POTABLE WATER

AND METHODS OF

DETECTING IMPURITIES.

BY

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PREFACE.

The object of this volume is to present clearly and briefly the essential qualities of potable water, how it may be obtained and the significance of chemical, bacterial and microscopical tests of its quality, both in themselves and relatively. There is also some discussion of the value of pure water, the relations between water and disease, and typhoid fever records as an index of the purity or impurity of public water supplies.

The need for some such concise, non-technical review as is here attempted has often been impressed upon the author, and will be evident, on reflection, to all who have had occasion to give attention to the subject. There are to-day some 5,000 cities and villages in the United States and Canada which have a public water supply, while a hundred or more are added to the list each year. A large proportion of these supplies are lacking in one or more of the essentials of potable water, comparatively few being treated in any manner to make good their deficiencies. Many of the very worst supplies are delivered to our largest cities, but this condition has been rapidly changing of late. An earnest agitation for better water is now in progress throughout the country. It is daily increasing in strength and already includes hundreds if not thousands of seekers for information that will throw light on their specific local problems. Most of the books on water supply now available are technical in character and relate to the design and construction of water supply and purification plants, to the technique of water analysis, or are devoted principally to statistics showing the effect of the quality of water on the typhoid death-rates of cities. These books are most excellent, but many searchers for knowledge wish something less detailed and technical, at least to begin with. Engineers and many water-works superintendents must, of course, plunge deeply into the subject, but hosts of superintendents of smaller works, together with water commissioners, members of boards of public works, health boards and city councils, mayors, physicians and public-spirited citizens, both men and women, now find themselves for the first time confronted with these important problems of pure water supply and desire to learn something about them without the expense of time or money required by extensive treatises. It is for such people, and for students in technical and medical schools that this volume is more especially designed.

It may shock some people to have it suggested that physicians and members of boards of health are in need of elementary training in matters pertaining to pure water. But such is the case. Until within a few years neither our medical nor engineering schools gave any adequate instruction in sanitary matters, and it is to be feared that some of each class are still deficient in that respect.

The author does not expect that those who have paid close attention to all phases of water supply for years past, whether engineers or otherwise, will learn much from this volume. To these, and to all who wish to pursue the matter further, recourse may be had to the following books: Reports of the Massachusett's State Board of Health since 1899; Hill's "Public Water Supplies"; Hazen's "Filtration of Public Water Supplies"; Fuertes "Water Filtration Works"; Kirkwood's "Filtration of River Waters"; Mason's "Water Supply, Chemical and Sanitary," and his "Examination of Water"; Frankland's "Micro-Organisms in Water"; Rafter's "Microscopical Examination of Potable Water"; Whipples' "Microscopy of Drinking Water"; Fuertes' "Water and Public Health"; Fanning's "Water supply Engineering"; Turneaure and Russell's "Public Water Supplies"; Weston's "Report on Filtration Tests at Providence"; Gould's "Elements of Water Supply Engineering"; Fuller's "Water Purification at Louisville" and also his Report on the Cincinnati experiments; the Report of the Filtration Commission of Pittsburgh, by Hazen, Sedgwick and others; the "Journal of the New England Water-Works Association" and other technical societies; the files of the "Engineering News," "Engineering Record," and other engineering journals.

In conclusion, it should be said that this volume replaces one in this series with practically the same title, but otherwise entirely dissimilar, by Charles Watson Folkard and others, published about twenty-five years ago. The original volume consisted of a paper and discussions before the Institution of Civil Engineers. Nothing could better illustrate the progress of sanitation than a comparison of many of the ideas expressed in the earlier volume with the theory and practice of the present day. The present volume has been written without regard to the contents or methods of the earlier one, and is in every respect except name an entirely new book. The present edition of this volume has been revised throughout, partly rewritten, and some new matter has been added.

M. N. B.

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CONTENTS.

POTABLE WATER.

POTABLE water is water suitable for drinking, whether made so by nature or art. While less than one per cent. of the water supply of a city is used for drinking and culinary purposes it is the almost universal practice to attempt to have the other 99 per cent. potable water also. This is due partly to the great cost and inconvenience that would result from a dual supply and partly to the danger that if two supplies were available that one would be taken for drinking purposes which happened to be most convenient at the moment, regardless of its quality. Without pursuing this phase of the subject further, it may be assumed that under present conditions the whole water supply of a city or town must be potable.

The quantity of water which, generally speaking, may be considered as sufficient for a city supply is a daily average of 100 gallons per capita. To secure this amount of potable water is becoming more difficult year by year. This is due to a variety of reasons, chief of which are increasing urban populations and a standard of purity which is constantly rising. The increase in population makes the problem doubly hard, because it means a demand for water in advance of the rate of accession to the population, owing to a disproportional waste of water and a diminution in the quantities of pure water available. All these things join in making determinations of the potability of water much more essential and far more in demand than heretofore. In the case of existing supplies it becomes necessary to study them closely to determine whether they are approaching the danger limit, and what, if anything, can be done to avert the danger, either by diversion of pollution or some method of purification. When it is decided to go afield for new sources of supply these must be studied with great care. Where purification is attempted frequent and careful examinations of the water must be made to determine whether the best results are being attained at a minimum expense.

The foregoing considerations suggest the following outline of the contents of this volume:

I. What constitutes potable water.
II. How potable water may be secured.
III. How to detect impurities.
IV. Some notable laboratories.

To avoid possible misunderstanding, it may be said here that the aim of this little book is not to present a manual on any phase of water-works design or construction, or on the examination of water, if that were possible in so small a compass. What is desired is to indicate clearly the proper standards for potable water, how these may be realized, and how the results actually attained may be judged.

WHAT CONSTITUTES POTABLE WATER.

The most vital quality of potable water is freedom from those polluting substances which are the direct causes of disease. But disease germs give no physical evidence of their presence, until after more or less elaborate culture, while color, turbidity, taste and odor are readily appreciable and may be very annoying to the eye, tongue and nose. Hence, to the popular mind water is judged by its obvious physical characteristics first of all. On this account it is often hard to arouse the water consumer and taxpayer to the importance of avoiding the use of sewage-polluted water, when harmless odors or color would give rise to a storm of protest and an urgent demand for the expenditure of money for their removal. Classed in order of importance the essentials of potable water are as follows:

(1) Freedom from disease germs.

(2) Absence of substances that derange and undermine the human system.

(3) Freedom from suspended matter, or turbidity.

(4) Absence of color.

(5) Absence of odor and taste.

(6) Coolness.

The disease germs most to be feared in drinking water are typhoid fever and cholera, both of which are due to sewage pollution. There is so little cholera in America that it is generally dismissed from consideration after having been mentioned. This is quite permissible, since all that is said regarding the prevention of the spread of typhoid fever through water applies equally to cholera. Typhoid fever is so very prevalent here that it merits far more consideration than it receives. Undoubtedly it would be rapidly exterminated, or reduced to small proportions, if the domestic water supply of city and country alike were permanently freed from contamination by human excreta. There would still remain milk and other food as means of infection, but with pure water for cleansing dairy utensils and diluting milk this source of danger, second only to water, would be almost wholly cut off. Infection through food other than milk is probably very small, except where conveyed by flies from improperly exposed and disinfected privy vaults to kitchens, pantries or dining tables. The close relationship between water supplies and typhoid fever will be discussed in a subsequent portion of this book.

Infectious diseases other than typhoid fever and cholera, if ever conveyed by water to any marked extent, would also be subjected to reduction in like manner by freeing water supplies from the effect of sewage pollution. Aside from infectious diseases, the digestive tract is more or less subject to derangement through the use of water containing matter in suspension, whatever its origin. Organic matter in considerable amounts may cause diarrhoea or dysentery, especially if it is derived from sewage; and it is possible that diarrhoea may be conveyed from person to person by water. Generally speaking, any of the mineral salts found in water would be objectionable to the taste or smell before becoming strong enough to lead to harmful results, except possibly the carbonates and sulphates causing hardness. Changing suddenly from hard to soft or soft to hard water causes much annoyance, to say the least, to some people.

Lead poisoning may be mentioned here, although this comes, if at all, through the action of water of certain classes in its passage through lead pipes.

Turbidity, or suspended matter, is objectionable both because of its possible derangement of the human system, as mentioned above, and on account of the bad appearance it imparts to the water and utensils holding it. Depending upon the fineness of the grains of suspended particles, and upon their color, it may cause variations in the appearance of water ranging from light, milky cloudiness through the whole range of grays, reds, yellows, browns and even to almost inky blackness, in coal-mining regions.

Color may be due to turbidity, but as often used in analytical reports, it refers more to an actual stain than to mechanically suspended matter. Iron may give a very decided reddish color, but if this filters out readily it may be set down as due to iron in suspension. If the iron is so combined as to require chemical rather than, or combined with, mechanical action, for its removal, then it may be classed more as a stain. One of the most fruitful sources of color is peaty soil and another is vegetable matter, where water, for instance, comes from swamps, or overflowed meadows, resulting in what some Westerners delight in calling "vegetable tea." Color may also be due to the development of low forms of organic life in the water.

Odor may be caused by the gases of decomposition of either animal or vegetable matter; by the decay of inert matter, or by the life processes of some of the lower organisms. Like color, it is seldom directly harmful, but it may be very annoying, or even nauseating. Nothing will raise a greater storm of protest against a water supply than some of the odors due to the life or decay of algae and similar lower organisms.

Coolness is essential to the agreeableness rather than the healthfulness of water, although partly through custom it has come to be considered one of the prime essentials of drinking water. It is rarely the case that coolness can be allowed much or any weight in choosing between sources of water supply, except where comparatively limited quantities are to be provided. Generally speaking, underground sources yield water many degrees cooler than surface sources and other things being equal this might be an important factor in deciding between two sources. One seldom sees it mentioned in an engineer's report on supplies of any magnitude, but in setting forth the attractions of cities and towns much stress is often placed on the fact that cool artesian water is available. The effect of such a supply in reducing ice bills might be quite large, as a whole. In most cases, other factors than coolness would have a preponderating influence in selecting a water supply, especially since water may be so readily cooled by ice. This suggests the importance of pure ice supplies, so the expenditure of huge sums for securing pure water may not be nullified by polluting the latter with impure ice. In general it may be said that ice should be cut or manufactured only from potable water. Freezing is not a safeguard against disease germs, but there is a tendency for the organic impurities to be forced downward as the ice forms on natural sheets of water, so unless the water is shallow the ice formed on streams or lakes may be somewhat purer than the original water. Artificial ice has the impurities, if any, concentrated in the center of the cake. It is common to distill or filter (sometimes both) water used in making artificial ice. Every housekeeper and head of a family should look carefully into the source of the ice supply. It is safer, in any event, to place ice around rather than in contact with water or food which is to be cooled, as then there is much less chance of contamination. This may result in an actual saving of ice and have the further advantage, in the case of water, of not producing so low a temperature and thus so much possible harm from drinking ice water. It is obvious to any person who has watched the cutting or manufacture, storage, transportation and delivery of ice that even if naturally pure it may become infected with disease germs before it reaches the ice chest or water cooler. A little reflection along this and similar lines will afford possible explanations of some of the "mysterious dispensations of Providence," and the spontaneous origin of disease, regarding both of which, happily, we hear less now than a few years ago.

Before leaving the consideration of what constitutes potable water a few words may be said regarding its advantages, for certainly they are fully appreciated in but few cities or towns, although there are great contrasts in this respect and there has been much improvement of late. The existence of intimate relations between water and health is accepted almost universally by all intelligent people, but it is unfortunately true that sanitary, like moral, principles, are much more readily accepted as abstract truths than made a part of daily practice. Thousands and thousands of men and women in their prime, and bright and promising youths, are sacrificed yearly to typhoid fever caused by drinking sewage-polluted water. To every such death there are from five to ten cases of sickness and recovery from this disease, which generally runs a wearisomely long course. Besides the typhoid there are many other and minor instances of bowel troubles. Allowing only 25,000 deaths from water-borne typhoid annually in the United States, and only six cases to each death, there would be 150,000 cases. For every reported case of typhoid with sickness extending over some weeks, it is safe to assume two cases, or 300,000 in all, of unreported typhoid and of water-borne diarrhœa and dysentery of longer or shorter prevalence.* This is an enormous debit against impure water. But it is far from being all. Everything that diminishes the natural attractions of water for drinking and bathing purposes, like turbidity, color, bad tastes and odors, tends to lessen the sum total of healthfulness and vitality. Scores of cities might be named where the water delivered to

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* The deaths from typhoid fever reported by the U. S. Census of 1900, totaled 35,379; from diarrhoeal diseases 46,907.

consumers regularly, or at frequent intervals, is so muddy as to make the thought of bathing in it repulsive; it suggests anything but cleanliness. Water of some sort is simply indispensable. The difference between the value of pure and impure water supplies is well nigh, if not absolutely, inestimable.

Though outside the scope of this volume, it may properly be noted in passing that the qualities that make water potable also enhance its value for many industrial purposes, so there is added reason for insisting on having only pure water.

HOW POTABLE WATER MAY BE SECURED.

Having outlined the characteristics and value of potable water it is in order to inquire how it may be secured, or, being secured, how it may be preserved from threatened contamination.

The natural aim is to search out and appropriate some source of supply which yields water possessing the desirable qualities already described. If the search is vain then artificial means must be provided to make good nature's omissions or, more likely, man's commissions.

Water supplies may be divided broadly into two great classes, surface and underground. Surface supplies are drawn from streams, lakes, or artificial reservoirs, and underground water from wells or filter galleries. Barring the collection of atmospheric dust and bacteria in its downward passage, rainwater is as pure as it can be made by nature's great distillery. It is after striking the earth, for the most part, that it becomes contaminated. In running over or through the earth it takes up mineral salts and organic impurities, gathering most of the former when passing through, and most of the latter when passing over the earth. The upper part of the crust of the earth is a great filter, which removes nearly all the suspended matter and also removes, or else transforms, most of the organic matter taken up by the water as it passes over the earth's surface, provided the journey is long enough. Underground supplies, therefore, unless taken near the surface, or subjected to special and immediate sources of pollution, are generally freer from organic impurities and bacteria of all sorts than are surface supplies, while the latter are more liable to contain only small quantities of mineral salts. Deep wells, in some parts of the country, yield water so heavily charged with mineral matter or with gases as to be beyond all possibility of domestic use. Even the water from comparatively shallow wells may be quite hard. But surface supplies gathered where limestone outcrops largely may also be hard, and in the West and Southwest some surface supplies take up so much alkali from the soil as to be unfit for any purpose.

Water gathered from cultivated fields is liable to contain much organic matter, inert and active, and clay, silt or sand in addition. Water from woods, meadows or swamps may contain much vegetable organic matter, objectionable in itself, or furnishing food to low forms of life that give rise to unpleasant tastes and odors.

Last, but not least, sewage pollution must be mentioned as the most dangerous of all sources of contamination. Where considerable quantities of water are involved sewage affects surface supplies far more extensively than underground, but small supplies from shallow public or private wells may be infected by one or a few privy vaults or cesspools.

the great menaces of the water supply of country houses and of villages without public water supplies and sewerage systems.

In matters of water supply, above all things else, even the appearances of evil should be shunned; so the first principle of securing potable water is to avoid all supplies known or liable to be polluted and to choose those above suspicion. Where polluted water cannot be avoided every effort should be made to stop the pollution and if this is not sufficient, then the water must be purified.

In case a water-works plant is being established, or a new source of supply added, the first object should be to select water of the highest standard of purity. The qualities to be sought are so important that they may be mentioned again: Freedom from disease germs, substances that derange the human system, color, odor, taste and sediment. The first is of the most importance by far.

The ideal plan would be never to

choose a water supply into which sewage, however small the quantity, is discharged, and never to allow such discharges into any existing source. It is difficult to carry out this ideal in any case and the magnitude of the task increases with the size of the supply. We are, therefore, sometimes forced to consider whether some small or remote source of sewage pollution may not be tolerated in order to render an otherwise satisfactory supply available, especially if all others worthy of consideration are much more costly. If the pollution be small some means of preventing it may often be found; if it is both remote and small the danger is correspondingly lessened. But where shall the limit be placed? Both individuals and communities are loath to incur trouble or expense beyond a certain point in order to avoid remote chances of danger or death. Each case has to be, and should be, settled on its own merits. Regret it though we may, it sometimes becomes necessary to take some risks, lest the financial burden due to avoiding them be greater than can be borne. There is a limit by law, in some places, and by local public opinion everywhere, beyond which tax rates and bonded debts cannot pass. It is less of a burden on one's conscience and far safer for all concerned to urge that no sewage pollution should be tolerated than to name any small percentage of quantity in relation to the total amount of water or any distance at which the admission of sewage could be winked at.

Fortunately there is always some avenue of escape from death-dealing water. Either a natural supply may be found, pollution prevented by legal measures, purification adopted, or, as a last resort, a dual supply may be provided, pure water in very limited quantities being furnished for drinking and cooking.

The pollution of public water supplies is prohibited with more or less specificness by the laws of many, perhaps all, civilized states. But laws alone are of little account unless backed by force. The requisite force may be that of strong public opinion (in fact must be, primarily) or it may be provided by the police power of the state. Unfortunately, in most of our states, public opinion in these matters is not yet strong enough to prevent water pollution, or to secure the passage of the legislation essential to that end. However strong public opinion may be, there are also some who will never yield to it except when compelled by force, and when that must be exerted the proceedings should be laid down by legislative and judicial deliberations, rather than by excited mobs. We need, then, wise laws to protect the purity of our public water supplies (in fact of all public waters); administrative power to supervise their enforcement; and a capable bench to judge offenders and mete out punishment to them. The questions involved are often more than local or even state concerns; they are sometimes interstate and may be international in their scope

Thus far in this country we have not gone much if any beyond state control of the purity of water, and not far in that. The general government interferes at times with the dumping of garbage and other solid refuse in navigable streams or lakes, but this seems to be a safeguard against obstructions to navigation, rather than to health. The legislatures of Vermont, New Hampshire, Massachusetts, Connecticut, New York, New Jersey, Ohio and Minnesota have given their State Boards of Health more or less adequate supervision of the public water supplies of the several states named, or have taken other notable steps for the protection of municipal water supplies.

It should be a misdemeanor, *if not a crime*, to discharge any polluting substance, but more especially sewage or human excrement, into any water used for public supply. This should apply even at points remote from water-works intakes. Further, the only safe way is the plan now in force in Massachusetts, New

York and Ohio, and partly in New Jersey, of requiring all plans for sewerage and sewage disposal systems to be approved by the State Board of Health or a State Sewerage Commission. In Massachusetts and Ohio the plan includes water supplies as well, while in New York the State Board of health may, on application from the localities concerned, establish rules for the sanitary protection of public water supplies. Such supervision, to be most effective, should be carried out with the aid of a competent staff of engineers, chemists, bacteriologists and legal advisers, varied in size to meet the wants of each state.*

The prevention of water pollution is a broader question than the preservation of water supplies, although the latter is the object of greatest importance. Waters not used as sources of supply must be protected from such gross pollutions as

* This legislation generally applies to inland or non-tidal waters only. The protective statutes of New York and Pennsylvania have been broadened and strengthened of late. Pennsylvania, in 1904, passing its first really adequate legislation on the subject. For a review of the statutes and common law decisions of the several states, see E. B. Goodell, water supply and irrigation paper No. 152, U.S. Geological Survey (Washington, 1905).

will give rise to offensive odors, or deposits on the beds and banks, and an eye should always be had to the possible future use of a stream or lake as a public water supply. The minor aspects of the subject do not conflict with the main point, but rather safeguard it, for if all the waters of a state are under surveillance there is less chance of overlooking minor dangers to public water supplies.

Strange as it may seem, most of the cases of water pollution that have been fought with success in the courts have related to nuisances, or damages to riparian owners, rather than the pollution of public water supplies. This is due partly to the fact that it is far easier to prove injuries or nuisances due to bad odors or objectionable deposits than those involving the spread of specific diseases by means of water taken into the human system. When public opinion begins to realize more fully the relation between impure water and disease, then there will be a like awakening on the part of the bench. The courts are generally in advance of the general public in these matters, but with the present practices regarding expert testimony each side in a suit can generally marshal as many so-called authorities as the other. The judges feel that one theory is offset by another, and in the absence of definite and specific proof that a typhoid patient was brought to his bed and death through drinking sewage-polluted water they often decide in favor of the alleged polluter, whether the case be brought to recover damages for death or sickness, or to enjoin the discharge of sewage by one municipality above the water-works intakes of another. Where the offender has been a private person or corporation relief from pollution seems to have been granted more readily. Cities may hesitate to prosecute each other, and too often one community suffering from sewage pollution is inflicting like injuries, in greater or less degree, upon those further down the stream. There may be a slight excuse in some of these cases of failure to proceed against another community, but what shall be said of those cities and villages which pollute their own water supplies, literally consuming their own sewage? That there are such, and not a few, cannot be contradicted, as physical examinations of sewer outlets placed above and sometimes near water intakes too often show, as well as the typhoid death rates of these shameless and suicidal communities.

Before passing to a consideration of artificial means of removing dangerous and objectionable qualities from water supplies not too badly polluted a few lines are demanded regarding the relation between water waste and impure water.

Many a city and town is suffering the ravages of the typhoid scourge, or other ills, because it allows itself to be imposed upon by the two-fold plea of the prohibitive expense of a purification plant and the menaces to health and infractions of liberty which would result from a curtailment of the consumption, or rather waste. It was stated near the outset that an average daily supply of 100 gallons per capita is commonly allowed in estimating the quantity of water required by a city. This is generally far more than can be legitimately used, but is exceeded by 100 to 200 per cent. in a number of American cities suffering from impure supplies. Some waste must be expected, but such amounts as these figures indicate are criminal, especially when the water is dangerous. By cutting down the consumption and waste to legitimate figures enough money might be saved in many suffering cities to pay the whole cost of purification works in a few years, and to meet the operating expenses as well. Where the water is supplied and paid for by meter measurement not only is the waste greatly cut down, but those who either waste or use large quantities of water pay for it, everyone contributing his proportionate share toward the expense of the supply. If no meters are used and so-called flat or schedule rates prevail, the careless consumer pays exactly the same as the careful one, though using from two to twenty times the amount of water. This is not only gross injustice, but it often robs the water department of so much proper income as to greatly hamper its operations.

If it is imprudent and unjust to let an ordinary supply run to waste without hindrance or compensation, what shall be said when the water has been purified at great expense? Even if the present supply of water be ample and pure the conditions of the future may change the situation completely, owing to the encroachment of population on drainage areas, the increase of urban population and the even more rapid increase in per capita water consumption. It is therefore the duty of every community not only to do all it can to conserve the purity of its water supply, but to conserve the volume of supply as well, against the almost inevitable day when it will become insufficient or need purification.

It is evident that if all population were excluded from drainage areas there could be no sewage pollution. The attainment of this ideal condition is possible only when the municipality or private company owns or controls the whole drainage area, although there are numerous gathering grounds having and likely to continue to have only sparse populations. A number of English cities own all or large portions of the drainage areas from which their surface water supplies are gathered. Birmingham, Liverpool and Manchester being notable examples.

In this country such ownership to any marked extent is rare, but it has been adopted by several cities and one or more private companies of late. In former years the practice was quite unnecessary here, owing to the scanty populations in the areas from which water supplies were drawn, but it is becoming more and more urgent, as the rural districts are filled with the villages and the country homes of city workers. New York City has spent some millions in buying land and buildings bordering on its reservoirs and their feeders. Boston and some of the municipalities in that section have done and are doing the same thing, on a smaller and perhaps wiser plan. Besides this, Boston has contributed large proportions of the cost of sewage purification plants for several towns and cities, in order to remove the sewage from its drainage areas. Rochester, N. Y., for many years, maintained a pail system for the removal of excreta from cottages on the shores of Hemlock Lake. In 1895 the city secured legislative authority to acquire title to a strip of land 200 ft. wide, around the lake in order to make the protection more sure. Up to Dec. 1, 1905, the city had acquired 14.62 miles of lake frontage out of a total of 15.93 miles. All cottages and hotels on the land acquired had been removed on the date named, leaving only a half a dozen cottages on the shore. A number of American cities have begun extensive tree planting on land bought to protect their water supplies. Included in these are Boston, or more correctly the Metropolitan Water & Sewerage Board, which is responsible for the development of a water supply for Boston and some twenty other cities and towns.—Woonsocket, R. I., Hartford and Middletown, Conn. The private water company supplying New Haven, Conn., has also done some planting. (See "Forestry on Water-Works Drainage Areas." Engineering News, January 15, 1903).

Where no land has been secured for the purpose under discussion, and often where it has, much good may be accomplished by maintaining a sanitary patrol of the drainage area, warning offenders and prosecuting them when necessary.

It was once considered better sanitary engineering to secure, even at greater cost, a water supply above suspicion than to attempt purification. This is still a wise policy, within certain limits, but often it is impracticable. Moreover, there is a growing belief that before many years public sentiment and State legislation will demand that all surface water supplies must be purified in this country, as they must in Germany. Even a small amount of pollution may cause an epidemic of typhoid fever, but if the water is purified just before being delivered to consumers, almost perfect safety is secured. Moreover, when this plan is pursued less remote sources become available or the continued use of old ones is feasible. The saving thus effected in pipe lines and other extensive construction will often go far towards the cost of the purification works. It must be understood that no general rule can be laid down here, each requiring a solution in accordance with local conditions.

It is also true that the particular system of purification to be adopted will depend largely on local conditions. Chief among these are: The character of the water to be treated; the cost of land required for filter sites and the nearness or remoteness of suitable filtering material; the cost of labor; whether extra pumping is necessary for one system and not for another; and the cost of coal and of chemicals, in case the latter be required.

Where the problem to be solved is the removal of bacteria and organic matter due to sewage pollution the nearly universal practice is to filter the water. This may be done by means of large artificial beds of sand, 3 to 5 feet deep, at the rate of 2,000,000 to 3,000,000 gallons an acre daily, or by passing the water through tanks containing sand or other filtering material, at daily rates of 90,000,000 to 125,000,000 gallons an acre.

The first system is known as natural or

slow sand filtration, and the second as rapid or mechanical filtration. Some writers also use the terms English and American, respectively, but these convey nothing in themselves, except historically, and are somewhat misleading in that respect. They have the further disadvantage of lending themselves to sentiment, prejudice and commercialism, instead of a scientific nomenclature. In this volume slow sand filtration and mechanical filtration, or treatment, will be employed to designate the two systems. Mechanical treatment is in some respects the preferable term, since the process may involve coagulation and sedimentation, as well as filtration. Mechanical is especially appropriate in any case, since in this system mechanical means are used to wash the filtering material. In fact the whole process is mechanical, as compared with the natural processes utilized in slow sand filtration.

For many years after the extensive use

of slow sand filtration in England and on the continent, and its more limited adoption here, the character and scope of the process was unknown. This was due to the idea that a mass of sand, perfectly inert in itself, could effect no chemical changes* in the contents of water, and the consequent belief that the only action of a filter bed was that of a strainer. The contrary could not be known in the early days of filter beds, because of the inadequacy of the old methods of chemical analysis and the fact that the bacterial examination of water had not been dreamed of then. The development of modern methods for the determination of the oganic contents of water, together with Koch's wonderful discoveries in the bacterial field, changed the whole conception of filtration. The organic chem-

* Commparitively little attention, in these later days, is given to the chemical changes in the organic contents of water, these generally being too small to be of any moment in themselves. In sewage purification, however, great stress is laid upon the reduction of organic matter by means of bacterial action.

ical determinations showed that matters in solution were reduced and sometimes nearly disappeared in the passage of water through the filter beds. This, obviously, could not be due to mere straining and was finally credited to oxidation. The assumption was correct, but the method by which the oxidation was effected was still misunderstood. With the general acceptance of the germ theory of disease and the ascertainment of the dimensions and other characteristics of bacteria the light began to dawn, but some stumbling blocks remained. It was now known that the deleterious effects of impure water were seldom caused by any specific chemical or chemical compound, but by germs with as fixed laws of development as the higher plants in the vegetable kingdom, to which bacteria belong. But these germs were only minute fractions, in size, of the voids between the grains of filter beds, so how could they be strained out by filtration? Until bacteriology was sufficiently developed to make the count of bacteria an easy task it was strenuously maintained by many that while filtration would effect an almost perfect chemical purification, through the removal of organic matter, it offered little or no restraint to the passage of bacteria. As soon as this development was attained and applied to samples of water before and after filtration it was conclusively shown that somehow the bacteria disappeared.

About this time bacteriology was added to chemistry in agricultural research and it was found that manures and other organic matters are broken down and transformed into plant food through the agency of bacteria. It being learned that the process was one of changing unstable nitrogenous compounds into stable nitrates the bacteria in question were named nitrifying organisms. The discoveries of the agricultural bacteriologists were seized upon by the water bacteriologists to explain the manner in which oxidation is effected. It was seen that nitrifying organisms, in vast myriads, developed in the filter beds, seized upon the organic matter and aided in transforming it into nitrates.

There remained to be found an explanation of the disappearance of the bacteria themselves, only a small percentage of the original numbers of which appear in the filtrate, under proper conditions. We now know that after a filter has been in use for a certain time a thin layer of sticky matter forms over its surface and thin films of the same substance cover each minute particle of filtering material, especially in the upper layers. It is these layers and films that retain the bacteria. Here the organisms in the water, harmful or harmless, are retained, and here most of them perish, only a few inches from the surface. Those that penetrate deeper are liable to be caught in much the same manner, and in addition they suffer through lack of food, the organic matter on which they depend for sustenance having been changed to other forms, or held on and in the sand above.

With all these facts known slow sand filtration takes on a new and brighter aspect. What once was considered a mere straining process is now seen to be due to chemical and bacterial agencies as well. In fact, while there were still numerous doubters of the germ theory of disease the leaders in bacteriology were fast proving that the very disease germs themselves were the indirect prey of other and harmless bacteria, or at least were not able to hold their own against the latter. Environment is a great force here. The disease germs are truly in strange and unknown waters when they reach the sewers, or a stream or body of water. Their natural habitat is the human body and there is a rapidly growing amount of evidence to show that they do not flourish and multiply outside it, although they may live for some time.

The devlopment of mechanical filtration is also an interesting story. It began in the early days when slow sand filtration was believed to be only a straining process. It was fostered by the muddiness of many southern and western waters and by a demand for the removal of color and vegetable matter. To remove mud, or finely divided clay and silt in suspension, large settling basins had been provided. These were often insufficient in size, beside which, no practicable amount of settling would fully clarify the water. Filter beds might clear it for awhile, but muddy water clogged them quickly and frequent scrapings were very expensive. Chemicals were used to assist or hasten clarification in the settling basins, but the removal of the mud thus thrown down was also a costly matter. Finally, the use of chemicals was combined with filtration and sedimentation was abandoned for the time. The process then became about as follows (sulphate of alumina being taken as the representative chemical, as it is practically the only one in use for this purpose now.) On adding the sulphate of alumina, or alum, to the water that chemical changes to hydrate of alumina, which has the appearance of large, light flakes. These passing downwards or onwards through the water entangle the suspended matters. The combination is partly removed by sedimentation, and what remains is caught by the filtering material. The rate of filtration is so rapid and the precipitate so heavy that in a short time the filtering material becomes clogged. It is not only the upper layers, as in slow sand filtration, that are fouled. The great pressure and rapid rate carry the impurities well into the sand or other filtering material, so the whole mass needs cleansing. By placing the sand on a false bottom and having a system of piping arranged for reversing the direction of the water through the material, the impurities may be washed out, going through a waste pipe to the sewer or other place of deposit. As the sand is likely to become packed by the head of water it is common to provide a revolving rake, turned by steam or other available power, to loosen the filtering material and to aid in scouring it and in rinsing off the accumulated foul matter. Sometimes the rake runs only at the beginning of the wash and again it is kept in constant motion, depending somewhat upon the ideas of the inventor or proprietor of the filter and largely upon those of the operator; or instead of a rake, compressed air admitted from below is used to agitate the sand, this being the more recent practice.

As stated, this system of water purification came to the front when it was still the fashion to call filter beds mere strainers. It was easy to demonstrate physically that the new method would remove sediment and color more readily than slow sand filtration. Some knowledge of the desirability of removing bacteria now coming to the front, it was also easy to claim that these were removed in great numbers by the close-grained layer of hydrate of alumina and mud which forms on the sand in the filter tanks, and quite as easy to proclaim that no such feat could be accomplished by the filter beds. A lack of knowledge of the capabilities of ordinary filter beds and a lack of interest in them as well, since for a time the sanitarians scarcely spoke a good word for them in America, made it a light task for the agents of mechanical filter companies to introduce their wares and to cry down slow sand filtration whenever any one had the hardihood to mention or uphold it. If the new process had not had its merits it would not have been adopted by 50 to 100 cities before slow sand filtration began to come to its own in this country. But the mechanical filters did some remarkably good work and could be installed with great comparative quickness and at no very great expense. Besides these desirable qualities, many of the earlier mechanical filters were of the pressure type; that is, were closed tanks, receiving the water direct from the pumping mains and pass-come packed by the head of water it is common to provide a revolving rake, turned by steam or other available power, to loosen the filtering material and to aid in scouring it and in rinsing off the accumulated foul matter. Sometimes the rake runs only at the beginning of the wash and again it is kept in constant motion, depending somewhat upon the ideas of the inventor or proprietor of the filter and largely upon those of the operator; or instead of a rake, compressed air admitted from below is used to agitate the sand, this being the more recent practice.

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The alum bogie was never so serious a drawback as the legal contentions between rival filter companies over the alleged infringement of patents. In the eighties, when mechanical filtration was being developed and introduced, the progress of the art was greatly retarded by patent litigation. This mattered less then, for slow sand filtration was still with little or no intelligent support in this country. The contentions were closed by uniting the conflicting interests in one company. Unfortunately for mechanical filtration, the strife broke out afresh, between the consolidated company and independent ones, just when unity was most needed. In England, Germany and Massachusetts the results of important researches regarding the methods and efficiencies of slow sand filtration became widely known in the last decade of the nineteenth century. In 1893, an epoch in slow sand filtration in America was marked by the completion of the city plant at Lawrence, Mass. This was followed by others, and by the publication of a vast mass of detailed information regarding the exact work accomplished, both practically and experimentally, at many different points. While patent litigation over mechanical filtration was in progress, and municipalities were awaiting the results, slow sand filtration came so prominently to the front, with such definite and well-authenticated results, that a number of cities which shortly before would have contracted for mechanical filters, had not the litigation occurred, now either adopted slow sand filtration or concluded to await further developments in both fields.

At this point it became evident that mechanical filtration was gravely handicapped through lack of disinterested scientific data. The only information regarding its possibilities was put forward by those having filters or filter rights to sell, and this information was for the most part very meager. Especially was this true regarding the bacterial efficiency of mechanical filters. The devices had been put on the market to clarify water, rather than to render it innocuous.

The demand for more definite information led to the mechanical filter tests at

Providence, in 1893, by Mr. Edmund B. Weston, in which for the first time some extended and reliable data were obtained. But these investigations were on a small scale and were in some other respects unsatisfactory. They have since been followed by elaborate studies of unit plants on a regular working basis, with able forces of engineers, chemists and bacteriologists in charge. In 1898 and 1899 large volumes were published giving the results of such tests at Louisville, Ky., Pittsburg, Pa., and Cincinnati, O., respectively. The Louisville and Cincinnati tests were conducted with Mr. George W. Fuller as Chemist and Bacteriologist-in-charge. Mr. Allen Hazen was Chief Engineer of the Pittsburg tests. In the Louisville tests, mechanical and electrical treatment were considered. In the Pittsburg and Cincinnati investigations both mechanical and slow sand filtration were studied exhaustively, together with some other processes or modified processes which need not be discussed here. In all three cities the two-fold problem was presented of removing large amounts of finely divided suspended matter and bacteria in high numbers. The conditions were far different from those at either the Experiment Station of the Massachusetts State Board of Health, at Lawrence, or at the filter plant connected with the water-works of the same city. In both these cases the problem is chiefly the removal of bacteria from sewage polluted water, the suspended matters in the Merrimac River only reaching at intervals of perhaps two or three years figures frequently attained at Pittsburgh and more especially at Cincinnati and Louisville.

Since 1898, important investigations of water purification have been made at Washington and New Orleans, reports on each having been published in 1900 and 1903, respectively.

The outcome of all these investigations and of the general development of both processes in recent years is the knowledge that either slow sand or mechanical filtration may be employed with perfect safety for the bacterial purification of water, and that either of them, combined with sedimentation, will effect a satisfactory clarification. With very large amounts of finely divided suspended matter it may be more economical to employ mechanical than slow sand filtration. It should be said further that there is reason to believe the two systems so nicely balanced in efficiency, and perhaps cost, as to render it impossible to tell without investigation and careful estimates which is best suited to each local case. Where land and labor are dear and filter beds need to be covered to prevent freezing, there is much to be said in favor of mechanical filtration. Where the water contains large amounts of minute particles of clayey matter in suspension sedimentation is generally a necessity, whatever else may be done, and coagulation may be required also. If the filtering material is to require very frequent cleansings, as with very muddy, slow settling waters, the advantages of some mechanical process for doing the work are apparent.

Another and a great advantage of mechanical filtration is its power of removing color from the water.

As to the relative costs of the two processes there has been much contention in the past, and there is little to be gained in discussing the matter, except as applied to specific cases. It must be remembered that with mechanical filtration the saving in capital charges due to lower first cost and the saving in labor is largely offset by the charges for chemicals. The Louisville and other city reports are veritable mines of information on these two systems of treating water, as are the reports of the Massachusetts State Board of Health, beginning with 1890, on slow sand filtration.

Sedimentation alone will do much towards clarifying some waters, especially those containing rather bulky particles, or matter of high specific gravity. For this purpose settling reservoirs or basins, not differing materially from ordinary reservoirs, except in having less depth, are employed. These must be in duplicate or some other multiple of a single day's supply, so the water of one may be settling while that in another, previously filled, is being drawn upon.

Where iron must be removed, as is the case with some ground waters, a combination of aeration and filtration has proven successful in numerous instances. Both mechanical and slow sand filtration have been employed for this purpose, lime, as well as sulphate of alumina, sometimes being used in mechanical filters.

Bad tastes and odors may be guarded against by the removal or prevention of conditions favorable to the development of lower forms of organic life, to which tastes and odors are largely due. Principal among these are the stripping of reservoir sites of organic matter which might serve as food for the lower organisms, and the covering of reservoirs to exclude light, or light and air, without which some of the organisms in question cannot grow. Filtration may be employed to remove organisms causing offensive tastes and odors, and aeration to remove odors, or a combination of the two. Aeration may also be employed to remove objectionable gases due to other causes than the life processes of low forms of organisms.

A new means of combating tastes and odors, or the algae that produce them, was publicly announced in May, 1904, and was used with success in many water-works reservoirs in both 1904 and 1905. The method is simple and relatively inexpensive, merely involving the addition of small quantities of copper sulphate to the water infested with the odor or taste-producing algae. This agent kills the algae. The species of algae giving rise to the taste or odor should be determined with certainty in advance of treatment, since 1 part of the copper sulphate to 1,000,000 parts of water is required for some varieties and from that down to one part in from 5,000,000 to perhaps 20,000,000 for others. The copper sulphate is applied to the water by placing it in bags attached to the stern or sides of a boat and by rowing or otherwise propelling the boat back and forth across the water to be treated. By this means the copper is dissolved and at the same time distributed through the water. With proper quantities and application of the copper sulphate most of the algae are killed within from a few to 24 or 48 hours, according to the variety of the organism and other controlling conditions. Care should be taken to distribute the agent throughout the whole reservoir or pond, and particularly in its shallow and stagnant portions. Some kinds of fish are killed with comparatively small doses of the copper, making it necessary, in some instances, to know in advance the nature of the fish as well as the algal contents of the water.

Some health authorities are not yet convinced of the wisdom of using copper sulphate, and are awaiting the results of detailed studies to determine what becomes of the agent and also its probable effect upon human beings who drink treated water. The chief investigations along these lines are being made by the Massachusetts State Board of Health, which began its studies of copper sulphate in 1903, but up to the beginning of 1906 had not published its final conclusions.

Detailed accounts of (1) the laboratory investigations and the early field tests of copper sulphates as an algicide, and (2) reports on the extended practical use of the agent in 1904, may be found in Bulletins 64 and 76, Bureau of Plant Industry, U. S. Department of Agriculture (Washington, D. C., May 7, 1904, and April 3, 1905, respectively). These bulletins were prepared by Messrs. Geo. T. Moore and Karl F. Kellerman, of the department named, to whom, and particularly to Dr. Moore, credit is due for the introduction of the method into practical use. A valuable symposium on copper sulphate as an algicide, and as a possible protection against typhoid fever germs in public water supplies, and on the probable effects of copper salts on man, was published in the Journal of the New England Water-works Association for December, 1905 (Tremont Temple, Boston, Mass). A great variety of opinion, some quite contradictory, was brought out in this discussion. There seemed to be general but not unanimous agreement that copper sulphate may be safely and profitably used as an algicide, but that as a germicide it should be used with the utmost caution, if at all, and then chiefly as an emergency measure, rather than as a substitute for filtration or as obviating the necessity of a new water supply. A number of articles describing the applica-cation of copper sulphate to water supplies in different parts of the country have been published in the technical journals. A tabulation of the main facts relating to nearly thirty of these applications is appended to the symposium already mentioned.

Hardness may be reduced by some chemical process which will remove or transform the carbonates and sulphates which cause it. Lime or some other chemical, depending on the nature of the hardness, is used as a precipitant. This is followed by sedimentation, and generally by filtration as well. Municipal water softening plants have been in use many years abroad, but their introduction this side of the Atlantic is of recent date, and up to 1905 the chief if not the only city plants in use are those at Winnipeg, Manitoba, and Oberlin, Ohio.

HOW TO DETECT IMPURITIES.

After what has preceded it is more evident than before that some quick and reliable method of testing the qualities of both natural and treated waters is essential. Without it, sources of public water supplies could not be chosen with intelligence, nor their quality properly conserved, while it would be useless to attempt to purify water if there were no reliable means of comparing the product with the original. For convenience, natural waters will be considered first. Remembering the qualities which constitute potable water it is readily apparent that the analytical tests to be applied fall under these heads: Chemical and physical; bacterial; microscopical. To these may be added visual inspection of drainage areas and all foreign matter reaching the water, in order to detect pollution;

and an examination of the typhoid statistics of the community using the water in question, which serve as a wonderfully good index to sewage pollution. The mortality from diarrhoeal diseases may be studied with possible profit. No attempt will be made to present the technique of water examination, nor to go deeply into the interpretation of analyses. There are several recent and most excellent books that do this at length. Instead, the general scope of water analyses will be outlined, with a few of the most salient features of interpretation. Then some examples will be given to illustrate how fully and beautifully typhoid fever statistics indicate the relative merits of the water supplies of different cities and variations in the character of the supply of a single city.

The chief physical characteristics of water are temperature, turbidity, color, odor and taste. The methods employed to determine these being for the most part quite obvious only turbidity and color determinations will be outlined here. One of the most recent methods of securing uniform and comparable records of turbidity is to note at what depth below the surface of the water under examination some bright metal can be distinguished. A platinum wire attached to a stick or rod graduated to inches, is often employed. The reciprocal of the depth of submergence is recorded, instead of the actual depth, for convenience in comparison. Thus, if the wire can be seen 25 inches beneath the surface the turbidity is 0.04; if only 1 inch, it is 1.

Obviously the scale may be graduated so as to read reciprocals as well as or instead of actual depths, thus saving calculations.

A refinement on this method of determining turbidity involves a standard of comparison consisting of the degree of turbidity corresponding to the introduction into an absolutely clear water of a known quantity of silica of a certain size of grain. By dilution, or else by varying the quantity of silica, as wide a range of turbidities as may be necessary can be secured. Such a standard or standards having been provided, natural waters in long tubes may be matched against the standards, each in its own rated tube, and records of turbidity made. It is also possible to refer platinum wire readings to the silica standard, by properly graduating the wire scale. Or, as a still further refinement, a candle or an electric turbidimeter, similar to the gas photometer in general principle, may be substituted for the platinum wire method, still retaining the silica standard.

The color is determined by placing the water in an opaque tube, with glass at each end, and comparing it with similar tubes of standard solutions, graded by the decimal system. When a solution is found which matches the natural water its number is recorded.

In place of the standard solutions, colored disks properly rated may be used.

Further information on the determination of both turbidity and color, with references to some of the literature of the subject, may be found in Water Supply and Irrigation Paper No. 151, "Field Assay of Water," by Marshall O. Leighton, published by the U. S. Geological Survey (Washington, D. C., 1905). The pamphlet also contains descriptions of field tests for iron, chlorides, hardness, carbonates, sulphates and calcium. For iron the color disks are used to measure the iron color, or more properly redness, produced by adding known quantities of chemical reagent to the water. For sulphates the turbidimeter is used. For the other named constituents various chemical tablets of rated strength are employed. The pamphlet describes a field outfit, readily carried by hand or on horseback, for making all the determinations named. For the most part the field assay of water by means of tablets was in an experimental stage in 1905, but gave promise of good results wherever a large number of comparative results are more important than a high degree of accuracy, as is very often the case.

At this point emphasis may well be laid on the fact that practically the whole range of sanitary water analysis is a search for indexes of purity or impurity, rather than an attempt to find specific contaminating matter. Of course color, turbidity, taste and odor can be recognized directly by three of the senses, but these qualities in themselves are not necessarily harmful. The chemical determinations of organic contents of water are designed to aid in tracing the history of the sample, whether the organic matter is of vegetable or animal origin, and if from sewage, the nearness or remoteness, in point of time, of its addition to the water. Likewise the bacterial examinations do not reveal, unfortunately, the true character of the germs, but simply aid in pronouncing upon the probable origin of the organic matter, as will be set forth at more length later on. The microscopic examinations are generally sufficiently definite in the identification of the larger organisms, and since the advent of the copper sulphate treatment of water for the prevention of algal growths, the microscope is of far more direct practical use to the water analyst than ever before.

The chemical analyses of water are generally confined to determinations of organic matter, or substances associated with it, and hence indicating its presence. The common procedure is to test for albuminoid and free ammonia, nitrites and nitrates, as being themselves organic in origin; for oxygen consumed as indicating the extent to which the free oxygen of the water has been taken up by the organic matter in the water; and for chlorine, as an almost sure index of sewage pollution, when found in quantities above the normal.

The ammonias and nitrogen compounds not only tell the amount of organic matter present, but their relative amounts, combined with the oxygen consumed and chlorine, are a guide to the character of the organic matter and the nearness or remoteness of the pollution in point of time. This will be the more readily understood on remembering what has been said regarding the changes in the form of organic matter wrought by the nitrifying organisms in ordinary filter beds. Whatever the origin of the organic matter, the bacteria break it down so the carbon is separated from the nitrogenous matter, and the latter is successfully transformed from albuminoid to free ammonia, nitrites and nitrates. Hence, if the nitrogen present was mostly in the form of albuminoid ammonia, and the oxygen consumed was low, it would appear that the pollution was recent; otherwise the available oxygen would be low (or the required oxygen high) and the nitrogen in more advanced stages. High free ammonia or high nitrates simply mean that the nitrifying process has gone further, but is not yet complete, hence there is danger that many disease germs may still be present and able to work mischief. If the nitrates are high, and the ammonias and nitrites low, then nature has done its work and no more chemical changes need be expected, except those due to the taking up of the nitrates for the support of organic life.

The chlorine found in water comes from two general sources: (1) It is condensed from ocean or other watery vapors; or (2) it has its origin in the common salt universally used by civilized peoples to season their food. Obviously, then, if we know the amount of chlorine normally present in the natural waters of a locality any excess may be attributed to sewage pollution, unless some other and special or unusual explanation is found. The chlorine once admitted to water remains there in solution, practically unchanged in any way, except by dilution or concentration of the water itself. If, therefore, a water is high in organic matter, and normal in chlorine, the pollution may be attributed to vegetable origin; if both the organic matter and chlorine be high the water has probably been polluted by sewage.

The normal chlorines for New England and for New York State, as determined by State Boards of Health and others, have been compiled by Daniel D. Jackson and published as Water Supply and Irrigation Paper No. 144, U. S. Geological Survey (Washington, D. C., 1905). The results are presented in both tabular and map form: the tables showing the amounts of chlorine, in parts per million, found in the normal or unpolluted water of numerous localities, and the maps showing isochloral lines, or lines formed by connecting all the points having the same normal chlorine. These lines are, in general, parallel with the coast line and show chlorine ranging from 6.0 parts per 1,000,000 on the coast to 1.0 near Concord, N. H., Springfield, Mass., and Newburgh, N. Y., and to only 0.3 diagonally across Northern Maine and across New York State, approximately from Plattsburgh to Geneva and onwards, and 0.2 at Buffalo, N. Y.

In making analyses for the mineral contents of water the results are positive and definite instead of being mere indexes. Few surface waters have objectionable quantities of mineral matter, except where there are extensive outcroppings of limestone, or the soil is highly alkaline. Most of the ground waters rejected on account of mineral contents, except those distinctly classed as mineral, are high in carbonates and sulphates (hard) or in iron. Sometimes soft or peaty waters take up lead from service pipes of that material. Whatever the material sought may be the chemist determines it in the most direct manner, compares it with a fixed standard and approves or condemns the water accordingly.

Bacteria live upon organic matter and wherever the latter is present in large quantities the former are to be found.

All organic matter undergoing rapid transformation is sure to be teeming with bacteria. This is especially true of organic human wastes. Hence, water in which bacteria are abundant is generally looked upon with suspicion, particularly if included among them are intestinal bacteria, such as the B coli communis, which abounds in domestic sewage. As for learning whether specific disease germs are present or absent in a given water supply the attempt can lead to no results but delusion, until bacteriologists get far beyond their present knowledge. The reasons for these statements are as follows: The isolation and identification of the typhoid germ from among many species, which is the problem in the case of water, is a long and tedious task at best, even if it can be done with anything like absolute certainty. It therefore follows that negative results are no assurance that the typhoid germ is not actually in the water, so the declaration, "no typhoid bacilli were found," may lead to trusting in the safety of a most dangerous water supply. Morever, even if the typhoid germs could be found it would not be until days or weeks after this particular bacillus, or its predecessor, was deposited in the water, and consequently disease might have been spread broadcast meanwhile. Of course, repeated isolations of the germ, even weeks after the pollution occurred, would be the most convincing evidence that the water was wholly unsafe. The chief danger from a misconception of the function of bacterial water analysis lies in the fact that the bacteriologist is often consulted when an epidemic is at its height, and if he says he finds no typhoid bacilli in the suspected water, as it appears from the best men in the profession that he must (provided he is honest and not deluded himself), then a bad source of supply may be continued in use. When a typhoid epidemic is at its height, the infection must have arisen two or three weeks earlier, giving ample opportunity for the real cause of the trouble to disappear from the water.

We come back, then, to our starting point: The presence of large numbers of bacteria indicates the presence, also, of large quantities of organic matter. If this is of human origin it is most dangerous. Danger being indicated and appreciated, steps may be initiated that will determine the facts in the case. If the chemical analyses show much organic matter in the water, in a state of decomposition, with high chlorine, and if many bacteria are present, it is time that something were done to remove the conditions, unless a satisfactory explanation can be found, which is quite unlikely. If the water in question is actually being consumed a study of the typhoid statistics of the community in question may prove instructive, while in any case the drainage area should be rigidly inspected to see if the water is receiving human excrement from isolated houses, villages or cities. These last two points are discussed further on.

The microscopic examination of water, from a thoroughly practical standpoint, is just out of its infancy. The microscope may give some indication of the origin of inert organic matter suspended in water. It will unquestionably enable the trained water naturalist to name the different micro-organisms in the water. The effect of a few species of these, occurring in large quantities, the microscopist can predict with certainty, and he may know, for a given source of supply, what organism is most likely to appear at varying seasons of the year and under different conditions of the water. When micro-organisms appear in large numbers, giving offence to sight, smell or taste, the species may be determined by a microscopical examination, after which copper sulphate in amount proportioned to the specific organism may be applied to the water to stop the troublesome growth.

Equally applicable to the methods of water examination is the fact that single analyses are almost worse than useless, except possibly where water is high in mineral matter or is obviously polluted. A series of analyses, systematically planned and executed, is required, if an intelligent and safe opinion on a water supply is to be pronounced. It is also of the greatest importance that the analyst should know the origin and environment of the water he is examining, preferably by personal inspection. This is the more apparent, in the case of sanitary analyses, when it is remembered that the analyses merely serve as indices to aid in judging the character and antecedents of the water.

Little need be said to show that one of the most efficient and incontrovertible means of detecting impurities in water is a visible inspection of the water and all that is discharged into it. If the banks of the streams, ponds or reservoirs in which water is gathered or stored are lined with privy vaults, if cesspools are near by, and if sewers are adding the volume of their flow to that of the water supply, chemists, bacteriologists and microscopists hardly need be called in to determine that the water is impure. Wherever population cannot be excluded from a drainage area strict sanitary inspection should be maintained to see that no pollution is permitted. With good laws for the punishment of offenders, or intelligent judges to lay down the common law, sanitary inspectors can do much for the purity of water supplies.

A word should be said regarding the collection of samples. This should be done by the analyst, or a person acting under his instructions, or some one thoroughly conversant with the essentials of taking samples. First of all, the receptacles in which the samples are placed must be thoroughly clean and as soon as filled must be sealed to prevent the introduction of foreign matter. The water must be collected in such a manner as to be representative of the average water furnished. For bacterial examinations the cultures should be planted as nearly as possible on the spot, and if shipping of the samples before planting is necessary the samples should be packed in ice. Plain directions for collecting and shipping samples may be obtained from many of the State Boards of Health and from analysts to whom samples are to be sent.

The close relation between water supply and typhoid fever is now almost universally recognized. Observations show that cities with exceptionally pure water have low annual typhoid death rates and that the rates commonly increase with the pollution of the supply. Where the typhoid death rate is persistently more than from 15 to 20 per 100,000 living population the chances are that the water supply is not what it should be. Of course there may be other causes for high typhoid rates than polluted water, but many of these are likely to be transient rather than permanent in character, and to give rise to epidemics, instead of uniformly high rates. Where vital statistics are properly kept it is a simple matter to determine the typhoid death rate, and it should be computed frequently and regularly. To the shame of many states and cities no properly classified records of disease and death are kept.

The substitution of filtered for crude and sewage-polluted water at Lawrence, Mass., in 1893, resulted in a marked diminution of the typhoid death rate, and the same has since been true in many other cities. A notable demonstration of the relative effects of impure and pure water on the typhoid death rates has occurred at Newark and Jersey City during the past few years. As the author of this volume has worked up these cases with care for use elsewhere, and as they are very instructive, it seems proper to quote at some length from the article in question.*

Two remarkable instances of a decrease in typhoid fever following a change from a sewage-polluted to a pure water supply have recently occurred in Newark and Jersey City. Both of these cities were for many years dependent upon the Passaic River for their water supply. The pumping stations of the two cities were about a mile apart, and but a few miles below the cities of Paterson and Passaic, the sewage of which is discharged into the river. Other communities

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* The Effect of a Pure Water Supply on Typhoid Fever in Newark and Jersey City.—*Engineering News*, Sept. 30, 1897.

contributed more or less to the pollution of the stream.

On April 26, 1892, the city of Newark abandoned the Passaic River and began using water brought some 25 miles from the Pequannock River by means of works built by the East Jersey Water Co. This stream is one of the highland tributaries of the Passaic, having a sparse population in its drainage area. Immediately after making this change in its source of water supply there was a great drop in the number of deaths from typhoid fever in Newark, but Jersey City, which used the Passaic water for about four years longer, continued to have a high mortality from typhoid fever until it also changed to the Pequannock supply.

The accompanying table has been prepared to show in detail the effect of pure water on typhoid in these two cities. The table has been made to cover a period of 11 years or from June 30, 1886, to June 30, 1897, in order that it might contrast five years of impure water and five years of pure water in Newark, leaving the year 1891-2 to stand by itself.

Mortality from Typhoid Fever

In Newark and Jersey City Before and After Introducing a Pure Water Supply.

	Newark					Jersey City				
				Death rate.						
	Deaths								Deaths	
Year ending June 30,	Total.	Typhoid.	Population.	Total per 1,000	Typhoid per 100,000.	Typhoid per 100,000	Total per 1,000.	Population.	Typhoid.	Total.
1887..	3,734	84	164,300	23	51	55	25	146,900	81	3,686
1888..	4,133	76	169,200	24	45	75	26	151,300	114	3,980
1889..	4,253	131	174,200	24	75	85	26	155,700	132	4,065
1890..	4,948	194	179,300	28	108	99	27	160,400	159	4,258
1891..	4,420	134	184,500	24	72	101	26	165,400	167	4,386
1892..	5,641	153	190,000	30	81	72	27	170,500	123	4,633
1893..	4,900	63	195,600	25	32	66	26	175,700	116	4,531
1894..	4,760	43	201,200	24	21	53	24	181,100	96	4,320
1895..	4,643	43	206,900	22	21	93	24	186,600	174	4,497
1896..	4,628	61	212,600	22	29	82	23	192,300	158	4,407
1897..	4,496	44	219,100	20	20	19	19	198,200	38	3,735

From this table it appears that in Newark for the five years when the supply was from the polluted Passaic the average number of deaths from typhoid fever was 70 per 100,000 of population, and that for the five years after the change to Pequannock the typhoid mortality was only 25 per 100,000.

Jersey City continued to use the foul Passaic for over three years after Newark changed to the Pequannock, so that its record for three years before and after Newark changed can be compared with the Newark record for the same period. Doing this, we find that for the three years ending June 30, 1891, Newark lost 85 per 100,000 of its citizens from typhoid, and Jersey City 95. For the three years ending June 30, 1895, Newark lost but 25, while Jersey City lost 71 per 100,000. Doubtless the water supplied to Jersey City during the last three-year period was actually worse than that furnished previously, although the typhoid death rate per 100,000 was less. This may be accounted for by the fact that the people were better aware of their danger in the latter than in the earlier period, and, therefore, took more pains to avoid the use of the crude Passaic for drinking purposes, some boiling and others filtering it before using, while many bought mineral or spring water. Besides this, it has been suggested that in a community using polluted water year after year, many people became partially or wholly immune. Credit should also be given to increased skill on the part of doctors and nurses, and increased vigilance on the part of health authorities in controlling infectious diseases.

The Pequannock supply was introduced gradually in Jersey City, an increasing percentage of the total consumption being furnished month by month during 1896, until in October the Passaic was entirely abandoned. The typhoid fever diminished with the decrease in the use of the Passaic water, as is shown by the following figures:

Month.	Per cent. Passaic water used.	Deaths from typhoid fever.	Month.	Per cent. Passaic water used.	Deaths from typhoid fever.
January.....	72	28	July.........	20	3
February ...	60	30	August	24	3
March	57	16	September ..	30	3
April	42	9	October......	11	4
May	50	6	November ...	0	1
June.	20	7	December ...	0	5

These figures are all the more striking since typhoid fever is generally more prevalent in the latter part of the year than at any other time.

For the year ending June 30, 1897, Jersey City used no water from the Passaic River. Her typhoid death rate for that year fell to 19 per 100,000 population, against 20 in Newark. For the year ending June 30, 1895, the last full year shown in the record during which Passaic water was used, the typhoid death rate in Jersey City was 93 per 100,000. The relative number of total deaths from typhoid in each of the two years was 174 in 1894-5, and 38 in 1896-7, or a decrease of 136. Part of this decrease is doubtless due to other causes than improved water supply, both Newark and Jersey City showing a marked decrease in the last few years in their total mortality rate. Newark has been gradually improving in this particular ever since the Pequannock supply was introduced. As it has now been five years since that event and the typhoid mortality has kept at a pretty constant rate, with one exception, ever since, it is only fair to give other departments of the city some credit for the reduction of the typhoid mortality. This seems all the more reasonable, since in 1895-6 the typhoid jumped from 21, for the two previous years, to 29; while the total mortality rate fell one point. Moreover, Jersey City showed a decrease in its total death rate before the new water supply was introduced.

Too much stress should not be laid upon the minor variations in these figures, for it is a well-known fact that mortality returns in this country are at best quite imperfect, and all populations between census years have to be estimated. In the present case the geometrical rate of increase in population between national census years was used in computing the yearly populations. This method gives a result for the year 1895 about 9,000 below the State Census for Newark, and 4,000 above that for Jersey City, or about 4% less, and 3% greater, respectively. These differences have very slight effect upon the death rates for 1895, but, of course, the discrepancy increases as the years go by. The tendency of these discrepencies is to make a worse showing for Newark, and a better one for Jersey City than would otherwise be the case, but this is so slight as not to affect in the least the main lesson of the table, that pure water materially reduces the typhoid death rate of a city.

The returns for the year ending June 30, 1898, show 31 deaths from typhoid fever in Newark and 79 in Jersey City; also total deaths of 3,932 in Newark and 3,727 in Jersey City respectively. Newark, therefore, improved on all the previous years included in the table. Jersey City, for some reason, did not make nearly so good a showing as in the preceding year, but it did far better than for years before. In the winter of 1898-9, it is both interesting and instructive to note that Newark drew small amounts of water from the Passaic River during severe cold weather. A sudden rise in the amount of typhoid fever followed soon after, especially in those sections which received the largest proportionate amounts of water from the old source of supply.

The total number of deaths from typhoid fever in Newark, was 50 in 1902 and 61 in 1903, giving approximate rates per 100,000 population of 19 and 23, respectively. The corresponding figures for Jersey City were totals of 44 and 36, and rates of 20 and 16.

The examination of treated or purified water does not differ essentially from that of natural water. Practically the same methods are followed in each case, and the results are compared to ascertain the degree of purification effected. Where the aim is to reduce or remove turbidity, color, taste, odor, iron or hardness it is, of course, a simple matter to determine whether the desired end has been obtained. If organic pollution is involved then the chief concern is the reduction in the number of bacteria.

This raises the point: How is the bacterial purification to be judged? We have seen that bacterial counts, or numerical determinations, and not identifications of kinds, is all that is practicable.

What, then, is the permissible number of bacteria in potable water? The standards are at best quite arbitrary. The aim is to have as few bacteria as possible. In natural waters, not subject to sewage pollution, the maximum permissible number of bacteria has been placed by various authorities at from 100 to 500. Where the water is treated, both experiment and practice show that properly designed and operated filters, of either type, will remove an average of 97% to 99% of all the bacteria. Obviously, percentages here may not always form a proper standard, especially with water high in bacteria. For instance: In water having originally 1,000 bacteria per cu. cm. there would be only 30 left with a 97% removal, but water containing 30,000 bacteria per cu. cm. originally would still have 900 after 97% had disappeared. It is conceivable, also, that a water some times in great need of purification, at others might be quite satisfactory in its natural state, in which latter case insistence on removing any fixed percentage of the bacteria might be absurd. These considerations suggest a standard composed of both a percentage of removal and an absolute number limit, the actual figures in each case varying with local conditions. The greater the danger of sewage pollution the higher the bacterial standard should be.

The frequency of making analyses is also a matter depending largely upon local conditions. Even with nătural waters analyses might well be made at least once a month, regardless of the purity of the supply. Once a week would be better and in most cases would be a wise expenditure of money, since it would afford a ready means of detecting any deterioration in the quality of the water. The poorer the water the greater the need for close watchfulness and frequent analyses, in order that prompt warnings may be given the consumers to boil it or avoid its use temporarily.

Where the water is being treated, analyses or tests of some sort should be made very often, to judge accurately and continuously of the efficiency of the process. In addition, separate samples of the effluent from each section or unit of the plant should be examined, to see whether all parts of it are working properly. If the purification plant is a large one daily analyses may be advisable, and may help reduce the operating expenses. This would be the case more particularly where chemicals were being used, the analyses, or tests of some sort, indicating changes in the character of the water and the amount or kind of chemicals needed. The analyst may also be the general superintendent of the purification works, thus tending to reduce the expenses.

SOME NOTABLE AMERICAN WATER LABORATORIES.

In the early days of American water-works neither chemical, bacterial nor microscopical examinations of water, as now understood, were thought of, or possible. Determinations of the mineral contents of water were first made and subsequently chemical methods for estimating organic matter were developed. Until recently the microscope was used as a diversion, or in the pursuit of natural history, rather than as an aid in securing and maintaining pure water supplies. Practical results from bacterial examinations of water were secured, at least in considerable numbers, before much had been accomplished in the same field with the microscope. All the earlier work, in each field, was done in private laboratories, investigators being engaged by cities or water companies as special needs for their services made themselves felt.

About 1888 the Massachusetts State Board of Health was made responsible for the sanitary protection of all the inland waters of the State and established the Lawrence Experiment Station to study the purification of water and sewage. Thereupon the Board began to make water examinations, literally by the thousand, and has continued the work to the present time. In the laboratories of the Board at Lawrence and at Boston it is probably safe to say that more chemical, bacterial and microscopical examinations of water and sewage have been made since 1888 than elsewhere in the world.

Perhaps the next most notable city laboratory in this country, in point of time and amount and character of work, was the Chestnut Hill laboratory of the Boston water-works, taken over, after many years of operation, by the Metropolitan Water Board. Microscopical work, in particular, was carried on here to a great extent.

Following some years after the Boston example, the water department of Brooklyn, now a part of New York, established a very complete laboratory at the Mt. Prospect reservoir, where the three branches of research discussed in this volume have since been pursued.

The value of the experimental work in water purification at Louisville, Pittsburg and Cincinnati was dependent on the fully equipped and manned laboratories established especially for the purpose in each city.

A feature of the water purification plant built at Albany, N. Y., in 1898-9, is the provision of a laboratory building in the center of the works, a feature since adopted at many purification works.

A number of the State Boards of Health, besides Massachusetts, have chemical and bacteriological laboratories, either independent or connected with the laboratory of some institution or individual.

The first private water company to equip a complete laboratory for use in connection with its regular work, so far as the author knows, was the Spring Brook Water Supply Co. of Wilkes-Barre, Pa., which controls a number of separate companies and sources of supply. This laboratory was established early in 1899.

It is not to be expected that every water-works plant in the country will have a well equipped laboratory for making water analyses. Many village plants are too small for this and many do not greatly need it, at present. But as time goes on and the significance and value of various branches of public health work become better known the number of laboratories for investigations in hygienic and sanitary matters will rapidly increase. The time has already come when no town of 10,000 inhabitants can afford to be without the regular services of a chemist and bacteriologist, working in either a private or public laboratory. The food, especially milk, as well as the water supply of all villages, towns and cities should be subjected to frequent and regular examination, besides which bacterial cultures should be made in connection with diphtheria, tuberculosis and other diseases. In the smaller towns this work might be done by health inspectors, trained in some one of our technical schools, now growing so rapidly in numbers and excellence. For the larger places the whole time of one or more competent men are needed for water inspection and analysis alone.

There is another phase of municipal laboratory work. Several of the recent laboratories originally organized for water or sewage examinations are gradually coming into extensive use for tests of materials and construction and of supplies. There are cement, asphalt and pipe coatings, coal and oil and other material to be analyzed, as well as water and sewage, all with great possibilities of direct money saving. The two classes of work, sanitary and general, may be carried on side by side without interfering with each other. Often both lines may thus be made possible where the expense of either alone would seem quite out of the question.

The time has come when it is no longer excusable for either public or private corporations to go on blindly using or abusing the forces of nature and transgressing the laws of health. Engineering, chemistry and biology have been developed in a marvelous way during the past two decades. Their lessons are available to all who will heed them and should be neglected by none who have the economic and physical welfares of whole communities in their keeping. Pure water is one of the essentials of modern life and he that aids in providing it confers comfort and health upon all who enjoy it and deserves the thanks of men and the blessings of heaven.

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