DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 3

SEWAGE IRRIGATION.—RAFTER

WASHINGTON
GOVERNMENT PRINTING OFFICE
1897

IRRIGATION REPORTS.

The following list contains the titles and brief descriptions of the principal reports relating to water supply and irrigation prepared by the United States Geological Survey since 1890:

1890.

First Annual Report of the United States Irrigation Survey, 1890, octavo, 123 pp.

Printed as Part II, Irrigation, of the Tenth Annual Report of the United States Geological Survey, 1888-89. Contains a statement of the origin of the Irrigation Survey, a preliminary report on the organization and prosecution of the survey of the arid lands for purposes of irrigation, and report of work done during 1890.

1891.

Second Annual Report of the United States Irrigation Survey, 1891, octavo, 395 pp.

Published as Part II, Irrigation, of the Eleventh Annual Report of the United States Geological Survey, 1889-90. Contains a description of the hydrography of the arid region and of the engineering operations carried on by the Irrigation Survey during 1890; also the statement of the Director of the Survey to the House Committee on Irrigation, and other papers, including a bibliography of irrigation literature. Illustrated by 29 plates and 4 figures.

Third Annual Report of the United States Irrigation Survey, 1891, octavo, 576 pp.

Printed as Part II of the Twelfth Annual Report of the United States Geological Survey, 1890-91. Contains a report upon the location and survey of reservoir sites during the fiscal year ending June 30, 1891, by A. H. Thompson; "Hydrography of the arid regions," by F. H. Newell; "Irrigation in India," by Herbert M. Wilson. Illustrated by 93 plates and 190 figures.

Bulletins of the Eleventh Census of the United States upon irrigation, prepared by F. H. Newell, quarto.

No. 35, Irrigation in Arizona; No. 60, Irrigation in New Mexico; No. 85, Irrigation in Utah; No. 107, Irrigation in Wyoming; No. 153, Irrigation in Montana; No. 157, Irrigation in Idaho; No. 163, Irrigation in Nevada; No. 178, Irrigation in Oregon; No. 193, Artesian wells for irrigation; No. 198, Irrigation in Washington.

1892.

Irrigation of western United States, by F. H. Newell; extra census bulletin No. 23, September 9, 1892, quarto, 22 pp.

Contains tabulations showing the total number, average size, etc., of irrigated holdings, the total area and average size of irrigated farms in the subhumid regions, the percentage of number of farms irrigated, character of crops, value of irrigated lands, the average cost of irrigation, the investment and profits, together with a résumé of the water supply and a description of irrigation by artesian wells. Illustrated by colored maps showing the location and relative extent of the irrigated areas.

1893.

Thirteenth Annual Report of the United States Geological Survey, 1891-92, Part III, Irrigation, 1893, octavo, 486 pp.

Consists of three papers: Water supply for irrigation, by F. H. Newell; American engineering and engineering results of the Irrigation Survey, by Herbert M. Wilson; Construction of topographic maps and selection and survey of reservoir sites, by A. H. Thompson. Illustrated by 77 plates and 119 figures.

A geological reconnoissance in central Washington, by Israel Cook Russell, 1893, octavo, 108 pp., 15 plates. Bulletin No. 108 of the United States Geological Survey; price, 15 cents.

Contains a description of the examination of the geologic structure in and adjacent to the drainage basin of Yakima River and the great plains of the Columbia to the east of this area, with special reference to the occurrence of artesian waters.

(Continued on third page of cover.)

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UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

SEWAGE IRRIGATION

BY

GEORGE W. RAFTER

WASHINGTON

GOVERNMENT PRINTING OFFICE

1897

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, February 4, 1897.

SIR: I have the honor to transmit herewith a paper entitled "Sewage Irrigation," by George W. Rafter, and to recommend that it be published as the third number of the series of papers upon water supply and irrigation. The manuscript of this paper as submitted by Mr. Rafter contains a considerable number of details, which have been to a certain extent generalized, and also gives a discussion of sewage purification in the United States, with descriptions of the works erected at various localities, together with an appendix containing a list of publications relating to sewage irrigation. The limit of 100 pages has, however, necessitated the dividing of the manuscript into two parts. The first constitutes this paper, while the latter has been held for publication in a future number of this series. It refers mainly to the results attained in various portions of the United States, and gives a few examples from the neighboring Province of Canada. The changes that have been made in Mr. Rafter's paper have been in the direction of adapting it to popular use, in order that the necessities and benefits of sewage irrigation may be more generally appreciated by the public.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

IRRIGATING CORN BY SEWAGE ON FILTER AREAS AT PLAINFIELD, NEW JERSEY

SEWAGE IRRIGATION.

By George W. Rafter.

IMPORTANCE OF SEWAGE IRRIGATION.

Owing to the rapid growth of urban population during the past few decades, and the consequent increase of pollution of streams from which water supplies are obtained, the subject of sewage disposal has come to be one of prime importance. As regards the United States, however, it is only within the past few years that the subject of sewage purification and its relation to the purity of streams has attracted general attention. In view of the large number of people concerned and the benefits to be derived from the dissemination of information on this subject, there is probably no topic relating to water supply and irrigation which is of greater importance to the country as a whole.

The citizens of all our municipalities are interested as a mere matter of sanitation in the innocuous disposal of sewage. Independent of commercial considerations, the towns should welcome any suggestion looking toward ridding them of what is in most cases a dead weight on the hands of the municipal authorities. The farmers, especially market gardeners in the vicinity of towns, should be able to utilize sewage with advantage to themselves, thus rendering beneficial what is otherwise a source of danger to health. It is the object of this paper[1] to point out to American farmers and to municipal authorities

[1]There is nothing especially new or original with the author in the methods of sewage irrigation which are here presented. It is merely proposed to describe, so far as possible in non-technical language and for the benefit of American farmers, not only what is being done to-day abroad, but also what is being done here at home. The author wishes in this connection to acknowledge his obligation to a number of sanitary engineers who have kindly placed at his disposal information and illustrative material embodied in this paper. In addition to courtesies received from gentlemen connected with the management and operation of sewage farms abroad, as acknowledged in the paper in connection with the discussion of the several farms described, the author is under special obligation to James Forest, esq., now honorary secretary of the Institution of Civil Engineers, for information as to how and where to see the best examples of sewage farming in England. Among American engineers to whom acknowledgment is due may be mentioned Samuel M. Gray, M. Am. Soc. C. E., of Providence; Allen Hazen, Assoc. M. Am. Soc. C. E., of Boston; Frank H. Snow, Assoc. M. Am. Soc. C. E., city engineer of Brockton, Massachusetts; George H. Carpenter, C. E., city engineer, Pawtucket, Rhode Island; Carroll Phillips Bassett, M. Am. Soc. C. E., civil and sanitary engineer, Summit, New Jersey; Benezette Williams, civil and sanitary engineer, Chicago; George H. Frost, C. E., business manager Engineering-News; M. N. Baker, Ph. B., associate editor of Engineering News; Col. George E. Waring, M. Inst. C. E., street commissioner, New York; and Harrison P. Eddy, C. E., superintendent of sewers, Worcester, Massachusetts.

the fact that under certain conditions sewage may be utilized with profit and to indicate in general terms how this may be done.

In the arid and semiarid portions of the West sewage utilization is of especial importance, for there every drop of water, especially during the summer season, is needed for the production of crops. The relatively small flow of the streams, combined with the warm climate, renders sewage especially obnoxious if not properly cared for, so that considerations of health and comfort are added to those of increased land values due to complete utilization of the water supply. The introduction of sewage irrigation in the West is more easily accomplished than in the East because of the general employment of water in agriculture. The first use of sewage in this connection in the West was probably at Cheyenne, Wyoming, in 1883. It has also been used at Colorado Springs and Trinidad, Colorado, at Fresno, Pasadena, Redding, Los Angeles, Santa Rosa, and Stockton, California, at Salt Lake City, Utah, and at Helena, Montana.

The popular idea, not only with us here at home but very largely abroad, is and has been that anything and everything connected with sewerage and sewage disposal is of so vile a character that it must be kept entirely out of sight. Out of sight, out of mind, has been the universal principle thus far. The immense aggregation of population in cities, however, by forcing the subject upon the attention of urban communities, has served to modify somewhat this popular misapprehension. At the present time the few persons who have thought out the rational view of these subjects hold that the old notion was, like many old notions, essentially wrong. Sewage is a great fact of existence, and the proper way is not to ignore it but to meet the problem on its merits, the same as other difficulties are met and overcome. In this spirit, in England, at any rate, it has become quite common to build the necessary works connected with sewerage and sewage disposal as ornamental as possible, and in the United States this plan has been likewise followed in a few places.

Sewage purification was first attempted in England about forty years ago. At that time extravagant and, in the main, essentially erroneous views were entertained as to the possibilities of its utilization in agriculture. Especially was this true as regards the manufacture of artificial fertilizers from the sludge of various chemical processes. Large investments of capital were made and concessions granted by towns to private companies, practically all of which were for processes of chemical purification. With very few exceptions these investments have all proved a dead loss. The purification of sewage by chemical treatment at a commercial profit has been found impracticable. In the meantime land processes, which have developed contemporaneously with the chemical purification processes, have in every sense held their own, until at the present time it can be said that under proper conditions a fair profit may be made by the cultivator from the utilization of sewage in agriculture.

About twelve years ago the author began to collect information in regard to the pollution of streams and the purification of sewage, with special reference to the conditions existing in the United States. At that time, aside from the work done by the Massachusetts State Board of Health and that just begun by the city of Philadelphia, very little information was available as to stream pollution in this country; necessarily one studying the subject must go to the foreign sources of information, and for this purpose nothing better could be found than the voluminous English sanitary reports, issued from time to time by various royal commissions and by a number of the large municipalities of that country. But since about 1886 the subject of sewage purification and its relation to the purity of streams has received much consideration in the United States, so that at the present time we have over sixty purification works in operation. American data are therefore accumulating rapidly, and we may hope in a few years more to have arrived at a full understanding of the more important principles involved in sewage purification and the prevention of pollution of streams as applied to our special conditions.

The conditions here are quite different from those existing abroad. In the first place, the streams are much larger, and so far as the production of mere effluvium nuisances is concerned they can take larger quantities of sewage without offense, although it ought not to be overlooked that since many of our streams are the sources of public water supplies the effect of sewage pollution may be even more harmful than though effluvium nuisances were produced, which, however unpleasant to the sense of smell, are not always the source of special impairment of health. Again, it may be pointed out that land, even in the immediate vicinity of large towns, is much cheaper here than abroad. In a number of cases in England the lands utilized for sewage irrigation have cost as much as £400 to £500 per acre, whereas with us frequently suitable lands can be purchased within practicable distance of towns for from one-quarter to one-eighth of these figures.

The large amount of experience gained abroad should have weight and value. For this reason an attempt is herein made to present saliently the current European practice of sewage utilization. We have tried too often to work out for ourselves what is popularly known as the American method, ignoring the experience of others. We may thus attain unto knowledge in the course of time, but meanwhile many unprofitable investments will be made and money and time will be unnecessarily lost. In this respect the conditions are similar to those seen in the development of ordinary forms of irrigation in the West, where frequently expensive works have been built and operated without a knowledge of the water supply or other conditions. A very cursory study of Old World irrigation would have saved considerable loss and resulted in more satisfactory results than those now attained. In many of these older countries, having physical and climatic conditions almost identical with our own, methods of agriculture and of controlling and utilizing water have been developed through the trials and failures of unnumbered generations. We are merely repeating many of their mistakes, and are only gradually coming to appreciate the fact that a more complete knowledge of the experience of the rest of mankind would be of incalculable value to us.

GENERAL PRINCIPLES.

The more important of the general principles discussed in this paper are brought together at this point for convenience of reference:

(1) Sewage purification is an imperative duty which municipalities owe to the owners of riparian rights, and which can not be neglected by municipalities without such an infringement upon those rights as it is now well established may be prevented by legal process.

(2) Sewage utilization should go hand in hand with purification. When operated with reference to all the necessary conditions, a proper degree of purification may be attained as well as satisfactory utilization.

(3) The proper method of utilizing sewage is, for purposes of irrigation, by means which do not differ, except in matters of detail, from those of ordinary irrigation as practiced abroad for centuries.

(4) In order to utilize sewage to the best advantage, the towns should construct, at their own expense, intermittent filtration areas on which the sewage may be efficiently purified when not required for use in agriculture. Farmers utilizing sewage in agriculture should be required to take it only as needed for the best results on crops.

(5) The theory of the action of intermittent filtration is in effect the theory of purification as effected by broad irrigation, the difference between the two being chiefly a matter of detail.

(6) In the purification of a strong acid sewage from manufacturing towns it may sometimes become desirable to treat the sewage by a chemical process before utilizing it in agriculture. For this purpose lime is the chemical commonly used.

(7) In case the effluent from sewage purification works or areas is to be passed into streams which are the source of drinking water for towns farther down, the degree of purification should necessarily be high. The experiments of the Massachusetts State Board of Health show that there is no trouble in removing from 95 to 99½ per cent of the organic impurity, as indicated either by the chemical constituents or by the bacteria. When as much as 99 per cent is removed, the sewage becomes chemically purer than the water of many wells, and there is, so far as known, absolutely no reason why it may not pass safely into a stream used as the source of a public water supply.

(8) Intermittent filtration areas are best constructed of coarse mortar sand, as shown by the experiments of the Massachusetts State Board of Health.

(9) Intermittent filtration is chiefly a biological process, in which the nitrifying organisms, with the assistance of oxygen and the minerals naturally in solution in sewage, resolve objectionable organic matter into mineral nitrates, etc., the whole process, when properly conducted, taking place without the production of objectionable odor. The conditions for successful treatment are, generally, intermittency of application and open spaces in the filtering material to which common air may easily gain access. Such filters may be expected to purify from 30,000 to 100,000 gallons per acre per day, the amount depending upon the quality of the material in respect to sand and water content, as defined by the studies of Mr. Allen Hazen.[1]

(10) Sewage may be purified by broad irrigation at all seasons of the year at any place where the mean air temperature of the coldest month is not lower than about 20° to 25° F., while by the use of intermittent filtration it may be purified fairly well down to a limit of 18° to 20° F., provided the sewage reaches the purification area at a temperature not lower than about 45° F.

(11) From the experience gained abroad it is clear that we may successfully cultivate almost any of the ordinary agricultural productions of the United States on sewage farms, due regard being had in every case to the special conditions required for each particular crop.

(12) The most efficient purification of sewage can be attained by its application to land.

(13) On properly managed sewage farms the utilization of sewage is not prejudicial to health.

(14) In comparing the results of sewage utilization as thus far obtained in the United States with the results obtained abroad it is clear that, generally speaking, we have not been specially successful. As one chief step toward a remedy for this we need to create in this country a class of sewage-farm managers who are thoroughly familiar with all phases of the question. Thus far the management of American sewage farms has been usually in the hands of committees of municipal councils having little or no knowledge of the real governing conditions.

(15) The experience in England, Germany, and France, and also that gained in this country, all points to intermittent filtration relief areas, on which any surplus sewage not required in agriculture may be purified, as the rational method of procedure.

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[1] From 30,000 to 100,000 gallons of ordinary raw town sewage may be so thoroughly purified that it may be admitted to streams from which public water supplies are taken. If a less thorough purification is required, or if the sewage has been previously treated with lime, from 200,000 to 300,000 gallons per acre per day may be successfully purified.

SEWAGE DEFINED.

Before proceeding to the main discussion, it is necessary to know the meaning of the terms in common use. By *sewerage* we refer to the general practice of removing the liquid and solid wastes of the human economy, as well as the washings of streets and manufacturing wastes, by water carriage. A *sewer* is the conduit in which, by the medium of water, such removal is effected. *Sewage* is the generic term, not only for the combined water and waste matter flowing in sewers, but also for the mixed solid and liquid matter handled either by pail or by pneumatic systems.

Ordinary city sewage contains a great variety of ingredients in addition to the waste water from kitchens, baths, laundries, and other domestic offices. In manufacturing districts it may contain the refuse substances of various manufacturing processes, the whole diluted with a considerable amount of water, to which, in rainy weather, in towns with combined sewerage systems, is added a large amount of sand and earth and organic matter from the street washings. With separate systems of sewers street washings are excluded, and the sewage, by reason of containing the house drainage only, has a much more uniform composition than is found in the sewage from combined systems; whence it results that the sewage from separate systems is somewhat more amenable to treatment, for two reasons: (1) because of more uniform composition; (2) on account of less variation in quantity. In case sewage is to be purified at sewage-disposal works, both these considerations lead to decrease in first cost of the works as well as to decrease in annual expense of operation. In case of utilization of sewage for irrigation, the same considerations lead to certainty and ease in the utilization as well as to decrease in the expense.[1]

In American cities, which use at least 60 to 100 gallons[2] of water per capita per day,[3] sewage is considerably more dilute than in foreign cities, where from 30 to 50 gallons per capita is more nearly the daily allowance. As remarked by Mr. Mills in the special report of the Massachusetts State Board of Health, we may say that the sewage of the average American town will contain something like 998 parts of water, 1 part of mineral matter, and 1 part of organic matter. The mineral matter, as it ordinarily exists in sewage, can not be considered as specially harmful, and from a sanitary point of view the object of

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[1] See Sewage Disposal in the United States, Rafter and Baker, Chapter VIII, "General data of sewage disposal," and Chapter IV, "The self-purification of running streams," etc., for detailed discussion of fundamental points only briefly touched upon here.

[2] In all cases by gallons is understood the United States gallon of 231 cubic inches, or 0.13368 cubic feet.

[3] For information as to the use of water in American cities and towns in detail, see the Manual of American Water Works. A few cases are cited on page 16, following.

sewage purification is chiefly to get rid of the one one-thousandth part of organic matter.[1]

Comparing several series of analyses, both American and English, it becomes apparent that ordinary town sewage in England is usually considerably more concentrated than that of the American towns. It is very important to bear this in mind in applying English data to American conditions. The elaborate experiments conducted by the Massachusetts State Board of Health at Lawrence, and which have been reported from year to year in the annual reports of that board from 1888 to the present time, indicate that there is a relation between the purifying capacity of different filtrating materials and the amount of impurity which can be removed from sewage of a given strength. This point is strongly brought out by the experiments conducted by the Massachusetts board. It follows, then, that if we prepare special areas of sewage purification in accordance with the indications of the Massachusetts experiments we may expect to apply somewhat larger volumes of average American dilute town sewage per unit of area than has usually been found expedient in English practice. If, therefore, we use English data without reference to the quality of the soil to which the sewage is to be applied, or of the sewage itself, we shall be likely to arrive, at times, at more or less erroneous conclusions.

As a summation of this part of the discussion, we may say that the chief object of sewage purification is to rid the sewage of the one one-thousandth part of organic matter which it contains, and that all of the appliances for sewage purification and utilization may be considered as directed toward this one point.

QUANTITY OF SEWAGE.

In considering processes for the utilization of sewage, either in agriculture or for its direct purification by chemical methods or by intermittent filtration, it becomes necessary to learn, first of all, what quantity of sewage may be expected from a given population, and, inasmuch as the flow of sewage will vary with the quantity of water supply, our first inquiry may be properly directed toward ascertaining the amount of water used in American towns. It may be pointed out, however, and, indeed, strongly insisted upon, that general discussion of this phase of the question can only be of use as indicating tested and approved methods of procedure. The conditions vary so greatly in different towns that each case must be taken by itself as a problem for special solution.

If we examine statistics of the average consumption of water per inhabitant in the various cities of the United States, as given in the Manual of American Water Works and in other publications, we

[1] See table in the Twenty-Sixth Annual Report of the State Board of Health of Massachusetts, 1894, page 457, for the average composition of the sewage used in the experiments conducted at Lawrence by that board from 1888 to 1894, inclusive.

learn that there are wide variations. Without attempting to show their extent here, we may cite the statistics of a few cities of the United States by way of illustration:

Average use of water in various cities of the United States.

City.	Population, 1890.	Daily use per inhabitant.
		Gallons.
New York	1,515,301	79
Chicago	1,099,850	140
Philadelphia	1,046,964	132
San Francisco	298,997	61
Buffalo	255,664	186
Washington	230,392	158
Allegheny, Pennsylvania	105,287	59
Lowell, Massachusetts	77,696	66
Fall River, Massachusetts	74,398	29
Cambridge, Massachusetts	70,028	64
Atlanta, Georgia	65,533	36
Dayton, Ohio	61,220	47
Troy, New York	60,956	125
Trenton, New Jersey	57,458	62
Portland, Oregon	46,385	203
Lawrence, Massachusetts	44,654	62
Manchester, New Hampshire	44,126	44
Williamsport, Pennsylvania	27,132	143
Birmingham, Alabama	26,178	162
Newton, Massachusetts	24,379	40

Many other cases could be cited from a vast mass of statistics bearing upon this subject now in existence, but the foregoing are sufficient to show that the use of water in towns, both large and small, does not follow any special law, and that the only way to proceed will be to consider each case on its merits. On this point we may say that usually the use is smaller in towns provided with meter systems than in those without, and, further, that in those towns where meters are being gradually introduced the tendency seems to be, on the whole, toward a reduction per capita of consumption; all of which again emphasizes the importance of studying each case on its merits.

In making arrangements for utilizing sewage in agriculture, or even for the purpose of purifying it in order to comply with sanitary requirements, it is very important to take into account the future growth of the town. The tendency of the last few decades has clearly been in the direction of great increase in urban population, as illustrated by the reports of the last census.

In addition to variations in quantity of sewage due to varying uses of water in public supplies, we may frequently expect to find variations due to infiltration of drainage water into the sewers themselves, which will of course increase the flow of sewage over and above that due to the water supply, and to leakage from the sewers through gravel and other porous material and through the seams of rocks, which tends to decrease the flow below the amount due to the water supply. Both of these sources of variation will frequently operate to modify conclusions based upon water supply purely.

According to Frederick P. Stearns, M. Am. Soc. C. E.,[1] the amount of ground water finding its way into the sewers of the main drainage system of the city of Boston is about 45 gallons per capita per day. This large filtration is due chiefly to the fact that many of the older sewers of Boston are built of either dry or relatively open rubble masonry, while some of them follow the threads of old water courses, both of these circumstances leading to relatively large contributions of ground water.

At East Orange, New Jersey, a separate system of sewers was carried out in 1886 and 1888. The infiltration as measured before any house connections were in use was, for 25 miles of vitrified tile sewers, about 2.5 gallons per second. For the main brick sewer, 4,000 feet in length, the infiltration was 5 gallons per second. The total infiltration from the whole system amounted at these rates to 650,000 gallons per day. The flush-tank flow was taken at 30,000 gallons per day, and after the house connections were made the house-sewage flow from the contributing population of about 15,000 was taken at 620,000 per day; hence the infiltration was 50 per cent of the total quantity.[2] The remedy for a leakage into the sewers of this character may be found in improved methods of laying the sewers themselves. In any case it may be pointed out that an addition to the sewage flow proper of 50 per cent in the way of ground water is an unnecessary addition to the expense of sewage purification, should any be required.

We will assume, as regards the present argument, that the sewers of a separate system may, with careful workmanship, be made practically impervious, and that the sewage flow will therefore be about represented by the amount of the public water supply. We will further assume that there is no good reason why, in a properly managed municipality, there should be used more than from 60 to 80 gallons of water per capita per day. At this rate the sewage flow of a population of 10,000 would amount to from 600,000 to 800,000 gallons per day. In combined systems where the sewers receive the rainfall as well as the sewage proper it will be necessary to provide, in any purification project, for taking care of and properly purifying a considerable portion of the storm water at each rainfall.

[1] Special Report upon the Sewerage of the Mystic and Charles River Valleys, as made to the State Board of Health of Massachusetts.

[2] See Inland sewage disposal, with special reference to the East Orange (New Jersey) works, by Carroll Phillips Bassett, M. Am. Soc. C. E.: Trans. Am. Soc. Civil Eng., Vol. XXV, p. 125.

STREAM POLLUTION.

It is a well-established principle of law that every riparian proprietor is entitled to have a stream of water flow by his realty as it is wont to flow by nature. From this principle we have derived the old and well-settled doctrine that to pollute a public stream is to maintain a common nuisance. The necessities and conditions of modern society have, however, tended to some modification of this principle as thus strictly announced, so that at the present time there are certain reasonable pollutions of streams, or, rather, there are certain specific cases in which a stream may be polluted to some extent without abrogating the essential force of the fundamental proposition. At the same time it must be remembered that the broad proposition that streams ought not to be polluted is on the whole sound.[1] Admitting such premise, we are forced to the conclusion that some form of sewage purification is necessary wherever an aggregation of human beings in thickly settled communities leads to the production of any considerable amount of sewage.

If, however, towns or manufacturing establishments are situated on tide water, there is no reason why the sewage may not be disposed of by discharging it into the ocean, provided such a discharge can be made without creating a nuisance along inhabited beaches, and also provided it is clear that such discharge is, on the whole, financially to the advantage of the community furnishing the sewage. But if on examining all the attendant circumstances it appears that the sewage can be profitably utilized in agriculture, then there is no reason why such utilization may not be made, even in the case of towns situated on tide water. We need, therefore, as a necessary part of our subject, to discuss the general question of purification of streams. This question has been the subject of a large amount of discussion in England, where interest in it may be considered as dating from the first report of the Health of Towns Commission, made in 1844.[2]

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[1] The legal aspects of stream pollution as the matter stands to-day are discussed in Sewage Disposal in the United States, Chapter VI. The attention of the reader is specially directed to the views of the Massachusetts Drainage Commission as there given. The report of that commission may also be referred to, though, as it has long been out of print, it is now difficult to obtain.

[2] This commission made two reports: The first, in 1844, published in two octavo volumes; the second, in 1845, also in two octavo volumes. These two reports may be taken as the beginning of sanitary science in England and in the civilized world generally. Previous to and at that time the condition of the English towns, especially in the manufacturing districts, as shown by the information contained in these two reports, was such that the present generation can only with difficulty realize it. These reports should be studied by any person wishing to compass the whole subject of sewage utilization, by way of showing the magnitude of the evil which has been combated and greatly mitigated since 1844.

Among the subjects which this commission was especially charged with investigating were the causes of disease among the inhabitants as well as the best means of promoting and securing the public health. The commission pointed out a large number of cases where stream pollution was undoubtedly the cause of insanitary conditions, and the notable sanitary reforms which have placed England as regards sanitary improvements easily in the front rank of nations have all been perfected since that date. During the same period the literature of sanitation has been enriched by a number of valuable reports in which every possible phase of stream pollution has been discussed.

Without referring here to all of the various commissions in detail, we may cite the Royal Sanitary Commission of 1869, and the Rivers Pollution Commission. The former recommended that any stream from which drinking water is taken should be effectually protected from sewage pollution. The principle laid down at that time has been gradually extended until we now formulate it by the statement that streams which are even likely to be a source of water supply ought not to receive sewage pollution, or, if they do, only under such regulations as will admit of immediate discontinuance of the pollution whenever the water is required for domestic purposes.

The Rivers Pollution Commission[1] in their report point out not only the evils of pollution by sewage proper, but also those produced by pollution from manufacturing refuse. As regards this second class of pollutions, from manufacturing refuse, the following classification can be made: Pollution by dye, print, and bleach works; chemical works; tanneries; paper making; woolen works; silk works.

The reports of the Royal Commission on Metropolitan Sewage Discharge and of the Royal Commission on Metropolitan Water Supply also contain much information relating to stream pollution.

In this country stream pollution has been generally discussed by the State boards of health of Massachusetts, Connecticut, Illinois, and some of the other States. In Massachusetts the State Board of Health made the following recommendations many years ago:[2]

(1) That no city or town shall be allowed to discharge sewage into any water course or pond without first purifying it according to the best process at present known, which is irrigation; provided, that this regulation does not apply to a discharge from sewers already built, unless water supplies be thereby polluted; and

[1] Rivers Pollution Commission (first commission). This commission made three reports. The first report deals generally with the best methods of preventing the pollution of rivers, with special reference to the conditions prevailing at that time on the River Thames. The second report deals with the River Lea. The third report deals with the rivers Ayr and Calder. Five volumes in all, 4°, London, 1866-67.

Rivers Pollution Commission (second commission). Report of the commissioners appointed in 1868 to inquire into the best means of preventing the pollution of rivers. This commission made six reports in all. The first report (2 volumes) treats of the pollution of the basin of the rivers Mersey and Ribble and of the best means of preventing pollution therein. The second report is taken up with a description of the A B C process of treating sewage. The third report (2 volumes) discusses the pollution arising from the woolen manufacture and processes connected therewith. Whoever would understand this division of stream pollution in all its phases should study this report. The fourth report treats of the pollution of the rivers of Scotland, and gives special consideration, among other subjects, to the pollution arising from paper-mill wastes, etc. The fifth report (2 volumes) treats of the pollution arising from mining operations and metal manufactures. The sixth report treats of the general subject of domestic water supply of Great Britain. A large amount of information about water supplies from cultivated and uncultivated areas and the contamination of water from manured and unmanured, cropped and uncropped land, is given, the whole forming a vast body of sanitary information pertinent to present conditions. Ten volumes, 4°, London, 1870-71-72-74.

[2] Seventh Annual Report, 1876, p. 12. To illustrate the pollution to which a single stream is subject, reference should be made to the Eighth Annual Report of the Massachusetts State Board of Health. In this it is stated that on the Nashua River are 92 mills, employing 5,543 persons. This stream drains an area of 437 square miles, with an average population of 106.5 to the square mile.

The reports of the Philadelphia water department, from the eighty-third to the eighty-sixth, inclusive, may be referred to for information in regard to stream pollution.

provided also, that any intended discharge of sewage can be shown to be at such point that no nuisance will arise from it.

(2) That no sewage of any kind, whether purified or not, be allowed to enter any pond or stream used for domestic purposes.

(3) That each water design should be regarded by itself in the preparation of plans for sewerage and water supplies.

(4) That accurate topographical surveys always be made of all towns before introducing water supplies or sewers.

(5) That steps should be taken by special legislation, based upon investigations and recommendations of experts, to meet cases of serious annoyance arising from defective arrangements for the disposal of sewage.

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In the Tenth Annual Report of the Connecticut State Board of Health (1888), Prof. S. W. Williston, of Yale University, has given an excellent account of the wastes from manufacturing processes, which may be referred to as perhaps the most useful recent contribution to the literature of river pollution. At any rate, it easily ranks first among recent American contributions to that literature. Professor Williston takes up in his report the waste due to various manufacturing processes, such as brass working, iron working, paper making, woolen, cotton, and silk mills, and so on, and gives under each head the chief sources of pollution.

As to brass works, it is stated that they are productive of little sanitary injury to a stream, although the discharge of their chief waste, sulphate of copper, is the most poisonous to fish of any of the manufacturing wastes. Brass works, therefore, usually cause the fish to leave any stream which receives a considerable quantity of refuse from the works. Aside from sulphate of copper, the other waste products of brass works are acids and oils. In many of the brass manufacturing establishments, especially those using the electro-metallurgical process, considerable quantities of cyanide of potash and ammonia are used. Goods requiring electroplating are first treated with an alkali to remove any greasy matters adhering to the metal, and are then subjected to a dilute acid bath in order to remove the oxides from the surface. They are then placed in a cyanide of potash solution, which acts as the carrier in the deposition of the metal upon the surface plated.

Cyanide of potash is a virulent poison, and Professor Williston states that a sufficient quantity is annually employed in the Naugatuck Valley, in Connecticut, to destroy all the inhabitants of the United States. Most of it, however, is neutralized by the other chemicals used, so that it is doubtful whether its contaminating influence is very great.

In the manufacture of iron the only waste of importance is that from the pickling baths used for giving a nonoxidized surface to either wire or flat sheets which are to be galvanized. Such iron is dipped in a solution of dilute sulphuric acid and then washed in water, after which it is again dipped in a vat containing a heated solution of lime, to neutralize any small amount of acid not removed by the washing in water.

IRRIGATION ON SIDEHILL AS PRACTICED AT WAYNE, PENNSYLVANIA.

The chief waste from this process is sulphate of iron, which at many works is allowed to pass directly into streams, although not all of it is thus allowed to go to waste, as a number of the large rolling mills of the country have appliances for saving the sulphate of iron; as, for instance, the Cleveland Rolling Mill, at Cleveland, Ohio; the Ferric Chemical and Color Works, at Worcester, Massachusetts; and the Washburn & Moen Wire Works, also at Worcester. A large proportion of the crude sulphate of iron of commerce consumed in the United States is produced at these several works.

The waste products from paper manufacturing are both organic and inorganic in character. In mills using jute, gunny sacking and old rope, and other similar substances as the raw material, the organic wastes of the wash water may become a very serious source of pollution if discharged into small streams or if a considerable number of mills all discharge their wastes into a stream of considerable size. Caustic soda and lime are used for cleansing rags in places where rags are the raw material of paper manufacture. These wastes are usually allowed to pass into the stream. In mills using sulphite and wood pulps the wastes from the wash waters generally contain a considerable amount of objectionable substances, the bleaching process also requiring a considerable amount of chloride of lime, which, in this country at any rate, usually passes into the streams without treatment. The bleaching wastes are especially injurious to fish.

In a woolen manufactory the most serious wastes are those derived from the washing of the wool; constituting, as it does, chiefly organic material, it may be considered one of the most objectionable organic wastes. The raw wool of the ordinary grades, as it comes to the manufactory, contains a third or more by weight of organic matter; this is ordinary washed wool. Unwashed fine wools may contain as much as 50 to 60 per cent of organic matter, which is removed chiefly by scouring in alkaline solutions of soda, although in some mills urine is used in this process, as it is believed to give a softer finish to the manufactured article than can be obtained by the use of ordinary alkalies.

The woolen mills also furnish a large amount of dye waste, such as extracts of logwood, fustic, camwood, madder, etc., which are used in different methods of dyeing with various mordants, such as copperas, crude cream of tartar, bichromate of potash, alum, blue vitriol, and muriate of tin. After treatment in the dyeing vat, the wool is washed in running water and, usually, the contents of the vat are turned into the nearest stream. It is waste material of this sort that causes the chief complaints as to discoloration of streams by dye wastes. A certain amount of oil is also used in woolen manufacture, and more or less waste therefrom passes into the stream.

In manufacturing cotton goods the wastes are both organic and mineral, the former being the more serious. In the manufacture of ginghams the following chemicals are commonly used: Sulphuric acid, nitric acid, muriatic acid, chloride of lime, sal soda, soda ash, bichromate of potash, alum, copperas, blue vitriol, lime, pearlash, stannate of soda, sugar of lead, indigo, cutch, sumac, alkali, soda, and the various aniline colors and dyes. Of the mineral matters, the most important are lime, chloride of lime, and bichromate of potash; of the organic dyestuffs, logwood. The waste from these various substances is usually allowed to pass without treatment into the streams.

In silk manufactures the raw silk as received is covered with a gummy substance which it is necessary to remove in order that the silk may possess the proper degree of pliableness. This silk gum, which is called sericine, constitutes from 20 to 25 per cent of raw silk and is mostly soluble in water. It is removed either by maceration or by scouring in a weak solution of soda. The refuse from these processes is usually turned into streams. The further processes of silk manufacture, as related to stream pollution, are those of dyeing, which are only of secondary importance. It is stated that there is less waste of dyestuff from silk mills than from mills manufacturing other kinds of fabrics.

In considering the effect of stream pollution we should bear in mind that all streams have some self-purifying power. Nature has provided in soils a natural agent for the innocuous resolution of organic matter into its simple constituent elements. The agent of nitrification exists in soils in vast quantities, and we may draw the conclusion that every rain washes these purifying agents into streams, where their work of destroying organic matter is continually going on, although not with the same degree of rapidity as in soils. One indispensable condition of the efficient action of the nitrifying agent is the presence of an adequate supply of oxygen. All natural waters contain more or less oxygen in solution, but unfortunately the stock is not large enough to admit of rapid action of the nitrifying agent. Hence it follows that, while it is true that the process of nitrification goes on in natural waters as in soils, it is also equally true that it proceeds much less rapidly there than in soils, with the result that a natural water is more easily overburdened with work of this character than a natural soil. This fact leads to the conclusion that soil is really the natural element in which to resolve objectionable organic matter into its simple, elementary forms, rather than water. Natural waters should be called upon to perform this duty only when no other means are available, it being remembered always that it is easy to overburden the purifying power of water in this direction.

It is still true that a stream may exert considerable self-purifying power, provided it is given time enough. This view is enforced by considering that in addition to the presence in our natural waters of the agent of nitrification there are also present certain classes of minute life which feed upon extraneous organic matter and which without doubt resolve a considerable portion of it through the operations of the life process. The Entomostraca, Rotifera, and Infusoria are the principal agents assisting in such reduction. Of these the Entomostraca are probably the most important. This branch of our subject leads to biological studies of great interest and importance, but which for lack of space can not be more than referred to in this place.[1]

VALUE OF SEWAGE.

From an agricultural point of view the nitrogen, phosphoric acid, and potash are the most useful ingredients of sewage, and accordingly it becomes of interest to establish the quantity of these three elements which may be found in ordinary sewage. Taking that of about average composition,[2] a net ton may be expected to contain nitrogen to the amount of from 0.15 to 0.25 pounds; phosphoric acid, from 0.045 to 0.065 pounds; and potash, from 0.025 to 0.040 pounds. With nitrogen at 17 cents per pound, phosphoric acid at 7 cents, and potash at 5 cents, the theoretical value of the fertilizing ingredients of such a sewage would be, per net ton, from about 3.5 cents to 4.5 or 5 cents. Taking into account, however, the various losses of the nitrogen, which is not only the most valuable but also the least stable element, as well as the expense of distribution, we may conclude that the manurial constituents of sewage have an actual value, when applied to good advantage in agricultural utilization, of from 1 to 2 cents or perhaps 3 cents per ton. We should note that this is the manurial value only.

Independent of the manure, the water of sewage has also a distinct value for irrigation. But by reason of the variation in local conditions, it is impossible to make any general statement of value which will apply to all cases, although in a general way we may say, taking into account the manurial constituents as well as the irrigation value of the water, that sewage, when applied to land at the best advantage, may be considered, with the present understanding of things, as worth from 2 to 4 cents per net ton. In some cases, by reason of its value for irrigation, it may be worth several times these figures.

We learn, then, that the irrigation value of sewage may be quite as important as the distinctively manurial value, and it is believed that the recognition of this factor has placed sewage utilization on a somewhat different plane from that formerly occupied. In order to illustrate this point let us consider the matter briefly from an historical point of view.

When sewage disposal as a necessary concomitant of the sewerage

[1] For an extended presentation of this phase of the subject see discussion, by the author, of Dr. Charles G. Currier's paper on Self-purification of flowing water and the influence of polluted water in the causation of disease: Trans. Am. Soc. Civil Eng., Vol. XXIV, p. 70.

[2] See extended tabulations from Wolff and Lehmann in the first report of the Rivers Pollution Commission, p. 27. Also see Storer's Agriculture, Vol. II, p. 70.

of cities first grew up in England very extravagant views were entertained as to the commercial benefits to be derived from sewage utilization. Many hundred patents were taken out, mostly, however, on chemical processes, and large investments of capital were made, which have generally proved failures. Following these failures there was a reaction, during the prevalence of which it was held that sewage could not be utilized at a profit. When we examine the whole matter practically we find that the failure, in a commercial way, largely pertained to the chemical processes, although it should not be overlooked that many of the early sewage farms, by reason of poor management, unnecessarily expensive first cost, and other causes, have never been financially successful. We shall also see, farther on, that the best method of managing such farms has only recently been understood, which may be given as another reason why many of the early farms have not been financially successful. The net result of all this has been that many experienced engineers, sanitarians, and agriculturists have held that it was impossible to utilize sewage at a profit.

There is, however, another phase of the question. The main object of sewage purification is to keep streams pure and to preserve the health of the citizens of our cities and of the surrounding country. It has therefore been held, and very properly, that the real object of sewage treatment is purification and not utilization, and that utilization, by introducing commercial considerations, will inevitably tend to lower the degree of purification. It has been held, in short, that sewage purification is a right which one community or individual owes to another, independent of any question of commercial profit. And while this proposition is undoubtedly true, it is believed that, with proper understanding of all the elements of the problem, a satisfactory utilization may be also attained without lowering the standard of purification.

On this point the author's views have undergone some modification since he examined in detail a number of European sewage farms in the fall of 1894. Previous to that time he was disposed to believe that sewage disposal should be placed entirely on the broad plane of purification rather than on that of utilization. At the present time he believes, as the result of seeing what is being done on the best sewage farms of England, Germany, and France, that the agricultural value of sewage may be fairly utilized, and still a high degree of purification attained.

Since the first development of sewage utilization in England the trade in commercial fertilizers has also greatly extended, and many writers have taken the ground that at the prevailing prices of commercial fertilizers agricultural lands can be manured more cheaply by their use than by the use of raw sewage.[1] In regions where the distribution of the rainfall is such as to fairly meet the necessities of

[1] See Agriculture in some of its Relations with Chemistry, by F. H. Storer, Vol. II, on this point.

agriculture this is probably true, but it is believed, with the present experience, that in any region where the distribution of the rainfall is such that periods of drought are likely to occur at the critical period of growing crops, provided sewage can be delivered upon agricultural lands by gravity, or even by a moderate pumping lift, a commercial saving will be effected, due to the irrigation value of the sewage, over any gain that can possibly be obtained by the use of commercial fertilizers alone. If pumping is required, its cost may, of course, enter in as a modifying element. At any rate the author wishes to place this thought before the scientific farmers of the United States as one well worthy of their most careful consideration. He desires further to say that from the experience gained in other countries, as well as our own, he believes that frequently lands in the immediate vicinity of our cities and towns can be improved in productiveness more by the general application of sewage irrigation than by any other method at present open to our farmers.

It should be remembered, however, that the quality of soils will enter into the final solution of the problem. Those best suited for sewage irrigation are open, porous, gravelly soils, while heavy clay soils may demand so great an expense of preparation as to render sewage utilization, except in special cases, practically impossible. As already hinted, each location presents its own special problem, which, to some extent, will demand its own special solution independent of all other cases. It can not be too strongly insisted, therefore, that each case must be studied by itself on its own merits; hence the foregoing statements are to be taken as general statements rather than universally true propositions.

METHODS OF SEWAGE DISPOSAL.

As the result of a large amount of experience gained abroad, sewage disposal or purification has resolved itself into three general methods, which are known as (1) chemical precipitation, (2) intermittent filtration, and (3) broad irrigation. In the present paper we are not specially concerned with chemical treatment, except as at times an adjunct of irrigation; nor are we concerned with intermittent filtration, except so far as it may be considered an adjunct of irrigation. For completion of the subject, however, we may briefly describe the process of treatment known as chemical precipitation.[1]

CHEMICAL PRECIPITATION.

In this process the sewage is allowed to flow into large tanks, in which it is dosed with certain chemicals; these form with the organic constituents an insoluble precipitate, which in its descent to the bottom of the tank may, under favorable circumstances, carry down with

[1] More complete descriptions may be found in the several standard treatises recently issued, as, for instance, Crimp's Sewage Disposal, Wardle's Sewage Treatment and Disposal, and Rafter and Baker's Sewage Disposal in the United States.

it the suspended matter of the sewage as well as a portion of the dissolved. To apply this treatment on a large scale, extensive works with a large number of tanks, together with machines for grinding and mixing the chemicals, as well as special mechanical arrangements for mixing the chemicals and sewage and caring for the sludge, are required, the whole including what is commonly called the chemical treatment of sewage, although the complete process is in reality partly chemical and partly mechanical.

The reagents now generally used are common lime, sulphate of alumina, and ferrous sulphite. These reagents are used either singly or in combination, as may be required to fit the case of each particular sewage undergoing treatment. The action of the reagents in producing a precipitation of the organic matter is not fully understood, although in a general way we may say that when lime is used there

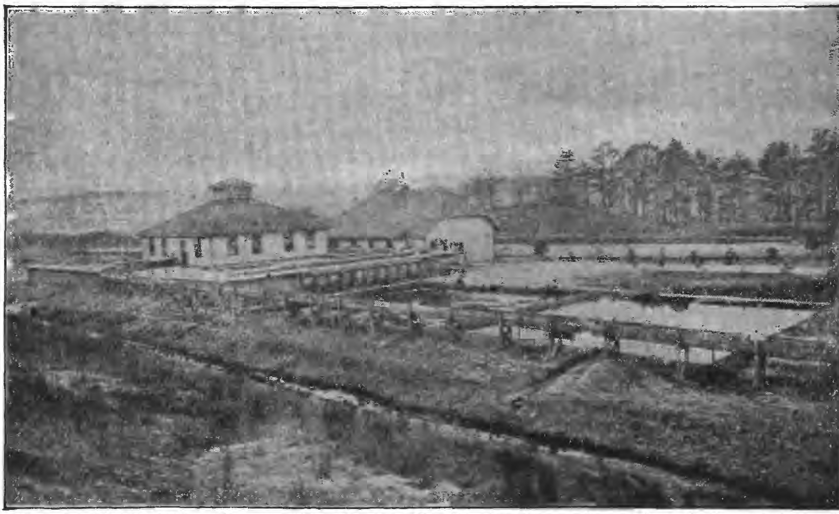


FIG. 1.—Mystic Valley Chemical Purification Works, showing sludge beds and effluent channel.

is a combination of some of the lime with free carbonic acid gas to form an insoluble carbonate of lime; also, probably, an additional part of the lime combines with a certain portion of the organic matters in solution to form an insoluble precipitate, which in its journey to the bottom carries down with it any portion of the suspended matters which have not entered into combination. The matter settling to the bottom is called sludge.

When sulphate of alumina is used, the precipitating effect is considered as due to a combination of the sulphuric acid of the sulphate of alumina with lime and other mineral bases existing naturally in the sewage. A flocculent alumina hydrate is also formed, which in conjunction with the mineral precipitate further entangles and carries down any suspended organic matter. At the present time, as a general statement, we may say that a combination treatment of lime and sulphate of alumina is preferable for ordinary sewage to the use of either of them alone, although the composition of the sewage should be taken into account in deciding.

In the case of ferrous sulphate, in order to secure a precipitating action it is necessary either that the sewage be naturally alkaline or, if not naturally so, that an alkali be artificially added. The result of this treatment is the formation of a flocculent hydrated oxide which carries down with it the suspended organic matter as well as a portion of the dissolved.

In order to insure the best results in chemical treatment the sewage should be treated while fresh and the chemicals added to the flowing sewage, in order that they may become fairly incorporated before it passes into the settling tanks. There should also be enough tank space to insure a thorough precipitation. Inasmuch as the sludge must be frequently removed from the bottom of the tanks, the mechanical arrangements should be such as to permit of its removal without interruption of the works.

Methods of chemical treatment may be classified as (1) intermittent treatment in shallow tanks from 5 to 8 feet deep, in which, after the addition and incorporation of the chemicals, the sewage is allowed to remain undisturbed until the completion of the process, when the clarified liquid is drawn off the top, leaving the sludge at the bottom; (2) continuous treatment in a similar series of tanks through which, after the addition and incorporation of the reagents, the sewage is allowed to flow slowly, crude sewage with freshly added chemicals passing in at one end and purified effluent passing out at the other; and (3) vertical tanks through which, after the addition of the chemicals, the sewage rises slowly. At the present time the continuous treatment, in which crude sewage with freshly added chemicals passes into one end and purified effluent passes out at the other continuously, is considered, as the result of experience, to be the preferable method of applying the chemical treatment.

As to the tank capacity required, we may say that in systems which are arranged with reference to receiving a portion of the rainfall the daily capacity should be nearly 50 per cent of the average daily flow, an allowance of this kind giving some leeway for contingencies when required. With the sewage from separate systems of sewers less leeway will be required.

Various methods of disposing of sludge have been used. One is to pump it into basins, from which it is subsequently conveyed to adjacent areas for utilization as fertilizer. It is also frequently deposited in large open basins surrounded by embankments, from which, after the larger portion of the water has drained away, it is removed either for use as a fertilizer or to some other point for filling in low land, etc. The liquid sludge is also sometimes run directly onto agricultural areas, where it is easily disposed of by plowing in. It may also be mixed with combustibles and disposed of by burning. In some cases it has been used to form compost heaps by mixing with earth, rubbish, vegetable mold, gypsum, stable manure, leaves, or other suitable materials. When disposal works are situated near tide water, the sludge may be disposed of by running it into dumping scows, which convey it to deep water for dumping. It may also be burned in a furnace similar to the garbage destructor, but for this purpose it requires partial desiccation before treatment. On the whole, the most practicable way of treatment is to compress it into solid cakes by the use of a filter press. In this form it is entirely innocuous, and may be stored, handled, or conveniently transported for use, either as a fertilizer or for filling in low lands or for other purposes. The liquid sludge, as it ordinarily comes from the settling tanks, contains from 90 to 95 per cent water and from 5 to 10 per cent solid matter.

The mixing of the chemicals with the sewage is effected either by the use of baffle boards in the conduit leading to the tanks, or, where this is impracticable, by the use of mixing wheels. As the problem is merely one of thorough mixing, it is unnecessary to discuss it at length. Usually very simple mechanical appliances are sufficient.

At the present time lime containing from 65 to 75 per cent available calcic oxide can be purchased in the eastern part of the United States at from $8 to $9 per net ton; ferrous sulphate or copperas containing 26 per cent of ferrous oxide can be bought at about $15 per net ton, and sulphate of alumina, containing 14 per cent of alumina, at about $25 per net ton. The exact price of these reagents of course varies in different localities as well as with the quality of the reagent itself.

In 1889 Mr. Allen Hazen, at that time chemist in charge at the Lawrence experiment station of the Massachusetts State Board of Health, carried out a very elaborate series of experiments on the chemical treatment of sewage. The details of these experiments may be found in the twenty-first annual report of that board, to which, inasmuch as we are not concerned other than generally with chemical treatment of sewage, the reader is referred for a more extended account. We may, however, refer to the following statement of costs per capita in comparison with degree of purification obtained, as given by Mr. Hazen.

Taking the percentage of albuminoid ammonia removed to represent organic matter, the experiments on chemical precipitation show that in addition to all suspended matter the following amounts of soluble organic matter may be removed:

	Per cent.
With lime, costing 30 cents per inhabitant annually	22
With copperas and lime, costing 30 cents annually	29
With aluminium sulphate, costing 30 cents annually	20
With aluminium sulphate, costing 40 cents annually	29
With lime, costing 27 cents annually	20
With copperas and lime, costing 20 cents annually	13
With copperas and lime, costing 31 cents annually	39
With aluminium sulphate, costing 23 cents annually	10
With aluminium sulphate costing 45 cents annually	47

By way of disposing in this place of the question of relative degree of purification attained by the different processes, it may be remarked that there is now a vast body of information—not only special experimentation like that at Lawrence, but results obtained in actual practice—all showing that land-treatment methods, when properly operated, easily remove all the suspended organic matter of sewage as well as from 95 to 99.5 per cent of the dissolved matter. As a problem of efficient purification, therefore, the superior efficacy of the land treatments may be conceded without further discussion.

INTERMITTENT FILTRATION.

In 1868 a commission, consisting of Sir William Thomas Denison, Edward Frankland, and John Chalmers Morton, was appointed to inquire how far the use of rivers or running waters in England for carrying off the sewage of towns and the refuse of manufacturing processes could be prevented without risk to the public health or injury to such processes in manufactures, and also how far such sewage and refuse could be utilized and got rid of otherwise than by discharge into rivers or running waters, or rendered harmless before reaching them. The commission was further charged with an inquiry into the effect on the drainage of lands and inhabited places of obstruction to the natural flow of rivers or streams as caused by mills, weirs, locks, and other hydraulic works, and into the best means of remedying any evils thence arising. The commission so appointed is commonly known as the Rivers Pollution Commission, although it was in reality the second of this name.[1] Dr. Edward Frankland, the chemist member of this commission, was at that time by far the ablest chemist in England, and the vast amount of original chemical investigation given in the commission's six reports is a monument to his genius for sanitary chemistry and to his capacity for work.

In the first report, issued in 1870, the commissioners discuss various experiments on filtration which had been carried out under the direction of Dr. Frankland. Among others, the statement is made that the practice of filtration of sewage through sand, gravel, clay, or certain kinds of soil, if properly carried out, is the most effective method for the purification of sewage to which reference had at that time been made. A series of experiments on soil of various character is also discussed in detail, from which it is concluded that the process of purification through soil is essentially one of oxidation, the organic matter being to a large extent converted into carbonic acid, water, and nitric acid.

As one of the necessary conditions of intermittent filtration, it is also shown that a continuous aeration of the filtering medium must be secured. In discussing this phase of the subject the commissioners point out that the inability to continually aerate the filtering

[1] See footnote on page 19.

medium is a chief reason why purification of sewage by upward filtration will necessarily be less effective than by the opposite or downward filtration; hence the name "intermittent downward filtration," as originally attached to this process. The theory is discussed in too much detail in the report in question to admit of more than casual mention here. As the result of the commission's work on this line, it was concluded that a new method of sewage purification had been brought out. On this point the commissioners remark in their summary that towns and manufacturers have the means of rendering the organic impurities dissolved in their waste waters so far harmless by slowly passing them through well-aerated filter beds as to admit of their being again useful for manufacturing purposes.

The experiments carried out in the commission's laboratory showed that a properly conducted system of intermittent filtration would cleanse town sewage sufficiently to enable it to be used for all but domestic purposes. The result of the treatment is a true oxidation, and consequently an entire transformation of nearly the whole of the organic matter in the sewage. From the remedial point of view the new treatment was therefore considered successful. But the commission remarks that, since sewage possesses high agricultural value, this method of treatment, if universally adopted, would be very wasteful, and is therefore only to be recommended on a small scale or where circumstances render any other process, such as sewage irrigation, difficult or expensive. The commission, however, believed that the operation of sewage purification by intermittent filtration could be conducted without serious nuisance.

While the commission thus announces a new and valuable discovery in sewage purification, still it expresses in the final summary the opinion that in all practicable cases broad irrigation should be used in preference to intermittent filtration, because, when irrigation is carefully and properly conducted, not only is sewage rendered inoffensive, but some return of profit may be derived from its employment. In the commissioners' opinion all the experiments made to that date went to show that sewage can be most beneficially employed as a manure, and that it is thus also most perfectly cleansed.

The Rivers Pollution Commission, while originating intermittent downward filtration and strongly recommending its use under proper conditions, still, rather singularly, did not propose a complete definition of it as a process of sewage purification. In 1882 a commission[1] was issued to George William Wilshere, the Baron Bramwell, Sir John Coode, and others to inquire and report upon the system under which sewage is discharged into the River Thames by the Metropolitan Board of Works, and whether any evil effects resulted therefrom; and if so,

[1] Metropolitan Sewage Discharge, Report of Royal Commissioners, 4 volumes of reports, minutes of evidence, appendices, etc., 4°, London, 1884-85. Presents every phase of the question of disposal of sewage of London as it existed twelve years ago.

what measures could be applied for remedying the same. This commission is known as the Royal Commission on Metropolitan Sewage Discharge. In its second report we find a definition of the difference between broad irrigation and intermittent filtration, in the following terms: Broad irrigation means the distribution of sewage over a large surface of ordinary agricultural ground, having in view the maximum growth of vegetation (consistent with due purification) for the kind of sewage supplied. Filtration means the concentration of sewage at short intervals on an area of specially chosen porous ground as small as will absorb and cleanse it, not excluding vegetation, but making the produce of secondary importance. The intermittency of application is a sine qua non, even in suitably constituted soils, wherever complete success is aimed at.

As to the value of intermittent filtration, the Royal Commission on

FIG. 2.—Filter area, with absorption ditches, as laid out in England.

Metropolitan Sewage Discharge states that, in its opinion, the process has great scientific merit and affords valuable practical advantages for the disposal of sewage in situations where broad irrigation is impracticable and where land suitable for filtration can be obtained. If, however, there should be a difficulty in obtaining sufficient area of land, the commission is of the opinion that, before applying it to land, sewage should be previously treated by some efficient process for removing the sludge. The recent studies of intermittent filtration by the Massachusetts State Board of Health have greatly advanced our knowledge of the true theory of intermittent filtration, although, as we have seen, the broad lines were well established by the Rivers Pollution Commission in its first report, issued in 1870.

Taking into account the present views, we may define intermittent filtration as a natural process of biologically reducing the nitrogen of complex, nitrogenous, organic matter to the simple forms of mineral nitrates and, probably, free nitrogen, the reducing action being due to two minute bacilli known as the nitrous and nitric organisms or ferments. The immediate result of the work of the nitrous organism is to convert ammonia into nitrite, while the nitric organism converts nitrite or nitrous acid into nitric acid, which, uniting with mineral bases, immediately forms mineral nitrates. The organisms producing these changes exist naturally in soils, and when specially prepared areas are properly treated develop in the interstices in vast quantities.

NITRIFYING FERMENTS.

No more fascinating chapter of science can be found than that pertaining to the development of our present knowledge of the real office of the nitrifying ferments. For many years the subject has been one of prolonged study by a number of the leading chemists and biologists of the age. Among these may be mentioned Schwann, Schultze, Pasteur, Schloesing, Muntz, Heraeus, P. F. Frankland, Warington, Winogradsky, and the biologists of the Massachusetts State Board of Health, working under the direction of Professor Sedgwick in that board's laboratory at Boston. Beginning with the

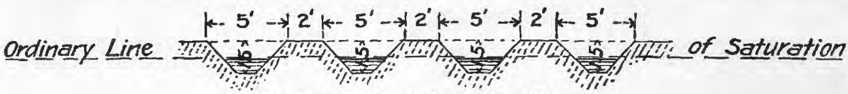


FIG. 3.—Section of absorption ditches.

work of Schwann and Schultze, as early as 1839, and ending with the work of Warington, Winogradsky, and the biologists of the Massachusetts board, we find a progressive advance from a knowledge, as the first step, that the decomposition of nitrogenous matter is due solely to the small vegetable organisms known as bacteria, to the final demonstration that the production of nitric acid is also due to a similar class of organisms. The complete account of the failures and successes encountered in the successive steps of the study is one of the romances of modern biology.

Without going into details, we will refer to two papers by Mr. Warington, one before the English Society of Arts, as published in that society's journal of April, 1882, the other as read before the British Association for the Advancement of Science at its annual meeting at Montreal in 1884. In his paper before the Society of Arts Mr. Warington set forth the theory of sewage purification by soil so clearly that we may draw upon it as perhaps, on the whole, the best concise general statement of the specific problem now under discussion thus far made. The paper begins by stating that dilute solutions of urine, which contain the essential constituents of plant food, undergo no nitrification when fully exposed to the air if only they have been previously boiled and the air supplied to them is filtered through cotton wool. If we add a small particle of fresh soil to sterilized solutions of this character, no action at first appears, but after a while nitrification begins and the ammonia of the urine is converted into nitrate. This action proceeds best in the dark, and its full completion requires the presence of some mineral base, as, for instance, lime. A solution which has undergone nitrification is capable of producing nitrification in another sterilized solution which, without the addition of the nitrified solution, would remain unchanged. If we boil the soil or the nitrified solution, we destroy the power of causing nitrification. As a final point, Mr. Warington states that nitrification is confined to the same range of temperature which limits other kinds of fermentation. At or near the freezing point the production of nitrates proceeds very slowly, but increases in rapidity with a rise of temperature, reaching its maximum at 99° F. Above this temperature the rate of nitrification diminishes, nearly ceasing at 122° F., and entirely ceasing at 131° F.

Mr. Warington also states that the purifying action of soil on sewage is probably due to three distinct causes: (1) Simple filtration, or the separation of suspended matter; (2) the precipitation and reduction by the soil of ammonia and various organic substances previously in solution; (3) the oxidation of ammonia and organic matter by the agency of living organisms. It is considered that the last mode of action is the most important, as without it sewage matter would accumulate in the soil and the filter area soon loose its efficiency. The simple filtering power of the soil will depend upon its mechanical condition, while the precipitating power is a chemical function, in which the hydrated ferric oxide and alumina and the silicates of soils probably play the principal part. The oxidizing power will depend partly on its mechanical, partly on its chemical, and partly on its biological condition. We now know that a porous medium is not absolutely essential for nitrification and that sewage may be nitrified in a glass bottle or when passing over polished pebbles. Although porosity is by no means essential to the nitrifying power of soil, it is a condition having a very favorable influence on the rapidity of the process, porous soil of open texture presenting an immense surface, which will become covered with a thin film of the nitrifying organisms, and which, by reason of its porosity, will be well supplied with the air requisite for the discharge of other functions. This fact explains why nitrification takes place more rapidly in soil than in liquid.

In his paper before the British Association in 1884 Mr. Warington remarks that further proof of the ferment theory is afforded by the fact that antiseptics had been found fatal to nitrification. In the presence of a small quantity of chloroform, carbon bisulphide, salicylic acid, and, apparently, also phenol nitrification entirely ceases. The action of heat is also equally confirmatory. Mr. Warington also refers to experiments as carried out at the Rothamsted experimental station, in which small quantities of the soil were taken at depths varying from 2 inches to 8 feet from freshly cut surface on the sides of pits sunk in clay soil. The soil so removed was at once transferred to a sterilized solution of dilute urine, which was afterwards examined from time to time to ascertain the degree of nitrification. From the results it appeared that in a clay soil the nitrifying organism is confined to about 18 inches of the top soil, and is most abundant in the first 6 inches. In a sandy soil, he remarks, we would expect to find the organism at a lower level than in clay, but at that time there was no direct evidence, although since then the later investigations have shown the presence of the nitrifying organisms at as great a depth in porous soils as 4 feet.

Another paper or series of papers by Mr. Warington which may be referred to is his six lectures on the investigations at the Rothamsted Agricultural Station before the Association of American Agricultural Colleges and Experiment Stations, at Washington, in August, 1891. In these lectures Mr. Warington brings the whole subject of nitrification down to date, but with such wealth of detail as to preclude more than a simple reference to the matter here. The reader interested in this particular phase of the subject can hardly do better than to study the lectures in question.

We have seen that Mr. Warington pointed out in his paper of 1882 that antiseptics are fatal to the life of the nitrifying organism. In the course of the experiments at Lawrence, Massachusetts, a number were made as to the effect upon nitrification of antiseptics, as well as other substances, among these being ammonium chloride, alkalies, acids, common salt, and sugar. The results indicated that many substances which would ordinarily be fatal to the nitrifying power of a filter if applied suddenly, can be efficiently treated provided the increase in quantity is gradual, thus giving the filter time in which to adapt itself to the various grades of work.

ESSENTIAL CONDITIONS.

We have seen that Mr. Warington pointed out in his paper of 1882 why porous soils would be much more favorable for intermittent filtration than those of close texture. We may now examine as to the quality of some best suited for such work.

In the Twentieth Annual Report of the Massachusetts State Board of Health we find stated as a fundamental proposition of intermittent filtration that sewage can be more efficiently filtered through open sand than through sand covered with soil, and that the upper layers of intermittent filtration areas should be of coarse sand, into which the sewage will disappear rapidly, leaving room for air to enter and come in contact with the thin laminæ of liquid covering the particles of sand. As regards the purification of sewage through the medium of nitrification, the chief points established are that the best results are obtained in filters which have been for some time in work, thus becoming adapted to the special service they are to perform; that free oxygen is indispensable for success; that sewage is best purified when held in thin films upon or between sand grains and gravel stones; and that the period of greatest distribution of the ordinary sewage bacteria corresponds with the time of most active nitrification. The experiments also indicate that the nitrifying organism probably attaches itself in very thin films over the surface of the sand grains and gravel stones of the filter area, and that for complete nitrification the sewage should remain in contact with the nitrifying organism a short space of time. If while in such contact the conditions are favorable to the complete admission of oxygen, we may expect the purification to be very complete. So important is this consideration that Mr. Allen Hazen, in one of his reports, has formulated the indispensable conditions of sewage purification as depending upon oxygen and time. All other conditions, Mr. Hazen says, are secondary. Even temperature is only a minor influence. If the organisms for purification have attached themselves to the sand grains and imperfect purification then occurs for any considerable period, it is conclusive evidence, Mr. Hazen says, either that there is too small a quantity of oxygen present in the filter or that the sewage is passing through so rapidly as not to afford time for complete oxidation. In a practical way, therefore, such filters must be so operated as to insure a slow enough rate to give the necessary contact between the sewage and the nitrifying organisms, while at the same time insuring the presence of an abundance of free oxygen in the interstices of the filter. Moreover, we must not overlook the necessity for the presence of an alkaline basic salt, and the fact that the temperature of the filter area generally must be somewhat above freezing, although it is true that such filters will operate below freezing for considerable periods of time without entire cessation of the nitrifying process. As to the alkaline base, if it does not exist naturally in the filtering material used it may be added artificially. For this purpose common lime sown broadcast over the area answers every requirement.

The experiments at Lawrence have been carried out with reference to materials of varying degrees of coarseness. In some of the tanks coarse mortar sands have been used, while in others sands of medium quality, as well as fine sands, have been experimented upon. One of the most interesting special experiments is as to the filtering qualities of a very fine sand in situ.

For the purpose of this experiment a natural area of fine river silt of about one-third of an acre was prepared by partial underdraining with drains 60 feet apart, which were designed chiefly to catch samples of the effluent. This area is on the banks of the Merrimac River, near the experiment station at Lawrence, Massachusetts, with its surface several feet above the ordinary stage of the river. The few underdrains laid were found of little use, because usually the liquid passes by them directly down to the plane of the water table. The surface of the location selected slopes at the rate of about 1 foot in 10 in one direction and about 1 in 100 in the other. A series of shallow trenches which follow the surface of the field are excavated in the original material. They are mostly made 1 foot wide top and bottom, with varying depths from 6 inches to 3 feet, and filled in with a coarse mortar sand. They are 5 feet apart, and are generally constructed with the surface of the coarse sand 4 inches below the adjacent original surface, except at the lower end, where, in a distance of 50 feet, the depth increases to 10 inches below the original surface. These trenches are each about 200 feet in length. The distance which sewage will flow in them varies with the amount applied and the amount of sediment upon the surface, which again varies with the quality of the sewage, the completeness of the nitrification, and the time elapsed since the surface was cleaned. As to the cleaning of the surface, it is found desirable that it be done occasionally, usually at periods of from one to three months. The removal of a quarter of an inch in depth from the surface of the coarse sand appears to be sufficient. During the winter the trenches have been covered with boards, with the result that the process of purification proceeded readily during the entire winter.

The result of this experiment indicates that in very fine sand of the quality here found from 50,000 to 60,000 gallons of sewage per day may be efficiently purified with a renewal of the sand in the trenches of perhaps 2 to 3 inches annually. Filters composed of either coarse mortar, sand or fine gravel, or coarse sand and gravel mixed may be expected, however, to filter from 80,000 to 100,000 gallons per day per acre.

Experiments with fine soil, with sand covered with soil, and with peat and loam and coarse gravel have all been carried out in great detail at Lawrence. The wealth of material relating to these different experiments precludes any adequate reference to all of them in this place. A few of the more interesting may be briefly referred to. For instance, one of the most important results brought out by the miscellaneous experiments is the fact that by systematically breaking the scum which forms on the surface of the filters a very much larger quantity of sewage can be purified without deterioration of the effluent than is possible when the scum is allowed to remain unbroken for long periods of time.

PERMANENCY OF SAND FILTERS.

As to the permanency of such filters, it is remarked that the leading fact of intermittent filtration is that the organic matters of sewage are destroyed instead of being stored in the filter, as is largely the case with other methods of purification. The experiments have further shown that the conditions allowing thorough purification of the maximum volume with the best results are such that a small percentage of the more stable organic matters of the sewage resist the reducing action of the filter and tend to accumulate in its upper layers, until after a time the surface becomes choked to such an extent that the sewage will not sink freely below it, thus violating the fundamental principle of intermittent filtration. As a remedy it is suggested that temporary relief may be obtained by simply turning the surface under, although evidently an indefinite use of the same material would be impracticable if anything like a maximum quantity of sewage were treated. Since the organic material thus accumulating is confined entirely to the upper few inches of the filter, it is considered best to occasionally renew the upper layers of sand.

Experiments were also made as to the nature of the clogging material, with the result of showing that it may be divided into two classes, the fats and the sludges proper, the former being in effect the carbonaceous element and the latter the nitrogenous. The result of the experiments is to indicate that the fats themselves do not accumulate in the sand in such a way as to choke the filter. The possibility is pointed out, however, that instead of being completely oxidized and destroyed the fats may be oxidized to some stable compound which clogs the sand. The experiments apparently indicate some action of that sort which thus far has not been well defined. It has been found that clogging is in no way a serious matter, and that an efficient remedy is found, as already indicated, in either turning over or scraping the surface of the filter. The fact brought out that when the sand is unworked the fats slowly oxidize indicates either that the total filter area for any given case should be large enough to admit of a portion of the filter resting occasionally for a few months, or that the sand, if removed, can after a while be again used, although it is probable that ultimately it would require washing in order to remove slight accumulations of silt material carried in suspension by the sewage.

Perhaps as important experiments as any are those relating to the mechanical condition of the filtering materials. As assisting study in this direction, the modern systems of mechanical analysis have been of great value. Indeed, we may say that the recent work along this line has largely given an entirely new phase to all agricultural questions relating to the condition of the soil. In addition to the work on mechanical composition of the sands used in filtration as accomplished at the Massachusetts experiment station, chiefly by Mr. Allen Hazen, similar questions have been studied at the agricultural experiment stations of South Carolina and of Maryland by Prof. Milton Whitney.[1] The studies of these two gentlemen have added greatly to our

[1] See the Second Annual Report of the South Carolina Agricultural Station and the Fourth Report of the Maryland Station; also, as regards methods of making mechanical analyses of sands for filtration purposes, Twenty-second Annual Report of the Massachusetts State Board of Health.

knowledge of this subject, although the earlier work of Hilgard and Johnson is classic.

In order to estimate the filtering capacity of any given material, it is important to understand the air and water capacity of the filtering material when drained, the term "water capacity" being taken to designate the amount of water retained in the interstices after thorough draining. The efficiency of the filtering process depends largely upon these two elements. The amount of water will depend not only upon the closeness of the packing, but also upon its uniformity, and at any given time upon the amount of organic matter stored from the material filtered. The water capacity will also depend largely upon the size of the particles, the finer sands holding much water, especially at the bottom, while with coarse sand the amount held will be nearly constant from top to bottom.

Studies have been made as to the limitation of the size of single doses of sewage. With very coarse material the amount of sewage which can be applied at any one time is limited by the slight retentive capacity, the addition of too large a quantity leading to passage through the filter in too short a time. The conclusion from the studies is that the single dose should not exceed the water capacity of the material, because, if it does exceed such limit, a portion will pass through at once, first forcing out the water previously held, leaving the filter before complete purification can take place. If the air limit is exceeded, the oxygen in the filter is liable to be exhausted before the oxidation is complete.

As to the purification attained by intermittent filtration, the Massachusetts experiments show that very high degrees are reached easily. By way of illustrating the matter, we may simply state that sewage has been purified to the extent of removing from 95 to 99.5 per cent of the polluting material. Sewage containing from 500,000 to 1,000,000 bacteria per cubic centimeter has been so far purified of bacteria that the effluents have frequently contained as few as from 25 to 100 bacteria per cubic centimeter. In order to appreciate this degree of bacterial purification, we may consider that well waters in common use frequently contain from 2,000 to 3,000 bacteria per cubic centimeter. As regards chemical and biological considerations, there is therefore no reason why such sewage effluents are not fit to drink.

The body of information in regard to sewage purification by intermittent filtration which is presented in the several reports of the Massachusetts State Board of Health has become so extensive that one must be an expert to keep in mind the many interesting and valuable results brought out. As assisting the general reader, who may not care to travel through the several thousand pages of matter given in these reports, reference may be made to a very excellent summary of the results obtained from intermittent filtration during seven years' experimentation at page 497 of the report of 1894, where may be found brief statements of yearly averages of the various kinds of filters experimented upon, as well as an outline of the most important features in the operation of each filter.

The subject of intermittent filtration has been discussed here because its theory of action applies to sewage irrigation as well, the chief difference between the two being in the method of application and in the agricultural results obtained. We shall see, however, that the two run together, crops being easily raised on filtration areas and the fields of sewage farms frequently irrigated when no crops are growing. The discussion of the theory of intermittent filtration is in reality, therefore, a general discussion of the theory of sewage irrigation. We shall see also that the agricultural utilization of sewage to the best advantage involves the use of intermittent filtration as an adjunct of broad irrigation.

IRRIGATION.

Ordinary irrigation, which consists in the application of water to the soil, in order to assist the growth of plants, has been practiced from the earliest days in Assyria, India, China, Egypt, Italy, France, Spain, and portions of England. Sewage irrigation, on the contrary, is, so far as known, a modern development. It has for its purpose the purification of the water which has been employed in carrying away the refuse of towns. The methods of applying sewage water do not differ greatly from those used in ordinary irrigation, except that by reason of the quality of the material which sewage water carries in suspension and solution special attention to the detail of the process is required, in order that the sewage water may not come in direct contact with the growing plants.

In selecting ground for a sewage farm account must be taken of the relative elevation of the farm and of the town, manufacturing establishment, or residence from which the material comes. Whenever possible, as a matter of economy, the farm should be selected with reference to the sewage reaching it by gravity. If, however, the location does not admit of such procedure, pumping may be resorted to, although this frequently will entail considerable additional expense in first cost of plant as well as in the annual outlay for operation and maintenance. In some cases, where land can be reached by gravity by going considerable distance or can be reached by pumping within a short distance, carefully prepared estimates, taking into account all the elements of first cost, as well as the annual cost of maintenance and operation, may show that it is cheaper to deliver the sewage a long distance by gravity than a shorter distance by pumping.

Formerly it was also considered important to select a sewage farm with reference to the surrounding inhabitation, because there was a prejudice against such farms on account of the assumed liability to effluvium nuisance. This objection has much less weight now than it formerly had, because experience has fully demonstrated that with proper management a sewage farm is no more objectionable on account of bad smells than any other form of farming. The odor of manure is unpleasant, although not specially unhealthful. Undoubtedly there are many barnyards, both in town and country, which are more unpleasant to the sense of smell than well-regulated sewage farms. We may conclude, therefore, in the light of present experience, that an objection to sewage farms on account of serious effluvium nuisance is not well founded. We may further consider that all sanitarians agree that the proper place for disposing of such town refuse is on land. When applied there with due reference to our present information as to the nitrifying process, there is no reason for the production of specially bad smells.

For the best results the topsoil of a sewage farm should be of a

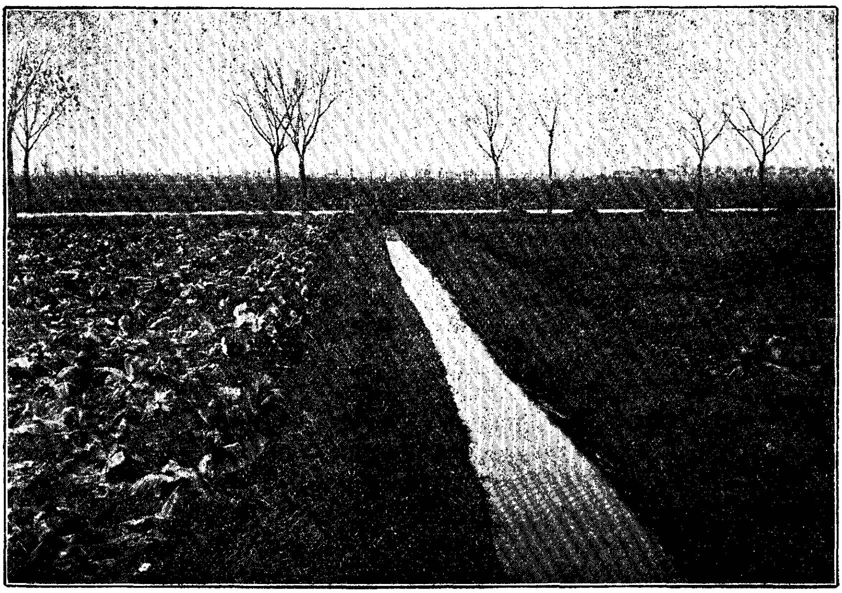


FIG. 4.—Distributing channel on the Berlin sewage farm.

permeable character, with a gravelly or sandy subsoil. If it be compact clay, the sewage can not enter, and the only purification attained will be that due to coming in contact with the soil by flowing over it. Clay soils, therefore, are not so satisfactory for sewage farming as open, gravelly soils, although, as we shall see in describing the sewage farm at Wimbledon, England, it is possible to so treat the sewage and prepare the farm as to attain a very high degree of purification even with clay soils, but the chance of doing this at a commercial profit is exceedingly small.

If not naturally level or of very uniform slope, a sewage farm for the best results should be leveled, so that the sewage may flow equally over every portion. It should also be laid out with distributing channels, as shown in fig. 4, having a proper inclination in order to deliver the sewage readily to all parts of the farm. Formerly it was considered necessary that the carriers be lined with earthenware, concrete, or other impervious material, to prevent the sewage sinking into the ground during its passage along them, but now the more ordinary practice is simply to make earth ditches, with flat slopes. Fig. 5 illustrates a common form of pipe distribution. As to the best size of the field for irrigation, everything depends upon the quantity of sewage to be disposed of and the character of the soil. On this point the advice of a person of experience in sewage farming will be especially valuable.

As to the difference in soils for sewage purification, we may refer to some opinions expressed nearly thirty-five years ago. In 1862 a Parliamentary committee, known as the Select Committee on Sewage of Towns, took a large amount of evidence and reported at length in

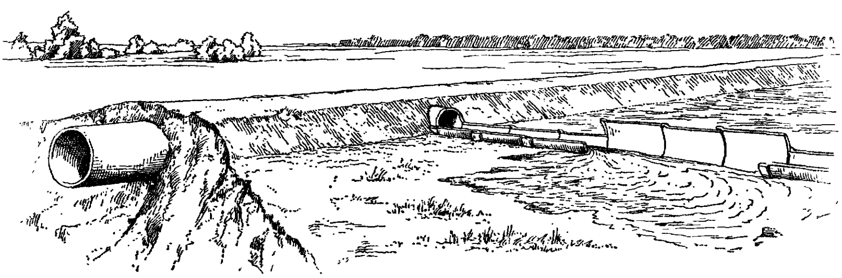


FIG. 5.—Pipe-distribution system.

regard to the agricultural utilization of sewage. Among other eminent authorities called before this committee was Dr. Augustus Voelcker, at that time one of the leading agricultural chemists of England, who testified that sewage could be applied with great advantage on light, porous soils, and, indeed, on all soils which resemble in character such land; but on heavy clay land it could not be applied with advantage, especially when the cultivation was such as to produce in dry weather cracks in the clay, through which the liquid might penetrate to some depth in the soil.

Prof. J. T. Way, another eminent chemist, stated before the same committee that, though valuable materials were contained in sewage, they were coupled with a condition as to constant use in all weathers and at all times which obliged one to limit the use of them, and that if iron pipes were laid over a farm and the farmer given the privilege of using sewage when he liked to apply it, leaving it unused so far as the growing crops were concerned when not needed, there would be no doubt as to the value of sewage in agriculture.

Professor Way also said that under given conditions sewage is of immense value merely as water for irrigation purposes, while under other conditions—for instance, in times of great rainfall—the water is so objectionable that one might better lose the manure than to be obliged to have the water. These opinions of thirty-four years ago are given here for the purpose of showing that even in the early days of sewage farming it was recognized that the necessity of caring for large amounts of water at all seasons might be a serious burden upon the success of such farming in a commercial way. The development of intermittent filtration since that time has, however, given us more thorough control of all the conditions than existed in 1862.

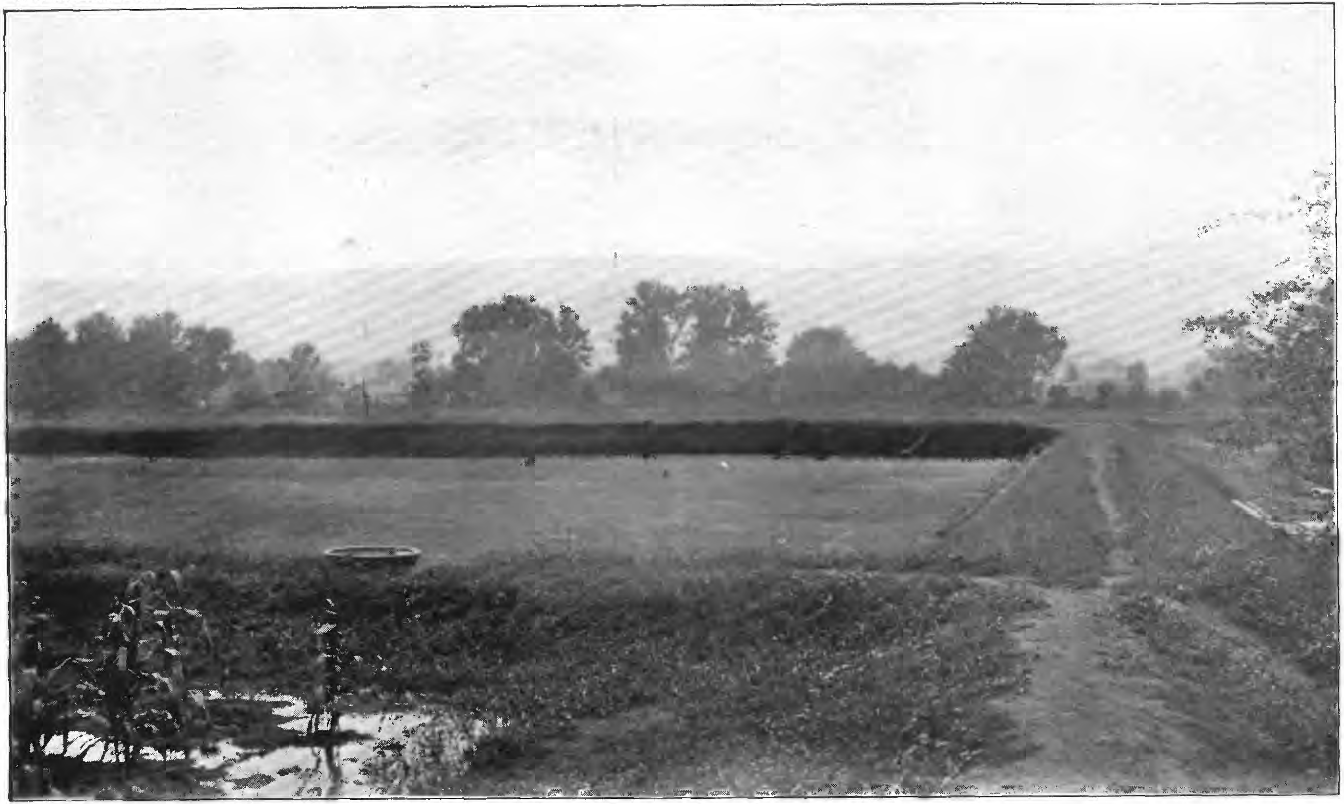
From our present understanding, the proper method of procedure is for towns to provide, where the conditions admit, intermittent filtration areas on which sewage can be cared for and efficiently purified whenever it is not needed for the purposes of agriculture. Such an arrangement will permit of using it under the conditions laid down by Professor Way; that is to say, the farmer may take it when he needs it and let it alone when it is not needed. As thus employed, there is no doubt that sewage irrigation may be made immensely profitable in all parts of the United States. We say all parts, because there is a popular notion that in the eastern part, at any rate, the rainfall is sufficient to meet all the requirements of agriculture. One needs, however, to study the history of irrigation in foreign lands only casually in order to learn that this impression, like many other popular impressions, is only in a moderate degree true. The author is decidedly of the opinion that irrigation occasionally applied, even in the East, would lead to a very great increase in the productiveness of farms.

By way of illustrating the foregoing proposition as to irrigation supplementing the natural rainfall, the conditions in the Po Valley, in the north of Italy, may be referred to. We have here an extensive plain on which irrigation has been practiced for over two thousand years. For 200 miles along the southern base of the Alps the rainfall in the early part of the year is usually sufficient for the spring crops. Later in the season the rainfall is less, but by the use of irrigation a second crop is raised after the first crop is removed in the early and middle part of the summer. In this way the total yield is nearly doubled.

FILTRATION AREAS NECESSARY.

In order to utilize sewage in the manner proposed, it will be desirable for municipalities to construct intermittent filtration areas at the expense of the municipality at large, on which sewage can be purified whenever not required for agriculture. During the season of actual growth, when sewage would be naturally used for irrigation, the filtration areas would be allowed to rest, thus perfectly fulfilling one necessary condition which we have already discussed in treating the subject of intermittent filtration.

Possibly the objection will be raised that under this arrangement the towns themselves would not realize a profit on the sewage. This,



FILTER AREAS AT PLAINFIELD, NEW JERSEY.

however, is not a matter of any moment. The towns, as we have seen, really owe it to the riparian proprietors on the streams below the points where sewage enters not to so foul the stream as to create a nuisance. It is a natural right of the riparian owners to demand that sewage pollution be prevented. It is a duty, therefore, on the part of towns to purify sewage before allowing it to enter streams. If in the process of such purification the towns can realize even a partial return, they have so much clear gain; they should look upon it as a partial recoupment of a necessary expense which otherwise would be much larger.

Experience has shown that there is no objection to raising crops on the intermittent filtration areas, and on several of the English sewage farms, as well as on those of Germany, this practice is quite common. It has also been done at South Framingham, Massachusetts; at Plainfield, New Jersey, and at other places in the United States. At South Framingham, in particular, the result of several years' experience is to indicate that Indian corn grows with the greatest luxuriance upon the filtration areas, so much so that in some years the standing crop has been sold in the field to the highest bidder at as much as from $30 to $40 per acre. At the same time the effluent from the South Framingham sewerage works, which flows into the Boston water supply, has been kept up to the proper standard of purity. The works at South Framingham are owned by the town.

OPINIONS OF FOREIGN COMMISSIONS.

Examples of this sort show the importance of approaching questions of sewage purification and utilization from a practical point of view, and with due reference to the recent information as to the effect of the nitrifying organism in preparing refuse substances for utilization by plant life. The problem takes on such new forms that much of the old information has little application. There are, however, a large number of opinions expressed in the past by government commissions and eminent sanitarians which are considerably enforced by the recent views. Let us refer a little in detail to several of these opinions which have been shown by the passage of time to be fundamentally sound. In 1857 a commission [1] was appointed to inquire into the best mode of distributing the sewage of English towns and applying it to beneficial and profitable use. This commission included among its

[1] Sewage of Towns Commission, Reports 1, 2, 3, 8°, London, 1858-61-65. These reports contain the details of careful investigations. Elaborate cultivation and feeding experiments were pursued extending over a period of several years, the results of which were presented in great detail in the second and third reports. In the appendix to the first report may be found an account of a visit made by a committee of the commission to Milan, Italy, for the purpose of examining the sewage utilization works at that place. This committee reported, under date of December, 1857, that the experience of the irrigation around Milan added a striking proof to that already obtained as to the value in agriculture of a command of pure water, and of the immense increase of that value obtained by the addition of sewage combined with the higher temperature derived by the liquid in its passage through the town.

members such eminent engineers and chemists as I. K. Brunell, Robert Rawlinson, Prof. J. T. Way, J. B. Lawes, John Simon, and Henry Austin. They studied the question in all its phases and carried out extensive experiments, which are detailed at length in their reports. In the final report, presented in 1865, the commission said that as a result of its labor and investigation it was of the opinion that the right way to dispose of town sewage is to apply it continuously to land, and that the pollution of rivers can be avoided only by such application; that the financial results of applying sewage to land differ under different local circumstances, because in some places irrigation can be effected by gravity, while in others pumping must be employed; also, because heavy soils, which may be alone available in some places, are less fit than light soils for sewage irrigation. The commission also expressed the opinion that where local circumstances are favorable, and undue expense is avoided, towns may derive profit from applying sewage in agriculture.

As a final summation, this commission states that wherever rivers are polluted by the discharge of town sewage into them, the towns may be reasonably required to desist from causing a public nuisance.

In 1865 another commission was appointed (referred to on p. 19), commonly known as the First Rivers Pollution Commission. It consisted of Robert Rawlinson, J. T. Harrison, and J. T. Way, who were charged with an inquiry as to how far the use of rivers and running waters in England for the purpose of carrying off the sewage of towns and populous places and the refuse arising from industrial processes and manufactures could be prevented without risk to the public health or serious injury to such processes and manufactures, and how far such sewage and refuse could be utilized other than by discharge into rivers or rendered harmless before reaching them.

In its report on the River Thames this commission suggests that the whole river be placed under the superintendence of one governing body, and that, after the lapse of a period to be allowed for the alteration of existing arrangements, it be made unlawful for any sewage, unless the same has been passed over land so as to become purified, or for any injurious substances or refuse from paper mills, tanneries, and other works, to be cast into the River Thames between certain limits defined in the report, and that any person offending in this respect be made liable to penalties to be recovered summarily. In their report on the River Lea the commissioners suggest that a similar arrangement be made for the more thorough control of that stream.

In 1868 the Queen's commission was issued to what is known as the Second Rivers Pollution Commission, whose work in the line of intermittent filtration has been referred to on pages 29 to 31. The scope of this commission's inquiry, as given on page 29, is seen to be the same as that of the First Rivers Pollution Commission. The Second Rivers Pollution Commission studied questions of sewage purification very broadly, making six reports in all, which are the great mine of information as to river and stream pollution at this day. As regards these particular subjects, in no civilized country has work approximating to that of the Second Rivers Pollution Commission been performed.

In the summary to the fourth report, on the best means of preventing the pollution of rivers, the commissioners take the ground that the question of how to prevent polluting liquids from gaining access to running water could not be successfully answered without first defining just what is meant by polluted water; and that following this line, for the purpose of efficient legislation, an arbitrary line should be drawn between waters which are to be deemed polluting and inadmissible into streams and those which may be considered innocuous and therefore admissible to streams. The commission therefore gives certain standards of purity, which it is not necessary to reproduce, and states that such standards have been formed with the most careful regard for the interests of both towns and manufacturers. It expresses the opinion that the adoption of the methods proposed would not inflict any injury on manufactures, but might, on the other hand, save the manufacturers from inflicting injuries upon themselves. It is also pointed out that one of the most crying evils in manufacturing districts is the want of clean water, and that therefore every successful effort to make dirty water again usable is a clear gain to the manufacturing class as a whole.

In 1876 the English Society of Arts took up the study of various subjects connected with the health of towns, and, as an authoritative scientific society of the country, appointed a committee to report to the society in regard to the various questions involved in sewage utilization and the allied sanitary subjects. In its report the committee states as its opinion that where land at a reasonable price can be procured with favorable natural gradients, with soil of the proper quality and in sufficient quantity, a sewage farm, if properly conducted, is apparently the best method of disposing of water-carried sewage.

The committee also cautions the reader to bear in mind that a profit need not necessarily be looked for by the locality or municipality establishing the sewage farm, but that the farmer may be expected to reap profits from the operation. As to the sludge from precipitation processes, it is pointed out that from the manurial point of view it is of low and uncertain commercial value; that the cost of its conversion into a valuable manure will preclude the attainment of any adequate returns for the outlay and working expenses connected therewith, and that means must therefore be used for getting rid of it without reference to possible profit.

In 1882 the Queen's commission was again issued to what is known as the Royal Commission on Metropolitan Sewage Discharge. The scope of this commission's inquiry has been already referred to on page 31, in our discussion of intermittent filtration. This commission reported that it was neither necessary nor justifiable to discharge the sewage of the metropolis in its crude state into any part of the River Thames, and that some method of precipitation should be used to separate the solid from the liquid portions of the sewage. As a preliminary and temporary measure, however, the liquid portion of the sewage remaining after the precipitation of the solids might be suffered to flow into the river at a period between high water and half ebb of each tide, and at no other time.

It is also strongly stated that the liquid so separated would not be sufficiently free from noxious matters to allow of its being discharged at the present outfalls as a permanent measure; it would require still further purification, which, according to present knowledge, could be accomplished efficiently only by applying it to land. Because of the difficulty of obtaining sufficient area for irrigation in the vicinity of London, the commission was of the opinion that this additional purification could be best effected by intermittent filtration, for which, from the information at hand, it was concluded that sufficient area was available, at any rate within convenient distance of the northern outfall. As to the southern outfall, the commission was unable to state from its investigations the quantity of available land; in case of insufficient land available, the clarified effluent of the southern outfall was to be conveyed to the north side by a conduit under the river.

In 1892 the Queen's commission was again issued to what is known as the Royal Commission on Metropolitan Water Supply,[1] which was charged with inquiring into the present source of supply of the metropolis and as to whether the quality and quantity were adequate, etc. This commission included among its members such eminent sanitarians as Sir George Bartley Bruce, George H. Hill, and James Mansergh. In summing up the matter this commission said that all possible vigilance should be exercised to prevent unnecessary contamination of the rivers Thames and Lea and their respective tributaries, as well as to insure the thorough treatment of all sewage, before it is allowed to pass into the rivers, by the most efficacious methods that experience and science may dictate.

The Royal Commission on Metropolitan Water Supply also remarked that advances had been made during the past twenty-five years in the construction of sewage works in the valleys of the Thames and Lea; that where such works had been constructed on an efficient system the sewage could be so dealt with at all times, except those of flood, that the effluents were clear and innocuous. It should be borne in mind that this opinion is expressed by a commission which included

[1] Metropolitan Water Supply, Report of Royal Commission on, 6 volumes, general report, minutes of evidence, appendices, index, plans, etc., 4°, London, 1893. The most recent and extensive information as to pollution of streams and its effect on the water supply of the metropolis as applied to the rivers Thames and Lea, from which that supply is drawn.

in its membership some of the most eminent sanitarians of the present day, and that the streams into which the sewage effluents pass are the sources of the water supply of the largest city in the world.

In 1874 Sir John Hawkshaw was commissioned to inquire as to the pollution of the River Clyde and its tributaries and how far the sewage refuse from the towns and manufactories could be utilized and got rid of without running into streams, etc. In his report it is pointed out very forcibly that those who own and manage manufacturing establishments have them wholly under control, and that they can therefore provide and enforce the necessary provisions and regulations for removing the nuisances which they so often create, and that by reason of this fact there can be no necessity for the fecal matter from such establishments being passed into the streams. He also points out, as has been done by a number of other commissioners, that wherever large populations are gathered and numerous manufactories exist on the banks of any river, combined action should be taken to secure the waters of the stream from pollution as far as practicable. As a mere matter of fairness the manufactories and all works and establishments similarly situated should be treated alike.

In 1875 the president of the English Local Government Board requested Robert Rawlinson and Clare Sewell Read to report to the board as to the several modes of treating town sewage. The report, submitted in 1876, is one of the most valuable contributions to the literature of sewage disposal thus far made. Among the conclusions Messrs. Rawlinson and Read point out: (1) That the scavenging, sewering, and cleansing of towns are necessary for comfort and health, and involve in all cases questions of how to remove town refuse in the safest manner and at the lowest expense. (2) That the retention for any lengthy period of refuse and excreta in private cesspits or in cesspools, or at stables, cowsheds, slaughterhouses, or other places in the midst of towns, must be utterly condemned. * * * (3) That the sewering of towns and the draining of houses must be considered a prime necessity under all conditions and circumstances. * * * (4) That most rivers and streams are polluted by the discharge into them of crude sewage, which practice is highly objectionable. (5) That as far as they have been able to ascertain, none of the existing modes of treating town sewage by chemicals appear to effect much change beyond the separation of the solids. * * * (6) That so far as examined none of the manufactured manures made by manipulating town refuse, with or without chemicals, pay the costs of treatment. * * * (7) That town sewage can best and most cheaply be disposed of and purified by the process of land irrigation for agricultural purposes where local conditions are favorable to its application. * * * (8) That land irrigation is not practicable in all cases. * * * (9) That towns situated on the seacoast or on tidal estuaries may be allowed to turn sewage into the sea or estuary below the line of low water, provided no nuisance is caused and that such mode of getting rid of sewage can be justified on the score of economy.

The foregoing include the opinions of practically all the leading sanitarians of England for the last thirty-five years, and, as will be seen, such opinion has been unanimous that the preferable mode of purifying town sewage is by application to land. So overwhelming is this evidence that we must, in the future, consider this part of the subject as what the lawyers call res adjudicata—a proposition absosolutely settled and no longer to be called into question. The progress of the recent views to which we have already referred has assisted in taking this proposition out of the realm of controversy.

In passing we may remark that similar opinions have been expressed by German, Italian, and French Government commissions; but these latter all fall so entirely within the line of the view taken by the several English commissions that it is unnecessary to cite them here,

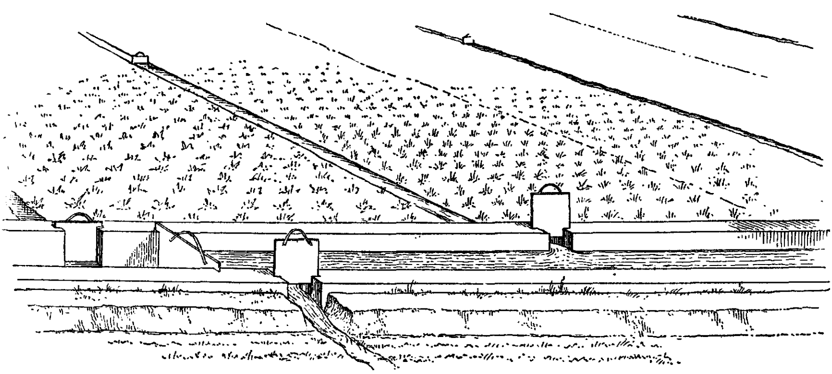


FIG. 6.--Ridge-and-furrow beds, with cropping.

the more especially because, sewage disposal having originated in England, the commissions of other countries have in their reports essentially followed the English views.

METHODS OF APPLYING SEWAGE.

As already stated, the methods of applying sewage in broad irrigation are substantially those of ordinary irrigation, with the exception of the necessity for closer attention to the detail. The principal special systems of irrigation used in sewage farming are known as (1) the ridge-and-furrow or bedwork system and (2) the catchwork system. Great variations from these two systems may, however, allowed.[1]

Figs. 6 to 13 illustrate a number of different methods of applying the sewage. We may also refer to the pipe-and-hydrant system, as

[1]For methods of laying out land applicable to sewage farms, see Les Irrigations, by A. Ronna (3 volumes, 8°). This is the most recent of the French text-books, and treats the preparation of land in full detail.

well as to the level-bed system, used when the filtration areas for intermittent filtration are utilized for raising crops.

In laying out land for the ridge-and-furrow system a series of slope beds are prepared, along the top of which supply carriers are laid, which are formed with level edges, so that the water flows over in a thin film and so on down over the slope beds with uniform depth. Such ridges are made in couples, with the slopes varying from 1 in 50 to 1 in 150. The amount of slope to be given in any particular case

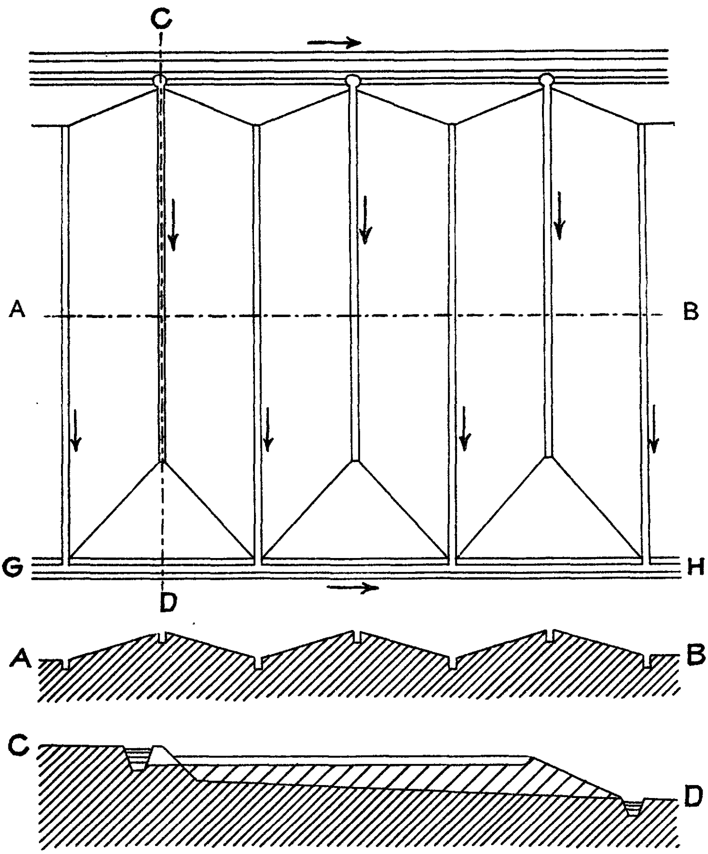


FIG. 7.—Plan and sections of ridge-and-furrow irrigation (Ronna, p. 438).

is purely a matter of judgment, in which the controlling factor is the porousness of the ground to be irrigated, the object of the slope being to insure that the water reaches in sufficient quantity all parts of the bed to be irrigated. Common dimensions of the beds are a total breadth of from 30 to 40 feet, or a breadth of slope on each side of the ridge of from 15 to 20 feet, although in exceptional cases, depending on just the use to which the beds are to be placed, the beds may be made larger. The length may be any convenient dimension suited to the contour of the area prepared. Land under such beds may be underdrained in accordance with the rules for underdraining which apply in ordinary farming, though in deciding whether or not to fully underdrain any given area it should be remembered that drainage increases the porousness of the soil.[1]

At the foot of the slopes a furrow is formed, which receives any sewage not absorbed in the passage over the beds and conducts it away to another and lower series of beds or to the outfall, as the case may be. Ordinarily the surface water of one irrigation should be passed over several beds in order to insure thorough purification. This is especially important where the beds are made of the sizes indicated in the foregoing. The thorough removal of the water at the

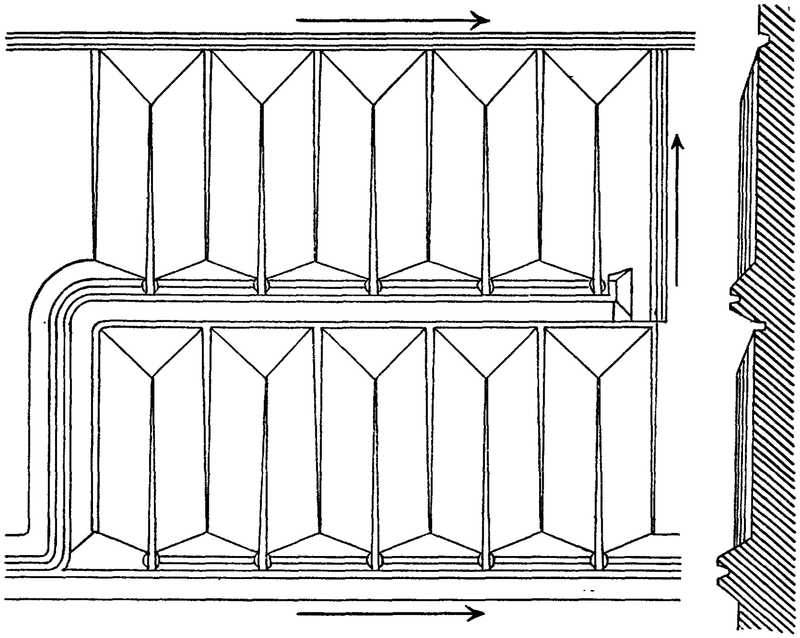


FIG. 8.—Double-bed ridge-and-furrow irrigation, with direct or secondary irrigation on the lower bed (Ronna, p. 449).

foot of the slopes, as well as the prevention of water-logging of the land, is insured by making a furrow at the foot of the slopes of ample dimension and with fall enough to produce quick drainage. Figs. 7 and 8 show the arrangement of the ridge-and-furrow system of irrigation.

In the catchwork system, which is more especially adapted to steep and irregular land, the liquid is delivered at the highest point of the area, the same as with ridge-and-furrow, a main carrier with level lip

[1] French, Henry F.: Farm Drainage; The Principles, Practice, and Methods of Draining Land, etc., 12°, New York, 1884. Waring, Col. George E., jr.: Draining for Profit and Draining for Health, 2d ed., 12°, New York, 1883.

on the lower side, along the highest contour, permitting the irrigation water to overflow the edge when dams are placed temporarily at various points on its course. At some distance lower down a catch gutter is formed on the contour, into which the unabsorbed overflow of the main carrier is caught as it flows downward. A damming of the catch gutter at suitable intervals causes it to overflow to the second, the same as in the case of the main carrier, and so on down to

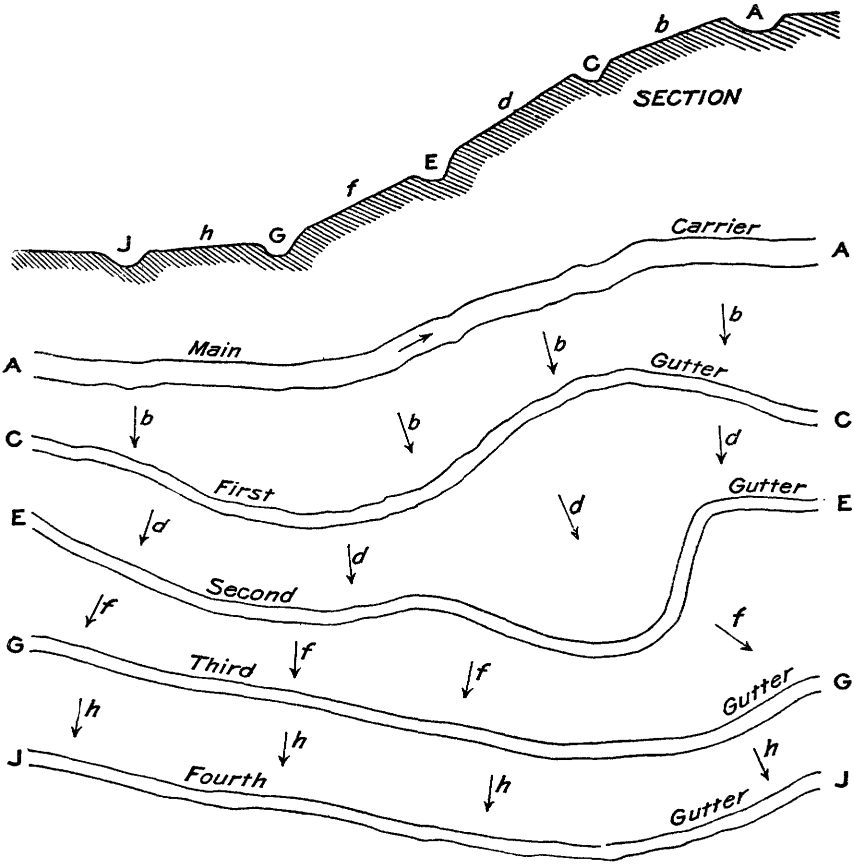


FIG. 9.—Catchwork system of irrigation.

the lowest contour of the area irrigated. The detail of this operation is illustrated by fig. 9.

According to Mr. Burn,[1] the great difference between the ridge-and-furrow system and the catchwork system is in the laying out of the ground. In the catchwork system, although the natural inclination of the ground is taken advantage of in the most direct and simple manner, still a considerable inclination is necessary for its successful application. The ridge-and-furrow system, on the other hand, is

[1] Burn, R. Scott: Outlines of Modern Farming, 6th ed., 12°, London, 1888. Treats extensively, among other subjects, of the utilization of town sewage, irrigation, etc.

more especially applicable to flat ground, such as is usually found in valleys or along the banks of rivers. In this system the necessary inclination is given by artificially throwing up the ridges, and the skill with which one part is taken advantage of to make up the deficiencies of another part will determine the degree of economical success. Generally speaking, the catchwork system is much cheaper than the ridge-and-furrow system, and at the present time the ridge-and-furrow system is only used where the ground is exceedingly flat or where for some special purpose the catchwork system is deemed to be specially undesirable.

Mr. Burn calls attention to certain points to be observed in laying out beds for the ridge-and-furrow system, as follows: If land

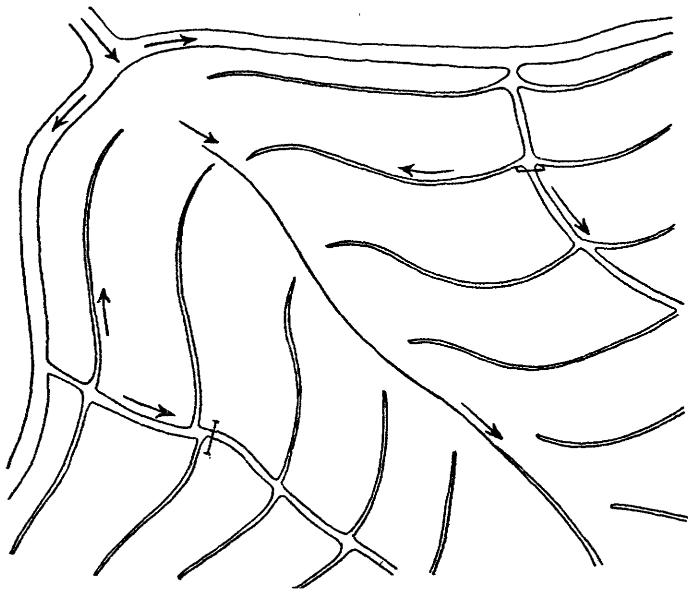


FIG. 10.—Distribution system adapted to irregular land (Ronna, p. 392).

intended for permanent meadow has a covering of sod, this should be removed by cutting into strips some 15 or 18 inches wide and placing carefully at one side. The inclined beds should next be made and the levels properly adjusted; then the channels of supply and the drains for leading off the water when used should be marked off. Cutting out of these may then be proceeded with, taking care in beginning the leading channels of supply that the soil taken out from these and the drains be carefully spread over the inclined surface. After the channels are all cut, if the ground is to remain down in meadow, the turf may be replaced. This work should be done with care in order to prevent irregularities of the surface. In all this work the point to be observed is that all parts of specially prepared surface shall receive their due supply of sewage. If hollows are left, the sewage will be likely to collect therein and become stagnant. Mr. Burn expresses the opinion that the objections which have been frequently raised to the rankness of sewage-grown grass have had their origin chiefly in the badness of the plan adopted for applying the sewage. If this is true, it is obvious that the small additional expenditure necessary to prepare the ground properly will be repaid.

As to the relative costs of preparing land for ridge-and-furrow irrigation, it has cost in England, in some cases, as much as from $100

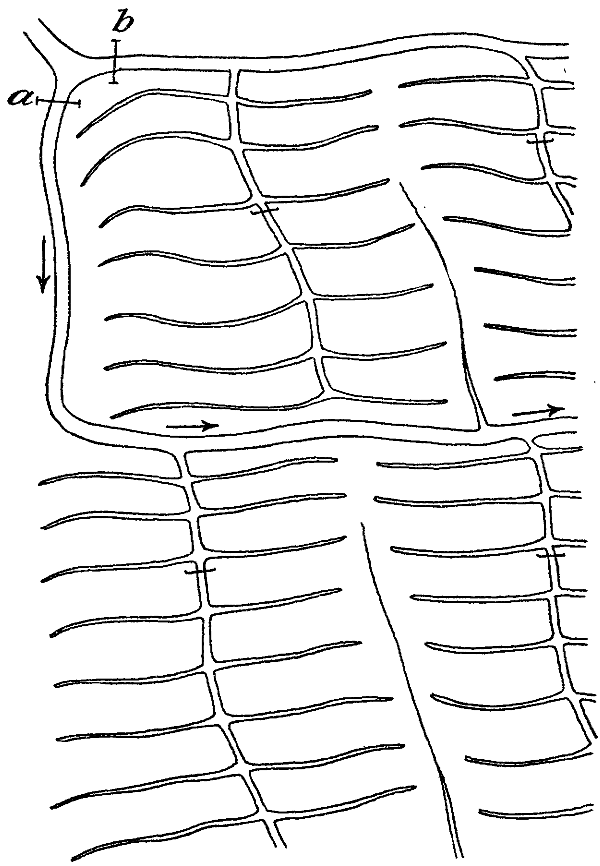


FIG. 11.—Double system of contour distribution controlled by end gates (Ronna, p. 395).

to $250 per acre, while catchwork systems have been carried out for from $10 to $25 or $30 per acre. The difference in price alone would lead to the use of the catchwork system and modifications of it in this country.

In a pipe-and-hydrant system of distribution a series of pipes is laid according to such a system (depending upon the topography) as will admit of reaching every point of the area to be irrigated with sewage. Formerly iron pipes were used for this purpose, but at the present time terra-cotta or vitrified tile pipes are quite commonly used. In order to render the irrigation of the field as convenient as possible, hydrants are placed at proper points, fitted with the usual coupling for connecting hose. Sewage is forced through these pipes, either by steam power or gravitation, as the case may be, and distributed to the surface of the fields by means of hose.

In a gravitation system a receiving tank is usually placed at a convenient elevation above the area to be irrigated, from which mains are laid to different parts of the irrigated area. In such a system the power with which the sewage flows from the hydrants is necessarily fixed by the height of the tank, but in a pumping system the power can of course be varied the same as in any other application of pump-

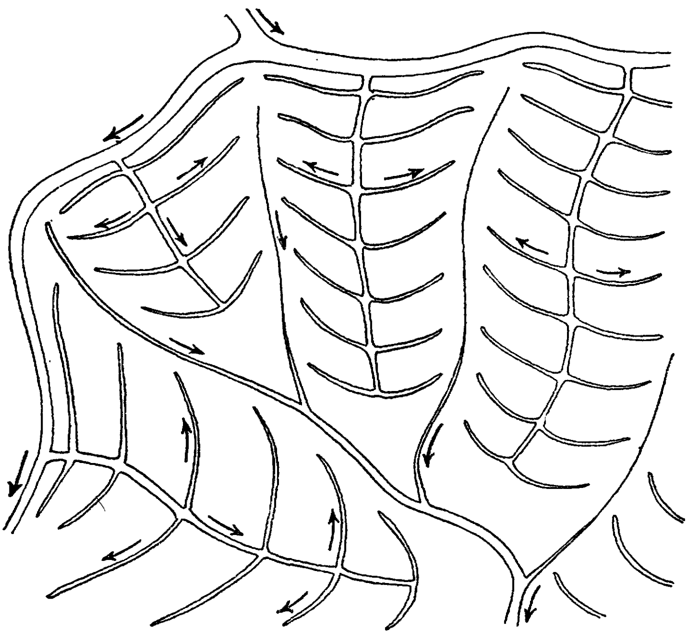


FIG. 12.—Distribution adapted to irregular ground (Ronna, p. 399).

ing. The detail of arranging such systems can not be given except in a very general way, because of differences in local conditions, but it will readily present itself to any engineer skilled in this class of work when the necessary preliminary data are placed before him. In England a large number of pipe-distribution systems have been carried out, while in this country the distribution at the Pullman, Illinois, sewage farm is effected in the same manner. The scarcity of water in southern California has also led to a considerable use of pipe systems there for the distribution of ordinary irrigation water, especially in the vicinity of Los Angeles.

One of the most complete systems of this kind is on a sewage farm at Rugby, England. This was established by Mr. G. H. Walker, who entered into an arrangement with the borough of Rugby to take the town sewage, which at the time of laying out the farm amounted to about 160,000 gallons a day. All cesspools were abolished in the town, and even the humblest cottage was provided with water-closets, so that the entire refuse of a population of 7,000 was delivered into the sewers.

The sewage flows from the town into an open brick reservoir 50 feet in diameter and 12 feet in depth, from which it is forced by steam pressure into a system of cast-iron pipes led over the farm. The

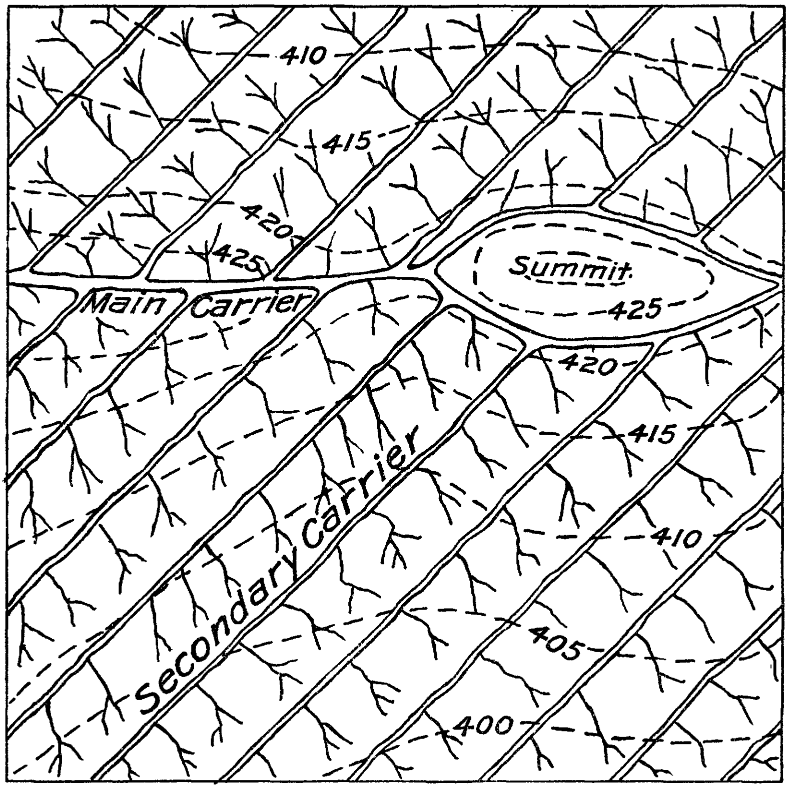


FIG. 13.—Distribution adapted to a field with ridge.

greatest elevation to which the sewage is pumped is about 60 feet above the reservoir, although a considerable portion of the land is over 20 feet above that level, and some of it as much as 20 feet below. The engine works a small air pump for the purpose of agitating the sewage in the receiving reservoir and preventing the deposit of solid matters.

The distributing pipes are laid over 420 acres of land, chiefly in grass, and comprise about 5½ miles, or about 691 feet per acre. The main distributary is 6 inches in diameter, with branches 3 inches in diameter. The total number of hydrants is 66, fitted with couplings for attaching hose from time to time to distribute the sewage in the neighborhood of each. The works originally cost about $32 per acre, but with the experience gained from these and other works it is believed that similar works could now be carried out for $25 or less per acre. Probably, by the use of terra-cotta pipe for that portion of the distribution system not required to take high pressure, the cost

FIG. 14.—Section of intermittent filtration area.

of such a system, with favorable topographical conditions and a large area, could be brought within $15 to $18 per acre. The cost of distribution is stated at not exceeding 1 cent per ton of sewage.

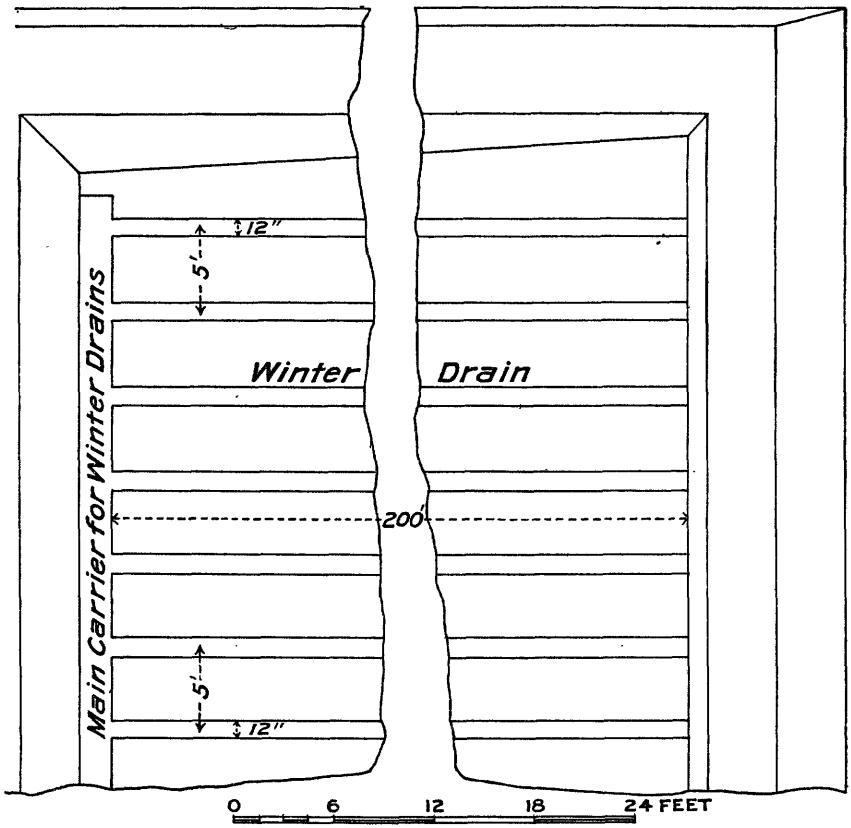


FIG. 15.—Plan of arrangement of winter drain on a filter area with absorption ditches.

In preparing intermittent filtration areas for the growth of crops level filter beds are made with low embankments around them, the area varying according to local conditions from 1 to 4 or 5 acres. Carriers are run on convenient lines for supplying sewage to these beds at suitable intervals. The area is also thoroughly underdrained, with the drains laid at least 5 feet deep. In some soils a slight advantage will be gained by making the drains as deep as 6 or 7 feet. In order to grow crops upon such areas the surface is prepared with a series of absorption ditches, where the sewage is allowed to stand until it sinks away into the ground, the length of time required for its disappearance of course varying according to the permeability of the soil. Absorption ditches are illustrated by figs. 2, 3, and 15. On clean sands, as experimented with at the Massachusetts experiment station, it was found that very large doses of sewage would sink into coarse sands in a very few minutes, but in fine sands, especially after they had been a long time in use, the period is considerably prolonged. In some cases it may be as much as twenty-four hours, the depth of sewage applied of course entering in as a controlling element.

If it is desired to dispose of sewage on filtration areas fitted with

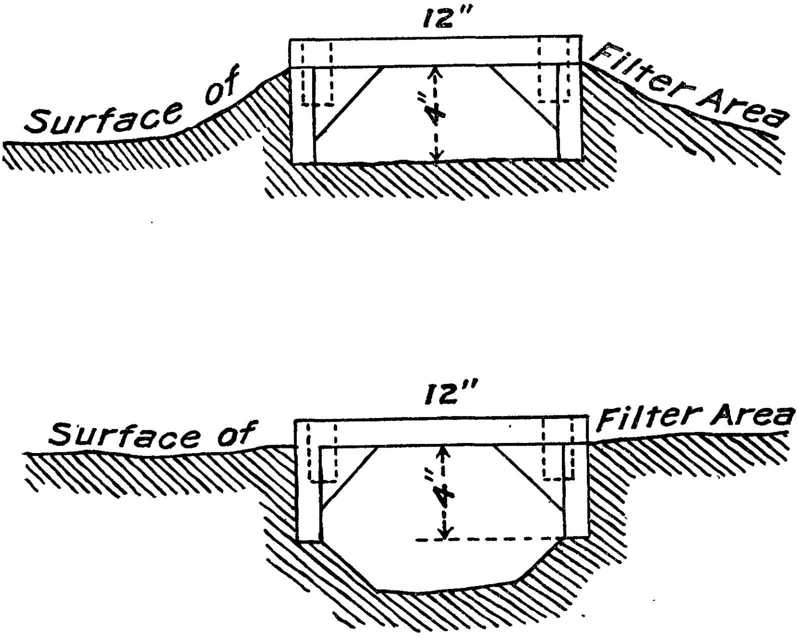


FIG. 16.—Cross section of winter drains.

absorption ditches during the winter season in extremely cold climates liable to heavy snowfall, and a high degree of purity of effluent is required, the ditches may be covered with boards, somewhat in the manner already described for the experimental sand-trench area at Lawrence. Where a lower degree of purity of winter effluent is sufficient, the areas may be left without any covering at all. Experience has shown that the sewage, by reason of reaching the fields at a temperature considerably above freezing, will penetrate beneath the snow, a film of ice freezing on the under side thereof and the process of filtration going on the same as if the snow were absent, except that the low temperature will tend to decrease the activity of the nitrifying organisms. This case, however, is provided for in a natural way. As shown by the experiments, the tendency in winter is for the nitrogenous matter to store itself in the sand by what in effect is a process of simple straining. As warm weather comes on in the spring, nitrification again resumes its sway, with the result of finally resolving the stored matter of the cold period. We have here a very interesting illustration of the fine balance of forces sometimes existing in nature. The nitrifying organisms, by reason of susceptibility to temperature, are enabled to carry on their work more actively in warm weather than in cold. The soil, acting as a simple strainer, strains out the objectionable matters in cold weather and stores them up until the period of activity of the nitrifying organisms shall have again come round, when these minute agents again successfully perform their appointed work.

BEST CROPS FOR SEWAGE FARMING.

A large amount of study has been directed toward the question of the best crops for sewage farming, especially in England, with the result of showing that in that country, at any rate, almost any crop which can be raised in ordinary farming can be cultivated on properly managed sewage farms with good effect. Among the crops ordinarily raised we may mention Italian rye grass, seeds, pasture, potatoes, wheat, oats, barley, mangolds, carrots, cabbage, parsnips, turnips, beans, rhubarb, celery, peas, lettuce, and corn. In southern climates the yam has been grown to good effect with sewage irrigation, while in southern California, orchards are successfully irrigated with sewage. The species of water willow known as osier is also grown extensively on sewage farms, not only because it is a valuable crop in the vicinity of towns, where it is extensively used in basket making, but especially because it has the property of absorbing large quantities of water. The American water weed, anacharis, is also a very gross feeder and will assimilate large quantities of organic impurity. Among other water plants which are capable of absorbing organic impurities may be mentioned duck weed, sedges, common reed, flowering rush, water lilies, liverwort, water cress, etc. There is, however, no special advantage in using some of these so long as plants having commercial value can be raised.

At the Doncaster sewage farm in England, in addition to wheat, barley, oats, rye, potatoes, rye grass, clover, meadow grass, and osiers, considerable quantities of small fruits, such as currants, gooseberries, and raspberries, have been successfully cultivated. At Berlin the chief crops are rape grown for seed to be used in the manufacture of oil, colza, mustard, carroway, hemp, and the cereals—wheat, rye, barley, and oats—with potatoes, beets, turnips, cabbage, and vegetables generally.

In the irrigation on the Plain of Gennevilliers, at Paris, by reason of the nearness of the fields to the city of Paris, the crops produced are chiefly those common to ordinary French truck farming. As we shall see farther on in discussing the Paris irrigation problem, very notable success has been attained here in the raising of all ordinary garden truck. Undoubtedly, however, the keeping of a large amount of live stock and the production of beef and dairy material is, on the whole, the most important branch of sewage farming. Italian rye grass in suited above all other grasses for irrigation, and in England, Scotland, and other countries yields, with sewage irrigation, prodigious crops of forage of best quality. Under favorable conditions it has yielded as much as 60 tons of green forage per acre per year. In an account of Italian rye grass which appears in Bulletin No. 73 of the North Carolina experiment station it is stated that Italian rye grass is scarcely hardy north of Washington, but is fully hardy in the Carolinas; that it resists drought well, but requires for the best results a deep, moist, rich soil. On poor soils it is stated to be of little value. The growth is upright, 2 or 3 feet high, and very leafy. On rich soils it should be cut every three or four weeks, as otherwise the heavy growth is apt to cause the grass to lodge and rot at the base of the culms. This grass shoots early in the spring and flowers in May. When grown for seed, it yields as much as 300 to 400 pounds per acre, worth from 3 to 5 cents per pound.

English perennial rye grass, the seed of which is quite similar to that of Italian rye grass, is also grown extensively in England, where it constitutes the chief grass of many of those famous pastures which have not been broken up or reseeded for over a century. It forms a very thick, compact turf, which is not easily broken by the feet of animals. This grass may be grown on the heavy clay soils of the South, but is not considered as fitted for the conditions of agriculture in the North.

The seed of the English perennial rye grass is much less expensive than that of the Italian rye grass, and hence is frequently used as an adulterant of the latter. The seeds of such weeds as are common to wet meadows are also frequently largely present in uncleaned samples of rye-grass seed. For these several reasons the Italian rye-grass seed should be purchased only of reputable dealers and under a guaranty of quality. A bushel weighs from 18 to 24 pounds. When sown alone, it requires from 45 to 50 pounds per acre.

Bulletin No. 73 of the North Carolina agricultural experiment station also states that Italian rye grass is one of the best grasses for temporary lays on good moist soil. It is best sown alone or with alsike clover. If sown in the fall, it will give five or six heavy cuttings in the succeeding year, and is best plowed up the next fall. If sown in the spring, it may be allowed to stand the second season. This grass has often been used in small quantities in mixtures to serve as a nurse for the less permanent and vigorous species, but it is now generally agreed that this is not the best practice, as the luxuriant growth of the rye grass is likely to smother out the grasses it was meant to assist. It disappears at the end of the second year, leaving the ground unoccupied for weeds to come in. Italian rye grass is stated as very exhausting to the soil, and hence becomes especially amenable to irrigation by sewage. According to the experiments of the English Sewage of Towns Commission, as well as the practical observation of farmers who have tried it in the South in this country, its value for feeding is very high. When grown in the South, in ordinary farming, it is necessary to reseed it every second year; but probably with sewage irrigation it could be carried to the third year, the same as the ordinary practice in English sewage farming. At the Berlin sewage farm, where a considerable quantity of Italian rye grass is grown, the best mixture has been found to be timothy and rye grass, about half and half.

Clovers and alfalfa are also crops which have been found to thrive well on moderate sewage irrigation at different places, especially the latter. This will grow in favorable soil anywhere from about sea level to 7,000 feet elevation. It may be seen very commonly in the valleys under the foothills of the Colorado and California mountains. It grows best in a light, rich, sandy loam, underlain by a loose, permeable subsoil, and its development is considerably influenced by such conditions as the depth and warmth of the soil, the depth of the ground water below the surface, and the physical character of the subsoil generally. Its cultivation has been most successful in the arid regions of the West and Southwest, where, because of the light rainfall, an artificially controlled water supply is commonly used. Experience there indicates that it grows better under irrigation than under any other conditions, as in this way the quantity of water exactly suited to its best development may be supplied. Good drainage is necessary, as otherwise the plants are likely to be killed by an excess of water either in the soil or on the surface. When undergoing irrigation, water should not be allowed to stand on the alfalfa field more than forty-eight hours, as otherwise the ground becomes saturated and the plant liable to be drowned out. A very complete account of alfalfa may be found in Farmers' Bulletin No. 31 of the United States Department of Agriculture.

Before the modern application of the practice of ensilage to the preservation of green crops came into use one great difficulty in the management of sewage farms related to the disposition of the enormous green forage crops which sewage-irrigated land produces. With ensilage, however, this difficulty is entirely done away with, and sewage farming may be considered to have taken by its use a new impulse. Most of the reiterated objections of from twenty to twenty-five years ago as to the impossibility of operating sewage farms at a profit have been removed, and, indeed, ensilage is another recent new application through which sewage farming may be said to have taken on such entirely different lines of development as to render many of the discussions of an earlier date of little value.

In eastern countries silos have been used for preserving corn for many hundred years. Underground pits are stated to have been used by the wandering tribes of Arabia in order to prevent victorious enemies from obtaining possession of food supplies. The Moors brought the art of ensilage into Spain, whence it found its way into France and Germany, and finally extended to England and the United States, in which latter countries its use has mostly grown up since about 1880.

As to the theory of ensilage, it may be remarked that if green crops are left exposed to the air for any considerable space fermentation begins, and if left unchecked will continue until putrefaction sets in and the crop becomes useless for feeding purposes. It is now understood that fermentation is produced by the active agency of bacteria. According to the researches of Pasteur there are certain ferments which continue their action without the presence of oxygen; such fermentation is called putrefaction, and is accompanied by the production of bad odors. It is the opposite of nitrification, which takes place only in the presence of oxygen, and is, when working to the best advantage, entirely unaccompanied by odor.

Again, all putrefactive fermentation is accompanied by the production of considerable quantities of heat. If we place a green crop in the silo, but leave it freely exposed to the air for a few days, it becomes heated to a temperature of from 125° to 150° F., at which point the bacteria are killed and the subsequent fermentation which would otherwise have been produced by them is arrested. The material so produced is called sweet silage, which remains aromatic by reason of having gone through merely what is called hay fermentation.

When, however, the green crop is put into the silo and subjected to pressure, with the exclusion of air immediately after being put in, the temperature does not rise above about 100° F. At this point the bacteria are not killed and the fermentation proceeds to the point of forming lactic or acetic acids, the process being accompanied by the loss of some of the saccharine matters, which are supposed to break up and form new combinations, passing away partly as gas. This process produces what is known as sour silage, in contradistinction to the kind which is termed sweet. Cattle soon learn to eat either variety with avidity.

We will not take up space to describe the process of ensilage in this place, but simply refer the reader to Bulletin No. 32 of the United States Department of Agriculture, where very complete detail as to the construction and cost of silos, as well as to crops best suited to the process, may be found. We may remark, however, that the most common ensilage crop of ordinary farming in this country is Indian corn. Over a large part of the United States from 15 to 20 tons of clean fodder per acre can be grown without difficulty under the conditions of ordinary farming. Considering the vigorous growths of Indian corn produced by sewage irrigation, it is probable that experience would soon show that on sewage farms from two to three times this quantity could be produced by growing, say, two crops on the same area in a season.[1]

In England the first experiments with rye-grass silage were made from ten to fifteen years ago, with the result of showing that there was no difficulty in preparing the rye grass for winter feeding in this way. At the present time ensilage is regularly used on nearly all the English sewage farms. Experience with it at the different farms will be given in the detailed accounts of the English sewage farms following.

As to the feeding value of sewage-grown grass, we may refer, for an authoritative exposition, to the reports of the English Sewage of Towns Commission. This commission experimented extensively on this subject and gave its report in great detail. Among other points presented, it shows that very large quantities of milk as well as beef can be produced from cattle fed on sewage-irrigated grass, and that the composition of the milk produced varied but slightly from that produced by cattle fed on ordinary unsewaged fodder. The milk from the sewage-grass-fed cattle was slightly less rich in casein, butter, and sugar than that from those fed on unsewaged grass.

In an experiment with oats, in which 135.5 gross tons of sewage were applied per acre, the gross value of the increased produce amounted to more than 10 cents per ton on the sewage employed; in another experiment, in which 510 gross tons of sewage were applied per acre, the gross value of the increased produce amounted to 3 cents per ton of sewage employed.

In the immediate vicinity of towns, where garden truck can be conveniently disposed of, truck farming will necessarily be an important branch of this special department of irrigation. When, on the other hand, the sewage farms are for any reason situated farther away from towns, dairy farming and the raising of cattle will become the leading branches, the cattle being fed on green forage during the summer and on stored roots, such as mangolds, beets, swedes, etc., and rye grass and corn silage in the winter. Working intelligently on these lines, it is believed that a fine profit can be realized from such farming in almost any locality.

QUANTITY OF SEWAGE TO BE APPLIED.

As to the quantity of sewage which may be applied per acre, the experiments of the Sewage of Towns Commission indicated varying amounts ranging from 400 to 500 gross tons per acre per annum on

[1] For literature of ensilage as applicable to American conditions, see Sewage Disposal in the United States, pp. 257-259.

heavy land in wet seasons on ordinary crops to about 9,000 tons per acre on grass plots.

As we have seen, the daily average sewage in this country will probably be at least 80 United States gallons per head, giving the annual amount of sewage per capita at 97 gross tons. On this basis the range of application per acre would vary from the sewage of 5 to that of 93 persons. Include some additional sewage which land may be expected to clarify without reference to the results of cropping, and we may take from 50 to 150 persons per acre per year, though the quality of the soil may be expected to materially influence the result. We may point out, however, that with intermittent filtration areas, provided by the towns for the purpose of purifying sewage when not needed in agriculture, the question of number of inhabitants per acre from which the sewage may be utilized has little significance further than as a guide in estimating the probable quantity of sewage which each farmer may be expected to require in ordinary seasons. For completion of our subject we may give in detail the statistics of the quantity of sewage utilized on a number of the foreign farms, drawing for our information upon the paper, "Notes on European practice in sewage disposal," by Charles S. Swan, M. Am. Soc. C. E., to be found in Volume VII of the Journal of the Associated Engineering Societies.

From the tabulations there given it appears that at the Croydon Beddington farm, with a gravelly soil, the volume of sewage used in broad irrigation may be as great as 3,860 cubic feet per acre per day, which amounts to an average depth of sewage on the area per annum of 32.3 feet. At Doncaster, with sandy or gravelly soils, the average application is 395 cubic feet per acre per day, amounting to a total depth on the area of 3.31 feet per annum. At Leamington, with a soil mostly gravel, the average application is 546 cubic feet per acre per day, amounting to a depth of 4.6 feet on the area.

At the Berlin Malchow farm, with a heavy soil, the average application ranges from 288 to 346 cubic feet per day, amounting to a total depth on the area of from 2.4 to 2.9 feet. On the Berlin Falkenberg farm, with a heavy soil, the average application is 483 cubic feet per acre per day, amounting to an average depth over the area of 4 feet. On the Berlin Osdorf-Grossbeeren farms, with sandy soils, the average application is from 616 to 640 cubic feet per acre per day, amounting to a total depth for the area of from 5.2 to 5.4 feet.

At the Paris Gennevilliers irrigation area, with sand and gravelly soils, the market gardeners apply about 1,305 cubic feet per acre per day, which amounts to 10.9 feet over the area per year. On this point attention is called to the account of irrigation at Gennevilliers on pages 93–98. In filtration without cultivation, as carried on at Gennevilliers, 3,616 cubic feet per acre per day, or a total depth of 30.3 feet per annum over the area, have been applied. The maximum limit at Paris with sandy and gravelly soils was formerly 3,915 cubic feet per acre per day, which amounts to 32.8 feet depth over the area, but during the last few years even larger quantities have been applied.

THE LIMIT OF TEMPERATURE.

Question is frequently raised as to the temperature limit at which the purification of sewage by either broad irrigation or intermittent filtration can be carried on, and widely varying opinions have been expressed. The last few years, however, have furnished a considerable amount of data on this point, which enable one to form more definite opinions than were possible formerly. If one takes a map of the United States on which the mean winter temperatures at the principal cities are laid down, it will be seen that the curve of 32° mean January temperature (January is taken as being the coldest month) passes between New York and Philadelphia, just south of Columbus and Indianapolis and St. Louis, and just north of Cincinnati. It also passes to the south of Dodge City, Kansas, and to the north of Oklahoma; passes south of Santa Fe, New Mexico, and thence curves north through the State of Nevada and a little to the west of Winnemucca. The curve passes about through the middle of the State of Washington. It may be assumed without discussion that at all points south and west of this line the temperature difficulty will never appear in connection with sewage purification by the land process.[1]

To the north of the line, however, we may define a strip of country the northern limit of which is between Boston and Portland, and to the north of Albany and Oswego, Rochester, Buffalo, Detroit, Grand Haven, Chicago, Keokuk, Dodge City, Denver, and Salt Lake City, within which limits, with proper management, sewage purification by the land process may be carried on in winter without serious difficulty. In the portion of the United States north of this latter limit, probably, special appliances would be needed for a successful winter purification. These conclusions are based upon a study of sewage as received at purification works in winter in comparison with soil temperatures at various depths, as kept at a number of sewage farms, as well as at the agricultural experiment stations in this and other countries.

Our first important fact is that the mean temperature of sewage is much higher than that of the air. At Lawrence, in January, 1888, the mean temperature in the main sewer was 46.5° F. The mean temperature of the air in January was 15.46° F. In 1889 the mean temperature in the main sewer was 45.9° in January, while the mean temperature of the air was 31.40°. Similar differences of temperature as between the sewage and the air are found to exist in other places. This considerable difference between the temperature of the sewage and of the air is sufficient to not only prevent the sewage from

[1] For map illustrating the foregoing in regard to temperature curve, see Allen Hazen, Filtration of Public Water Supplies; New York, 1895.

freezing readily, but to keep the ground itself open and free from frost. In regions of large snowfall the sewage passes under the snow, forming a crust of ice on the under side, and the irrigation goes on through the unfrozen soil the same as when snow and low temperature are absent. The difference in the degree of purification attained has already been discussed in the foregoing pages.

As to how the sewage retains sufficient heat to prevent freezing of the ground, we have to consider that water not only parts with its latent heat very slowly, but even after the freezing temperature of 32° F. is reached every pound of water still contains 142 heat units, which must be entirely withdrawn before a given pound of water can become frozen solid. Another reason why a body of water which is continually receiving accessions of water at considerably higher temperature than the mean of the body will freeze with great slowness may be found in considering that after the formation of an ice cover the loss of heat from the water is still further retarded by the condition that it can then take place only by conduction through the ice cover, which has a low rate of conductivity, thus leading to still further retardation in the process of loss.

The quality of the material of which filter areas are formed will, however, influence somewhat the rate of loss of heat in cold weather. According to the classical experiments of Schubler on the physical properties of soil, it appears that the relative power of retaining heat varies greatly in different soils. According to his experiments, lime sand required three hours and thirty means to cool from 145° to 70° F.; clay loam cooled between the same limits in two hours and thirty minutes; heavy clay in two hours and twenty-four minutes; pure gray clay in two hours and nineteen minutes; garden soil in two hours and sixteen minutes; humus in one hour and forty-three minutes, while water required thirty hours and seven minutes in cooling from 145° to 70° F. The conditions were the same for all of these materials.

Schubler's experiments also show that black soils retain their heat better than those which are white and light colored, and that this property resides almost wholly in the surface. A practical application of this fact may be made by constructing the broad surface of artificially prepared filtration areas of dark-colored sands or gravels.

Temperature observations as made at the Berlin sewage farms show that the mean of the soil temperatures there is considerably above that of the air. The same fact has been, generally speaking, brought out by an extensive series of soil temperatures taken at the various agricultural experiment stations in this country, although there are exceptions, which, however, do not invalidate the general proposition.

Without presenting the full information upon which these deductions are based, we may say that generally at a locality with a mean air temperature for the coldest winter months not lower than about 20° to 25° F., and with sewage distributed to a purification area at a temperature not lower than about 45° F., purification by the land process may be effected without serious interruption from frost, the winter purification being, as already pointed out, less than that realized in summer. If the mean winter temperature falls for any considerable length of time much below 20° to 25° F., there will probably be trouble from frost. By reason, however, of the facility with which the level embanked areas of the filtration process may be operated as continuous filters during extreme cold weather, it is probable that the filtration process, pure and simple, may be operated at a somewhat lower temperature than the broad irrigation process. As a safe limit, the lowest mean air temperature for filtration may be set at from 18° to 20° F.

The foregoing statements as to practicable mean winter temperatures are to be considered, however, in relation to the quality and temperature of the soil used. Before deciding as to just what can be reasonably expected in a given locality, therefore, one should have at hand a statement of the physical properties of the soil as well as the mean temperatures of the coldest months. As repeatedly pointed out, sandy soils are preferable for both irrigation and intermittent filtration. As regards temperature, this preference arises not only on account of their open texture, but because they possess greater capacity for heat. The great desideratum of successful sewage purification in winter is a medium which will prolong the time of congelation. It is considered that sand answers to this requirement better than any other material.[1]

COST OF LABOR ON SEWAGE FARMS.

When examining a number of the best-managed sewage farms of England in the fall of 1894, the author was much surprised to learn that, generally speaking, somewhat higher wages are paid on sewage farms than on farms of the same character in the immediate neighborhood, and one reason why he is now of the opinion that sewage farming may be made commercially profitable in the United States is derived from the consideration that the wages actually paid for labor on many of the English farms are quite as high or even higher than the present rate of wages for farm labor in many parts of this country.

As regards a comparison, therefore, between the English sewage farms and American conditions, the frequently urged objection that we could not afford the large amount of labor required here certainly has no weight. In order to present this phase of the question in

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[1]The reader wishing to go extensively into the rela tions of temperature to winter purificatin should consult Chapter XVII of Sewage Disposal in the United States, on "The temperature of the air and of natural soils, and its relation to sewage purification by broad irrigation and intermittent filtration," where an extended discussion may be found.

some detail, the author is enabled, through the kindness of Mr. S. S. Platt, Assoc. Mem. Inst. C. E., borough engineer at Rochdale, England, to include the following statements as to the actual prices paid during 1895 at a number of the English sewage farms. This information was gathered by Mr. Platt directly from the managers of the several farms:

At Birmingham, with an area of 1,300 acres, 222 men, 14 women, and 22 children were employed as an average during the year 1895. The men received 21s. per week, the women 10s., and the children 8s. On similar farms worked by ordinary methods in the neighborhood men received, in 1895, 16s. per week, women 9s., and children 6s.

At the Burton-on-Trent farm, with an area of 575 acres, the force employed consists of 4 wagoners, at 20s. each per week; 3 cow men and a shepherd, 19s. per week; 24 ordinary laborers, at 17s. per week, and 7 laborers attending to the sewage distribution, at 23s. per week; 2 foremen, at 30s. per week, one of them being furnished with a horse in addition; 1 weigh clerk, at 20s. per week; 2 men with steam cultivator, 1 at 27s. 6d. per week and 1 at 21s. per week. Four boys are also employed, 1 at 4s. per week, 2 at 7s. per week, and 1 at 9s. per week.

At the Crewe sewage farm, with an area of 269 acres, the average labor consists of 20 men, receiving from 14s. to 21s. each per week. On ordinary farms in the neighborhood of Crewe common labor receives from 14s. to 16s. per week.

At Croydon, with a total area of the two farms of 630 acres, the labor employed is as follows: One man at 32s. per week, 1 at 30s., 1 at 27s., 2 at 26s., 2 at 25s., 12 at 24s., 2 at 23s., 1 at 22s. 6d., 8 at 21s., 5 at 20s., 1 at 19s. 6d., 18 at 18s., 3 at 17s., 4 at 16s., 2 at 15s., 2 at 14s., and 1 at 13s. 6d. The total number of men employed at Croydon is found to be 68, and the average weekly wage is 19s. 10d. per week. On ordinary farms in that vicinity the wages of common laborers range from 18s. to 20s. per week. Carters receive 23s. per week.

At West Derby, with an area of 207 acres farmed, the labor varies from 22 to 40 men, according to the season, the wages paid ranging from 10s. to 24s. per week. On ordinary farms in the vicinity about the same rates are paid. The head foreman receives 30s. per week, together with free use of a cottage, garden, and coal. Six of the regular farm hands are also furnished with cottages and garden free.

At Northampton the total area farmed amounts to 688 acres, the labor including about 50 men, 25 women, and 12 boys. The wages paid are from 15s. to 18s. per week for the men, 10s. for the women, and from 5s. to 10s. for the boys. On ordinary farms in the neighborhood the wages range about 1s. per week less.

At Nottingham the total area farmed amounts to 908 acres, requiring from 40 to 50 men and from 15 to 20 boys. The men receive from 14s. to 17s. per week wages, and are also furnished with good houses and large garden, rent free. Manure and seed potatoes are also furnished free. The boys receive from 4s. to 10s. each per week. On ordinary farms in the neighborhood men receive 12s. to 15s. per week, without house and garden, and boys about 1s. less per week than on the sewage farm. On the sewage farm all the men employed are paid extra for overtime and are allowed harvest piecework at the same rate per acre as strangers who are not found houses.

At Oxford the total area farmed is 370 acres; the amount of labor fluctuates from 15 to 30 men, according to the season, together with 2 women and 4 boys. The men receive from 12s. to 15s. per week, women 6s. per week, and boys from 3s. to 5s. per week. On ordinary farms in the neighborhood men receive from 11s. to 12s. per week and women 6s. per week.

At Tunbridge Wells, on the north farm, consisting of 191 acres, 1 man is employed flowing sewage at £1 per week and cottage, 5 laborers at 16s. and cottage, 1 laborer at 16s. per week without cottage, and 1 boy at 10s. per week. On the south farm, which consists of 199 acres, 1 man is employed flowing sewage at £1 3s. and 6d. per week and cottage, 4 laborers at 16s. 6d. per week and cottage, 1 laborer at 19s. per week without cottage, 3 at 15s. per week without cottage, and 1 boy at 9s. per week.

At Warwick, with an area of 134 acres, 10 men are employed at 15s. per week and cottage. On ordinary farms in the vicinity the laborers receive from 10s. to 13s. per week.

At Wimbledon, with an area of 70 acres, the labor varies from 3 to 8 or 10 men, depending upon the season. The price of labor ranges from 21s. to 30s. per week, at which prices it is stated that the very best men of the vicinity are obtained. The amount expended in wages on this farm during the year ending March 31, 1896, was £639 3s. 2d.

At Wolverhampton, with an area of 600 acres, the labor amounts to about 22 men and 3 boys, the men receiving from 18s. to 20s. per week, and the boys 6s. Laborers on ordinary farms in the vicinity receive about the same price.

Relative to the cost of management on a number of the leading English sewage farms, we may refer to a return showing the salaries and emoluments of sewage-farm managers, etc., as contributed by Joseph Gordon, Mem. Inst. C. E., borough engineer at Lester, which may be found in Volume XV of the Proceedings of the Association of Municipal and Sanitary Engineers and Surveyors. From this return it appears that at Birmingham the management of the farm is in the hands of a general manager or superintendent, who receives a salary of £350, with use of horse and wagon. At Burton-on-Trent the manager receives a salary of £150 per annum; at Crewe, a salary of £160 per annum. At Croydon the manager of the Beddington farm receives £220, with house and gas provided. The manager of the Croydon Norwood farm receives a salary of £156. At Northampton the manager receives a salary of £250, and is furnished in addition thereto with house and garden and horse and wagon.

At Nottingham the management is in the hands of the farm bailiff, who receives a salary of £300 per annum.

At Tunbridge Wells there are two farm bailiffs, who each receive a salary of £120 per annum with house and garden and the produce of a cow.

At Warwick the farm is managed by a superintendent, under the direction of a committee, who is paid £120 per annum.

At Berlin, as stated by Mr. Roechling in his paper on "The sewage farms of Berlin," which may be found in Volume CIX of the Proceedings of the Institution of Civil Engineers, the labor of the sewage farms is largely performed by misdemeanants; that is, by men sent for various minor offenses to the city house of correction. In 1890 the total number of misdemeanants employed on the Berlin sewage farms amounted to 737, their labor costing the sewage farm about 13 cents each per day. Besides this number of misdemeanants a large number of free laborers were employed on the farms at an average price of about 40 cents per day. By observation it has been concluded that the work performed by two free laborers at this price is fully equivalent to that of seven of the misdemeanants. At this rate it is clear that from a pecuniary point of view there is no saving to the farm management from the employment of the misdemeanants, as, at the rates mentioned, the labor done by misdemeanants at a cost of 91 cents per day is performed by free laborers at a cost of 80 cents per day. There is, however, a decided advantage to the administration of the house of correction, which is also owned and managed, as well as the sewage farm, by the city authorities. As a matter of philanthropy Mr. Roechling says the employment of the misdemeanants may be also highly commended, as it gives the men a chance to acquire regular habits while undergoing their punishment.

In considering the significance of the price of labor paid in England and in Germany in its application to American conditions, it must be remembered that in England the price of the ordinary crop sent to market from the sewage farms will compare with the prices prevailing in the United States very much in the same way and in the same ratio as that which obtains between the price of labor in the two countries. In Germany, on the contrary, where labor is considerably lower, the prices of produce are also lower, all of which must be taken into account in drawing conclusions as to the possibilities of establishing sewage farms here. In France the price of labor does not vary greatly from the price in Germany.

SANITARY CONDITION OF SEWAGE FARMS.

There has been much discussion at various times as to the sanitary condition of sewage farms, and formerly much apprehension was expressed as to the possibility of contaminating not only the well waters of the surrounding areas, but also the atmosphere in the vicinity. As to the contamination of well waters, the development of a clear understanding of the actual facts in regard to nitrification has gone a long way toward relegating this particular objection to sewage farming to the region of exploded objections, which, as we have seen, is now occupied by a large array of the arguments of the opposition as advanced from twenty to twenty-five years ago. At the Berlin sewage farm the effluent is so pure that it can be admitted into any water course, and can not be distinguished by the senses from the clearest spring water.

In order to obtain information as to the extent to which sewage farming may affect the health of the inhabitants of the farms, the Berlin authorities have established a system of registration of all cases of sickness and death. The following facts bearing upon the sanitary condition of the farm are derived from Mr. Roechling's paper already referred to. The average annual population to which the figures apply was, during the five years from 1885 to 1889, 1,580, of which 986 were men, 285 were women, and 327 were children under 15 years of age. The 958 adult male population included 850 misdemeanants, who were probably impoverished in health by irregular habits of life. The records show that the death rate per 1,000 from all causes was 11.24 in 1885, 9.22 in 1886, 14.83 in 1887, 6.79 in 1888, and only 4.81 in 1889. Of the total deaths, 16 per cent were men, 9 per cent women, and 75 per cent children, the mean rate of the whole five-year period being 9.75. The death rate from the seven principal zymotic diseases, smallpox, scarlet fever, diphtheria, typhoid fever, measles, whooping cough, and diarrhea, was 4.32 in 1885, 3.69 in 1886, 4.15 in 1887, 1.13 in 1888, and nothing in 1889, the mean rate during the period from these causes being 2.53. The period covered by these statistics is, of course, too short for definite conclusions to be drawn, although it may be stated that the same low rates have continued until the present time. If, however, statistics mean anything, they indicate clearly that the conditions of this farm are not in any degree unhealthful. It may also be stated that drinking water for use on the farms is obtained by wells sunk at the points where water is required. With one exception there has been thus far no indication of any trouble with these wells. The reports also show that the sewage farms do not exert any detrimental effect upon the health of cattle kept upon them or on the adjoining farms. At Berlin it is even said that the small sickness which has occurred among the cattle has been imported.

The question of the sanitary conditions of sewage farms was examined at length by a committee appointed by the Royal Agricultural Society in the sewage-farm competition of 1879, to which we have referred. This committee concluded that sewage farming is not in any degree detrimental to life or health. Statistics presented by it show that the rate of mortality, on an average, for the number of years that the farms considered had been in operation does not exceed 3 per cent per annum, the result comparing favorably with that obtained somewhat more recently at Berlin.

We are obliged to conclude, therefore, that properly managed sewage farms are not detrimental to health.[1]

NUMBER OF BACTERIA IN SEWAGE-FARM EFFLUENTS.

By way of showing the degree of bacterial purification effected by sewage farms we may refer to the following observations made by Prof. E. Ray Lankester on the sewage and effluent of the Oxford sewage farm, England, and the water of the Oxford River, into which the effluent from this farm discharges. These observations were made on the given dates in the summer of 1892.[2]

Comparison of number of bacteria in sewage and in river near Oxford, England.

Sample from—	Bacteria per cubic centimeter.					
	June 27.	July 21.	July 28.	July 29.	September 11.	October 5.
Sewage	648,000	12,000,000	1,688,000	1,688,000	528,000	2,486,000
Effluent	42,000	20,500	60,000	60,500	27,000	27,000
River above effluent	1,020	4,700	14,300	24,300	1,800	2,000
River below effluent	900	11,000	24,900	24,900	9,072	14,580

Professor Lankester states that the most important fact brought out by these studies was that the species of bacteria which belong characteristically to sewage (*B. coli communis*, etc.) were not found in the sewage, but only fluviatile species. He further states that it may be asserted in a general way that the effluent contains no more bacteria, nor other kinds of bacteria, than are to be found in other streams draining from agricultural lands in the neighborhood.

SEWAGE FARMING IN ENGLAND.

Having taken a rapid review of the general subject of sewage irrigation, it is now in order to briefly describe a few of the more notable examples of sewage farming abroad and in this country. First may be considered the English farms, and then, briefly, those of Germany and France. Five examples are given from England typical of prevailing conditions, these being the Croydon Beddington farm and the Leamington, Birmingham, Wimbledon, and Doncaster farms. There

[1] See paper by Dr. Alfred Carpenter, of Croydon, read before the British Medical Association in 1888. Dr. Carpenter lived for many years in the immediate vicinity of the Croydon Beddington farm.

[2] Statement by Prof. E. Ray Lankester to the Royal Commission on Metropolitan Water Supply, Appendix C, 61.

are probably more sewage-purification works in England than in any other country, but they all present merely variations in details.

In regard to the present views of English engineers, sanitarians, and sewage-farm managers, it may be stated that the consensus of opinion, as it appeared to the author in 1894, was decidedly in favor of the land purification process. If for any reason it is necessary that the effluent from sewage-purification works should pass into a stream which is the source of a water supply, the further consensus of opinion appeared to be that it should, before receiving the land treatment, be clarified to the extent of removing all of the suspended and a small portion of the dissolved matter by some of the more inexpensive chemical processes. The same views, it is believed, are now held in the United States by many competent engineers, although the effluents from high-grade intermittent filtration areas are also unobjectionable.

CROYDON–BEDDINGTON FARM.

Croydon Borough is a suburb of London, with a stated total population of about 115,000 to 120,000, the daily flow of sewage amounting to an average of 4,500,000 gallons. In addition to the Beddington irrigation farm the borough has another farm at Norwood. The area at Norwood is stated at 105 acres and that at Beddington 525 acres, making a total area of 630 acres, of which about 525 acres are actually under cultivation. Inasmuch as the Beddington farm is the more interesting of the two, we will confine our description entirely to it. At Beddington 425 acres are in irrigation, the balance of 100 acres being occupied by the farm buildings, cottages, roads, and the ground too high to be reached by the sewage, which is delivered upon the farm by gravity. The buildings upon the Beddington farm include 4 farmhouses, superintendent's residence, and 14 cottages. This farm was designed and laid out by the eminent English sanitary engineer, Baldwin Latham. When irrigation first began, in 1860, the original area was much less than at present, additions having been made from time to time to accommodate the growth of the town and consequent increased flow of sewage.

A considerable portion of the soil is an open, porous, black loam from 6 to 10 inches in depth, with occasional areas of a light, free, open soil, but all suitable for irrigation. The subsoil is gravel and sand. The farm has a gentle slope from east to west averaging from 1 in 150 to 1 in 250. The River Wandle flows to the south and west of the farm. The first underdrains were laid under a portion of the farm about fifteen years ago. They have been laid wide apart, and in some cases as much as 9 feet in depth; conductors vary from 4 inches to 2 feet. The chief value of these drains is that they help to dry the land out quickly after the sewage is taken off.

The slope of the soil of this farm is so uniform that about the only preparation required was a slight adjustment of the surface by raising at some places and lowering at others, but so little of this as not to cut through the top soil. The main carriers along the higher portions of the farm are usually of concrete about 3 feet wide, and level or nearly level where the ground permits. The secondary carriers are also in some cases of concrete. The small distributaries are made with a plow, a furrow being laid from the secondary carriers down the line of greatest descent and at a distance from each other of from 40 to 50 feet, in order to flow the sewage over all portions of the area to be irrigated. Heavy galvanized-iron or wooden stoppers are used at varying distances down these trenches. For this work, when the field is undergoing irrigation, a man passes over and places the stops at each

FIG. 17.—Outdoor ensilage of rye grass at Beddington.

point as needed. On the lower side of each field there is a collecting ditch, into which the effluent water passes. The arrangement of the farm is such that the effluent of the first irrigation is passed over the fields a second time, and, when necessary, a third time. In this way very efficient purification is attained. The time occupied in passing through three irrigations is stated at from three to four hours. As to the loss of water from irrigation, the general statement is made that about 2 out of every 3 gallons of sewage passed onto the farm flow off as purified effluent, the third gallon having been either evaporated or absorbed by the land or growing crop.

The principal crops raised are Italian rye grass, pasture, mangolds, and other root crops, osiers, cereals, and cabbage. Rye grass, the principal crop, is stated to exhaust itself on this farm in about three years, when it is followed by a crop of mangolds, cabbages, or wheat and oats, with a return after that to rye grass. Five or six cuttings of rye grass are grown in a season. Mangolds yield especially well here. Wheat and oats are grown chiefly for the straw. Enough horses are kept for working the farm. About 200 milch cows are also kept for the purpose of consuming the large quantities of rye grass and roots grown.

As to the purification effected at Croydon, no analyses appear to have been made in recent years. From a series made after the farm had been in operation for about ten years it is concluded that the purification attained then was very efficient.

This farm was visited by the author on October 20, 1894. At that time of year the main crops had been removed, although fine fields of cabbage and mangolds were still standing, and a casual glance at them indicated the successful results in sewage utilization obtained at this farm. The last cutting of rye grass of the season was in progress at that date, and in one field an outdoor rye grass ensilage stack was in process of making, as illustrated by the photograph, fig. 17. Several pasture and cut rye-grass fields were under irrigation, the sewage coming onto the same black and filthy, and absolutely without any preliminary straining or purification. The first irrigation showed marked improvement; the second showed still more improvement, and, finally, after the third, the effluent flowing in the ditches appeared as bright and sparkling as any stream of water flowing from agricultural lands. The floating matters of the sewage are stated to have never given any trouble on this farm.

Mr. Greenwood, the farm superintendent, stated that 100 acres additional had just been purchased, and it was contemplated to purchase about 50 acres more in the spring, making the total area of the farm when this is done about 675 acres. During the year 1893 the farm is stated to have paid £3,000 more than all cost of operation, not including, however, interest on first cost.

As to the cost of laying out this farm, it may be remarked that by reason of the use of concrete carriers and distributaries the first cost was higher than would now be considered necessary. At the present time the laying out of the farm could be accomplished for somewhat less than the actual cost when done thirty-seven or thirty-eight years ago.[1]

There are a number of country houses along the highways leading through or at the sides of this farm. The author was accompanied on his visit by Lieut. Col. Alfred S. Jones, V. C., a well-known English sanitary engineer, whose residence is on the banks of the River

[1] This is not intended as in any degree a criticism on the work of Mr. Latham. In 1858–1860, when this farm was laid out, we had much less knowledge derived from experience in sewage irrigation than at present. Probably the leading idea was to make permanent work, and from this point of view the work must be considered very successful. Since 1860 we have learned that sewage can be distributed in ordinary earth channels equally well, thus not only materially decreasing the first cost, but rendering it easier to realize a profit on sewage-farm investments as well.

Wandle, near the point where the effluent from the Beddington farm enters that stream. In the course of a walk about the farm, a stop was made at the residence of a gentleman whose garden plat of 3 or 4 acres is surrounded on three sides by the irrigation fields of this farm. As to the question of nuisance, the owner stated that no nuisance had ever been created by the sewage irrigation that he had considered in any degree objectionable, although there were occasionally slight smells in warm weather. When the place was first occupied by him, over twenty years ago, he had rented, but on the expiration of the lease he had bought the freehold of the property, because it suited him, and he had not considered in making such purchase that the value of the property was in any degree injured by the presence of the sewage farm. He also said that a neighboring cow yard, where a considerable number of cows were kept for the purpose, as already stated, of feeding sewage-grown produce, was regularly a source of much more serious effluvium nuisance to the neighborhood than ever came from the farm itself. At the time of the author's visit, in October, absolutely no smell of any sort could be detected in any part of the irrigated fields.

The statement was made that no difficulty with the irrigation had ever been found here in the severest cold weather. Ice forms on the surface, but the sewage flows underneath it, sinking away into the ground, and the purification still going on, although probably a larger area is required in winter for a given purification than in warm weather. As one of the model English sewage farms, the Croydon Beddington farm has been frequently described.[1]

LEAMINGTON FARM.

In the Royal Agricultural Society's sewage farm competition, to which reference has already been made, one of the prizes awarded was to the sewage farm at Leamington Springs, which is owned by Lord Warwick. This farm was visited by the author on October 25, 1894.

The borough of Leamington Springs has a stated population of 27,000, although there is considerable variation in the population, owing to the large number of visitors during the season. The sewage is delivered by the borough upon a farm of about 400 acres, owned by the Earl of Warwick, at a distance from the borough of about 2 miles. The borough receives £300 per year for the sewage, and its responsibility ceases when the sewage is delivered at the point agreed upon on the farm, which is at an elevation of about 131 feet above the pumping station. In the agreement it is stipulated that the effluent from the farm shall be purified to the satisfaction of the conservancy commission of the River Leam, into which it finally flows.

[1] See Crimp's Sewage Disposal and Rawlinson and Read's Report on Sewage Disposal as made for the Local Government Board in 1876. An extended series of analyses of the sewage and effluent not only of this farm but of the Croydon Norwood farm may be found in this report.

The present flow of sewage in wet, rainy weather is about 800,000 gallons per day. In dry weather it is somewhat less. The sewage is to be pumped only between sunrise and sunset, except that in the winter months pumping may begin one-half hour before sunrise and continue to one and one-half hours after sunset. In order to take care of the flow of sewage during the night a storage tank is provided at the pumping station of about 1,250,000 gallons capacity, or enough to hold more than one day's flow, which receives the night flow and also provides for contingencies.

The farm is under the charge of Mr. Castle, as farm bailiff, who stated that the farm operations had been in every sense commercially successful. As a matter of business caution he declined to state just what profits had been obtained, but intimated that in no year were

FIG. 18.—Field of cabbage at Leamington.

they less than 8 per cent. The crops raised are rye grass, roots, cabbages, wheat, oats, and barley. The grains are sown in rotation after roots and cabbages, and are not themselves irrigated at all, the heavy irrigation of the preceding crop of roots being relied upon to support the grain crops. About 150 head of cattle, mostly thoroughbred shorthorns, are kept upon the place, and a large amount of milk is sold, this being considered of superior quality. There are also about 10 acres of fruits which are irrigated lightly. The topsoil of the farm is black and porous, with a gravelly subsoil at from 12 to 15 inches below the surface.

One of the most interesting points learned on this farm was in regard to the process of ensilage. Mr. Castle stated that they had for several years made rye-grass ensilage both in silos and in stacks in the field and had been entirely successful in both ways. The most of the silage is made sweet or without salt, but in order to make sweet silage with the best results it is necessary that the silo be filled very quickly, or if stacked that the stack be completed and weighted within one day, before any heating begins. The statement was also made that during 1893 a cubic foot was cut out of one of the silos and found to weigh 57 pounds, at which rate a cubic yard would weigh 1,539 pounds.

Sewage is delivered to the different parts of the farms in a few lines of main carriers of vitrified tile, which deliver it at convenient points into wells provided with gates, from which it flows out into distributing carriers and from there into the secondary distributaries laid on the contours, and is thence flowed over the land by spade gates after the usual manner. The standing crops of roots and cabbages were very fine and spoke well for the thoroughness of the cultivation, as well as the efficiency of sewage irrigation as practiced on this farm. The effluent before leaving the farm is passed over a field of osiers, whence it flows into the River Leam bright and sparkling.

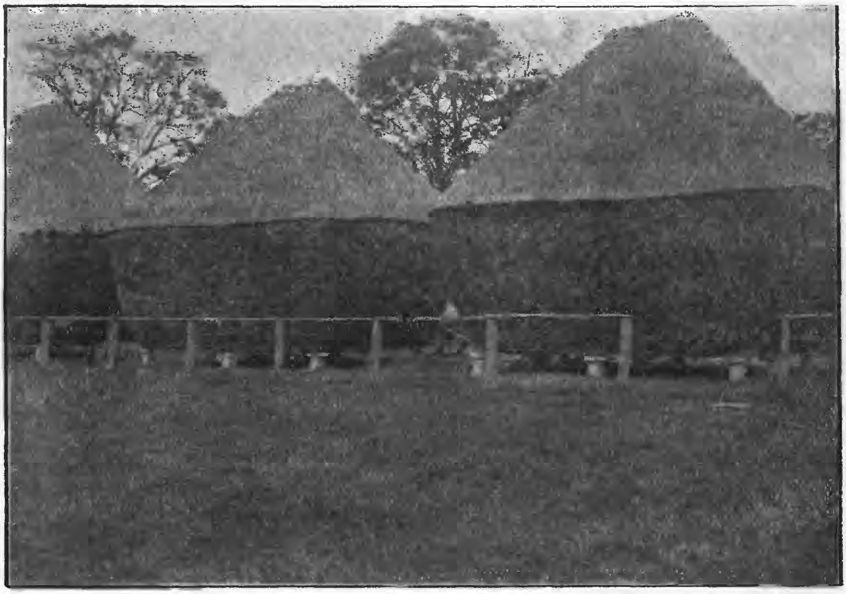

FIG. 19.—Stacks of sewage-farm wheat at Leamington.

The following details in regard to the cropping at Leamington have been obtained from the report of the Royal Agricultural Society's committee, made in 1879:

Rye grass is grown both for sale and for home consumption. It is not allowed to stand longer than two years, and about 25 acres are sown each year, usually in the autumn, at the rate of 3 bushels of seed per acre. A crop sown in September, 1877, was cut eight times in 1878 and six times in 1879, and then plowed up. In 1878 the cutting of rye grass commenced on February 2. In 1879 that sown in 1878 was first cut April 7. The first cutting yielded 4 tons per acre of green grass; the second cutting, June 4, yielded 16 tons of grass per acre; the third cutting, on July 8, 14 tons of grass per acre; the fourth cutting, August 14, 8 tons; the fifth cutting, September 14, 6 tons; the sixth cutting, October 6, 5 tons; and the seventh cutting, in November, 2 tons per acre, giving a total yield of 41 tons of green grass per acre for the year.

Mangolds are also grown largely on this farm. The seed is drilled in rows 26 inches apart and the plants are hoed out to 10 inches distance in the rows. The sewage is not applied until the plants begin to bulb, when they are irrigated. In 1878 this crop received 21 dressings of sewage while under cultivation, or 8,265 tons of sewage per acre, equivalent to an irrigating depth of 81.8 inches of water in addition to the rainfall.

Ordinary cabbages for market are planted on the level in rows 22 inches distance and the plants 17 inches apart in the rows. The cabbages are irrigated during the period of growth. In 1878 one field in this crop received 17 dressings of sewage, amounting to about 6,102 tons, equivalent to an irrigating depth of 60.4 inches in addition to the rainfall. Parsnips are grown on the level, 6 pounds of seed per acre, drilled in rows 14 inches apart and hoed out 6 inches in the row. The crop is not irrigated, but usually succeeds cabbage or second-year rye grass which has been sewaged.

Carrots are drilled in rows on the level at 14 inches distance and are hoed out to from 4 to 6 inches in the rows. Six pounds of seed per acre are sown. The crop is not directly irrigated with sewage, but, like parsnips, succeeds, either directly or after a second year, a crop that has been heavily dressed with sewage.

Potatoes are planted in drills 24 to 26 inches apart and 12 inches from plant to plant in the rows. They usually succeed rye grass which has been cut the full number of cuttings the previous year. Potatoes are not directly sewaged during the period of their growth. Rhubarb is one of the permanent crops at Leamington, as well as elsewhere. It costs about £50 per acre to purchase roots, prepare the ground, and plant out, and the crop is stated to realize about £40 per acre per year. The plants are irrigated with sewage during the period of growth.

A large acreage of wheat is grown on the farm, but as a rule not under the influence of sewage. Generally the wheat follows some crop which has been heavily sewaged. A considerable quantity of oats is raised, and they generally yield well. This crop, like wheat, is not directly irrigated, but usually succeeds rye grass. Barley is also grown, but not with direct sewage irrigation, following, the same as the others, crops which have been heavily irrigated.

Large quantities of beans are grown as part of the miscellaneous production, and which are not directly irrigated with sewage. They usually follow some root crop or cabbage.

Turnips and swedes are also grown on this farm. Green crop turnips are sown broadcast, about 3 pounds per acre, and are fed off on the ground to sheep. The swedes are drilled 16 inches apart and hoed out to 9 inches in the rows; 2 pounds of seed are drilled per acre. Sewage is used for irrigating this crop to a moderate extent. Turnips and swedes usually follow either wheat, barley, or oats, although occasionally turnips are cultivated after rye grass.

Seeds, such as clover, trefoil, and alsike, are also grown to some extent. Clover is occasionally irrigated in dry seasons with moderate dressings of sewage. Generally, however, the seed crops are not irrigated.[1]

BIRMINGHAM PRECIPITATION WORKS AND FARM.

The sewage-purification works at Birmingham present some points of difference from those at the two English towns already considered. Thus Croydon and Leamington Springs are both residence towns purely, with a sewage consisting of ordinary house drainage without any manufacturing waste, whereas at Birmingham we have the sewage of a large residential area as well as that of one of the most extensive manufacturing districts in England.

The natural drainage of this district is into the River Tame, a small stream tributary to the Trent. At an early period the passage into these streams of large quantities of manufacturing refuse forced upon the Birmingham corporation the necessity of considering some form of sewage purification. In 1871 a special sewerage inquiry committee of the Birmingham common council reported at length as to the best means of treating the Birmingham sewage in order to prevent the serious pollution of the River Tame and its numerous small tributaries, which at that time threatened the corporation with damage suits on every hand. This report is specially referred to because of the thoroughness with which the inquiry was made by the committee. It is included in a volume of nearly 250 pages, and gives in succinct form a résumé of the whole question of sewage purification as it stood at that time. The committee recommended the exclusion of manufacturing wastes from the sewers and the purification of the sewage itself by intermittent filtration through the land. Subsequently the report of the committee was somewhat modified; the manufacturing wastes were allowed to go into the sewers, and a crude chemical precipitation treatment, to be followed by broad irrigation, was carried out.

[1]Further details of the Leamington farm may be found in the report of the Royal Agricultural Society's committee already referred to. Extended extracts have been made from this report because of the statement made by Mr. Castle that there has been no material change in the management of the farm at Leamington since that report was made in 1879.

Following on this line, the corporation applied to the Local Government Board, under the public health act of 1875, for an order to form a number of detached urban and rural sanitary districts into a united district for the purpose of sewage disposal. The total area of the drainage district, as now constituted, is 47,275 acres, with a stated population in 1894 of from 700,000 to 800,000.

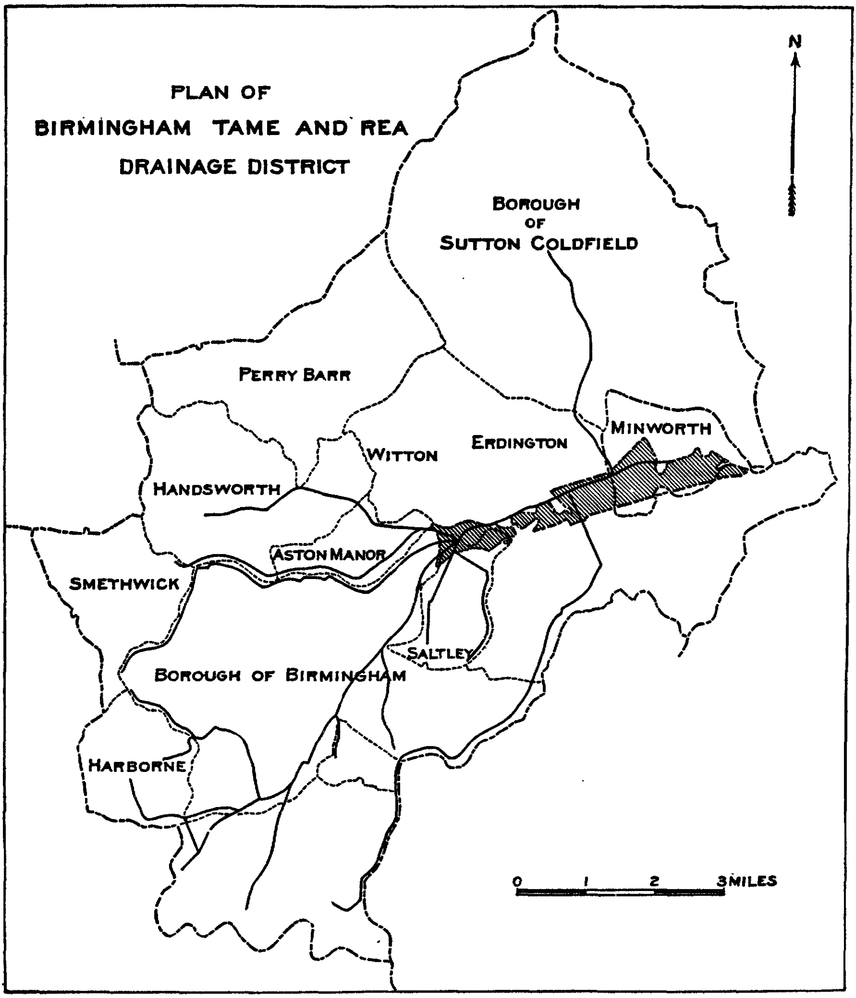

FIG. 20.—Plan of Birmingham Tame and Rea drainage district.

Beginning in 1880, the joint board of the Birmingham Tame and Rea Drainage District began the purchase of land for a sewage farm, and have gradually acquired, up to 1894, an area of 1,300 acres available for sewage disposal. Some of this land has been rented at the rate of £4 per annum per acre, while the cost of that of which the freehold has been purchased outright, including timber, buildings, mill rights, tenants' compensation, etc., has amounted to £152 per acre. As stated by Mr. W. S. Till, city engineer of Birmingham, all this land is very favorable for the purification of sewage, the natural surface being, as a rule, even and unbroken and, with the exception of about 100 acres, of such a level as to admit of irrigating the entire area by gravitation. The subsoil is gravel and sand, varying from 6 to 10 feet in depth. The land is drained to a minimum depth of 4.5 feet, but in many cases, owing to the level nature of the area, a somewhat greater depth has been found necessary at the lower end of the drains. The drains consist of 3-inch and 4-inch agricultural drain pipes placed from about 45 to 65 feet apart and discharging into terra-cotta main drains of 9-inch, 12-inch, 15-inch, and 18-inch diameter, which in turn discharge into the main outfall channels. Roads 12 feet wide, with passing places at intervals, have been laid out in order to meet the various requirements of cultivation, as well as for the conveyance of produce. Farm buildings have been erected in a central position, with entrance lodge, manager's house, and a number of laborers' cottages. Several of the farm buildings and houses existing upon the area have been repaired and extended.

The method of treating the sewage as now carried on is described by Mr. Till substantially as follows: The sewage on arriving near the liming sheds at the upper end of the works is mixed with lime, both to neutralize the acids, which are present to an unusual extent in Birmingham sewage by reason of the large amount of iron manufacturing, and also to assist precipitation, which, however, is stated to be not necessary to so great an extent now as formerly.

The sewage then passes through large roughing tanks, where the coarser impurities are precipitated, whence it passes by the main conduit to the irrigation area, where it is further treated by ordinary irrigation on crops. In order to remove the sludge the precipitating tanks are cut out in regular order and the sludge is elevated by bucket dredges and pumps into movable wooden carriers, in which it flows into beds formed in the land in the vicinity of the precipitation plant. As it comes from the tanks the sludge contains about 90 per cent of water, but after lying on the ground for two weeks much of this water drains away or is evaporated, leaving the sludge in a layer about 10 inches thick and of a consistency which admits of its being dug into land. Crops are then planted on the sludge beds, and after a time the sludge becomes pulverized and capable of receiving irrigation. About 50 acres of land per year are required for sludge, and the same land may, if necessary, receive a coating of sludge once in two or three years. The amount of sewage now regularly treated is about 22,000,000 gallons per day. The controlling board farms the whole of the land itself, no portion being sublet.

The Birmingham sewage farm was visited by the author on October 26, 1894, and some facts were obtained in addition to those stated, which are derived from a paper on the work of the Birmingham Tame and Rea District Drainage Board, by W. S. Till, C. E., engineer to the board, kindly furnished to the author by Mr. Till at the time of his visit. As one fact of interest, it may be mentioned that the men doing the work of digging the sludge into the land work in gangs and are paid by the cubic yard of sludge actually removed from the tank and dug into the land. Working in this way, they make from 28 to 30 shillings each per week. The cost of labor at Birmingham and vicinity has already been given on page 67.

According to a statement of the assistant farm manager, Mr. Henry Rumble, the land receiving sludge is now allowed to remain fallow until after the following winter, when it is plowed and put into rye grass, to be followed by cabbage, and finally, after about four years, celery is grown upon the land which has received sludge. The celery so grown is of fine quality; that seen growing and in process of gathering was the largest and finest celery the author has ever seen. The statement was also made that the celery from the Birmingham sewage farm brought a slightly higher price than that of the ordinary market gardens of the vicinity, by reason of its superior quality. In addition to rye grass, cabbage, and celery, crops of mangolds, swedes, kohlrabi, green-top turnips, potatoes, and roots of various kinds are raised. Large amounts of milk are sold, as well as beef cattle and swine. At the date of the author's visit a fine herd of 180 swine was observed on the farm.

The sewage farm itself is conducted on lines similar to those followed on farms previously visited, and little need be said in relation thereto. The precipitation tanks work on the continuous principle, and are arranged in the usual manner for cutting out in order to remove the sludge. At present about 1,120 pounds of lime are used per 1,000,000 gallons of sewage treated. Taking 22,000,000 gallons as the mean daily flow, we have then a total daily use of lime of about 24,600 pounds.

WIMBLEDON PURIFICATION WORKS AND FARM.

At Wimbledon we have still another interesting case of sewage purification, which differs in several particulars from those thus far described. This place is a residential suburb of London, situated only about 5 miles southwest of Westminster Abbey. The population is estimated at 26,000. The dry-weather flow of sewage amounts to about 780,000 gallons per day. The average wet-weather flow, which includes a considerable amount of storm water, is stated as about 50 per cent greater. The soil about Wimbledon consists of a heavy clay, on which it is impracticable to purify crude sewage by the ordinary methods of land treatment, especially in a dense residential district where only a limited area in a single body can be found. It became necessary, therefore, to treat the sewage by a crude process of chemical precipitation or clarification before applying it to land in order to bring the whole treatment within the limits of the available area. The farm consists of 70 acres, of which 67 are irrigated.

The works have been designed with reference to first applying the treatment with lime or other chemicals, to be followed by broad irrigation. Detail as to the chemical part of the treatment may be obtained by reference to Mr. Crimp's Sewage Disposal, from which work, as well as the reports of the Wimbledon local board, the main statements of this paper, aside from those gathered by the author on a visit to the farm in question on October 22, 1894, have been taken.

An interesting feature of the works at Wimbledon is the disposal of the sludge, which is substantially as follows: From the settling tanks

FIG. 21.—Pile of pressed sludge at Wimbledon.

the sludge is swept, when necessary, into a sludge reservoir, whence it gravitates as desired into iron receivers. Lime is then thoroughly mixed with it and air pressure applied to the surface of the sludge, which is thus forced up through an iron pressure pipe into filter presses. The original filter presses employed were made by Johnson, but Mr. Crimp states that two of Goddard, Massey & Warner's now in use, of recent construction, possess improvements in detail over the original presses. As to the labor of sludge pressing, it is stated that the working expense at Wimbledon amounts to about 59 cents per ton of sludge pressed. It should be said that while two men are constantly employed at the work, they could easily press much more sludge if it were there to press. The cost of this item of work may be expected, therefore, to decrease as the production of sludge increases.

The sludge is pressed into cakes and is stated to be readily sold at the works for about 1s. a ton. Ten tons of sludge as taken from the settling tanks is reduced to 2 tons of cake, 8 tons of water being pressed out. The total quantity of sludge produced in the year 1892 was 5,430 tons, while the total quantity in 1893 was 5,344 tons. It will be seen, therefore, that during those two years the flow of sewage must have been substantially the same. The 6 precipitating tanks in use have a total capacity of 530,000 gallons.

A statement of the annual receipts and expenditures in connection with the sewage farm from 1883 to 1893, inclusive, as derived from the annual reports of the Wimbledon local board, shows that, even with the difficult conditions for successful utilization prevailing at Wimbledon, the sewage farm has paid a small profit every year since it was started, except in 1892, which is said to have been a specially unfavorable year.

The crops grown are rye grass, mangolds, osier, and garden produce. The great decrease in the number of cows kept in and about London has reduced the amount obtained at present for rye grass to a much less figure than formerly. One of the most interesting points to be noted is the great number of good residences located near the farm. According to the statement of Mr. J. Snook, the farm manager, no complaints have been made by the adjacent residents for several years.

The effluent from the precipitation tanks is fairly clear, while the final effluent from the irrigation is bright and sparkling. As stated, the soil is of very heavy clay, which has been underdrained 6 feet deep with lines of drains 60 feet apart. The upper or surface soil has been lightened by mixing ashes with it. Ordinary plowing is to the depth of 1 foot, and once in about three years subsoil plowing to the depth of 2 feet is used. Root crops and cabbages are mostly grown in ridges, between which the irrigation is made.

As originally laid out there were a number of obvious errors in this farm which effectually prevented for several years either a thorough purification of the sewage or a satisfactory utilization of it in agriculture on the heavy clay soil. At the present time the ashes of the town are regularly taken out upon the farm and mixed with the top soil for the purpose of lightening it. Filters of burnt clay have also been constructed for the purpose of receiving storm waters during periods of heavy rainfall. The settling tanks are also provided with valves, by means of which any excess of sewage, due to sudden storms, escapes and is discharged upon these filter beds. These storm-water filters are used on an average from eight to twelve times a year.

The main carriers of this farm are composed of cast-iron pipes, from which the sewage is drawn as desired at different points by means of ordinary sluice valves. The secondary carriers leading from the cast-iron mains are either concrete or stoneware half pipes, laid as shown in fig. 5. The distributaries are laid with a plow and finally finished by spade labor. As a general rule their direction is that of the greatest fall. The distributing channels are cut at a definite distance of 33 feet apart, in order that when cutting the grass the laborer may know the area of the piece he is cutting, as the rye grass when sold standing is disposed of by the square yard.

There is less variety to the crops on this farm than on the others described, because of the large quantity of sewage disposed of per area. Italian rye grass, mangolds, and osiers, the three main crops grown, are those which best stand large quantities of sewage without difficulty.

Experience on the heavy clay lands of this farm indicates that ground to be sown with rye grass should be plowed deeply in the autumn and allowed to remain in the furrow during the winter, in order that the soil may be broken down by the disintegrating action of frost. There is no objection to frequent applications of sewage during this period. As early as practicable in the spring the land should be pulverized by harrowing and the rye grass sown to the amount of not less than from 4 to 5 bushels of selected seed per acre. At Wimbledon the grass grows very rapidly, and with favorable weather the first cutting is sometimes made within eight weeks after sowing. The cuttings immediately succeeding will be heavier than the first, the plant deteriorating rapidly after five or six cuts have been removed. For the best results in the production of forage, rye grass should not be allowed to flower, as a loss of over 50 per cent in weight follows the flowering stage. With favorable conditions and sufficient applications of sewage, as many as eleven cuttings, weighing in the aggregate in the green state about 100 tons, have been obtained in the two seasons following the planting of the seed. After two seasons deep plowing and subsoiling should, if necessary, be resorted to, and the process gone through again. With good cultivation, rye grass may be grown for several years on such heavy soils as those at Wimbledon. The average price obtained for the rye grass at Wimbledon was stated by Mr. Snook to be about £15 to £20 per acre per annum. In some years more than this may be obtained.

In regard to osiers, it was stated that this has been found one of the most valuable crops raised. The demand has always thus far been good, since large quantities are annually imported for basket making and other purposes from Holland and the north of France. This plant likes moisture, and, so far as known, will grow upon any kind of land except peat bog. The kinds found most suitable at Wimbledon are the new osier and the golden willow. The first named is dark skinned and very suitable for basket making. The golden willow is smaller and of finer growth than the osier.

In setting an osier field, sets or cuttings are selected from growing willows, which are cut in lengths of about 16 inches and planted about 1 foot apart in one direction and about 1½ feet in the other. The cuttings should be planted with their ends nearly level with the ground in order to insure straight shoots. They come into full bearing in the third year, although a fair crop may be got the first year. The maximum growth is attained in about ten years, after which the plant slowly declines, and in the course of fifteen to twenty years it will require reseeding.

The crop is gathered soon after the fall of the leaves by cutting as close to the main stock as possible. The annual yield per acre is stated at from 6 to 7 tons. The price obtained at Wimbledon is about £12 per acre per annum for the rods. This is for osiers; the golden willow yields less and does not bring so high a price as the osier.

The effluent from the Wimbledon farm flows into the River Wandle. As observed by the author, just above the point of junction with the river it was in every way as bright and sparkling as any stream flowing from agricultural lands.

DONCASTER FARM.

As another interesting example of sewage purification and utilization by broad irrigation, we may briefly refer to the farm at Doncaster, which, however, was not visited by the author, but of which it is deemed well to give an account, because Doncaster, while not receiving a prize in the Royal Agricultural Society's sewage farm competition of 1879, was still strongly commended by the committee in their report as an admirable example of thrifty management and an excellent illustration of how sewage can be applied in general farming.

The population of Doncaster is stated at about 30,000 at the present time, with a dry-weather flow of sewage of 700,000 gallons per day. The main drainage works of the town were carried out in 1870, but soon thereafter an injunction was obtained against the Doncaster corporation restraining them from discharging sewage into the River Don. In consequence of this injunction sewage-disposal works were established in 1873. The area available for sewage disposal is about 278 acres, with a very undulating surface. The soil varies between the limits of light sand and stiff red stratified clay. There is also an area of about 20 acres of pasture land laid out for sewage irrigation.

The principle of surface preparation followed was, by reason of the undulations, to change the surface as little as possible. According to Mr. Brundell, the designing engineer, no attempt was made to alter the surface, but the flow of sewage was fitted to the surface by the use of main carriers led along the summits and from them by means of contour distributaries the sewage was finally led over the entire area. Figs. 7 to 13 show how the distribution of sewage on such an area may be treated.

The main carriers are of terra-cotta pipe, laid either below the surface or in embankments, as may be required. This form of carrier has already been referred to, and is illustrated by fig. 5. The pipes are sometimes worked under a small head. The sewage is pumped from the borough of Doncaster out onto the sewage farm, a 21-inch cast-iron main with a total rise of 22 feet being used for this purpose.

A great variety of crops are produced on this farm. According to the report of the judges in the Royal Agricultural Society's sewage farm competition, they have been successful in raising black currants, gooseberries, wheat, barley, oats, rye, beans, potatoes, turnips and swedes, clover, clover seed, rye grass, meadow grass, and osiers. A considerable amount of live stock is also kept upon the farm. In the early days there was some prejudice against the milk produced, but it is now accepted without hesitation. The effluent is stated to flow into the River Don in a state of much greater purity than the water of the river itself, which is seriously polluted by the towns above Doncaster.

SEWAGE UTILIZATION IN GERMANY.

The sewage farms of Berlin are the most extensive thus far carried out. Since they exemplify both in their preparation and management the best scientific sewage farming of the present day, attention will be confined to a consideration of them, although descriptions might well be given of the large farms at Dantzic, Breslau, and other points.

BERLIN SEWAGE FARMS.

The information concerning these farms was obtained by inspection by the writer in November, 1894, and from a paper on the sewage farms of Berlin by Mr. Roechling, to be found in Volume CIX of the Proceedings of the Institution of Civil Engineers. The detailed statistical statements, as published annually by the Berlin authorities, for the years from April, 1891, to March, 1893, are also at hand. Inasmuch as Mr. Roechling's paper covers nearly every phase of sewage farming at Berlin, it has been used in some sort as a syllabus in preparing this short account.

At the date of the last census, in December, 1890, the population of Berlin was 1,578,794, the area on which this population is located amounting to about 24½ square miles. The area, not only of the city of Berlin, but of the surrounding country, is generally level. The only stream of any size is the River Spree, flowing through the middle of the city, which, however, is far too small to admit of the discharge of the sewage of a city of the size of Berlin without treatment.

The sewerage system, as designed by Mr. Hobrecht, the city engineer, is what is known as the radial system, wherein the entire area has been divided into twelve separate districts, which, so far as the collection of the sewage is concerned, are independent of one another. Each district has a pumping station, from which the sewage is raised direct to the sewage farms, although in some cases two drainage districts are united to one main. This peculiarity of the Berlin system has determined largely the location of the farms at several different points about the city.

The River Spree flows from west to east through the city. From the systems north of the river the sewage is sent northward, and from the south of the Spree, south; so that, with the exception of a single 12-inch pipe, no sewer or pumping main has been carried under the river. The southern farms are located at a distance from the central part of the city of as much as 12 miles. This makes the disposal of farm produce somewhat difficult. The north and northeast farms are only about one-half the distance of the southern farms from the center of the city, and, consequently, it is stated that the produce there-

FIG. 22.—General view of the North Berlin sewage farms, the village of Malchow in the distance.

from is far more readily disposed of than that of the farms to the south. This statement is made by the Berlin authorities as a reason why the northern farms show better financial returns than the southern.

The general character of the area included in the Berlin sewage farms is well shown by fig. 22, from a photograph. The most of it is practically level, although there are frequently small eminences attaining a height of from 10 to 15 feet above the general level. The soil is generally light and sandy, although in the northern farms there are considerable patches of clay. The subsoil is coarse, open material for nearly the whole area. Taken as a whole, the soil is well adapted for sewage irrigation.

The total area of the Berlin sewage farms as they existed in 1894 is stated at about 20,000 acres, although only a little over half of this was under irrigation at that time. This great property is not only all owned by the municipality, but is mostly farmed by it as well. During the last few years, however, there has been considerable demand for land by market gardeners, who rent the land and take sewage only when they desire it, whence it has resulted that the area farmed by the city itself has been somewhat lessened. The leased land is first prepared for irrigation by the city and then rented out as required. The annual rental for this prepared land is about $21 per acre, while ordinary land in the vicinity brings only about $8.50 per acre, the difference of $12.50 per acre being due to the increased value of land with sewage irrigation. There has also been a demand for rental of

FIG. 23.—An effluent channel on the Berlin sewage farm.

sewage by the farmers who prepare their own land and only take the sewage as required for the best results. In 1894 sewage was applied to about 1,000 acres in this way.

In considering the results of sewage irrigation at Berlin it should be remembered that the water supply has by metering been kept at a very low point, so that the daily use of sewage amounts to only about 14 or 15 gallons per capita. Including the storm water, the daily flow of sewage averages about 25 gallons per capita. The sewage is therefore more concentrated than that of any town thus far considered.

The rising mains from the pumping stations terminate at standpipes erected on the highest points at various parts of the farms. These are open at the top and act as safety valves as well as pressure gauges for indicating the actual head on the mains at any particular instant, this fact being indicated by a float on the inside of the pipe carrying a flag by day and a lantern by night. On account of the location of the standpipes on the highest points, they form landmarks visible from all parts of the farms. The distributing pipes of cast iron start from the standpipes and radiate in all directions to various parts of the farms, their diameters being reduced gradually at their farther extremities. At various places they are provided with sluice valves and side branches which empty into small tanks dug into the ground. The open earth carriers begin at these tanks. There are sluice gates on the distributing pipes at intermediate points as required.

The laying out of the Berlin farms has been done according to the following scheme: The open effluent ditches, of which an example is shown in fig. 23, follow along the lowest levels of the farm; the bottom width is about 18 inches and the side slope 1½ to 1. The farm has been thoroughly underdrained, mostly with 2-inch pipes laid on the parallel system at distances varying from 16 to 33 feet. The average depth of the feeders is from 3 to 4 feet. The feeders lead into master drains varying in size from 3 to 6 inches, which finally lead into the main effluent ditches just referred to.

In designing the beds the topographical conditions of the ground were very carefully taken into account, and generally sloping ground was utilized for grass plats, to be treated by broad irrigation. The nearly level portions have been made into filtration areas, and the level ground into tanks in which surplus sewage can be filtered by intermittent filtration as required. The irrigation and filtration plats are, so far as possible, rectangular in form, with areas of from 5 to 6 acres. The tanks, however, are larger. They include plats of ground from 5 to 22 acres in extent, surrounded by embankments about 3 feet in height and from 13 to 20 feet wide at the top, in order to furnish space for wagon roads. In summer the tanks are used as filters to dispose of storm waters, and in winter they are used as reservoirs at such times as, owing to long-continued frost, the land is frozen to a depth preventing ordinary irrigation. The Berlin authorities consider the tanks as a necessary adjunct of any sewage farm operated like that at Berlin, although the degree of purification effected by them is apparently not so high as that of the grass plats or the filtration beds. The 5 or 6 acre plats are also subdivided into what are called quarters, in order to enable the irrigation to be properly applied.

Reference has already been made to the earth tanks at the outlets of the main distributaries. The main carriers, which are merely ditches cut in the ground, illustrated by fig. 4, start from these. They vary in depth from 18 inches to 3 feet, and, entering each 5 or 6 acre plat at the highest corner, pass down one side to the lowest quarter to be irrigated, and so on to the next plat. Secondary carriers, which are also mere earth trenches, are taken off from the main carriers to irrigate such plats as the main carriers do not traverse. From the secondary carriers the sewage is distributed over each plat and quarter thereof by still smaller earth carriers, which are frequently furrows cut with the plow.

The surface of the permanent grass plats has been graded to a uniform slope and the irrigation takes place from the level furrow at the upper end, which, when full, overflows, allowing the sewage to pass in a thin film down the slope. This method of irrigating the grass plats is the one generally followed at Berlin.

The beds have been laid out in terraces, each terrace being made level and separated from the one below by an embankment. The cultivation beds are formed with ridges about 3 feet wide, with the furrows between the ridges 2½ feet wide and 1½ feet deep. Sewage flows into the ditches from one side until nearly full, when it is allowed to stand and filter away through the soil. Turnips, mangolds, cabbages, and other root and vegetable crops are grown on the filter beds.

The foregoing account of the method of laying out pursued at Berlin indicates that both broad irrigation and filtration are used on the Berlin sewage farms, the grass plats representing the broad irrigation and the level beds intermittent filtration with cultivation, while the tanks represent intermittent filtration without any attempt at utilization. As we have seen, this principle is the one now universally adopted in the laying out and management of modern sewage farms. We may conclude, also, from what has preceded, that the principle of leasing sewage to private farmers is developing with considerable rapidity at Berlin, which is in line with the best results in agricultural utilization.

As indicated on page 58, the crops raised at Berlin include a considerable variety of roots, cereals, and ordinary vegetables, as well as oil seeds, which are grown quite extensively. Detailed statements of the yields may be found in either Mr. Roechling's paper in the Proceedings of the Institution of Civil Engineers, already referred to, or in the annual statements published by the city of Berlin of more recent date. These statements show a loss during the early years of these sewage farms, but since the laying out of the farms was completed and more experience has been gained they have shown some small profit.

While the rainfall at Berlin is not large for the whole year, it is heaviest during the growing months, which complicates somewhat the problem of sewage irrigation there.

The best returns have come from the Falkenberg farm, which in 1890 earned about 3¼ per cent on the capital expenditure. This must be considered a very favorable result, especially when it is understood that ordinary land in the vicinity of Berlin does not give an average yield of more than 3 per cent. In comparing the results of sewage farming at Berlin with ordinary farms it snould, however, be borne in mind that the foregoing figures do not include any rent for the land. In case a rental of as much as $5 per acre (20 marks) were to be included, the farms would hardly be more than self-supporting. It is the opinion of the managers of the Berlin farms that with the gradual improvement in the condition of the area under cultivation for a number of years the profits of sewage farming may be expected to increase somewhat. As remarked by Mr. Roechling, the degree of purification attained is the chief test to be applied to a sewage farm; and if wanting in this respect, the farm must be said to be a failure. This point is specially important to bear in mind in considering questions of sewage purification and utilization, because, with the evidence at hand, it is indisputable that with proper management sewage farms may be so operated as to not only utilize sewage at an agricultural gain, but also to give out an effluent of a very high degree of purity. At Berlin the water flowing in the effluent ditches is as clear and sparkling as any flowing from agricultural lands, and the author was informed by one of the head gardeners in the course of walking over the farms that the laboring men who carry their dinners out in the fields were in the habit of frequently taking water from the effluent ditches for drinking, and this, too, in spite of the fact that the use of the water for this purpose had been prohibited by the authorities in charge.

A large number of analyses have been made not only of the Berlin sewage as it comes to the farms, but also of the final effluent. The results are given in such detail as to render any adequate presentation impossible at this place for lack of space. They may be found in Mr. Roechling's paper or in the annual municipal statements. In a general way they indicate that the purification attained is in the highest degree successful.

SEWAGE UTILIZATION IN FRANCE.

Sewage utilization in France, as a whole, has been less generally attempted than in either England or Germany, although the employment of Paris sewage on the Plain of Gennevilliers is, perhaps, on the whole, the most successful case of profitable utilization in agriculture to be found anywhere. The soil of that plain is exceedingly well adapted for the purpose, being light and open, with gravel subsoil of considerable depth. It therefore serves the purpose of a natural filter. Thus far only a small portion of the sewage of the city of Paris has been utilized at Gennevilliers, the remainder being allowed to pass directly into the River Seine. Only a portion of the sewage of Paris is water carried, the balance being disposed of by the pail system, although a recent decree of the French Senate makes it imperative to now construct sewers and connect all houses with the water-carriage system.

The utilization of all the sewage of Paris by irrigation has been discussed extensively by the engineers of the city and by Government commissions for many years, with the final result that under a decree of the Senate, bearing date July 10, 1894, the municipality of Paris is authorized to make a loan of 117,500,000 francs for the purpose of extending the sewers to those districts of the city which are now served by the pail system, and also for preparing the necessary areas for land purification at various points in the vicinity of the city.

THE PLAIN OF GENNEVILLIERS.

The history of the irrigation at Gennevilliers is exceedingly interesting. As the result of a considerable discussion, the municipality in 1869 laid down at its own expense the necessary carriers, subcarriers, conduits, and pipes for distributing sewage on land at this place and conceded to the owners and lessees the free use of it until 1880, since which time they have been obliged to pay a price for the use of the sewage. At first there was very great prejudice against not only the use of the sewage as manure, but also against the produce grown by its aid. This gradually died out, and the number of users of sewage has increased from year to year, until in 1891 the total area available at Gennevilliers, which amounts to about 776 hectares, or 1,917 acres, was taken up.

The crops grown under sewage irrigation at Gennevilliers have been successful in the highest degree. They comprise absinth, artichokes, asparagus, beans, beets, cabbages, carrots, celery, kohl-rabi, cucumbers, leeks, melons, onions, parsnips, peppermint, potatoes, pumpkins, spinach, tomatoes, turnips, clover, rye grass, mangolds, wheat, oats, and Indian corn. The market-garden produce yields abundant crops. Indian corn has also an exceedingly good growth here, the stalks attaining a height of from 9 to 10 feet. In order to obtain definite information as to the results to be derived in the agricultural utilization of sewage on the Plain of Gennevilliers, the French minister of agriculture in 1874 appointed a commission to study the question in its economical aspects. The report of this commission shows the following as the yields of vegetables which under favorable conditions may be expected there: Cabbage, as much as 75,000 kilograms to the hectare.[1] Mangolds are stated as yielding 120,000 kilograms per hectare; carrots, 50,000 kilograms per hectare, and beans 15,000 kilograms per hectare. The experience of the last few years is stated to fully confirm the results of the commission of 1874.

Artichokes, which are extensively grown for consumption in France, are stated to yield from 36,000 to 50,000, and even as many as 80,000, heads per hectare. Cauliflowers amount to from 35,000 to 40,000 kilograms per hectare. Garlic yields 37,000 kilograms per

[1] The kilogram is equivalent to 2.2 pounds, and the hectare to 2.47 acres; hence the stated yield of cabbage, in our measures, is 34.14 tons per acre.

hectare; celery, 100,000 kilograms per hectare; onions, 60,000 to 80,000 kilograms per hectare; potatoes, 30,000 to 40,000 kilograms; salsify, 10,000 to 12,000 heads, or 25,000 kilograms, to the hectare.

As to the mean value of the number of crops raised, the following figures are given: Cabbage, from 3,000 to 4,000 francs per hectare; cauliflowers, 5,000 to 10,000 francs per hectare; carrots, 3,000 francs; artichokes, 5,000 to 6,000 francs; onions, 3,500 francs per hectare, etc. (three thousand five hundred francs per hectare amounts to 1,416 francs, or about $281, per acre.) The French reports abound with statements as to the degree of purification attained at Gennevilliers, but these are omitted in this place for lack of space. The author visited the Plain of Gennevilliers on a rather warm day early in December, 1894. The effluent was bright and sparkling, and as he was

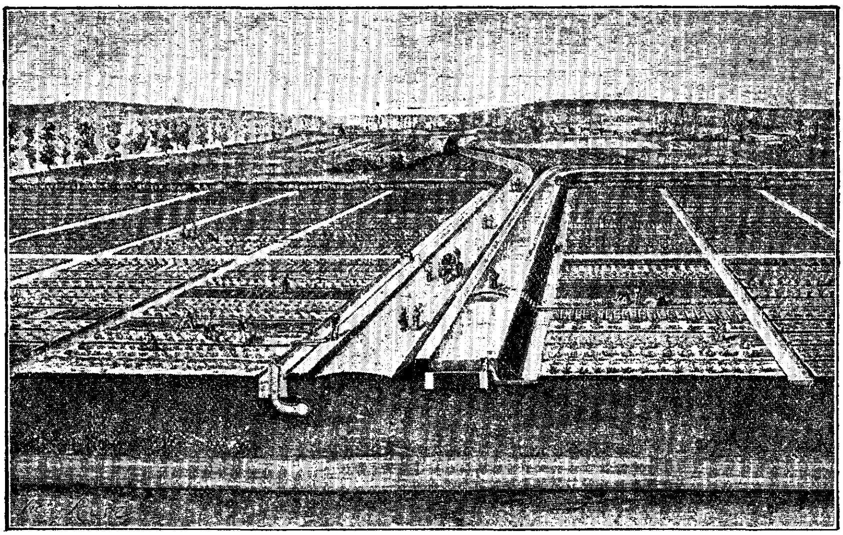

FIG. 24.—Diagrammatic view of the irrigation fields at Gennevilliers.

exceedingly thirsty after a long walk he had no hesitation in dipping up the water of the effluent channel and drinking it, the gentleman accompanying him having made the positive assurance that no harm would result therefrom. Thus far there is no reason to believe that the effluent from sewage irrigation from the Plain of Gennevilliers may not be used as drinking water regularly with impunity.

The available area at Gennevilliers having been all taken up, the engineers of the city of Paris proposed to extend a main for irrigation to the edge of the forest of St. Germain, a few miles distant from the municipal usine at Clichy, the point from which the sewage is diverted from the main outlet sewer of Paris to the Plain of Gennevilliers. Although the sewage irrigation at Gennevilliers had been very successful, the project of irrigation in the forest was opposed strongly by the citizens of the neighboring communes. Petitions were made and protests forwarded to the French Senate, the whole forming a large volume of considerable interest as indicating the persistency of the public opposition to the carrying out of great works of public utility of this character. On the part of the city of Paris, however, an equal persistency has been manifested, with the result that the city has finally received authorization to carry out the scheme of purification of Paris sewage, as already detailed in discussing the decree of July 10, 1894.

Among other interesting statistics which have been gathered in regard to sewage purification at Gennevilliers, the French reports indicate that, as in England and at Berlin, the health of people living on and about the sewage farms has not been in any degree impaired. So extensively has the evidence on this point multiplied from the different places where sewage utilization works have been carried out that we may conclude here, as in respect to other details already discussed,

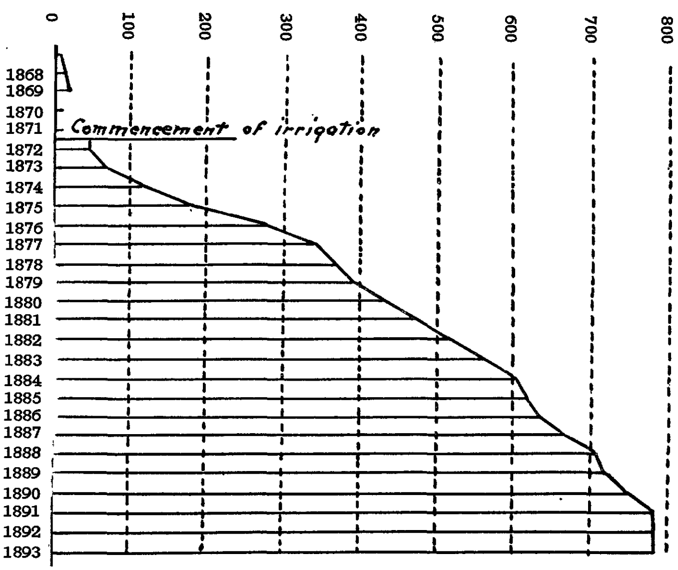

FIG. 25.—Diagram illustrating increase in use of sewage at Gennevilliers. The numbers denote hectares.

that properly conducted sewage utilization is not in any degree prejudicial to the health of either the people engaged in it or those living in the vicinity.

Among other interesting features at Paris, the Model Garden should be mentioned. This includes an area of 6 hectares, on which precise experiments as to the utilization of sewage have been carried on for a number of years under the most scientific conditions possible of attainment, in which have been noted the weight of seed sown, the yield therefrom, the amount of sewage applied, the amount of rainfall, variation in quantity of sewage applied, and many other things tending to afford a definite scientific basis of positive information for the agricultural utilization of sewage.

The results of the experiments at the Model Garden have never been published in full, and the author is indebted to Mr. George Bechmann, chief engineer of the sanitary department of the Seine, for information as to these valuable results. As visited in December, 1894, the Model Garden presented evidence of the many careful and systematic experiments carried out, although at that season of the year little idea could be formed of the relative benefits of sewage to different crops, for the reason that crops were not then growing.

The following particulars as to the irrigation of Gennevilliers are derived from the report of Mr. Bechmann for the year 1893. According to the report, the area under irrigation has remained stationary at 776 hectares since 1891, in which year, as already stated, the entire available area was taken up. Of this area of 776 hectares, 6 hectares belong to the city of Paris and constitute the Model Garden and its dependencies. The remainder is composed of various-sized parcels which are the property of the individual cultivators, who receive sewage only when they desire it. Fig. 25 shows graphically the increase in the use of sewage in Gennevilliers from year to year.

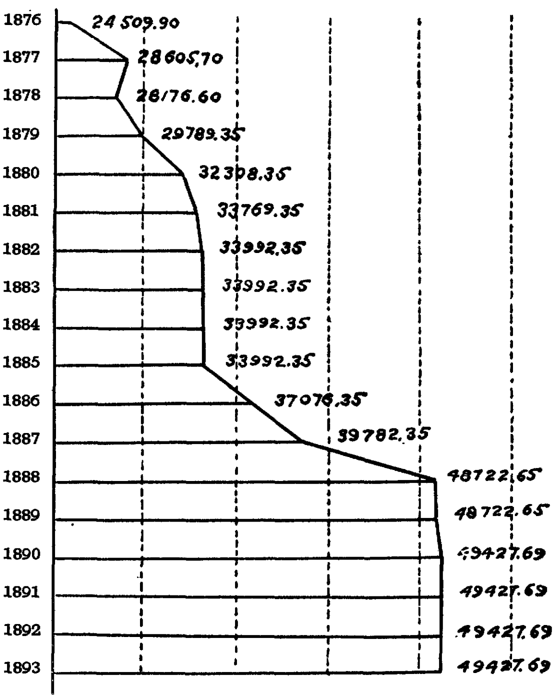

FIG. 26.—Diagram illustrating progressive increase in length of distribution conduits at Gennevilliers. The numbers denote meters.

The sewage is distributed by means of a system of main and secondary channels, with a total length at the present time of 49,427.7 meters. The progressive increase in length of these conduits from the beginning to 1893 is shown by fig. 26. The distribution service is in charge of the agents of the city of Paris, who work according to a system, irrigating successfully the three belts into which the plain has been divided. The force having this work in charge consists of 3 foremen and 23 ordinary workmen, who perform all the labor necessary for a proper and successful distribution of the sewage. Foremen receive 170 francs per month and laborers from 145 to 150 francs per month.

The total volume of sewage distributed in 1893 was 33,421,299 cubic meters. Each hectare of the plain, therefore, received on an average a little more than 43,000 cubic meters, the distribution per acre being, thus, 625,293 feet. The amount actually distributed each month is shown by fig. 27, while the least area irrigated in one day varied from month to month as per fig. 28. From this figure we learn that the minimum area per day was 49 hectares in February, and the maximum area 133 hectares per day in September.

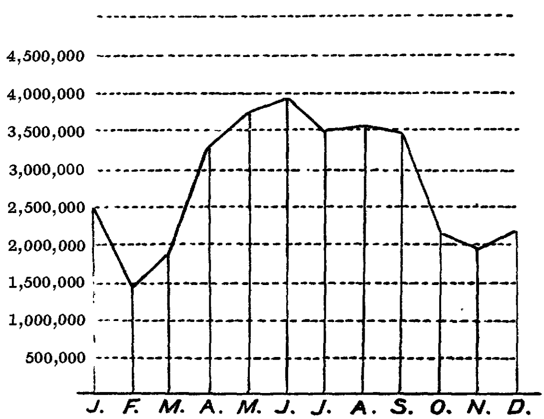

FIG. 27.—Diagram illustrating distribution of sewage by months at Gennevilliers. The numbers denote cubic meters.

Of the 6 hectares belonging to the city of Paris and included in the Model Garden, 3 hectares and 85 ares were rented in 1893 at an annual rental of 600 francs per hectare. The remainder of the 6 hectares was devoted to various experiments, principally to intensive irrigation, wherein from 80,000 to 130,000 cubic meters of sewage per hectare per year were applied. Mr. Bechmann states that the application of such large quantities of sewage is not prejudicial either to the purification or to the success of the crops. The experiments at the Model Garden have been directed specially for a few years toward the cultivation of nursery stocks of various sorts, and the results obtained are stated to have been remarkably good.

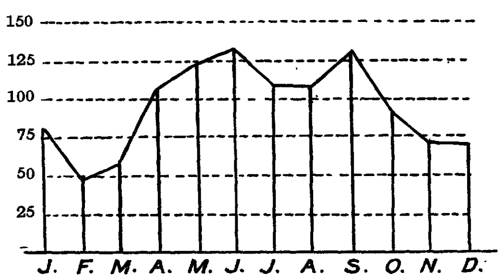

FIG. 28.—Minimum amount of sewage distributed per day by months in 1893. The numbers denote hectares.

The cost of the irrigation at Gennevilliers is said to have been 0.0022 franc per cubic meter of sewage distributed. In our currency this would amount to 0.00043 cent per cubic meter.[1]

The purification attained during the year 1893, as determined by a series of analyses regularly made at the municipal observatory of Montsouris, continues to be absolutely satisfactory. Without referring to the degree of purification attained as indicated by chemical

[1] The cubic meter equals 35.94 cubic feet, or 1.33 cubic yards.

analyses, we may merely call attention to the bacterial purification. According to the Montsouris laboratory determination, the sewage as it flows in the Clichy main contains 29,454,000 bacteria per cubic centimeter, while the water of the Asnieres effluent drain contains only 5,380 bacteria per cubic centimeter, and that of the Epinay drain 26,500 bacteria per cubic centimeter.

The foregoing is an exceedingly inadequate account of sewage utilization at Paris. The literature of the subject has grown very extensive, and whoever would familiarize himself with all that has been done at Paris must go through this large mass of literature in detail.

SEWAGE PURIFICATION IN THE UNITED STATES.

At the present time there are upward of 60 sewage-disposal plants in operation in the United States and the Dominion of Canada. The limited space here available will not permit an account of these works, but in a subsequent pamphlet of this series it is intended to give a brief description of a few of the more recent or more interesting establishments. Facts concerning many of these may be found in the columns of Engineering News and Engineering Record and in Sewage Disposal in the United States, which latter contains descriptions of and reference to works built in the United States previous to 1893. A complete discussion of existing American works would fill a large volume.

As examples of sewage utilization we may refer to Pullman, Illinois; Los Angeles, California; South Framingham, Massachusetts; Meriden and Bristol, Connecticut; and Plainfield, New Jersey. Intermittent filtration without any attempt at sewage utilization is also practiced at Marlboro, Brockton, and North Brookfield, Massachusetts; Summit, New Jersey; Pawtucket, Rhode Island; and also at a number of other towns. Examples of precipitation plants may be seen at Worcester, Massachusetts, and Canton, Ohio.

Much has been done toward advancing knowledge of sewage purification in this country. At the present time the scientific part of the subject is somewhat in advance of the practical application, and herein lies ground for criticism. The managers of American works have frequently failed to understand the importance of closely following rational theory. It is believed that with good management the American works can be quickly made to show as good results as can be obtained anywhere, for generally they have been well designed—a fact which may be set down to the credit of the engineers.

FILTER AREAS AT PAWTUCKET, RHODE ISLAND.

INDEX.

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1894.

Report on agriculture by irrigation in the western part of the United States at the eleventh census, 1890, by F. H. Newell, 1894, quarto, 283 pp.

Consists of a general description of the condition of irrigation in the United States, the area irrigated, cost of works, their value and profits; also describes the water supply, the value of water, of artesian wells, reservoirs, and other details; then takes up each State and Territory in order, giving a general description of the condition of agriculture by irrigation, and discusses the physical condition and local peculiarities in each county.

Fourteenth Annual Report of the United States Geological Survey, 1892–93, in two parts, Part II, Accompanying papers, 1894, octavo, 597 pp.

Contains papers on potable waters of the eastern United States, by W J McGee; natural mineral waters of the United States, by A. C. Peale; results of stream measurements, by F. H. Newell. Illustrated by maps and diagrams.

1895.

Sixteenth Annual Report of the United States Geological Survey, 1894–95, Part II, Papers of an economic character, 1895, octavo, 598 pp.

Contains a paper on the public lands and their water supply, by F. H. Newell, illustrated by a large map showing the relative extent and location of the vacant public lands; also a report on the water resources of a portion of the Great Plains, by Robert Hay.

A geological reconnoissance of northwestern Wyoming, by George H. Eldridge, 1894, octavo, 72 pp. Bulletin No. 119 of the United States Geological Survey: price, 10 cents.

Contains a description of the geologic structure of portions of the Big Horn Range and Big Horn Basin, especially with reference to the coal fields, and remarks upon the water supply and agricultural possibilities.

Report of progress of the division of hydrography for the calendar year 1893–94, by F. H. Newell, 1895, octavo, 176 pp. Bulletin No. 131 of the United States Geological Survey; price, 15 cents.

Contains results of stream measurements at various points, mainly within the arid region and records of wells in a number of counties in western Nebraska, western Kansas, and eastern Colorado.

1896.

Seventeenth Annual Report of the United States Geological Survey, 1895–96, Part II, Economic geology and hydrography, 1896, octavo, 864 pp.

Contains papers by G. K. Gilbert on the underground water of the Arkansas Valley in eastern Colorado; by Frank Leverett on the water resources of Illinois; and by N. H. Darton on a reconnaissance of the artesian areas of a portion of the Dakotas.

Artesian-well prospects in the Atlantic Coastal Plain region, by N. H. Darton, 1896, octavo, 230 pp., 19 plates. Bulletin No. 138 of the United States Geological Survey; price, 20 cents.

Gives a description of the geologic conditions of the coastal region from Long Island, N. Y., to Georgia, and contains data relating to many of the deep wells.

Report of progress of the division of hydrography for the calendar year 1895, by F. H. Newell, hydrographer in charge, 1896, octavo, 356 pp. Bulletin No. 140 of the United States Geological Survey; price, 25 cents.

Contains a description of the instruments and methods employed in measuring streams and the results of hydrographic investigations in various parts of the United States.

Survey bulletins can be obtained only by prepayment of cost as noted above. Postage stamps, checks, and drafts can not be accepted. Money should be transmitted by postal money order or express order, made payable to the Director of the United States Geological Survey. Correspondence relating to the publications of the Survey should be addressed to **The Director, United States Geological Survey, Washington, D. C.**

WATER-SUPPLY AND IRRIGATION PAPERS.

1. Pumping water for irrigation, by Herbert M. Wilson, 1896.
2. Irrigation near Phœnix, Arizona, by Arthur P. Davis, 1897.
3. Sewage irrigation, by George W. Rafter, 1897.
4. A reconnoissance in southeastern Washington, by Israel C. Russell, 1897.
5. Irrigation practice on the Great Plains, by E. B. Cowgill, 1897.
6. Underground waters of southwestern Kansas, by Erasmus Haworth, 1897.
7. Seepage waters of northern Utah, by Samuel Fortier.
8. Windmills for irrigation, by E. C. Murphy.
9. Irrigation near Greeley, Colorado, by David Boyd.
10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker.

In addition to the above, there are in various stages of preparation about twenty other papers relating to the measurement of streams, the storage of water, the amount available from underground sources, the efficiency of windmills, the cost of pumping, and other details relating to the methods of utilizing the water resources of the country. Provision has been made for printing these by the following clause in the sundry civil act making appropriations for the year 1896-97:

Provided, That hereafter the reports of the Geological Survey in relation to the gauging of streams and to the methods of utilizing the water resources may be printed in octavo form, not to exceed 100 pages in length and 5,000 copies in number; 1,000 copies of which shall be for the official use of the Geological Survey, 1,500 copies shall be delivered to the Senate, and 2,500 copies shall be delivered to the House of Representatives, for distribution. (Approved, June 11, 1896; Stat. L., vol. 29, p. 453.)

Application for these papers should be made either to members of Congress or to

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C.