VAN NOSTRAND SCIENCE SERIES.

No. 18. *Price 50 Cents.*

SEWERAGE

AND

SEWAGE

PURIFICATION

By M. N. BAKER, Ph. B., C. E.

Associate Editor, "Engineering News."

Joint Author "Sewage Disposal in the United States."

Author "Sewage Purification in America,"

"British Sewage Works."

Fifth Edition, Revised and Enlarged.

NEW YORK:

D. VAN NOSTRAND COMPANY,

25 Park Place.

1913

THE

VAN NOSTRAND

Allan.

No. 12. THEORY OF VOUSSOIR ARCHES. By Prof. Wm. Cain. Third edition, revised and enlarged.

No. 13. GASES MET WITH IN COAL MINES. By J. J. Atkinson. Third edition, revised and enlarged, to which is added The Action of Coal Dusts by Edward H. Williams, Jr.

No. 14. FRICTION OF AIR IN MINES. By J. J. Atkinson. Second American edition.

No. 15. SKEW ARCHES. By Prof. E. W. Hyde, C.E. Illustrated. Second edition.

No. 16. GRAPHIC METHOD FOR SOLVING Certain Questions in Arithmetic or Algebra. By Prof. G. L. Vose. Third edition.

***No. 17. WATER AND WATER-SUPPLY. By** Prof. W. H. Corfield, of the University College, London. Second American edition.

No. 18. SEWERAGE AND SEWAGE PURIFI-cation. By M. N. Baker, Associate Editor "Engineering News." Fourth edition, revised and enlarged.

No. 19. STRENGTH OF BEAMS UNDER Transverse Loads. By Prof. W. Allan, author of "Theory of Arches." Second edition, revised.

No. 20. BRIDGE AND TUNNEL CENTRES. By John B. McMaster, C.E. Second edition.

No. 21. SAFETY VALVES. By Richard H. Buel, C.E. Third edition.

No. 22. HIGH MASONRY DAMS. By E. Sher-man Gould, M. Am. Soc. C.E. Second edition.

No. 23. THE FATIGUE OF METALS UNDER Repeated Strains. With various Tables of Results and Experiments. From the German of Prof. Ludwig Spangenburg, with a Preface by S. H. Shreve, A.M.

No. 24. A PRACTICAL TREATISE ON THE Teeth of Wheels. By Prof. S. W. Robinson. Third edition, revised, with additions.

No. 25. THEORY AND CALCULATION OF Cantilever Bridges. By R. M. Wilcox.

No. 26. PRACTICAL TREATISE ON THE PROP-erties of Continuous Bridges. By Charles Bender, C.E.

No. 27. BOILER INCRUSTATION AND CORRO-sion. By F. J. Rowan. New edition. Revised and partly rewritten by F. E. Idell.

***No. 28. TRANSMISSION OF POWER BY WIRE** Ropes. By Albert W. Stahl, U.S.N. Fourth edition, revised.

No. 29. STEAM INJECTORS; THEIR THEORY and Use. Translated from the French by M. Leon Pochet.

No. 30. MAGNETISM OF IRON VESSELS AND Terrestrial Magnetism. By Prof. Fairman Rogers.

No. 31. THE SANITARY CONDITION OF CITY and Country Dwelling-houses. By George E. Waring, Jr. Third edition, revised.

No. 32. CABLE-MAKING FOR SUSPENSION Bridges. B. W. Hildenbrand, C.E.

No. 33. MECHANICS OF VENTILATION. By George W. Rafter, C.E. Second edition, revised.

No. 34. FOUNDATIONS. By Prof. Jules Gaudard, C.E. Translated from the French. Second edition.

No. 35. THE ANEROID BAROMETER; ITS Construction and Use. Compiled by George W. Plympton. Eleventh edition, revised and enlarged.

No. 36. MATTER AND MOTION. By J. Clerk Maxwell, M.A. Second American edition.

***No. 37. GEOGRAPHICAL SURVEYING; ITS** Uses, Methods, and Results. By Frank De Yeaux Carpenter, C.E.

No. 38. MAXIMUM STRESSES IN FRAMED Bridges. By Prof. William Cain, A.M., C.E. New and revised edition.

No. 39. A HANDBOOK OF THE ELECTRO-Magnetic Telegraph. By A. E. Loring. Fourth edition, revised.

***No. 40. TRANSMISSION OF POWER BY** Compressed Air. By Robert Zahner, M.E.

No. 41. STRENGTH OF MATERIALS. By William Kent, C.E., Assoc. Editor "Engineering News." Second edition.

No. 42. THEORY OF STEEL - CONCRETE Arches, and of Vaulted Structures. By Prof. Wm. Cain. Fifth edition, thoroughly revised.

No. 43. WAVE AND VORTEX MOTION. By Dr. Thomas Craig, of Johns Hopkins University.

No. 44. TURBINE WHEELS. By Prof. W. P. Trowbridge, Columbia College. Second edition. Revised.

No. 45. THERMODYNAMICS. By Prof. C. F. Hirshfeld. Second edition, revised and corrected.

No. 46. ICE-MAKING MACHINES. From the French of M. Le Doux. Revised by Prof. J. E. Denton, D. S. Jacobus, and A. Riesenberger. Sixth edition, revised.

SEWERAGE

AND

SEWAGE

PURIFICATION

By M. N. BAKER, Ph. B., C. E.
Associate Editor, "Engineering News."
Joint Author "Sewage Disposal in the United States."
Author "Sewage Purification in America,"
"British Sewage Works."

Fifth Edition, Revised and Enlarged.

NEW YORK:
D. VAN NOSTRAND COMPANY,
25 Park Place.
1913

PREFACE.

One of the earliest volumes in this series was "Sewerage and Sewage Utilization," by Professor W. H. Corfield, of the University of London. Appearing in 1875, when only a few score American cities had sewerage systems worthy the name, and when sewage purification was practically unknown in this country, the little book was and for many years continued to be of great service this side the water.

When, after twenty years, the publishers requested the author to revise the book, he found revision, or even re-writing, entirely out of the question, so ill-suited were its matter and method to modern American conditions.

There being a strong demand for a brief but comprehensive book on the subject, it was decided that an entirely new one should be written.

Professor Corfield entitled his discussion

"Sewerage and Sewage Utilization." The present author prefers to use "Purification," rather than "Utilization," in his title. In making this change he does not wish to detract from the importance or possibilities of utilization, but simply to put purification, or the sanitary problem, first, and utilization, or the commercial problem, second. In addition, utilization is only one of several processes of purification.

There are now in the United States some fifty cities and villages, many institutions, manufactories and houses, employing one or another system of sewage purification. The studies of the Massachusetts State Board of Health have given an impetus to intermittent filtration of late, but chemical precipitation is practiced in many places and broad irrigation is quite common, especially in the West, where "Water is King," and the sewage is used for plant drink rather than plant food.

It is hoped that this little book will be of use to some engineers, especially those whose practice has been in other lines of engineering, and to that vast and rapidly growing body of sewer commissioners and superintendents, boards of public works, boards of health, mayors and city councilmen, and public spirited citizen in general, all of whom are of late taking a growing and most promising interest in sanitary problems.

M. N. B.

104 Tribune Building,
New York, Dec. 31, 1895.

PREFACE TO THE SECOND EDITION.

In the nearly ten years that have elapsed since the appearance of the first edition of this little book, the newer and so-called bacterial processes of sewage treatment have been announced, passed through an experimental stage and come into extensive use. Meanwhile the author has improved many opportunities to visit American sewage purification works, old and new, and during 1904 spent several months abroad, chiefly in Great Britain, visiting sewage works and meeting a number of the men prominently connected with British progress in this field. As a consequence of the events named above, the section of this book which deals with the purification of sewage has been largely rewritten and somewhat extended. Few changes in the other section, on sewerage systems as contrasted with disposal works, have been deemed necessary.

M. N. B.

220 Broadway,
New York, May 5, 1905.

CONTENTS.

SEWERAGE AND SEWAGE PURIFICATION.

WHY A SEWERAGE SYSTEM IS NEEDED.

An abundant supply of pure water is one of the greatest advantages which any community can possess. This is so generally recognized that every American town with a population reaching into the thousands has, or is planning to obtain, a public water supply. Such a supply having been secured, distributed through the streets and houses, used and enjoyed, what disposition shall be made of it? Obviously its removal may be the very reverse of its introduction. As it was distributed through a network of conduits diminishing in size with their ramifications, so it may be collected again by similar conduits, increasing in size, as one after another they unite in a common outlet. But the outgoing volume is far different from the incoming. The influent was pure and limpid; the effluent has been fouled in performing the services demanded of it, and should it accumulate and remain at any point it would decompose and give rise to offensive odors. Moreover, in its various fields of usefulness, the once pure water may have taken up germs of disease which formerly habited the human body, causing sickness and perhaps death, and which might give rise to like dire results should they again secure access to man. What, then, shall be done with the fouled water that has been collected? In general, there are but two answers: Either it must (1) be turned into a body of water so large as to dilute it beyond all possibility of offence, and where it cannot endanger human life by polluting a public water supply, or (2) it must in some manner be purified.

This fouled water is called sewage; the conduits which collect it constitute the sewerage system; and the means adopted to get rid of the collected matter is termed sewage disposal. The terms sewerage and sewage, it may be noted here, are often confounded, even among engineers. The use of sewerage to indicate the matter carried by a sewer, is obsolete, so that one might about as properly write or speak of purifying water-works as of purifying sewerage.

To go a little further with definitions, it may be stated that conduits which carry water collected from street surfaces, during and after rains, or ground water collected from beneath the surface, or both, are called drains. Where one set of conduits removes sewage and another carries surface and ground water, it is said that the separate system of sewerage is in use, a term which may be applied where the drainage system has not yet been constructed, but only sanitary sewers, as they are often called, have been provided. Where one set of conduits conveys both sewage and drainage water, it is called the combined system of sewerage. Obviously, various modifications of those two systems are possible, both for whole cities and for limited areas within one municipality.

To make the distinction between sewers and drains more complete, it may be said that sewers carry water fouled with organic wastes from the human system, from various cleansing processes common to all households, and also manufacturing wastes; while drains convey rain or ground water only. The drainage, however, may contain much organic matter gathered by the rain in passing over roofs, yards and streets, or by the ground water as it percolates through polluted soil; but this matter, in most cases, is far less likely to give offense or menace health than that contained in sewage.

Before entering into a discussion of sewerage systems it will be well to consider briefly why they are needed, for the engineer and the sanitarian must for many years to come meet the objections to this class of improvements put forth by men either ignorant of the principles involved or, worse yet, of those whose first impulse is to strenuously resist any new demand upon the pnblic treasury, without regard to its character.

Public water supplies and sewerage systems naturally go hand in hand. Where neither exists water is generally drawn from wells, often in close proximity to privies and sink drains, and subject to gross pollution from them. Should there be a case of typhoid fever in a given house typhoid germs, which always exist in great numbers in the dejecta of the patient, might readily find their way into the well, and thus into the digestive system of other members of the family, of visitors, or of neighbors using the well. Thus the disease is spread from one member of a family to another and from family to family. Besides this danger, there is always the more remote one from the dreaded cholera, should it visit the country, and the ever present one of poor health and consequent greater susceptibility to all forms of disease.

A sanitary sewerage system cannot be installed until a public water supply has been provided. It is needed as soon as that is accomplished, for while the wells can then be abandoned the volume of waste water is greatly augmented by the water-works system. Its foulness is also greatly increased through the introduction of water closets. Without sewers and with a public water supply cesspools must be employed. With cesspools begins a continuous and far-reaching pollution of the soil, much more serious than that which commonly results from privies and the surface disposal of slops. The pores of the ground become clogged with organic waste; nature's beneficent process of oxidation is arrested; putrefaction sets in; and poisonous gases are generated. These gases may find their way through foundations into houses and also directly into the outer air, especially during sudden rises in the ground water level.

The cellars of houses on small lots may be made damp by leaching cesspools. Such wells as still remain in use are also liable to pollution from cesspools on neighboring premises. Water tight cesspools, while possible in theory and often demanded by health ordinances, are a luxury that only a few can afford, owing to the cost of frequent emptyings. Even in permeable soils the emptying of leaching cesspools as often as health and decency demand will generally cost more than the increase in taxes due to the construction and maintenance of a sewerage system.

A village or town without water-works and sewers is at great disadvantage as compared with communities having these conveniences and safeguards. Industries and population are not so quickly attracted to it; the health of the municipality is almost sure to be poorer and its death rate higher. These statements hold, only in lesser degree, where a public water supply but no sewerage system has been provided. The full benefits of water-works cannot be enjoyed until sewers are put in, because many people will make the absence of sewers an excuse for the non-use or limited use of the water supply.

Who can describe the trials and tribulations which beset health authorities in their efforts to secure the proper disposal of privy and cesspool matter? If there is little but privy matter to be removed the difficulties are not so great, because in this country such a condition seldom exists, except in small communities, where the houses are set in ample lots, with gardens, and with an abundance of farm land near by, so that the vault matter is in demand for fertilizing purposes. With denser populations and larger areas, the emptying of vaults is a more serious matter, requiring the greatest care to prevent nuisances, and often, if not generally, entailing expense upon the householder. Cesspools are unmitigated nuisances, and however well built or frequently emptied, the satisfactory disposal of their contents is practically impossible. The matter has comparatively little value as a fertilizer and dumping upon unoccupied land is met with increasing protests, even if the land is located in remote and sparsely settled towns.

The Value of a Sewerage System.

To express the value of a good sewerage system in lives or dollars saved is simply impossible. Other sanitary improvements precede, accompany and follow this, each adding to the healthfulness of the community. The decrease in the death rate for a term of years can be given, but no man can express in percentages the part played by each factor. We know that pure air, pure water, and a pure soil are essential to good health and long life. Among the greatest polluters of air and soil, and by all odds the greatest enemy to pure water, is the contaminating matter from privies, cesspools and improper systems of sewerage and sewage disposal. These are such truisms that to expand upon them in these days of progress seems almost absurd.

Only one illustration will be attempted. More than 35,000 deaths a year are caused by typhoid fever in the United States. Keep from the lips of our people all water containing germs from the excreta of typhoid patients, and milk diluted with such water, or contaminated with it through washing milk cans and bottles in it, and the disease would soon be practically wiped out. This can be effected only by providing every one with a pure water supply, which, with other much desired ends, would be greatly advanced by the provision of properly designed sewerage and sewage disposal systems for both town and country.*

GOOD ENGINEERING ADVICE ESSENTIAL.

Simple and convincing as the arguments for efficient sewerage systems seem, years of agitation are often necessary to awaken sufficient interest in the subject to secure their introduction. One cause of this is the failure to present to the people a well-considered scheme, capable of being understood in its broad outlines by the average citizen and in all but its most technical details by any live business or professional man. How rarely this is done until years have been spent in well nigh useless effort, money as well as time often being wasted

* For the salutary effect upon the general health of individuals, and especially of women, conferred by the abolition of outside privies, more or less exposed to the public view, cold in winter, insufferably hot and odorous in summer, impossible of access without getting wet during rains or snows, see Waring's "How to Drain a House," Second Edition. This book discusses other benefits to health and otherwise, conferred by a proper system of disposal for household wastes of the kind under discussion here.

in this way. Good engineering advice is needed from the very start in this or any similar enterprise. Otherwise a chaotic mass of opinions as to what should be done speedily develops, factions spring up and even political parties take sides on the questions involved.

Preliminary Reports and Plans.

Such preliminary studies as are required need not be very expensive, but they are essential to a proper understanding of the subject. Among the data which should be determined as early as possible are: (1) The area to be served, with its topography and the general character of the soil. (2) Whether the separate or combined system of sewerage, or a compromise between these two, is to be adopted. (3) Whether subsoil drainage shall be attempted. (4) The best of the available means of final disposal of the sewage, often the most difficult of the problems involved where purification is necessary. (5) Population, water consumption and volume of sewage for which provision must be made, together with rainfall data, if surface drainage is to be installed. (6) Extent and cost of the proposed system. (7) Method of meeting the cost of the sewerage system. (8) The needs for sewerage peculiar to the locality, with a study of the health and mortality of the town.

These are the main points involved in sewering and draining a town. It may serve either as a mere outline, or the details suggested by the various heads may be so worked out as to form a complete design for the system.

There is nothing like public confidence, and the quickest way to unsettle a community and to delay the introduction of public improvements, is to lay before the people a number of conflicting plans. A well-considered preliminary study is likely to at once commend itself to citizens and taxpayers, and if months or even years go by without further action it continues to be a rock upon which to build in the future. Succeeding engineers can but commend what has been so well put in the past, if they be possessed of sense and ability, and the popular conception of what should be done is strengthened with each endorsement of previous recommendations.

The above being true, great care should be taken on the part of local authorities to select the right man for the preliminary studies, and the fortunate engineer should exercise even greater care in fulfilling the trust confided in him. The same holds good regarding final plans and actual construction.

Generally speaking, the smaller the community or the amount of money available, the greater the need for the best obtainable advice, although of course the less intricate the problem the cheaper its solution, even by the most talented expert. It is only a false economy that dispenses with engineering services, or employs the cheapest, because money is to be had only in small quantities. Experience is an expensive teacher, and the community that realizes this at the start will pay the engineer and secure the benefit of his training in the school of well-directed experience, instead of taking a more expensive course of its own in the school of headstrong, blundering, haphazard experience, which so many municipalities have entered.

Let us now suppose that a village, town, or city has so far decided in favor of a sewerage system as to be ready to have preliminary studies made. We will also suppose that it has decided to have these studies of a comprehensive character. The authorities hesitate somewhat between employing a local engineer of good general standing in his profession, and with some experience in sewerage construction, and an engineer of national reputation in this line of work. Wishing the best they half decide to engage the latter, but inquiry develops the fact that his charges are high, although none too high considering his experience and knowledge, that he must be paid for time spent in travelling, and that a comparatively large amount of ordinary surveying and simple compilation of facts and figures must be made, requiring a number of days from a principal and assistants. Both the local man and the expert are finally engaged, the latter to act principally in an advisory capacity throughout the study.

Referring to the above outline for the preliminary study, it will be seen that the local engineer will make the surveys, collect the information regarding population, water consumption and rainfall and other merely local data upon which the design for a sewerage system will depend. This he will submit to the expert for use in preparing the report of the latter. It is not necessary to separate any further the work of the two engineers. The evolution of the report and recommendations may therefore be considered as the work of one engineer from start to finish. Indeed it is likely to be so to a very large extent in practice, the division of labor generally being carried far to one extreme or the other: That is, either the expert is called in to amend and approve the results of complete studies by an engineer with less experience than himself, or he employs his own assistants, local engineers or otherwise, to do the bulk of the routine work involved.

The various parts of the study in their order may now be taken up, as follows:

(1) *The area to be served, with its topography and the general character of the soil.*

A contour map of the whole municipality, showing the location of the several streets, streams, ponds, or lakes and contour lines for say each 5 ft. of change in elevation is essential to the best results and must be provided sooner or later if a sewerage system is to be carried out on intelligent lines. Such a map will be of service for other purposes and would be a good investment for any municipality.

The general character of the soil can usually be ascertained without much difficulty by more or less casual observation, and by inquiring among residents, builders and others who have dug wells and cellars, or observed the same while being dug. The kind of soil is important as affecting the cost of trenching, and its natural wetness or dryness, together with the ground water level, will be a further indication of the difficulties likely to be met in construction, and of the necessity or desirability of providing underdrains for removing ground water or lowering its level, which is further considered below.

(2) *Whether the separate or combined system of sewerage, or a compromise between these two, is to be adopted.*

Obviously, these points depend almost wholly upon local conditions, including financial as well as natural factors. The size and cost of combined sewers is truly enormous as compared with those on the separate plan, since the surface drainage in times of heavy rainfall is many times as great as the flow of sanitary sewage.

In the older towns and cities it is sometimes the case that drains designed to remove only surface water were constructed long ago, before modern plumbing methods were introduced. Such drains were loosely built, may have been poor in grade from the start and were never designed to receive sewage. To-day, however, they are serving as sewers and giving much trouble and offense through stoppages and stagnation. Besides this, they are polluting the soil by means of numerous leaks. In designing a comprehensive sewerage system for such a city, it sometimes happens that these old drains can be relegated to their original purposes and sanitary sewers introduced to care for house wastes alone.

Where a town or city is entirely or practically without either sewers or drains, it often happens that it may consider itself fortunate if it can put in sanitary sewers on the strictly separate plan, leaving surface drainage for future generations, it may be. Here financial limitations govern, and this has been the experience of many American municipalities now possessed of first-class sanitary sewers.

Many a town is so situated that street gutters and natural water courses alone make ample provision for surface drainage. Again, the street gutters may be insufficient, through various causes, and storm drains thus be necessary, but there may be numerous natural outlets for these at frequent intervals, thus requiring only short lines and thus comparatively small storm drains. At the same time the only suitable outlet for sewage may be at a point remote from the city, thus necessitating a long, large and costly outlet sewer, if the combined system were to be employed, as against a comparatively small and inexpensive outlet for sewage alone.

But strongest of all is the case for the separate system when the sewage must be purified. It is simply out of the question for any city to build works large enough to treat the full flow of a combined system at times of maximum rainfall. Some of the sewage must pass away entirely untreated, or very inadequately purified. Generally speaking, each added drop of water is so much more burden, for while it is true that the sewage is thereby diluted, it is also true that the capacity of the works is taxed so much the more.

If crops are being raised, or even simple intermittent filtration is in vogue, periods of heavy rainfall are just the times when a smaller rather than a larger volume of sewage is desired, while at chemical precipitation works heavy increases in the sewage flow are always unwelcome. The volume to be treated is one of the greatest factors in sewage purification, and the original size of a plant, and largely its cost, vary directly with the volume, while cost of operation is far more largely dependent upon volume than strength of sewage. The essential point is, that the combined system means great extremes and sudden fluctuations of flow, and whatever the character of the industry such conditions are consistent neither with economy nor the best results.

Sometimes more or less limited areas of a town may require the combined system through lack of facilities for near-by disposal of surface water, and again roof water alone may need to be taken into the sewers. As stated above, local conditions and relative costs are the governing factors in deciding between the separate and combined systems.

An old fallacy concerning the combined system may be mentioned, although it has now well nigh disappeared: It is that the storm water will flush the sewers. Regarding this it must be remembered that the sewage flow is continuous and likewise the dangers of and from stoppages, while rainfalls are uncertain in frequency and amount. As a matter of fact special pains are now taken by the best engineers to give combined sewers such a section that the dry weather flow will be in a small channel as much as possible like that which might be employed for sanitary sewers.*

(3) *Whether subsoil drainage shall be attempted.*

As for providing underdrains for removing ground water, this will also in most cases depend upon local conditions. It is always an advantage to lower the ground water level in places where it is high enough to render the ground wet at or near the surface through a large part of the year. As sewers are generally placed below the level of cellar bottoms and underdrains are most commonly put below or at least not higher than the sewers, it follows that when of ample size underdrains will lower the

* More extended discussions of the combined and separate systems may be found in Waring's "Sewerage and Land Drainage," Staley & Pierson's "Separate System of Sewerage," and the many reports of engineers on proposed sewerage systems.

ground water level to a considerable depth below the surface and render house foundations practically dry. It may be necessary to supplement the street underdrains by branches running to the houses, and even extending through large lots.

The advantage of rendering dry the soil beneath and around habitations need not be enlarged upon here, as it is so generally well known. But it may not be known to all that underdrains are often such great aids to good sewer construction as to warrant their introduction for the benefits caused during construction alone. This is the case where the trenches are so wet as to render the making and setting of cement joints difficult. By putting in underdrains in advance of the sewer proper the trench may be kept dry and the work greatly facilitated, even where temporary pumps must be provided to remove the water collected.

Where it is desirable for any reason to keep down the sewage flow to the lowest possible point, underdrains are also of value without regard to sanitary conditions. This may be the case where the sewage is to be purified, or simply to be pumped, or where several municipalities use a joint outlet sewer, each contributing towards the maintenance of the outlet in proportion to the amount of sewage from its individual system. The latter conditions are found in a joint outlet in New Jersey, where Orange, Bloomfield and Montclair use the same trunk sewer to the Passaic River, and have as the only basis of dividing the cost of maintenance the amount of sewage contributed by each.

Of course the aim in good sewer work is to reduce the infiltration of ground water to a minimum, but all engineers and contractors know that in very wet soils tight joints can be made only with difficulty and practically never with absolute certainty. The volume of flow in the outlet of the sanitary sewers at East Orange, N. J., was at one time fully half ground water, according to careful estimates, and that was after the sewerage system was well established.

It must be remembered that with the

2-ft. lengths of vitrified sewer pipe now almost universally used, there are 2,640 joints to the mile. These joints are made of cement, and are not for a moment comparable with the joints of molten lead, with their subsequent heavy calking, used in water main construction.

In view of the above it is evident that underdrains should be used where they may be expected to benefit the health of a community by lowering the ground water level; where they will be sufficient aids to sewer construction to warrant their introduction for this purpose, to which is also to be added their permanent benefit; and finally, where it is desirable to employ them to prevent an increase through infiltration of the volume carried by the sewage, in which case the benefit to health will also accrue.

(4) *The best of the available means for the final disposal of the sewage.*

Until recently this part of the problem, at least in America, meant only into which of the near-by streams or lakes or at what point in tide water could the crude sewage be discharged at the least cost and with the minimum of offence. Too often the matter of offence was given only scant consideration, and sometimes none at all. Unfortunately many cities are to-day facing the problem in the same manner, but the advance of modern sanitation is rendering this more and more imposible.

The cardinal principle in the ultimate disposal of sewage is that no public water supply should be endangered thereby. Strange to say, this must be interpreted as meaning that no city should endanger the water supply of either itself or its neighbors. This is almost inconceivable, for while one can imagine a city mean or ignorant enough to endanger the lives of the citizens of an adjoining community, it seems incredible that any municipality should be sufficiently reckless to poison its water supply with its own excreta. But both conditions exist and must be combated. This deplorable state of affairs may be explained in part by the general ignorance of sanitary matters which has prevailed until of late, and in fact is seen still to exist when one compares what is with what should be. It does seem, though, that common sense and common decency combined ought to be sufficient to prevent a city from drinking its own sewage or forcing it down the throats of others.

Coming back to the cardinal principle expressed above, it may be asked "what constitutes the endangering of a public water supply?" No very definite answer can be given at present, owing to our lack of knowledge regarding the exact length of time which disease germs from the human system will live in water. The Massachusetts legislature some time ago said that no excreta should be discharged into a stream within 20 miles of any point where it is used for a public water supply, but in the matter of new water and sewerage construction it has practically placed the subject in the hands of its State Board of Health. There are no data to-day which will warrant an engineer in saying that disease germs may not be conveyed more than 20 miles by the waters of a stream and afterwards cause sickness and perhaps death. The engineer and sanitarian will consider the distance which must be traversed by the sewage and the dilution which it would receive before reaching a public water supply, together with the minimum length of time which would elapse before a disease germ could pass from one human system to another, a most important point. Unless distance, dilution, and time are great, sewage should be purified or carried elsewhere for disposal.

Of course there may be cases where sewage disposal seems to claim preference to water supply, in the use of a stream. Each of these must be adjusted on its own merits. The willful pollution of public water supplies, even if it seems remote, should no longer be tolerated, and where new sewerage systems are being built, it is unnecessary that it should be.

Given a body of water, not used, nor likely to be employed for a public water supply, the case is far different. Knowing the amount of water and the probable quantity and character of the sewage, it is generally easy to determine whether all the crude sewage of the city can safely be discharged into the water in question. Averages are of no use here. The water available during a hot dry summer, when the stream, pond or lake is at its lowest, and banks and beds are exposed to the sun, is what must be considered.

Partial purification may be sufficient through a few months or all of the year for some cities, and works have been carried out on that basis. But most plants in this country have been built under conditions that demand continuous operation at their utmost efficiency.

Where sewage is discharged into large bodies of water, either lakes or the ocean, it is generally necessary to make a careful study of the prevailing currents in order to determine the most available point or points of discharge in order to prevent the sewage becoming stagnant in bays or the washing ashore of its lighter portions. Such studies are commonly made by floats, as direction of current is generally the factor of prime importance.

When it is decided that purification must be employed, it becomes necessary to select the method best suited to local needs and conditions. This matter can better be discussed after the subject of purification has been taken up in detail, further on, and so will be dropped for the present.

In concluding this phase of the subject, or postponing its further consideration, it may be said that until new advances have been made in the recovery of fertilizing matter from sewage, no compunction need be felt in discharging such into any body of water which can receive it without harm. Where such water is available it is often a mere question of the relative cost of an outfall to it and a shorter outfall with purification works to a nearer point of discharge where purification is necessary. Of course treatment of the sewage is sometimes the only course which has a shadow of practicability. Again all consideration of such a procedure is often rendered unnecessary by an especially available point for the discharge of unpurified sewage. Where there is uncertainty it is best to keep on the safe side and provide purification at the start. Uncertainty to-day in these matters means certainty in favor of purification to-morrow, so fast are we advancing in sanitation and so rapid is the increase of population and also of the pollution of our streams.

(5) *Population, water consumption, and volume of sewage for which provision should be made, together with rainfall data if surface drainage is to be installed.*

The basis for population studies will generally be the United States census for a number of decades past, with figures for as many intermediate years as possible filled in from State and local numerations. From these figures percentages of growth for decades or shorter intervals may be computed and population curves plotted, and from one or both of these, coupled with present local conditions and future prospects, the population for the next 30 to 50 years may be forecast by decades or half decades. In small and rapidly growing communities it must be remembered that the percentage of increase is generally less as the population becomes greater.

It is desirable to design a sewerage system large enough to serve for a number of years to come, say 30, though parts of the work need not be made so large, as pumping or purification works where either or both of these are necessary.

It is rarely the case that the whole population of smaller communities is connected with the sewers until years have elapsed after the construction of a system. This is due to lack of sewers on some streets and to that strange perversity of human nature which leads many people to put off the making of sewer connections as long as possible, notwithstanding the fact that the soil of their premises is daily becoming more and more polluted with excrementitious matter, and that the yearly expense of properly cleaning privies and cesspools is greater than the interest on the investment necessary for making sewer connections. In some communities allowances for these delays may be made in designing pumping or purification works, but the pipe system should be large enough at the start to serve each street and district for an indefinitely long period. The advantages of the use of city sewers are so great that all property is bound to be connected with them sooner or later, leased property without these conveniences soon dropping in market value. In view of these facts the population figures are sometimes based on an estimatad number of people per acre, or per lineal foot of sewer, more especially where a separate system of sanitary sewers is being constructed. Safe figures of the latter class cannot be laid down for general application, but must be decided on after a careful study of the community in question, the character of its residence property and general population. Often it is necessary to divide a city into districts for its population and rate of flow studies. Thus the residence sections occupied by the wealthiest classes will be comprised of a comparatively small population per acre, due to the large size of the lots. The population will grow more dense in the passage through the sections occupied by the less wealthy, the well-to-do and finally the tenement sections. The portions of a city devoted to manufacturing will in some cities contribute sewage and manufacturing wastes in pretty close proportion to the number of employees, while in others, or in different lines of industry, the sewage yield will vary more especially with the character of the goods being produced.

The total water consumption is of course mainly dependent upon the population, and these two factors together enter largely into the amount of sewage requiring removal and disposal. No fixed rule can be laid down for water consumption, except that in general it is on the increase in all American cities, and in many places has reached immense and sometimes alarming proportions. It may be kept down by proper inspection and the use of meters for the prevention of waste, as it is absolute waste and not beneficial use which is responsible for high water consumption.

The instances are rare where it is safe to allow for less than 60 gallons per capita per day as the average water consumption of a town, if most of the people patronize the public water supply. If a general rule were to be laid down 100 gallons would be a safer figure. Obviously not all the water which passes through a water-works system reaches the sewers. In summer much of it is employed for lawn and street sprinkling and similar purposes, very little of which reaches the sewers even where the combined system is in use, and practically none where a separate system of sanitary sewers is employed. But while all this tends to diminish the sewage yield the infiltration of ground water, already discussed, increases it, and average daily figures have been discussed above, while works must be built on the basis of maximum daily, or even hourly, yields. Altogether, then, 100 gallons per capita will be none too large except in particular cases or possibly for the immediate present, where a portion of the works can be built for future enlargement.*

The total daily flow of sewage is not distributed evenly through the 24 hours. The actual percentages at different hours of the day vary widely, according to the nature and occupations of the contributory populations. In most towns there should be scarcely any sewage, if the sewers are tight enough to prevent infiltration, between say 10 P. M. and 4 to 6 A. M., a period of from six to eight hours. As a matter of fact few sewerage systems exist where the flow during these hours is not considerable. From two-thirds to three-fourths of the daily flow generally occurs during from—say nine to twelve hours of the day, the particular hours varying somewhat in different communities and having little or no significance in designing the smaller portions of most pipe systems, but affecting the outlets and being of great

* For an extended study of water consumption, with figures for a large number of American municipalities and with much other data on the relation of this subject and of population to amount of sewage, see Rafter & Baker's "Sewage Disposal in the United States."

importance where the sewage must be lifted or treated before its final discharge. Moreover, there are generally from one to three hours in the day when the flow is considerably above the average for the heaviest ten hours. The actual amount of sewage for these hours must be taken into consideration in the separate system and the plant designed accordingly. For ordinary laterals, these fluctuations need not be taken into account, for in the best practice these are generally more than ample for their duty. As the sewers increase in size and territory served, and as disposal works are reached, the flow during maximum hours becomes of more importance. Roughly speaking, 10 per cent. of the total daily flow in one hour may be considered a perfectly safe limit.*

When the sewers are being proportioned for their respective streets and districts, density of population must be considered. It is generally necessary to arrive at this

* Staley & Pierson, in the "Separate System of Sewerage," give the maximum hourly flow as twice the mean hourly flow, which would be about 8 3 per cent. of the total daily flow.

in an arbitrary way, as actual figures, except for the whole town, are seldom available except in communities long since sewered, or that may be considered as having reached their full growth. The proper figures must be reached for each community separately, so no attempt will be made to give them here.

Rainfall data are liable to be very scarce in all but the larger cities and towns, and at points where the national and state weather bureaus have stations or observers. Such defects in the records as exist through lack of observations, simply, cannot be remedied, but it sometimes happens that figures for near-by towns will do very well. But even when records are available they may not be sufficiently detailed for the purposes under discussion. Monthly or weekly totals are of scarcely any use, and even daily records do not completely meet the necessities of the case. What is desired where storm sewers are to be provided is the duration and rate of precipitation of the heaviest rains. A very heavy shower of 15 minutes may cause more inconvenience and damage, if the sewers are inadequate, than a steady rain extending over a day or two. There is, of course, a limit to the size of sewers, imposed by financial, and in some cases by physical conditions. Oftentimes, where sharp, heavy rainfalls occur, their complete speedy removal is impossible, and the surface water simply must be allowed to stand for awhile. Sewers may generally be so designed that they will speedily remove the total rainfall except at long intervals when an unusual precipitation occurs.

After a careful study of all the rainfall records available and a consideration of the slope and character of the drainage area, especially whether closely built up, with paved streets, many roofs, small areas in forest and under cultivation, or the contrary, the rate of rainfall per hour which shall furnish the basis of calculations may readily be decided upon by any competent engineer. A maximum rate of 1 in. per hour may be considered as a liberal figure in some localities. The proportion of this which will reach the sewers during a given time will depend upon such local factors as slope of land, whether its surface is covered with houses and paved streets, cultivated fields, or forests, and the permeability of such soil as is exposed.

(6) *Extent and cost of the proposed system.*

This is a matter largely dependent upon the local treasury, or the willingness of the people to incur indebtedness, levy general taxes, or pay special assessments for benefits, as the case may be. The ideal plan is to afford every building in the community an opportunity to connect with the sewerage system. This cannot often be done at the start, and in most instances sparsely settled outlying districts must wait long and weary years before the sewers reach them, although their taxpayers may be called upon year after year to pay taxes to redeem the bonds, meet interest, maintenance and repairs. The oldest and most thickly settled portions of the community naturally will be sewered first, after which the system should be carried as far out in various directions as the funds available will permit. The exact course followed will depend largely upon the legislative authority conferred upon a given municipality to raise money for sewerage construction. Practice in the several States, and often in the various cities and towns of one State, varies widely in these particulars. Sometimes the city authorities have full power to lay out as complete a system as they deem best, either issuing bonds for its construction or levying assessments for benefits upon abutting property owners for a part or the whole of the work. Again, there is authority only for the construction of trunk sewers and other works for final disposal, the building of laterals depending entirely upon the initiative of property owners. All the local conditions, legal and otherwise, must be ascertained before the extent of the system can be settled. All work should be planned and carried out with the future in view and should be complete and adequate in itself and in relation to other parts of the system, so that reconstruction will not be necessary for years to come, if ever.

It appears from the above, and from a simple common-sense view of the subject without regard to what has been written, that the extent of the system will be governed very largely by the local pocket-book and existing statutes, and that it should be made to suit the most pressing needs of the community and be capable of easy extension as soon as possible.

The cost of the system will be a matter for estimate in each case. Most sewer work, especially for sanitary sewers, is so simple, and there is now so much of it being estimated upon and carried out by engineers and contractors, that it is comparatively easy to figure up the approximate cost of a sewerage system. Local prices of labor and freight rates on sewer pipe, cement and brick, where the latter is used, are the main factors, and must be decided upon by each engineer in making up his cost estimates. The technical papers now publish exhaustive detailed lists of bids for sewer work all over the country, and the reports of city engineers, superintendents of sewers, sewerage committees and boards of public works often abound in figures or quantities and cost of work actually done.

(7) *Method of meeting the cost of the system.*

As stated above, this is often laid down by law, so that there is little choice to be had, except in the details. But ample latitude is sometimes left and generally the details of carrying out even fairly definite laws afford a chance for a considerable amount of variation, together with much study.

Broadly speaking there are two methods of raising money to defray the cost of a sewerage system: (1) By making the work a charge upon the whole municipality, raising the money by taxation or a bond isssue; and (2) assessing the cost upon the property specially benefited. A combination of these plans is very common. The first one is sometimes put into effect and the second with comparative infrequency, except for single streets or drainage districts of a city with independent outlets. The trouble with the second plan is that it is not easy to determine the proportionate amount of benefit which each property owner receives, unless it be in the most simple cases.

The cost of constructing and operating a water-works system is met by the yearly rentals charged for water furnished the users of the same, but the general aim in the case of sewers is to make their use as popular as possible. Therefore, the most common practice in this country has been to charge nothing for using the sewer. An entrance fee, sometimes designed to repay the city the cost of supervising the work, and sometimes intended to help pay for or maintain the system, is often charged for connecting with the sewers and paid once for all.

The actual cost of house connections is always, so far as the writer knows, borne by the house owner.

Where the general public and the property especially benefited, that is, actually or potentially served by the system as constructed, share the cost, it is divided in various proportions, seemingly without rhyme or reason, in many instances. It may be the city or it may be the property benefited that pays all the way from one to three-fourths of the cost, or perhaps through a wider range. With the separate system of sanitary sewers a popular plan and an apparently fair one, where the cost is simply to be divided as stated just above, is to assess upon abutting property the cost of the smallest-sized lateral sewer, or in other words of a sewer just large enough to serve the houses on one street of moderate length. The further cost of the system or extensions, would then be raised in the general tax levy or by a sale of bonds.

The assessments for benefits are levied upon the frontage bordering on the streets in which the sewers are laid, or upon the area of the lots, or are divided between these methods. The whole subject under discussion is a complicated one and has never received the consideration it deserves from municipal officers.*

But to one such an official, great credit should be given for having made a very exhaustive investigation of the problem and presented a solution which aims to be fair, conducive to the rapid extension and use of his particular sewerage system, and in many points admirably adapted to other localities. This study was made by Mr. F. H. Snow, City Engineer of Brockton, Mass., and the plan recommended was adopted by that city. A summary of Mr. Snow's report is given below, the importance of the subject, the lack of both popular and technical information regarding it, and the value of the report itself, seeming to warrant the devotion of a few pages to this purpose.†

The population of Brockton is about 30,000. The sewerage system includes a

---

* A monograph, entitled "Special Assessments," by Victor Rosewater, (Columbia College Studies in History, Economics and Public Law) will be of interest and value to those who wish to pursue the general subject further.

† This summary is condensed from an editorial digest and discussion by the writer which appeared in "*Engineering News*" of Ju y 19, 1894.

receiving reservoir, pumping station, force main and filter beds. The first cost of the system, so far as constructed, was raised by an issue of bonds. The summary is as follows :

In arriving at the proper plan for Brockton, Mr. Snow studied with great care the various methods of assessments already in use, after first having shown that the benefits of a sewerage system were partly public and partly private, and should be borne accordingly. Public benefits are, of course, to be met by general taxation. The proportion to be paid by the public has been fixed by the Massachusetts legislature at not less than one-fourth nor more than two-thirds of the total cost of the sewerage system. For private benefits a variety of methods are permitted by the statutes, such as frontage and area assessments, yearly rentals, entrance fees, or a combination of these.

* * * * * *

Either the frontage or the area plan alone is shown by Mr. Snow to be inequitable, diagrams being used to illustrate how by either plan differences in the shape of lots may allow several houses on one lot and only one or two on another, each lot having the same area or frontage, as the case may be. The entrance fee is also shown to be unjust, unless it is graded in accordance with benefits received, while, in addition, a large fee would be required at the start, when there were but few connections, or else reliance on the general tax levy would be necessary.

The method finally recommended by Mr. Snow is given in his report as follows :

It is recommended that one-fourth of the total cost of the sewerage system be raised by first assessment, one-half by rental, and the remainder by general tax. It is also recommended that first assessmant be based on area and frontage of land adjacent to sewers—0.6 on area within 125 ft. of the street line and 0.4 on frontage; that the first assessment be collected in one payment and credited to construction account; that the unit of rental be 1,000 gallons of water reaching the sewer, this to be ascertained from meter gagings of the water department, and to be corrected for water finding another outlet than the sewer by a system of discounts; 70 per cent. to be deducted from water supply of shops and 20 per cent. from water supply of houses having sill-cocks.

And it is further recommended that abuttors be not compelled to enter the sewer as soon as completed; that no one be allowed to enter without a permit ; that no rent be charged users before January 1, 1895, rents starting from that date ; that such rents be charged from the first of the month following that in which the permit is dated ; and that all deficiencies be made up in the early years by general tax levy.

It is further recommended that the following prices be assessed per unit : For first assessment, 0.3 cents per square foot, and 15 cents per front foot ; for rental, 28 cents per 1,000 gallons entering the sewer ; and that $8.40 be charged for unmetered connections, subject to a discount of 20 per cent. for sill-cocks.

* * * * * *

These first assessments represent the value of the sewerage system to land, in enhancing its price without regard to whether the sewers are used by the owners of the land. The amount raised by general taxation will likewise represent the benefit to the community as a whole, without regard to the location of the sewers. Benefits from actual use of the sewers are to be paid by rental, according to the amount of sewage contributed, and the sums so raised will be applied to paying off the bonds, meeting interest and to maintenance. The rentals will pay two-thirds of the total yearly charges, leaving the balance to be met by general taxation.

It is eminently fitting that rental should be based on the amount of sewage contributed, since upon the latter depends the size of the sewers, and notably the cost of constructing and operating the pumping plant and filter beds. Fortunately at Brockton 65 per cent. of the water connections are metered and the records of the water department are well kept, so that the sewer rentals can easily be based on the water consumption. Obviously on many premises some of the water used does not find its way to the sewers, hence the proposed deduction of 20 per cent. of the consumption for houses having sill-cocks for hose and of 70 per cent for shops.

* * * * * *

The unit of 28 cts. per 1,000 gallons of water was arrived at by computing the probable yearly expenses of the sewerage system until 1900 and the probable water comsumption for the same period. It should be stated that the water consumption in Brockton is phenomenally low, only 25 gallons per capita. The yearly rate of $8.40 for unmetered houses was chosen because the minimum rates for metered water are such as to make it an object to water users to have a meter when the water consumption goes above a point that would call for such a rental.

Coming to the amount to be raised yearly in the tax levy, the problem is simple, the amount being the difference between the total amount to be raised and that provided for as outlined above.

Although this system has been worked out to meet the situation of Brockton, which is in a number of respects unique, the general principles involved may be applicable in other places. The special conditions at Brockton are as follows: (1) No sewers are yet in use, although the city has a population of about 30,000; this renders possible the adoption of any desirable system without the unfairness, real or fancied, which follows a change in the case of old systems. (2) It is expected that the whole city will be sewered in a comparatively few years, so that the total cost of the system can be readily estimated, which is essential to this plan. (3) The large percentage of metered water taps and the fact that the city owns the waterworks, so that water and sewer departments can co-operate, while each desires to keep the water consumption down, are favorable to a yearly rental plan, based on water consumption. Modifications of these conditions might make the system difficult of application or might cause friction when applied. Nevertheless the principles at the bottom of it seem correct, and this general distribution of the burden of a sewerage system, whether in these or other proportions, seems fair and likely to be popular. General public and individual private benefit are each recognized and the latter is divided into two classes, (1) potential benefit through increased value of a certain piece of property because the sewer passes by it and may be used, and (2) the actual benefit through use.

Two dangers which beset the extremes of the two methods most usually employed to raise money for sewers seem likely to be counteracted to a large extent by this plan: (1) When the whole cost is put in the general tax levy or is met by bonds, the interest and principal of which must be met by taxes, it is difficult to secure money for extentensions, every taxpayer wishing to keep the rate down, and those living on sewered streets having no direct interest in extensions. In the Brockton plan the tax levy is increased by only one-fourth the total cost of the sewers, the bulk of the expenditure being put upon those whose land is improved or those who, by use of the sewers, are saved the expense of cleaning cesspools or privy vaults. The taxpayer feels that the sewerage system is, to large extent, self-sustaining, like a municipal water-works plant. (2) The other danger is that where property benefited bears the whole expense of sewers it will, in case of assessments for frontage or area, try to keep the sewer out of the street. But in Brockton a given property owner will be paying towards one-fourth the cost of the system whether the sewers are in his street or not, and once in his street he need pay only an additional one-fourth for property benefit, unless he wishes to connect with the sewer. The sewer once in, however, he will already be paying towards one-half of the total cost of the system and the additional expense for the use of the sewer will seem small. Moreover, by economy in the use of water his rental may be kept low, and most people do not consider themselves extravagant water users.

(8) *The needs of sewerage peculiar to the locality, with a study of the health and mortality, of the town.*

Little need be said on these phases of the subject. The adoption of a scheme and the raising of money for its realization may be greatly aided by showing that local conditions imperatively demand the improvement. A study of the health and mortality of the town, and comparisons of the results with like studies of communities enjoying good sewerage systems is often helpful in enlisting popular enthusiasm for sanitary progress. But such work must be done wisely and false statements and impressions regarding the relation between unsanitary conditions and disease avoided as one would shun poison. There has been so much ranting of late regarding deadly disease germs lurking here, there and everywhere that many persons on reflecting that they and most of their neighbors still live, grow suspicious and feel inclined to discredit the germ theory of disease and the advantage of cleanliness in all the departments of life. It must be remembered that just as there are thousands of visible forms of plant life, of which only a very small percentage are poisonous, so among the many invisible forms of plant life known as bacteria or microbes there are only a few harmful germs. These few, it must be taught, give rise to dire results when allowed access to private water supplies, like house-wells, through leaching privies and cess-pools, or to public water supplies by discharging crude sewage into streams or lakes from which such supplies are drawn. Furthermore, unsanitary conditions, while not giving rise to certain forms of disease, may render the human system unfit to ward off attacks of the same. Facts like these, reasonably presented, may sometimes do a world of good in an engineer's report, while the too common exaggerations would disarm instead of assure the people.

Adoption of the Engineer's Report.

The report of the engineer having been completed and submitted to the proper officials its adoption by them them may be assumed. Sometimes the plan recommended has to be submitted to a popular vote, but more often where a vote is taken it is only indirectly upon the specific plans proposed, the real question being whether bonds shall or shall not be issued for the execution of the scheme. After the general report is adopted the next step is to select an engineer to prepare detailed plans and specifications preparatory to advertising for bids from contractors. Frequently the engineer who made the preliminary studies is engaged as designing engineer and sometimes to supervise construction as well. This course has the advantage of continuing the services of one more or less familiar with local conditions, and with the plan for sewering the town already partially worked out.

Design and Construction of the Conduit System.

The first work of the engineer will be to design his pipe or conduit system. For this task the topographical map already mentioned will be a help, but this should be supplemented by a profiles of all the streets in which sewers are to be laid, in order that the proper grades may be determined and the accessories of the systems designed.

Numerous diagrams and tables are available for use in designing conduit systems, rendering separate computations with the aid of complicated formulæ altogether unnecessary, unless the engineer wishes to make his own figures.* In the separate system it is generally best to use 8-in. pipe as the minimum size, in order to lessen the risk of stoppages, although 6 ins. is ample for the volume of sanitary sewage from an ordinary residence street of medium length.

Pipe sewers are generally made of vitrified clay, with a salt-glazed surface. Cement pipe (cement and sand) is also used in some cities. The size of pipe sewer was for many years limited to a diameter of 24 ins. but some of the manufacturers now make pipe 36 ins. in diameter for general use. The 24 in. limit was in force because of the difficulty and expense of making the larger pipe and the comparative ease of laying brick sewers of any size from 24 ins. up. Monolithic sewers

* Mathematical discussions of sewer formulæ are beyond the scope of this work. See Baumeister's "Cleaning and Sewerage of Cities" for a brief but able presentation of the subject, illustrated by diagrams, and Flynn's "Flow of Water in Open Channels, Pipes, Sewers, Conduits, etc.," for tables. Staley & Pierson's "Separate Systems of Sewerage" may also be consulted. More recent books are "Ogden's Sewer Design" and Folwell's Sewerage."

have been used for a limited extent, the conduits being built in place from cement mortar.* In very wet ground cast iron pipe with lead joints is used, either because it is specially desirable to prevent infiltration or because of fear of damage through settlements.

The pipe should be laid to grade with great care, and a good alignment should be secured. Holes should be dug for the bells of the pipe so that each length of the latter will have a solid bearing throughout. When the material is such as to make uncertain a solid support for the pipe, sand, gravel, concrete, plank or piles should be employed for the purpose. If rock is encountered in trenching, it will be necessary to provide a bed for the pipe which will not be washed into fissures by the stream of sub-soil water which is likely to follow the sewer when the ground is saturated. At Little Falls, N. Y., in the case of a vitrified pipe line for a water supply conduit, such a washing-out of material occurred,

* Concrete, both plain and reinforced with steel, has been coming into use since the first edition of this book was written (1895), but more particularly for large sewers.

causing settlements and the pulling apart of joints. The trench was opened through the rock portion and the pipe embedded in concrete.

Subsoil Drains, or Underdrains.

Where sewers are in wet sand or gravel, subsoil drains, or, as they are more usually called, underdrains may be laid beneath or alongside the sewer to advantage, as discussed above. These are generally simple agricultural tiles from 3 ins. in diameter upward. They have no joints, being simply hollow cylinders, and are laid with their ends a fraction of an inch apart, wrapped with a cheap so-called muslin cloth, or other suitable material to keep out the dirt until the matter in the trench becomes thoroughly packed about them. These underdrains may almost always be emptied into the nearest stream, provided it is not used as a public water supply. This qualification is on account of the fact that the sewers may leak and sewage thus flow directly into the underdrains. Such danger may seem remote, but it was considered sufficient to cause the city of Boston to refuse to pay a promised sum toward the cost of thé sewers of South Framingham, Mass., so long as the sewer underdrainge discharged into a stream tributary to one of the sources of the Boston water supply. Boston had agreed to make this contribution in order to induce the town of Framingham to remove its sewage from the Boston water works. This made purification necessary, which in turn demanded that all the sewage should be pumped to the filter beds and irrigation area. Naturally the town did not wish to pump and purify the underdrainage, but after some years of delay and an offer of an additional sum from the city of Boston the town constructed reservoirs and filter beds for the purification of the underdrainage, all of which must be pumped a small lift.

Perhaps one of the best examples of subsoil drains beneath sanitary sewers, or at least the best example which has been described and illustrated in detail, is at

Newton, Mass., where drains were placed below many miles of sewers.*

Manholes.

Manholes should be placed at all changes of grade and at all junctions between two or more street sewers. These are built of brick and afford access to the sewer for inspection. In addition they are sometimes used for flushing. They are provided with iron covers, the latter often being pierced with holes to afford ventilation to the sewers. When the covers are so perforated pails are often suspended beneath to catch the dirt from the street surface, especially when the manholes are in macadamized gravel or dirt streets.

On long stretches of straight sewers lampholes are somtimes put in between manholes, consisting generally of a vertical piece of pipe extending from the sewer nearly to the surface and provided with a cover. These are valuable aids to inspection.

---

* See *Engineering News*, January 2, 1896, for illustrated description of this system.

Sewer Grades.

The grades of sewers should be sufficent, where possible, to give them a self-cleansing velocity, thus rendering stoppages from ordinary suspended matters impossible. Baumeister, in his "Cleaning and Sewerage of Cities," makes the following statements on this subject:

Practical experiments show that sewers of the usual sections will remain clean with the following minimum grades: separate house connections, 2 per cent.; extreme cases, 1 per cent. Small street sewers, 1 per cent.; extreme cases, 0.7 per cent. Main sewers, 0.7 per cent.; extreme cases, 0.5 per cent. The extreme cases are for sewers carrying only rain or quite pure water.

The following empirical formula will give the minimum grade for a sewer of clear diameter equal to *d* inches and either circular or oval in section:

$$\text{Minimum grade, in per cent} = \frac{100}{5d+50}$$

Flushing Devices.

Where very low grades are unavoidable and at the heads of branch sewers where the volume of flow is small, flushing may be used with advantage. In some cases a copious supply of water is turned into the sewer through a manhole from some stream, pond or lake, or from the public water works system. Generally, however, the water introduced is allowed to accumulate before discharge, being held back, for instance, by plugging up the lower side of a manhole until the water accumulates in it, then suddenly withdrawing the plug and releasing the water, upon which it rushes down the sewer carrying before it practically all obstructions, except in extreme cases.

Instead of relying upon clear water, as described above, it may be sufficient at some points on the system to simply back up the sewage by plugging the manhole outlet, thus flushing the sewer with the sewage itself.

The necessity of frequent and regular flushing has given rise to automatic flushing tanks. These generally make use of the siphon for self-discharge, although there is on the market a purely gravity flush tank, which tips by its own weight when full. Whatever the means of discharge the feed to the tank is regulated by a valve or cock on the supply pipe, so the tank will fill and empty once in a given number of hours.

Y-Branches for House Connections.

Provision for house connections should be made when laying sewers, in order to avoid as much as may be tearing up the streets after the pipe system is in and the breaking of holes into the sewer. It is a wise plan to lay the house connections from the street sewer to the curb, or even across the sidewalk, while the street is dug up. At the least Y-branches for house connections should be put in at frequent intervals, say from 25 ft. apart upwards, according to the character of the street. When the sewer is put down deep quarter bends are sometimes provided and the house connection pipe carried vertically upwards until within a few feet of the surface to avoid deep digging. However the house connection may join the sewer, or any two sewers join each other, the direction of flow in connection and street sewer should be as nearly the same as possible, and the entering sewer should be at a little higher level than the sewer entered in order to increase the velocity of the influent sewage and thus lessen the tendency to retardation and stoppage which naturally results where two confined streams with matters in suspension unite.

Depth of Sewers Below Surface of Ground.

No general rule can be laid down for the depth of sewers further than that they must be deep enough to admit of house connections with a proper fall, and on the other hand should be as near the surface as possible to save the expense of deep trenching. Of course they must be kept below the point at which danger from freezing might arise, but the natural depth is usually sufficient to make such a consideration unnecessary, especially as the temperature of sewage is generally a number of degrees above that of the atmosphere at the street surface.

Ventilation of Sewers.

The ventilation of sewers is a subject still fraught with many fears and perplexities. In the early days of sewers the conduits were faulty in the design of their cross-sections, in their grades and in their construction. Practically all of these conduits originally carried surface water, and through infiltration large quantities of ground water. Many of these conduits, as stated at the beginning, were built to carry storm water alone, in other words were simply drains. With the advent of ample public water supplies and modern plumbing, which, with its many fixtures providing hot and cold water at every hand led to high water consumption, houses were connected with the drains, thus converting them into sewers. Still later, the convenience of this practice being recognized, conduits were designed and built to carry both drainage and sewage, but these sewers on what we now call the combined system were little or no better in design and construction than the old surface drains. The consequence of all this was that the uneven bottoms made long stretches of sewer little or no better than cesspools, and this cause, with poor construction, gave rise to stoppages which still further aggravated the stagnation. Decomposition, without the presence of a plentiful supply of oxygen, evolved offensive gases, which sought the upper air through all possible channels. Street inlets for surface water and manholes for cleaning belched forth gases whose malodorous presence was easily recognized. Too often these odors were noticeable in houses. To prevent such a state of affairs various methods of sewer-ventilation were tried, which it is unnecessary to describe here. In modern work of good design sewers are built with the intention of removing all sewage immediately before offensive decomposition has time to begin. The grades are as nearly perfect as possible, the interiors are reasonably smooth to prevent adhesion of putrescible matter, and the manholes have perforated covers to aid in ventilation. In some cities ventilating shafts are provided to supplement the manholes, these sometimes being the soil pipes of the houses, the main trap being omitted for this purpose. The latter practice is recommended by some of the best engineers and sanitarians of the day, the theory being that by such means well constructed sewers are kept so filled with fresh air, and so free from bad gases, that no harm can arise if occasionally a trap to some wash bowl or water closet fails and the sewer air reaches a dwelling room. But notwithstanding these opinions the majority of sanitarians still object to ventilating sewers through houses and insist upon the main trap.

It seems obvious that in the separate system of sewers, with its small laterals, a 4-in. ventilating pipe is not needed every 50 or 100 ft. on both sides of the street to change the air in a 10, 8, or even, as is sometimes the case, a 6-in. street sewer. The most common practice is to assess the whole or a considerable portion of the cost of such small sewers upon abutting property owners. Where this is done it may be difficult to say to one man out of perhaps five, "you must for the general good omit the usual main trap from your soil pipe in order that the street sewer may be ventilated; or if you object to that you may run a separate ventilating pipe from your house sewer at a point just outside your main trap to the top of your roof." Naturally, most men would object to such an alternative, preferring not to risk, as they might think, with ample support from engineers and others supposed to know, the lives of themselves and their families, nor to spend money to avoid such a risk while four of their neighbors were not called upon for either risk or sacrifice. To be sure some means might be devised to assess the cost of these extra pipes upon the town at large, where the people refused to allow the ventilation through their soil pipes, but this would give rise to some trouble, at the best, so that the wisest course might be to provide extra ventilation, if experience showed it necessary, entirely at town expense, and independently of dwellings. The matter of ventilation is further discussed at the end of the next section.

Misapprehensions Regarding So-Called Sewer Gas.

Before leaving this subject a few words seem necessary regarding misapprehensions on the question of so-called sewer gas and the conveying of disease germs thereby. And first, there is no specific and definite sewer gas for which a chemical formula or combination of symbols can be laid down. The air in sewers contains in greater or less degree some of the gaseous products of decomposition whenever chemical changes are taking place in the organic matter conveyed by or deposited in the sewers. This air is harmful if breathed, just the same as any other foul air, and to no greater extent, except for the slight possibility that it may contain harmful bacteria. The disease germs which may be expected in sewage are essentially water-borne instead of air-borne, and develop in the human intestines rather than in the throat, nose or lungs, and therefore gain access to man chiefly through food and drink. The germs carried by so-called sewer gas must obviously be air-borne and from their origin are not likely to be found in sewage, or if found they would be in small quantities; but while all this is true it does not make sewer air any more desirable for breathing. The evils to which impure air give rise are invidious, attacking the weak and undermining the physical system of both weak and strong, rendering them more susceptible to various forms of sickness, notably the zymotic or filth diseases. Thus it is evident that no matter how much the nature of the dangers from this source may have been misunderstood in the past they are sufficiently grave to demand all reasonable efforts to ward them off. The first aim should be to prevent, as far as possible, the formation of foul air within the sewers, and the second to keep such air as may form away from mankind. After good design and construction of the sewer conduits, as such, have been secured ventilation should be called upon for the introduction of a plentiful supply of fresh air and the removal of foul air to points where it will be diffused throughout the atmosphere without offense. Stagnation of air within the sewers must be avoided.

Dr. Billings' Opinions on Sewer Air and Ventilation.

Before leaving this subject some quotations may be introduced to advantage from the exhaustive work entitled "Ventilation and Heating," by Dr. John S. Billings, formerly Surgeon-General U. S. A., and a recognized sanitary authority. Among other things Dr. Billing's says:

The air of an ordinary modern, fairly well constructed and ventilated sewer appears to differ from the street air chiefly in having a higher proportion of carbonic acid.

* * * * * *

Specific pathogenic micro-organisms have not been found in the air of sewers * * * * As regards house drains and soil pipes, the condition of the air in them depends greatly upon whether they are properly ventilated or not. So long as the fixtures connected with them are in daily use these pipes are lined with a moist slimy layer of organic matter, in which bacteria of various kinds grow in immense numbers. If the supply of air is abundant, these bacteria are mostly aërobic and the substances produced by their action are, as a rule, odorless and are rapidly carried away, by the next flush of liquid, if soluble.

* * * * * *

In hospitals, before the introduction of antiseptic methods of treatment of wounds, the pyogenic organisms were of course very numerous in the hospital drains, and there are several cases in which localized outbreaks of erysipelas and unhealthy wound action appeared to be connected with the passage of the house drain air into the ward.

* * * * * *

Distinguished English sanitarians believe that typhoid fever has been spread through the gases coming from foul sewers, but I know of no satisfactory evidence of such an occurrence. Diphtheria and typhoid fever are diseases which prevail more extensively where there are no sewers than in the sewered part of the cities, even where the sewers are badly constructed.

While I do not attach much importance to sewer air as a means of transmission of specific disease, I believe that its continuous inhalation is dangerous, owing to the large amount of volatile organic matter which it contains, and for that reason, as well as to prevent the formation of explosive mixtures and of unpleasant odors, continuous ventilation should be provided for all sewers, house drains and cesspools.

In well constructed sewers Dr. Billings considers ventilation an easy matter, which can generally be effected by frequent openings to the outer air, and always at each dead end of a sewer. Special tall ventilating shafts, or ventilation through factory furnaces or chimneys he considers as of little value, stating that the influence of such shafts or chimneys extends only to the nearest air inlet.

Ventilation through house soil pipes is approved where the sewers and house connections are properly designed, constructed and operated, and all are under the control of the municipal engineer, provided also the houses on a given street are nearly uniform in height. Where opposite conditions prevail, so that the air in the sewers is bad, and the tops of the soil pipes of one house would end under the windows of another, the Doctor thinks that main traps should be placed on all soil pipes and air inlets and outlets be placed on the sewers at intervals of 300 to 400 ft.

Features Peculiar to the Combined System.

Coming now to sewers of the combined system their most notable differences from separate sanitary sewers are their greater size and the use of catch basins or inlets for the admission of surface water. They are generally of brick, stone, or concrete, or a combination of two or more of these, instead of being chiefly of vitrified pipe. Still another distinctive feature is the provision of storm overflows, by means of which the main sewers, when overcharged at times of heavy rainfall, may empty a part of their contents through a short conduit into some water course. At such times the sewage is diluted by the rain-water, while the stream which receives the overflow is also of an unusually large volume. The relief thus afforded renders possible smaller conduits than could otherwise be used without backing up sewage into houses or flooding streets and cellars on the lower levels of the city.

Size, Shape and Material of Combined Sewers.

The actual size of the sewer of course depends upon local conditions, as to a large extent does its shape and material. Where the depth of flow varies greatly it is desirable to give the sewer a cross-section designed to suit all flows as fully as possible. Experience has shown this to be an approximation to the cross-section of an egg placed upright on its smaller end. With this section a maximum depth and velocity of sewage is secured for a minimum flow, rendering deposits and stoppages far less liable. With sewers having a flow more nearly constant and equal to their full capacity the form may be modified to that of an ellipse, a horse shoe with an arc of a circle for an invert, or bottom, a circle, or some modification or combination of these, according to circumstances. For the larger sewers brick is by far the most common material, both because of its cheapness and of its adaptability to any shape. Stone inverts are sometimes employed on heavy grades, notably where much sand is carried in suspension, in order to present a more lasting surface to the scouring and wearing effect of gritty material. Concrete is sometimes used for inverts, where leakage may be expected, or in material liable to movement, but more commonly it affords a foundation for the brickwork. The concrete is also sometimes extended up the sides of the sewer, and sometimes completely around it.* If the material is liable to much settlement, as in marshes and bogs, the sewer may be constructed on a timber platform, the latter sometimes being supported by piles, generally having at least a thin layer of concrete between it and the invert.

It not infrequently occurs that sewers must be constructed through rock. In comparatively rare cases this is sufficiently solid to warrant the use of an unlined tunnel, where grades are sufficient to permit a

* See foot note, page 60.

rough surface. But generally stones and uneven walls left after blasting make lining necessary, which is commonly composed of brick, with any spaces behind the ring or rings filled with brick or stone masonry, or concrete.

Catch Basins or Rainwater Inlets.

A catch basin is generally placed at each street corner, with a grated opening, or otherwise, giving the surface water access to a chamber or basin beneath the sidewalk, from which a pipe or other conduit leads to the sewer. Catch basins may be provided with water traps to prevent the sewer air from reaching the street, but these traps are liable to lose their seal through evaporation in dry weather, unless they are renewed by manual labor from the public water supply system. To prevent the carrying of street washings into the sewers catch basins should be provided with silt chambers of considerable depth with overflow pipes leading to the sewers, and thus lessen the bulk of the heavy suspended matters in the silt chamber to be removed by buckets and carted away at proper intervals. In the case of long street blocks catch basins may be placed in the centers of the blocks, as well as at street corners.

Storm Overflows.

Storm overflows are simple in theory, and often so in construction, the main point being to ensure an overflow into another conduit when the flow reaches a certain elevation in the sewer. Where main and intercepting sewers are at right angles to each other the connection is sometimes so made that the dry weather flow drops into the intercepting sewer, but the flood flow, with its greater volume and velocity, shoots over the interceptor, in part, and into and through the overflow sewers. The lower portions of main sewers formerly discharging at many points into a stream or lake are sometimes utilized in this manner when intercepting sewers are added.

The junction of large sewers, and other complications in combined sewerage systems, sometimes afford ample opportunity for the engineer and contractor in designing and building masonry suitable for such places.

Sewers designed to remove surface drainage alone are practically the same as combined sewers, without house connections, and need no discussion here.

Pumping Stations, Receiving Reservoirs and Force Mains.

A large percentage of the sewerage systems of the United States and Canada operate wholly by gravity, but it is sometimes necessary to pump a part or all of the sewage of a city. The lifts involved are usually quite low, so that high-priced pumping machinery is not required. It may be necessary to thoroughly screen the sewage before it passes to the pumps, or to provide these with valves not likely to be injured by the miscellaneous bulky substances in the sewage.

The Shone hydro-pneumatic system, used successfully at the World's Columbian Exposition and elsewhere in this country and abroad, may sometimes be used to lift sewage to higher levels. In this system compressed air from a central station is automatically discharged into a receiving chamber with which the sewers are connected, whenever the chamber fills to a certain point. The air under pressure forces the sewage through the outlet pipe.

Where pumping is necessary receiving reservoirs with more or less storage capacity may sometimes be provided with advantage, to equalize the work demanded of the pumps and perhaps to permit shutting down the pumping plant at night. Such reservoirs are generally covered, unless in very isolated localties, and may be ventilated by connecting with the smokestack, or the gases from the ventilator may be conveyed to the furnace fire.

Force mains are generally required in connection with pumping plants, but sometimes the latter are so near the point of outlet, serving as mere vertical lifts, that the discharge pipes from the pumps cut no figure. When employed the force main will naturally be of cast iron, similar to that for a water supply system.

Tidal Chambers.

Besides receiving and storage reservoirs at pumping stations these may be required where the disposal of sewage is into tide water under such conditions that it is necessary to discharge it on ebb tides. The main distinguishing features of such reservoirs, as compared with these described above, is an arrangement of gates which will permit of emptying the reservoir in a brief period. These gates should be easily handled in order to reduce the cost of attendance. This may sometimes be effected by mechanical power provided by the outflowing sewage.

Final Plans and Specifications.

Before bids for construction are invited full plans and specifications should be prepared by the engineer. The plans should be in sufficient detail to make the general design and all the accessories of the system perfectly plain to bidders, and the specifications should be explicit upon every point which comes within their scope. Blue prints of the plans and printed copies of the specifications should be ready for all inquiring bidders in advance of the date fixed for opening bids. The specifications are usually accompanied with the form of contract to be executed between the city and the successful bidder. In the matter of specifications and forms of contract the engineer should generally work in conjunction with an able lawyer, the city's permanent legal representative, or otherwise, according to circumstances. Years of experience on sewer work in a particular city may fit an engineer to cope single-handed with all the legal questions involved, but in the long run co-operation with members of the legal profession will prove advantageous. When difficulties with contractors arise the city's legal adviser is pretty sure to be called in, so it is well that he should be consulted at the start. Outside of his own particular city the engineer may be practically helpless in legal matters, owing to the wide divergence of laws relating to public improvements in cities of the same and of different states.*

SECURING BIDS AND AWARDING CONTRACTS.

In no department of the engineer's work can more money be saved his employers than in the securing of numerous truly competitive bids from able contractors and in deciding to whom the contract should be awarded. On the proper performance of these duties depends not only the first cost of the improvements, but the interest and maintenance account and to a large extent the successful operation of the undertaking. It is more essential to secure an able and honest contractor than a low bid; more important that the work be done well than that it be done cheaply. The number and character of the bidders on a given job will depend upon the importance of the work, the publicity given to the proposed letting and the character

* A form of specification and contract is given in Staley & Pierson's "Separate System of Sewerage" Prof. J. B. Johnson's "Engineering Contracts and Specifications" is a valuable book devoted exclusively to the subjects named in its title.

of the plans, specifications and forms of contract. In these days of numerous contractors eager for work at a fair price it is only necessary to present a clear idea of the work to be done and just conditions for its execution to secure an abundance of proposals on almost any job, provided only the opportunity to bid be brought to the attention of the possible bidders. Most cities and towns are obliged by law to advertise all contract lettings where more than a small cost is involved. It is generally required that the advertisements shall appear in one or more local newspapers and permissible that it be inserted in others. The local newspapers, even in the large cities, reach only a small proportion of possible bidders, almost exclusively those of the city in which the papers are published. For this reason, and because of the better results which experience teaches are to be secured thereby, the practice of advertising engineering contracts in engineering journals is rapidly growing in favor of late. When such a course is pursued the work in hand is brought to the attention of the contractors of a great section of the country, or of the whole country, if of sufficient importance, instead of to those of one city, and the number of bids received is in like proportion. But this is not the only advantage. The wider competition renders far more difficult, yes, practically impossible, except under the most corrupt city governments, the growth of a ring of local contractors who through combinations, personal favoritisms and even worse, maintain prices at a high point, at the same time generally doing poor work.

The bids having been received, they should be referred to the engineer for tabulation and recommendation. From his estimates of quantities he can determine the relative aggregate prices of the several bidders, and from his knowledge, through acquaintance and inquiry, of the bidders, and of the probable cost of the work in question, he can decide upon and report the most favorable bid. As stated above this is by no means always the lowest bidder, and it should nct be obligatory upon the city to award the contract to the parties who offer to do the work for the least money. Unfortunately the experience of many cities in having their officials award contracts to favored bidders has led to legislative enactments affecting some localities which make it imperative that contracts shall be given to the lowest bidder, although often the privilege of rejecting all bids and readvertising is given. This is a long step in advance, but where the officials can be trusted time and expense can be saved both city and contractor by allowing an award to other than the lowest bidder, if demanded by the best interests of the city, based on past records of contractors and the danger of poor work at excessively low prices. Such a course, aside from obliging a city to accept an undesirable bid, discourages designing contractors and those who, in their eagerness for work, figure too low, and does not call upon responsible men, of good judgment, to be to the trouble and expense of putting in bids the second time.

The Proper Execution of the Contract.

The contract having been awarded and construction started, it devolves upon the engineer to give the contractor all necessary lines and grades, and any information needed and not provided in the plans and specifications. It is also his duty, both personally and through his inspectors, to see that the work is done according to the plans and specifications. This requires the most careful and conscientious attention on the part of able men. Every detail of construction must be watched with an eagle eye and no work not subject to complete examination after it has been executed should be allowed to proceed in the absence of the inspectors. On pipe work or conduit construction, especially, one inspector should never be called upon to look after work in more than one street at the same time. Pipe and brick must be examined with the greatest care, the former piece by piece. Cement should be subjected to proper test to show its fitness for the use to which it is to be put. This requires at least a simple testing laboratory, and the provision of a fully-equipped one is money well spent where much work is to be done. After the sewers are completed they should be tested for obstructions, the small sewers by passing a ball through, or otherwise, and large ones by having a man go through them.

Regulations for the Use of Sewers.

These include all necessary precautions for the prevention of obstructions, chief of which, perhaps, is the proper laying and joining to the street sewer of house connections. This work is often, if not generally, done by plumbers, but all such should work under a license, revokable for non-compliance with city and town ordinances, and should be under the supervision of the engineering, sewer or health department. The size, grade and material of house connections should be specified in the above regulations, and in order that prosecutions and punishments may be possible for offenses against these and other rules it is necessary to have an ordinance or ordinances passed, embodying all the necessary rules and regulations and providing penalties.*

Operating the System.

The sewers completed their operation is nearly always very simple, especially where pumping or purification is not necessary. A superintendent of sewers, in fact if not in name, is generally employed to have general charge of the sewerage system. This official often oversees house connections and frequently has charge of minor, and sometimes of important extensions of the system. He removes stoppages and looks after flush tanks and other devices for keeping the sewers clean. If pumps are used these are likely to be in sole charge of the pumping engineer, although he may be under the superintendent. Where purification is employed a man independent of the superintendent may or may not have charge. All purification

* A model ordinance will be found in the "Separate System of Sewerage."

plants should be under the immediate direction of the most competent men attainable, within reasonable limits, as intelligence and knowledge are absolutely essential to their continued, and often to their temporary success. Politics and political berths should be kept clear of this department of the sewerage system, if from no other—it should be from all parts.

Sewerage Committee, Board of Public Works or City Council.

The above considerations suggest the question, should the construction and operation of a sewerage system be entrusted to a sewerage committee entirely independent of other departments of city government, to a board of public works charged with other municipal improvements of an engineering character, or to the city council? The answer to this, like that to so many other questions already raised in this volume, is that local conditions often determine what is best.

It is interesting to note that English cities and towns, as clearly shown in Dr.

Albert Shaw's "Municipal Government in Great Britain," manage in an admirable manner practically all their public works through their city councils and committees of the same, always relying, however, upon able and experienced engineers and others for technical advice and the details of operation. In this country the mistrust of city councils has been, and largely is so great that the first thought of tax-payers on undertaking the installation or extension of some important public work is to entrust it to a special and independent body of men.

The English system has the advantage that all public improvements are thereby carried out with due consideration to their relation to each other and to the finances of the city as a whole. A board of public works entrusted with streets, sewers, water and lighting plants, if the two latter be operated by the city, would be a close approach to the English plan, and would in many instances have its advantages over that plan under American conditions. Generally speaking independent sewer commissions, if only composed of the right men—and it is this which counts more than any system—have built and are managing sewerage systems with good results in this country. But from the nature of the case they cannot always so plan their work, for instance, as to interfere as little as possible with good street pavements, because they have no control over the time and place of laying such. Whatever the system, an able city engineer, or engineer of the sewer department, should be given the practical settlement of all engineering questions.

Sewage Purification in its General Aspects.

Having treated the other phases of the subject as fully as the space available will permit, there remains for consideration the important matter of sewage purification. This has been reserved to the last, except for the incidental references to it already made, because it is quite complete in itself and demands independent handling. The main principles of sewerage construction, aside from disposal works, have been established for many years, but the best means of rendering sewage fit to discharge into water courses or other bodies of water not suitable for the reception of crude sewage are problems of yesterday, to-day and even of the future. Enough has been settled, however, to render no longer valid the plea that sewage purification is as yet in too experimental a stage to forbid efforts in that direction. We know to a certainty how sewage may be rendered harmless. Further knowledge will probably be in the line of making present processes do more work without additional cost. The facts are, that the two older systems of sewage purification now in use, land treatment and chemical precipitation, were practised for many years in a blind rule o'thumb way, and often with good results, before their fundamental principles were discovered. Since the discovery of these principles, or natural laws, we can do nearly always what formerly was done only occasionally.

Blood pulsed through man's veins for

countless centuries before Harvey discovered the law of circulation, and many maladies incident to blood and circulation were helped or healed in utter ignorance of the law, but since and by means of the discovery what a revolution there has been in medicine and hygiene! We look forward to more progress in these particulars, but we do not for this reason hesitate to avail ourselves of all that has been accomplished. But this is exactly what some people would do in the matter of sewage purification, or at least they offer as an excuse that the science is in too tentative a stage to warrant the adoption of any plan as yet, their real motive too often being a desire to keep the municipal purse strings pulled tight.

What is most needed now is not new processes, but the careful carrying out of well-known methods, with observations on the results obtained under all the varying circumstances which naturally arise in different localities and under varying conditions at the same works. We have a host of suggestive and many conclusive deductions drawn from careful and long-continued experiments, both at home and abroad, but we need, particularly in America, to have more of the scientific spirit and method which have made the laboratory work so successful applied to the daily operation and study of actual sewage works. Instead of caviling at the uncertainties of sewage purification those who raise questions might better take their turn at efforts to perfect, simplify and cheapen the already admirable processes now available. They may rest assured that the worst yet attained by intelligent effort along the new lines of work is infinitely better than the shameful prostitution of streams and lakes now going on throughout this broad land, a marring of the beautiful face of nature, rendering limpid waters black and repugnant, changing their refreshing breezes to sickening odors, while life-giving water is made a death-dealing poison, and all through sewage pollution.

Before taking up sewage purification in detail it will be well to consider what sewage is, from the standpoint of the chemist and bacteriologist, and what should be expected or desired in the way of its purification. Sewage, when fresh, and as it appears at the mouth of an outlet sewer, is generally a cloudy, opaque grey liquid, with some large particles of suspended matter not easily broken up in transit, as orange peels, rags, paper and various nondescript articles too numerous to mention. It very often has a faint, musty odor, and in both looks and smell is sometimes quite comparable with the suds-water of family laundry work. Nearly all of the sewage is simply water, the total solids in supsension averaging perhaps 2 per 1,000, of which a half may be organic matter. It is this 1 part in 1,000 which is to be removed or so changed in character as to be rendered harmless.

These facts regarding the composition of sewage are far different from the popular conception, which pictures a vile mass, indescribable in appearance and odor. Such ideas are gained in part from the known contents of cesspools and from improperly constructed and neglected sewers, but they arise largely in vivid imaginations. They would be applicable in many respects to sewage allowed to stagnate and take on putrescible decomposition, as happens in cesspools and obstructed sewers, or where the sewage stands on the surface of poorly graded land disposal areas, or accumulates in any similar manner before being purified.

The greatest danger from sewage is in the harmful bacteria which it conveys, but even these are not to be feared if kept out of the human system, to which they rarely gain access except through water used for domestic purposes or in connection with milk supplies.

Generally speaking, sewage swarms with bacteria, engaged, when sufficient oxygen is present, in the laudible occupation of converting unstable organic matter which might become offensive into fixed mineral compounds of a wholly unobjectionable character. These plants may number millions to the teaspoonful, and yet be wholly invisible, so minute are the organisms and so hidden is the mighty work in which they are engaged. To isolate the harmful from the harmless with certainty, if at all, is an achievment for some future Pasteur.

The organic matter and the bacteria always accompany each other. If all the bacteria should be removed or killed, but some of the organic matter remain, another crop of microbes would develop as if by magic as soon as seed was sown, although the renewal of disease germs in their orginal quantities would rarely, if ever, occur except from a source the same as or similar to the original. But, remove all the organic matter and all the bacteria food is gone—and without food death comes swiftly, even though the bacteria be legions.

From the above it may be inferred that all sewage purification processes are valuable in so far as they remove or change the composition of organic matter. Mechanical straining, sedimentation and chemical precipitation are largely removal processes, while septic tanks, broad irrigation, intermittent filtration, contact beds and percolating filters change the putrescible organic matter into stable compounds.

Either form of land treatment may be employed where practically complete purification is desired. Straining or sedimentation will remove only a small portion of the organic matter. Chemical precipitation and the use of septic tanks will do more, but must be supplemented by irrigation or intermittent filtration where a high degree of purity is required. Contact beds and percolating filters, generally preceded by septic tanks, but sometimes by sedimentation or chemical precipitation instead, may be relied upon to produce a non-putrescible effluent relatively free from suspended matter, but generally high in bacteria. Aeration may also be be called in to supplement other processes, but the part which it can perform is far more limited than is supposed by many.

The object of sewage purification, then, being the removal of organic matter, and certain modes being available for the partial or complete accomplishment of this end, the question is, which is the most desirable? Like nearly all the other questions which have arisen in the course of this book, and like most other questions in engineering, other sciences or the arts, there is no one answer. The degree of purification required and the local conditions which make one system cheaper than another in construction and operation all have their weight in selecting a system of disposal.

It sometimes happens that a partial removal of the organic matter contained in sewage is ample, in which case the 20 to 30 per cent., more or less, that can be accomplished by either sedimentation or straining will be sufficient. If better results are wanted and some 50 per cent., or slightly more, of purification is needed, the sedimentation may be accelerated by the use of certain chemicals, which constitutes chemical precipitation, or the septic tank may be employed. If neither of these will suffice, the effluent from either process, or in fact from sedimentation or straining, may be applied to a sewage farm, intermittent filters, contact beds or percolating filters ; or where plenty of land is available, all previous treatment may be dispensed with and intermittent filtration or irrigation, commonly known as sewage farming, or a combination of these two land processes, may be brought into requisition to do all the work. Obviously where only partial purification is required there may be a wide range of choice between the methods named.*

Although the object of sewage treatment may sometimes be the removal of bacteria, the chief aspect of most of the sewage works now in operation is to prevent nuisances in the nature of foul sights or odors. Where public water supplies are involved the aim is to keep the sewage out, or to purify the water, or both.

SEDIMENTATION.

This is effected by allowing the sus-

* See "The Partial Purification of Sewage," by Col. Geo. E Waring, Jr., *Engineering News* of Jan. 4, 1894, for an extended discussion of the subject named in the title just quoted.

pended matters to settle in tanks. The partially clarified liquid is drawn off, leaving the solid matter, called sludge, at the bottom for subsequent disposal. This process, as has been intimated, is akin to chemical precipitation, so the shape of the tanks, the relative merits of continuous and intermittent settlement and the treatment of the sludge will be taken up later on.

Experiments with sedimentation at Lawrence, Mass., during the last three months of 1893, indicated a subsidence of 18.2 per cent. of the albuminoid ammonia and 12 per cent. of the bacteria in the crude sewage during a period of four hours. The same experiments in 1894 showed a much better average for organic matter, as measured by the albuminoid ammonia, but about the same results for bacteria, the respective figures being 30 and 14.6 per cent. In 1895, there were removed 48 per cent. of the total albuminoid ammonia, and 31 per cent. bacteria; in 1897, about 35 per cent. of each.*

---

* Reports of the Massachusetts State Board of Health, 1893, p. 4[illegible]6, for 1894, p. 454, 1805, p. 451, and 1897, p. 415.

These experiments were discontinued early tinued early in 1898.

It is hard to imagine conditions in actual practice which would warrant the construction of tanks of sufficient capacity to admit of four hours settlement where only a 30 to 40 per cent. removal of the organic matter could be expected. With smaller tanks the work done would of course be less, so sedimentation is not likely to be employed except where a small amount of purification at a slight expense is all that is needed.

Mechanical Straining.

This admits of a great variety of practice, ranging from attempts to remove rags, paper and other large substances to an approximation to intermittent filtration. Wire screens or filters of various materials may be employed. Generally little is accomplished, but in well-constructed and operated plants screening or straining may be an important factor in the purification effected. As a preliminary to intermittent filtration, coke strainers, or thin filter beds, were used at Lawrence during the last seven months of 1894, removing 52.4 per cent. of the albuminoid ammonia in the original sewage.* These beds ranged from 1½ to 8 ins. in thickness during the experiments, and the sewage passed them at an average rate of about 345,000 gallons a day for six days in the week. A depth of 6 ins. of coke is given as desirable and it is estimated that when straining ordinary sewage from 5 to 8 cu. yds. of coke would have to be removed per 1,000,000 gallons filtered.

Mechanical straining through coke or sand at the rates named might perhaps more properly be termed continuous rapid filtration. Some of the better of the results given are about the same as those secured in the same experiments by means of chemical precipitation, using 1,000 lbs. of sulphate of alumina per 1,000,000 gal-

* Report of the Massachusetts State Board of Health for 1894, p. 455. The reports of the Massachusetts State Board of Health from 1894 to 1902, inclusive, contain accounts of various further experiments with coke, anthracite and bituminous coal as screens. From 3 to 15 ins. of these materials, working at rates of 1,000,000 gallons a day and upwards, removed from 32 to 62 per cent. of the total albuminoid ammonia.

lons of sewage, or 7 grains per gallon, and allowing four hours for precipitation. The mechanical straining usually employed is insignificant in results compared with the above. The same may said of sedimentation. Both processes in these experiments, as well as the chemical tests carried on simultaneously, were intended to facilitate and relieve the work of filter beds.

Chemical Precipitation.

Sedimentation alone removes only such suspended matter as will sink by its own weight during the comparatively brief time which can be allowed for the purpose. Some of the lighter matters may of course be carried down by the heavier particles, but the total results are comparatively small. If the process could be continued long enough, practically all matters in suspension might be removed, but those in solution would remain and putrefaction might begin in the sludge, if not in the sewage undergoing clarification. By adding certain substances chemical action sets in and precipitation occurs. Some of the organic substances are brought together by the formation of new compounds, and as they fall in flaky masses they carry with them other suspended matter. As in sedimentation or straining, a part of the bacteria are removed by mere entanglement, while every grain of organic matter removed decreases by so much the bacterial food supplies, and thus the potential number of bacteria.

A great number and variety of chemicals have been employed as precipitants, but years of experience have resulted in the general adoption of lime, sulphate of alumina and some of the salts of iron, more especially ferrous sulphate or copperas, or a combination of two of these, as best suited for the chemical precipitation of sewage. The character of the sewage and the relative cost of the several chemicals in a given locality should be determining factors. Lime is cheap almost everywhere, but the comparatively large quantities required increase greatly the amount of sludge. Sulphate of alumina is not so readily obtained, and often must be transported such a distance as to make freight rates quite a factor in its cost. It is often used in conjunction with lime, producing a less amount of sludge than lime alone and in some cases doing more effective work. Where either an acid sewage or one containing iron salts is to be treated, lime may be used without the sulphate of alumina and a considerable saving effected. If the acid or iron salts are discharged at intervals the sewage must be tested from time to time to determine when to modify the amount of chemicals artificially applied. A very interesting example of this sort is found at Worcester, Mass., where large quantities of acid and iron are discharged into the city sewers from manufacturing establishments.*

In buying chemicals of any kind great care should be exercised in determining the available amount of the active agent, as the amount of calcium oxide in lime, or of alumina in sulphate of alumina, different products varying greatly in this respect,

* See *Engineering News*, No. 15, 1890, and July 28, 1892; also Rafter and Baker's "Sewage Disposal in the United States."

notably the lime from different quarries and kilns.*

The chemicals should be added to and thoroughly mixed with the sewage before the latter reaches the settling tank. The mixing may be effected in nearly all cases by projections into the channel leading to the tank, called baffle plates.

Experience has demonstrated that the tanks should be long and narrow, and that they should be operated on the continuous rather than the intermittent plan. The width of the tank may be, say one-fourth its length. In the continnous plan the sewage is constantly flowing into one part of the tank and discharging from another in a more or less clarified state. In the intermittent system a tank is filled and then the flow turned elsewhere, allowing the sewage in the first tank to come to rest. Where the continuous plan is used the sewage generally flows through a set

* For the theory of the actions of the various re-agents, the quantities employed and their costs, both in experimental and practical work, see Kafter and Baker's "Sewage Disposal in the United States." The brief limits of this volume render it possible much more than a discussion of general principles; detailed figures, unaccompanied by the data upon which they are based, are apt to be misleading.

of tanks without change of gates or other interruption until one compartment needs cleaning. This compartment being cut out and left to itself for a while, the clarified sewage is then drawn off gradually from the top through a hinged pipe, the upper and open end of which takes sewage from the surface on opening a valve in the horizontal portion of the drain pipe beyond the hinged joint. When the effluent is decanted to the top of the deposited sludge the valve just mentioned is closed and another one, in the sludge pipe, opened, allowing the sludge to flow out, or to be pumped out for final disposition. The tank should then be thoroughly cleaned, after which it may be treated with disinfectants or deodorants, if desired, before being again put in use.

The disposition of sludge is one of the most vexed problems connected with sewage disposal. It is a pasty, semi-liquid mass, ordinarily containing from 90 to 95 per cent. of water and 10 to 5 per cent. of solid matter. The most common method of disposal, and perhaps the one most generally available and satisfactory, is to squeeze as much water as is possible out of the sludge by means of presses designed for the work. This greatly reduces the bulk of the material. The liquid from the press goes back to the tank for further treatment. The sludge cake, as it is called, may be handled easily. It is sometimes burned and sometimes hauled away by farmers for use as a fertilizer. There have been great expectations on the part of projectors of chemical precipitation works that the farmers would vie with each other in securing the sludge, and even pay good money for it. The general experience, both in this country and abroad, has been that a city is lucky if it is able to induce anyone to haul the sludge away for it.

In some cases peat or some other absorbent is mixed with the sludge to render it more easily handled and removed in bulk. Again, it is run out on the surface of coarse sand and gravel beds and its liquid parts reduced by draining and drying. Some of the difficulties connected with this last method are :

(1) In wet weather little drying takes place, and during the colder months the sludge accumulates in considerable quantities. (2) Manual labor must be employed to remove the sludge from the draining and drying beds. (3) Where chemical precipitation is employed suitable land, in character and extent, is often not to be had.

At Birmingham, England, large volumes of sludge are pumped through force mains distributed through portable pipes to and covered with earth.

There remains another method available for some seaside cities, and that is dumping in the ocean by means of large steam sludge ships. Thousands upon thousands of tons are so disposed of from the sewage works of London and Manchester, England, and Glasgow, Scotland.

The capacity of the settling tanks is often the chief factor in determining the cost of installing precipitation works. Assuming that the sewage should be one hour in passage through the tanks, and that the maximum flow is twice the average, provision must be made for one-twelfth the total daily flow, where house sewage only is treated. This makes no allowance for throwing out a portion of the tanks for cleaning or repairs. It would certainly be erring on the safe side, if at all, to provide a tank capacity equal to one-eighth the total maximum daily flow. Where sewage from a combined system is treated, it is of course practically impossible to provide a tank capacity sufficiently large to treat all the sewage. Either the excess of storm water must be discharged into natural water courses along the lines of the sewers or pass by the works without treatment. If ample tank capacity is available it may be possible to treat all the sewage during the first part of a moderate rain. This would mean the purification of the foulest portion of street and other washings, after which in many localities it might be admissible to forego all attempts at purifying the sewage, as the results which could be obtained would be comparatively insignificant. During such a heavy rainfall the sewage of a combined system would be many times diluted, and where the effluent from the works discharges into a stream the latter is also greatly increased in volume. It is evident that where purification is proposed in connection with a new sewerage system the separate plan will practically always be adopted. Most purification plants in this country have been built at the same time as the collecting system, and in such cases the separate plan has been used. Worcester, Mass., was forced to adopt purification after many miles of combined sewers had been built, and after it had converted a brook with a considerable drainage area into an outlet sewer. Its later sewers have been built for house wastes only, and hundreds of thousands of dollars have been spent since the sewage works were built in excluding surface water from the sewers.

The Septic Tank.

The septic tank, as we now know it, has been developed since 1894. In effect, it is a sedimentation basin, so designed and operated as to lessen the sludge deposit by dissolving a portion of it and by reducing another portion to gaseous form. This reduction or hydrolysis of the sludge is brought about by anaerobic bacteria, which work in the absence of air, and are thus directly opposed in character to the aerobic bacteria or nitrifying organism of sewage farms, intermittent filters, contact beds and percolating filters. Since inorganic matter is not acted upon by the bacteria, its exclusion from the septic tank is desirable. To this end, small grit chambers are provided, through which the sewage passes on its way to the septic tank. The high specific gravity of the sand and other mineral matter in the sewage causes much of it to sink in a brief period of time, while the remainder of the suspended matter, including the lighter organic sludge, passes into the septic tank. Since the admission of air to the septic tank would tend to displace the anaerobic bacteria by aerobic, the tank inlets and outlets are generally submerged a foot or so beneath the normal sewage level. The tanks are made long and narrow, thus affording time for sedimentation, and have a sewage depth of 6 to 9 feet. For convenience in removing sludge, their bottoms slope to one or more sumps or gates.

Whether or not septic tanks should be covered has not been universally agreed. It is held by some that a roof, excluding light and air, is a great help, if not a necessity, to the highest efficiency; while others argue that roofing is unnecessary to full bacterial action, except in very cold climates, and that a roof need be provided, if at all, only for such tanks as are near dwellings or much-traveled highways, and which on that account might give offense to residents or passers by.

Any fairly water-tight material may be used in constructing septic tanks; probably concrete, either plain or reinforced, is now used more commonly than any other material. The roof, as well as the walls and bottom, may be of concrete, or where low first cost is an object, wood may be used for roofing.

Since the action of the septic tank is due to anaerobic bacteria, while further purification is effected by aerobic germs, and since the septic effluent is not only high in anaerobic germ contents, and nearly if not quite without available oxygen, the septic effluent is sometimes aerated before being passed to filter beds. Weirs over which the effluent flows in a very shallow stream or a series of overflow steps are used for purposes of aeration.

The amount of sludge removed by septic tanks cannot yet be safely predicted for a given sewage works until actual tests have been made. Such figures as are available show wide variations at different localities. No one should be deluded by observations of the amount of sludge remaining in a septic tank, since large volumes of sludge in a finely divided state may pass off in the effluent. Volume for volume, however, this finely divided suspended matter will make far less trouble than the sludge from ordinary settling tanks or from chemical precipitation works. Some of it is already a mineral ash, subject to no further organic change, and the balance is partly reduced to mineral matter and also to food for the low forms of organic life.

Such sludge as remains in septic tanks may be disposed of by the means already described.

In some cases, probably due to the character of the sewage or to improper operation, sludge from septic tanks is offensive when first exposed to the air. Under such a condition the sludge disposal should be carried on at a remote point, or the sludge should be buried quickly a few inches beneath the earth. Investigations should also be made to determine whether the odors cannot be prevented by a change in the design or operation of the tank.

Were it within the scope of this book, and less free from conflicting claims, it would be interesting to attempt to trace the history of the septic tank. The subject involves claimants in Great Britain, the United States, Germany and France; and also many early tanks installed and used with success, though with little or no understanding of the principles involved, long before the name septic tank came into use. It is now generally recognized that the man who gave the septic tank its name and brought it into scientific prominence was Donald Cameron, of Exeter, England, but up to early in the year 1905 it was not generally conceded that Cameron's work entitled him to patent control of the septic tank process. The question was then in the courts of the United States for trial, but had never been legally raised in Great Britain, so far as the author of this book could learn.

Artificial Aeration. — "Electrical" Processes.

While the oxygen of the atmosphere may be made one of the greatest agents in purifying sewage, some writers and others have laid too much stress upon the value of artificial aeration. Mountain streams, which tumble over rocky beds, are noted for their purity, and this has been attributed largely to the aeration which the water receives. It should be remembered that the waters of such streams are generally of a high degree of purity to start with, often being little different from rainwater just from the clouds, and that the aerating process is quite commonly a long one. It has been further observed that even badly polluted streams show greatly improved chemical analyses at points a number of miles below the source of contamination. But here, sedimentation, and the action of both animal and vegetable life in their more minute forms, play a notable part in the purification process, and the time-element is also important.

It has been well established by the Massachusetts State Board of Health in its Lawrence work that the two essentials for the removal or transformation of the organic matter in sewage are oxygen and time, where dependence is placed on a nitrifying or oxidizing process. The time-element has been largely ignored by some theorists, a few of whom have put their theories into practice. Purification plants have been built, and more have been projected, in which the great reliance has been put upon artificial aeration, either by forcing air into the sewage or by causing the latter to fall through the air in drops or streamlets. This has been accompanied by rapid filtration, generally through sand. Now aeration of the sewage, or of the filtering material, may be employed as an aid to sewage purification, but like all things else it has its limits. It can maintain a supply of oxygen which is of use up to a certain point and this will be of value. All in excess of this amount is of no value, and even this is not of use unless time is given for the action of the oxygen and of the nitrifying organism. The latter develops rapidly in the presence of oxygen and organic matter, transforming the latter into mineral compounds. These facts are overlooked by some of the promoters of aerating processes,the assumption seeming to be that given a plenty of air the desired work will be accomplished almost instantly. The facts are that sewage soon loses all the available oxygen taken up by it during aeration and needs to be aerated again and again until all the organic matter is transformed. The time-element can best be secured, almost invariably in some form of filter bed.

Perhaps there is an even greater misunderstanding regarding so-called electrical methods of sewage purification. These processes, which have met with but little favor, simply prepare by electrical means some chemical agent which performs all the work accomplished and might be obtained in some other manner, although possibly at greater expense. In the Woolf and Hermite processes either sea water or a solution of common salt, according to the readiness of obtaining one or the other, is partially decomposed by an electric current, and sodium hypochlorite is formed. The solution is mixed with the sewage and acts as a deodorizer and germicide, its efficiency depending on its strength. The organic matter remains in the sewage and is subject to secondary decomposition later on. The product obtained by this process might be of value under certain conditions, the same as other good disinfectants are, but there seems to be no reliable information to show that anything further can be expected of it.

The direct treatment of sewage by electricity has been talked of for some time but it still remains a dream.

Broad Irrigation or Sewage Farming.

Where sewage is applied to the surface of the ground upon which crops are raised the process is called broad irrigation, or sewage farming. The practice is in most respects similar to the ordinary irrigation of crops with clean water, the sewage being applied by a variety of methods, according to topographical and other natural conditions and the kind of crops under cultivation.

The land employed for this method of purification should preferably be composed of a fairly light, porous soil. The crops should be such as require, or at least develop best under a large amount of moisture. Where the soil is heavy and wet, and the crops cannot stand much water, the sewage must be applied sparingly, and so a large amount of land and much labor must be provided. As broad irrigation areas may be prepared at comparatively small expense it is sometimes feasible to make use of land not so well suited to the purpose as might be desired, provided it can be obtained cheaply enough and too much stress is not laid upon the raising of crops. The less the attention paid to cropping, generally speaking, the greater the amount of sewage which can be put on a given area of land. Wet, clayey soils can take but little sewage under any circumstances, but sometimes improve with cultivation and the application of sewage.

The application of an average of from 5,000 to 10,000 gallons of sewage per day to one acre of land is considered by many as a liberal allowance. On the basis of 100 gallons of sewage per head of population this means that one acre of land is sufficient for a population of from 50 to 100 persons. More could be purified if the crops would stand it, but for each kind there is a limit which if passed means the destruction of the crop.

Allowing even 10,000 gallons of sewage, or 100 persons, to an acre in a city of 20,000 inhabitants would require 200 acres. To find suitable land at a low price near cities is not always easy. The larger the city the greater the difficulty. Labor, too, is a big item in sewage farming on this side the Atlantic, especially near cities. As a partial offset to this, great cities afford excellent and never-failing markets. Another great obstacle to adequate financial returns from sewage farming in America is the deplorable fact that political ends and not business principles govern in large numbers of our cities, though there is good reason to predict a great change in this respect ere long. Where such conditions do prevail, however, the positions of both superintendents and laborers on sewage farms are almost sure to be considered rewards for and encouragements to party service, with results most unfavorable to the enterprise in hand. Sewage farming means the selling as well as the raising of crops, and perhaps of live stock, and so requires business ability and agricultural skill. The latter must be accompanied with the faculty of handling considerable bodies of men.

These apparently discouraging statements are meant rather as warnings. They are necessary because of the glowing representations which have been made regarding the profits of sewage farming by those who have not looked at all sides of the question. I am not unmindful of the results of sewage farming abroad, but European conditions are far different from ours. Many of the European farms are most admirably managed, both from an agricultural and business standpoint, and not a few of them have to contend with soil far less favorable than could be found in many sections of the United States. I do not say that an American city could not conduct so great an enterprise in a creditable manner, for we have many well-conceived and well-operated municipal works of great magnitude. I do say that high prices for land near large cities, costly labor, a constant warfare against corruption with too frequent surrenders, and our sudden and complete changes in government all make sewage farming more difficult here than abroad.

For the present, sewage disposal cannot be accomplished in this country at a profit. It is sometimes possible to regain through the raising of crops a part of the expense entailed in removing and purifying sewage, and this is the only method by which any considerable portion of the expense has yet been recovered here or elsewhere. We should be thankful for the day of small things, and wherever a revenue can be obtained from irrigation area or filtration beds our efforts should be to secure it. But the logic of figures will often show that some method of disposal that carries with it no financial returns is the cheapest, in which case instead of crying over spilt and wasted sewage, we may laugh over a saving in capital, interest and maintenance.

Wherever irrigation, pure and simple, that is the application of water to crops for the sake of moisture, can be practiced to advantage, sewage farming should receive serious consideration, for in such localities every drop of water is valuable. As ordinary irrigation may yet be used in the East as well as in the West, (it is already practiced to some extent in the South) the use of sewage for mere watering as well as fertilizing may some day be seen here and there throughout the length and breadth of the land. This is a subject which demands careful investigation and perhaps might be taken up with advantage by some of our agricultural experiment stations and by any live official in a position to do so.*

* For an article on "The Use of Sewage for Irrigation in the West" see *Engineering News* for Nov. 3, 1892; the substance of the article is also given in Rafter and Baker's "Sewage Disposal in the United States." A later treatment of the subject may be found in "Sewage Irrigation," Nos. 3 and 22 of Water Supply and Irrigation Papers of the U. S. Geological Survey, by Geo. W. Rafter, M. Am. Soc. C. E. In March, 1905, the author of this book visited the sewage farm of Pasadena, Cal., and also land to which some of the sewage of Los Angeles is applied. As a result, he is more than even convinced of the wisdom of using sewage for irrigation wherever water is scarce.

Sub-Surface Irrigation.

Before passing on to intermittent filtration a word should be said regarding sub-surface irrigation. The system is capable of use on a small scale, chiefly for private dwellings, various public institutions and small communities where for any reason surface disposal would be objectionable. The sewage is distributed through agricultural drain tiles, laid with open joints, and placed only a few inches below the surface. Provision should be made for changing the disposal area as often as the soil may require by turning the sewage into sub-divisions of the distributing pipes. The sewage is generally discharged automatically at intervals on the filling of a tank to a certain height. Where surface application can be practiced it would generally, if not always, be preferable to this system.

Intermittent Filtration.

This method of sewage purification is capable of producing the highest results under favorable conditions, and those conditions prevail perhaps more widely in this country than like ones for any other system.

The process is a most simple one. With a competent man in charge large areas of beds can be operated with cheap labor. The construction of the beds is nearly as simple as their operation, only common labor being required, except for putting down pipe and accessories.

The essential features of filter beds are some 4 to 5 feet of medium-sized sand, located above the natural ground water level; a pipe system for distributing the sewage to one or more points on each bed, and another beneath the bed, for collecting the purified liquid. In operation, the sewage is turned on to one bed for a given length of time, and then to another, in order to give the first a rest, or literally a breathing spell. When the beds become clogged with the matter retained on their surface and in their uppermost part, they may be raked over, or the sludge, and with it a thin layer of sand, may be scraped off.

If the beds are scraped, it will eventually be necessary to make good the sand removed, although this will not be required until perhaps a foot has been taken off, which should not result for a long time.

Intermittent filtration is a nitrifying process effected through the agency of oxygen and bacteria, and requiring time for these two factors to act. A more complete definition is perhaps that given in the Report of the Massachusetts State Board of Health for 1893, as follows:

> The process * * * consists of intermingling the sewage in the pores of the filtering material, with sufficient air for a sufficient time, in the presence of micro-organisms which quickly establish themselves there.

Experience has taught that a good filtering material is one composed of clean, sharp sand with grains of uniform size, and having interstices forming about one-third the total volume. The interstices serve as air spaces. When the sewage is admitted to the sand not all the air is driven out, and hence there is a store of oxygen to be drawn upon by the bacteria.

As more and more sewage is added the oxygen is exhausted, the nitrifying bacteria diminish in numbers, as they cannot live without air, and the efficiency of the purification process diminishes. If the application of sewage ceases, the beds gradually become drained as the sewage goes down, air is drawn into the pores of the bed, until finally a new supply is secured and the operation can be repeated. The sewage in filter beds spreads itself in thin films over the sand grains, thus giving bacteria an opportunity to develop, feed upon the organic matter, and so break it up as to cause the formation of new compounds, until the organic matter is transformed into inorganic.

If intermittent filtration were a mere straining process, then the finer the sand used the higher the degree of purification. As already pointed out, it is a nitrifying rather than a straining process, so the aim must be to select a material of the size best suited to that end, and which will at the same time give the highest rate of filtration with the least expenditure of labor.

The finer materials give a low rate of filtration and a high degree of purity. The sewage not only enters the sand slowly, but a long time is required to drain it out and renew the air. If crowded, poor results and ultimate clogging follow. With coarse material the sewage passes through too rapidly for nitrification to take place. The drainage and air renewal can therefore be effected quickly. It is thus evident that with very fine material the sewage must be applied slowly, with long intervals of rest, while with very coarse material the rate of application must be yet slower and the rests far more frequent, though short. As compared with material of a medium size, the fine does not give sufficiently better results, in actual practice, to warrant its adoption, nor does the higher rate possible with the coarse material. The slow rate of filtration and the tendency to clog, on the one hand, and the very frequent manipulation of gates to throw the beds into and out of use, on the other, are against the extremes. Moreover, the very coarse materials are not so certain in their removal of bacteria as fine ones. Here, as elsewhere, a happy mean is to be sought. Rejecting the extremes, the Massachusetts State Board of Health, in its report for 1891, gives as the range of available material sand having 10 per cent. of its weight composed of grains finer than 0.03 to 0.98 millimeters (0.0012 to 0.0392 ins.).

All material in filter sands finer than 0.01 mm. (0.0004 ins.) is classed as organic matter. The maximum size of the coarser materials included in the above range was about 0.5 in. in diameter, and the minimum size of the finest material was 0.01 in. in diameter.

As the work done by a filter is largely determined by smaller particles of sand, and as a sand of uniform size is desired, the Massachusetts State Board of Health has adopted two standards for comparing different materials. The sand is subjected to mechanical analysis to determine the percentages, by weight, of the total which have grains below a certain diameter. The diameter at the 10 per cent. point is taken as the effective size, and the uniformity coefficient is the ratio between the diameter of the grains at the 60 and 10 per cent. points.

Although a range in the size of the sand grains may be allowed, the coarse and finer particles should be fairly well intermingled. Or, in other words, there should not be strata of fine and coarse material in a filter bed. The effect of stratification is well expressed in the report of the Massachusetts State Board of Health for 1892, as follows:

> We have thus found that with a coarse material above a fine one in the same filter there is a chance of trouble from a clogging of the fine material below the coarse; and this is far worse than surface clogging, for the latter can be completely remedied by disturbing the surface or by scraping. We have also found that a fine sand supported by a coarse sand will keep its lower layer saturated and act as a water seal, allowing the passage of water, but not of air, and may in this way prevent the necessary circulation of air, and reduce the action of the filter to mere straining.

* * * * * * * *

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

Not all communities are so fortunate as to have ideal filtering material conveniently located for sand filter beds. If not, then the choice may be between extending the outfall sewer to a distance, with or without pumping, and the adoption of a site giving poor material and thus requiring a larger area, or an inferior sand may be the only kind available far or near. The Lawrence experiments, to which reference has freely been made, have now been carried on for about seventeen years, and the results of fifteen years' studies of a great variety of material under widely different conditions are on record in the published reports of the Massachusetts State Board of Health. Actual results obtained at city filter beds are also available, so that with expert advice any community may ascertain the approximate possibilities of such materials as are at hand. While a wide range of sands and gravels may be counted on for giving good results, under proper conditions, it is necessary to determine those conditions in order to know what area of beds to provide, and how to apply the sewage after the disposal grounds are ready. The area and volume of sand or gravel required for the intermittent filtration of sewage are so large that the transportation of material any great distance is out of the question. Generally speaking, the beds are constructed in material as naturally deposited, top soil and loam of course being removed, together with any pockets of other unsuitable material.

The sewage is carried to the several beds through open or closed channels built in the embankments, with distributing chambers where two or more beds join together. Ordinary sewer pipe, half pipe, brick, concrete or even wood conduits may be used. The distributing chambers may be of any of the above materials, excepting sewer pipe, but are generally of masonry. Wood carriers or accessories are to be avoided, if possible, on account of becoming sewage-soaked, and thus liable to give off bad odors.

The sewage should be brought onto the beds so as to disturb their surface as little as possible, and great pains should be taken to distribute it evenly over the whole bed.

The underdrains should rarely, if ever, be placed more than 50 feet apart, and should be provided with manholes, or inspection chambers at all intersections. Underdrains are sometimes put much nearer together than this. Their size and depth will be governed by the amount of effluent they are expected to remove, the ground water level and possibly other local conditions.

Before admitting sewage to the beds it is generally advisable to screen it, at least sufficiently to take out paper, rags and large floating matter. The screening chambers often serve to some extent as settling tanks, but must be of pretty large size to remove any considerable proportion of the total matters in suspension.

Crops are sometimes raised on filter beds, which is equivalent to practicing broad irrigation in summer and filtration the remainder of the year. The beds generally being thoroughly underdrained, and the soil often more permeable than that of a broad irrigation area, larger doses of sewage may probably be applied to crops on filter beds than those growing on ordinary sewage farms.

The size of each bed should be such as to permit an easy and equable distribution of sewage over it. Where the total filtration area is small it must be divided so as to permit of intermittent operation; that is, if a bed is to be in use and at rest for equal periods, then at least two beds would be necessary, and so on according to the relative periods of use and rest. Some additional area should also be provided for use while beds are being scraped or in case of an emergency. If a large area is laid out so that the size of the beds is limited only by convenience in use, then an acre may be a very acceptable size.

As to degree of purification which may be expected, and the rate of filtration, it may be said, without going into details, that practically all of the organic matter may be removed from sewage by intermittent filtration at rates approximating 100,000 gallons per acre per day, with the best material and all conditions favorable. With unfavorable conditions the rate may be as low as 30,000 gallons per acre per day or even less.

Contact Beds.

To make possible an increase in the low rates feasible with intermittent filtration under even the best conditions, and also to lessen the clogging of such beds (the two efforts being largely identical), the Massachusetts State Board of Health early began to experiment with various preliminary processes of sewage treatment, including rapid filtration of various sorts and sedimentation. A little later than these experiments, and in some instances coincident with them, a number of men began experiments on their own account. These included the late Colonel George E. Waring in America, and Scott-Moncrieff, Dibdin and others in Great Britain. In the latter country intermittent filtration has almost always been supplemental to broad irrigation or sewage farming. The clayey nature of most of the available land and the density of population, made imperative some change in sewage treatment in Great Britain, and from about 1892 on gave rise to a multiplicity of new schemes. Except for details these schemes may be narrowed down to contact beds and percolating filters, with the septic tank, which has been described already, available as preliminary to either of these, and also to broad irrigation and sewage farming. Although, as a rule, it is dangerous to credit these newer processes to a single man, the contact bed may be ascribed to W. J. Dibdin, for some years Chemist to the London County Council. The percolating filter, as described in subsequent pages, cannot be so readily credited to a single individual, since the Massachusetts State Board of Health, Colonel Waring, Scott Moncrieff and several others had a hand in its development. Both the contact bed and the percolating filter, in their working form and the extent of their use, are essentially British. It may also be stated here that the septic tank was combined with contact beds almost if not quite from the beginning of the development of the former by Donald Cameron.

The contact bed differs from the American type of intermittent filter in being composed of much coarser material, generally enclosed by water-tight walls and floor, the basin thus formed being provided with inlet and outlet gates. It also differs from the intermittent filter in that when in use the outlet gates are closed, the bed filled quickly and held full for two hours or so, then emptied quickly and kept empty for two to four or five hours. The series of operations is called a cycle, and there are from two to four cycles in each 24 hours. The filling and emptying gates are frequently worked automatically by means of specially designed apparatus.

Contact beds are built for operation singly, in pairs and in groups of three; the sewage in the last two cases passing through two or three beds in succession. When built in pairs a coarse and a fine bed are provided. The coarse material is approximately from 3-4 to 2 ins. in greatest diameter, and the fine material from 1-4 to 1 in. The material now most commonly used in contact beds abroad is hard clinker from soft coal or from refuse destructors, but coke, broken stone, gravel and other substances may be employed. Care should be taken to select a material which does not readily disintegrate. The coarse beds are sometimes called primary, and the fine ones secondary, and sometimes the terms single and double contact beds are used.

The relatively large size of the material composing these beds, and of the interstitial spaces, permits quick filling and emptying, and facilitates also a rapid renewal of the air supply in the free spaces or pores of the bed. The latter, in turn, favors an enormous bacterial development and a correspondingly speedy breaking down and transformation of the organic matter of the sewage. As can be understood, holding the sewage in the bed in contact with the bacterial agents gives the beds their name.

Some form of preliminary treatment, most commonly septic or sedimentation tanks, has been found advisable before applying sewage to contact beds, particularly where only a single contact is provided. A high degree of bacterial removal is not commonly effected by contact beds, unless very fine material is employed, but the organic matter in the sewage may nevertheless be so transformed as to prevent nuisance from subsequent putrefaction, which is usually the main object of sewage treatment. With such an object it is reported that satisfactory results have been obtained when passing settled or septic sewage through double contact beds at rates of from 500,000 to 1,000,000 gallons an acre of total surface area.

Percolating Filters.

Trickling, streaming and intermittent continuous filters are some of the names that have been applied to the last class of filters awaiting consideration, but both reason and usage are on the side of the term percolating filters.

The essential features of percolating filters are the use of large-sized material, with the freest possible aeration and drainage, and a uniform distribution of the sewage over the filter in drops, small streams or spray. The sewage has an uninterrupted passage through the drainage system of percolating filters, just as through intermittent filters, but the sewage is applied continuously, or with numerous brief interruptions that break the continuity but a little, in the case of percolating filters, and the distribution is so even and rapid, and the pores of the filters are so large, that no sewage stands on the percolating filters, whereas the surface of intermittent filters is often flooded hours at a time.

Percolating filters are generally built on a solid floor of concrete or other water-tight material, and enclosed by open-jointed walls, the latter consisting of large fragments of the medium, laid up with open joints, or regular sized moulded or cut pieces, laid pigeon-hole fashion. The body of percolating filters is composed of clinker, stone or other fairly cohesive material, in particles from the size of a hen's egg or a man's fist up to that of a man's head, the larger pieces being placed at the bottom.

Distributors for percolating filters may be revolving radial arms of wrought-iron pipe, perforated, or revolving radial weirs, or fixed pipes provided with mere perforations or with spray nozzles. Drains, formed in the concrete or other solid floor, or consisting of specially moulded tiles, are used to ensure thorough drainage.

The effluent from percolating filters, even when the original sewage is given a preliminary treatment, is usually high in finely divided suspended matter, and also in bacteria, but, as a rule, the effluent is non-putrefactive and, being largely mineral matter, is easily removed or reduced in quantity by a brief period of sedimentation. The rates claimed for percolating filters, dosed with septic sewage, range from 1,000,000 to 10,000,000 gallons an acre, but in the present state of the art 2,000,000 to 3,000,000 gallons seems high.

Sewage Purification Plants Not Nuisances.

There is often much opposition to sewage purification plants by those living or owning property near by on the ground that such works must of necessity be a nuisance. From experience gained by visiting many such plants, both in this country and abroad, and from studying the subject in other ways for years, I know that well conducted plants are entirely inoffensive, either within or without their enclosures. The employees about such works are as healthy as similar classes of men in other occupations, and the same holds true of the families of these men living on the European sewage farms.

The crops raised on sewage farms are as safe eating as those of the same kind raised elsewhere. There are objections, however, to applying sewage to crops for human consumption which are to be eaten without being cooked, but meat and milk from sewage farms is usually as good as when produced under other conditions.

Good design and construction, followed by proper methods of operation, are all that are needed to make sewage purification a success, when once the right system has been adopted and put into use. No one system can be said to be the best for all localities. The special problems of each community must be met and solved case by case and out of several systems and combinations of systems the best for the conditions at hand must be chosen.

The Present Status of Sewage Purification.

In the United States, chemical precipitation is no longer being adopted for new plants. The septic tank has come more rapidly into favor than contact beds or percolating filters, but some men of practical experience seem strongly inclined to plain sedimentation rather than the septic tank. Comparatively few percolating filters have been built, but small contact beds are in use in a number of cases. Intermittent filtration has for years been the system most in use in America, and seems likely to continue to lead where sandy land for filter beds is available at a reasonable price. In our Far West, sewage irrigation is frequently practiced, but as a rule the sewage is merely a substitute for water in sections where irrigation is a necessity. What appears to be the most successful sewage farm in the United States treats the sewage of Pasadena, Cal. Large and paying crops of walnuts are raised each year. On a visit to the Pasadena sewage farm in March, 1905, the author was told that a large number of orange trees would be set out soon, and that sewage would be put on these in the summer and on the walnut trees in the winter.

Early in 1904 the author visited twenty-four sewage works in Great Britain and three on the continent of Europe. He found numerous chemical precipitation plants and sewage farms still in use, at the works visited and elsewhere, but many of these were being converted to, or supplemented by, the newer processes. The septic tank was widely used. Contact beds were numerous and percolating filters were fast becoming so.

In America the septic tank, contact beds and percolating filters are far less often used, compared with other processes, than in Great Britain. Local conditions abroad, it should be remembered, are widely different from local conditions here. The streams of Great Britain are small and the population dense, requiring more sewage works than are yet felt to be necessary in the United States, and the clayey soil and absence of good natural filtering material in England and Scotland compels the adoption of clinker, coke and other substitutes. All these things should be remembered in selecting a mode of treatment and filter bed material for American sewage works.

If it seem to any that the newer processes of sewage treatment have been but briefly discussed, the author would point out the fact that in 1904 there was published a whole volume in this series, entitled, "The Treatment of Septic Sewage," by George W. Rafter, M. Am. Soc. C. E. Later in 1904, the author of the book now being brought to a close, embodied his recent observations in Great Britain and at Paris, Frankfort and Wiesbaden, in "British Sewage Works." Present day sewage treatment, from the viewpoint of British authorities, is set forth in Barwise's "The Purification of Sewage," Rideal's "Sewage and the Bacterial Purification of Sewage," and Dibdin's "The Purification of Sewage and Water." The first American book on sewage was Rafter and Baker's "Sewage Disposal in the United States," a large treatise on the subject published early in 1894, before the septic tank, contact beds and percolating filters had come into public view. A revision of this treatise is under consideration.

No. 63. HOUSE-DRAINAGE AND SANITARY Plumbing. By W. P. Gerhard. Twelfth edition.

No. 64. ELECTROMAGNETS. By A. N. Mansfield. Second edition, revised.

No. 65. POCKET LOGARITHMS TO FOUR Places of Decimals. Including Logarithms of Numbers, etc.

No. 66. DYNAMO-ELECTRIC MACHINERY. By S. P. Thompson. With an Introduction by F. L. Pope. Third edition, revised.

No. 67. HYDRAULIC TABLES FOR THE CALculation of the Discharge through Sewers, Pipes, and Conduits. Based on "Kutter's Formula." By P. J. Flynn.

No. 68. STEAM-HEATING. By Robert Briggs. Third edition, revised, with additions by A. R. Wolff.

No. 69. CHEMICAL PROBLEMS. By Prof. J. C. Foye. Fifth edition, revised and enlarged.

No. 70. EXPLOSIVE MATERIALS. By Lieut. John P. Wisser.

No. 71. DYNAMIC ELECTRICITY. By John Hopkinson, J. N. Shoolbred, and R. E. Day.

No. 72. TOPOGRAPHICAL SURVEYING. By George J. Specht, Prof. A. S. Hardy, John B. McMaster, and H. F. Walling. Fourth edition, revised.

No. 73. SYMBOLIC ALGEBRA; OR, THE ALGEbra of Algebraic Numbers. By Prof. William Cain.

No. 74. TESTING MACHINES; THEIR HIStory, Construction and Use. By Arthur V. Abbott.

No. 75. RECENT PROGRESS IN DYNAMOelectric Machines. Being a Supplement to "Dynamo-electric Machinery. By Prof. Sylvanus P. Thompson.

No. 76. MODERN REPRODUCTIVE GRAPHIC Processes. By Lieut. James S. Pettit, U.S.A.

No. 77. STADIA SURVEYING. The Theory of Stadia Measurements. By Arthur Winslow. Eighth edition.

No. 78. THE STEAM - ENGINE INDICATOR and Its Use. By W. B. Le Van.

No. 79. THE FIGURE OF THE EARTH. By Frank C. Roberts, C.E.

No. 80. HEALTHY FOUNDATIONS FOR Houses. By Glenn Brown.

***No. 81. WATER METERS: COMPARATIVE** Tests of Accuracy, Delivery, etc. Distinctive Features of the Worthington, Kennedy, Siemens, and Hesse meters. By Ross E. Browne.

No. 82. THE PRESERVATION OF TIMBER BY the Use of Antiseptics. By Samuel Bagster Boulton, C.E.

No. 83. MECHANICAL INTEGRATORS. By Prof. Henry S. H. Shaw, C.E.

No. 84. FLOW OF WATER IN OPEN CHAN-nels, Pipes, Conduits, Sewers, etc. With Tables. By P. J. Flynn, C.E.

No. 85. THE LUMINIFEROUS AETHER. By Prof. De Volson Wood.

No. 86. HANDBOOK OF MINERALOGY; DE-termination, Description, and Classification of Minerals Found in the United States. By Prof. J. C. Foye. Fifth edition, revised.

No. 87. TREATISE ON THE THEORY OF THE Construction of Helicoidal Oblique Arches. By John L. Culley, C.E.

***No. 88. BEAMS AND GIRDERS. Practical For-**mulas for their Resistance. By P. H. Philbrick.

No. 89. MODERN GUN COTTON: ITS MANU-facture, Properties, and Analyses. By Lieut. John P. Wisser, U.S.A.

No. 90. ROTARY MOTION AS APPLIED TO the Gyroscope. By Major J. G. Barnard.

No. 91. LEVELING: BAROMETRIC, TRIGONO-metric, and Spirit. By Prof. I. O. Baker. Third edition.

No. 92. PETROLEUM; ITS PRODUCTION AND Use. By Boverton Redwood, F.I.C., F.C.S.

No. 93. RECENT PRACTICE IN THE SANI-tary Drainage of Buildings. With Memoranda on the Cost of Plumbing Work. Second edition, revised and enlarged. By William Paul Gerhard, C.E.

No. 94. THE TREATMENT OF SEWAGE. By Dr. C. Meymott Tidy.

No. 95. PLATE-GIRDER CONSTRUCTION. By Isami Hiroi, C.E. Fourth edition, revised.

No. 96. ALTERNATE-CURRENT MACHINERY. By Gisbet Kapp, Assoc. M. Inst., C.E.

No. 97. THE DISPOSAL OF HOUSEHOLD Wastes. Second edition. By W. Paul Gerhard, Sanitary Engineer.

No. 98. PRACTICAL DYNAMO-BUILDING FOR Amateurs. How to Wind for Any Output. By Frederick Walker. Fully illustrated. Third edition.

No. 99. TRIPLE-EXPANSION ENGINES AND Engine Trials. By Prof. Osborne Reynolds. Edited with notes, etc., by F. E. Idell, M.E.

No. 100. HOW TO BECOME AN ENGINEER; or, The Theoretical and Practical Training necessary in Fitting for the Duties of the Civil Engineer. By Prof. Geo. W. Plympton.

No. 101. THE SEXTANT, and Other Reflecting Mathematical Instruments. With Practical Hints for their Adjustment and Use. By F. R. Brainard, U. S. Navy.

No. 102. THE GALVANIC CIRCUIT INVESTI-gated Mathematically. By Dr. G. S. Ohm, Berlin, 1827. Translated by William Francis. With Preface and Notes by the Editor, Thomas D. Lockwood. M.I.E.E. Second edition.

No. 103. THE MICROSCOPICAL EXAMINATION of Potable Water. With Diagrams. By Geo. W. Rafter. Second edition.

No. 104. VAN NOSTRAND'S TABLE-BOOK FOR Civil and Mechanical Engineers. Compiled by Prof. Geo. W. Plympton.

No. 105. DETERMINANTS. An Introduction to the Study of, with Examples and Applications. By Prof. G. A. Miller.

No. 106. COMPRESSED AIR. Experiments upon the Transmission of Power by Compressed Air in Paris. (Popp's System.) By Prof. A. B. W. Kennedy. The Transmission and Distribution of Power from Central Stations by Compressed Air. By Prof. W. C. Unwin. Edited by F. E. Idell. Third edition.

No. 107. A GRAPHICAL METHOD FOR SWING Bridges. A Rational and Easy Graphical Analysis of the Stresses in Ordinary Swing Bridges. With an Introduction on the General Theory of Graphical Statics, with Folding Plates. Second edition. By Benjamin F. La Rue.

No. 108. SLIDE-VALVE DIAGRAMS. A French Method for Constructing Slide-valve Diagrams. By Lloyd Bankson, B.S., Assistant Naval Constructor, U. S. Navy. 8 Folding Plates.

No. 109. THE MEASUREMENT OF ELECTRIC Currents. Electrical Measuring Instruments. By James Swinburne. Meters for Electrical Energy. By C. H. Wordingham. Edited, with Preface, by T. Commerford Martin. With Folding Plate and Numerous Illustrations.

No. 110. TRANSITION CURVES. A Field-book for Engineers, Containing Rules and Tables for Laying out Transition Curves. By Walter G. Fox, C.E. Second edition.

No. 111. GAS-LIGHTING AND GAS-FITTING. Specifications and Rules for Gas-piping. Notes on the Advantages of Gas for Cooking and Heating, and Useful Hints to Gas Consumers. Third edition. By Wm. Paul Gerhard, C.E.

No. 112. A PRIMER ON THE CALCULUS. By E. Sherman Gould, M. Am. Soc. C.E. Third edition, revised and enlarged.

No. 113. PHYSICAL PROBLEMS and Their So-lution. By A. Bourgougnon, formerly Assistant at Bellevue Hospital. Second edition.

No. 114. USE OF THE SLIDE RULE. By F. A. Halsey, of the "American Machinist." Fourth edition, revised and enlarged.

No. 115. TRAVERSE TABLE. Showing the Dif-ference of Latitude and Departure for Distances Between 1 and 100 and for Angles to Quarter Degrees Between 1 Degree and 90 Degrees. (Reprinted from Scribner's Pocket Table Book.) Third edition.

No. 116. WORM AND SPIRAL GEARING. Re-printed from "American Machinist." By F. A. Halsey. Second revised and enlarged edition.

No. 117. PRACTICAL HYDROSTATICS, AND Hydrostatic Formulas. With Numerous Illustrative Figures and Numerical Examples. By E. Sherman Gould.

No. 118. TREATMENT OF SEPTIC SEWAGE, with Diagrams and Figures. By Geo. W. Rafter. Second edition.

No. 119. LAY-OUT OF CORLISS VALVE GEARS. With Folding Plates and Diagrams. By Sanford A. Moss, M.S., Ph.D. Reprinted from "The American Machinist," with revisions and additions. Second edition.

No. 120. ART OF GENERATING GEAR TEETH. By Howard A. Coombs. With Figures, Diagrams and Folding Plates. Reprinted from the "American Machinist."

No. 121. ELEMENTS OF GAS ENGINE DE-sign. Reprint of a Set of Notes accompanying a Course of Lectures delivered at Cornell University in 1902. By Sanford A. Moss. Illustrated.

No. 122. SHAFT GOVERNORS. By W. Trinks and C. Housum. Illustrated.

No. 123. FURNACE DRAFT; ITS PRODUCTION by Mechanical Methods. A Handy Reference Book, with figures and tables. By William Wallace Christie. Illustrated. Second edition, revised.