A DISCUSSION

OF THE

PREVAILING THEORIES AND PRACTICES

RELATING TO

SEWAGE DISPOSAL.

BY

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PREFACE.

THIS discussion of questions relating to sewage disposal is prompted by reason of the disregard with which these questions have been treated in this country until very recent years, and the prominence lately given to the method of sewage disposal by land. It deals rather with the principles embraced in the prevailing methods of sewage disposal than with methods of mechanically treating sewage.

The more thoroughly these questions are discussed the more generally will they be understood and the more speedily effectual will become the efforts that are directed to the devising of practicable methods of finally and inoffensively disposing of the sewage of populous districts.

We have in nature conclusive evidence of the existence of a natural process of purification of polluted waters. This process is of such a character that it can be utilized in the purification of sewage; and with our present methods of sewerage and drainage it must become the foundation of any successful method of sewage disposal.

The author's aim in this discussion is to set forth this natural process of purification together with the various considerations embraced in questions of sewage disposal in a simple and practical manner.

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INTRODUCTION.

In nature there is a great storehouse of energy, a beautiful exhibition of harmonious motion among countless bodies, and a wonderful manifestation of balanced forces. We observe there that laws are few, simple, and immutable. The energies, forces, and processes of nature may be utilized by man in various ways, and the extent to which man can direct them to his own ends is a measure of his intellectual and material advancement. Philosophers and scientists have labored to develop and establish the principles involved in natural laws, and to formulate them in a manner to be attainable by all. With every new facility for analyzing nature they have discovered some new principle of life or of force which serves to correct errors in theories that may have been previously formulated upon a partial knowledge of natural law or upon imperfect observations of natural phenomena. The formulated results of their researches have frequently been termed impracticable theories; yet they are at the foundation of substantial advancement in the arts, of the productive application of natural processes and forces, and of prosperity and wealth in the ordinary affairs of life; and they are becoming more and more to be so understood and to be proportionately appreciated. It may therefore be expected that the results of the scientific researches now in progress will inspire far greater confidence than formerly among people generally, with regard to the applicability of these results to useful and practical purposes. In fact it is just such a confidence and appreciation that is most needed to stimulate investigators and others to even more energetic efforts than heretofore in the development of a practicable science.

Nature never fails to reward a searcher in her storehouse of riches; and any investigator relying upon the unswerving stability of natural law, upon the steady balance and interchangeability of energy and force, and upon the positive sequence of cause and effect, can be assured of connecting any observed phenomenon in nature, no matter how singular or exceptional, by a chain of convincing evidence in line with natural law, with some prime natural cause. And any truth or principle of nature thus established is of value, for it is always of some practical utility.

But it is seldom that the scientist and the philosopher, the discoverers and developers of natural laws, principles, forces, and processes, are the ones to practically apply the results of their own efforts. This frequently and generally falls to the lot of others, middlemen as they may be called, who weigh these results and determine the range of usefulness. Among these middlemen engineers may be classed, who, by admitting that a study and knowledge of natural law and force is essential to the intelligent and economical application of the involved principles, and by accepting the consistencies and the science of nature, have elevated their occupation from a mere trade or art of directing men and handling materials to a profession that is closely connected in various ways with many departments of science. They give material and productive form to the deductions of natural science. Their education and training should develop such a capacity and a desire for scientific studies, that they may be among the first to group and analyze the results of scientific research, and may possess a skill to properly apply these results in practice. They cannot consistently permit their conservatism and their almost constant contact with material things to divert their interest and sympathy from the scientific part of engineering, nor to bias their judgment regarding the results of scientific research when accompanied by reasonably conclusive evidence of its truth and value.

Thus the mutual dependence of the departments of natural science and practical engineering becomes so intimate as to invite a respectful coöperation of the workers in both departments, in order that the results of their combined efforts may be the more speedily directed to useful purposes. But it is not enough that reciprocal efforts should be confined alone to these two classes of workers, for it is necessary that the public, which is yet not altogether free from scepticism regarding scientific discoveries, but upon whom to a great extent must depend the fulness and rapidity with which such discoveries can be applied, shall be brought to see and appreciate their merit and utility.

Such an understanding and appreciation, at least with regard to matters of sanitation, might perhaps be rendered the easier if the laws, the principles, and the processes of nature, as they affect the customs and health of people in communities and assemblages, should be more generally and specifically taught in the schools, oftener discussed by the press, more precisely and popularly treated in current literature, and generally made more familiar topics.

In this connection it may be noted that the accumulating and convincing evidence of the relation of the vital activity of living organisms to the decomposition of organic matter, together with the almost constant publicity which this relation and its accompanying evidence is receiving, renders it one of the most generally accepted of the newly developed processes of nature.

We now believe that by this process all decomposable and putrescible matter may be transformed into other and more stable compounds, and that all organically polluted waters may be purified.

In all probability many of the troubles experienced with public water-supplies and with sewage have been, and still are, due to a disregard or misunderstanding of the principles involved in natural processes of purification. In fact there is probably no branch of engineering that requires a more general and thorough knowledge of natural laws, principles, and processes, and a greater skill in the application of these to useful purposes, than does that branch which appertains to the selection and development of water-supplies and to sewage disposal.

In the discussion contained in the succeeding chapters it is admitted that the vital activity of living organisms is primarily responsible for the decomposition and destruction of organic matter, as such, in polluted waters; that this vital process in its completeness is a provision of nature to maintain the purity of the elements which support life; that observation and study of the conditions in nature which affect this process are essential to its proper application; and that the application of this natural process to the purification of such a grossly polluted and polluting matter as sewage should observe, with a proper margin of safety, the limitations that nature has placed upon it. It regards sewage disposal as admitting of the fullest discussion, because it is only of recent years that the population of cities in the United States has become sufficiently dense to feel the serious effects of careless and temporizing methods of sewage disposal, and because the greatly diversified conditions in this country require a more or less modified application of the experiences in foreign countries.

Moreover, it regards the results of experiments of the Lawrence Experimental Station in Massachusetts as authoritatively instructive regarding the principles involved in the natural process of purification of polluted water, and the author does not hesitate to frequently refer to the reports of the State Board of Health, under whose directions these experiments have progressed, and to freely quote from the pages of these reports.

SEWAGE DISPOSAL.

CHAPTER I.

SEWERAGE AND SEWAGE.

RECORDS of drainage works of considerable magnitude date back to the early centuries of the Christian era. Notwithstanding the fact that we possess but meagre and indefinite descriptions of these works, there remains enough of the works themselves to demonstrate a regard of the ancients for systematic drainage.

However far sanitation as a science may have advanced at that early period, it began, we are informed, during the decline of the Roman Empire, so to decay that in the Middle Ages—when civilization had apparently retrograded, when barbaric customs had supplanted hygienic observances, when crusades, feudal strifes, and political disturbances had hindered the advancements of nations in peaceful pursuits—it had few if any votaries. Modern sanitary science attributes some, at least, of the devastating plagues of that early day to the neglect of observing proper and hygienic methods of living.

It was not until after the beginning of the present century that the modern systems of drainage and sewerage began to be developed. It is easy to conceive that the introduction of water under pressure as a public supply so prompted and encouraged a liberal use of water for all domestic and industrial purposes that the necessity arose for a method of house-drainage that would quickly and effectually remove soiled water from the premises. It was but natural to discharge this soiled water into any street drains that may have been in use to remove storm-water, inasmuch as excrementitious matter was removed by methods that were independent of the system of public drainage. But the convenience of water under pressure within the dwelling, and the ease with which it could be utilized to remove waste matter, gradually led to the introduction of toilet-room fixtures and to improved facilities of house-drainage connecting with cesspools.

Of this practice in London, Sir J. W. Bazalgette wrote that "up to about the year 1815 it was penal to discharge sewage or other offensive matter into sewers." Doubtless at that time the experience in London demonstrated what a later experience in many other cities has proved, that an accumulation of filth in cesspools about the premises is a menace to health, and that sanitary regulations require a prompt and complete removal of excrementitious matter. As a matter of expediency it was permitted to enter the public drains; but when once the safety and practical utility of this practice became established, then followed the enactment of laws and regulations making it obligatory to discharge excrementitious matter into the public sewers, and thus officially recognizing one of the first principles of modern sanitation, namely, the prompt, rapid, and complete removal of filth from all habitations; and originating the "water-carriage" system of sewerage. So in London "in the year 1847 the first act was obtained making it compulsory to drain houses into sewers."

Somewhat later the "water-carriage" system of sewerage became developed into the "combined" system, which provides sewer capacities for the united drainage of storm-water and all domestic and industrial waste; and into the "separate" system, which provides sewer capacities for sanitary drainage and for a portion of storm-drainage from roofs, yards, and courts.

In order that the pipes and drains comprising a system of sewerage and drainage might be in as perfect accord as practicable with the essentials of proper sanitary drainage, it became necessary to adopt such sectional forms of sewers, such limiting gradients, such methods of ventilation, flushing, and construction, and such restrictions with respect to the intoduction of solid and insoluble refuse into sewers, as would insure a velocity of flow, a circulation of pure fresh air, and a continuity of movement within the sewer, that would serve to prevent deposits, putrefactive changes, and offensive gases therein. The principles and rules of guidance in matters of this kind are already so well outlined in various publications as to need no elucidation here; in fact any effort in that direction would be quite foreign to the objects of this discussion.

With respect to the two systems of sewerage, no valid claim can be made of the general adaptability of either system to the exclusion of the other. The varying physical conditions of any territory to be drained and the economic aspects of the questions at issue must decide in each case whether the system of sewerage should be the "combined," the "separate," or a combination of the two systems. So far as concerns the sanitary conditions which may prevail within the sewers of either system, the sewers of each having had bestowed upon them equal skill in design and construction, they are shown by experience to be equally good. The mere application of a few principles to the design of sectional forms and capacities of sewers is now so well defined as to become a comparatively simple process. Indeed questions of design are of less importance than the more complicated ones relating to the adaptation of a system of sewers to the natural conditions of any locality. These questions involve considerations of a present and future disposal of sewage, which, in turn, are affected by various conditions, both natural and artificial, that independently or in combinations may have a diversified bearing and may lead to very dissimilar conclusions in different localities.

It is not usual that the inception and construction of the first sewerage works of most cities involve comprehensive plans of main drainage and sewage disposal; for such works very often continue to progress regardless of many of the requirements of a comprehensive system, until the commercial and industrial interests of the city shall have become so developed and established as to admit of an intelligent study of such problems and a definite outline of such plans.

Even then various artifices and makeshifts are frequently resorted to in order to postpone, for as long a time as possible, expenditures of money in a public improvement, which, though evidently needed for the public good, is non-productive of revenues. In short, complete main-drainage and sewage-disposal works in almost any city are the result of a process of evolution through various stages of development, requiring in many instances more or less modification or abandonment of previously constructed works.

Sewage is a complex mixture with water of the various waste products of life and industry from densely settled communities, of which the solids are properly restricted to those that are susceptible either of solution in water or of becoming speedily disintegrated while in a state of transit. The measure of the volume of any dry-weather flow of sewage is practically the volume of the water consumed by that part of the community connected with the sewers, frequently somewhat increased by the additions of ground-water that may have filtered through the joints and brickwork of the sewers. Its chemical composition and degree of dilution varies with the character of industrial pursuits, with the amount of mineral matter naturally dissolved in the water-supply, and with the volume and rate of water-consumption. The mineral matter held in solution is, as a rule, stable; but the organic impurity, consisting largely of excrementitious matter, is in a state of decomposition and imparts to sewage an offensive character.

In England a determination of excrementitious matter in sewage was as follows (*vide* Dr. C. Meymott Tidy):

"Every adult male person voids on an average 60 oz. (= three pints) of urine daily. The 60 oz. contains an average of 2.53 oz. of dry solid matter, consisting of

Urea	512.4	grains
Extractives (pigment, mucus, uric acid)	169.5	"
Salts (chiefly chlorides of sodium and potassium)	425.0	"
	1106.9	" = 2.53 oz.

"Every adult male person voids about 1750 grains (or 4 oz.) of fæces daily, of which 75 per cent. is moisture. The dry fecal matter passed daily is therefore about 1 oz. per adult head of the population. Of this *dry* fecal matter about 88 per cent. is organic matter (of which 6 parts are nitrogen) and 12 per cent. inorganic, (of which 4 parts are phosphoric acid). Of this dry fecal matter 11 per cent. is soluble in water."

Another determination for a mixed population of 10,000 inhabitants gives 22,659 lbs. of fresh urine, or 956 lbs. of dry constituents, which is equivalent to about 36¼ oz. of fresh urine and 1.53 oz. of dry constituents for each person per 24 hours; also 1775.5 lbs. of fresh fæces, or 415.8 lbs. of dry constituents, which is equivalent to 2.84 oz. of fresh fæces and .66 oz. of dry constituents for each person per 24 hours.

The Rivers Pollution Commission of England, in the report on the pollution of the Mersey and Ribble basins, gives the following condensed results showing the average composition of sewage collected from thirty towns, and fairlv representative:

IN PARTS PER 100,000.

Description.	Solution.	Suspended Matter.			Total in Solution and Suspension.
	Total Solids.	Mineral.	Organic.	Total.	
Water-closet Towns..	72.2	24.18	20.51	44.69	116.89

The results of recent investigations in the United States with respect to the composition of sewage are perhaps succinctly condensed in the report of the Massachusetts State Board of Health of 1890, which states that:

"Sewage varies much in the amount of impurity it carries, depending upon the amount of water used. It is much more dilute in American than in European cities. Here a sewage stronger than ordinary would contain, say, 998 parts of pure water, 1 part of mineral matter, and 1 part of animal and vegetable matter.

"Sewage would become entirely purified if we should take out the 2 parts of mineral and organic matter and leave the 998 parts of pure water; but, as the mineral matter is not generally objectionable, we are satisfied to call sewage purified if we succeed in taking out the 1 part of organic matter.

"Of the two parts of mineral and organic matter in one thousand parts of sewage, about one half is in suspension and can be strained out by the finest strainer that water will pass through; the other half is dissolved in water and cannot be thus strained out.

"Sewage as it issues from the city sewers contains no dissolved oxygen and no oxidized nitrogen. The available oxygen of the water has all been consumed in the oxidation of a portion of the carbon of the organic matter, and has not sufficed for the oxidation of the nitrogen also. In this condition it is not the repulsive fluid it is popularly supposed to be. Further and complete decomposition can only go on by access of an additional supply of oxygen which the sewage may take up from the air or from the water into which it flows."

The average composition of the sewage of Lawrence, Mass., for a period of twelve months in 1888 and 1889, during which time there were made numerous analyses, is:

IN PARTS PER 100,000.

1888 and 1889.	Residue on Evaporation.		Ammonia.		
Mean of 12 months.	Loss on Ignition.	Fixed.	Free.	Albuminoid.	Sum.
Unfiltered sewage, ...	19.11	29.83	1.8202	.5302	2.3504
Sewage filtered through filter-paper, ...	12.10	23.53	1.7710	.2675	2.0385
Per cent., ...	63	79	97	50	87

The total solids of unfiltered sewage are here 48.94 parts per 100,000, or about $\frac{1}{20}$ of 1 per cent.; and they are a little less than one half the total solids in sewage as given by English analyses, namely, 116.89 parts per 100,000.

Just how to remove from sewage or to render innocuous this small fraction of decomposable organic matter, seldom exceeding $\frac{1}{10}$ of 1 per cent., is the problem that is involved in all methods of sewage disposal. Whatever may be the method employed, it must be of prompt application; for untreated or undiluted sewage will within a very few days after its discharge from sewers, and under favorable conditions of temperature and rest, undergo such putrefactive changes as will evolve gases of a highly offensive character, and as will render the sewage difficult of treatment.

CHAPTER II.

VITAL PROCESS OF PURIFICATION.

SCIENCE tells little that is satisfactory of the origin of life and matter; of the almost spontaneous development of the one and of the subtle processes at work in the transformation of the other. It tells us, however, that matter is indestructible, and is composed of a few elements united in obedience to natural law into bodies of a variety of forms and conditions. Of these forms of matter, some become the embodiment of life and energy; and others are inert and passive, but contribute in some measure to the support of life. Science tells us further that there is a continual transition of matter between the vegetable and the animal forms, and between the organic and the inorganic state. Thus the active and living forms of to-day die, decay, and are resurrected in other new and living forms, just as the animal creation by its life processes, its death and decomposition, supplies vegetation with sustenance; or as vegetation, both dead and alive, contributes to the support of animal life. In many instances, at least, it is now known that organized life is the agent of these transformations. Thus in the decomposition of nitrogenous matter micro-organisms are known to be the active agents. This was indicated by the experiments of Schwann and Schultze in 1839, and later by Pasteur, who showed that the putrefactive change of organic matter was due to the vital activity of minute forms of life.*

Micro-organisms are forms of life which are invisible to the naked eye, among which certain forms known as bacteria, and now regarded as belonging to the vegetable kingdom, are asserted to be the principal agents in the purification of water polluted with organic matter. So minute are these plants that the characteristics of many of them cannot be satisfactorily studied even with the most powerful microscopes; conse-

* Schlœsing and Muntz in 1877 brought forward practically conclusive proof of this. See Mass. St. Bd. of Health Report, 1890.

quently many of the investigations regarding their life habits which had been made by the aid of the microscope previous to the year 1881 are somewhat indefinite. In that year, however, Koch developed his method of growing these bacteria by "cultures" on gelatin plate and in other nutritive compounds, by means of which growths they began to be studied in "colonies" by the naked eye.

These bacteria pervade the air, the water, the soils, and are to be found almost everywhere in nature. They are abundant in the human system. Some varieties are supposed to be the origin of certain diseases. The readiness with which they may be taken into the human system by means of water and food-supplies has led to an extended study of their life habits and processes by many investigators, prominent among whom are Koch and Pasteur. To these gentlemen is assigned the chief credit of the development of the science now known as bacteriology.

The application of this science to questions of sewage disposal is of much service.

The organic impurity of fresh sewage, being in a state of decomposition, gives off organic vapors which are somewhat offensive. There are, however, no putrefactive changes in sewage in the condition in which it is ordinarily discharged from public sewers, but in it are a vast number and many varieties of bacteria, very often to the number of several hundred thousand or even a million per cubic centimetre (about a cubic $\frac{3}{8}$ inch), and no free oxygen; for the oxygen that the water of sewage may have contained previous to its pollution with organic impurity has been consumed in chemically uniting with the carbon of this impurity, thus forming carbonic acid and free ammonia. Aside from this initial chemical reaction there is little change to be noted in sewage until after it is dispersed through a body of water or distributed over porous ground, when there begins a process of change of the nitrogenous parts of the organic matter from the state of ammonia to that of nitric acid; which acid, in its turn, unites chemically with some mineral dissolved in the sewage to form a harmless inorganic compound, usually termed nitrate in a sanitary analysis.

This process is termed nitrification. It is likewise one of purification; for it denotes a change of the nitrogen compounds, which constitute the unstable and polluting constituents of sewage, from the changeable organic condition to the stable and harmless inorganic condition, by virtue of their continued union with oxygen as the process of change proceeds. In its results it amounts to an oxidized or burned-up condition of the organic impurity; but of the process itself the active agents are certain varieties of the bacteria which infest sewage and which have the power of decomposing the nitrogen compounds in the presence of oxygen. Of this vital action of bacteria upon organic matter there is proof; for if sewage be sterilized—that is, exposed for a time to a temperature sufficiently high to destroy any life that may be in it—there will take place no change in the nitrogen compounds, even in the presence of air or other source of oxygen, until seeded with sewage or other decomposing matter known to contain the nitrifying organism. Likewise, antiseptics will arrest decomposition; and the change from one condition to another of the organic impurity is practically confined to a range of temperature between 32° F. and 131° F., which range is identical with that admitting of life among bacteria. Of nitrification the report of the State Board of Health of Massachusetts states that: "Oxidation of organic matter, such as we have under consideration, does not go on in nature without the presence of these minute organisms, even though the supply of oxygen is unlimited. By chemical means, as in the use of oxidizing agents, such as nitric acid, potassium permanganate, and the like, we can break up organic matter and accomplish its partial oxidation. The effect of these oxidizing agents is, however, limited to the carbon, hydrogen, and sulphur of the organic compounds, and does not extend to the nitrogen. Ammonia is invariably formed when nitrogenous organic matter is thus treated. Except when we have the action of nascent oxygen, as in the galvanic decomposition of water, we may say that the oxidation of organic nitrogen requires the presence and vital activity of bacteria." The Board of Health found nitrification to be practically arrested at temperatures of sewage below 39° F.

Nitrification, which is a process of nature requiring the presence of oxygen, produces no offence. It is analogous to fermentation and putrefaction, of which processes the former is produced by living yeast-cells, and the latter by bacteria which are supposed to be of a different variety than the nitrifying species, inasmuch as they are active in the absence of oxygen at favorable temperatures. Thus sewage left to stand insufficiently diluted with water will putrefy and exhale sulphuretted and phosphuretted hydrogen gases.

The method by which the activities of the nitrifying organisms decompose organic matter has not yet been made clear by the bacteriologist; but the observed results of these activities leave no doubt of a process of decomposition and purification. Several investigators have succeeded in isolating a bacillus which would completely nitrify ammoniacal solutions.

But all bacteria in sewage do not appear to have the same functions; for certain varieties are known to have the power of reducing nitric acid —that is, the power of absorbing a portion of the oxygen of nitric acid and of thus reducing nitrates to the less oxidized condition of organic matter as represented by the nitrites, or even to ammonia as some chemists assert. In fact these distinctive and apparently opposite functional characteristics may have been potent factors in leading to the discordant and conflicting opinions as formerly expressed by independent investigators. Thus when the Massachusetts State Board of Health took up its investigation the following views as stated in its report were current, namely:

1. "That there is a group of bacteria capable of oxidizing ammonia to nitric acid, and another and separate group able to reduce nitrates to nitrites in the presence of organic matter. Both

kinds are widely and abundantly distributed. Attendant circumstances determine whether the reducing or the oxidizing groups will gain the upper hands." (*Heræus.*) *

2. "That all kinds of bacteria, under favorable circumstances, are capable of producing nitric acid, and that the same organisms in the presence of organic matter are capable of reducing nitrates." (*Celli* and *Zucco. Leone.*)*

3. "(*a*) That different species of bacteria vary greatly in their ability to reduce nitrates; and (*b*) that there is no reliable evidence that any individual species is able to oxidize ammonia either to nitric or nitrous acid." (*Warrington. Frankland.*)

But the results of the investigations of the Massachusetts State Board of Health showed that, while there was no doubt a nitrifying organism, it did not respond to "culture" on the gelatine plate. Concerning these organisms the report states that "they are grouped very characteristically in irregular clumps and are held together by a jellylike material. Each aggrega-

* See Report of E. O. Jordan and Ellen H. Richards in Report Mass. State Bd. of Health, 1890.

tion is indeed a typical zoöglœa. . . . These masses of zoöglœa, obtained as a pure culture from a nitrifying solution, resemble significantly the zoöglœa discharged in considerable quantities from the filter-tanks at Lawrence." *

" Besides the bacteria found in the materials of which the filters are made, the microscope reveals a variable quantity of brown flakes, or flocks of amorphous matter, which appear to be largely a peculiar form of bacterial jelly, myco-derm or zoöglœa. This is so constant through-out all the tanks, and apparently so characteristic, that it demands special consideration. From what has been said above it is evident that it is the only organic material, visible with the micro-scope, which occurs throughout the tanks from top to bottom. It cannot be regarded as an accidental accumulation of *débris*, since it is ssen-tially uniform in character and is attached to the sand-grains as if it had formed there, rather than as if it had been accidentally detained. From its

* See Report of E. O. Jordan and Ellen H. Richards in Report Mass. State Bd. of Health, 1890.

connection with the sand-grains and its microscopical appearance there is no reason to doubt that it is, for the most part at any rate, the peculiar gelatinous condition of bacterial development known as mycoderm or zoöglœa. Its abundance in the sands is remarkable, nearly every grain, in some cases, being clothed with a mantle of zoöglœa. We have reason to believe that in this stage the bacteria are still alive and active though they may not grow upon our gelatine plates. We also have some indications that a sand-filter is ineffective until this zoöglœa has begun to form, although it appears that a mature filter is not a mechanical purifier, but rather a respiratory mechanism. The analogy to fermentation by yeast, in which a large amount of chemical change is effected by a relatively small amount of yeast, naturally suggests itself, inasmuch as the chemical changes effected by a mature filter are enormous and out of all obvious proportion to the discoverable changes in the zoöglœa or the nitrifying organism. The analogy is entirely reasonable, since fermentations produced by bacteria are known to resemble closely those produced by yeast. It is also possible that the zoöglœa in the filters represents the nitrifying organism in a peculiar phase of its life-history."

The vital process of purification when considered simply as a theory is the most rational one that has ever been advanced to explain the transformation of organic matter in polluted water to inorganic compounds. With no other foundation than the analogous process, which may be observed everywhere in nature, of vegetable life absorbing from disorganized nitrogen compounds the elements of its existence, in which process water performs the interesting and important part of collecting these compounds from the air and soils and of delivering them to vegetation in a proper condition for absorption and for transformation into living forms, the theory, as such, is a very substantial one. But it has become more than a theory, it has become an established fact; for the opinions derived by analogy from the observed phenomena of nature have been substantiated and conclusive evidence has been furnished by the independent investigations of various scientists, leading to a consensus of conclusions regarding its truth.

In fact, the principles of this process are now known to possess an important bearing upon questions relating to the purity of water supplies and to successful sewage disposal, and they are coming to be generally regarded in carrying out projects for the satisfactory accomplishment of these ends. A failure to accord to them due consideration may result in much future trouble and annoyance.

The acceptance of the vital process of purification in a measure sets aside the purely chemical theory. While it is true that chemical reactions do occur and are a part of this process, it is now held that these reactions are rendered possible only by the activities of bacteria, thus becoming secondary and dependent rather than primary factors of the process of purification.

CHAPTER III.

DISPOSAL BY DILUTION.

THE disposal of sewage by dilution is simply the discharge of sewage into bodies of water sufficiently large to prevent offensive decomposition.

The recipient body of water naturally assumes the same relation to the outfall sewers as does the house-drain to the dwelling; in other words, the service which the main drains of the country perform for communities in the removal of waste matter is but analogous to that which is performed by the house-drains of the sewer system for every habitation. Indeed, so natural is the transition from the artificial to the natural water-carriage system of sewerage that we find creeks and rivers used as public sewers, not only as a measure of expediency and economy, but also as though by virtue of an inalienable right and indisputable authority inherited from nature.

Should these creeks and rivers be of large volume as compared with the amount of sewage entering them, of high velocity, and of continuous flow, then the disposal of sewage by water becomes so simple, so complete, and so effective that, as such, there seems to be little or nothing more to be desired. But should the receptacles of sewage be small brooks and tributaries in which the constant flow is but little greater than the amount of sewage entering them, then the resulting conditions may cause offensive odors or even nuisances during warm seasons of the year. Such outfalls must ultimately be abandoned for less objectionable ones into larger bodies of water, or the sewage must be diluted to such an extent or treated in such a manner as to prevent offence.

When, however, the outfall sewers discharge into tidal rivers, the conditions affecting sewage disposal by dilution become more complex, for the sewage oscillates up and down the river with each ebb and flow of the tide, and partakes of a resultant translation downward and seaward that is dependent upon the relative effects of the natural and tidal flows of the river. If these be such that the sewage is retained for some time in the tidal prism of the river, offensive putrefaction may take place.

To a certain extent the period of retention may be determined by series of float observation so prolonged as to include the combined and resultant effects of winds, tides, and the natural flow of the river at the different seasons of the year. At the same time, other physical characteristics of the river affecting sewage disposal by dilution, such as temperature, specific gravity, and chemical characteristics, may be determined. But unfortunately the necessary time and means are not always available for the purpose of collecting by such tedious methods those data that are necessary for reaching positive conclusions in advance of the construction of a system of sewers, and it frequently becomes necessary to execute the work expeditiously and economically, and to utilize for the then present purposes the most available points of outfall, awaiting the time when sewage, acting the part of the float in the tidal prism of the river, will demonstrate wherein lies the danger, if any, of offensive putrefaction.

But realizing the advantage of anticipating an evil or unfavorable result, rather than of awaiting its coming, and having available data relating to the discharge of the river, then the rate and amount of translation may be approximately estimated, as follows: At the point of outfall determine the cross-section of the river or estuary. Compute the volume of the tidal prism above this section, having for bounding surfaces the areas respectively of overflow at mean high tide and at mean low tide, and an altitude equal to the mean tidal rise or fall; a quantity of water equalling the volume of this prism, and that of the natural flow of the river (usually at a low stage) must discharge through the section of measurement during the time of ebb tide, and must spread out in a reach of the river below. Now the distance which sewage would be carried up stream by a flood tide would depend upon the relative portions of the tidal prism which would be filled by the up-stream flow of the tide and the natural flow of the river, assuming the tidal flow to act piston-like upon the flow of the river. This method assumes that the velocity of flow through the cross-section is uniform, that there is no dispersion of the sewage and no wind effects, conditions which in nature do not obtain, consequently the method is but a crude substitute for the more reliable ones of direct observation. However, by whatever method the effects of a sewage disposal into tide-water may be determined, whether by the actual experience with sewage discharged at convenient points, or by the more rational method of collecting and analyzing those data that may relate to such a disposal of sewage, and of drawing conclusions therefrom, it follows that, if offence become assured as a result of a certain line of practice, or if it be anticipated as a result of a close and careful investigation, a future disposal must contemplate works to remove the sewage to more remote points, where no ill effects will result. Such works may consist of long lines of intercepting and outfall sewers leading to some distant locality where the sewage can be safely thrown into water or upon land ; or of a plant for purifying the sewage before discharging it either into water or upon land. Their precise character, however, will depend upon local requirements and natural facilities, in whatever way that they may affect the questions at issue.

Having briefly alluded to the several conditions under which sewage disposal by water is met with in practice, it will be interesting to consider the amount of dilution that may be necessary to prevent offensive putrefaction of sewage, and the processes of nature that result in the purification of sewage-polluted water.

The amount of sewage that may be committed to a body of water without fear of offence is dependent upon the balance which may exist between the natural processes of decomposition and of purification, as they may be active in the polluted water. Should the products of decomposition of the organic impurity exceed an amount that can be naturally absorbed by the diluting water, the exhalation of offensive gases will ensue. On the other hand, if these products be all absorbed no offence will follow, although the water may be somewhat unsightly.

It is not easy, however, to determine just what the relation by volume of the sewage to the dilutent should be for there is not available a sufficient amount of experimental data and observations upon the subject to admit of a positive conclusion. Moreover, that relation which might answer in one locality would not necessarily apply in another, for the dissolved and suspended constituents of natural waters in a normal condition, their average temperature and their organized life, are all subject, more or less, to seasonal and geographical variations, which variations, as associated with other physical properties of natural waters, will qualify its natural purifying power. Such observations as have been made in different localities enable us to form certain estimates and deductions as to what this relation should be.

The State Board of Health of Massachusetts, which through its eminent scientists and engineers has given considerable attention to the study of the water supplies of Massachusetts, has suggested, as a result of experiment and observation, that, in a river continuously flowing at a sufficient velocity to prevent deposits, there should be a discharge of 2.5 to 7 cubic feet per second for every one thousand inhabitants, which is equivalent to a dilution from 16 to 45 times the volume of sewage, assuming the rate of water consumption per capita to be 100 gallons per day, and that the amount of water consumption is a measure of the volume of domestic sewage.

It was recommended for Chicago by the Drainage and Water-supply Commission that provision be made in the discharging capacity of the new drainage canal, now under construction, for a dilution of sewage with water from Lake Michigan to the amount of four cubic feet per second per one thousand inhabitants, which is equivalent to a dilution of about 26 times the volume of the sewage, assuming the daily rate of water consumption to be 100 gallons per capita. By daily pumping 440,220,867 U. S. gallons of pure cool water from Lake Michigan into the navigable outlet basin of the Milwaukee River at a point about 3½ miles from the harbor entrance, this basin, which receives daily about 13,000,000 gallons of sewage from a large district of the city of Milwaukee, is so completely flushed and the sewage so thoroughly diluted as to effectually abate the intolerable nuisance of putrefying sewage that had for years annoyed the inhabitants of that city. In this instance a dilution of about 34 times the volume of sewage prevents offence; but it is estimated, as the result of experiments made upon a small scale, that a dilution of 25 to 30 times the volume of sewage would be equally effective.*

But degrees of dilutions somewhat less than those just stated have been found to give offence. Thus the sewage of the city of Chicago as it flows from the Bridgeport pumping-station through the Illinois and Michigan Canal, diluted with four times its volume of water from Lake Michigan, has given offence at Joliet, 33 miles below the point

* See article by G. H. Benzenberg, C.E., in Trans. Am. Soc. C. E., Nov. 1893.

of its discharge into the canal. The Blackstone River of Massachusetts, receiving the sewage of Worcester and diluting it by a continuous discharge of 1.77 cubic feet of water per second for the sewage of each one thousand inhabitants, is very offensive immediately below the city; but at Uxbridge, 16 miles below, the discharge of the river for each one thousand inhabitants is 3.88 cubic feet per second and gives with this degree of dilution no offence to dwellers along the river.*

It is, therefore, quite clearly indicated that a proper disposal of sewage into a river continuously flowing with a sufficient velocity to prevent deposits should be restricted to that amount of sewage which the river can absorb and purify without offence at a stage of minimum flow. And usually it may be well to observe the same relation between the volumes of sewage and diluting water, even when the natural flow of a river becomes opposed by tidal currents; for the ebb and flow of the tide affects the natural flow of the river very much as would a dam periodic-

* Report Mass. State Bd. of Health, 1890.

ally lowered across the river and as often raised therefrom, inasmuch as such a damming back of the water simply change the conditions of flow without affecting the actual amount of water that is discharged into the sea.

It is particularly necessary to observe proper proportions of sewage dilution and a favorable temperature of the diluting water when the discharge of sewage is into harbor basins or estuaries; for there various conditions combine to produce serious pollution. These conditions and their effects will appear in a more striking light when illustrated by practical examples. The city of Milwaukee discharges a large portion of its sewage into the Milwaukee River. This river drains a watershed of about 675 square miles; but, notwithstanding so large a drainage area, its average summer flow is not over 15,000,000 gallons per day, and at exceedingly dry times it ceases altogether. It discharges into Lake Michigan through a long basin that has been artificially made navigable for lake craft for a distance of about 2½ miles from the harbor entrance. The current through this basin is naturally exceedingly sluggish during the ordinary summer flow, and is subject to the effects of winds upon the lake.*

The amount of sewage daily discharged into this basin is, as has been stated, about 13,000,000 gallons. The velocity of natural flow through this basin being insufficient to carry into the lake the insoluble portion of sewage, it deposits upon the bottom of the basin and in the slips as a semi-fluid sludge, which, during the summer when the temperature of the water in the basin becomes 70° F. or more, putrefies and exhales unwholesome and offensive gases. To obviate the annual summer-stench nuisance, there was constructed a conduit 12 feet in diameter and 2500 feet long from the lake to a point in the river about 3½ miles above the harbor entrance, where there is a dam. Through this conduit a volume of water equal at least to 25 times the volume of the daily flow of sewage, is daily pumped from the lake into the river during a

* G. H. Benzenberg, Trans. Am. Soc. C. E., Nov. 1893.

considerable portion of each year, thus effecting a thorough dilution of the sewage, a cessation of putrefaction, a removal of all discoloration from the river water, and a complete abatement of the stench nuisance.

Likewise the city of Chicago has for years discharged 85 per cent. of its sewage into the Chicago River. This river drains a flat territory of about 130 square miles lying between Lake Michigan and the Des Plaines River, and discharges into Lake Michigan at a point very nearly in the east-central portion of the city. For a distance of 1 mile from its mouth and for 6 miles or more along both the north and the south branch, this river has been artificially formed into a navigable basin of 10 to 15 feet in depth and of an average width of 150 feet; in which basin at times of summer flow there is no perceptible natural current. On the South Branch is located the Bridgeport pumping plant, which lifts the sewage from the river, diluted as it is at this point with four times its volume of lake water, and discharges it into the

Illinois and Michigan Canal, thereby reversing the natural direction of flow and drawing water into the river channel from the lake. At times of overflow from the Des Plaines River nearly all flood-water passes through the Ogden-Wentworth Ditch into the South Branch, thence through this branch into the lake. For years, the insufficient dilution, high temperature of the river water, and masses of putrefying deposits of organic matter had caused intolerable nuisances at many points along the river. The production of these offences has lately been somewhat impeded by pumping the sewage and by flushing the river channel with lake water; but eventually when the new drainage canal, now under construction, is completed, which is intended to remove the entire sewage of Chicago diluted with about 26 times its volume of lake water to the Illinois River, these offences will be completely removed and the river water rendered clear, cool, and unobjectionable.*

The sewage of the city of London is dis-

* See Reports Chicago Drainage and Water-supply Commission.

charged into the Thames at the mouth of Barking Creek, about 30 miles or more from the open sea. The average natural flow of this river is about 1,620,000,000 U. S. gallons per day, while that of the driest years is about 1,080,000,000 U. S. gallons per day. The water consumption of London for a population of 5,237,000 is about 205,500,000 U. S. gallons per day, of which amount about 156,000,000 U. S. gallons per day is taken from the Thames. The available dilution of the sewage by the average natural flow of the river, as measured by the volume of water consumption, amounts to about nine to six times the volume of the sewage. Now the sewage which is discharged into the Thames has been estimated to remain in the tidal prism of the river, from twelve days during heavy floods to thirty-three days during dry-weather flow; consequently, with the under-dilution which the sewage receives, it is very likely to putrefy. In fact, in the year 1884 the Royal Commission on Metropolitan Sewage Discharge reported "that during hot and dry weather there is serious nuisance and inconvenience extending to a considerable distance both below and above the outfall, from the foul state of the water consequent on the sewage discharge. The smell is very offensive and the water is at times unusable." This Commission, assuming that the chief cause of the offences which it had observed in the river Thames lay in the putrefaction of the insoluble portions of the sewage, which were either deposited or were wafted to and fro by the tide, recommended the removal of these insoluble matters from the sewage previous to discharging it into the river.

Several cities of this country which discharge sewage into estuaries at points a long way removed from the open sea, and which have had experiences similar to London, are adopting a similar method of sewage treatment, but with what degree of success is not yet apparent. On the other hand, the cities of New York, Brooklyn, and Jersey City, which discharge sewage into the Hudson and East rivers, tidal estuaries, have as yet experienced, as a result of this practice, no serious offence, because there is an ample dilution, a sufficiently low temperature of the water, and the requisite rapidity of dispersion to prevent nuisances.

But to refer again to the cities of Chicago and Milwaukee, it is well-known that the temporizing methods of sewage disposal as long practised in these two cities had led to very grave and serious offences, and as a result may have caused impressions quite prejudicial to sewage disposal by dilution. But, as a matter of fact, until the introduction of the present methods of flushing the river by pumping into it large volumes of water from Lake Michigan, these cities neither disposed of their sewage nor diluted it, but turned it into a sluggish basin, as into a cesspool, to deposit sludge and to putrefy, until floods in the rivers should remove the deposits of sludge and carry it into the lake, or until cool weather should arrest putrefactive decomposition.

In these practices the principles of natural inoffensive purification were wholly ignored; and not until the results of temporizing expedients became no longer endurable were the facilities and means supplied by the communities with which to correct the evils.

But this phase of the subject cannot be here passed over without a brief reference to the bearing which the physical characteristics of water have upon sewage disposal by dilution. When sewage is discharged into quiet or slowly-moving bodies of water, the greater part of the insoluble portion of it eventually deposits, the heavier particles falling near the sewer outfall and the lighter ones becoming more widely distributed. From these decomposing deposits gases may emanate. If they exceed an amount which the diluting water can absorb, that is, if they produce over-saturation in the water, they will bubble through into the atmosphere. The rapidity with which these gases can be formed will depend very much upon the temperature of the water surrounding the deposits from which they arise, a high temperature promoting rapid decomposition. It was noted in the Milwaukee River that at temperatures below 69° and 71° F. there was no visible exhalation of gases, but that at higher temperatures they bubbled forth profusely. Similar phenomena can be noticed in any sluggish stream receiving more sewage than it can sufficiently dilute, or in any shallow pond containing deposits of organic matter; for the gases bubble out much more freely at summer than at winter temperatures.

These observations indicate that the diluting water should be as free as possible from organic impurity in order that it may absorb and oxidize the gases from decomposing sewage; that its temperature should be sufficiently low to prevent or arrest putrefaction; and that it should have a sufficient movement of translation to give the requisite amount of dilution.

The conditions affecting the disposal of sewage when sewage is discharged into the open sea, bays, lakes, ponds, or into similar non-flowing bodies of water are quite different from those in flowing rivers, although the process of purification of organic impurity of sewage is precisely the same in either instance.

Here the only natural means of removing and distributing the sewage are the inconstant and fluctuating tidal and wind currents. It is, therefore, necessary that proper dilution be attained by a dispersion of the sewage through the body of water into which it is discharged. The method by which such dispersion can be effected will depend very largely upon the local conditions. Even the rate of dispersion will depend to a considerable extent upon the relative physical condition of the sewage and the diluting water, and upon the manner in which the fluids are brought in contact. Should the weight per unit of volume and the temperature of each be identical, there would be a rapid intermingling of the particles of the one with those of the other. But should the sewage be at a higher temperature than that of the receiving water it would tend to rise and distribute over the surface of the water, if discharged beneath it; or should the sewage be colder than the receiving water, it would tend to displace it. Thus in one instance dispersion would be accelerated and in the other retarded.

In a similar manner a difference in the weight per unit of volume of the two liquids at the same temperature would affect the rate of dispersion, as when sewage is discharged into salt water.

One is not impressed regarding the sensitiveness of water of different densities to temporarily stratify, as it were, on being brought into contact, until having made the experiment; neither does this physical characteristic seem of much practical importance; but it is the advantage that is taken of just such principles of nature as is here involved that affords the economical and successful solution of many engineering problems.

In 1889 the State Board of Health of Massachusetts made some observations on the discharge of the sewage of Boston into the sea at Moon Island, and states that "at Moon Island, the outlet of the Boston Main Drainage System, the sewage collected in eleven hours is generally discharged in a body in about half an hour, and no sewage is to be found in the tidal current into which it enters two hours after it leaves the sewer." As one of the experiments of that Board of Health, sewage was discharged for four hours on a falling tide at the rate of 1,500,000 gallons per hour. When sailing in the stream of sewage, on its leeward side, the odor was found to be disagreeable for a distance of one half-mile from the outlet, but at a distance of three-quarters of a mile from the outlet no odor could be detected. The flow of sewage could be followed by the eye, by means of the comparative stillness and browner color of the sewage, to a point one mile from the outlet. At one and one-quarter miles distant sewage effect was scarcely discernible, and at one and one-half miles no trace of sewage was visible, although floats which started with the sewage had gone far beyond this limit.

Chemical analyses of the sea-water, made at the same time, fully substantiate the physical observations and are as follows (expressed in parts per 100,000):

	Free Ammonia.	Albuminoid Ammonia.	Sum of Ammonias.	Chlorine.
Salt water, up stream from area containing sewage..........	.0056	.0098	.0154	1,675
Salt water, down stream from area containing sewage......	.0056	.0095	.0151	1,746
Water within area containing sewage at the following distances from outlet:				
400 feet...	2.500	.5310	3.031	773
1,600 "	.1944	.0636	.2580	1,570
3,200 "	.0416	.0254	.0670	1,621
4,700 "	.0224	.0116	.0340	1,694
6,200 "	.0184	.0156	.034	1,689
7,200 "	.0136	.0108	.0244	1,687
9,200 "	.0104	.0096	.0200	1,710
Water in mid-stream at crossing of North Ferry to East Boston....................	.0480	.0154	.0634	1,581

"From these analyses it appears that in the stream of sewage at 400 feet from the outlet of the sewer the upper eight inches in depth was about one-half sewage. At 1600 feet distant it contained about one-eighteenth of its bulk of sewage, and at 3200 feet, five-eighths of a mile distant from the outlet of the sewer, the ammonias indicated the amount of sewage added to be but one per cent. of the volume of the water, and the same amount as found in mid-stream at the crossing of North Ferry to East Boston. Beyond this distance the amount of ammonia added became one-half of one per cent. at a mile, and less than one-tenth of one per cent. at one and four-fifths miles from the outlet."

This report further states that "the discharge of sewage from the reservoir at Moon Island is begun either one or one and a half hours after high tide, when the outward current past the outlet is well established. About 15,000,000 gallons of sewage are discharged in about forty minutes. As the sewage is lighter than the sea-water, it rises towards the surface soon after being discharged and spreads out until it has a depth of less than a foot. Half an hour from the beginning of the discharge the sewage covers an area about half a mile in diameter. In this condition the sewage, already considerably diluted, moves outward with the current and further dilution takes place, the process going on most rapidly at the bottom of the layer of sewage. Up to a certain stage in the progress of this dilution, the surface of the sewage contains enough greasy matter to prevent waves, except when the wind blows very hard. When the dilution of the sewage has progressed so far that waves begin to form and its specific gravity has approached that of the sea-water, it rapidly becomes mixed with water from greater depths, and very soon cannot be distinguished by the eye or nose from unpolluted sea-water. The last change here described usually takes place in less than an hour and a half after the sewage is discharged, and at a distance from the outlets not exceeding two miles."

"On one occasion bottles were filled every fifteen minutes from the area of sewage going outward with the current. These bottles were kept in an office for a long time, and those taken one hour or more after the beginning of the discharge never showed by their appearance or odor that they contained any sewage."

The sewage from the Boston disposal works is daily discharged into the open sea after but a few hours' detention in storage reservoirs on Moon Island, and is not, therefore, in a state of putrefaction. Under such conditions it is evident that sewage may be completely and rapidly dispersed over an extended area and through a large body of water in a state of agitation by winds and tides, if it be unrestricted in the expanse of its movement and if the time and manner of discharge be judiciously regulated.

Somewhat different is the disposal of sewage in inland lakes, for then there are no tidal currents to be advantageously utilized in bearing away the sewage. In Chicago, previous to the introduction of the pumping and flushing system, sewage would be detained in the river basin for a week or more in a state of active putrefaction, to be suddenly flushed into the lake by the flood-waters of the Des Plaines River or of the North Branch. So great an accumulation of putrid matter must necessarily become discernible in a very large volume of lake water when suddenly discharged from a swollen river, yet it will become so dispersed and diluted as to arrest putrefaction, and as not to affect to any noticeable extent the sanitary conditions of Chicago except through an occasionally contaminated water supply. At Milwaukee, because of littoral currents, the polluted water from the Milwaukee River or the sewage from the pumping-station had been discernible by means of a discoloration of the lake water for a distance of six miles, but since the flushing system has been in operation the river discharges can scarcely be detected from the lake water.

Wave action in itself will give a very wide dispersion of sewage and will prevent deposits of insoluble matter in considerable depths of water. Consequently, to avoid the danger of contaminated water supplies, the intakes of water-works should be widely separated from the sewer outfalls.

Nature affords us much evidence regarding the natural purification of polluted waters. This natural process, particularly as it applies to the purification of sewage-polluted waters, has been much discussed, seriously doubted by some investigators, and emphatically denied by others. These adverse opinions have been based largely upon evidence furnished by the results of the chemical analyses of water, and have been formulated upon the assumption that all progressive changes among the organic constituents of water are due entirely to a purely chemical action caused by the variable affinities of oxygen for the elements composing the several organic compounds. But as investigations concerning these changes in water have proceeded, they have gradually developed the fact that chemical action between the nitrogenous constituents, at least, of dissolved organic impurity and oxygen is rendered possible only by the action of living micro-organisms, and that without these micro-organisms there can be no chemical oxidation. Furthermore, these investigations have shown that opinions and judgments regarding the character of a water, based solely upon the evidence furnished by chemical analyses, may be erroneous, for the dissimilar activities of the so-called nitrifying and reducing bacteria may cause such discordant fluctuations of the nitrogenous compounds between the organic and inorganic state in which they may be found in water that the results of chemical analyses alone may afford no true evidence regarding the progressive changes touching the purification of water. To make this still clearer, chemists have asserted that nitric acid, the completely-oxidized condition of nitrogenous matter, may be reduced in the presence of organic matter both to nitrites and free ammonia; but these two nitrogen compounds represent, as usually interpreted in a sanitary analysis, certain intermediate stages in the process of nitrification of organic matter in polluted water; consequently it would appear as though the mere determination of these intermediate conditions of the nitrogenous matter might be misleading evidence regarding progressive purification to an extent proportional to the reduction of nitrates.

That living organisms are primarily the cause of the decomposition and oxidation of organic impurity dissolved in water is certainly in accord with some of the observed processes of nature. In support of this theory it has been frequently observed that the water of a sewage-polluted river progressively improves as it departs from the point of pollution to an extent that is not altogether accounted for by the additional dilution that the sewage receives as the result of the natural accumulations to the volume of flow of a river, and that the number of the bacteria contained in this water diminish with the decrease in the organic impurity. Nearly every lake or pond receives many impurities from its watershed, and yet it does not show cumulative stores of impurities, nor does it become permanently offensive nor dangerously polluted. In fact, it has been demonstrated that a water known to have been polluted by sewage may be organically improved by storage in reservoirs and by circulation through the pipes of a water-supply system. If this be generally true of sewage-polluted surface waters artificially stored and circulated for a limited time, it should be at least equally true of the same waters in their normal condition in nature.

It must be, therefore, that in the associated presence of unstable organic matter and organized life, and in their common disappearence, there is illustrated the balance in nature of the law of supply and demand by which an overproduction in one direction is prevented by consumption and death in another.

The teachings of nature alone are sufficiently conclusive to establish the progressive improvement and the purification of polluted normal waters.

It has already been stated that the work of the organisms in purifying polluted water depends upon having available a supply of oxygen. Now it is known that in water the available supply of oxygen is greatly distributed, for water becomes saturated when it has dissolved about 3 to 4 per cent. of its volume of oxygen; therefore, if sewage turned into a body of water be more than sufficient to absorb all the dissolved oxygen in the water in the process of purification or be insufficiently dispersed, the changes will become, to a certain extent, putrefactive, and will result in the exhalation of offensive gases.

The offence of these gases and of the organic vapors of sewage consists in the bad odors which they may impart to the atmosphere, rather than to any specific poisonous and disease-producing properties that they may possess in the highly-diluted condition in which they are inhaled. When inhaled continuously, however, physicians ascribe to them a depressing and enervating effect upon the system which renders the person less fortified against disease.

There is no conclusive evidence to show that offensive putrefaction in a highly polluted water exposed to the open air has been the direct source of disease, for the fresh air dilutes the exhaled gases sufficiently to render them innocuous.

The bad odors themselves are no criterion of the depleting effects of the gases upon the oxygen of the atmosphere; for they may become an intolerable nuisance long before the life-supporting properties of the atmosphere are prejudically affected by them.

Therefore, to prevent offence to the æsthetic taste and to render the air about sewage-polluted bodies of water wholesome, it is necessary to observe the bounds which nature has placed upon the natural purifying powers of normal waters, and not to transgress them by committing to a water more decomposing matter than it can purify. In other words, let the dilution be sufficient to insure both the absorption of all the gases of decomposition and a proper supply of oxygen, then nature will see to the results.

It is now quite generally admitted that some diseases may be readily communicated to the human system through drinking-waters. This admission is based upon the connection supposed to exist between some specific living organism and certain diseases, more particularly cholera and typhoid fever. The evidence indicating the danger of infection from this source has been by some asserted to be sufficiently strong to warrant the prohibition of further disposal of sewage by discharging it into bodies of water. But from a standpoint that fully comprehends all the elements involved in the question, can this position be sustained?

It is known by the evidence submitted that very many of the natural waters have received the excrement of persons afflicted with disease, and presumably have thereby become infected with disease-producing germs; but there is nothing among the results of bacteriological research to indicate, at least in this country, any progressive increase of these germs in water after it is thus infected. But, on the other hand, they indicate that the germs rapidly disappear. Certain it is that the natural environments in water are unfavorable to the life of these germs, otherwise it would be difficult to conceive of a water once infected becoming again wholesome. Nature seems to have set limits beyond which these organisms cannot go. Whether it is the physical conditions of the water or the living organisms that thrive and abound therein that are most inimical to the life of the disease-germs, does not seem to be clearly established. However, it is generally admitted that the hardier, stronger, and more active water bacteria are thoroughly antagonistic to the disease-producing variety, and that the one speedily destroys the other.

In line with this view are the investigations of the Massachusetts State Board of Health, which indicate that in the Merrimack River water, such as is used for the water supply of Lawrence, typhoid-fever germs live in rapidly-decreasing numbers for a period of 12 to 15 days. The duration of life and rate of decrease of the typhoid germs seemed to be less in the natural river water than in the filtered water. The longest duration of life observed was 31 days.

The Report of the Royal Commission on London Water Supply, dated Sept. 8, 1893, says that "it appears to be the belief of bacteriologists that such [typhoid] dejecta begin to lose their virulence after a very few days, and the longest period for which the typhoid bacillus has as yet been found to retain its vitality when in fecal matter does not exceed 15 days."

On the whole, the results of investigation appear to substantiate the observations and teachings in nature that disease-germs do not thrive in normal waters.

If, then, the conditions in normal waters be so unfavorable to their vitality, and if the harmless variety of water bacteria destroy them, it is but a fair inference that such disease-germs as may find entrance to sewage from human habitations and other sources can find neither congenial environments nor long life among the multitudes of vigorous bacteria of the harmless kind that are known to infest sewage. But assuming that some may survive and may reach the sewer outfall and may live in the waters receiving the sewage for certain periods of time, possessed of their vitality and infectious powers, is the position of strict prohibition of sewage disposal into water even then wholly tenable? The sanitary view of the situation, namely, that any custom or practice which tends to jeopardize the health of a community should be abandoned, is worthy of all consideration. But there is a practical and popular aspect of the question which will influence and control innovations in established customs and practices even more than will the scientific aspect, and which demands experimental proof, not only of the necessities for change but also of the practical utility of sewage disposal by other and more scientific methods.

It is exceedingly difficult to adduce both experimental evidence and practical proof of infection in any special instance by sewage-polluted water in an amount and in a manner that is thoroughly convincing. However, it must be admitted that the general drift of the statistical evidence thus far collected is to the effect that the cities which use as a public water supply an unfiltered water containing sewage impurities have a higher death-rate from typhoid fever than do other cities using either unpolluted water or sewage-polluted water that has been filtered before use. But this shows, as will be seen more clearly further on, rather that cities and towns should use more circumspection and care in the development, treatment, and distribution of public water supplies than it does that they should prohibit sewage disposal by water.

Furthermore, would the abandonment of systematic sewage disposal into water afford immunity from infection? As an illustration of this point, let it be assumed that a city discharges sewage from a combined system of sewers into a river from which, at points below, water is abstracted for public supplies. If this city be obliged to abandon the practice of discharging crude sewage directly into the river and be, therefore, required to previously treat it, it would construct disposal works of a capacity to treat the daily flow of domestic and industrial sewage, and would allow the storm-water to flow directly into the river because of the impracticability of handling and treating it at disposal works. The storm-water, as it flows through such a system of sewers, would become more or less polluted by sewage; and it might, consequently, carry infection directly into the river. But even assuming that the city be sewered by the separate system of sewers, there yet remains the danger of infection from polluting matter which abounds more or less in the midst of every thickly-settled community, and which may be washed into the river by any and every storm. This illustration truly depicts the condition of many cities in this and other countries as regards sewerage and sewage disposal.

Then, again, from ships, steamboats, and other craft plying a navigable river there may fall fresh excrement containing disease-germs, which, because of their direct contact with the river, may be even more infectious than though they had entered the river through a system of sewers. Also from squatters' shanties, from houses which are not connected with any sewer though in the city, from the abodes of people living along the banks of a river and beyond municipal regulations, infectious matter of various kinds may reach the water. In fact, there is evidence to show that infection of a water may occur quite as readily through isolated and uncontrollable sources as through the sewers themselves.

It is, therefore, evident that as a practical problem the prohibition of sewage disposal by water will not and cannot prevent infection of streams, rivers, lakes, and other large natural bodies of water; consequently, as a reliable sanitary measure, prohibition must fail.

But this conclusion now exacts proof, either of the wholesomeness of waters that are available as public water supplies, even though they may have been polluted by sewage at some point more or less remote, or of some practical method of purifying water, so polluted, previous to use for domestic purposes. A thorough discussion of these points would require a complete review of what is known of methods of water purification; but as this is beyond the scope proposed for this discussion, the author hopes to present conclusive proof of these questions by illustration and by reference to the results of existing practices.

To illustrate one element of the question, let us refer to the analogy between air and water. We inhale the same atmosphere that receives the exhalations from healthy and diseased persons and animals in open and in confined places; from the public sewers and house-drains; from the many industrial establishments which turn into the atmosphere offensive, disagreeable and poisonous gases; and from various sources of putrefaction that abound more or less in the vicinity of every town; and we do not hesitate to confine many patients suffering from various causes in the same hospital; yet dependence in every instance to prevent evil results rests largely upon the diluting and oxidizing properties of the atmosphere.

In a similar manner water containing free oxygen (as do all unpolluted surface-waters) is a natural purifying agent for any organic polluting matter that may enter it. The air, it is true, can destroy and render innocuous impurities much more readily than can water, because of the greater mobility and diffusing properties of gases than of liquids; but we have no conclusive evidence in nature to show that purification in the end is any more completely accomplished by the air than by the water.

As the purifying power of air depends largely upon circulation, temperature, and dryness, so does the like property of water depend upon the varying physical conditions peculiar to itself. There is no arbitrary standard or formulated method by which the scope of these powers can be calculated, as this is a question to be determined in specific cases by special investigation. Thus, in the case of pollution either of air or of water, security from evil results depends largely upon the dilution and the complete oxidation of the contained impurities—becoming, therefore, an element of time and distance.

Arguments have already been advanced denoting a progressive process of purification of natural waters by dilution and oxidation of organic impurity. When this process has rendered organic impurity, as such, no longer recognizable, or has so far removed it that the remnant is of no practical importance, then the water is considered wholesome from a chemical standpoint.

In line with this view, various cities take their water supplies from the same rivers into which sewage is discharged, and furnish the water directly to consumers without further purification than perhaps some settlement in basins. In many instances no unhealthful effects seem to result from this practice, especially when the nearest point of sewage pollution is quite remote from the intake of a water supply.

But the results of chemical analyses are alone not a true index of the potability of a water; for, as has been previously shown, disease-germs, which are not discernible by chemical analysis, preserving their vitality for a time, may introduce into water intended for domestic uses an element of danger, even though the water may be chemically recognized as wholesome. Consequently, when the interval of time or distance relative to the points of pollution and intake of a water supply is not sufficient to insure the wholesomeness of a water, it becomes obligatory, with due regard for the health of a community using such a water, either to provide a new and uncontaminated supply or to prevent pollution of the water or to purify the polluted water before use.

The choice between an old and a new water is a matter of local consideration.

To prevent the pollution of streams by sewage is a matter of much difficulty, as may be further illustrated by the assumed case of two cities located on the same stream, from which each derives its water supply and into which both discharge sewage.

The city situated the further down the river apprehends serious pollution of its water supply by the sewage from the other city, and requests that city to take measures to prevent pollution of the water by purifying its sewage. The answer is: "While we deplore the fact that your citizens should feel apprehensive of danger because of their water supply being contaminated by sewage impurities from our city, we cannot concede your request to be either equitable or consistent, inasmuch as you enjoy the same privilege and employ the same method of sewage disposal as do we, to the detriment of the waters of the river below you to an extent that may cause apprehension on the part of your neighbor similar to that which you feel towards this city. If you consider your present water supply unwholesome, why do you not secure a new source of supply? If this be impracticable, then why do you not purify the river water before using it?

"Our sewerage system has already been a source of heavy expense to us, and now to acquire sewage-disposal works of a capacity to admit of purifying our sewage before turning it into the river would require a large additional expenditure of money. This additional cost, together with the annual cost of maintenance and of operation of the disposal works, would be a constant source of expense, which could only be met by a direct tax upon our community; for disposal works cannot be, in so far as we may judge from the experience of other cities, the source of any net revenues. Our present method of sewage disposal causes no one any nuisance; and to us it is a method of great convenience. Any expenditures, therefore, in disposal works are practically for the purpose of securing to you immunity from sewage impurities in a permanent and natural water-course, which you have made a source of water supply. Moreover, you are aware that the volume of water that is daily consumed by any community is about equal to the volume of sewage that is daily discharged by it; therefore it should be easier, cheaper, and much more efficacious to remove the organic impurity and bacteria from any given quantity of the river water which constitutes your water supply than it would be for this city to remove very many times the amount of the same organic impurity and the same variety of bacteria from an equal volume of sewage. Furthermore, since water is an article of use and is in demand by every citizen of any town or city, every one is willing to buy it delivered in his house, just as he would buy any other necessity of life; therefore a sufficient sum of money can be easily collected by water rates to operate, maintain, and eventually to pay for any water-purifying works that you may construct."

Although this is an assumed instance, it illustrates the conditions of many cities in this country with respect to water supplies and sewage disposal, either as they exist to-day or as they will exist but a few years hence; and the arguments in favor of sewage disposal into streams, as presented, are very pertinent to the general situation. It is even true that the latest information regarding the practicability of purifying polluted water presents new and even greater obstacles than ever to the prohibition of sewage disposal into streams. How, then, can the purity of public water supplies be secured? The best and most practicable method of water purification is filtration through sand. Proof that any infectious properties of sewage-polluted waters may be removed by sand filtration may be had by examining the results already attained in practice in the filtration of public water supplies. The city of London, which receives the greater portion of its water supply from the grossly sewage-polluted rivers Thames and Lea, after sand filtration, has had an average of only .46 per cent. of the total number of deaths from typhoid fever between the years 1868 and 1880. In the year 1892 the cities of London and Berlin, both using for public water supplies sewage-polluted river water after sand filtration, were practically free from typhoid fever, having had deaths from that cause of but .49 and .42 per cent. respectively, of all the deaths for the year.

In Chicago the deaths from typhoid fever during the years 1892 and 1893 were respectively 6.72 and 2.64 per cent. of the total deaths; in Philadelphia in 1892 they were 2.22 per cent. of the total deaths; in Boston in 1892 they were 1.22 per cent.; in New York in 1892 they were .9 per cent.; in Brooklyn in 1892 they were .8 per cent. Not one of these five American cities used filtered water with the exception of Brooklyn, which has a portion of its supply from ground sources; yet the death-rate from typhoid fever is higher than in cities using sewage-polluted water that had been filtered. The water supplies of Chicago, Philadelphia, and a portion of that of Boston were known to have been more or less polluted by sewage at that time. Moreover, several of these cities and other cities of the United States are known to have had the benefits of special legislative enactments to aid in preserving the purity of their water supplies.

The city of Lawrence, Mass., is situated on the Merrimack River, and takes its water supply from that river about nine miles below the point where the city of Lowell discharges its sewage; and having had annually many deaths from typhoid fever, that city constructed a sand-filter with which to filter the waters of the Merrimack River. This filter was started in operation in September, 1893 ; and for the three following months it removed 98 per cent. of the bacteria of the river water and converted a large part of the organic matter into harmless inorganic compounds. After two weeks' storage of this filtered water in a storage reservoir and supply-mains there remained but one half of one per cent. of the original bacteria in the water, and these were of harmless varieties. Moreover, there were during these months but four deaths from typhoid fever ; whereas for the same months of the preceding five years the average number of deaths from the same cause was 18. In the report of the Lawrence Water Board for 1893 it is stated that "thus far the filter has performed its work satisfactorily, the results of which are already apparent to every user of city water. From the day of letting on the water to the present there has been a continuous and ample supply of filtered water received into the pump-wells and pumped into the reservoir. The construction of this sand-filter has proved the theory that water can artificially be made pure and wholesome; and from the best scientific advice we now can say that the city of Lawrence enjoys the benefits of as pure water as any city in the country."

With regard to the results of the experiments in water purification by sand filtration of the Massachusetts State Board of Health, it is stated in the report of that board for 1892 that "the results of experiments, which show that in all of these filters adapted to the purification of drinking-water more than ninety-nine and one half per cent. of the applied bacteria were removed, together with the actual experience of many European cities having remarkably low death rates from diseases known to be capable of conveyance by drinking-water, while using filtered water drawn from polluted sources, leave no room for doubt as to the efficiency of such filtration, when properly conducted, as a safeguard against water-carried diseases."

Thus we observe that the practical utility and efficiency of slow sand filtration is established as a means of removing bacteria, disease-germs, and organic impurity from sewage-polluted waters.

And now it can be further asserted of sewage disposal by dilution that it is not only impracticable to prevent infection of waters by prohibiting such a method of sewage disposal, but also, as a general proposition and in the majority of cases, it is wholly unnecessary to do so ; for it is far better to insure the safe and potable qualities of a water either polluted or liable to become polluted by sewage by filtration immediately before use rather than to resort to the questionable and uncertain method of attaining the same end by measures prohibitive of sewage disposal into water.

In some instances it may be necessary to enact and enforce measures to prevent the undue pollution of streams, just as ordinances are enforced by cities to prevent the pollution of the atmosphere by foul odors from accumulations of garbage, by unwholesome and offensive smoke, and gases from public buildings, manufactories, and other industrial works, or just as a nuisance would be abated. But in the light of our present knowledge of the natural processes at work in the purification of polluted waters, and of our ability to make practical application of these processes in sewage disposal and in the purification of water supplies, there is less occasion than ever of any general and far-reaching legislation directed either to the regulation or the prohibition of sewage disposal by water. Legislative action upon this and kindred matters will be of far more public benefit if directed to the collection and systematizing of those data from a practical as well as scientific standpoint as will admit of a more thorough and general knowledge of the involved natural laws and processes and the application of them to useful purposes, and to the subsequent dissemination of this knowledge.

Before concluding this chapter it is necessary to especially refer to the sewage disposal of many inland towns which are so situated as to have neither large nor permanent streams into which to discharge sewage. Such towns, when supplied with both public water supplies and sewerage, need not necessarily be constrained to treat the sewage because of the want of such disposal facilities. For it may be quite practicable, at least in some instances, by means of water impounded in a reservoir above the sewer outfall to maintain a continuous and uniform flow in a stream that may occasionally go dry, and to periodically flush out the channel of any accumulated deposits. But even without such natural advantages for flushing and diluting reservoirs of water and in the absence of facilities or financial ability to construct, maintain, and operate disposal works of any kind, it is much safer and better to temporarily turn the crude sewage into the channel-way of such non-permanent stream at some point that may be sufficiently far removed from habitations to prevent resulting offence, than to retain it in either tight or leaching cesspools; for, if so discharged into the channel of a stream of this kind, much of it will flow away, the suspended matter in sewage that may deposit will be greatly distributed, and the organic vapors and any gases of putrefaction that may be given off will be more distributed, more diluted with pure fresh air, and consequently much less objectionable to a community from any standpoint from which this method of disposal can be viewed than if confined in cesspools from which very offensive gases of putrefaction are exhaled in close proximity to dwellings. Moreover, the danger of polluting subsoil waters by the one practice is far less than by the other; for any sewage that may filter into the soils from the bed of a small stream will be subject to the immediate purifying influences of porous soils to a far greater degree than if it filtered from a defective or a leaching cesspool into and through the subsoils. Furthermore, the bed of such a stream will be cleaned quite as often and quite as thoroughly by the occasional flushing that it may receive from storm-waters as will the cesspool, when subject to no greater vigilance or to no more rigid enforcement of city ordinances regulating the cleaning and disinfecting of cesspools than is usually exercised by municipal authorities.

On the whole, it may be said of sewage disposal by dilution that it is the simplest, most economical, most expeditious method of sewage disposal that has yet been tried; and it is as fully efficacious as any when the self-purifying powers of water are duly regarded.

The objections that have been raised to the method are not, in many instances, valid; for many of them are based upon a wrong rather than a proper application—as when more sewage is committed to a stream than it has the volume of flow to sufficiently dilute, remove, and purify.

CHAPTER IV.

DISPOSAL OF SEWAGE BY IRRIGATION.

SEWAGE disposal by irrigation consists in the application of raw sewage to land for the purpose of raising crops. At the time of the original application of irrigation to the disposal of sewage, great stress was laid upon the manurial value of sewage; its advocates arguing that the nitrogen, phosphoric acid, and potash salts, which are constituents of sewage and which are essentially plant-foods, could and should be utilized in the production of crops.

In line with this view many scientists of England had attempted by chemical analysis to demonstrate the commercial value of these constituents as fertilizers. For instance, by one investigator the yearly solid and liquid excretia of one adult was estimated to yield 16.41 pounds of nitrogen—an amount that was sufficient, it was said, to fertilize 800 pounds of wheat, rye, or oats, or 900 pounds of barley, and was equivalent to 75 pounds of Peruvian guano. Hofmann and Witt estimated the manurial value of one ton of London sewage to be about 4 cents; Lawes and Gilbert, 4 to 5 cents; Bailey Denton, 3⅓ cents. Brady and Montague estimated London sewage to be worth annually about 14 million dollars, while still another eminent authority placed the annual value at about 20 million dollars.* Although these estimates were necessarily theoretical, having been based upon the results of chemical analyses in the laboratory of sewage, soils, and plants, still they had the indorsement of such eminent scientific authority that it was but natural to have attempted the utilization of the manurial elements of sewage by applying the sewage to the growing crops of farm-land. These attempts have demonstrated the available fertilizing properties of sewage to be far less than had been predicted of them as a result of laboratory experiments; for they yielded no profitable

* *Vide* "The Treatment of Sewage" by Dr. C. Meymott Tidy.

increase to the productions of the farms, and established the fact that there is a wide difference between the theoretical and the commercial value of sewage. Moreover, they have clearly indicated two distinct aspects to the disposal of sewage by irrigation—namely, the sanitary and the commercial aspect.

On the one hand, the sanitary aspect of sewage irrigation has been shown to exact the prompt, continuous, and inoffensive disposal of the sewage upon the land, and thus to enforce almost continuous and unseasonable irrigation, and to compel the growing plants and the soils to evaporate and to absorb a very large amount of water in order to become possessed of the manurial properties of the sewage. On the other hand, the commercial aspect of sewage irrigation has been shown to demand inexpensive methods of distributing the sewage upon the land, and to require both seasonable and intermittent irrigation and fertilization of crops.

Thus the farmer in his efforts to render sewage irrigation profitable and at the same time to duly regard the sanitary conditions exacted of him, found himself in a dilemma: for if he irrigate continuously he must ruin his best and most profitable crops, or if he fail to irrigate continuously he must neglect the prompt and proper handling of the sewage, and thus become liable to prosecution for creating a nuisance.

As a result of the experience in England of sewage disposal by irrigation, it is shown that such a method of disposal is incompatible with the attainment both of a profit from a sewage-farm and of good sanitary conditions upon it; that as a private enterprise sewage-farming is a signal failure; and that municipal control of a sewage-farm is necessary if it be operated in the interests of sanitation.

The amount of land that may be required for sewage irrigation and the expense of preparing it cannot be determined by any fixed rule. Smooth and gently-sloping land affords an easy and comparatively economical distribution of the sewage. A close, fine-grained and retentive soil can naturally take care of much less sewage than can a free and porous one. If the purpose be a complete utilization of the sewage,—in other words, the application of just so much sewage to land as can be readily appropriated, absorbed, and evaporated by growing plants, as is the case where land is used for market gardening,—a much larger acreage of land will be required than though the land were kept saturated with sewage, as is usually the case in broad irrigation of grass-lands.

The published results of sewage irrigation in England, where the average daily water consumption is about 40 to 50 U. S. gallons for each inhabitant, is to the effect that for complete utilization of sewage one acre of ground is required for every 30 to 50 inhabitants, but when thorough sanitary precautions may in a measure be disregarded, that an acre of ground will annually take care of an average of 5000 to 7000 tons of sewage, the equivalent of about 100 inhabitants.

Mr. Kuechling, in the Transactions of Am. Soc. C. E. of January, 1888, states with respect to the extensive sewage-farms of Berlin, Germany, which among others he visited in 1884, that sewage irrigation was commenced with a proportion of 250 persons per acre, which proportion was in the succeeding years reduced to 100 per acre; and that "the director of the farms, a highly-cultivated gentleman, stated that the tendency was to still further reduce the amount of sewage put upon the land. He hoped to get it down to a basis of 75 persons per acre per year, but preferred to reduce it to 50. . . . By such reduction he hoped to make a slight profit, also to do away with the alleged pollution of the subsoil waters and effect the abatement of the stench nuisance that occurs on all sewage-farms at pretty much all seasons of the year."

The effect of sewage irrigation upon the healthfulness of the locality adjacent to sewage-farms and upon the farm itself does not appear to be fully established, because statistical information in matters of this kind is difficult of access, and to be of much value it is necessary that observations be carefully recorded during a considerable period of years. However, the summation of the evidence thus far recorded seems to be to the effect that sewage irrigation is not injurious to health provided the sewage be fresh when applied to the land.

With respect to the exhalation of offensive vapors and odors from sewage-irrigated land, there seems to be a considerable difference of opinion among those who have visited sewage farms. Some assert that no offensiveness prevails, while others with apparently as good opportunity of judging positively affirm the contrary. These differences of opinion may in a measure be due to differences of individual judgment as affected by the æsthetic tastes and the imagination; consequently, what one might consider offensive another would not. Even the same individual visiting a farm at different seasons of the year may form very different opinions regarding its offensiveness or non-offensiveness; for the variation in temperature and relative humidity of the atmosphere, the state of the growing crops, whether luxurious or not, and other changeable conditions about a sewage-farm may be the cause of very different sensations. In fact, there seems to be no other way of reconciling the conflicting views that have been expressed upon this subject.

There seems, however, to be no good grounds of expecting sewage-farms, even under the best of management, to be entirely free from odor; for even from fresh sewage a musty and somewhat offensive odor is exhaled. So far as is known no ill effects have followed the inhaling in the open air of these organic vapors from fresh sewage, and the musty odor which is characteristic of them soon disappears by air dilution.

If by any neglect or mismanagement sewage be allowed to pond upon the surface of the ground, or sludge be permitted to collect either upon the stalks of the growing plants or upon the ground, there will result in a warm, humid atmosphere putrefactive decomposition of the organic impurity, causing offensive odors. Therefore the sanitary condition of any sewage-farm depends quite as much upon the management of the farm as upon the character of the sewage that is applied to the land.

The pollution of subsoil water has been regarded in several instances as the result of sewage irrigation. Doubtless if the land be kept almost continuously flooded with sewage, as is the case with broad irrigation, the subsoil waters may become polluted; but if the sewage be applied to the land intermittently, so that the soil may be aerated and cultivated, as would be the case in the complete utilization of sewage, it does not appear probable that pollution will affect the subsoil water. For irrigation, in that event, becomes combined with intermittent filtration, and the conditions are thereby rendered favorable for the natural purification of any sewage that may seep into the ground.

The United States, lying as it does between the fifteenth and the twenty-fifth degrees of latitude and between the sixty-seventh and one hundred and twenty-fifth meridians, and with elevations varying between the extremes of sea-level and the highest peaks of the Sierra Nevada and

Rocky Mountains, and with a geology representing the oldest as well as the most recent formations, and with a range of mean annual temperature from 41 to 72 degrees Fahrenheit, must possess conditions of climate and atmosphere, of soil and topography, more varied than can be found in almost any other country.

The rainfall over this country has a great range of seasonal distribution, and varies from a mean of 4 inches to 94 inches per annum. Its distribution is such that in almost any portion of the United States east of the one hundredth meridian the production of good crops is almost annually assured. But from this meridian to the Pacific Ocean, excepting a strip of territory along the northwestern coast, and from the northern to the southern boundary of the country, there is a vast territory of about 1,300,000 square miles, or of about four tenths of the entire area of the United States, that is dependent for agriculture almost entirely upon irrigation. Of this arid territory there is an area of about 126,000 square miles that has a mean annual rainfall of less than 10 inches, and about 259,000 square miles over which it is between 10 and 15 inches.

The main drainage of the eastern and southeastern coast country is by many rivers and tributaries of moderate length and of heavy average slope; while that of the central or Mississippi River basin is by rivers of great length and of moderate average slope, bearing vast quantities of silt and débris. The rivers of the so-called arid country west of the one hundredth meridian are in some respects quite in contrast with those just described; for they flow from their mountain source through deep cañons into the plains, where they spread out in thin sheets over broad sandy beds, or divide into various small shallow streams. In dry hot weather they almost disappear in the sands. Few, if any, of their tributaries are perennial streams. Thus, in a country as varied in its characteristics as is the United States it is not at all probable that the results of experience of foreign countries in sewage disposal by irrigation will be found applicable, excepting, perhaps, in those districts of similar climatic and meteorological conditions.

Although it may be somewhat difficult to anticipate the extent to which sewage disposal by irrigation may become popular in the United States, yet it may be fairly assumed that in the localities where soil, climate, and rainfall favor the annual production of good crops it is by itself of exceedingly questionable utility. Moreover, it is very probable, especially with respect to large cities, that the acquirement of a sufficient amount of land under municipal ownership or control for such a purpose will be found exceedingly difficult; for instance, a city of 30,000 inhabitants will by the best authorities in England require about 300 to 600 acres of land, the number of acres depending upon the completeness of the utilization of sewage. But this relation of acreage to the number of inhabitants would not necessarily follow in this country: for here the average daily water consumption is from two to three times greater than in England; consequently, there will be needed a somewhat greater acreage of land. Furthermore, there are the disadvantages of the additional expense of cultivating sewage-irrigated land over that of cultivating non-irrigated land; of the offence associated with the handling of sewage; and of the commercial losses almost sure to ensue—all of which render this method of sewage disposal more or less unpopular in localities where irrigation is not naturally needed, and quite cumbersome and impracticable with respect to large and populous cities. Small inland towns, which have no streams available into which they may permanently discharge sewage, may find in sewage irrigation a method of some utility; for, the volume of sewage to be disposed of being small, it is quite probable that a sufficient amount of land can be acquired near the town by purchase or rental for a reasonable expenditure of money to effectually dispose of the sewage—at least for that portion of the year when sewage might become offensive if discharged directly into a stream of insufficient volume to properly dilute it. But any value which this method of sewage disposal may have will be most appreciated by towns in a locality where irrigation is a necessity; not that sewage possesses manurial properties, nor that its application to land is scientifically proper, but rather because water having become an urgent necessity is acceptable in any condition. In such localities it is quite probable that sewage may be quite completely utilized for farm irrigation at seasonable times; because, the local demand for all garden and farm produce being naturally great, the sewage will in all probability be given a wide distribution over the land in order to avoid over-irrigation and a resulting injury to the growing crops.

The complete utilization of sewage is apparently the only truly sanitary method of sewage disposal by irrigation. This, however, is only practicable during the productive seasons of the year, and by intermittent irrigation; for at such seasons and by this method the commercial and sanitary aspects of sewage irrigation may be made most nearly to harmonize. But when the irrigation season is over, and until it shall have returned, it is quite probable that in the majority of cases the commercial interests alone will largely determine the disposition to be made of the sewage.

The practice of the city of Pullman, Illinois, near Chicago, with a population of 12,000 inhabitants, has frequently been referred to as an instance of the successful disposal of sewage by irrigation; but the evidence thus far made public does not sustain the view of successful practice for that city; for it indicates that for a considerable portion of each year the crude sewage is turned into Lake Calumet, and that the application of other fertilizers than sewage has been found more profitable upon the corporation farm.

Even in foreign countries the practicability of utilizing the manurial properties of sewage is considered doubtful. How much less in this country, where the dilution of sewage in towns having a bountiful water supply is so great that the organic impurity seldom exceeds one part in two thousand parts of sewage, should it be expected to derive any practical benefits from sewage as a fertilizer!

But attaching to sewage a value in those portions of the United States susceptible of successful irrigation, it is even then scarcely to be anticipated that irrigation as a means of sewage disposal can be successful without considerable expenditure of money, either to compensate those who may be induced to take care of the sewage at unseasonable periods for irrigation, both for services and for the rental of lands, or to acquire and to make use of facilities for disposing of the sewage at intervals by other methods than by irrigation. Thus far there is nothing in the experience either in this country or in foreign countries to conclusively indicate that the productions of a sewage-farm will be the source of net profit, though the income derived from the sale of them will materially reduce operating expenses.

On the whole, from the standpoint of complete utilization of sewage, it appears highly probable that sewage irrigation will be quite unpopular in the naturally productive sections of the country, excepting it may be among some of the small inland towns and cities, which may successfully apply sewage to land during the growing seasons of the year. The method is more adapted to an irrigating country. But in any event it will be quite necessary to associate with sewage irrigation other methods of sewage disposal that will be effective where irrigation becomes impracticable, as it will for a period of each year.

There can be no definite rules laid down to guide in the selection of proper land for sewage irrigation, or in the laying out of a sewage-farm. Generally it is preferable that the soil be light, open, porous, and well drained; but in practice such land as may be available must be used, and if it does not naturally possess the ideal conditions for successful sewage irrigation it must be artificially improved. If the soils be variable in character it is advisable to subdivide the farm with reference to these varying qualities of soil, in order to bring together as much as possible in beds and plats soils of equal producing, absorbing, and purifying characteristics. Such a subdivision can be readily made by earth embankments.

Usually the sewage is brought to the irrigation farm in pipes and carried to the various subdivisions of the farm by earth or masonry-lined open carriers, and from these carriers distributed over the ground through earth trenches or by broad irrigation. The carriers should be so elevated above the surface of the surrounding ground as to be easily drained; otherwise the detention of sewage within them may cause offence. The vapors from fresh sewage flowing in open carriers need be the source of no apprehension, for they quickly become diluted by the atmosphere.

The method of conducting the sewage under pressure through closed subsurface pipes and of applying it to the growing crops by sprinkling through hose and nozzle attached to hydrants connecting with the pipe system is one which is sometimes advocated because of the uniform distribution of sewage that can be thus attained, but which is largely impracticable because of the heavy expense involved in pressure subsurface pipe-carriers and the necessary attachments, because of the cost of labor in applying the sewage, and because of the sanitary objection to throwing crude sewage upon the leaves and stalks of growing vegetation.

The details and general arrangement of a sewage-farm should be as simple and inexpensive as possible; therefore every possible advantage should be taken of the slopes and configuration of the ground, and of the variable absorbing powers of the soils. The fields and plats should be so graded that the ponding of sewage will be obviated; otherwise the putrefaction of ponded sewage may cause a serious nuisance. The arrangement of carriers should facilitate the prompt delivery of sewage to any part of the farm, and the quick and uniform distribution of it over any plat or field. As a general rule the more porous the soil of any farm or subdivision of a farm may be, the greater should be the number of carriers and the smaller should be the size of the individual field or plat to be irrigated; for it is evident that the more porous a ground may be the more readily it will absorb, and the greater its absorbing power the more rapidly should the sewage be distributed over it. This can be accomplished in a practical manner only by having numerous carriers and small plats of ground.

To what extent auxiliary means of disposing of sewage at times unseasonable for irrigation may have to be provided, and the character of these auxiliaries, and whether settling-tanks shall be used to remove some of the heavier suspended matters in the sewage before irrigation, and whether underdrainage of any part or parts of the field shall be necessary, are all matters for local and special consideration. The mechanical details can be readily worked out when once the general outlines of an irrigation farm are developed in accordance with the general principles that have just been outlined.

What may have been accomplished in some localities, and the methods which may have been there employed, are matters of general interest rather than of general guidance in special cases. Therefore the arrangement of a sewage-irrigation farm and the design of its different parts and details that may have been successful in one instance is no criterion in another instance except to the extent of identical natural conditions and advantages.

CHAPTER V.

DISPOSAL OF SEWAGE BY INTERMITTENT FILTRATION.

FILTRATION is popularly understood to be a simple straining process, whereby a liquid having matters in suspension is relieved of them and becomes more or less clarified by percolating through some porous substance. This impression —so far at least as it relates to the filtration of polluted water—fails to comprehend the most important function of filtration, inasmuch as a filter which is properly constructed and operated possesses the property of removing organic impurity dissolved in water by a process of natural purification. The process is a natural one, because it depends upon the prevalence of certain natural conditions for its successful procedure, as, e.g., the presence both of oxygen and of living micro-organisms.

It is well known that a percentage of the volume of any porous material consists of voids or open spaces between the individual particles. Now if a porous material be properly selected and made into a filter, a liquid in percolating through it becomes subdivided into innumerable fine streams which partially occupy the voids of the filter or channelways. Thus a large surface of the liquid is exposed to contact with the air also contained within the filter, which affords favorable conditions for the natural oxidation of the dissolved organic impurity. In time the air becomes exhausted from the filter, and then the only available oxygen for purification is that which may be in solution in the liquid being filtered. If this liquid be sewage, which is known to have no dissolved oxygen, the purifying power of the filter ceases the moment the air supply is exhausted; consequently it becomes necessary to cease at intervals the application of sewage, in order that the sewage may drain from the filter, and that the air may enter and fill the voids thus vacated. By this means filtration becomes intermittent, which term implies an alternate filling of the voids of the filtering material with sewage and with air.

The difference between irrigation as treated in the preceding chapter, and intermittent filtration as here considered, is that in the former case the sewage which is applied to the land is in proportion to an amount which the growing plants will absorb, while in the latter case it is in proportion to an amount which the land will naturally absorb and purify; the purified effluent being permitted to drain away through porous subsoils or collected into subsurface drains which discharge into a neighboring stream or ravine.

The practical value of intermittent filtration in its application to the purification of sewage was first recognized in 1870 by the Rivers Pollution Commission of England, as a result of the investigations of its chemist, Dr. Frankland. Since that date it has been put to practical test in several foreign cities; and its principles have been subjected to more or less searching investigation by various scientists. Prominent among these investigations are those of the State Board of Health of the State of Massachusetts. That board, by legislative authority, commenced a set of experiments in 1888, which are yet in progress, with a view of arriving at a thorough and complete knowledge of all the facts and principles involved in this process of purification, and of determining its practical utility in that State. The author has freely quoted from the records of this board, in order to outline the utility of intermittent filtration for the disposal of sewage, and because they are more complete and comprehensive than any previous experiments.

With respect to filtering materials, the board states that: "With the gravels and sands, from the coarsest to the finest, we find that purification by nitrification takes place in all, when the quantity of sewage is adapted to their ability, and the surface is not allowed to become clogged by organic matter to the exclusion of air.

"With fine soils, containing, in addition to their sand-grains, two or three per cent. of aluminia and oxide of iron and manganese and six or seven per cent. of organic matter, we find that, when only six inches in depth, resting upon fine, sandy material, they retain water so long that the quantity that can be applied is so small, and the interval in which this must settle and dry away to allow air to enter the filter is so long, that the amount of sewage that can be purified is very small. When the quantity applied is adapted to its ability, such a filter may give an excellent effluent, quite free from bacteria.

"With greater depths of soil the quantity that can be filtered will evidently become less; and, with the depth of five feet of such a soil we have found nitrification did not take place; and, although it is probable that no bacteria came through, the organic matter in the effluent was, at the end of two years, nearly as great as in the sewage. This soil remained continually so nearly saturated that, when only 5000 gallons per acre were being filtered daily, although free to drain over every square foot of the bottom, sufficient air could not be taken in to produce any nitrification; and the chemical results with this material was, throughout the two years of its trial, nearly the same as would be expected if the filtration had been made continuous instead of intermittent.

"With peat upon the surface of a filtration area, even to the depth of only one foot, its imperviousness to liquid, and the quantity that it will retain until it evaporates, renders intermittent filtration impracticable; and a sand area thus covered with peat can be rendered efficient for filtration only by the removal of the peat from the surface."

In order to prove that intermittent filtration is not a straining process, and that it does not depend upon the size of the sand-grains, the board had constructed a filter five feet in depth, in which the filtering material was of washed gravel-stones the size of beans, from which all sand had been screened. The filter was operated for nine months, filtering daily the equivalent of 81,400 gallons of sewage per acre, resulting in an average analysis of the effluent from this filter during the last two months of the period that showed 98.6 per cent. of the organic impurity and 99 per cent. of the bacteria to have been removed from the sewage. Then for a succeeding three-months the quantity of sewage applied to the filter was the equivalent of 126,000 gallons per acre per day, with a resultant effluent, the average for the last month, indicating that 98.5 per cent. of the organic impurity and 99.6 per cent. of the bacteria had been removed.

The Board of Health, in conclusion, states that: "These results show more definitely than any others the essential character of intermittent filtration. We see that it is not a straining process. By the application of a small quantity of sewage over the whole surface of the tank each hour, each stone in the tank was kept covered with a thin film of liquid, very slowly moving from stone to stone, from the top towards the bottom, and continually in contact with air in the spaces between the stones. The liquid, starting at the top as sewage, reached the bottom within twenty-four hours, with the organic matter nearly all burned out. The removal of this organic matter is in no sense a mechanical one of holding back material between the stones, for they are as clean as they were a year ago; but it is a chemical change, aided by bacteria, by which the organic substances are burned, forming products of mineral matter, which pass off daily in the purified effluent.

"The liquid flowing out at the bottom is a clear, bright water, comparing favorably, in every respect that can be shown by chemical or biological examination, with water from some of the wells on the streets of our cities that are used for refreshing draughts by the public during the summer."

Of the general results of intermittent filtration of sewage, the Board of Health states that: "Filter-tank No. 1, which is one of the original filters, and has been in use four years, has filtered sewage during the past two years—1890 and 1891—at an average rate of 85,920 gallons per acre daily for every day in that time, and with a removal of 94 per cent. of the organic matters, as shown by the albuminoid ammonia, and 98 per cent. of the bacteria. Filter-tank No. 2, also one of the original filters, has filtered for the same period at an average rate of 49,360 gallons per acre daily, and has removed 97.5 per cent. of the organic matters and at least 99.99 per cent. of the bacteria of the applied sewage. With many other filters correspondingly good results have been obtained."

The basis of judgment regarding the degree of purification of sewage attained by intermittent filtration is, with respect to the organic impurity, the extent to which the ammonias representing this impurity are changed into nitrates, harmless inorganic compounds, caused by the reaction of the nitric acid formed by the bacterial oxidation of the ammonias upon some of the minerals dissolved in sewage; and, with respect to the living organisms common to sewage, the extent to which these bacteria are removed, or their vital activities arrested, as determined by bacteriology. The process of change among the nitrogenous constituents of sewage is technically known as "nitrification," of which a concise description will be found in Chapter II.

The mechanical composition of the sands that are considered the best suited for filtration may be judged of by the following table, in which "the figures given show the per cent. by weight of the different materials having smaller diameters than the sizes given in the first column":

MECHANICAL COMPOSITION OF FILTERING MATERIALS.*

Diameters in Millimeters.	Per Cent.							
	Filter No. 5.	Filter No. 4.	Filter No. 2.	Filter No. 9.	Filter No. 6.	Filter No. 1.	Filter No5A	Filter No.16
Finer than 12.6	99	......	......	......	83	100	100	98
" " 6.2	96	......	......	......	73	97	95	27
" " 2.2	92	......	......	......	57	85	31	0
" " .98	89	......	......	100	32	53	4	......
" " .46	80	......	100	91	13	7	2	......
" " .24	67	100	90	26	7	1.5	1.5	......
" " .12	51	85	43	3	4	0	1.0	......
" " .06	33	35	10	0	2	......	0.5	......
" " .03	16	10	2	......	0.5	......	0.0	......
" " .01 (organic)	6	1	0	......	0	......	......	......

"These materials may be said to include the whole range of sands available for sewage purification. Anything as fine as No. 5 is too fine for advantageous use, while at the other end it would hardly be safe to depend upon a gravel coarser

* Report of 1891, Mass. State Board of Health.

than No. 16, with a filtering stratum not over 5 or 6 feet in thickness.

"With the mixed materials, Nos. 5 and 6, the smaller particles fill the spaces between the larger, and these finer portions determine the capillary attraction of the filter, its resistance to the passage of sewage, and, in fact, its action in every way. The appearance of No. 6 is coarser than No. 1, and the average size of its particles is greater, but its finest portion determines its character as a filter, so that it is practically finer than No. 1."

SIZE AND UNIFORMITY OF FILTERING MATERIALS.*

Number of Filter.	Ten per Cent of Material Finer than (Millimeters).	Uniformity Coefficient.	Albuminoid Ammonia. Parts per 100,000.
No. 5	0.02	9	95.0
" 4	0.03	2.3	18.0
" 2	0.06	2.3	0.9
" 9	0.17	2.0	0.7
" 6	0.35	7.8	0.8
" 1	0.48	2.4	0.4
" 5A	1.40	2.4	0.5
" 16	5.00	1.8	0.3

* Report of 1891, Mass. State Board of Health.

In the table on page 113 "uniformity coefficient" is a term used to designate the ratio of the size of the grain which has 60 per cent. of the sample finer than itself to the size whicn has 10 per cent. finer than itself. "Albuminoid ammonia" represents the organic matter natural to the material of the filter. The heavy lines across this table* indicate about the range of the variations in the size of the grains of sands that are best suited to practical uses.

MECHANICAL ANALYSIS OF SANDS.

	Effective Size 10 per Cent Finer than	Uniformity Coefficient.
	Millim.	
Filter-tank No. 1, Lawrence, Mass.	.48	2.4
" " " 9, " "	.18	2.0
" " " 2, " "	.08	2.0
Sewage-filters, Gardner, Mass.	.10-.24	6-14
" " Marlborough, Mass.	.12	3.4
" " South Framingham, Mass.	.35-.42	4-5
Water-filter, Lawrence, Mass.	.25-.30	2.5-4.5
" " Birmingham, England.	.27	1.8
" " Southwalk, Vauxhall & Co., London, England.	.29	2.0
" " Poughkeepsie, N. Y.	.25-.35	1.8-1.9

* The lines were drawn by the author.

The results of the mechanical analysis of the sands of various filtering materials that are now in use in several places for the filtration of sewage or water, as taken from the 24th Annual Report of the State Board of Health of Massachusetts, are given on page 114 as a matter of general interest.

"The amount of sewage which can be applied in a single dose does not, however, give any indication of the amount of sewage which can be purified in a given time. With the fine materials the sewage enters the sand slowly, and time must be allowed for this slow process, and afterwards for the water to drain out at the bottom, drawing in at the same time fresh air from the top to purify the next portion of sewage to be applied. Two or three days must be allowed for this to take place in sands as fine as Nos. 2 and 4, and probably a longer time might be advantageous under some conditions. With the coarser sands the draining and renewal of air is more rapid, and applications may follow each other at shorter intervals without danger of exhausting the air. The following table shows the doses which have been proved to be adapted to the various materials under the most favorable conditions of management, such as weekly raking of the surface and absolute uniformity and regularity of the application of sewage:

Material.	Diameter of Grain. Millimeters. 10 per Cent Finer than,	Depth of Material.	Size of Dose.		Number of Doses in one Week.	Average Amount Applied Daily. Gallons per Acre.
			Gallons per Acre.	Per Cent. of Volume of Filter.		
No. 16	5.00	5 feet	2,800	0.17	500	200,000
" 1	.48	5 "	40,000	2.45	18	103,000
" 6	.35	4 "	70,000	5.37	6	60,000
" 9	.17	5 "	120,000	7.36	6	103,000
" 2	.06	5 "	140,000	8.60	3	60,000
" 4	.03	5 "	80,000	4.91	3	34,000
" 5	.02	5 "	0	....	....	0

"The smallness of the average amount applied daily on No. 6 is in part due to its less depth (four feet instead of five), and in part to the much smaller volume of its pores, owing to its being a mixed material containing particles having a wide range in their diameters. As has been said, any practicable dose on No. 5 is an overdose. It must be borne in mind that the above figures are only applicable to the comparatively clean materials, under the most favorable conditions, and that so large doses cannot be permanently applied with good results without renewing of the surface materials."

In addition to the foregoing results, there are others, both interesting and instructive, which the author has summarized as follows:

1. *Stratification and Effects of Horizontal Layers.* — "In all the filters filled during the earlier years of the experimental station, the filtering material was put in position by throwing it into water. This method always results in some stratification, the larger particles settling at once to the bottom, while the finer grains remain longer in suspension; and in case the process of filling is interrupted, even for a few minutes, the finer particles settling out from a continuous layer of much finer sand.

"We have thus found that with a coarse material above a fine one in the same filter, there is a chance of trouble from a clogging of the surface of the fine material below the coarse; and this is far worse than surface clogging, for the latter can be completely remedied by distributing the surface or by scraping. We have also found that a fine sand supported by a coarse sand will keep its lower layer saturated, and act as a water-seal, allowing the passage of water but not of air, and may in this way prevent the necessary circulation of air and reduce the action of the filter to a mere straining. Thus the possibility exists that different materials which by themselves may be suitable for the purification of sewage by intermittent filtration may be so combined in a filter that oxidation is rendered imperfect or impossible."

"The above examples are perhaps extreme cases. With less marked differences in the sand grains, or with gradual instead abrupt transition from coarse to fine, the causes of failure might be reduced or even eliminated. In the many cases where the fields available for sewage filtration contain layers of various materials, the different sands must be separately studied, in order to determine the probable action of existing combinations; and, in case the natural conditions are unfavorable, changes may be made which will improve the action of the filter."

2. *Effect of Snow and Frost.*—"The two essential conditions to the passage of sewage through the filters in winter are that sewage shall never be put into snow, and that the filtering material shall be open enough to absorb its dose rapidly."

"At Gardner, Massachusetts, with only a limited filtration area, and with its sewage chilled nearly or quite to the freezing-point before reaching the beds, and of course, at times put directly into snow, the filters have become badly frozen and have refused to perform their work. At Framingham and Marlborough, with warmer sewage, the results have been more favorable; the beds have regularly taken all the sewage and have yielded well-purified effluents. A few beds at Marlborough have indeed become frozen and disabled; but with the ample area provided, the loss of a couple of beds is not serious: they can be allowed to wait for a thaw, while other beds continue to do the work."

"The results at Framingham and Marlborough (Massachusetts) demonstrate that with a sufficient use of porous material and with not too cold sewage intermittent filtration can be successfully carried on in very severe winter weather, although with less complete purification of the sewage than at other times. With colder sewage, however, and only limited area, the problem becomes very difficult, and the present data are inadequate for satisfactory discussion."

3. *Permanency of Filters.*—"Of the nitrogen stored in the filters more than 98 per cent. is in the form of insoluble albuminoid ammonia, so that it would seem that the insoluble organic matters are mainly responsible for the clogging of the filter."

"The constancy of the percentages of storage of insoluble nitrogenous matters is remarkable. Taking the final results, the highest are not twice as great as the lowest, and with seven filters out of nine the percentages are between 66 and 80. This can only be interpreted as showing that there are substances in sewage so stable as to resist, for a very long time at least, the oxidizing action of the filters.

"We have not as yet obtained a permanent condition of equilibrium with no further increase in storage. On the contrary, the organic matters have been steadily increasing, and at a rate approximately equal to 70 per cent. of the insoluble matters applied. This accumulation has now proceeded so far in some of our filters as to seriously cripple them."

4. *Clogging of Sand.*—"Our present knowledge in regard to the conditions of clogging may be summarized as follows:

a. "Other conditions being the same, the clogging of a filter is proportional to the amount of sludge carried by the applied sewage."

b. "Other conditions being the same, a larger proportion of the sludge of the applied sewage is stored at a high rate of filtration than at a lower rate."

c. "The same quantity of matter stored causes more trouble at high rates than at lower rates."

d. "The condition in which the clogged sand exists on the filter has an important influence upon the results obtained, and it is not clear that the most favorable conditions have as yet been secured."

e. "The clogged sand by itself becomes slowly oxidized, but to what extent is as yet uncertain."

f. "The clogged sand under some conditions may serve as a filtering material with good results."

"While it must be admitted that the subject is by no means exhausted, the indications point to a much slower clogging of actual filters, run at moderate rates, than has been observed in the experimental filters pushed to their full capacity."

5. *Acid Sewage.*—"The effect of acid is quite similar to the effect of frost; both tend to prevent nitrification, and check, but do not entirely prevent, the oxidation of organic matter."

"If the sewage is only occasionally acid, or if the filtering material contains available base, the acid will not injuriously affect the result. If, however, the filtering material contains no lime, and the sewage is so constantly and strongly acid as to interfere with the results, a little limestone, put upon the surface, or dug into the upper layers of the filter, will completely overcome the effect of the acid."

6. *Systematic Scraping.*—" The filters used for the disposal of sewage at Gardner, Mass., are systematically scraped, with a two-day interval of applying sewage, and apparently with excellent results."

7. *Area of Filters.*—" It is evident that filters should be provided for the maximum rather than for the average sewage-flow; but, on the other hand, a filter in good condition should be able to take much more sewage for a single day than it would be safe to apply every day, and so the increased size of filters would not need to be as great as the ratio of the maximum to the average daily flow.

" In severe winter weather, under ordinary conditions, it seems inevitable that filters will occasionally become disabled by frost; and, although such a filter can be put in operation by the free use of a pick, making holes to the porous material, it would be much cheaper and more satisfactory in every way to have enough area so that in such cases the frozen bed could be allowed to remain unused until the next thaw.

"Beds will also at times become clogged, and require to be treated in some way before applying more sewage; and as it may not be always convenient to attend to such matters at short notice, it is desirable to have extra area, which will allow the treatment to be undertaken at a convenient time. From every point of view, then, and entirely aside from the important question of a factor of safety, it seems desirable, even necessary, to have the filtering area larger than is indicated by the Lawrence experiments. These experiments should be taken to indicate the theoretical rather than the practical limit of the process. They afford a convenient, and, when used in the proper way, a reliable basis for estimates; but the figures should not be used to represent the possible average yearly work of a large plant."

Probably no experiments that have ever been made to determine the principles involved in purification of polluted water by intermittent filtration have been so comprehensive in their scope or so carefully or fully recorded as have the experiments made by the eminent scientists and specialists under the direction of the State Board of Health of Massachusetts. The results are worthy of the skill, time, and expense bestowed upon them; for they are fruitful in matters of general interest and importance. While, as the Board of Health states, the experiments indicate the processes and results of natural purification of polluted water under the most favorable conditions, yet they have developed much information that is of practical utility, and have demonstrated that Nature has provided all that is required for the complete purification of waters containing organic impurity, and that to render this processof Nature available in sewage disposal it is necessary to observe the varying mechanical and chemical conditions of both soil and sewage, and to avoid restricting the process by artificial conditions or burdening it with more work than can be accomplished.

It is now interesting to know to what extent the results as attained by the careful and elaborate experiments at the Lawrence experimental station may be verified in the practical application of the purification of town sewage by intermittent filtration. Of such an application there are three good examples in the present practices of the towns of Framingham, Marlborough, and Gardner, Massachusetts.

At Framingham is is said that, "owing to the height of the land above an adjacent brook and the porosity of the material, only a limited amount of underdrainage was found to be necessary; and most of the effluent, instead of coming out of the underdrains, passes for a long distance through the ground, and appears in the form of springs at the edge of the low land near the brook. That portion of the effluent which comes out through the underdrains is very well purified, particularly in summer, while that which passes a long distance through the ground and comes out at the springs is completely purified." *

* See Report Mass. State Board of Health for 1892.

"The results obtained at Framingham in the disposal of sewage have been very satisfactory, indeed, as all of the sewage has been filtered without causing offence in the neighborhood, and without injuring the small brook into which the effluent flows."

"The water from the underdrains as dipped up and examined at the sewage-field is perfectly clear, colorless, and odorless, and furnishes no indication of being other than good spring-water; When, however, it is subjected to the severer tests of the laboratory, and the water is shaken in a half-filled gallon-bottle, after it has stood a day, a musty and even an offensive odor is sometimes noticed. The analyses show that 98 per cent. of the organic matter, as represented by albuminoid ammonia, is removed from the sewage when the effluent leaves the underdrains, and they also show a reduction of 91 per cent. in the amount of free ammonia."

At Marlborough a portion of the suspended matter of the sewage is separated by means of screens and separating-tanks before the sewage passes onto the filter-beds. "The sand is somewhat finer than at Framingham . . . and it was found necessary to underdrain the land. . . . The filter-beds were prepared for use by the removal of very nearly all of the loam." . . . "The results obtained at Marlborough have on the whole been satisfactory, as the sewage has been purified to the extent of removing 95.5 per cent. of the organic matter as represented by the albuminoid ammonia; and it has been shown that it is feasible to purify the sewage in this way without causing offence in the neighborhood. There has been, however, at times a strong odor from the sludge-beds when the sludge was allowed to remain upon them a long time, and even when the sludge-tanks are emptied twice a month upon the beds, and the sludge is removed as soon as it dries, there is considerable odor while it remains on the beds." *

At Gardner "the beds had to be almost wholly artificial, and their total area was neces-

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* See Report Mass. State Board of Health for 1892.

sarily quite small. The material is coarse sand, and the beds are very thoroughly underdrained by lines of tiles laid twenty feet apart and from four to five feet beneath the surface. Although the area of the bed is limited, it has been found feasible to dispose of all of the sewage by filtration in summer and obtain a good effluent, if the sediment is frequently raked in or removed from the surface of the beds; but in the cold winter weather, when this sediment cannot be removed, the beds have become partially clogged, and some of the sewage has run over into the brook. . . . The analyses show that 89 per cent. of the organic matter as represented by the albuminoid ammonia, is removed from the sewage by filtration."

The results obtained in these towns,—Framingham, Marlborough, and Gardner,—which have a population respectively of 9,239, 13,805, and 8,424 inhabitants, demonstrate very clearly the practicability of this method of sewage disposal, when applied to small- and medium-sized towns; and where there are available a sandy, coarse-grained and well-drained soil and proper facilities for the uniform distribution of the sewage over the filter-beds and for keeping the pores of the sand from becoming seriously clogged. Moreover, these practical examples of intermittent filtration of sewage demonstrate that the slower the rate of filtration and the longer the course taken by the sewage in transit through the soils the more effectively is purification accomplished, and therefore that time and distance are important elements of successful filtration.

With respect to the application of this method of sewage disposal throughout the country, it does not appear that the application can be other than sectional, unless the soil conditions in many localities be artificially made favorable. But even in those localities where the method may be usefully applied, there appears no conclusive warrant in the results of the investigations as thus far made public that crude sewage can be applied, even to land of the most favorable mechanical mixture, with a continuous and an equal degree of success from year to year, without first removing the suspended and insoluble solids of sewage which constitute about 50 per cent. of the total organic impurity, and which are quite likly to clog the soil, and to thus impair its filtering and purifying capacity. As has been shown, the condition of the experimental filters of Lawrence, Massachusetts, indicate a steady accumulation of the organic matter of sewage at the rate of 70 per cent. of the insoluble matter, and that this accumulation has seriously crippled most of the filters. Therefore it follows that clogging of the sands of filter-beds is in practice an element of danger when sewage is applied to the land in its crude condition. Admitting, however, that the rate of filtration in these experiments has been fully up to the purifying capacity of the severally-graded sands, and that the clogging of the sands of the filters was consequently greater than it would have been had the rate of filtration been considerably less than the purifying capacities of the filters, yet whatever be the rate of filtration it is apparent that there is a continuous process of clogging within the upper layers of a filter. However, there may be a rate of application of sewage to sand-filters, whereby an equilibrium of the conditions in a filter may become established, as when the oxidation of the accumulating insoluble organic matter within the filter by the air and water becomes equal to the rate of clogging; but this point of balance among the natural processes at work in a filter does not seem to have been determined. While from a scientific standpoint it may be advisable to determine as nearly as practicable this point of balance, and may be considered the part of judicious foresight to so restrict the application of sewage to filtering-areas that the limits of safety with respect to clogging be not disregarded, yet from other standpoints the rate of filtration so restricted may be impracticable, as when in the enforcement of measures of economy in the management of municipal affairs, the authorities controlling expenditures favor the utilization of no greater acreage of land than will admit at the present time of a passably purified effluent. The inevitable and progressive clogging of the land that will follow such a disregard of the equilibrium of the process of Nature will sooner or later necessitate the extension of the filtering-area or a frequent scraping and removing of the surface layers of the filter-beds. But for extensions which are due to a diminution of the filtering capacities of the soils rather than to the increase of the volume of sewage, and for expenses resulting from the removal of clogged sands, the public, who judge largely by results, are very liable to attach reasons derogatory of this process of sewage disposal rather than of the method employed in applying the sewage to the land or of the proportionment of volume and acreage. On this line of reasoning it would seem, therefore, that to insure a successful application of sewage to land by this method of sewage disposal, it would be advisable either to combine intermittent filtration with the growing of crops upon the filtering-area, or to precede it by the removal of the insoluble matter from the sewage. For, on the one hand, the growing of crops would favor an extended distribution of the sewage upon the land and the revenues accruing from the sale of the crops would in a measure offset the annual expenditures necessary to maintain and operate the additional land required as a preventive of clogging; and, on the other hand, the insoluble portion of the organic impurity of sewage, after being separated from the water, could be so disposed of as to cause little or no trouble and offence, and the strained or settled sewage could then be safely applied to the filtering-area in volumes quite equal to the purifying capacities of the sand.

This view may seem somewhat speculative because of the brief experience in sewage disposal of the cities and towns of this country; but there is much evidence in the results of experiments as thus far made public, and in the results of sewage disposal by land in this country, to admit of and support such a speculation. Moreover, this view is further supported by the results of the trials to filter the water from sediment-bearing rivers for public use, which results indicate that water from such sources to be successfully filtered at a rate to render filtration commercially practicable should be preceded by sedimentation.

It is apparent that in the purification of crude sewage by intermittent filtration, as in that by irrigation, the sanitary and commercial interests are somewhat at variance; for the former requires a rigid adherence to such methods as will insure by natural processes a thorough purification of sewage, while the latter for purposes of retrenchment or economy seeks a minimum of expenditure upon land and upon the manipulation of sewage. There is urged, on the one hand, a slow rate of filtration and a wide distribution of sewage, and, on the other hand, a rapid filtration through porous ground of as small superficial area as possible.

To what extent the opposing elements of these two aspects of sewage disposal may be harmonized will depend very much upon the advantage that is taken of local conditions and sentiments, and upon the inclination of the management of a filtering area towards the attainment of good sanitary results. But for guidance in these particulars there can be no specific rules or regulations: they are not matters to be successfully treated of in text-books; and the success that may follow the application of this method of sewage disposal in any instance will depend quite as much upon the judgment displayed in harmonizing the involved natural principles and the results of experiment and experience with the special conditions of the locality in question, as it will upon the simple applications of principles and results as they may be found arranged and recorded in books of reference.

It would seem difficult indeed to harmonize the sanitary and commercial aspects of sewage disposal by intermittent filtration in a section of country where the prevailing characteristic of surface soils is that of fine grain and close texture, as is true of a very large part of the central and southern portion of the United States; for this method of sewage disposal in these localities is not only naturally inapplicable but also quite inadmissible, except by incurring a heavy expense in transporting gravel and sand and of constructing artificial filter-beds, together with such accessories as may be necessary to remove insoluble matter from sewage before filtering it. In fact, it is not very probable that in such localities many attempts will be made to harmonize these aspects, as they relate to intermittent filtration; for there will be found other methods of disposal more in consonance with the sectional and local peculiarities that can be utilized whenever the treatment of sewage becomes necessary.

CHAPTER VI.

PURIFICATION OF SEWAGE BY CHEMICAL PRECIPITATION.

THE application of a process of chemical precipitation to the purification of sewage is said to date back more than a century; and during the period from the first application of this process to the present time there have been hundreds of patents taken out for the purpose of chemically purifying sewage.

Either the patentees or their associates by enthusiastically offering large prospective returns from the sale of the precipitants from sewage induced organized private capital to invest in these patented processes and in the plants and equipments necessary to carry them into effect; but these attempts, like the attempts to utilize the manurial properties of sewage by the irrigation of growing crops, have generally proved abortive commercial ventures.

The commercial unproductiveness of such enterprises has probably been largely due to the impracticability of attaining in practice the favorable results that had been predicted as a consequence of investigations and experiments in the laboratory, and has perhaps been more thoroughly demonstrated in England than elsewhere; for there any efforts to mechanically dispose of sewage were largely directed to the utilization of its manurial elements, and methods having this end in view were given the preference in application.

Of all the processes that have been tried there are only a few that are practicable, and these few nearly all involve the use of lime, alum, some salt of iron, or a combination of two or more of these chemical compounds. In the eight or more cities in this country where the sewage is purified by chemical precipitation, nearly all use lime and either alum or a salt of iron.

The amount of chemicals necessary to be used in practice depends very much upon the chemical characteristics of the sewage. There are instances where it is necessary to vary during each day the amount of chemicals that may be necessary for precipitation, because of the varying acidity of the sewage produced by occasional discharges of acids from manufactories.

The experiments that have been made at the Experimental Station at Lawrence, Mass., in precipitating the solids from sewage have given the following results:

1. With respect to the amount and cost of chemicals:

"The experiments indicate that a certain definite amount of lime gives as good or a better result than either more or less, and that in general the more copperas, ferric sulphate, or alum used the better the result; and that ferric sulphate and alum usually require no lime for complete precipitation, while with copperas a definite amount of lime must be used."

It was determined that about 1800 pounds of lime per one million gallons gave the best results, and cost annually about 30 cents per inhabitant.

Of the other chemicals for the same annual cost per inhabitant it was found to take per 1,000,000 gallons:

1000 pounds of copperas, and 700 pounds of lime.
270 pounds of ferric sulphate.
650 pounds of alum.

2. With respect to the comparative advantages of the different chemicals:

"The lime process has little to recommend it. Owing to the large amount of lime-water required, and the difficulty of accurately adjusting the lime to the sewage, a very close supervision would be acquired to obtain a good result, and even then the result is inferior to that obtained in other ways.

"Precipitation by copperas is also somewhat complicated, owing to the necessity of getting the right amount of lime mixed with the sewage before adding the copperas. When this is done a good result is obtained."

"With more than one half a ton per million gallons, the improvement does not compare with the increased cost."

"Ferric sulphate and alum have the advantage over both lime and copperas, that their addition in concentrated solution can be accurately controlled; and the success of the operation does not depend upon the accurate adjustment of lime or any chemical to the sewage.

"The results with ferric sulphate have been, on the whole, more satisfactory than those with alum. This seems to be due in part to the greater rapidity with which precipitation takes place, and in part to the greater weight of the precipitate. It is probable, from the greater ease with which ferric sulphate is precipitated, that it would give a good result with a sewage that was not sufficiently alkaline to precipate alum at once.

"It is quite possible that the same process would not give equally good results upon all kinds of sewage. For this reason, and also on account of changes in the price* of the several

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* At Lawrence, Mass., the cost of lime was $9 per ton; of copperas, $10 per ton; of alum, $25 per ton. The cost in solution for alum was 9 cents per pound; for ferric oxide, 3 cents per pound; for copperas, 2 cents per pound; and for lime, ½ of a cent per pound.

chemicals, it is impossible to say that one precipitant is universally better than another."

"Using equal values of the different precipitants, applied under the most favorable conditions for each, upon the same sewage, the best results were obtained with ferric sulphate. Nearly as good results were obtained with copperas and lime used together, while lime and alum each gave somewhat inferior effluents."

"When lime is used there is always so much lime left in solution that it is doubtful if its use would ever be found satisfactory except in case of acid sewage."

3. With respect to the purity of the effluent from the precipitation tanks:

"It is impossible to obtain effluents by chemical precipitation which will compare in organic purity with those obtained by intermittent filtration through sand.

"It is possible to remove from one-half to two-thirds of the organic matter of sewage by precipitation, with a proper amount of an iron or aluminum salt; and it seems probable that, in some cases at least, if the process is carried out with the same care as is required in the purification of sewage by intermittent filtration, a result may be obtained which will effectually prevent a public nuisance."

"A very large proportion of bacteria and of the other organisms is removed."

About all that can be expected of chemical precipitation, when practised on a large scale, is to remove the undissolved and suspended matter in sewage, thereby clarifying and in a measure deodorizing it. Very little, if any, of the dissolved organic matter is removed. Therefore, as a purifying process, chemical precipitation cannot rank high.

The expense of treating the sewage and of disposing of the sludge has been found to vary from fifty cents to one dollar per inhabitant per annum. The expense depends very much upon the character of the sewage, the facilities for disposing of the sludge, the income that may be derived from its sale, and the amount of seep and storm-water that must be handled with the sewage. The value of the sludge is indeed low, and usually there is little demand for it. As it comes from the precipitation tank it contains ninety per cent. or more of water, and in this condition is almost unsalable. When pressed it contains about fifty per cent. of moisture, and may be salable as sludge-cake; but even then it is of low manurial value, and something to be gotten rid of as quickly as possible to avoid offense. It would not require a very shrewd farmer to see that a little conservatism on his part regarding the use of such compounds as a fertilizer, or even a refusal to buy it might very consistently result in his being requested to remove it for whatever use could be made of it. In fact, the putrescible character of sludge and the necessity for a continual production of it in disposing of sewage by chemical precipitation, are conditions that maintain a continuous supply of an article for which there can be no commercial demand, inasmuch as a prompt removal is obligatory. This fact, together with the comparatively low order of sludge as a fertilizer, should correct any erroneous impression that in practice any large and continuous revenue can be derived from the sale of this article.

In small towns where this method of sewage disposal may be in use, the sludge, being of a small amount, can be readily disposed of by digging it into the ground, or by giving it to the farmers; but in large towns, where the amount is great, the removal must be accompanied with expense to the city or town, and the method of least expense is naturally the one to be chosen in any specific case, whatever it may be.

The effluent from a chemical precipitation works containing practically all the dissolved organic matter of the untreated sewage is in a putrescible state, and may under conditions of high temperature or insufficient dilution putrefy and again become offensive. This process, therefore, is one to be used in a guarded manner where only a partial purification of sewage is necessary, by removing the insoluble matter, and where the effluent will not be exposed to conditions promoting subsequent putrefactive changes.

CHAPTER VII.

GENERAL DISCUSSION.

THE theory already referred to, that sewage disposal should be one of sewage utilization, because sewage contains the elements which through the processes of Nature are requisite for the support of vegetable life, might doubtless have more application in practice were the conditions governing the production and disposal of sewage such that Nature could regulate both the supply of sewage and the demand for it. But so long as the demand is fixed entirely by Nature and is subject to a seasonal fluctuation and requires a wide distribution, and the supply is controlled wholly by artificial conditions and is practically constant and concentrated, there can be no systematic and uninterrupted utilization of sewage.

No matter what may be the intrinsic value of the manurial constituents of sewage, so long as the conditions affecting the supply and demand can neither be controlled nor regulated, its commercial value must remain very small, indeed—so small that sewage is much more likely to become a source of expense than one of revenue to any community having it to dispose of.

What becomes of sewage apparently concerns communities very little, so long as it becomes neither offensive nor dangerous to health. Results are what people look to; and, aside from the commercial bearings of sewage disposal, it matters not to them whether the process of disposal be one of utilization, purification, or of simple disappearance, so long as it occasions no danger or annoyance. But to insure exemption of offence from sewage, it is necessary to artificially remove the decomposable matters from it, or to surround it by such natural conditions as will admit of and promote natural purification. In a broad sense, therefore, the final object of any method of sewage disposal is purification, involving the removal, the destruction, or the wide distribution of the small percentage of putrescible organic matter of sewage. In other words, a foul and decomposing fluid must be transformed into a clear and stable one, or so diluted with water that natural processes of purification will either prevent offensiveness or render it indiscernible.

Purification is a slow but progressive process, requiring a considerable interval of time for its accomplishment, and any interval of time less than this will result in a proportionally less degree of purification; but the interest of communities can usually be sufficiently well subserved by the attainment of such a degree of purification as will prevent offence to the senses or as will avoid danger to health through the medium of drinking-water. The process has, therefore, a twofold bearing, upon which bearings the topical discussion of the preceding pages has aimed to throw some light. However, in this discussion no definite limits to the degree of purification has been fixed, either as regards offences to the senses or as to the pollution of water supplies;

indeed, it is quite impracticable to do so; for any standard of purity, to be practically applicable, must be elastic enough to suit a variety of localities and conditions, and must consequently become indefinable except in particular instances.

Oxygen, derived largely from the atmosphere, is the promoter and supporter of purification; while both water and earth are, in a great measure, the medium through which the process takes place. In water organic matter becomes dissipated by dilution and oxidation. On land it disappears by evaporation, oxidation, and absorption; but there is no evidence to show that the process of purification is any more complete in the one medium than in the other.

The ability of land to purify organically impure water is definitely proven.

Nature furnishes pure spring or ground waters from rain-water that has previously absorbed from the air and from the surface of the ground much putrescible organic impurity, and thus offers direct evidence that a wide distribution and a slow rate of filtration of impure water can affect complete purification. This evidence is the origin of the conception of intermittent filtration as a process of purification—at least with unfailing supplies of oxygen and life and with unlimited time and distance for its completion.

But in Nature the removal of this impurity in water is no more a question of utilization by growing vegetation than it is that of purification by filtration through the ground. Therefore, in practice, in imitation of the process of Nature, the disposal of sewage upon land becomes a question not of utilization or of irrigation or of intermittent filtration, but rather one of land disposal for the purpose of purification, embodying all these special methods of treatment. By laboratory experiments and experience on a large scale in filtering sewage through porous earth, it has been demonstrated that purification can be accomplished by artificial filtration; that in artificial filtration there is danger of the pores of the ground becoming clogged by the insoluble matter in sewage, thus more or less completely arresting the process of purification; that such fine soils as clay, loam, and peat do not admit of successful filtration, because of capillary attraction; that snow and cold hinder or arrest it; and that still other contingencies may combine to prevent successful purification by land at high rates of filtration.

We know that capillary attraction must seriously affect filtration. Nearly all soils have at least 30 per cent of their volume as voids; but this or any other percentage of voids or air-space in any ground is no index of its filtering capacity. For instance, the air-space of a mixture of coarse sand and gravel is composed of a comparatively small number of large voids, but the air-space may be about the same percentage of the total volume of the mixture, as is that of a fine loam or garden soil wherein the air-space is composed of a large number of very small voids. Though both of these materials may hold the same amount of water when saturated, yet when free to drain the sand and gravel will loose from

75 to 80 per cent of its water, while the soil will loose little or none, and in any event at a slow rate of percolation. The water remains in the soil because of capillary attraction, which is greater in this instance than is the attraction of gravity drawing the water downwards. The sand and gravel, by careful applications of sewage, may be made to purify sewage, but at a rate of filtration far less than the ability of such a filter to drain; on the other hand, the fineness of the voids in soil renders such a material retentive of water and consequently valueless for filtering purposes. To underdrain such soil may in a measure increase its filtering capacity by promoting a freer and more direct circulation through the pores of the filtering material from the outer air to the drain; but the drains would not be at all likely to free the soil of water. In fact, from such a soil the moisture is largely removed by evaporation from the surface layers —these layers, as fast as deprived of water by evaporation, becoming supplied by capillarity from layers at greater depths; that is, a reten-

tive soil is drained of its water by evaporation from the surface of the ground far more than by percolation through it. Were this not a provision of Nature to support vegetation, a fine and retentive soil would become quite as unproductive as porous and well-drained sands. This process is the one that contributes materially to the productiveness of a great part of our Western States, where fine soils nourish vegetation during droughts by drawing water from the subsoils by capillarity—a process of natural pumping,—just as a sponge or linen towel will draw water to a considerable height until saturated. Although retentive soil admits of some filtration, yet the amount is so small that the use of it for sewage-disposal purposes requires the sewage to be widely distributed and the land to be cropped, for the greater portion of the moisture must be removed by absorption of plants and by evaporation.

The more porous the soil the less capillary attraction affects filtration; for this reason sandy land is capable of disposing of more sewage than is loam land.

The extent to which snow and cold may affect filtration is largely a question of geographical location.

The clogging of the soil of disposal areas, in view of the results of the experiments of the Lawrence (Mass.) Experimental Station, as recorded in Chapter V, is to be apprehended ; and it may result in the serious impairment of the filtering capacity. These experiments indicate that any land, whether it be loam, sand, or gravel, if the amount of sewage applied but approximate that amount which limits the original filtering capacity of the material, will sooner or later become impaired both as a filtering and a purifying medium.

This condition of soil impairment may not become prominently apparent for several years, but it cannot be expected that land can receive the insoluble matter of sewage day after day and month after month, in large quantities, without becoming gorged, as it were, by the accumulations. Clogging seems inevitable as the result of a continuous application of crude sewage. In all probability it will become evident much earlier in loam lands than in sand and gravel lands, because the tendencies to economize in the management of municipal affairs, as is frequently apparent, may prevent a proper discrimination between the filtering capacities of the two materials and the consequent utilization of less loam land than is really necessary for the continuous attainment of purification, and may result in such an injudicious apportionment of area and volume of sewage as to speedily overtax the fine soil.

Glancing back to the table on page 116 it will be seen that the Lawrence (Mass.) experiments indicate the purifying capacities of the various materials experimented with to be from 200,000 to 34,000 gallons per acre per day, which amount of sewage is the equivalent of about 3000 to 500 inhabitants per acre. But it should be remembered that these experiments were conducted with a view of determining maximum and theoretical values, and were the recipient of far more skilled and careful attention than will ever prevail in practical sewage disposal by land. Moreover, many of the filters became clogged, and were thereby seriously cripped because of a continuous storage of insoluble matter. The results of these experiments with respect to the filtering capacities of various materials, while instructive, are not intended for application in practice without much modification. As a matter of fact, having in the majority of cases to take land in its natural condition, without the opportunity of either choosing the material or arranging it in the best manner for filtration, and having usually to rely on unskilled labor to manage the disposal areas, it is obvious that the amount of sewage to be applied should be very much less than the theoretical amount. A reduction of one-fourth to one fifth would usually be none too much.

In England it was originally estimated that by intermittent filtration one acre of land could filter the sewage of 2000 inhabitants; this value has since been reduced to 1000 inhabitants per acre under most favorable conditions of filtering material and management.

On the irrigation farm of Berlin, the decrease, as stated on page 87, is from 250 to 75 or 50 inhabitants per acre. It is seldom on any of the irrigation farms of foreign countries that the proportion exceeds 300 per acre.

Some sanitarians of this country assert that an acre of good land without cropping should purify the sewage of 1000 to 2000 people. While it is to be hoped that such results may be attained, and that the practice in this country may find purification of sewage practicable at higher rates of filtration than has prevailed in the practice of foreign countries, yet such a conclusion does not seem admissible in the light of such experiments as have been made in this country. Such high rates of filtration of crude sewage, with no more skilled management than will ordinarily obtain, would cause the ground to become clogged, unless it should be of a sandy nature in a country of light rainfall, where the evaporation and oxidation of the insoluble substances arrested by the sand would be rapid.

Moreover, there is no good sanitary reason, so far as purification may be concerned, why the cropping of disposal areas should be discountenanced. To do so is neither in imitation of Nature nor in accord with those considerations of economy which aim to reduce the cost of sewage disposal by land through the returns in crops from cultivated disposal-lands. In fact, the tendency is rather to crop disposal land than otherwise, as evidenced by the practice of Framingham, Mass., a town admirably located, as we may judge, for the exclusive disposal of sewage by intermittent filtration, which in 1892 raised crops of various kinds of vegetables with such satisfactory results as to repeat the experiment with additional acreage in 1893. And it may be quite safely predicted that the practice of sewage disposal by land in this country will, in imitation of the purifying process of nature, sooner or later, favor the cropping of lands to any extent that may be admissible in the interests of an economical and sanitary management. In a very large portion of the central and western United States, the prevailing fine, loamy and clayey soils can advantageously afford natural facilities for no other method of land disposal of crude sewage than that which would admit of a wide distribution of sewage coupled with the cropping of lands. Here the admissible population to be served per acre of land should, with due regard to purification and to the avoidance of offence, scarcely ever exceed 200 to 400 per acre, and even a less number may be found advisable to insure freedom from clogging.

At unseasonable times for cropping, land disposal in almost any locality must, in the case of porous soils, become one largely of intermittent filtration or, in case of retentive and non-filtering soils, one largely of deposit and evaporation, wherein the sewage in flowing over the land becomes clarified because of depositions of suspended matter.

The proportions of population to the acre of land, as generally given, is largely one of general averages. But in practice the capacity of soils for purposes of sewage disposal is in every instance a question of specific amount rather than one of general average, and as such the acreage of land for any assumed number of population should be based entirely upon a conformation of the physical characteristics of the soils of available land, with the special and local requirements of the place. In other words, in sewage disposal by land there is in every instance a specific amount of work to be accomplished by natural processes ; consequently, the amount of the work should harmonize with the peculiar conditions of the soil in the locality in question. Average ratios of population and land, arbitrarily chosen, are simply the average results of land disposal of sewage in many or few places ; and, as such, cannot become such a criterion for practice in specific instances as can the results of a purely mehanical process.

Any practice of land disposal that burdens the natural process at work in the removal of the organic impurity of sewage impairs the filtering and purifying capacity and ability of the land. This can be obviated, either by so wide a distribution of sewage over the land as to insure the proper and effectual assistance of Nature in the work, or by removing the insoluble matter from sewage previous to applying it to land in intermittent filtration.

By clarifying sewage before applying it to land and by the use of sandy ground for filtering purposes, the area of disposal land may be reduced to its smallest limit, cropping may be avoided, and the theoretical filtering capacities of land may be most nearly approximated.

The disposal of sewage into watercourses has indeed been a most natural transition from the disposal of excrement into the waste water from habitations; the only difference being that the conditions affecting the removal of sewage by natural waters are fixed by Nature, while those effecting the removal of excrement through artificial channels are wholly controllable and adjustable. But such a method of disposal involves a process of purification quite as much as does land disposal. It became a custom both from motives of economy and expediency—of economy, because it utilizes a natural drain and a natural vehicle for the removal of waste and of products of decomposition; and of expediency, rather because it was thought proper and desirable to remove sewage in this manner than because of motives of self-interest or of a disregard for a neighbor's convenience. But this practice of sewage disposal has been the occasion of objection because of the offensiveness and malodorousness of waters excessively charged with sewage; and, of condemnation, because of supposed danger to health of water abstracted from sources of supply previously polluted by sewage. The cause of offence can be removed, as has been shown in Chapter III, by restricting the amount of sewage entering a given volume of water to that which can be removed and purified by the natural processes prevalent in normal waters.

The most significant element of sewage disposal by water is the one that involves questions affecting the purity of water supplies. There is always a natural abhorrence to partaking of a water supposed to be polluted with fecal matter. Whatever may be the elements of danger to health in a water thus contaminated, considerations of self-respect and decency do not tolerate its use as a public water supply. While a water that at some time of its history has been polluted with sewage may not be necessarily dangerous to health, yet of a source of water supply so contaminated there are frequently good grounds for a suspicion that the intervals of time and distance between the point of pollution and the point of abstraction may not have been sufficient to insure complete purification. Merely prohibiting the discharge of sewage into sources of public water supplies cannot remove this suspicion of danger, for other sources of pollutions, some of which have been enumerated in another chapter, and which are quite uncontrollable, are in many instances of quite as grave consequence.

Inasmuch as the extent of the pollution of surface-water can neither be wholly controlled nor regulated, and since the provisions which, in the main, are sufficient to prevent any ill effects coming from a surface-water that may have received pollution from uncontrollable sources can be made quite as effective in the majority of cases of sewage pollution, it follows that one of two things should be done by cities and towns with regard to their water supplies, namely: that they either derive their water supplies from unpolluted sources or adopt such measure as shall prevent contaminated water reaching the consumers. One or the other of these courses is always available; and while the one that secures a supply of water from an unpolluted source is by far the more preferable from a sanitary standpoint, still the other course can attain to a safe degree of purity.

As though in anticipation of a general want, it has been demonstrated by successive years of trial that artificial filtration by natural processes can be relied on to purify organically polluted water, to remove infectiousness, and to be thoroughly practicable. By its application to the purification of water supplies, water can be purified immediately before consumption, and thus completely avert not only the dangers but also the suspicions of contamination. To partake of a water that has been properly filtered, even though known to have contained organic impurity previous to filtration, need cause no shock to any considerations of decency; for the water has been actually purified by a process that is entirely similar and analogous to that one which renders spring and ground waters pure and palatable, even though they had previously been in contact with decomposing organic matter abounding almost everywhere upon the surface of the ground. In fact, the conditions of a water purified by filtration bears the same relation to the condition of the water before filtration as does the refined condition of an article of diet or commerce as compared with a former natural or crude condition; the impurities being simply associated with the past history of the water or article, and the purified or refined condition of either being none the worse for having originally contained them. But it may be still contended that the proper way of securing freedom from impurities in water is to prevent pollution ; but this measure, in a general application, is wholly impracticable, and in particular application with regard to sewage it may be further stated in contravention that to wholly remove this cause of pollution would require a change no less radical than one preventing the introduction of excrement into the waste-water from habitations. But sanitary science has found no satisfactory substitute for the method in current use of removing excrement by water-carriage; and it is by no means ready to advocate the exclusive application of sewage to land or the disposing of it by any method wholly independent of a discharge into natural waters. There is yet no immediate probability of any such radical change of present practices.

Doubtless the disposal of sewage in most instances should have regulation : even legislative enactments may in some case be necessary ; and this is true of any method of disposal, whether it be by land or by water. But legislation for this purpose would in all probability be more effective if directed to the regulation than to the prohibition of approved practices of sewage disposal, and rather for specific than for general application; and, while it is seeking the purification of sewage as a proper sanitary measure, it should recognize that water disposal involves a process of purification quite as much as does land or any of the other methods of sewage disposal.

Furthermore, legislative enactments, intending to regulate or to prohibit practices that may affect the purity of drinking-water, would be even more efficacious, more tangible, and more certainly productive of good to communities, if exacting greater care in the purification of water supplies immediately before distribution to consumers, than if solely directed to the prevention of the ingress of organic matter and its accompaniments into natural waters.

Failures and evil effects following the disposal of sewage into water are, in all probability, the result more of misapplied principles and temporizing methods than of lack of natural powers of self-purification in water.

Considering both land and water disposal of sewage in its broadest sense, there are manifestly advantages and disadvantages to each. Either method will fail to give good results, if the natural conditions under which purification may progress be not strictly observed—for instance, land disposal may result in a serious pollution of the ground-waters, an impure effluent into water-courses, and offensive odors upon and about a disposal area; and water disposal, in putrefactive changes of organic matter in water overcharged with sewage; and both methods may then admit infectiousness into water supplies. Moreover, the insoluble part of sewage may deposit in bodies of water or it may accumulate upon the surface or within the pores of the ground because of insufficient distribution; thus admitting, under favorable conditions, of putrefactive and objectionable changes. The clogging of the ground will seriously impair its filtering and purifying capacity.

A wide distribution of sewage, either through water or upon land, will prevent offence from deposits. Such a distribution can usually be more readily and economically attained in water than upon land; for, in the one case, the currents and general mobility of the water will generally and widely distribute the sewage without mechanical assistance, while in the other case the deposits must be frequently raked and eventually mechanically removed from the disposal area, or the land allowed a considerable time of rest, in order that natural disintegration of the insoluble matter of sewage may take place.

In the event of the removal of the insoluble portion of sewage becoming necessary before its application to land or discharge into water, chemical precipitation may be used to effect clarification. In a dual process of this character it is quite probable that the disposal of the effluent from the precipitation tanks may be less liable to subsequent pollution, and may become more quickly purified if applied to land, provided the land be in every respect suitable for intermittent filtration, than if thrown into water; for the chemicals remaining in the effluent have been known to promote rapid decomposition after discharge into water

In practice, chemical precipitation is largely confined to the removal of insoluble matter ; and, consequently, gives incomplete purification of sewage. It therefore is more properly the preliminary part of some dual process, the combined effects of which is complete purification.

The present approved practices of sewage disposal have now been discussed quite in detail, somewhat generally and comparatively analyzed, and the conditions and principles which are necessary to the attainment of satisfactory results in practical applications of these methods, have now been outlined. In this discussion and analysis no attempt has been made to bring out the constructive features, or to define the precise applications of any particular method of disposal. Whatever bearing the views and discussions as herein contained may have in specific instances in determining a proper mode of sewage disposal is wholly a question of local issue. To advocate any method of sewage disposal previous to a thorough knowledge of a locality is but to acknowledge a bias its favor or to affirm of it a general applicability.

Neither of these positions is a safe one to assume; for the most approved method of disposal will invariably hinge upon its natural adaptability to the conditions of the locality in question.

The author would sum up the discussion in a few general conclusions:

1. Any acceptable method of sewage disposal should aim to purify the sewage. Thus far, in practice, sewage purification has been attained only by natural processes. Water and land disposal of sewage involves natural processes of purification, and either method properly employed can afford practically complete purification.

2. The purification of sewage by water involves dilution, settlement, and bacterial oxidation of the organic impurity of sewage.

Crude sewage can usually be most expeditiously, economically, and effectually disposed of by water. All things considered, this method of disposal, when available, is in all probability the best that has yet been practised. Proper dilution and favorable temperature can prevent nuisances.

Sand filtration of polluted waters can remove any contained sewage impurity and infectious matter.

There appears no occasion for general legislative enactments looking to the prohibition of sewage disposal by water; but measures regulating the method and extent of sewage disposal by water may, in specific instances, be required.

3. Purification by land disposal involves both irrigation and intermittent filtration, neither of which methods is likely to be long employed to the exclusion of the other.

Crude sewage applied to any land at a rate remotely approximating filtering capacity will in all probability cause a clogging of the land and a consequent reduction of its filtering and purifying capacity. Land so clogged must receive long rest or must have the clogged earth removed. Land disposal of crude sewage may be successful if such sewage be given a very wide distribution over the land.

Because of the many and variable disadvantages which will attach to land disposal of sewage in various parts of the country, it may be considered as available only in the event of a lack of facilities for water disposal.

4. Chemical precipitation is but a semi-purifying process, practically restricted in its workings to the removal of the suspended matters of sewage. As a part of a dual process involving either water or land disposal, it is valuable as preventing either the clogging of the land or deposits of insoluble organic matter in bodies of water. The sludge can have little or no commercial value, chiefly because its presence, as a highly putrescible substance, causes an emergency which prevents any regulation of supply and demand, by which regulation only can any article either have a commercial value or become salable.

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