through the city. The greater part of the new works emptying at Barking Creek were completed in 1864, and in 1865 works on the opposite side of the river at Crossness were also completed. Ten years after the opening of these works it became necessary, on account of sewage carried up the river from these outfalls, to build large settling tanks in which the sewage was collected and chemicals were added for the purpose of precipitating the solid matter before discharging the clarified sewage into the tidal estuary. The solid matter resulting from this precipitation is taken out to sea in sludge boats, and the sewage is discharged between high and the middle of ebb tide. During 1901 and 1902 the average volume of sewage discharged daily amounted to 234,508,000 gallons and 47,673 tons of sludge were carried to sea each week. Twenty-two thousand tons of protosulphate of iron and five thousand tons of lime were used during the year.

Boston, Mass., together with the cities and towns surrounding it and composing a metropolitan district, with a population of 1,200,000 and having an area of 187 square miles, collects its sewage into three main systems, all of which discharge into strong tidal currents in the outer parts of Boston harbor. With two of these systems the discharge is continuous, while in the other the sewage is collected in large storage tanks and allowed to pass out on the ebb tide. Two of these points of discharge have been in operation for many years, and, notwithstanding the volume of the sewage, amounting at the present time to about 120,000,000 gallons daily, so efficient is the disposal because of dilution, sedimentation, and the rapid carrying away by swift tidal currents, that well-patronized summer resorts exist within short distances of the points of discharge.

The sewage of Greater New York all empties into New York harbor by means of many sewers, and is so diluted and dissipated by the swift and deep tidal currents that it is well cared for and practically unnoticeable. The sewage of Buffalo enters the Niagara River between Lakes Erie and Ontario. The sewage of St. Louis enters the Mississippi River, as does now the main portion of the sewage of Chicago through the Chicago drainage canal and the Illinois River, and in each instance, on account of the large volume of water flowing in the river, the disposal from some points of view is adequate.

Sewage Farms.—Berlin, Germany, passes its sewage to immense sewage farms, which have been in operation for many years, and are eleven thousand acres in extent; Paris, a portion of its sewage to farms at Gennevilliers and other places, where it is adequately cared for. Many other cities and towns, both in Great Britain and upon the Continent, follow the same method of disposal satisfactorily. This method can be carried out successfully, however, and at a profit to the farm only where the sewage is comparatively rich in organic matter, that is, where the volume of water is small compared with the population producing the sewage. It is with considerable difficulty even then that these farms can be made to return a profit above the cost of operation. It goes without saying that American sewage cannot be disposed of satisfactorily in this manner, being altogether too dilute; and any attempt so to utilize it means generally the use of only that portion valuable for irrigation, with the direct discharge of the remainder, unpurified by filtration through the soil, into the most convenient body of water. Sewage irrigation or farming, however, was the first attempt properly to purify sewage upon land, but having, sometimes at least, for its main object the utilization of the sewage rather than its purification; a profit from the farm being deemed of more importance than purification.

Continual agitation upon the subject of the prevention of the pollution of streams by sewage making a wide-felt demand for a thorough understanding of proper and efficient purification, scientific studies upon this subject were begun practically about eighteen years ago. It had been observed that the passage of sewage through soil not only caused the removal of the suspended matters, but that the matters in solution were also changed or destroyed, that is, they did not appear in the effluent unless in an unrecognized form. The knowledge of germ life and the science of bacteriology having practically its beginning at about this period, it was believed that these changes occurring in sewage were caused by bacterial life in the soil. These first investigations were made by Schloessing and Muntz in France, and Warrington and Frankland in England. Their experiments were upon a laboratory scale and, without attempting to show that bacterial life was present by means of observation, they did demonstrate that, if germicides were added to the filter or to the sewage, purification in the filter did not occur. They also observed that their small tube filters, containing the earth, marbles, and other media experimented with, not only purified the sewage, but the filters themselves remained fairly clean, and organic matter accumulated very slowly within them. These investigations were very meagre and not long continued.

Toward the end of 1887, however, the State Board of Health of Massachusetts established an experiment station for investigations upon the subject of sewage purification, and accomplished and published the results of the most important scientific studies that had ever been made upon this subject. This experiment station is still continued. During the past eight or ten years much work along the same lines, but upon a larger scale, has been done in England, practically all of this work being based upon the Lawrence data, with such additions in construction of filters and methods of application of sewage as local needs have suggested. Many of these English studies have been largely carried on by cities and towns with the intention of applying the results directly to their own problem of sewage disposal, and thus have a practical and in some cases limited bearing only, and are without such thorough investigation of the science of the subject as has been aimed at in the long-continued Massachusetts experiments.

Sewage farming having caused the recognition of the fact that it could not be successful except with comparatively small volumes of strong sewage and where land was plentiful and cheap, nearly all the scientific investigations at the Lawrence experiment station have centred upon evolving processes of sewage purification by means of which the largest possible volume of sewage can be efficiently purified upon the smallest possible area and at a minimum cost. These studies have nearly all been upon bacterial methods of purification, that is, the oxidation or purification of the organic matter in sewage by means of the bacteria which establish themselves sooner or later in sewage filters of all kinds. With these studies others have been made in regard to methods for the treatment of sewage preliminary to filtration, which would result in allowing larger volumes to be efficiently purified upon given areas than is possible with untreated sewage.

Theory of the Bacterial Purification of Sewage.—In the purification of sewage by the action of bacteria the process is about as follows: The bacteria in the sewage, in the presence of oxygen, first attack the carbonaceous matters, carbonic acid being formed, nitrogen and hydrogen are set free and unite to form ammonia, this in turn uniting with the carbonic acid, forming ammonium carbonate, which goes into solution. The next step is the oxidation of the nitrogen of the free ammonia, first to nitrous acid and then to nitric acid, by the nitrifying bacteria working in the presence of oxygen. The nitric acid then unites with a base, such as sodium or potassium, present in the sewage or the filter, and sodium or potassium nitrates are formed. These are, in the small amount present, innocuous mineral salts, and appear in solution in the effluent. In this work of the bacteria much of the organic matter is also changed to gaseous forms, and many gases are set free. If filtration through properly prepared filter beds is carried on slowly enough, all the organic matter in the sewage applied to these beds can be changed either to gaseous forms, such as carbonic acid, ammonia, free nitrogen and hydrogen, which escape into the air, or to mineralized bodies, which appear in solution in the effluents of the filters. Such thorough purification as this, however, is not generally necessary, nor is it practicable in many instances, except where the volumes of sewage to be dealt with are comparatively small and where land is cheap.

Intermittent Filtration.—Next to sewage irrigation or farming, in which mere driblets of sewage are generally applied to each acre under cultivation—at Berlin the volume is from five hundred to five thousand gallons—the best results and the best purification can be obtained by filtration through properly prepared filter beds of sand or similar material. In order that good work may be done in such beds they must be constructed of sand coarse enough to allow sewage to enter easily, and the sewage must be applied in such a manner, at such intervals and in such volumes, that it will pass through the entire area of the filter in a fairly uniform manner, and meet an abundance of oxygen within the filter.

Physical Characteristics of Sand Used for Filtration.—At the Lawrence experiment station a method for determining the efficiency of sands in sewage filtration was elaborated from practical experience. By this method the sand is sifted through sieves, these sieves being so calibrated that the approximate size of the sand grains passing through can be easily determined. It was found that the quantitative and qualitative efficiency of sands used in filtration depends to a considerable extent upon the finer particles present. Owing to this, a certain arbitrary standard was adopted, called the "effective size"; this being the diameter in millimetres of the finest ten per cent. by weight of the sand grains. Following this standard, if a sand is stated to have an effective size of 0.25 mm., the meaning is that ten per cent. by weight of the sand consists of grains with an average diameter less than this figure. The determination of the volume of water which a certain depth of sand of a known grade, well underdrained, will hold by capillarity is easily made. The knowledge of these two facts gives adequate data to enable one to foretell the volume of sewage which can be held by a well-underdrained sand filter of a given depth, or, in other words, its time of passage through such a filter when successive applications are made; this having a direct bearing upon the volume that can be purified satisfactorily and successfully upon a given area.

An average sand has about thirty-five per cent. of open space; that is, when this sand is dried and packed as closely as natural, the space between the grains filled with air amounts to about thirty-five per cent. of the total volume of the sand. This percentage of open space differs but little with coarse and fine sand. When a coarse sand, well underdrained, has water applied to it for a considerable period, it will hold but a small portion of this water by capillarity, while each finer grade will hold more and more, until a grade is reached that will hold itself practically saturated to within a few inches of its surface; that is, the open or air space present when the sand is dry will be filled with water.

Rate of Filtration Through Sand Filters.—A sand as fine as this last grade, which will in fact resemble clay, is practically useless in sand filtration of sewage. Any sand, ten per cent. by weight of the grains of which have a smaller diameter than 0.05 mm., is of small value for sand filtration, especially in a cold climate where freezing occurs in winter, although areas constructed of a grade of sand as fine as this can be used if trenched with coarse sand, and if the sewage is applied to these trenches. All grades of coarse sand are valuable for filtration purposes, none being too coarse to effect good results, if the underdrains of the area are placed at sufficient depths and a proper distance apart. A rate of filtration equal to 100,000 gallons per acre per day can easily be maintained upon coarse sand filters with sewage of average strength. On two filters of the same grade of coarse sand the rate that can be maintained depends very largely upon the strength of the sewage; that is, upon the amount of organic matter present in each unit volume of water going to make up the volume of sewage. Many weak sewages from towns having a considerable length of pipes laid but with comparatively few connections, or systems into which ground water enters in considerable volume, can be filtered through sand with satisfactory purification results at rates at least three times as high as the figure given above—that is, if the filters are properly cared for.

Care of Sand Filters.—The care of sand filters is, of course, one of the main points in maintaining permanency of operation. In order that the surface of the beds may not become clogged, much of the matter reaching them in suspension in the sewage either has to be raked up and removed from time to time, or else ploughed under. With a fresh sewage—that is, a sewage where the mixture of filth and organic matter of all kinds with the waste water of the town has just occurred and little time has been given for mechanical, chemical, and bacterial actions to take place in the sewers—we have a liquid containing organic matter in quite a different form from the same matter in the sewage when opportunity has been given for these various actions to take place. A fresh sewage generally contains free oxygen, nitrogen in the form of nitrates and nitrites, the proportion of organic matters in suspension to those in solution is comparatively large, and the matters in suspension are in comparatively coarse particles. When sewage reaches a filter area in this condition, the matters in suspension are easily strained or filtered out upon the surface of the bed and can be removed by raking. If then they are mixed with loam or sand—that is, composted—they cause little or no offense, and even when placed in a heap without mixture with soil or loam, the organic matter generally decomposes so slowly that little, if any, nuisance occurs. As fresh sewage flows along in the sewers and mechanical, chemical, and bacterial forces have a chance to act upon it, the organic matter present undergoes a decided change. The chemical and bacterial change is practically the breaking up of the organic matter into simpler forms, and the mechanical change is the disintegration of the matters in suspension into finer particles. Sewage in this condition—that is, with much of its suspended organic matter either changed to soluble forms or finely disintegrated—is designated as stale sewage, and, when it flows upon a filter bed, much more of the organic matter present in it is carried into the pores of the filter than when the sewage reaches the bed in a fresh state. Upon the surface of beds receiving such sewage, little matter accumulates that can be removed by raking, but the disappearance of this matter by bacterial oxidation can be very much aided if the surface of the bed is loosened from time to time by raking, harrowing, or ploughing.

Method of Operation of Sand Filters.—In order to purify sewage satisfactorily while passing it through sand filters, an abundance of air in the pores of the filter is a necessity. To assure the presence of this air, the application of sewage must be intermittent—that is, it must be applied from time to time and in limited volumes. If we should apply sewage continuously to a sand filter, keeping the surface of the sand covered with sewage, the entire open space in the filter would become filled with liquid, air would be excluded, and those organisms which oxidize the organic matter by working in the presence of air would be either destroyed or rendered unable to work successfully. This fact has often been proved, and is what occurs when attempts are made to purify

sewage by passing it in any but very limited amounts through soil or clay—materials useless in sewage purification. Instead of oxidation in such beds, if they are overworked, we have reducing actions occurring, oxygen is taken from the oxides in the soil or clay or sand, and the base of these oxides passes into solution. Putrefaction of the organic matter of the sewage also occurs, with the production of odors, and an effluent often less pure than the applied sewage is the result. In order to prevent this the volume of sewage applied to any intermittent sand filter must be such that under no conditions will the sewage entering the filter exhaust the air present, or keep the surface of the filter covered for too long a period. The volume of sewage which can be applied to filters of coarse or fairly fine sand with good results varies comparatively little, but the method of application should vary considerably if good results are to be obtained. That is to say, with a filter of fine sand the sewage should be applied in large doses as it enters the filter slowly, and when once it has passed below the surface of the sand a considerable period should elapse before another application is made, in order that air may enter the upper portion of the filter. With a filter of coarse sand, into which the sewage enters readily, more frequent applications of a smaller volume of sewage is the preferable manner of operation, in order that the sewage may not pass through the filter too quickly. Much air may be made to enter the filter by this manner of flooding, as the sewage disappears quickly from the surface of the coarse sand. This difference of action of different sands can be modified very much, however, by different distribution of the underdrains. By such equalization as can be obtained in this way a filter of coarse sand may be worked practically in the same manner as a filter of finer sand, and vice versa.

The following table shows first the average results for one year obtained when filtering sewage through two different experimental filters that had been in operation for ten years at the Lawrence experiment station when these results were obtained. One of these filters (A) is constructed of coarse mortar sand and the other (B) of fine river silt trenched with a coarser sand, the coarse filter being operated at a rate three times as great as the fine filter, or approximately 60,000 and 20,000 gallons per acre daily respectively. In the same table are given the results from a third filter (C) of coarse sand, operated at a rate of 300,000 gallons per acre daily, the sewage applied to this filter being of such strength, however, that 300,000 gallons contained no more organic matter than the 60,000 gallons applied to Filter A:

TABLE I.—PARTS PER 100,000.

	Sewage (A and B).	Filter A.	Filter B.	Filter C.
Ammonia—				
Free	3.8200	0.5502	0.0660	0.0404
Albuminoid—				
Total	.8000	.0697	.0166	.0306
In solution	.3800	....	....	....
In suspension	.4200	....	....	....
Chlorine	8.4800	8.3600	7.8900	2.8200
Nitrogen as—				
Nitrates	.0000	2.7100	2.9300	1.2500
Nitrites	.0000	.0118	.0009	.0044
Oxygen consumed	3.9000	.4500	.1100	.3400
Bacteria per cubic centimetre	4,760,000	28,800	58	15,800

In calculating the percentage of purification obtained by filtration the common method is to show the removal

PERCENTAGE PURIFICATION.

	Albuminoid ammonia.	Bacteria per cubic centimetre.
Filter A	91.3	99.4
Filter B	97.9	99.9
Filter C	96.2	99.7

or oxidation of organic matter as shown by the determinations of albuminoid ammonia in the sewage applied to and the effluents from the filters, and this is given in this instance in the table below. True purification in sand filtration is by nitrification, and it will be noticed that the nitrogen appearing as nitrates in the effluents of Filters A and B in the accompanying table, accounts for a large part of that present in the sewage as free and albuminoid ammonia.

Sand Filter Areas.—Massachusetts has more sand filter areas for the purification of the sewage of cities and towns than any other State in the country at the present time. These filters are in successful operation, and undoubtedly produce better results in the New England climate than could be obtained the year round by any other method of filtration yet known. At the end of the year 1902 there were fifteen cities and towns in the State, besides many large institutions, disposing of and purifying their sewage upon sand areas. It is well to describe one or two of these areas, with the results which are being obtained from them.

Sewage Disposal System of Brockton.—The city of Brockton has a population of approximately 40,000. The sewerage system was first put into operation in the year 1894, the sewage being conveyed through main sewers to a pumping station on the outskirts of the city. At this pumping station the sewage is received into a covered masonry reservoir, from which it is pumped to the filtration area. In designing this system it was planned to take house sewage only, and to exclude all surface water and as far as practicable all ground water from the sewers. There are several main lines of brick sewers, but the principal part of the system is constructed of pipe sewers. The main sewer, which is brick, is laid in the valley of a river and considerably below the level of the water in that river. On this account at times of high water in the river the surface of the ground in the vicinity of the sewer is flooded. When the main sewer was completed and before any connections had been made, the amount of leakage into this sewer was measured at a time when the water in the stream was low, and the results were as follows: In a section of the sewer about 2,000 feet long the leakage of ground water was found to be about 17,000 gallons per day, or about 45,000 gallons per day per mile of sewer. The entire amount of leakage in the main sewer amounted to about 61,000 gallons per day per mile of sewer, and this has increased, when the meadows along the river are flooded, to about 178,000 gallons per day per mile of sewer; these figures being given to illustrate the amount of ground water which may in some locations enter a well-constructed sewer. The measurements were made in a section of brick sewer of a maximum size, at the lower end, of 23 by 48 inches, underdrains were built beneath the sewers to take care of the ground water, if possible, and particular care was taken in construction to make the sewer tight.

From the masonry reservoir already mentioned, which has a capacity of 619,000 gallons, the sewage passes through screens consisting of iron slats with an open space between them of three-quarters of an inch, and then to the pumps. It is necessary to clean the screens several times each day while the pumps are being operated, and the material removed is burned beneath the boilers in the pumping station. The solid matter which accumulates in the reservoir is stirred up from time to time and pumped to the filter beds, this stirring being done by means of an agitator, consisting of perforated pipes laid on the bottom of the reservoir and connected with the force main through which sewage can be discharged under a head. The force main from the pumping station to the filtration area is a cast-iron pipe 24 inches in diameter and 17,500 feet in length. The filtration area comprises approximately thirty-nine acres, on which twenty-three filter beds have been constructed, each having an area of about an acre. The beds were prepared for receiving sewage by the removal of the loam from the surface, and from twelve beds the subsoil was also removed. The sewage is distributed on the beds by means of wooden carriers which are laid across the bed from the centre of one side, so arranged as to discharge the sewage at several points. The grade of sand and soil in these beds differs very widely in different beds and in different portions of the same bed. The subsoil has an effective size of about 0.07 mm., and the effective size of the various grades of sand found varies from 0.07 to 0.75 mm. The underdrains in the filters are laid about sixty feet apart and discharge into two main underdrains. The heavy sewage which accumulates in the bottom of the reservoir is, when pumped to the beds, generally discharged upon a special sludge bed. The average volume of sewage reaching these beds amounts to about 900,000 gallons per day. The average analysis of the sewage and effluent during a certain period is shown in the following table:

TABLE II.—PARTS PER 100,000.

	Sewage.	Effluent.
Residue on evaporation—		
Total	72.0200	48.3000
Loss on ignition	34.9200	......
Ammonia—		
Free	4.7383	.1633
Albuminoid—		
Total	0.9058	.0163
In solution	.4983	......
In suspension	.4075	......
Chlorine	10.9100	10.4200
Nitrogen as—		
Nitrates	......	3.1667
Nitrites	......	.0056
Oxygen consumed	13.0300	.1700

The percentage purification obtained by these beds is about ninety-eight per cent., as shown by the organic matter determined as albuminoid ammonia.

Sewerage and Sewage Filtration at Marlborough, Mass.—Marlborough is a Massachusetts city of about 17,000 people. The sewerage system was constructed in 1891; and was designed to take house sewage only. All the sewage is collected in a system of pipe sewers and conveyed by gravity through a main pipe sewer to settling tanks and filter beds about three and one-half miles away from the city. In constructing the sewers considerable ground water was encountered, and a large amount of this water leaks into these sewers. In this city, in distinction from Brockton, no underdrains were laid beneath the sewers to care for the ground water. The average amount of sewage reaching the beds daily is about 1,500,000 gallons, the amount varying very much at different times of the year. Accurate measurements have shown that the volume during wet months, such as in the early spring, is four or five times that flowing in the dry months of the late summer and early fall. The sewage at the filtration area enters settling tanks, two in number and with a combined capacity of 16,000 gallons. When the average volume of sewage is reaching these tanks, it is about twenty minutes in passing through them, this time being very much decreased as the volume of sewage increases, and of course increased when the volume of sewage decreases. The material which accumulates in these tanks is usually removed about once each fortnight and is discharged upon special sludge beds, where it is allowed to dry, and is then raked up and carried away, this material being used by the farmers in the vicinity as a fertilizer. The sewage in the tanks passes upward through horizontal screens having a one-inch mesh, before its discharge into the carriers leading to the filter beds. There are twenty-six of these beds having a combined area of about eleven acres. In preparing them nearly all the loam was removed, but the subsoil was allowed to remain in place. The beds were originally underdrained by lines of pipe about fifty feet apart, with a depth of from five to eight feet beneath the surface. On account of these drains receiving a large amount of ground water, it was found that their capacity was insufficient to remove both ground water and effluent, and additional underdrains were put into place.

The material in the beds is quite uniform in grade, and has an effective size of about 0.14 mm. The sewage is discharged upon these beds near the corners, and the

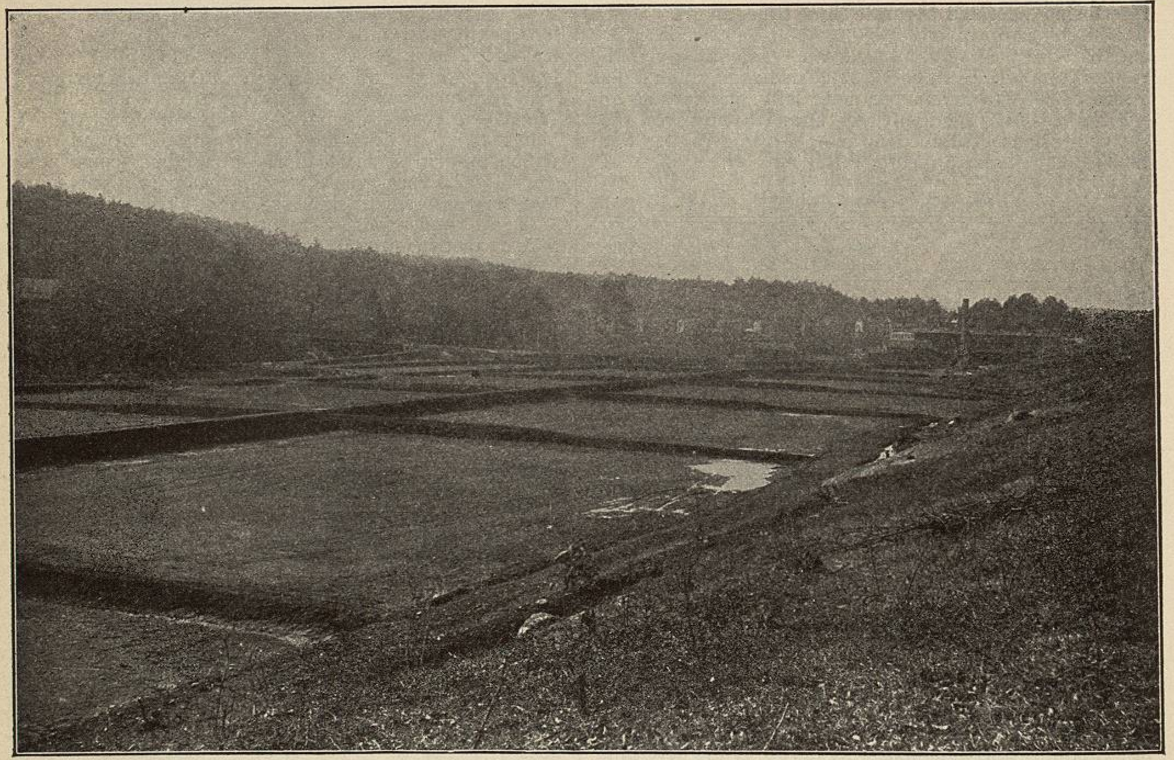

FIG. 4189.—A Massachusetts Filtration Area.

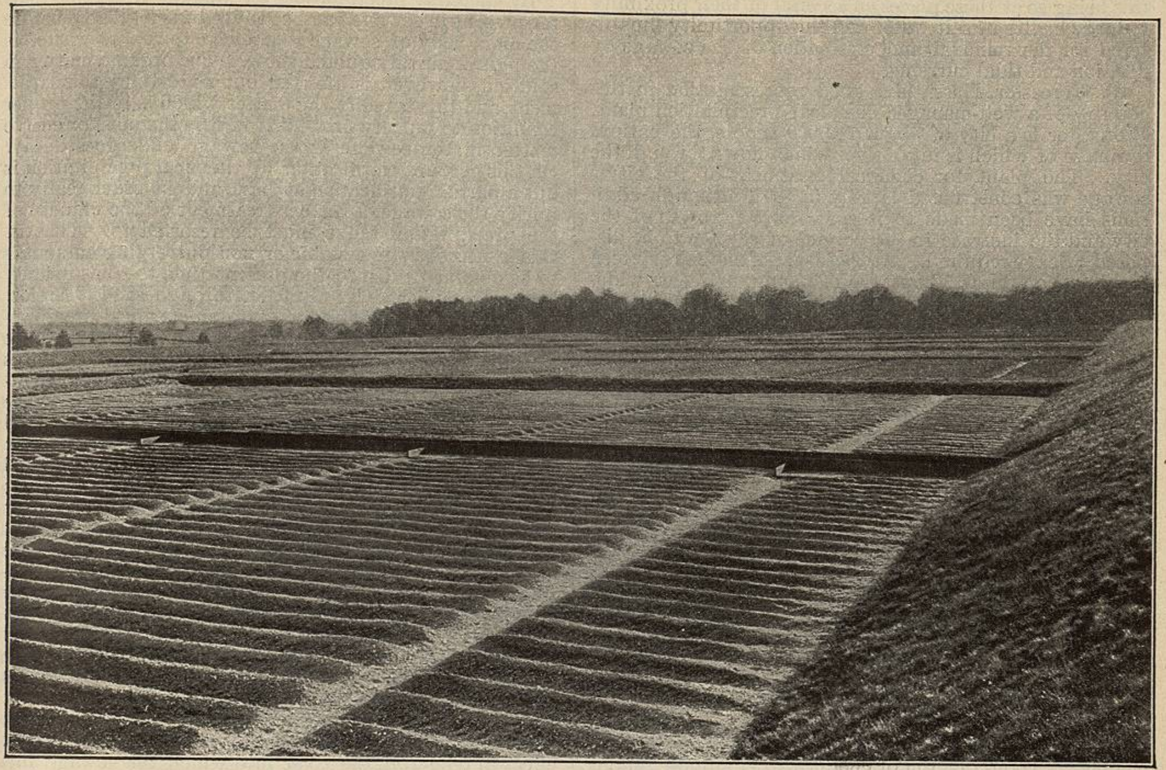

FIG. 4190.—A Massachusetts Filtration Area.

general method has been to turn all the sewage on to one, two, or three beds, according to the quantity flowing, and allowing it to flow upon these beds for twenty-four hours. In wet weather, of course, the flow has to be more widely distributed over the entire area. The sewage is applied to the beds in rotation, and once in about five weeks the surface of each of the beds is raked to remove the surface deposit, and then harrowed and allowed to remain out of operation for a short time; the solid matter which accumulates on the surface being removed before the surface is harrowed. In the fall the beds are ploughed and the surface is left in ridges and furrows, so that the ice forming upon the beds rests on the ridges and protects the sand from freezing, the sewage running in the furrows beneath this ice. The beds receive no attention in the winter in regard to surface management, but in the spring they are raked and then ploughed, harrowed, and graded, and remain level throughout the summer. The average rate of filtration at this area approximates 100,000 gallons per acre daily. The following table gives a fairly average analysis of the sewage applied to and the effluent from this area:

TABLE III.—PARTS PER 100,000.

	Sewage.	Effluent.
Residue on evaporation—		
Total	61.0000	24.8000
Loss on ignition	37.0000	......
mmonia—		
Free	2.4000	.6203
Albuminoid—		
Total	.5800	.0328
In solution	.2000	......
In suspension	.3800	......
Chlorine	5.8000	5.0000
Nitrogen as—		
Nitrates	......	.5400
Nitrites	......	.0171
Oxygen consumed	3.9000	.3400

The average purification by these beds is about ninety-four per cent.; that is, ninety-four per cent. of the organic matter in the applied sewage does not appear in the effluent from the filters.

Chemical Precipitation.—In the early days of sewage disposal, when it was considered that in most instances the removal of the larger portion of the matters in suspension in sewage was efficient purification, the coagulation of these matters by means of chemical precipitants was a favorite process, and very many costly works were erected in England and on the Continent, to be used in purifying or clarifying sewage in this way. The chemicals most generally used in chemical precipitation are lime, sulphate of alumina, and salts of iron. These chemicals by decomposition form, with other elements present in the liquid, gelatinous bodies like aluminum hydrate, which entangle or coagulate a considerable percentage of the organic matters in suspension in the sewage, together with some of the matters in solution. The specific gravity of the precipitant and coagulated sludge causes more or less satisfactory sedimentation to occur. The supernatant liquid is then run off, and the accumulated sludge either passed to sludge beds or to filter presses, or both. The filter press is simply a machine in which the sludge is placed to undergo compression whereby it is freed from a considerable percentage of its water, while the solid matters are retained by the cloth bagging in which the sludge is placed. Sometimes this sludge, when sufficiently dry, will be carted away by farmers, to be used as a fertilizer, but generally only after having had a very large percentage of its water removed from it by pressing; and more frequently it cannot be disposed of in any way except by the expense (chargeable to the operation of the works) of carting it away to be composted, or used in filling in low ground. This method of sewage treatment is in use in many places in England and on the Continent, and in a few places in this country. Its successful use, however, is generally confined at the present day to such locations as London, England, or Providence, R. I., where all that is at present considered necessary in the treatment of the sewage is the removal of the suspended matters;