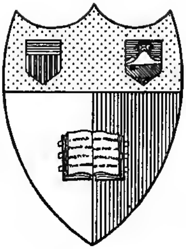

WORKS OF
PROF. A. PRESCOTT FOLWELL

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SEWERAGE

THE DESIGNING, CONSTRUCTING AND MAINTAINING OF

Sewerage Systems and Sewage Treatment Plants

BY

A. PRESCOTT FOLWELL
Past President American Society of Municipal Improvements
Member Society for the Promotion of Engineering
Education; Editor Municipal Journal

EIGHTH EDITION, REWRITTEN
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PREFACE TO THE EIGHTH EDITION

During the twenty years since the first edition of "Sewerage" was published effort has been made to keep it up-to-date by revising it from time to time, six such revisions having been made. Developments in the science and art, however, seem to call for a more general revision of the entire arrangement of the work and a change in typography and illustration to bring it more into keeping with recent practice. The author has consequently rewritten the entire book, making very considerable changes in the portions dealing with sewerage systems, but only minor ones in those treating of sewage disposal, which was rewritten about two years ago.

Among the more important changes are the devoting of more space to the calculating of the sizes of sewers, especially storm sewers, and to pumping sewage; the condensing of Part II—Construction, and Part III—Maintenance, each to one chapter; and the use of many more illustrations, only a few of those in the previous editions being used.

The aim throughout has been to cover thoroughly the fundamental principles and approved practices of both sewerage and sewage treatment, giving the latest developments in each but using caution in crediting enthusiastic claims, even of experts, until fully substantiated by practical experience.

New York, N. Y.
June 1, 1918

PREFACE TO THE FIRST EDITION

For a number of years the author has been looking for the appearance of a work on Sewerage which should embody the most recent data and ideas relating to the subject and treat of both the Combined and Separate Systems in a comprehensive manner, recognizing the fact that such a work is needed by city engineers and engineering schools. None such has appeared, and he has consequently undertaken the task of supplying the deficiency.

No attempt has been made to treat at length the subject of Sewage Disposal, for the reasons stated in Chapter II. Parts II and III on the Construction and Maintenance of Sewers will, he believes, be appreciated by those who are called upon to superintend such work without previous experience, and even, he hopes, give valuable hints to many who are not novices; although he recognizes that the ground is by no means completely covered. For much of the matter therein contained he is indebted to the engineering periodicals, particularly the *News* and *Record*, but the greater part of it has never, to his knowledge, appeared in print.

While primarily intended for practising engineers, the work has also been arranged with the idea that it may be useful as a text-book in engineering schools; Part I having already been so used by the author, and Part II having been largely given in the form of lectures to his classes.

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SEWERAGE

PART I. SEWERAGE SYSTEMS

CHAPTER I

GENERAL OUTLINE OF SUBJECT

ARTICLE 1. PRINCIPLES AND DEFINITIONS

EVERY community produces waste matters that must be disposed of in some way. These are generally classified as garbage, ashes, rubbish, and sewage.

Sewage is the liquid waste of a community. It is of three general classes: *Domestic sewage*, which is the water-borne excrement, washing and dish water, and other dirty water from places of human residence, business buildings or institutions; *industrial sewage*, which is the liquid wastes from various manufacturing and industrial processes; and *storm sewage*, or the water flowing off of street surfaces, adjacent land, and roofs during rain storms. The two first named are commonly combined for removal and called *house sewage.**

The removal of sewage from the residences and centers of industry of a community is demanded on two grounds: The higher one of public health and the more popular one of convenience. In designing a system, each of these must be kept constantly in mind, the former being always given predominance if they conflict in any way.

---

* Some call this "sanitary" sewage—to the author's thinking an absurd misnomer. The term "house sewage" has been adopted as a standard by the American Society of Municipal Improvements.

There are two imperative essentials to sanitary sewerage:

I. That all of the sewage be removed without delay to a point where it may be disposed of properly.

II. That it be so disposed of as to lose permanently its power for evil.

The removal of sewage is accomplished by means of systems of conduits called *sewers*. Such removal is called *sewerage*, and the system of conduits by which it is effected is called a *sewerage system.*

In some cases house sewage is removed in one set of sewers and storm water in another set, the former being called *seperate sewers,** and the latter *storm sewers.** In other cases the same sewer receives both kinds of sewage, in which case the sewer is called a *combined sewer* and the mixture of house and storm sewage is called *combined sewage.* When only house sewage is flowing in a combined sewer, this is often referred to as the *dry-weather flow.*

Where a sewerage system consists of combined sewers only, it is known as a *combined system;* where the house sewage is removed by a system of separate sewers and the storm water is removed by another system of sewers (if removed in sewers at all), this is called a *separate system* of sewerage. In some cities the separate system is used in part of the area and the combined system in the remaining part and the sewerage system of such a city is called a *mixed system.*

After it has been removed to a greater or less distance, the sewage must be discharged into a stream, the ocean, or other large body of water. Such discharge is always necessary, because the enormous volumes of water flowing in sewerage systems cannot practically be destroyed or harmlessly dissipated.

In some cases it is necessary to partially purify or otherwise alter the nature of sewage before so discharging it, and this is called *sewage treatment.* *Sewage disposal* is the final getting

---

* Some use the term "sanitary sewers" instead of "separate sewers." Others call these "sewers," and call storm sewers "drains"—a very confusing use of terms, since drainage is the removal of subsurface water, and the use of commercial "drain tile" for such sewers would not be permitted. The terms used here are those recommended by the American Society of Municipal Improvements.

rid of the sewage that reaches the outlet of the sewerage system, and may or may not include sewage treatment.

The prime object of a sewerage system is to conduct to an appointed outlet the sewage that is received at numerous points along its route, and this should be done as rapidly and continuously as possible. No part of the sewage should be retained in any portion of the system for any considerable time, either in its liquid form or in the shape of deposits upon the bottoms or walls of the conduits or their appurtenances, for such retention may permit of putrescence of the organic matter carried by the sewage before it reaches the place assigned for disposal.

ART. 2. ADVANTAGES OF SEWERAGE

The water-carriage system has now been adopted almost universally for the removal of excreta where this service is performed by the municipality, and its use is always understood when the term "sewerage" is used. There are still a number of cities which are using, generally in limited areas in the outskirts, what is known as the "dry sewage" method, by which excreta are removed in pails or boxes, generally mixed with powdered soil or other absorbent. More common is the use of cesspools—pits into which excreta and polluted household waters are discharged. These should be cleaned out periodically, the material removed generally being called "night soil." Such cleaning is not ordinarily done by the municipality. Cesspools, unless watertight (which they seldom are), pollute the soil under and around dwellings. The material in them putrefies and gives off foul gases which, if house plumbing is connected with them, may enter such plumbing and pollute the air of the dwellings. Deposits of excreta on the surface of the ground in privies may pollute the soil and give off offensive odors; but the most serious objection is that flies have access to them and are known to have spread typhoid fever and possibly other diseases because of this; and the same danger is attached to cesspools or privy vaults that are not covered.

(The typhoid rate in certain sections of large cities has been reduced more than 50 per cent by sewering and abolishing surface privies and open vaults.) The use of the out-door privy is inconvenient and in stormy and cold weather even unhealthful. The removal of night-soil involves an expense which, if capitalized and added to the construction-cost of the cesspool, would in almost every case more than suffice for the construction and maintenance of a house sewerage system in a city or any well-populated community.

The water-carriage system meets the principal requirement of a sanitary system—it removes all the house wastes and removes them immediately. It also performs the by no means unimportant service of removing surface water and generally drains wet ground also. In convenience it is excelled by no other system. Where the territory is quite thickly populated, as in the average town, it is in the end cheaper than cesspools or any other method.

Arguments advanced against it are that a large amount of water is needed for its efficient working, that it pollutes streams, and that it causes the waste of the valuable fertilizing properties in the sewage. As to the first, the water entering a separate sewer consists almost exclusively of that which is used in the household, drawn from the water mains, and the amount so drawn need be only very slightly increased for any purposes connected with the sewerage. The matter of pollution of streams is a serious one, and in many cases large sums are spent in reducing such pollution to a minimum. The loss of fertilizing materials by discharging them into the streams is less important than was at one time believed, both because the value of such materials is less than was assumed and because the apparent loss is probably not ultimately a total one. The consensus of opinion is that the two latter objections are more than balanced by the advantages which it offers in comparison with any other method yet tried for the removal of excreta and liquid wastes. It cannot, of course, be stated with certainty that no better system will ever be devised, but up to the present time none has been proposed which promises to prove anywhere near as satisfactory for the great majority of cities.

As to whether the combined or the separate system of sewerage shall be adopted in a given case, or even a mixed system, decision should be based on considerations to be discussed later. These generally have to do with relative cost of construction and efficiency of service rendered, relative importance of removal of house and of storm sewage, effect upon the body of water receiving the sewage, whether or not the sewage will be treated, and what existing sewers (if any) it is desirable to incorporate into the proposed system.

ART. 3. CONSTITUENTS OF A SEWERAGE SYSTEM

A modern sewerage system comprises several or all of the following:

A system of *conduits* or *sewers*, or several systems, all converging toward a common outlet. Each system of sewers consists of a *main* or *trunk* sewer, which receives the flow of several *sub-main* or *branch* sewers, which sub-mains in turn receive the flow from the *lateral* sewers, sometimes called "collecting sewers" (although, of course, the main and sub-main sewers also collect as well as carry the sewage brought to them by laterals). A system of sub-mains and laterals is sometimes called a "reticulation system." A sewer that extends from the lower end of the collecting system to the point of final discharge is called an *outfall* sewer.

Manholes at intervals along each line of conduits. These are to give access to the sewer, and are generally in the form of a shaft or well extending vertically from the sewer to the ground surface, where it is provided with a removable cover.

Lampholes (now seldom used), or small shafts extending from sewer to ground surface, down which a lamp can be lowered to facilitate inspecting the sewer from a manhole.

Branches (called T-branches or Y-branches, or simply T's or Y's) built into the sewer by which to join to it house connections, inlet connections or other pipes.

House connections—pipes connecting individual buildings with the sewers.

Inlets—openings in the street surface through which storm water enters the sewer system.

Inlet connections—the pipes connecting individual inlets with the sewer.

Flush tanks—contrivances, generally placed at the upper ends of the collecting sewers and underground, by which water is discharged into the sewers for flushing out any deposits.

Pumps, "ejectors," "lifts"—appliances for raising the sewage from a low sewer to a higher one, an outlet, or a treatment plant.

Treatment plants, for removing or rendering less objectionable putrescible and other matters in sewage so that it can be discharged into a given body of water without so polluting it as to violate laws, either federal, state, or local, or produce obnoxious or dangerous conditions.

In addition, there may be many other features, such as appliances for forced ventilation of the sewers, tide gates at the outlets, overflows by which storm water may leave combined sewers for neighboring streams, etc., which will be referred to in the following chapters.

ART. 4. DESIGNING A SEWERAGE SYSTEM

The designing of a sewerage system involves a determination of where the sewage shall be discharged, whether it shall be treated and how and where, whether it shall be collected by the separate or the combined system, the proper size and shape of conduit to be used at each point, the location, depth, and grade at which it is to be laid, the materials of which it may be constructed; also what appurtenances (such as manholes, inlets, etc.) are necessary, and where, and their details.

The amount of polluting matter in the water which flows in sewers is so small that the laws of hydraulics apply to the flow of sewage in sewers, and consequently these laws are employed in designing sewerage systems.

The application of these laws, however, is limited in certain respects by the nature of sewage; one important factor being the tendency of the matters in suspension in the sewage to settle out if the velocity of flow becomes too low, thus placing a minimum limit upon the velocity of flow that is practicable. Another important factor is the offensiveness to sight and smell as well as the danger to health of the exposure of sewage in open conduits, as a result of which it seems to be necessary to carry sewage entirely in closed conduits.

There are several other essential or occasional characteristics of sewage which need to be considered in designing a sewerage system, and these and their effects upon the design form an important feature of the study of sewerage.

Aside from the nature of sewage, the principal factor in designing is the amount of sewage which the sewers will be called upon to carry and the fall in the hydraulic gradient of the sewers which creates the velocity with which it flows through them. The hydraulic gradient cannot for very long distances depart materially from approximate parallelism to the street surface without involving excessively deep cutting for constructing the sewer; and in general it may be said that the grades of a street under which a sewer is laid to a considerable degree determine the grade of the sewer.

The hydraulic gradient at the outlet of a sewer system can be no lower than that of the body of water into which it discharges. Generally speaking, also, it does not seem practicable to construct sewers above the surface of the ground, except for short stretches under unusual conditions. It is thus seen that the hydraulic gradient is to a large extent controlled by the topography of the city in question. The determination of this topography by surveying methods is therefore one of the important preliminaries to designing.

Where the topography does not permit the laying of the sewers at such grades as will produce the desired velocities and at the same time keeping the hydraulic gradient at the outlet at or above the level of the water into which the sewage is to be discharged, it is generally necessary to pump the sewage at the outlet or at one or more other points, or use some other mechanical means for raising it from a lower to a higher level.

To a certain and sometimes a very considerable extent, the design of a sewerage system may be affected by the method to be employed in treating the sewage, or by the absence of any treatment. For instance, if treatment is to be provided it is generally facilitated by the use of the separate system rather than the combined. Also, some methods of treatment operate best on sewage that has been thoroughly agitated, other methods on sewage that is fresh and unagitated.

Unless a city which is to be sewered is practically level throughout, the topography more or less definitely and imperatively divides the total area into several districts or drainage areas, each of which will be sewered by a small secondary system of its own. The effluents from several such drainage areas may discharge independently, each through its own outlet, or all or several may discharge into a common main sewer and be carried to a common outlet. In this respect a sewerage system almost exactly duplicates, on a smaller scale, the system of rivulets, brooks, and river which go to make up the surface drainage system of a large water shed.

Every branch of a sewerage system, or at least of so much of it as has one common outlet, is to a greater or less extent dependent upon every other. The minor lines must be so located as to elevation that they can discharge into the larger ones, and, on the other hand, each of the latter must be given such depth and capacity that it will be possible for it to receive the flow of all of the smaller sewers for which it forms the natural outlet. Consequently, no one sewer line or group of sewers should be designed without a thorough study and understanding of its relation to all other portions of the entire sewerage system, both those now existing or to be constructed in the immediate program, and those which will be required in future extensions of this system.

All of the elements of a design are so interrelated that generally only tentative decision can be made of any one of them until similar decision has been made of all and their effects on each other studied.

The more important matters to be investigated and data to be obtained in preparing a sewerage design are as follows:

Point of Discharge:

The bodies of water available.

Dilution furnished by each, involving a study of minimum flow (if a stream), current, tides, winds, etc.

Character of the water with respect to its effect upon sewage discharged into it.

Possibility of the formation of deposits of sewage matters or the creation of other nuisances.

Whether water is or may be used as source of a potable supply.

Laws—federal, state, or local—bearing upon discharge of sewage into bodies of water.

Method of Treatment, if any.

Chemical and physical analysis of sewage and of the water into which it is to be discharged.

Amount of dilution of sewage by ground or surface water; separate or combined system.

Amount of water available for diluting effluent, minimum flow

Climate—summer and winter temperature, humidity.

Amount of fall available at site of plant, or necessity of pumping.

Area of sites available and nature of soil.

Amount of sewage, mean and maximum.

Legal requirements.

Separate, Combined, or Mixed System.

Whether sewage will be treated, now or in the future.

Number, location, size, and condition of existing sewers that might be used in the new system.

Practicability of placing overflows at various points.

To what extent and over how large an area the removal of surface water is necessary.

Location, Depth, and Grades of Sewers.

Street layout, including widths of streets.

Existence and depth of rock, quicksand, ground water, and other difficult conditions under each street.

Depth of basements and cellars below street level along the line of sewer.

Grades of the streets or other ground surface along the line of the proposed sewers.

Limitations of velocity of flow of sewage, to avoid deposits due to sluggishness on the one hand or abrasion due to high velocity on the other.

Size of sewer as affecting grade.

Sizes and Shapes of Sewers.

Amount of sewage, mean and maximum rates, for some years in future.
Grades of sewers.
Nature of ground (support offered for sewer).
Position of sewer relative to ground surface.

In addition to the above, there will be, in most cases, special considerations peculiar to the city in question that should be given more or less weight in solving the problems presented. Financial limitations imposed upon the engineer will generally restrict his choice of solutions and especially the extent of immediate construction.

CHAPTER II

AMOUNT OF HOUSE SEWAGE

ART. 5. COMPOSITION OF SEWAGE

SEWAGE may contain any combination of the innumerable materials that find their way into sewers, and varies considerably in the different cities, and from hour to hour in a given city.

Domestic sewage consists of the water used in the residences of the city after pollution by such use, the pollution consisting chiefly of human excrement, both solid and liquid, dish water (in which is found soap, grease, and particles of animal and vegetable matter), wash water (containing soap, bluing and cloth fibers), pieces of paper, matches, hair, bits of cloth, and occasionally discarded garments, bones and garbage and other matters that should not reach the sewers. Also more or less dirt enters many sewers through the covers of the manholes. The pollution carried by the water forms less than one-tenth of 1 per cent of the sewage in most cases, although this varies with the amount of water per capita entering the sewer, which amount may be increased by seepage of ground water into the sewer, and occasionally (but inadvisably) by rain water discharged into it from roofs. The appearance of domestic sewage is that of wash water in which float occasional particles of fæces, paper, matches, etc., and often with a film of grease on the surface. There is generally a slight but not particularly offensive odor. Both turbid appearance and odor increase with the age of the sewage, and most of the solid matter is rendered more comminuted by agitation of the sewage during its passage through the sewer. The temperature is generally about 45° to 55° in the coldest weather in northern cities and 65° to 75° in the hottest weather. As a general thing, the sooner the temperature is taken after the sewage enters the sewer, the nearer will it approximate to about 55° or 65°. (Discharge of steam into a sewer, which should not be permitted, will of course, raise the temperature.)

Grease and soap carried into the sewer by warm water tend to adhere to the walls of the sewer at the water line when the water cools. Dirt and any other matters heavier than water tend to settle to the bottom of the sewer. Fæces and some other matters that at first float on the surface tend to settle down when broken up by agitation or by bacterial or chemical action.

Industrial sewage may contain any of the waste fluids that are discarded by manufacturing plants or other industries. Among these are pickling acids from metal industries, grease from wool-scouring, alkalies from paper mills, spent dyes from cloth and silk mills, tar from gas works, wastes from tanneries, creameries, packing houses, soap, glue, fertilizer and yeast factories, breweries, etc. Steam is sometimes discharged into sewers from boilers, steam-heating and other plants, but this should not be permitted. The same is true of gasoline from dry-cleaning plants and garages, which has caused scores of explosions in sewers, doing tens of thousands of dollars worth of damage. The amount of solid matter in industrial sewage has been found to run as high as 7 or 8 per cent, or one hundred times as great as in the case of the average domestic sewage; as a rough estimate of all industrial sewages, it might be said that they would average about five to ten times as strong as domestic sewage. In amount, industrial sewage may, in a manufacturing city, total from one-half to three or four times as much as the domestic sewage; but in a large city where much of the industry is commercial, it seldom exceeds 25 to 50 per cent of the domestic. Industrial sewage is often more foul in appearance and odor and contributes more deposits on the walls and bottom of the sewer than does domestic. Also, it varies more from hour to hour, since in most plants the wastes are discharged at intervals of several hours, and not at all at night.

Storm sewage consists of rain water discharged from roofs and streets, carrying with it such dust and dirt of various kinds as may have collected upon either of these. Where the street is not paved, heavy storms may carry sand, gravel and soil into the inlets; where the street is macadamized, the fine material worn from the surface by traffic is washed to the sewer; and in all cases, a greater or less amount of the dirt which collects on roadways and sidewalks is washed into the sewer, the most important of this being horse droppings, although dead leaves and newspapers often form no inconsiderable nor unimportant part of the material removed from the streets. In a light drizzle, very little of this may be washed into the sewer; and after a heavy down-pour of a few minutes the streets may be washed clean, so that the succeeding run-off is comparatively pure water. It results that the nature of the storm sewage of a given city depends upon the kind of pavement, or absence of any, grade of the street, the number of shade trees, etc.; while the character at any given time depends upon the intensity and duration of the rain fall.

Precipitation in the form of snow does not immediately reach the sewer, but ultimately does so, except for such as is carted away and the greater or less amount that may be absorbed by the ground where this is not covered with impervious pavement. If thawed rapidly by a warm rain, it may add greatly to the amount of storm water and also to the impurity, the various kinds of street dirt accumulating on the snow, frequently for weeks at a time.

In addition, more or less ground water finds its way into many sewers, both separate and combined, through porous joints or walls. This is called seepage.

In the above paragraphs the matters that go to make up sewage have been the chief consideration. The physical, chemical, and bacterial composition and characteristics of sewage will be discussed later.

ART. 6. AMOUNT OF DOMESTIC SEWAGE

Since domestic sewage consists almost entirely, as to volume, of the water that enters the houses from the water mains, a close approximation to the volume to be expected from a given population can be made by using for this purpose the figures for the water consumption of the town in question. All of this does not reach the sewers, however, much of that used for steam purposes (all used by steam railroads) and that used for street and lawn sprinkling and the leakage from mains and services and other small amounts failing to reach them. On the other hand, to that which reaches the sewers must be added seepage of ground water, which should be negligible, but in some systems forms more than half of the sewage reaching the outlet. With the domestic must be included that which is sometimes classified as "commercial," being that from stores, saloons, hotels, etc., since this is similar in character and is discharged into the separate sewers; although it is desirable to consider it separately when designing the collecting sewers for the commercial district. The same applies to industrial sewage, or liquid trade wastes.

WATER CONSUMPTION

Domestic, commercial, and industrial consumption can be determined only by placing water meters on the individual services. If meters are not used generally in the city in question, an approximate estimate can be based upon figures for other cities. The total amount will be determined largely by the population, and is generally expressed as the average per capita for the total population of the city. Most figures available are for total consumption of all kinds—domestic, commercial, industrial, public, and unaccounted for; and comparatively few can be relied on for accuracy. Table No. 1 gives the several rates for fourteen cities which metered practically all of their consumption, which figures are probably more reliable than the great majority of those that are available. The rates of domestic consumption here given vary from 8.8 to 58.8 gallons per capita per day. The average for those cities in which 99 per cent or more of the services are metered is 29.8 gallons.

TABLE NO. 1

ANALYSIS OF WATER CONSUMPTION IN 1914 IN CITIES ALMOST WHOLLY METERED

From report of Committee on Water Consumption of American Water Works Association

City.	Population.	Per Cent of Services Metered.	Per Cent Minimum Night Rate is of Day Rate.	CONSUMPTION PER CAPITA PER DAY.					TOTAL UNACCOUNTED FOR	
				Total.	Metered Industrial.	Metered Commercial.	Metered Public.	Metered Domestic.	Per Cent.	Gals. per Capita.
Milwaukee, Wis.	430,000	99.4	62.5	111.4	41.4	32.0	5.6			
New Orleans, La.	360,000	99.7	....	57.2	*	13.0	3.2	16.8	37	24.2
Rochester, N. Y.	250,000	99.5	42.0	95.0	18.3	12.2	4.8	31.2	30	29.5
Utica, N. Y.....	95,000	99.3	....	78.7	41.9	..	2.2	20.9	18	13.7
San Diego, Cal..	85,000	100.0	....	80.6	7.2	12.1	9.6	36.1	19	15.6
Wilkinsburg, Pa.	80,000	99.0	....	107.0	59.6	..	2.4	25.5	18	19.5
Buffalo suburbs .	50,000	100.0	....	131.5	98.5	..	..	8.8	18	24.2
Lexington, Ky..	40,000	100.0	42.5	62.1	18.0	16.0	8.4	16.8	5	3.0
Madison, Wis. ..	27,000	99.2	14.1	79.0	6.1	6.5	3.4	35.3	36	27.7
Oak Park, Ill...	26,000	100.0	44.5	69.0	8.6	1.7	2.5	52.4	6	3.8
Pine Bluff, Ark..	16,000	100.0	83.8	71.6	*	7.5	..	12.3	72	51.8
Elyria, O.......	16,000	100.0	38.3	121 1	47.0	7.2	5.6	38.8	18	22.5
Corning, N. Y. .	14,900	99.0	16.0	83.3	16.7	7.2	1.4	58.0		
Monroe, Wis....	3,000	100.0	56.0	79.0	38.5	..	..	33.3	9	7.2
Mean..........			44.4	87.6	29.4	10.5	4.5	29.7	24	

* Included in commercial.

In general, it is probable that the domestic consumption of most cities lies between 20 and 50 gallons per capita per day, with 15 and 100 as the extreme sexcept for a few cases of excessive waste. Anything more than 30 or 40 gallons is generally waste. Large cities have been thought by some to have a higher domestic rate than small ones, but meter records do not seem to furnish support of this idea, except in so far as a larger percentage of residences use the public water supply in cities than in villages.

The effect of meters is to reduce waste of water; consequently figures from metered cities (the only ones reliable) show lower rates than exist in unmetered cities. In unmetered cities the rates may run as high as 100 or 150 gallons. It does not seem to the author that an engineer is justified in designing for more than 100 gallons average per capita rate, however, using factors to provide for temporary excess in rate and future growth in population. If the rate ever exceeds this, the city should meter or suffer the consequences. If a city is fairly well metered, the existing rates as measured, increased perhaps by 10 to 25 per cent as a factor of safety, may be used.

Having assumed a per capita rate of domestic water consumption, the total amount to be provided for in designing sewer capacity will be the maximum rate occurring at any time during the next thirty to fifty years. The total domestic water consumption will equal the average per capita rate times the population (assuming that the entire population uses the public supply and the sewers, which is the only safe assumption). This population will be that thirty to fifty years from now. Just how distant a future should be selected is a matter of judgment. There are objections to giving a sewer a capacity more than two or three times that demanded by present requirements, which will be explained under the head of "Flow in Sewers." In addition, if the difference between the cost of capacity for fifty years in the future and that for one hundred years be placed at interest during the first fifty years, at the end of that time it will probably amount to sufficient to provide the additional capacity required throughout the second fifty years. There is also the possibility that the growth in population will be less than anticipated, or the per capita rate of consumption decrease, in which case the cost of the unnecessary capacity would be wasted.

POPULATION

Each lateral sewer is to be given a capacity for the ultimate population of the street that it sewers, and each secondary system of sewers a capacity for the ultimate population of its district. The growth of a city consists partly in extension of territory and not wholly in increasing density on its present area. The problem, therefore, for all except the trunk sewers that sewer the entire city, is that of determining the maximum population of each block, collection of blocks, drainage area, etc., during the future period decided upon.

Table No. 2

ESTIMATING POPULATION FROM SCHOOL ATTENDANCE

Figures from the 1910 Census of the United States

Geographical Division	Total Population	School Attendance	Percentage of Total Population in School	Percentage of All 5 to 20 Years Old in School
New England..........	6,552,681	1,222,228	18.7	66.1
Middle Atlantic........	19,315,892	3,531,373	18.3	62.9
East North Central.....	18,250,621	3,576,003	19.6	65.5
West North Central....	11,637,921	2,530,591	21.7	67.9
South Atlantic.........	12,194,895	2,418,444	19.9	56.7
East South Central.....	8,409,901	1,730,191	20.6	57.9
West South Central.....	8,784,534	1,795,100	20.4	57.1
Mountain.............	2,633,517	505,191	19.2	65.8
Pacific................	4,192,304	700,770	16.7	65.7
United States..........	91,972,266	18,009,891	19.6	62.3

Forecasting Population. We have, therefore, to estimate the future population of the city at large and that for each district. Forecasting of population is generally based upon present population and an assumed rate of growth. Present population can be determined accurately only by an actual count—a census. The federal government makes such counts at ten-year intervals. Several of the states take census counts five years after each federal census. These figures should be used, supplemented by any others obtainable. Some cities take an occasional police census, each patrolman making house-to-house calls and determining the number of residents in his "beat" on a given day. In the so-called "school census" method, it is assumed that the ratio between school attendance and total population in a city is practically constant, and this ratio having been determined in a census year, the population in any other year is reckoned by multiplying by this ratio the school attendance for that year. The ratio is not generally an actual constant, but is nearly so when there is no change in character of population. Other methods use, instead of the school attendance, the local telephone or business directory, or list of registered voters. These are not so reliable as the school census method.

Where possible, the population should be determined for smaller units than the entire city—the smaller the better. The most desirable subdivision would be into the commercial, industrial, dense residential, medium residential, and sparse residential districts.

Forecasting population may be done by assuming that the rate of growth of the city in question in the future can be represented by the same algebraic formula as applies to the past; or by assuming that it will be the same as the average of certain other selected cities that were, at least twenty or thirty years ago, of the size of the one in question. The formula used is generally obtained by plotting as many successive population figures as are obtainable, fitting a curve as nearly as possible to these, and determining a simple formula that will approximately fit the curve (frequently of the form $P=a+bx^c$). One method is to assume that there will be a certain *percentage* of increase in each *decade*, determining what percentage will best fit past records. Another is to use a percentage of increase that becomes smaller each succeeding decade. Another (used by the U. S. Census Bureau for interpolating between decennial census figures) is the arithmetical increase, assuming that each year the same number of individuals will be added to the population as the average during the previous census interval. In forecasting population it is a more or less common practice to estimate maximum and minimum extremes for each future year, between which extremes it is believed that the figures reached will lie. Generally the maximum will be used for estimating sewage flow.

Using the composite growth of several larger cities as a standard is done as follows: Having carefully selected the cities, the curve of growth of each is plotted. On each curve is then located the point at which the population was the same as the present population of the city under consideration. All the curves are then superimposed so that this population point in each comes at a given fixed point in the composite diagram, all having one common horizontal axis but with entire disregard of the years in each case. From the several curves in the composite diagram, as they extend beyond the common population point, may be estimated an average, a maximum, or a minimum curve of probable growth. (See illustration, Fig. 2.)

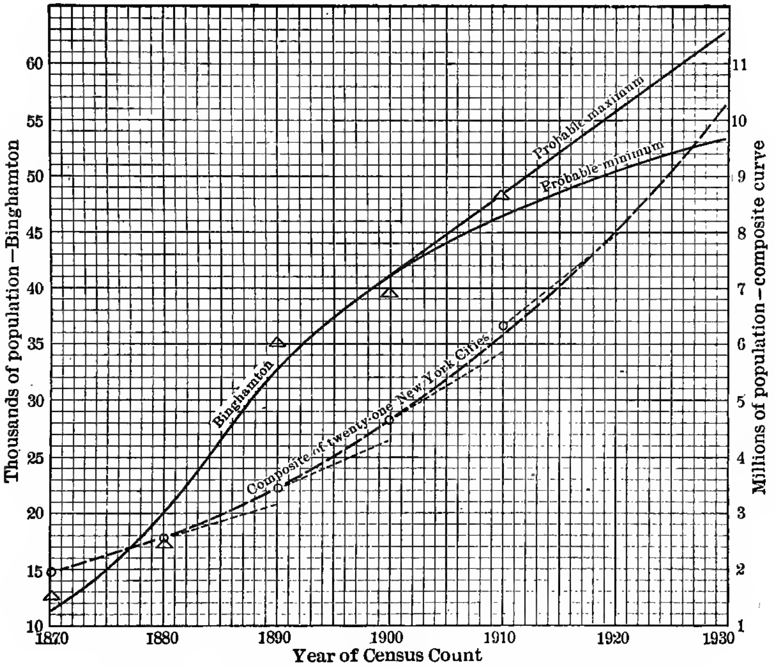

Fig. 1.—Extended Curve Method of Forecasting Population.

As a city grows in population beyond a certain point, its rate of growth generally decreases gradually. The growth of small cities is generally much more irregular than that of large ones. Any city is liable at any time to a sudden increase or decrease of growth caused by unforseeable circumstances. The maximum limit of population of any given area is generally more closely predictable than its rate of growth.

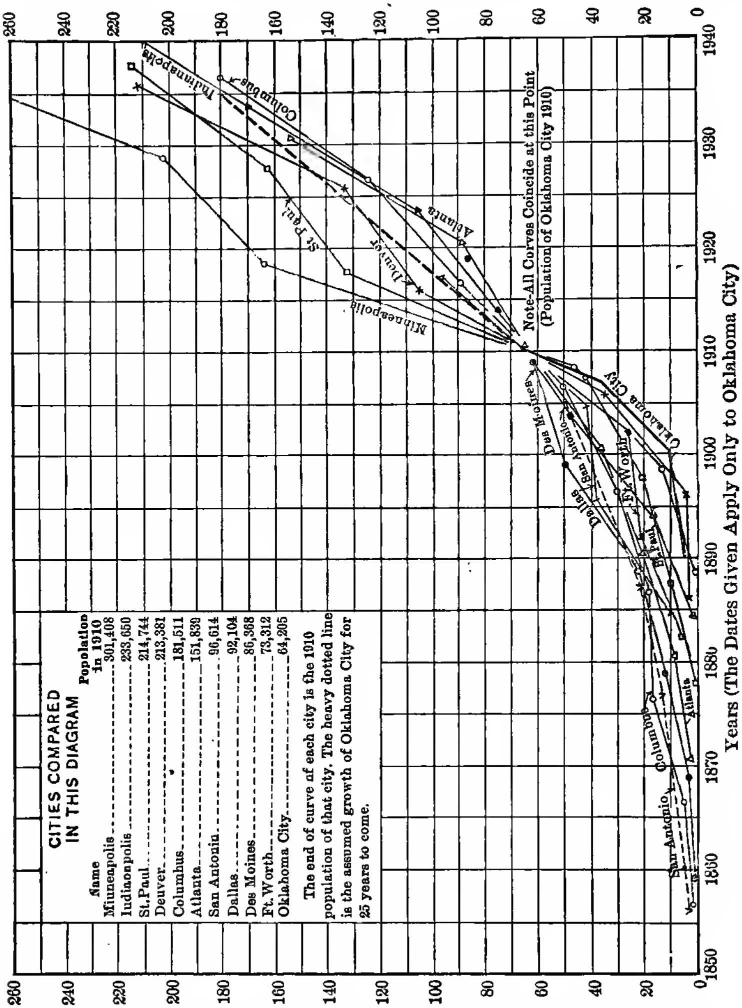

FIG. 2.—COMPOSITE DIAGRAM METHOD OF FORECASTING POPULATION.

Population Density. For designing most of the lines of a sewerage system, what is needed is an estimate of the maximum density of population that will be reached during the life of the sewer on the limited area served by the sewer line in question. This density tends to approach a maximum beyond which it will not grow, and under certain circumstances it may even decrease. Possibly the best plan for forecasting the maximum density of population of an area of a given character is to take a comparatively small area of the same character which has apparently reached its maximum density (such area being taken in another city, if one cannot be found in the city in question), and determine the density per acre on this area; then apply this per-acre density to the entire area which it is believed will take on this character during its development. In determining the density of the given area, street areas are included; but cemeteries, parks, bodies of water, and other areas permanently withdrawn from habitation are excluded in this calculation and also in all calculations and forecasting of population.

Instead of actually counting the population on a given area, it may be assumed to be divided into blocks of a given length and breadth, streets of a given width, building lots of a given average size and a given average number of occupants to each. The calculation of density is then made by substituting proper figures in the formula:

$$D=\frac{43{,}560lbo}{fd[lb+w(l+b+w)]},$$

in which D is population per acre;

l is the average length of city block in the area;

b is the average breadth of city block in the area;

o is the average number of occupants to a residence lot;

f is the average number of front feet to a lot;

d is the average number of feet depth to a lot;

w is the average width of street.

Example: Given the average block as 400 ft. by 200 ft., streets 66 ft. wide, lots 50 ft. by 100 ft., and $o=6$. Then

$$D=\frac{43,560\times400\times200\times6}{50\times100[400\times200+66(400+200+66)]}=34 \text{ approximately.}$$

For a tenement district, each building on a lot 50 ft. by 90 ft. and containing 80 occupants (all average figures), $D=525$. (The density of the 17th Ward, New York City, in 1910 was 521.)

A block with lots 25 by 80 ft., seven occupants each, represents fairly well the most dense residence section of an average city of 25,000 to 50,000 population, giving $D=100$.

Actual densities, determined by census counts, are given in Tables Nos. 3, 4, 5, and 6, the three last showing also the rate of growth and illustrating the fact that, for a given district, density frequently reaches a maximum and then decreases. To assist in making similar calculations, the number of persons per dwelling and per family for several cities and the averages for each of the states are given in Tables Nos. 3 and 7, while Table No. 8 shows the tendency of size of family to decrease slightly.

For congested districts in Eastern cities, the following general averages are suggested in lieu of estimates based on specific figures for the place in question. West of the Mississippi valley and in the southern states possibly one-half of these maximums would be sufficient.

Until the city exceeds 25,000........	75 per acre
Between 25,000 and 50,000.........	100 per acre
Between 50,000 and 100,000........	150 per acre
Between 100,000 and 250,000.......	200 per acre
Between 250,000 and 500,000.......	250 per acre
Between 500,000 and 1,000,000......	350 per acre
Over 1,000,000.....................	500 per acre

These congested districts will ordinarily be found immediately surrounding the business center, and as this expands the congested districts will be pushed out and the population

Table No. 3

DENSITY OF POPULATION, CITIES OF 100,000 AND UP, 1890

Average for City and Densest Ward

(From the U. S. Census of 1890)

City	Per Acre		Persons per		
	Dwellings	Persons	Dwelling	Family	
Allegheny	3.25	20.66	6.36	5.06	
3d Ward	13.57	93.63	6.90	4.70	Business section; residents of good class.
10th Ward	0.55	2.88	5.22	5.02	Residences of mechanics on high ground.
Buffalo	1.49	10.65	6.86	4.97	
2d Ward	7.71	61.80	8.02	5.84	Mostly business; many hotels. and tenements.
12th Ward	0.21	1.34	6.33	5.81	Suburbs, good class of laborers; park, cemeteries, etc.
Chicago	1.24	10.70	8.60	4.99	
16th Ward	8.07	117.27	14.52	4.78	Polish and German artisans and laborers.
Cincinnati	2.26	20.02	8.87	4.67	
7th Ward	12.19	154.88	12.71	4.08	Centrally located; good class of Germans.
Cleveland	2.75	16.41	5.96	4.93	
10th Ward	8.95	50.31	5.62	4.85	Dense population of laborers in cheap tenements; 77 acres; contains cemetery.
Detroit	2.81	15.63	5.57	4.88	
3d Ward	5.24	29.97	5.72	4.61	Business and manufacturing; railroad yards; negroes, French, Italians, Poles and Germans.
Indianapolis	3.03	15.14	4.99	4.57	
23d Ward	7.69	37.22	4.84	4.64	No description given.
Jersey City	2.23	19.59	8.78	4.73	
3d District	13.75	151.01	10.98	4.79	Residents of moderate means.
Kansas City	1.11	6.39	5.74	4.96	
6th Ward	6.12	39.93	6.52	5.05	Mostly good class of residents. Some Italians and cheap tenements. Gasworks.
Louisville, Ky.	3.16	20.36	6.45	4.89	
3d Ward	6.01	40.04	6.66	4.49	Mostly Germans. Two breweries, market, woolen mill.
Milwaukee	3.02	18.79	6.22	4.92	
2d Ward	6.23	42.53	6.82	4.71	Mostly Germans; some Russians and negroes; brewery and small factories.
Minneapolis	0.76	4.98	6.52	5.01	
6th Ward	5.12	38.14	7.46	4.96	Mechanics, laborers, railroad employees; small section of cheap tenements.
Newark	2.05	15.99	7.81	4.67	
15th Ward	7.92	63.08	7.96	4.37	Irish tenements; a few Italians; a number of shoe factories.
New Orleans	1.81	10.20	5.63	4.98	
6th Ward	8.77	56.26	6.41	5.28	No description given.
New York	......	......	18.52	4.84	
10th Ward	13.60	523.6	38.5	4.90	
Pittsburgh	2.17	13.75	6.33	5.33	
7th Ward	19.02	137.26	7.22	5.21	Good class of residents.
St. Louis	1.55	11.50	7.41	4.92	
8th Ward	14.34	143.25	9.99	4.25	Tenements; Russians, Poles, negroes, Italians, Bohemians. Low class of prostitutes.
St. Paul	0.64	4.05	6.35	5.15	
4th Ward	5.14	42.57	8.28	5.76	Business, hotels, tenements; State Capitol, county courthouse, and prostitutes.

TABLE NO. 4

POPULATION PER ACRE IN NEW YORK CITY WARDS, 1860 TO 1910

Ward No.	1860	1870	1880	1890	1900	1910	Ward No.	1860	1870	1880	1890	1900	1910
1	118	94	116	72	62	64	13	308	312	353	429	599	664
2	31	16	20	11	18	11	14	292	276	314	293	355	399
3	39	39	38	40	19	20	15	139	139	161	128	122	154
4	265	286	253	215	236	257	16	129	138	149	141	151	160
5	133	102	94	74	49	34	17	220	228	317	312	395	521
6	310	245	234	269	214	210	18	128	118	148	141	136	139
7	202	226	253	290	451	516	19	22	58	107	158	174	198
8	215	195	196	171	159	181	20	152	170	194	190	202	165
9	138	148	170	169	185	215	21	119	138	162	153	147	152
10	273	377	432	524	653	604	22	40	47	73	101	124	137
11	304	328	351	384	505	696	23*	..	..	6.6	12.6	31	63
12	5.5	8.6	14.8	45	87	147	24*	..	..	1.6	2.5	5.3	13.8

* Bronx Borough, annexed between 1870 and 1880.

NOTE.—The wards are numbered consecutively (approximately) from the Battery northward. The 10th Ward is north of Grand street and east of Broadway. The 11th is along the East river south of 14th street, and the 13th is immediately south of it and the 17th immediately west. The section between Broadway and East river, 14th and Grand streets is probably the most densely populated of any city of the world.

TABLE NO. 5

POPULATION PER ACRE IN CHICAGO, BY WARDS, 1900 AND 1910

Ward	1900	1910	Per cent Change	Ward	1900	1910	Per cent Change
1*	30.4	20.5	−33	19	81.3	90.7	12
2	55.6	53.5	− 4	20	61.6	77.1	25
3	46.3	48.1	4	21*	52.4	49.9	− 5
4	51.1	51.7	1	22*	54.7	51.4	− 6
5	21.5	25.5	19	23*	57.0	55.4	− 3
6	36.1	47.0	30	24	38.8	46.8	21
7	13.2	21.7	64	25	13.1	24.0	83
8	3.6	4.8	33	26	9.3	16.1	72
9	71.8	70.0	− 3	27	2.1	5.5	156
10	74.3	80.8	9	28	31.6	38.7	23
11	51.4	51.5	0.1	29	8.0	12.8	60
12	17.4	31.8	82	30	41.2	40.1	− 3
13	27.1	36.7	36	31	4.5	7.0	54
14	38.5	41.2	7	32	4.7	8.3	75
15	43.9	53.9	23	33	2.9	5.5	91
16	72.8	81.5	12	34	8.3	21.2	155
17	91.9	97.4	6	35	5.7	12.0	112
18	49.1	40.8	−17	Averages	13.9	17.9	28.6

* Lake front business section.

TABLE NO. 6

POPULATION PER ACRE IN BOSTON, BY WARDS, 1895 TO 1910

Ward	1895	1900	1905	1910
1	17.7	19.2	21.4	24.9
2	60.5	64.2	72.6	80.7
3	42.0	43.9	44.7	46.2
4	44.4	44.0	41.5	44.1
5	62.7	62.0	61.7	61.9
6	95.1	104.3	102.3	122.0
7	43.0	37.5	39.5	37.9
8*	135.0	168.5	180.4	190.0
9	124.5	132.0	118.9	141.5
10	57.2	56.2	60.5	64.3
11	30.0	29.1	33.7	41.4
12	92.0	100.6	92.5	103.4
13	40.7	37.4	35.4	35.3
14	47.4	53.0	54.7	58.2
15	67.2	71.1	73.3	76.6
16	28.9	35.5	38.9	45.6
17	45.8	54.4	52.8	57.4
18	98.6	101.9	100.6	103.3
19	29.4	35.7	38.4	41.7
20†	12.6	19.0	24.4	32.5
21†	30.1	37.3	41.5	50.5
22†	29.3	33.7	36.5	38.1
23†	2.4	3.1	3.5	4.0
24	5.6	8.3	9.7	11.6
25	5.5	7.0	8.0	9.7
Av. Density	20.0	22.7	24.1	27.1

* Low rental tenement houses. † Desirable residential sections.

of those invaded by business will begin to decrease. For transportation and manufacturing districts, the population may be given a nominal density figure of 10 for yards, factory grounds, etc. The density of other residence districts will generally vary with their distance from the business center, although it will be considerably affected by the location of rapid transit lines, topography as determining desirability and cost of constructing residences, effect upon the city's growth of suburbs or neighboring cities, etc. (For a more full discussion of the subject of forecasting population, see chapter I of "Municipal Engineering Practice.")

TABLE NO. 7

PERSONS PER FAMILY AND PER DWELLING IN 1900 AND 1910

POPULATION	2,500 to 25,000		25,000 to 100,000				MORE THAN 100,000			
	1900		1900		1910		1900		1910	
State	Per Family.	Per Dwelling.	Per Family.	Per Dwelling.	Per Family.	Per Dwelling.	Per Family.	Per Dwelling.	Per Family.	Per Dwelling.
New England										
Maine	4.4	5.1	4.4	6.1	4.6	7.2				
New Hampshire	4.3	4.9	4.9	7.7	4.7	6.8				
Vermont	4.3	5.1								
Massachusetts	4.7	5.5	4.5	6.4	4.7	7.1	4.9	8.8	4.8	8.9
Rhode Island	4.6	5.7	4.7	7.6	4.8	7.1	4.5	6.9	4.6	7.8
Connecticut	4.5	5.3	4.7	7.5	4.7	7.8	4.6	7.1	4.6	7.2
Middle Atlantic										
New York	4.3	5.0	4.6	6.6	4.4	6.3	4.7	11.7	4.6*	12.7*
New Jersey	4.6	5.4	4.7	6.3	4.7	8.0	4.5	8.2	4.6	9.0
Pennsylvania	4.7	5.0	4.7	4.9	4.7	5.0	4.9	5.6	4.8	5.7
East North Central										
Ohio	4.2	4.8	4.4	4.9	4.2	4.7	4.5	6.2	4.3	5.7
Indiana	4.2	4.5	4.5	4.9	4.3	4.6	4.3	4.7	4.0	4.4
Illinois	4.4	4.8	4.6	5.1	4.3	4.8	4.7	8.8	4.6	8.9
Michigan	4.5	4.9	4.3	4.7	4.2	4.6	4.7	5.5	4.4	5.4
Wisconsin	4.6	5.0	4.8	5.3	4.7	5.3	4.8	6.2	4.6	6.2
West North Central										
Minnesota	5.0	5.3	5.3	6.5	5.3	6.6	5.0	6.5	5.0	6.5
Iowa	4.3	4.4	4.5	5.0	4.4	4.7				
Missouri	4.4	4.7	4.5	4.8	4.2	4.5	4.5	6.7	4.3	5.2
North Dakota	4.9	5.6								
South Dakota	4.7	5.1								
Nebraska	4.5	4.7	5.2	5.9	4.6	5.0	4.9	5.7	4.7	5.2
Kansas	4.3	4.5	4.2	4.7	4.1	4.4				
South Atlantic										
Delaware	4.3	4.3	4.7	4.9	4.7	5.1				
Maryland	4.6	4.8	...	...	...	...	4.8	5.7	4.7	5.5
Dist. of Columbia	...	...	...	...	...	...	4.9	5.6	4.6	5.7
Virginia	4.7	5.3	4.7	6.0	4.7	5.4	...	...	4.7	5.7
W. Virginia	4.8	5.1	4.5	5.5	4.5	5.3				
N. Carolina	4.5	5.1	...	...	4.4	4.8				
S. Carolina	4.8	5.2	4.0	6.4	4.2	5.7				
Georgia	4.3	4.9	4.2	5.2	4.0	4.6	...	...	4.3	5.1
Florida	4.4	4.7	3.9	4.5	4.5	4.8				
East South Central										
Kentucky	4.5	4.9	4.5	5.5	4.1	5.1	4.6	5.9	4.3	5.4
Tennessee	4.7	5.2	4.5	5.3	4.4	5.1	4.6	5.6	4.2	4.9
Alabama	4.4	4.8	4.3	5.2	4.1	4.6	...	...	4.3	4.9
Mississippi	4.4	4.9								
West South Central										
Arkansas	4.4	4.7	4.6	5.2	4.5	4.8				
Louisiana	4.5	4.8	...	...	4.2	4.6	4.6	5.4	4.6	5.0
Oklahoma	4.5	4.7	...	...	4.6	5.3				
Texas	4.7	4.9	4.7	5.1	4.6	5.0				
Mountain										
Montana	4.8	5.1	4.7	5.4	4.6	5.2				
Idaho	4.3	4.6								
Wyoming	5.2	5.5								
Colorado	4.2	4.5	4.5	4.9	4.4	4.6	4.3	4.9	4.2	4.8
New Mexico	4.0	4.4								
Arizona	4.4	4.6								
Utah	4.9	5.1	4.5	5.2	4.6	5.2				
Nevada	3.8	3.9								
Pacific										
Washington	4.6	4.8	5.1	6.1	4.6	5.2	...	...	4.6	5.3
Oregon	4.3	4.7	5.4	6.2	...	...	...	...	4.9	5.5
California	4.2	4.4	4.4	4.8	4.0	4.4	4.6	5.9	4.3	5.3

* 4.5 and 6.2 omitting New York City.

TABLE No. 8

AVERAGE SIZES OF FAMILIES, 1850 TO 1910

	1850	1860	1870	1880	1890	1900	1910
United States	5.55	5.3	5.1	5.0	4.9	4.7	4.5
N. Atlantic Division	5.45	...	...	4.8*	4.7	4.6	4.5
N. Central Division	5.69	...	...	5.1	4.9	4.6	4.4
Western Division	4.18	...	...	4.7	4.9*	4.4	4.5
Virginia	...	...	5.3	5.4†	5.4†	5.1	4.9
N. Carolina	...	...	5.2	5.2†	5.3†	5.1	5.0
New York City	...	...	...	5.0	4.8	4.7	4.7
Brooklyn	...	...	...	4.9	4.7	4.6	4.6
Philadelphia	...	..	...	5.1	5.1	4.9	4.7
St. Louis	...	...	...	5.4	4.9	4.6	4.4
Chicago	...	...	...	5.2	5.0	4.7	4.6

* Increase in female population. † Negro population.

MAXIMUM RATES OF SEWAGE

For any given area, the average amount of domestic sewage to be provided for is estimated by multiplying the estimated maximum population of that area by the average per capita domestic consumption of water. Sewers must, however, have capacity for the maximum flow at any minute of the year, which of course will be at a rate greater than the average for the year. The consumption may run 20 to 30 per cent above the yearly average for several consecutive weeks, 50 per cent higher during several consecutive days, and 100 per cent higher during occasional hours. Sewer gaugings at Des Moines, Ia., are shown graphically in Fig. 3; curves for a number of commercial, an industrial and two residential districts of Cincinnati, in Fig. 4, give the percentage that the flow for each hour of the day was of the average for the entire day. It appears from these that the maximum domestic sewage rate may be assumed as 70 to 100 per cent greater than the daily average; this including seepage in both average and maximum. Allowing for water supplied to residential sections that does not reach the sewer, we may assume that the maximum domestic sewage flow is 75 per cent greater than the average domestic water supply.

This is for the combined flow from several thousand people. The flow from a single household comes in short flushes at considerable intervals. While the total daily flow may average 500 gallons, the discharge of laundry tubs may for two or three minutes equal 10 to 20 gallons per minute, or at the rate of 14,400 to 28,800 gallons per day, or about thirty to sixty times the average rate; while during only one hundred to two hundred minutes out of the day would there be any flow at all from a single house into the sewer. With one hundred houses connected to a sewer (say 600 population), the probability of more than two or three of these flushes reaching a given point in the sewer at the same time is remote, and the flow would probably be continuous (except at night) but still not uniform, and the maximum might be expected to be 200 per cent or more of the

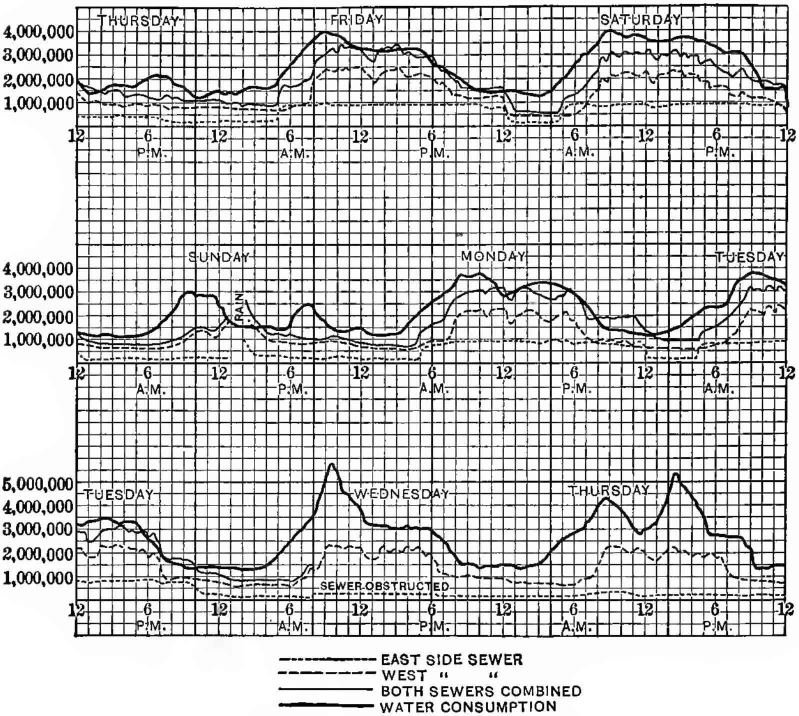

FIG. 3.—GAUGINGS AT SEWER OUTLETS AT DES MOINES.

average. It will probably be safe practice to allow for fifty times the average flow where only two or three houses are tributary; double the average where the tributary population number 1000, and 75 per cent more than the average where they number 3000 or more.

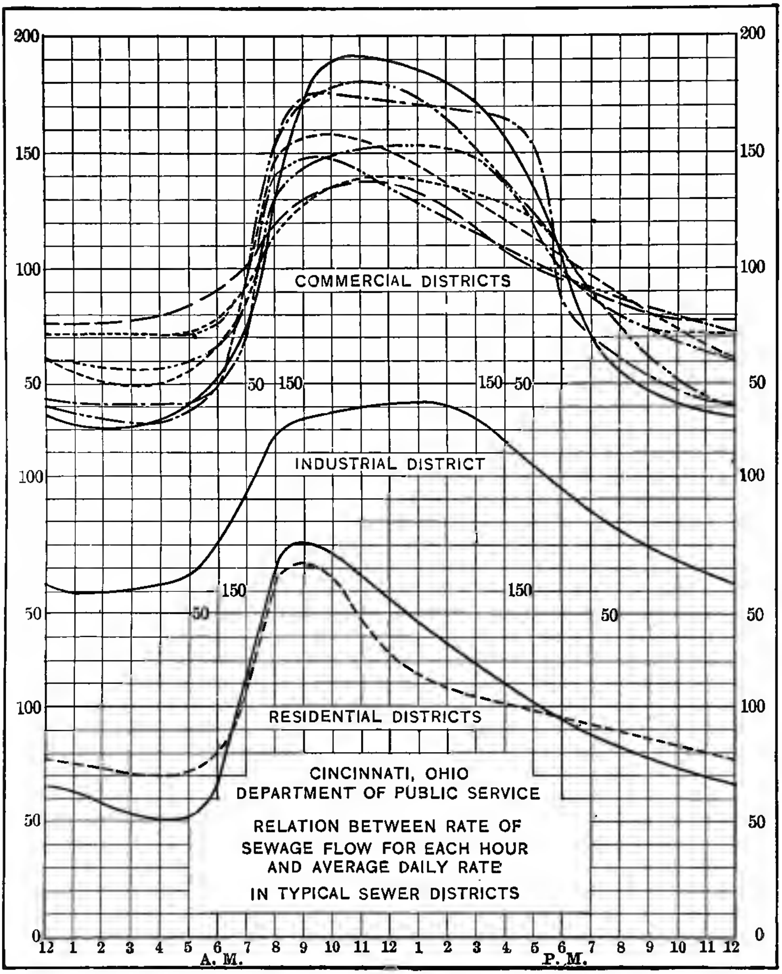

FIG. 4.—VARIATIONS IN SEWAGE RATES IN CINCINNATI.

Each line represents the record of a single district in Cincinnati, eight being commercial districts, one industrial, and two residential.

If, for areas containing 3000 or more population, we assume a yearly average of 100 gallons per capita per day, this gives a maximum rate of 175 gallons per day, which equals .1215 gallon per minute, or .00027 cubic foot per second. Therefore, if we use these assumptions in our estimate, the estimated maximum population of a certain area times .00027 will give the maximum number of cubic feet per second of sewage to be provided for in that area.

Water used in flushing separate sewers should be included under domestic sewage, and if much water is to be so employed it is necessary to provide for it in a sewage treatment plant. This is not necessary in designing the sewers, however, since the purpose of such water is to gorge the sewer for as great a distance as possible. Where automatic flush tanks are used, it is not generally advantageous that they should discharge more than 300 or 400 gallons each per twenty-four hours.

ART. 7. COMMERCIAL AND INDUSTRIAL SEWAGE

In the business and manufacturing sections of a city, the amount of domestic sewage reaching the separate sewers is comparatively small, but that of the commercial and industrial sewage may be considerable, especially that coming from manufacturing plants. The amount of sewage coming from stores, office buildings and other non-manufacturing properties will generally be a function of the number of persons occupying the premises during business hours. Figures for the amount per capita or the number of people to be anticipated are very few In Table No. 1 it is seen that in the cities entered therein the industrial and commercial consumption of water combined amounted to about 45 per cent of the total consumption, but the commercial was less than 15 per cent and apparently was between the 5 and 15 gallons per capita of the total population of the city.

In estimating the amount of commercial sewage per unit area, we may employ the method of estimating population and average amount of sewage per capita. An office building may have an occupant for each 50 to 200 square feet on each floor. (This including allowances for halls, elevators, etc. New York's labor law requires floor area of 32 square feet for each employee in fire-proof buildings and 36 square feet in non-fire-proof buildings.) The total floor area of a building will be the ground area times the number of floors and the latter will depend upon the size of the city, value of plant, and local laws and customs. Some of the larger cities have buildings of from 15 to 40 stories. One of the latter covering an area of ½ acre may contain by day more persons than the population of a small city, reaching possible 5000 per acre. In a commercial city it may easily be that 30 per cent of the total population is occupied during the day in the business district.

The water consumption of such day occupants is not nearly so great as in their residences, and the maximum rate of 20 gallons per day for each individual will ordinarily be sufficient allowance for use of water by water-closet flushes, wash basins, etc. Even this low average will give very considerable quantities of sewage to be provided for from office buildings or those containing other industries where no water is employed in the manufacturing, where the occupants average one for each 50 square feet of floor space and the stories run up to 10 or more. In the Cincinnati plans it was estimated that the maximum rate of sewage discharge in a commercial district varied from 12,000 to 77,700 gallons per acre per day, depending upon the extent of development. In New York the consumption in hotels was found to average 526 gallons per day per 1000 sq. ft. of floor area; that in office and manufacturing buildings averaged 250; and that in tenement and apartment houses averaged 230 gallons.

The amount of sewage from manufacturing plants varies so widely with the nature of the manufacturing process that no general rule can be given for even an approximate estimate. Some industries use and discharge through the sewer or some other outlet enormous quantities of water, these including breweries and paper mills, while others use practically no water whatever for manufacturing processes. If it is known or can be foreseen what kind of manufacturing will be undertaken on a given territory, provision for its waste water can be made in the sewers. Otherwise, possibly the only practicable plan is to provide such capacity as would be called for by residence occupancy; then, if it develops in the future that this capacity does not suffice for manufacturing wastes, either the industries must themselves be required to provide for their own waste water, or a supplementary sewer or system of sewers can then be provided.

ART. 8. AMOUNT OF SEEPAGE

If the soil is continuously or occasionally wet at the depth to which the sewer is to be laid (and this includes a larger proportion of localities than most persons realize, since, in most towns, previous to constructing the sewer system, few excavations of any kind have been carried to this depth), an allowance must be made for ground water entering the sewer through its joints or walls. Sewers can be made absolutely tight by using iron pipe, and practically so by the use of special jointing material and special pains in the laying of vitrified or cement pipe; but the majority of sewers are laid with the ordinary Portland cement joint; which, as ordinarily made, is more or less porous. The use of iron pipe or special jointing material adds to the cost, but it is coming to be appreciated that, where ground water is anticipated, their use results in ultimate economy. Where Portland cement joints are used in wet ground the infiltration may with care be kept down to 1 cubic foot per second for each 50 to 100 miles of sewer; but under extreme conditions the seepage has been known to more than equal the entire capacity of the sewer. (The average leakage of 137 miles of 8-inch to 36-inch sewer in Boston was found to be .06 cubic foot per second per mile, there being double this seepage in the spring.) Some engineers have estimated seepage as a certain percentage of the domestic sewage, but there seems to be no logical excuse for this, but the seepage would seem naturally to vary with the number of joints and to a certain extent with the circumference of the pipe. For this reason, 3-foot lengths of pipe should give but two-thirds as much seepage as 2-foot lengths (assuming sufficient ground water to supply all that the leaks will take). In some cases large amounts of ground water have entered the sewer through branches left for house connections which were not sealed against the entrance of ground water.

In general, the allowance to be made for seepage should be governed by decision as to the methods and material decided upon for making the sewer joints and the probability of the ground water plane being above the level of the sewer.

ART. 9. MAXIMUM TOTAL RATES

The total amount of sewage flowing in a separate sewer is the sum of the domestic, commercial, and industrial sewage and ground water seepage. The last is continuous and ordinarily varies slowly with the rise and fall of the ground water. Domestic sewage reaches a minimum between twelve and three o'clock at night (depending upon the local habits of the people), and remains very small, except for the water escaping through leaking house fixtures, until about five or six o'clock in the morning, when it rises rapidly and continues high for about twelve hours, then falls at a more or less uniform rate until a minimum is again reached. Commercial and industrial sewage is ordinarily zero from closing-down time in the evening until the beginning of work the next morning, except for leaking fixtures and unless night work is carried on. During the day the amount of this sewage flowing in the trunk sewers may be nearly uniform or may be subject to sudden considerable fluctuations at one or two or more periods, depending upon the nature of the manufacturing process.

The sewer must, of course, be of ample capacity to carry the maximum rate of flow due to any or all of these four classes of sewage that reach it. Concerning commercial and domestic sewage, it is a common plan to assume that the maximum rate during any one day is 75 per cent greater than the average.

As to the manufacturing waste waters, the same allowance should be sufficient for them also, and if it is found that discharge of an entire daily contribution in one or two flushes is practiced and is objectionable, it may be made compulsory that this discharge be continued throughout the day by providing storage tanks or otherwise.

We would therefore have the maximum capacity of sewer to be provided equal to 175 per cent of the maximum daily rate of combined domestic and industrial sewage, together with the average daily rate of ground water infiltration. As a further safeguard, a factor of safety is ordinarily employed of 2 for the smallest sewers and of $1\frac{1}{2}$ for the larger sewers; while for the trunk sewers the factor may be reduced to $1\frac{1}{4}$. That is, the actual capacity when running full is made from 2 to $1\frac{1}{4}$ times the amount calculated by the above assumptions and estimates. This allows for errors in assumptions as to future growth in population, use made of given districts, etc. Estimates of small districts are more liable to error than is that of the large district that embraces all of them, since in the latter the errors may balance, or that of one small district will be a smaller percentage of the total sewage flow than of its own flow only.

CHAPTER III

AMOUNT OF STORM SEWAGE

Art. 10. Rates of Rainfall

The amount of storm-water reaching a given sewer depends upon the rate of rainfall, the time during which this rate is continued, the proportion of the rainfall which flows off, and the time taken by a raindrop after falling to reach the point in the sewer system under consideration. This last depends on the shape, extent, and nature of the surface over which this raindrop must flow and the length and grade of the sewer through which it must pass after having entered it. As in the case of separate sewers, there may be more or less infiltration of ground water into storm sewers, but this is generally so small in amount compared to the maximum amount of storm-water to be handled that it may be disregarded.

It is apparent that the rate at which water falling as rain reaches the sewer depends to a greater or less degree on the rates of rainfall from minute to minute and not upon the total amount that flows during a day or even an hour. Records giving the amount of rainfall per day are therefore valueless to the sewerage engineer, but he needs to know the maximum rate for shorter intervals, such as five or ten minutes. Gauges are in use which automatically register the rate of rainfall continuously or at intervals of about five minutes, and such gauges are now found in most of the large cities, operated either by a city department or by the United States Weather Bureau.

Intelligent designing of a sewerage system for a given city requires a knowledge of the maximum rainfall rates to be expected in the city in question for intervals of not more than five or ten minutes. As will be explained later, what is needed is not simply the maximum rate for any five-minute period, but a record of a considerable number of consecutive five-minute periods both before and after the occurrence of a maximum or very high rate. The engineer should obtain all available records of his own locality from the United States Weather Bureau or other reliable source; and in addition should study all similar records available that apply to the section of country in which lies the city in question and where the conditions affecting intensity of rainfall are similar. Even then there may occur at any time in the future a rainfall greater than any to be found recorded; but the courts have held and common sense affirms that neither the engineer nor the city can be held responsible either legally or morally for not anticipating such an event.

A common method of utilizing information collected as suggested above is to plot on cross-section paper the several maximum rates recorded for periods of 5, 10, 15, etc., minutes up to two or three hours; the rates being used as ordinates and the lengths of periods as abscissas; then draw a more or less regular curve which shall as nearly as possible pass through the maximum points. It may then be assumed that this curve will represent the maximum intensity of rainfall for which the engineer is justified in designing the sewer.

A city may not be justified in spending the money required for constructing a sewer capable of carrying the run-off from the greatest storm of which there is record, as a considerable percentage of this sum could be saved by providing the less capacity which would suffice for all storms except those occasional cloudbursts which may occur at intervals of ten or twenty years. It has been calculated in some instances that the amount of money so saved, if placed at interest, would provide sufficient funds to pay for all damage done by the very infrequent storms of excessive intensity which such a sewer would not remove promptly. On the other hand, the loss resulting from flooding of streets and cellars by water rendered more or less foul by the dirt washed from the street surface may be very considerable; goods may be damaged, business interrupted, building foundations weakened, and health of citizens impaired by dampness after the floods have withdrawn. The decision as to whether or not to provide capacity for these unusual storms must be made for each case by the engineer or the city authorities as their judgments dictate; but probably in nine cases out of ten the wisest decision would be not to endeavor to provide for very infrequent storms of unusual intensity—say those occurring less often than once in ten years.

If it is decided that storms occurring less frequently than once in ten years may be disregarded, plot as above the maximum rate for each year for each record for 5-, 10-, etc., minute periods; add together the durations, in years, of the several records, divide this by ten, and the quotient will give the number of points plotted for each precipitation period that may be disregarded. This number of highest rates having been eliminated, a curve can then be drawn that will embrace all of the remaining high rates. (See Fig. 5.)

A number of diagrams showing records of this kind for several sections of the country, and curves embracing the maximum rates for which formulas have been calculated, have been prepared and made public from time to time by a number of engineers. Some of these formulas are as follows:

For Boston, Mass. (by Sherman):

Maximum (once in 8 or 10 years), $r=\frac{38.64}{t^{0.687}}$. Ordinary, $r=\frac{25.12}{t^{0.687}}$.

For Philadelphia, Pa. (by Webster):

Maximum recorded, $r=\frac{30.585}{t^{0.5263}}$. Extraordinary, $r=\frac{18}{t^{0.5}}$. Ordinary storm, $r=\frac{12}{t^{0.6}}$.

For the United States east of the Rocky Mountains (by Talbot):

Maximum (not exceeded more than once a century), $r=\frac{360}{t+30}$. Ordinary, $r=\frac{105}{t+15}$.

Vicinity of New York City (by Kuichling), heavy rainfalls of uniform intensity: $r=\frac{120}{t+20}$.

For San Francisco (by Le Conte):

Maximum recorded, $r=\frac{7}{t^{0.6}}$.

In each of the above, r is intensity of rainfall in inches per hour and t is the minutes of time for which this intensity was the average.

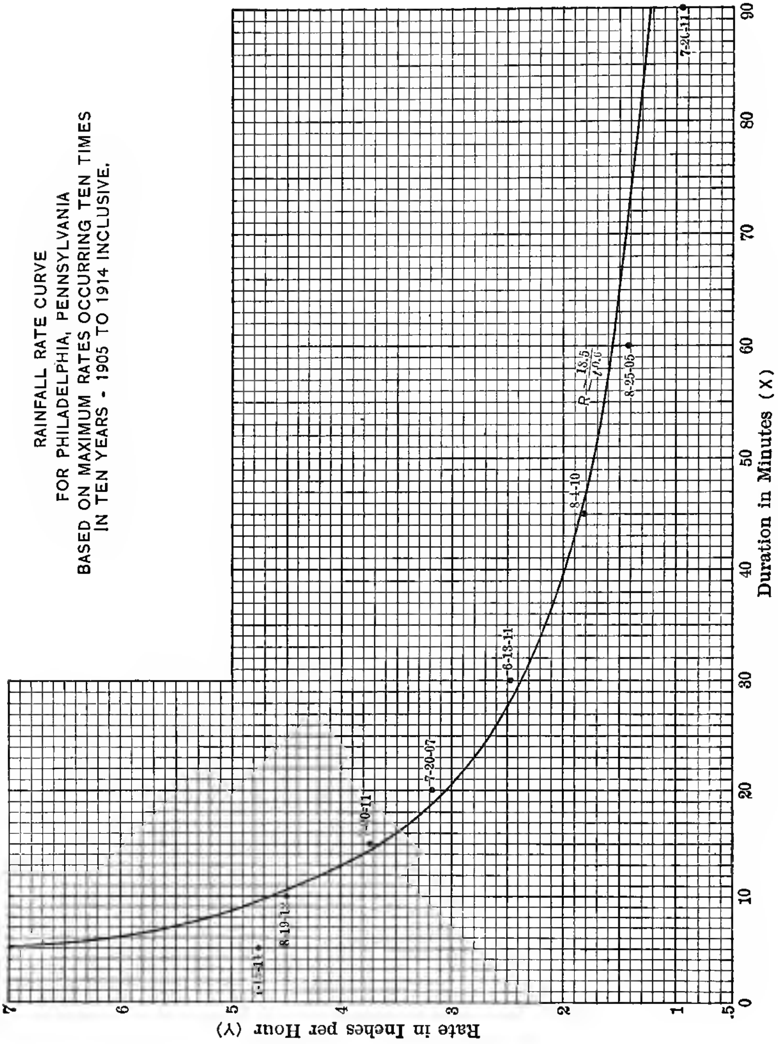

FIG. 5.—PHILADELPHIA RAINFALL DATA AND CURVE.
Each dot represents a rate (at the date indicated) that was equaled or exceeded not more than ten times during the period.

Table No. 9 gives a number of the maximum rates of rainfall recorded; and in the last column, for comparison, the rates corresponding to Webster's "extraordinary," which might be adopted as reasonable for sewer design.

TABLE No. 9

RECORDS OF SOME SEVERE STORMS *

Location.	Date.	Depth in Inches.	Duration.		Average Rate per Hr.	Webster's "Extraordinary."
			Hrs.	Min.		
Albany, N. Y.	July 10. 1876.	1.12	0	10	6.72	5.7
Alpena, Mich	September 20, 1884	1.05	0	11	5.73	5.4
Amanda, Ia.	July 31, 1878.	1.56	0	15	6.24	4.7
Atlanta, Ga.	April 24, 1889	1.12	0	10	6.72	5.7
Atlanta, Ga.	July 23, 1898.	4.30	0	51	5.06	2.5
Berne, Ind.	August 16, 1913	2.55	0	30	5.10	3.3
Biscayne, Fla	March 28, 1874.	4.10	0	30	8.20	3.3
Brandywine Hundred, Pa.	August 5, 1843	10.00	2	0	5.00	1.6
Cambridge, Ohio	July 16, 1914.	7.09	1	30	4.73	1.9
Catskill, N. Y.	July 26, 1819	18.00	7	30	2.40	0.85
Chicago, Ill.	May 25, 1896	1.24	0	15	4.96	4.7
Collinsville, Ind.	May 23, 1888	1.70	0	12	8.50	5.2
Concord, Pa	August 5, 1843	16.00	3	0	5.33	1.3
Embarrass, Wis	May 28, 1881	2.30	0	15	9.20	4.7
Flatbush, L. I.	August 22, 1843	9.00	8	0	1.12	0.82
Ft. Leavenworth, Kan	July 21, 1887.	1.90	0	20	5.70	4.0
Ft. McPherson, Neb	May 27, 1868	1.50	0	5	18.00	8.0
Ft. Randall, S. D.	May 28, 1873	1.56	0	15	6.24	4.7
Ft. Scott, Kan	October 2, 1881.	1.80	0	20	5.40	4.0
Galveston, Tex.	June 4, 1871	3.95	0	14	16.93	4.8
Huron, S. D	July 26, 1885.	1.30	0	10	7.80	5.7
Indianapolis, Ind.	July 12, 1876.	2.40	0	25	5.76	3.6
Jewell, Md	July 27, 1897.	14.75	18	0	0.82	0.55
Lebanon, Pa.	July 10, 1914.	5.00	2	0	2.50	1.6
Long Branch, N. J.	July 14, 1912.	0.80	0	5	9.60	8.0
Newton, Pa.	August 5, 1843	5.50	0	40	8.25	2.8
Newton, Pa.	August 5, 1843	13.00	3	0	4.33	1.3
New York, N. Y.	May 22, 1881	1.15	0	10	6.90	5.7
New York, N. Y.	November 18, 1886	0.25	0	2	7.50	12.7
Osage, Ia.	August 26, 1881	1.40	0	15	5.60	4.7
Ottawa, Ohio	August 21, 1913	2.28	0	40	3.42	2.8
Palmetto, Nev	August 7, 1890	8.80	1	0	8.80	2.3
Paterson, N. J.	July 13, 1880.	1.50	0	8	11.25	6.4
Philadelphia, Pa.	September 12, 1862	9.00	5	0	1.80	1.0
Portsmouth, Ohio	June 22, 1851	1.75	0	15	7.00	4.7
Sandusky, Ohio	July 11, 1879.	2.25	0	15	9.00	4.7
San Francisco, Cal.	December 20–21, 1866	7.76	8	45	0.89	0.79
St. Louis, Mo.	August 15, 1848	5.05	1	0	5.05	2.3
Stroudsburg, Pa.	August 1, 1913	7.50	3	50	1.96	1.2
Tridelphia, W. Va.	July 19, 1888.	6.90	0	55	7.53	2.4
Washington, D. C.	July 26, 1885.	0.96	0	6	9.60	7.3
Worthington, Minn.	August, 20, 1913	8.00	11	0	0.73	0.70

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* By C. P. Birkinbine, with last column added by author.

The records seem to show, where any information on the subject is given, that the maximum intensity usually lasts but a few minutes, seldom more than ten; that it sometimes occurs at the beginning of a storm, sometimes at the middle or end of it, quite a number of storms stopping within ten or twenty minutes after the maximum rate is attained.

It is to be borne in mind that a rate for any given time—say thirty minutes—is the average for that time, during which there may have been a maximum rate for five or ten minutes several times this average. For use in calculating run-off from small areas, actual rainfall for each of a number of successive minutes is desirable; but for general purposes the amount is usually expressed as the rate per hour. One advantage of this is that one inch per hour on an acre equals almost exactly one cubic foot per second.

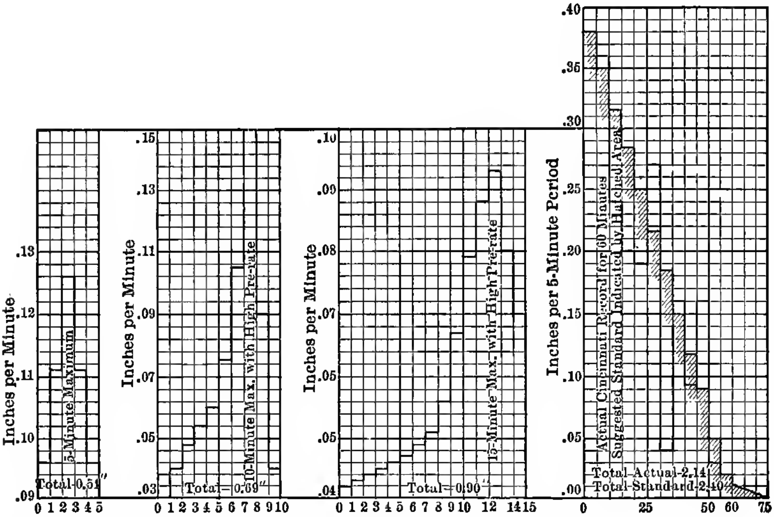


Fig. 6.—Diagram Showing Actual Rates of Individual Rainfalls. From Cincinnati Records.

Each shows the rates for successive five-minute periods of the storm that gave the maximum total for the period stated.

Few data are available showing how large an area is experiencing a maximum rate at a given moment. Frequently,

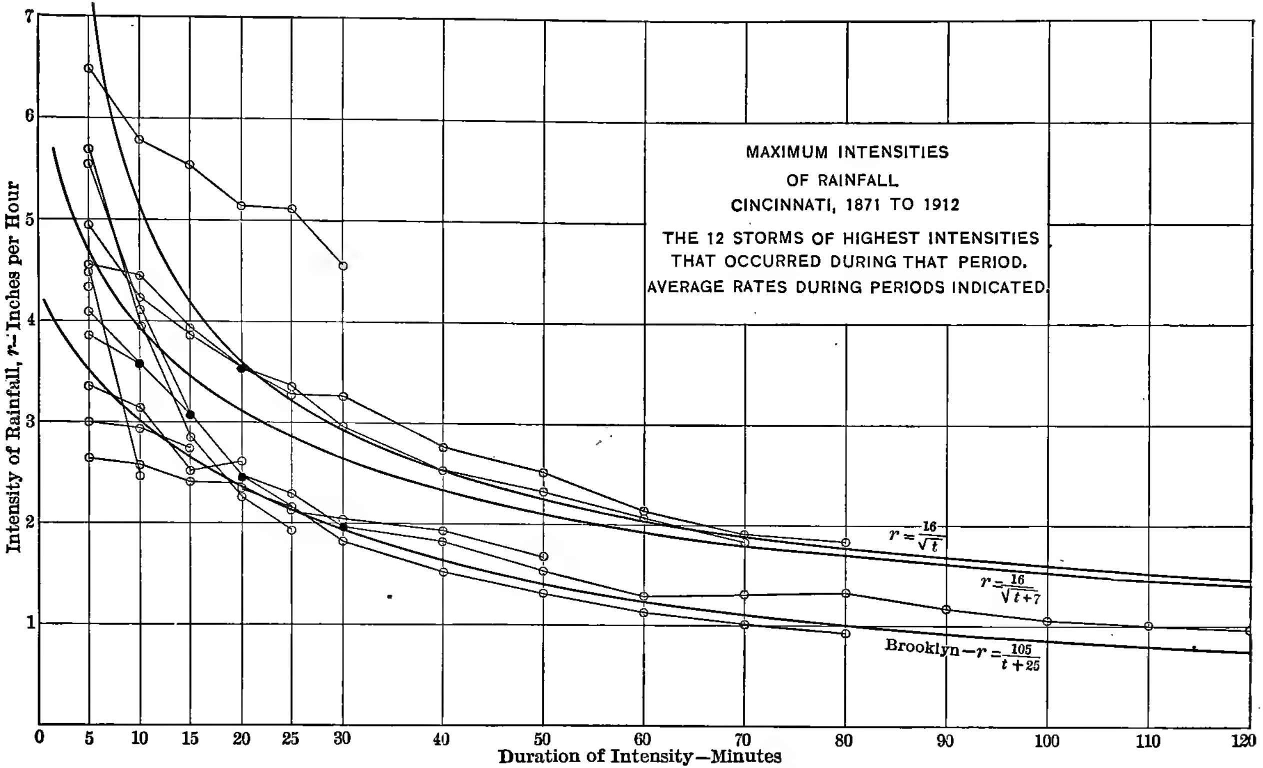


FIG. 7.—MAXIMUM RAINFALL CURVES AT CINCINNATI; WITH SUGGESTED CURVES FOR USE IN DESIGNING.

if not generally, a heavy fall occurs over only a limited area at a given moment, but the area of heavy precipitation progresses continuously, frequently up or down a valley. As will be shown later, if this progression is from the upper limits of the storm sewer system towards the outlet, the tendency to gorge the sewer is increased; while if the progression is in the opposite direction, it diminishes the maximum flow in the sewer.

ART. 11. RUN-OFF TO SEWERS

If intense rainfalls continued at a uniform rate for considerable periods of time and if all of the rain falling flowed directly into sewers, calculating the size of sewer required would be comparatively simple, given an assumed maximum rate of rainfall to be provided for. Neither of these conditions exists, however. Rainfalls at high rates ordinarily vary from minute to minute, the maximum rate usually lasts for less than ten minutes, and the area covered by this maximum rate frequently is quite limited in extent and changes in position continuously. Also, in no case does all of the rain flowing upon a given city area reach the sewers, either directly or ultimately; and that which does reach them occupies a greater or less period of time in doing so.

Percentage Reaching Sewers. Any ground in the city area absorbs rainfall reaching it to a greater or less extent. If it be porous sand, it may absorb practically all of the rainfall except that, if the storm be of long duration at a comparatively high rate of fall, the pores of the sand may become filled and additional rain reach the surface more rapidly than it can be transmitted to the underlying soil, in which case part of the succeeding rainfall will flow off over the surface. The more compact the soil, the less the time it will take to fill the pores and the less the rate at which they can transmit water to the lower strata; consequently, the lighter will be the rainfall that will produce a surface run-off and the shorter the storm which will be required to completely fill the pores. Tin roofs and some other kinds will discharge all of the rain reaching them, although some may be retained in gutters by deposits of leaves, be lost to the ground below by the over-flowing of gutters, leaking of leaders, etc. Shingle roofs, and to a less degree, slate roofs, will absorb a small amount of water at the beginning of a storm, but in a short time will discharge all the rain falling upon them. The same is true of concrete pavements in yards, sidewalks and roadways. Macadam roadways, when not oiled, may be classed in this respect with clay or other non-porous soil. A brick pavement with cement joints will act in much the same way as a shingle roof. Asphalt and other pavements in which the surface is a continuous layer of bitumen will shed practically all of the water reaching it, retaining only such small amounts as may collect in depressions in the surface and be absorbed by the dust and dirt thereon. In addition, there is to be considered the fact that under certain atmospheric conditions an appreciable amount of rainfall that rebounds as spray when the drops strike the surface is taken up as vapor by the atmosphere.

From the above it is evident that the amount of water running off from a surface depends largely upon the porosity of that surface and of the material underlying it; also upon how long a time the rainfall has continued prior to the moment under consideration. In a closely built-up business section in which the entire area of the district is covered with tin or other impervious roofs of buildings, paved yards, streets and sidewalks, the amount of rainfall ultimately reaching the sewer may amount to 90 per cent or even more of the total. On the other hand, in a residence section where the houses are scattered, the surrounding private property is of uncovered porous soil, the sidewalks contain only narrow strips of concrete or perhaps no non-porous paving whatever, and the roadways are either natural soil or comparatively porous macadam, the percentage of rain reaching the sewer may be very much less, being only 5 or 10 per cent for light rainfalls and possibly not more than 30 or 40 per cent for the heaviest down-pours.

Sufficient data are not available for making accurate estimates of the amount of run-off from areas of different characters, except possibly under the conditions described above as pertaining to a business district. It may generally be assumed as an approximation, however, that at the time of the heaviest down-pour (assuming this to follow a rainfall which has already filled the pores of the soil), 95 per cent of the rainfall upon the roof area will be discharged into the sewer, from 75 to 100 per cent of that falling on the roadway (less if this be sand with no surface treatment) and from 15 to 50 per cent from the natural earth surface in yards, parks, etc., depending upon the nature of the soil.

In making such estimate, it must constantly be borne in mind that the estimate should be based on future conditions, so far as they can be foreseen, rather than present ones. If it is probable that within the economic period of design (generally thirty to fifty years), the area under consideration will develop as a business section, although it is now a residential one, the run-off should be calculated for such future conditions. Several of the older cities of this country have suffered damages amounting to hundreds of thousands of dollars and have had to rebuild their sewers at the cost of millions because of the rapid development of large portions of their area from residential sections to business ones entirely covered with buildings and impervious pavements and yard surfaces.

A study of rainfall data of Washington, D. C., Savannah and St. Louis by Prof. A. J. Henry of the U. S. Weather Bureau showed that the maximum intensity of rainfall occurred within five minutes after the beginning of the storm in 17 per cent of the storms in Washington, 10 per cent in Savannah, and 31 per cent in St. Louis. In 10 per cent of the storms in each city, however, the maximum intensity was preceded by forty minutes or more of rainfall in Washington, forty-three minutes in Savannah, and forty-two minutes in St. Louis; and from 2 per cent of the storms in St. Louis to 6 per cent in Washington were preceded by nearly or quite an hour of rainfall. Since the longer the preceding rainfall the greater the percentage of run-off, and since sewers should be designed for the maximum run-off from at least 90 to 98 per cent of all storms, a saturation of surface and filling of inequalities caused by an hour of rainfall should generally be assumed. W. W. Horner of St. Louis, from extensive investigations in that city, concluded that in that time the maximum run-off from impervious surfaces would be reached, and 83 per cent of the maximum from pervious areas; the run-off at the end of the hour from the impervious surfaces being 95 per cent of the rainfall, and that from the average previous areas in a residence district being 50 per cent.

Emil Kuichling in 1909 estimated the "factors of imperviousness" (ratios of run-off to rainfall) at times of maximum discharge, as follows:

For roof surfaces assumed to be watertight........	$f=0.70$ to 0.95
For asphalt pavements in good order..............	0.85 to 0.90
For stone, brick, and wooden block pavements with tightly cemented joints........................	0.75 to 0.85
For same with open or uncemented joints..........	0.50 to 0.70
For inferior block pavements with uncemented joints	0.40 to 0.50
For macadamized roadways......................	0.25 to 0.60
For gravel roadways and walks..................	0.15 to 0.30
For unpaved surfaces, railroad yards and vacant lots	0.10 to 0.30
For parks, gardens, lawns, and meadows, depending on surface slope and character of subsoil.........	0.05 to 0.25
For wooded areas or forest land, depending on surface slope and character of subsoil..................	0.01 to 0.20

In the preparation of the plans for sewering Cincinnati, in 1912, the following imperviousness factors were used: Roofs, 90 per cent; asphalt, brick, and wood block pavements, 85 per cent; granite block pavements, 75 per cent; macadam and cobble pavements, 40 per cent; gravel and poor macadam, 20 per cent; Brick sidewalks, 40 per cent; cement sidewalks, 75 per cent; unpaved yards and lawns, 25 to 15 per cent, and 10 per cent if not tributary to paved gutter.

In selecting imperviousness factors, the largest should be used that will be produced by any conditions likely to be caused by the development of the area in question during the entire economic period of design.

Time for Reaching Sewers. An appreciable time is required for any particular drop of water, after reaching the surface of roof, yard, or street, to find its way into the sewer. That from the roof must flow to the roof gutter, in this to the rain-water leader and through the leader either directly to the sewer or across the sidewalk and down the gutter to an inlet. Rain falling upon yard surfaces must flow across such surfaces to the sidewalk and across sidewalk and down gutter to inlet. That falling on the sidewalks and roadways has the least distance to travel, some of it reaching the inlet almost instantly, but even then requiring a few seconds to flow through the inlet connection to the sewer. The time required for a given drop to reach the sewer depends upon the distance which it must travel over each kind of surface and its rate of flow over such surface.

Practically no data have been collected for estimating velocity of flow of rainfall over the various surfaces, and the difficulty of collecting such data is great. The velocity undoubtedly varies with both the slope and nature of the surface. Over a grass-covered, flat area the velocity will be very much less than down a steep, rocky surface, roof or pavement. The velocity of flow in a gutter is much greater where this is of smooth asphalt or concrete than where it is of cobble stones or of earth overgrown with weeds. Some engineers use a fixed period, such as five minutes, as the average time required for all the rainfall on a single city block to reach the inlet at the lower corner of such block. The time ordinarily lies between three and ten minutes. W. W. Horner concluded that water from improved streets and roofs reaches the sewer in from two to five minutes with street grades of 0.5 to 5 per cent, but that during even heavy rains the rate of flow over grass plots does not exceed 0.1 to 0.2 foot per second.

Assume an impervious area, all sloping at a uniform rate toward an inlet, so that water flows over its entire surface at a uniform velocity. Also assume a rainfall of the same intensity r over the entire area and maintaining this continuously during the period of one minute, and then ceasing. Consider such amount of such area that ten minutes will be required for rainfall to flow from the furthest point to an inlet at one side of the area. Let v represent the uniform rate of flow over the surface, in feet per minute. From the inlet as a center and with v, $2v$, etc., to $10v$ as radii, draw a series of arcs across the area in question. (These arcs may be called run-off contours, and the areas between them run-off areas.) Then during one minute the rain which has been falling upon the surface of this area within the arc v will all have entered the inlet; that within the second run-off area, between arcs v and $2v$, will have flowed into the area between arc v and the inlet; and that from the tenth area, between arcs $9v$ and $10v$, will be between $8v$ and $9v$. During the second minute, the rain which fell upon the second area will enter the inlet, that which fell upon the third area will reach the first, etc.

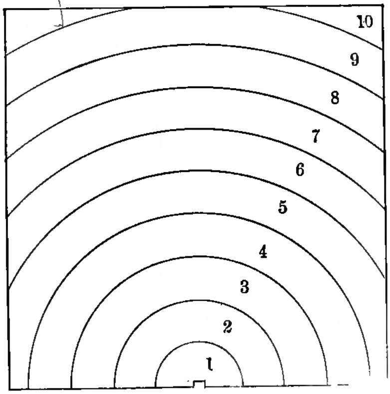


FIG. 8.—DIAGRAM OF RUN-OFF CONTOURS AND AREAS.

Although the intensity of rainfall r was the same on all the areas, and although the velocity of flow has been the same for all parts of the surface, the areas from which the run-off reaches the inlet during successive minutes, and consequently the amounts of such run-off, will differ because of the different areas included between successive pairs of arcs. In the illustration, there will be considerable increase in volume per minute reaching the inlet during the first five minutes, a slight decrease during the next three minutes, and a rapid decrease during the final two minutes. This condition is upon the assumption that the rainfall continued one minute and then stopped entirely.

Assume now that the rain continues at the same intensity r for ten minutes. Then each of the run-off areas, 1, 2, 3, etc., will continue to receive and pass on towards the inlet the same amount of run-off per minute. During the second minute the inlet will receive the run-off from areas 1 and 2. During the third minute that from areas 1, 2, 3, and during the tenth minute, the sum of the run-off from all 10 areas. If there is no additional area draining to this inlet, the total amount reaching it after the tenth minute will remain constant so long as the intensity of rainfall remains constant, and will be equal to Ar, in which A is the total area.

Given the same area, let us now assume that the rainfall during the first minute totals .01 of an inch, during the second minute totals .02 of an inch, and gradually increases to .1 of an inch during the tenth minute. During the first minute the rainfall reaching the inlet will be that equivalent to .01 inch on area No. 1. During the second minute the rainfall reaching the inlet from area No. 1 will be that caused by the .02 inch, but that reaching it from area No. 2 will be caused by the rain of the previous minute, or .01 inch. Similarly, the run-off reaching the inlet during the tenth minute will be that produced by rainfall of 0.1 inch on area No. 1, .09 inch on area No. 2, .08 inch on area No. 3, etc., and .01 inch on area No. 10.

We may now assume an area in a business district where the entire surface is covered with roofs, court yards and street paving, all of which is impervious, and that it yields practically 100 per cent of the run-off. All of the area draining to one inlet may be assumed to have (as such areas very frequently do have) a slope of less than 2 feet per 100, which for practical purposes may be considered uniform throughout. (If all roof water is carried directly to the sewer, the total area of the roofs would be deducted from the area considered, so far as this calculation is concerned. If the roof water leaders discharge upon the ground surface, their run-off is to be included, but we may neglect the effect of the elevation of the roof upon the time of run-off, since the time required for reaching the surface from an ordinary roof is in most cases less than one minute.) The probability is that run-off from this area does not follow a direct route to the inlet, but flows to and along the nearest street gutter. In drawing the run-off contours on such an area, therefore, having determined or assumed a certain rate of flow in feet per minute, we may locate points on the one-minute contour by laying off this distance from the inlet out to the gutters of the radiating streets; other points are determined by finding points on the area that slopes toward each gutter. from which the distance to that gutter and down the gutter to the inlet equals the same one-minute distance. Then, connecting these points, we have the one-minute contour. In the same way, taking twice this distance, we may locate the two-minute contour, etc.

Next, assume varying rates of flow for different sections of the area. We may then use the same method for locating the minute-contours, except that we will use for each section of the area the rate of flow determined for that section. For instance, if it be assumed that the run-off from yards to the gutter will be at the rate of 0.4 foot per second, while the flow down the gutter to the inlet will be at the rate of 2 feet per second, then, if the center of the block be 100 feet from the gutter, it would take four minutes and ten seconds for water from the center of the block to reach the gutter, and during the fifty seconds remaining of a five-minute interval it would flow 100 feet in the gutter. Consequently, one point in the five-minute contour for this block would be in the center of the block opposite a point in the gutter 100 feet from the inlet.

The above analysis of run-off forms the basis of the calculation of run-off by the rational method.

One more assumption of the problem needs to be qualified for practical use. It has been assumed so far that the entire area is impervious and that the run-off is therefore 100 per cent of the rainfall. As we have seen, under certain conditions this percentage may not exceed 20 or 30. To allow for this (since it is run-off and not rainfall with which we are concerned) we may assume for each area a factor of imperviousness, I, and multiply the area by this. Then if this product AI be multiplied by the rainfall rate R, AIR will represent the run-off.

In order to avoid the tedious calculation of run-off by the rational method, many engineers use formulas which take into account only a few of the variable conditions. In fact, it is only within the past ten or fifteen years that the rational method has come into anything like general use. Most of these formulas were based upon measurements of rainfall and sewer flow in certain cities or even smaller areas, and, since they are largely empirical, will only by chance give correct results for any other areas. The best known of these formulas are as follows:

Craig: $Q=440\,Bc\left[\text{hyp. log}\left(\frac{8L^2}{B}\right)\right].$

Dredge: $Q=1300\frac{M}{L^{2/3}}.$

Dickens: $Q=825M^{3/4}.$

Fanning: $Q=200M^{5/6}.$

Kirkwood: $D=\left(\frac{A^2}{58{,}040S}\right)^6.$

Hawksley: $\log d=\frac{3\log A+\log N+6.8}{10}.$

Adams (Brooklyn, N. Y.): $\log D=\frac{2\log A+\log N-3.79}{6}.$

Bürkli-Ziegler: $Q=ARc\sqrt[4]{\frac{S}{A}}.$

McMath (St. Louis): $Q=ARc\sqrt[5]{\frac{S}{A}}.$

Parmley: $Q=ARc\sqrt[4]{\frac{S}{A^{2/3}}}.$

Hering: $Q=ARc\frac{S^{.27}}{A^{.15}}.$

Kuichling (Rochester): $Q=Aat\,(b-ct).$

In the above,

A is the drainage area in acres;
$a=\frac{\text{proportion of impervious surface}}{t}$;
B is the mean breadth of the drainage area in miles;
c is a constant varying from 0.37 to 1.95 in Craig's formula, and from 0.75 for paved streets to 0.31 for macadamized streets in the Bürkli-Ziegler and McMath formulas;
d is the diameter of the sewer in inches;
D is the diameter in feet;
L is the extreme length of the drainage area in miles;
M is the drainage area in square miles;
N is the length in feet in which the sewer falls one foot;
Q is the cubic feet per second reaching the sewer;

R is the average rate of rainfall in inches per hour during the heaviest rainfall (one inch per hour, all flowing off, is practically the same as one cubic foot per second per acre);
In Kirkwood's and Adam's formulas $R=1$; in McMath's, $R=2.75$.
S is the general fall of the area per thousand;
t is the duration in minutes of the intensity $(b-ct)$, in which b is 2.1 for Rochester, N. Y., and c equals .0205.

Of the above formulas, those most frequently used are probably the McMath and the Bürkli-Ziegler, which are the same except for the exponent of the fraction $\frac{S}{A}$. That of McMath was based upon measurements made at St. Louis, and Mr. McMath himself has stated that he considers this formula adapted to large areas only and that it was derived in an entirely empirical manner from St. Louis data only. This formula is no longer used in St. Louis, but the rational method was adopted some years ago. The use of these formulas is still quite general but is not to be recommended. It is probably due largely to disinclination to incur the labor involved in the rational calculation, and a feeling that the factors of imperviousness, intensity of rainfall, etc., must be estimated upon such unsatisfactory data that the result is not sufficiently reliable to warrant the labor involved. It is true that there is some uncertainty in the data available for use in such calculations, but many investigations have been made during recent years which have gradually reduced such uncertainty, and more general use of the method will undoubtedly increase the reliability of the results obtained. At least, this method may be expected to give much more reliable results than the formulas, especially under conditions to which the formulas do not apply with any exactness, which conditions are themselves indefinite or unknown. As an illustration of the unreliability of the formulas, it is found that the several formulas give the following quantities of run-off from a 10-acre area with a 1 per cent slope: Hawskley, 12; Adams, 15; Bürkli-Ziegler, 27; McMath, 21; Parmley, 39; Hering, 20. An area of 57.1 acres of St. Louis with a slope of 1 per cent gave 122 cubic feet per second by the rational method and only

91 by the McMath formula. Capt. R. L. Hoxie compared actual measured flows in Washington sewers with run-offs from the same areas calculated by three of the formulas, with the following results:

Rainfall.	Hawksley.	Kirkwood.	Bürkli-Ziegler.	Actual Maximum Flow.
0.5″ in 15 min.........	43.2	51.7	137.6	300
0.55″ in 37 min........	43.2	51.7	61.9	180

The discrepancies are largely due to the causes already referred to—that the formulas are empirical and that factors are taken as constants which are really variables. One of these errors is in using a fixed rate of rainfall, regardless of the section of the country under consideration, as is done by the Hawksley and Kirkwood. Also, the character of the majority of street surfaces has changed in imperviousness and smoothness since most of these formulas were devised. It seems certain that any formula that would represent by variable factors all the conditions that affect run-off would be so complicated that its use would probably be more difficult, and tedious than the solving of each problem by the rational method. The rational method is used by the cities of Baltimore, Boston, Cincinnati, Queens Borough (New York), Pawtucket, R. I., St. Louis, and many other cities.

One of the first exponents of the rational method, the late Emil Kuichling, made extensive gaugings and studies of rainfall and sewer flow in Rochester, N. Y., from which he derived certain conclusions that would seem to be general in their application. These are as follows:

> 1. The percentage of the rainfall discharged from any given drainage area is nearly constant for rains of all considerable intensity and lasting equal periods of time.
>
> 2. The said percentage varies directly with the degree of urban development of the district, or, in other words, with the amount of impervious surface thereon. . .
>
> 3. The said percentage increases rapidly, and directly or uniformly with the duration of the maximum intensity of the rainfall, until a period is reached which is equal to the time required for the concentration of the drainage-waters from

the entire tributary area at the point of observation; but if the rainfall continues at the same intensity for a long period, the said percentage will continue to increase for the additional interval of time at a much smaller rate than previously. This circumstance is manifestly attributable to the fact that the permeable surface is gradually becoming saturated and is beginning to shed some of the water falling upon it; or, in other words, the proportion of impervious surface slowly increases with the duration of the rainfall.

4. The said percentage becomes larger when a moderate rain has immediately preceded a heavy shower, thereby partially saturating the permeable territory and correspondingly increasing the extent of impervious surface.

5. The sewer discharge varies promptly with all appreciable fluctuations in the intensity of the rainfall. (Transactions Am. Soc. C. E., Vol. XX., page 37.)

The maximum rate of rainfall seldom lasts more than a minute or two, and the longer the period considered, the lower is generally the maximum rate for the period. It follows, therefore, that an area that has a shorter run-off time than another will contribute a larger maximum run-off per unit of area.

Storms seldom increase or decrease at a uniform rate, but by examining the records of excessive rainfalls in the locality in question, each represented by a curve as in Fig. 6, we may select for any given area the curve that will give the maximum run-off for such area; or such curve as would produce the run-off of the second or third greatest intensity, if we desire to reject rainfalls of infrequent occurrence in the calculation. The run-off calculated as resulting from a given rainfall will be a maximum when the sum of the products of rainfall rates during successive minutes as one factor, and the run-off areas used in succession (beginning with that furthest from the inlet) as the other factor, is a maximum.

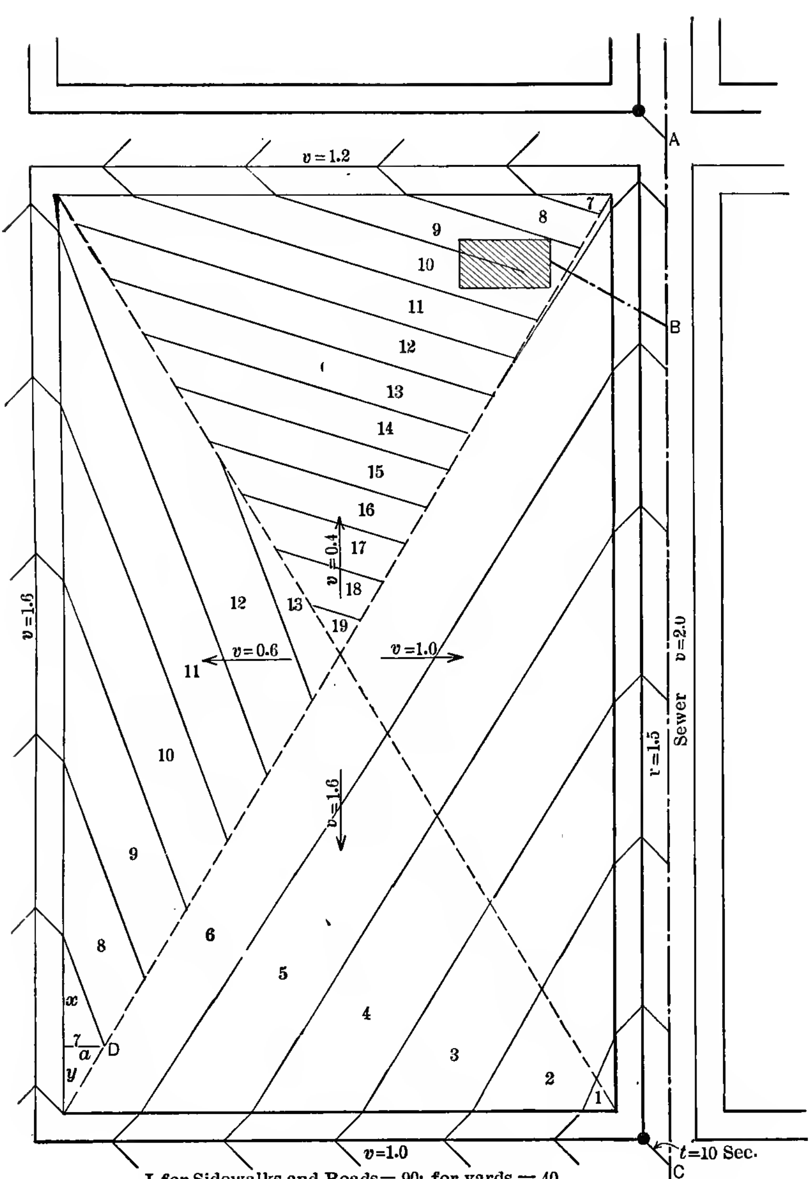
In the majority of rainfall records, the rates are given as the averages during successive five-minute periods. Consequently, five-minute contours will generally be used. As shown above, if the one-minute run-off areas can be assumed as equal, it is perfectly accurate to use as the maximum rainfall rate the average for the run-off time of the block in question. It is ordinarily assumed that such condition exists in city blocks, and the maximum average rainfall for five- or ten-minute periods is used. It is evident from the previous discussion that this does not give maximum run-off. It will appear later that this error does not greatly affect the calculation of capacity required for the main sewer; but it does affect that required for the inlet connections to the sewer and the inlet itself.

CALCULATING RUN-OFF FROM A RESIDENTIAL CITY BLOCK

This block (see Fig. 9) is 300 by 500 ft. measured on the property lines; sidewalks 15 feet wide, roadway 30 feet. Gutter grades are such as to give the estimated velocities of 1.0, 1.5, 1.2, and 1.6 feet per second as indicated. It is assumed that the conditions as to cross-slopes of sidewalk and roadway and grading of lawns will be such ultimately as to carry the run-off from property line to gutter and street center to gutter each in fifteen seconds, and across the yards to the sidewalk at the rate shown—1.6, 1.0, 0.4, and 0.6 feet per second, respectively; the grading of yards being such that the diagonals define the drainage slopes to the four sidewalks. Also that the imperviousness of sidewalks and roadways will be .90 and of yards .40. Also that at maximum flow ten seconds will be consumed in flowing from the inlet (in the lower right-hand corner of the block) to the sewer at *C*.

The one-minute contour crosses the gutter on the bottom street (60–10) 1.0 or 50 feet from the inlet; and the right-hand street (60–10) 1.5 or 75 feet from the inlet. This contour crosses the right-hand property line at a point opposite a point in the gutter (60–10–15) 1.5 or 52.5 feet from the inlet; and the center of the street opposite the same point. The two-minute contour crosses the right-hand gutter at a distance (60×1.5) or 90 feet beyond the one-minute contour, and is the same distance from such contour measured along both property line and center line of street. And each contour to the 6th is 90 feet beyond the previous one. From the point where the one-minute contour crosses the property line, measure at right angles to such line (60×1.0) = 60 feet, which will be a point on the two-minute contour (or such contour extended into the slope to the lower sidewalk, in this case). From the two-minute contour at the property measure 60 feet, which will give a point on the three-minute contour, etc. Draw straight lines through these points and those where the corresponding contours cross the property line, extending the contours to the lot diagonals. Do the same for the lower street. The seventh contour will cross the gutter $(7\times60)-10-\frac{500+30}{1.5}$ or 56.7 seconds of flow along the top gutter, or 56.7×1.2 = 68 feet from the corner. The eight-, nine-, and ten-minute contours cross the top gutter at uniform intervals of (60×1.2) or 72 feet apart. And the intervals between them in the yard area, measured normal to the top gutter, is (60×0.4) or 24 feet. All the contours in each area of uniform slope are parallel. Those in the left-hand street and yard area are located in the same way.

Then all the yard area between the inlet and contour 1 represents the area of such surface from which the run-off reaches the sewer in one minute, and the same of the street areas. The sum of all of the areas between contour 1 and contour 2 represents the surface from which the run-off reaches the sewer during the second minute after it fell. Up to area 13 there are two yard and two street areas to be added to give the successive minute run-off quantities; but beyond



I for Sidewalks and Roads = .90; for yards = .40

FIG. 9.—DIAGRAM FOR CALCULATING RUN-OFF FROM A SUBURBAN CITY BLOCK 300 FT. BY 500 FT.

this there is but one area for each minute. Rain falling just above the intersection of the diagonals requires nineteen minutes to reach the sewer.

We may now prepare a table like that shown herewith for calculating the run-off. It may be sufficiently accurate for practical purposes to plot the diagram, Fig. 9, on cross-section paper and determine each area by counting the squares it covers, estimating fractional squares; but generally a simple formula for calculating it will be apparent. For example, in area 7 at the left-hand corner, which is triangular in form, drop a perpendicular from the vertex D to the base, call it a and call the part of the base above this x, and that below it y. Then $a : y = 300 : 500$; $a : x = 0.6 : 1.6$; and $x + y = 96$ feet. From which a is found to be 22.15 feet. Area 8 on this slope has three times the area of 7, area 9 has five times the area, etc.

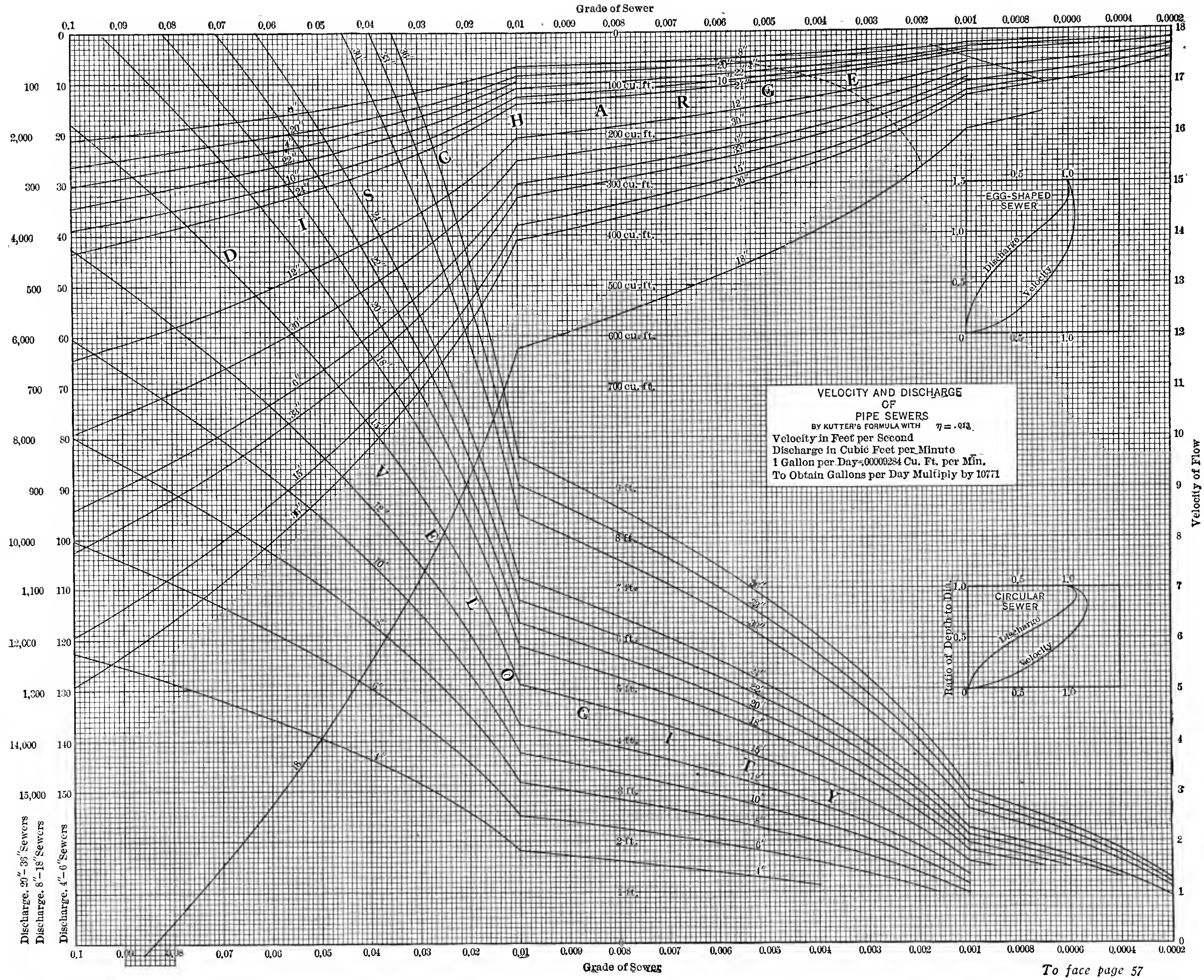
Each area within the property lines is then multiplied by 0.40, and each in the street is multiplied by 0.90, and the products placed in the proper columns, and the sum of such products for each minute taken and entered in the column "Total *AI*."

CALCULATION OF RUN-OFF FROM SUBURBAN CITY BLOCK

A in square feet. *R* in inches of actual rainfall

Minute-Area No.	Area of St. I = .90.		Area of Yds. I = .40.		Total *AI*.	First Position.		Second Position.		*R'*.	*AIR'*.
	Total.	*AI*.	Total.	*AI*.		*R*, In. per Min.	*AIR*, Cu. ft. per Min.	*R*, In. per Min.	*AIR*, Cu. ft. per Min.		
1	3,250	2,925	445	178	3,103	.054	14.0	.058	15.0	.012	3.1
2	4,500	4,050	4,860	1,944	5,994	.056	28.0	.060	30.0	013	6.5
3	4,500	4,050	10,510	4,204	8,254	.058	39.9	.062	42.6	.040	27.5
4	4,500	4,050	16,160	6,464	10,514	.060	52.6	.066	57.8	.080	70.1
5	4,500	4,050	21,340	8,536	12,586	.062	65.0	.082	86.0	.150	157.3
6	4,800	4,320	22,670	9,068	13,388	.066	73.6	.120	133.9	.110	122.7
7	5,200	4,680	1,370	548	5 228	.082	35.7	.080	34.9	.080	34.9
8	5,040	4.536	5.260	2.104	6,640	.120	66.4	.062	34.3	.065	36.0
9	5,040	4.536	8.770	3,508	8 044	.080	53.6	.058	38.9	.055	36.9
10	5,040	4,536	12,280	4,912	9,448	.062	48.9	.056	44.1	.050	39.4
11	4,410	3,969	15,520	6,208	10,177	.058	49.2	.054	45.8	.035	29.7
12	820	738	13 370	5,348	6,086	.056	28.4	.052	26.5	.027	13.7
13	....	....	5 910	2,364	2,364	.054	10.6	.050	9.85	.023	4.53
14	....	....	3,530	1,412	1,412	.052	6.12	.048	5.65	.020	2.35
15	....	....	2,930	1,172	1,172	.050	4.90	.046	4.49	.015	1.46
16	....	....	2.265	906	906	.048	3.62	.042	3.17	.010	0.75
17	....	....	1,610	644	644	.046	2.47	.040	2.15	.009	0.48
18	....	....	945	378	378	.042	1.32	.036	1.13	.007	0.22
19	....	....	255	102	102	.040	0.34	.030	0.25	.003	0.03
Total	51,600	46,440	150,000	60,000	106,440	....	584.7	....	616.5	....	587.6
Mean rates in inches per minute and run-off based on such mean rate................						.0603*	534.9	.0580*	514.5	.0423*	375.2

* Equivalent to 3.6, 3.5 and 2.5 inches per hour, respectively. A rate of 3.1 inches per hour (see cumulative rainfall curve) would give a run-off of 458 cubic feet per minute, Total *AI* = 2.443 acres.



VELOCITY AND DISCHARGE
OF
PIPE SEWERS
BY KUTTER'S FORMULA WITH $\eta = .013$

Velocity in Feet per Second
Discharge in Cubic Feet per Minute
1 Gallon per Day=.00009284 Cu. Ft. per Min.
To Obtain Gallons per Day Multiply by 10771

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We must now select a storm having a nineteen-minute period that will give a maximum run-off from this area. Since the maximum *AI* is that for the 6th area and the center of the peak is about the 7th, a period reaching its maximum rainfall about (19−7=)12 minutes from the beginning, or during the third five-minute period is required. Taking storm No. 5, in Table No. 10, the nine minutes before and five minutes after the maximum five-minute period, or .22-, .27-, .41-, and .29-inch rates, and developing these to estimate the one-minute rates, we have those given in the table as "*R*, first position." Multiply each *AI* by its corresponding *R*, and divide by 12 to reduce to cubic feet, obtaining the products *AIR*. Then the run-off from the 19th area, 0.34 cubic feet, reaches the sewer during the same minute as do the 10.6 cubic feet from the 13th area and the 14.0 cubic feet that has been falling on the first area during that minute. Altogether 584.7 cubic feet entered the sewer from this area during that minute.

TABLE NO. 10

RAINFALL DURING FIVE-MINUTE PERIODS OF EXCESSIVE PRECIPITATION IN CINCINNATI

Hundredths of an inch

Storm No.	Total Previous Precipitation.	Five-minute Periods before Maximum.						Max.	Five-minute Periods after Maximum Occurred.									
		6	5	4	3	2	1		1	2	3	4	5	6	7	8	9	10
1	1	..	..	11	20	20	22	32	27	23	12	12	15	11	5			
2	*T*	..	..	..	..	8	23	46	6	5	11	7						
3	3	..	..	..	..	18	25	34	6	13	4	17	7	2	2	1	0	
4	3	..	..	..	..	..	24	28	11	24	4	1	1	9	4	3	2	2
5	3	..	..	..	22	22	27	41	29	5	3	3	11	7				
6	2	..	..	..	..	..	..	47	18	6	5	6						
7	1	..	..	..	..	..	24	25	19	11								
8	1	..	..	..	..	..	..	37	4									
9	1	10	18	13	10	20	17	22										
10	1	..	..	..	..	..	..	38	36	24	20	19	27	4	16	9	16	3

To try whether the flow might not have been greater two minutes earlier, move all the values of *R* up two spaces, as in the second position, filling the two lower spaces from the rate of the previous minute; bringing the maximum *R* opposite the maximum *AI*. This gives a total run-off of 616.5 cubic feet, or nearly 6 per cent greater than during the minute previously calculated, although the average rate during the entire nineteen minutes is only .0580 inch per minute (3.5 inches per hour) as against .0603 inch by the first position.

If, instead of using this analytical method, we multiplied the total *AI* by the average rate for the entire period, we would obtain 534.9 cubic feet and 514.5 cubic feet respectively. If we take the nineteen-minute rate from the curve Fig. 7, or 3.1 inches per hour, we obtain a run-off of 458 cubic feet. It is apparent, therefore, that the analytical or "additive" method may give considerably larger results than using the average rate for an area of this size. Again, if we omit from consideration areas 16 to 19, and use as multiplier the 15-minute rate 3.5 (Fig. 7), we obtain a run-off of 507 cubic feet; illustrating that in using the average-rate method we may sometimes obtain a larger total run-off by omitting small distant areas from the calculation.

Again, we may try the use of a rate R' from storm No. 2, which has a higher rate during the maximum five minutes, but lower rates both before and after this. Applying this as before, we find a run-off of 587.6 cubic feet, or somewhat less than rainfall R gave. In this case the run-off obtained by using the average rate for the entire nineteen minutes is nearly 40 per cent less than by the analytical method.

QUANTITY FLOWING IN SEWERS

In the above we have considered the run-off over the surface of the ground to an inlet. We will now consider the maximum capacity of sewer required at different points in the line of the same.

Evidently a length of sewer receiving the sewage from only a single inlet will need to carry as a maximum only the maximum amount entering such inlet. A short distance further on, however, the discharge from another inlet will be received, and this will be repeated at intervals. Moreover, in the case of a main sewer, there will usually be, at intervals of a few hundred feet, branch sewers discharging into the main sewer the storm-water that each has collected from a number of inlets. It is apparent that if it takes one minute for the run-off from inlet Number 1 to flow through the sewer to inlet connection Number 2, the sewer flow will be increased at the latter point by run-off from inlet Number 2 that occurred one minute later than did that which is already in the sewer from inlet Number 1. Similarly, this combined volume will be increased at inlet connection Number 3 by the amount of run-off that entered such inlet two minutes later than did that contributed by inlet Number 1.

If we assume a sewer following a long street, and an inlet at the lower corner of each block on such street, and that all these blocks have the same AI and run-off time, and that the grade of the main sewer is such that the sewage flows between each successive pair of inlets in a constant time T, then it is apparent that the maximum flow immediately below inlet No. 5 is equal to the product of five times the common block-area (that is, the total area draining to the sewer above such point) and the run-off per unit of area due to the maximum average rate of rainfall for a period of time equal to $5T$ plus the run-off time for one block. For 5 we may substitute any number of inlets, so long as the conditions named are constants.

If we assume that an entire drainage district is composed of areas, each draining to an inlet, and each having such run-off time and imperviousness, respectively, that the maximum run-off from all areas under similar rainfall conditions will be the same, and that the distances between inlet connections and the velocity of flow in the sewer are such that the discharges from successive inlets reach a given point in the sewer at uniform intervals of time, then the maximum flow in the main sewer just below the lowest inlet will be equal to the sum of the AI's of all the areas into which the drainage district is divided, multiplied by the maximum average rate of rainfall for the period of time required for the run-off from the furthest end of the furthest block to reach the point in the main sewer under consideration.

The above assumption is quite commonly made in designing storm sewers, the calculation being further simplified by assuming or estimating an average factor of imperviousness for the entire district under consideration; the quantity flowing at any given point in the sewer then being calculated as the product of the total area of the district draining to this point, the average factor of imperviousness of such area, and the maximum average rate of rainfall for the period of time required for the run-off to reach the point of sewer in question from the furthest part of the district. It is apparent from the analysis of the run-off from a single city block that this method of calculation involves an error which in some cases may be considerable, unless there actually exists throughout the city the uniformity of conditions described in the previous paragraph. In perhaps the majority of cities there is an approximation to this uniformity that is sufficiently close to warrant the use of this average-rate method; but where there is any considerable variation in any of the factors assumed to be uniform, the sewer flow from the area so affected should be calculated by the analytical or additive method.

The problem may be further complicated by a consideration which is of little importance in the small area of a city block, viz., that the storm center causing a maximum rate of rainfall is probably travelling in some direction over the city area, and this direction may be from the upper end of the drainage area toward the outlet of the main sewer. Should this be the case and the rate of travel of the storm center be that of the flow of sewage in the sewer, each successive inlet would discharge into the sewer its maximum rate of run-off just as the maximum run-off from all the inlets above arrived at its connection; in which case the total sewage flow at the sewer outlet would be that due to a run-off from the entire area draining to the sewer caused by the maximum rate of precipitation for the run-off time of a single block, rather than that due to the *average* precipitation for the length of time required for the drainage from the furthest inlet to reach the outlet. As this time may be an hour or more and the maximum average rate of rainfall for such period is perhaps only one-fifth as great as the maximum for a five-minute period, it is apparent that the condition described would not be even approximately provided for by using the average method described in the previous paragraph. For a storm center, however, to follow the line of the sewer and move at approximately the rate of flow in the same can be considered as one of those most unusual conditions which a city is not justified in providing against because of the great expense involved and the low probability of its occurrence.

CHAPTER IV

FLOW IN SEWERS

Art 12. Fundamental Theories

The flow in an ordinary sewer must be due to one cause only—the attraction of gravitation. The velocity of this flow is retarded by friction and other obstacles affecting it along the line of the sewer.

The general formula for the velocity due to gravity of a freely falling body is $V=\sqrt{2gh}$, where V is velocity in feet per second, h is head in feet, and g is acceleration due to gravity, being about 32.16 feet per second. In the case of running water h is the fall of the surface of the water from the point of no motion to the point in question. Therefore, if there were no opposing forces a stream would flow more and more rapidly along its course as the total head became greater; and its velocity would become constant only when the surface was level, and therefore h constant. There is, however, friction between the moving water and the sides of a sewer, and this must be overcome by some force. Since the only force available is that due to gravity, called into play by the creation of a head h, a part of this force must be used in overcoming friction. If it is not all so used the remainder goes to create additional velocity. Friction, it is found, increases with the velocity of the moving body, so that, as additional increments of speed are created by h, a larger proportion of the head is consumed in overcoming friction, until at last all of h is so consumed and none goes to increasing the velocity—that is, the velocity remains constant.

Friction also varies with the roughness of the surface. The total amount of energy lost in friction also increases with the duration of its action, which is proportional to the distance travelled l.

An important condition affecting the velocity of flow in sewers is the proportion between the cross-sectional area of the stream and the length in this cross-section of the line of contact between the water and the bed of the stream. Speaking generally, the energy of the flowing sewage varies directly as the mass and this varies directly as the cross-section (assuming a constant velocity); while the total friction on the sewer wall varies directly as the area of contact between it and the sewage. Consequently velocity is increased by increasing the value of the former in proportion to the latter. The ratio between these, or $\frac{\text{area of section}}{\text{wetted perimeter}}$, is called the "hydraulic radius" or "mean depth" and is customarily represented by the letter R.

From these considerations it follows that V varies as $\sqrt{2gh}$ and as some function of (R), and inversely as some function of (l). The effect of roughness may be represented by a factor a. A formula for velocity would therefore be in the form $V=a\frac{\sqrt{2gh}f(R)}{f(l)}$. In 1753 Brahms proposed as a formula representing the resultant effect of these accelerating and retarding influences $V=c\sqrt{RS}$, in which V = mean velocity of current, c is an empirical constant which includes $\sqrt{2g}$ and a, R is the hydraulic radius, and S is the sine of the surface slope, or $\frac{h}{l}$. This formula, now generally called Chézy's formula, has been made the basis of others, most of which differ among themselves only in the values given to c; but it is now recognized that V does not vary exactly as the square root of R and of S, although it does approximately, and this formula may therefore be written

$$V=a\sqrt{2g}\frac{f'(R)}{f'(l)}\sqrt{\frac{h}{l}R}=b\frac{f'(R)}{f'(l)}\sqrt{RS},$$

$b\frac{f'(R)}{f'(l)}$ being equal to the c of Chézy's formula. From this it follows that c is not a constant for any particular sewer or stream, but varies with both R and l. The principal cause affecting the value of c, however, is the condition as to roughness of the wetted perimeter.

If we wish to obtain the velocity of flow in any sewer by this formula it is necessary to select proper values for c, R, and S. S can be obtained readily by dividing h by l. The value of c and R and their relation to V will now be discussed.

For c most of the older formulas gave constant values; but since V varies with different materials of channel walls, whose character does not affect the values of R and S, this variation must be recognized in a variable c by means of a new factor or by a new equation. Most of the efforts looking to greater accuracy have been directed toward determining values for c and thousands of experiments have been made for this purpose. Of these, the formula evolved from the records of a large number of experiments by two Swiss engineers, Ganguillet and Kutter, usually called "Kutter's formula," has for about twenty-five years been held to give results more nearly approximating the actual velocities than any other. This formula is, for English measure,

$$c=\frac{41.6+\frac{.0028}{S}+\frac{1.81}{n}}{1+\left(41.6+\frac{.0028}{S}\right)\frac{n}{\sqrt{R}}},$$

in which n is a "coefficient of roughness" of the sides of the channel, such coefficient having been obtained by averaging many experiments. In the selection of value for n great care and judgment must be exercised, particularly for small sewers in the calculation for which n has a greater effect than in that for large channels.

The values of n are aproximately:

Sides and bottom of channel lined with well-planed timber....	.009
With neat cement, clean glazed sewer-pipe, and very smooth iron pipe..	.010

With 1 : 3 cement mortar or smooth concrete or iron pipe	.011
With unplaned timber and ordinary iron pipe	.012
With smooth brick-work, concrete, or ordinary pipe sewers	.013
With ordinary brick-work	.015
With rubble or granite-block paving	.017

Kutter's formula is seen to provide for variations in *c* due not only to the character of the channel but also to changes in *R* and *S*.

This formula has been used to calculate the tables Nos. 11 and 12, *n* being taken as .013 in the former and .015 in the latter. If it is desired to use another value of *n* the corresponding values of velocity and discharge can be obtained very approximately by multiplying the quantities given in each table by the factors given below it for that purpose. For ordinary pipe or concrete or good brick sewers *n* may be taken as .013; for ordinary brick or smooth stone as .015. For extra smooth work *n* may be taken as .011.

The uncertainties necessarily existing in the estimates of the amount of sewage to be provided for and the difficulty of selecting just the proper value for *n*, owing to the non-uniform character of the interior surface of the sewer, make a refinement of calculations out of keeping with the data used. Moreover, in the case of vitrified clay or concrete pipe, the market sizes must in the end be those selected, and there is a considerable jump between the capacities of consecutive sizes. For instance, an 8-inch pipe on a 1 per cent grade will discharge about 498 gallons per minute when running full; a 10-inch pipe running full with the same grade will discharge about 925 gallons per minute, and a 12-inch pipe about 1530 gallons per minute. For this reason it is sufficiently accurate and often more convenient to use curves plotted from the tables, having the grade and corresponding velocity or discharge as coordinates, from which the flow through any customary size of sewer at any practicable grade can be found at a glance and with as great accuracy as is required for ordinary use. Such a diagram can be readily prepared on a sheet of cross-section paper, a curve being drawn for the velocity and another for the discharge of each size of sewer.

TABLE No. 11

VELOCITY AND DISCHARGE IN SEWERS 4 TO 36 INCHES DIAMETER, OF VITRIFIED PIPE OR SMOOTH CONCRETE

Velocity in Feet per Second; Discharge in Cubic Feet per Minute; Sewers Flowing Full

(Formula $V = c\sqrt{RS}$; c calculated by Kutter's formula, with $n = .013$. $Q = 60aV$.)

Grade of Sewer.	4-inch		6-inch		8-inch		10-inch		12-inch		15-inch		18-inch	
	V	*Q*	*V*	*Q*	*V*	*Q*	*V*	*Q*	*V*	*Q*	*V*	*Q*	*V*	*Q*
.1	5.75	30.13	7.99	94.10	10.04	210.3	11.94	390.8	13.73	647.0	16.24	1196.0	18.59	1971.5
.05	4.06	21.28	5.64	66.48	7.09	148.6	8.43	276.1	9.70	457.1	11.48	845.0	13.13	1393.0
.04	3.63	19.03	5.05	59.45	6.34	132.9	7.54	246.9	8.65	407.8	10.26	755.6	11.74	1244.0
.03	3.15	16.47	4.35	51.25	5.49	115.0	6.53	213.7	7.51	353.9	8.89	654.4	10.17	1078.0
.02	2.57	13.44	3.56	42.00	4.48	93.90	5.33	174.5	6.13	289.0	7.25	534.2	8.30	880.4
.01	1.82	9.50	2.52	29.70	3.17	66.38	3.77	123.4	4.33	204.3	5.13	377.8	5.87	622.6
.008	1.61	8.37	2.25	26.53	2.83	59.35	3.37	110.3	3.87	182.6	4.59	337.7	5.25	556.8
.006	1.38	7.18	1.95	23.00	2.45	51.39	2.92	95.55	3.35	158.2	3.97	292.5	4.55	482.3
.004			1.59	18.71	2.00	41.85	2.38	77.98	2.74	129.1	3.24	238.3	3.70	392.9
.002					1.40	29.38	1.67	54.61	1.91	90.40	2.27	167.3	2.60	275.9
.001							1.17	38.41	1.35	63.58	1.60	117.7	1.83	194.3
.0009											1.51	111.4	1.73	183.9
.0008													1.63	173.1
.0007													1.52	161.2

For $n =$ .011	.012	.013	.015	.017
Multiply *V* or *Q* by 1.20	1.09	1.00	0.84	0.73

1 gallon per day = .00009284 cubic foot per minute.
1 cubic foot per minute = 10,771 gallons per day.

Table No. 11—*Continued*

VELOCITY AND DISCHARGE IN SEWERS 4 TO 36 INCHES DIAMETER, OF VITRIFIED PIPE OR SMOOTH CONCRETE

Velocity in Feet per Second; Discharge in Cubic Feet per Minute; Sewers Flowing Full

(Formula $V = c\sqrt{RS}$; c calculated by Kutter's formula, with $n = .013$. $Q = 60aV$.)

Grade of Sewer.	20-inch		22-inch		24-inch		30-inch		33-inch		36-inch	
	V	*Q*	*V*	*Q*	*V*	*Q*	*V*	*Q*	*V*	*Q*	*V*	*Q*
.1	20.08	2628	21.51	3407	22.91	4319	26.84	7905	28.69	10220	30.46	12920
.05	14.18	1857	15.20	2407	16.19	3052	18.97	5586	20.27	7225	21.54	9136
.04	12.69	1661	13.59	2153	14.47	2729	16.96	4995	18.13	6461	19.26	8171
.03	10.98	1438	11.77	1864	12.53	2363	14.69	4325	15.70	5595	16.68	7075
.02	8.97	1174	9.61	1522	10.23	1930	11.99	3532	12.82	4568	13.62	5777
.01	6.34	830	6.79	1076	7.24	1366	8.48	2497	9.06	3230	9.63	4085
.008	5.67	742	6.07	962	6.47	1210	7.58	2233	8.11	2889	8.61	3653
.006	4.91	643	5.26	833	5.60	1057	6.57	1934	7.02	2502	7.46	3164
.004	4.00	524	4.29	679	4.56	860	5.35	1576	5.72	2040	6.08	2580
.002	2.81	368	3.01	477	3.21	605	3.76	1109	4.02	1434	4.28	1814
.001	1.98	259	2.12	336	2.26	427	2.66	782	2.84	1012	3.02	1281
.0009	1.87	245	2.01	318	2.14	404	2.51	741	2.69	959	2.86	1213
.0008	1.76	231	1.89	299	2.02	380	2.37	697	2.53	902	2.69	1141
.0007	1.64	215	1.76	279	1.88	354	2.20	650	2.36	841	2.51	1065
.0006	1.51	198	1.63	258	1.73	327	2.04	600	2.18	777	2.32	984
.0005			1.48	234	1.58	298	1.86	546	1.99	708	2.11	896
.0004			1.32	208	1.40	265	1.65	486	1.77	620	1.88	798
.0003					1.20	227	1.40	413	1.52	541	1.62	686
.0002					0.98	186	1.13	335	1.22	435	1.30	555

TABLE No. 12

VELOCITY AND DISCHARGE IN SEWERS 33 INCHES TO 120 INCHES DIAMETER, OF BRICK OR CONCRETE OF ORDINARY SMOOTHNESS

Velocity in Feet per Second; Discharge in Cubic Feet per Minute; Sewers Flowing Full

(Formula $V = c\sqrt{RS}$; c calculated by Kutter's formula, with $n = .015$. $Q = 60aV$.)

Grade of Sewer.	33-inch		36-inch		42-inch		4-foot	
	V	Q	V	Q	V	Q	V	Q
.05	17.17	6120	18.27	7750	20.37	11765	22.36	16865
.04	15.36	5473	16.34	6930	18.21	10517	20.00	15080
.03	13.30	4738	14.15	6000	15.77	9108	17.31	13057
.02	10.85	3868	11.55	4900	12.88	7437	14.13	10658
.01	7.68	2735	8.16	3464	9.09	5258	9.99	7537
.008	6.86	2444	7.30	3096	8.14	4700	8.93	6738
.006	5.94	2115	6.32	2679	7.04	4067	7.73	5832
.004	4.84	1726	5.15	2186	5.75	3243	6.31	4759
.002	3.41	1216	3.63	1540	4.05	2339	4.45	3354
.001	2.40	856	2.55	1085	2.85	1648	3.13	2365
.0009	2.27	810	2.42	1027	2.70	1561	2.97	2240
.0008	2.14	763	2.28	967	2.55	1470	2.80	2110
.0007	2.00	713	2.13	903	2.38	1373	2.61	1972
.0006	1.85	658	1.97	834	2.20	1269	2.42	1822
.0005	1.68	598	1.79	759	2.00	1155	2.20	1658
.0004	1.49	532	1.59	675	1.78	1028	1.96	1477
.0003	1.28	457	1.37	580	1.53	883	1.68	1270
.0002					1.23	712	1.36	1026
.00015							1.16	878

For $n = .011$	.012	.013	.015	.017
Multiply V or Q by 1.43	1.29	1.19	1.00	0.87

TABLE No. 12—*Continued*

VELOCITY AND DISCHARGE IN SEWERS 33 INCHES TO 120 INCHES DIAMETER, OF BRICK OR CONCRETE OF ORDINARY SMOOTHNESS

Velocity in Feet per Second; Discharge in Cubic Feet per Minute; Sewers Flowing Full

(Formula $V = c\sqrt{RS}$; c calculated by Kutter's formula, with $n = .015$. $Q = 60aV$.)

Grade of Sewer.	5-foot		6-foot		8-foot		10-foot	
	V	Q	V	Q	V	Q	V	Q
.05	26.05	30700						
.04	23.30	27450	26.34	44690				
.03	20.17	23765	22.81	38700				
.02	16.47	19405	18.62	31600	22.53	67965	26.03	122700
.01	11.64	13717	13.17	22345	15.93	48050	18.41	86755
.008	10.41	12267	11.78	19980	14.25	42970	16.46	77590
.006	9.01	10617	10.19	17295	12.33	37200	14.25	67175
.004	7.36	8665	8.32	14113	10.07	30370	11.63	54840
.002	5.19	6110	5.87	9956	7.10	21435	8.21	37600
.001	3.66	4311	4.14	7030	5.02	15150	5.81	27380
.0009	3.47	4083	3.92	6659	4.76	14353	5.51	25960
.0008	3.27	3849	3.70	6276	4.49	13533	5.19	24475
.0007	3.05	3597	3.46	5870	4.20	12660	4.86	22895
.0006	2.82	3326	3.20	5429	3.88	11710	4.50	21195
.0005	2.57	3028	2.92	4946	3.54	10675	4.10	19325
.0004	2.29	2700	2.60	4411	3.16	9532	3.66	17267
.0003	1.97	2324	2.24	3801	2.73	8228	3.17	14927
.0002	1.60	1882	1.82	3083	2.22	6694	2.58	12168
.00015	1.37	1615	1.56	2650	1.91	5760	2.23	10510
.00012			1.39	2353	1.70	5137	1.99	9375
.00010					1.55	4672	1.81	8542
.000095					1.25	3783	1.77	8320
.000090							1.72	8096

It is now generally considered that Kutter's formula gives somewhat too small values for sewers under 15 or 18 inches diameter.

Other formulas for calculating flow in sewers and similar conduits have been advocated from time to time. Perhaps of the recent ones that of Williams and Hazen has been most extensively used. This formula is as follows:

$$v = CR^{0\cdot63}S^{0\cdot54}$$

Comparing this with the Chézy formula, it is seen that the c of that formula equals $CR^{0\cdot13}S^{0\cdot04}$ in the Williams formula—a much simpler value than Kutter's c.

It must be remembered that the formulas and tables of velocity are supposed to apply only when the sewage has reached a constant velocity. Previous to this, when the friction does not consume all of h, the remainder is creating increments of velocity. Since the same amount of sewage must pass all sections of a sewer between two inlets, however, it follows that, previous to the flow obtaining its maximum and constant velocity, the depth of sewage must have been greater, increasing up stream to the point of entry. An initial velocity of entrance in the direction of the sewage flow will reduce the amount and extent of this non-uniform flow with larger cross-section, but will have little effect upon the ultimate constant velocity.

V is the mean velocity. The effect of friction is exerted along the wetted perimeter and grows less toward the center of the stream. The surface of flow also is retarded by friction with the air, and frequently in the case of house-sewage by a greasy scum which floats upon the surface. The velocity given is really the volume of flow divided by its area.

Since V varies as $f(R) = f\left(\frac{\text{area}}{\text{wetted perimeter}}\right)$, it follows that the size of the sewer and the shape of the cross-section have considerable effect upon the velocity of a stream. The maximum value of $\frac{\text{area}}{\text{perimeter}}$ for a sewer flowing full is obtained, we learn from geometry, by making the cross-section circular; that is, for pipes of the same area but different shapes of cross-section, flowing full, the circular gives the largest R. But this is not always true when the sewer is *not* flowing full.

If we examine the effect of depth of flow in a given circular sewer upon the value of R we find that if the depth $d=\frac{D}{2}$ (D equalling the diameter of the sewer), $a=.3927D^2$, $p=1.5708D$, and $R=0.25D$. If the depth $=D$, we find $a=0.7854D^2$, $p=3.1416D$, and $R=0.25D$ as before.

Table No. 13

d Depth.	p Wetted Perimeter.	a Area of Flow.	R Hydraulic Radius.	$2\sqrt{R}$	By Kutter's Formula.	
					Corrected Proportional Velocities.	Corrected Proportional Discharge.
Full 1.0	3.142	0.7854	0.25	1.00	1.00	1.000
0.95	2.691	0.7708	0.286	1.07	1.11	1.068
0.9	2.498	0.7445	0.298	1.09	1.15	1.073
0.8	2.214	0.6735	0.304	1.10	1.16	0.98
0.7	1.983	0.5874	0.296	1.08	1.14	0.84
0.6	1.772	0.4920	0.278	1.05	1.08	0.67
0.5	1.571	0.3927	0.250	1.00	1.00	0.50
0.4	1.369	0.2934	0.214	0.93	0.88	0.33
0.3	1.159	0.1981	0.171	0.83	0.72	0.19
0.25	1.047	0.1536	0.146	0.76	0.65	0.14
0.2	0.927	0.1118	0.121	0.69	0.56	0.09
0.1	0.643	0.0408	0.0635	0.50	0.36	0.03

As the depth of the sewage decreases from that of half the diameter, the area decreases more rapidly than does the wetted perimeter, and consequently R decreases more and more rapidly as the depth diminishes. The above table shows this very plainly. The diameter is here taken as unity, the sewer circular.

The formula for R for circular sewers for any given depth of flow is

$$R=\frac{\text{area}}{\text{wetted perimeter}}=\frac{\frac{2a\pi r^2}{360}-r^2\sin a\cos a}{\frac{2a}{360}\times 2\pi r},$$

$$=\frac{r}{2}\left(1-\frac{180\sin a\cos a}{a\pi}\right),$$

in which r = the radius of the sewer perimeter;

a = the number of degrees in the angle whose cosine is

$$\frac{r - \text{the depth of flow}}{r}$$

For the egg-shaped sewer (see Art. 15) somewhat different values are found.

TABLE No. 14

EGG-SHAPED SEWER

(D = horizontal diameter; H = vertical diameter)

d in parts of H.	d in parts of D.	p in parts of D.	a in parts of $D.^2$	R in parts of D.	$1.8587\sqrt{R}$	By Kutter's Formula.		d in Circular Sewer in parts of D.*
						Corrected Proportional Velocities.	Corrected Proportional Discharge.	
Full 1.000	1.50	3.965	1.1485	0.2897	1.000	1.00	1.00	1.209
0.667	1.00	2.394	0.7558	0.3157	1.045	1.06	0.69	0.750
0.333	0.50	1.374	0.2840	0.2066	0.846	0.77	0.18	0.354
0.267	0.40	1.159	0.20485	0.1768	0.781	0.70	0.12	0.284
0.220	0.33	1.012	0.15510	0.1532	0.727	0.63	0.081	0.228
0.200	0.30	0.937	0.13471	0.1437	0.704	0.60	0.064	0.214
0.133	0.20	0.706	0.07497	0.1062	0.606	0.49	0.030	0.141
0.067	0.10	0.463	0.0279	0.06026	0.455	0.33	0.008	0.075
0.033	0.05	0.321	0.0102	0.03177	0.331	0.23	0.002	0.039

* To give equal discharge in circular sewer of same capacity—i.e., one whose diameter $= 1.209D$.

By Table No. 13 it is seen that when a circular sewer is half full the wetted perimeter and area of flow are each half of that for a full sewer. When the depth is but $\frac{1}{4}$ the diameter, however, the wetted perimeter is $\frac{1}{3}$, the area of flow less than $\frac{1}{5}$, and R about $\frac{4}{7}$ that of a full sewer; and when the depth is $\frac{1}{10}$, the wetted perimeter is about $\frac{1}{5}$, the area $\frac{1}{19}$, and R about $\frac{1}{4}$ that of a full sewer.

In the last two columns we have the proportional velocities and discharges for various depths of flow, with allowance made for variations in c, calculated by Kutter's formula, with sufficient accuracy for ordinary use. The fifth column shows proportional velocities if c is considered as not affected by changes in R. A comparison of the fifth and sixth columns shows the effect upon the coefficient c of variations in R, since if $c=x$ for a full sewer, for one .2 full it equals $\frac{56}{69}x$ and for one .8 full $\frac{116}{110}x$.

Reference to Table No. 13 shows that if, in a circular sewer with a depth of flow of $\frac{1}{4}$ the diameter, the velocity is $1\frac{1}{2}$ feet per second (the minimum velocity of flow ordinarily permissible for house sewers), in the same sewer flowing full the velocity will be 2.3 feet per second. It also appears from this table that the greatest velocity is attained, not when the sewer is flowing full, but when the depth is .81 of the diameter, and that the maximum discharge occurs when the depth is .9 of the diameter. From this it follows that a circular sewer can never flow full unless under a head.

The Tables Nos. 11 and 12 for flow in sewers give the velocity and discharge for full sewers only, the velocity being the same for a sewer half full, while the discharge is one-half as great. They do not give the maximum capacity of the sewer, which is theoretically 1.07 times that given; but the velocity and discharge for sewers flowing full are most convenient for use and are on the safe side of exact accuracy.

Where it is desired to obtain the velocity or discharge of a sewer flowing partly full, the tables can be entered with the quantities corresponding to the other conditions, the velocity or discharge of the sewer as if it were flowing full obtained, and such part of this taken as is indicated by the above table for the given depth. For instance, if it is desired to find the discharge of a 10-inch circular sewer, grade 1 : 200, when the depth of flow is 0.4 the diameter, we find from the table that the discharge if running full would be about 650 gallons per minute; we multiply this by 0.33 and obtain 214 gallons, the volume required. Or, given the volume, 215 gallons, and the grade, 1 : 200, to find the depth of flow; we find the flow of a full sewer, 650 gallons, divide 215 gallons by this, obtaining $\frac{1}{3}$, and find the depth corresponding to this proportion of the flowing-full discharge, or 0.4.

The velocity obtained by the formula or from the table is that for a straight pipe of a uniform cross-section and condition of surface. In a system of sewers there are numerous curves, irregularities of surface, manholes, house-branches, etc., each of which may exert a retarding influence upon the sewage. It is thought that there is no appreciable diminution of velocities in a curve whose radius is at least five times the diameter of the sewer; but as the radius shortens, this loss increases—perhaps as the third or fourth power of $\frac{d}{c}$, in which d is the diameter of the pipe and c is the radius of the curve. The foaming or impact created by an angle, however, may cause a very considerable loss of head, and consequently sharp bends should be avoided unless it is desired to reduce the velocity.

The obstructions to flow offered by manholes, house-connections, etc., can be almost entirely avoided by careful designing and construction. That due to roughness of the material of construction should be kept low, but will necessarily be considerable, and should be adequately allowed for in the Chézy formula by modifying the value of c.

ART. 13. LIMITS OF VELOCITY

The formula for the quantity of sewage that will flow through a given sewer per second is $Q=Va$, in which a is the area of the stream flowing. It would appear that, given Q, V and a could take any value so long as $Va=Q$. a is, however, limited in its maximum by economic considerations, also sometimes by structural ones (see Art 14). If pure water were the material flowing through the sewers, V might vary from 0 to infinity, but it is limited within a comparatively narrow range by the character of ordinary sewage for the following reasons:

House sewage contains some matter that is slightly heavier than water, also much which is lighter; the former tends to settle in the bottom of a sewer, the latter to collect along the edges of the stream. Ashes, garbage, clothing, and other refuse matter should be kept out of the sewers by laws rigidly enforced, but in spite of all precautions such material will at times reach them. Dirt and sand frequently enter separate sewers through the ventilation holes in manhole heads or through defective joints in the sewer. As no system is perfect or perfectly managed, provision should be made for a certain amount of such matter. It is found that if the velocity of a stream be sufficiently great, matter suspended in the water will not be deposited, but a retarding of the velocity at any point may cause a formation of deposits there. Experiments have been made to determine the velocities necessary for flowing water to render it capable of transporting matter of various sizes and densities, though usually earth, sand, gravel, and stones have been used. The results obtained by DuBuat are those usually quoted, and are given as being approximately correct for channels of uniform cross-section. The velocities are those sufficient to move the particles along the bottom of the channel and are in feet per second.

TABLE NO. 15

MATERIALS MOVED BY WATER FLOWING AT DIFFERENT VELOCITIES

Material.	Bottom Velocity.	Mean Velocity.
Pottery-clay	0.3	0.4
Sand, size of anise-seed	0.4	0.5
Gravel, size of peas	0.6	0.8
" " " beans	1.2	1.6
Shingle, about 1 inch in diameter	2.5	3.3
Angular stones, about 1½ inches in diameter	3.5	4.5

Other experiments have given slight variations from these figures, but they are sufficiently accurate for ordinary use. It must be remembered that they apply to loose material only. Where clay or sand has formed a compact deposit in a sewer many times these velocities may be required to move it. Just which of these or similar materials the sewage should be given sufficient velocity to hold suspended is a question. But it has been found in practice that an actual velocity of 1½ feet per second will ordinarily suffice to prevent deposits where domestic sewage alone is admitted.

Where storm-water from the streets is admitted to the sewers, clay, sand, gravel, leaves, etc., as well as lighter matter are washed through the inlets. The velocities in these sewers should be sufficient to prevent the deposit of such material, which velocity, according to the table given above, would needs be about 3 feet per second.

The velocity given for separate sewers—$1\frac{1}{2}$ feet per second —is that which should be maintained as a minimum by the ordinary minimum daily flow; that for storm sewers—3 feet per second—is the least which should be attained in time of storms.

The average daily flow in separate sewers may be taken (Art. 9) as $\frac{4}{7}$ of the maximum to be provided for, and the ordinary minimum as $\frac{1}{2}$ of this. At night-time, when the absolute minimum usually occurs, the sewage is composed of comparatively pure water and a lessened velocity due to a shallower flow will not be particularly detrimental. Two-sevenths of the maximum volume for which the sewer is designed may therefore be assumed as that for which the velocity should be $1\frac{1}{2}$ feet per second. For reasons to be given, a separate sewer is usually designed to be 50 to 100 per cent larger than required by the assumed volume of sewage, so that the ordinary minimum can be taken as being $\frac{1}{5}$ to $\frac{1}{7}$ of the capacity of the sewer. Reference to Table No. 13 shows that this quantity is carried when the depth of flow in the sewer is .25 to .3 the diameter and when the velocity is .65 to .72 that for a sewer flowing full. It follows from this that the grade of a separate sewer should be such that the velocity when flowing full is at least $\frac{1.5}{.65}$ to $\frac{1.5}{.72}$, or 2.3 to 2.1 feet per second.

In the case of storm sewers, which carry no house sewage and are thus dry for a large portion of the time, it may be assumed that in general any storm that will wash any considerable amount of gravel and dirt into them will require at least one-third of the capacity of the sewer. Such grades should, therefore, be given these as will cause a velocity of at least 3 feet per second when the sewer is flowing one-third full, or 3.5 feet when flowing full. Smaller showers, which will give less depth of water in the sewer, it may likewise be assumed, will contribute only such matter as is transported by less velocities.

It may in some cases be necessary to construct sewers giving somewhat lower velocities than these, but this should be done only after careful consideration of the problem. Separate sewers should never be designed with grades giving a less velocity than 2 feet per second when flowing full, nor storm sewers with those giving less than 2.5 feet.

Where a combined sewer is in question—i.e., one which daily carries house sewage, but which also has sufficient capacity for and acts as a storm sewer—the requisite velocity must be obtained for both house and storm sewage. But except in very unusual instances a grade that will meet the requirements of house sewage will more than satisfy the demands of storm water transportation. For, since the maximum amount of house sewage per second per acre in a residence district will be about $\frac{80 \times 175}{7.48 \times 86,400} = .022$ cubic foot, while the storm-water from such an area may be 3 cubic feet per second, or 140 times as great, if a circular sewer is designed to give a velocity of $1\frac{1}{2}$ feet when it is carrying $\frac{1}{140}$ of its full capacity, its velocity when flowing full will be about 9 feet, or more than twice the desired velocity; while with an egg-shaped sewer under the same conditions a velocity of 4.7 feet when flowing full is obtained.

The subject of maximum velocities has received little attention, probably because the dangers connected with excessive velocities are not so great as those resulting from a too slow rate. Such dangers do exist, however. The more immediate one is that the consequent shallowness of the current which would in many cases result would occasion the deposit of the larger floating solids, which might result in obstinate obstructions in the sewer. In the mains this can be obviated by reducing the size of the sewer to the point where the necessary depth is obtained. But it is usually not in the mains but in the branches that steep grades are possible. To reduce the sewer to such a size as would give any considerable depth to the daily flow on very steep grades would call for a diameter much below that usually adopted as a minimum. An 8-inch sewer whose grade is 1 : 10 gives a theoretic velocity of 10 feet per second when flowing full. To secure a flow in this pipe having an average depth of 4 inches would require the sewage from a population of 6500.

As a general rule, it may be said that the ordinary depth of flow in any sewer should not be less than 2 inches; nor should it be less than ½ the radius of the invert, since if it is, there is much more danger of deposits forming along the edges and even in the center of the stream. It will sometimes be impossible to meet this requirement fully, but it should be kept in mind as extremely desirable.

Another objection to too great velocity is the danger of attrition of the sewer-invert by the scouring action of sand, stones, etc., swept rapidly over it. In brick sewers this objection is frequently and successfully met by lining the invert with granite blocks or hard paving bricks. Many old brick sewers have had their inverts entirely cut out by abrasion. So far no instances of serious wear in well-made concrete sewers have been brought to the author's notice; and the same is true of stone blocks and high-grade paving brick. Also few instances of serious wear of vitrified clay pipes are recorded.

The former objection is the serious one, since the time taken to wear out a sewer-invert must be considerable if good material is used, and replacing it is a matter of expense only. But the forming of deposits in the sewer endangers the health of the community.

It is difficult to set a maximum limit to the velocity allowable, but it may generally be taken as from 8 to 12 feet per second. From 3 to 5 feet per second is probably the most desirable velocity,

ART. 14. SIZE OF SEWERS

If a separate sewer were constructed to exactly meet the theoretical requirements as above outlined it would continually increase in size from the head to the outlet, by a small increment below each house connection, by a larger one below each tributary branch or lateral; but between the first two connections it should be of sufficient size to carry the sewage of one house only, which would be about $\frac{6\times175}{7.48\times86,400}=.0016$ cubic feet per second, which at a velocity of 2.5 feet per second would call for a pipe of .00064 square feet area, or $\frac{1}{3}$ inch diameter.

This method is not closely followed for the reasons that the data on which are based the calculations of volume of sewage as well as the formulas of flow cannot be exact enough to warrant it; that the estimate of ultimate population may be exceeded; that the per capita water-consumption may increase beyond the maximum assumed, factories or other large contributors of sewage locate at points where they were not expected, or for some other cause the amount of sewage reaching any lateral may be largely exceeded.

This excess can be allowed for in a general way by use of "factors of safety." It is advisable to design the laterals of a capacity double that calculated, particularly since the cost is not thereby largely increased, and the velocity in a sewer flowing half full is as great as that in one flowing full. The mains need not have so great an excess of size, since they carry the sewage from many laterals, and it is not probable that *all* these will receive double the calculated amounts of sewage. It will probably be sufficient to increase these by 50 per cent of the estimated capacity. The volume of sewage reaching the trunk or outfall sewer can be still more closely calculated, and an increase of 25 per cent may be made as giving it sufficient capacity. The greater the probable accuracy in forecasting future sewage quantities, the lower may be the factor of safety used.

With this increase, the head of each lateral would still be less than $\frac{1}{2}$ inch in diameter. This would be too small to adopt in practice for several reasons: because an individual house will contribute sewage at occasional maximum rates far exceeding 175 per cent of its daily average; because a very small sewer would be stopped too frequently by pieces of paper, or by other legitimate sewage matter; and because it would be too difficult of access for inspection and cleaning. The last two objections could, it is true, be met theoretically by making the house connection of a size so much smaller that nothing could pass it which would obstruct the sewer. But such construction would be impracticable.

There is no particularly good reason, however, why a house-connection might not be made of 2-inch pipe and the sewer of 3-inch or 4-inch; and systems are in existence and reported working satisfactorily where such sizes are in use. But such construction would generally compel a change in the stock dimensions of all house-plumbing and connected appliances, and give rise to inconveniences more than balancing the saving in cost. A 4-inch house-connection is, however, ample for any building containing less than 50 persons and which contributes only ordinary house sewage.

The sewer might, then, where the grade is fairly steep, be constructed as a 4-inch pipe from the head to such point as the calculations fix for an increase in size; but it is better to make the minimum diameter 6 or 8 inches, for then there would be less probability that anything passing the house-connection, in which the velocity may be considerable, would obstruct the sewer. It is thought that the weight of evidence tends to show that with 4-inch house-connections, 8-inch sewers are obstructed much less frequently than are 6-inch. Among other reasons for this is the fact that a 6-inch stick, chicken-bone, etc., will pass a 4-inch trap, but an 8-inch one will not; and that a 6-inch stick is more apt to become wedged across a 6-inch pipe than across an 8-inch one. Some engineers have used the 6-inch as the minimum to be employed for sewers, but the prevailing practice in this country is to use 8-inch. In England 9 inches is generally the minimum size.

In the case of storm sewers, the only change of conditions affecting the volume of sewage which is likely to occur is in the imperviousness of the contributing area. If this is taken at the maximum, as for a business district, no allowance need be made. In any case, the allowance for change can best be made in the selection of the factor of imperviousness and the sewer built of corresponding capacity. It is probable that no condition of size or character of tributary area will in actual practice call for a storm sewer of a diameter less than 10 or 12 inches, and 15 or 18 inches is used as a minimum by many engineers.

A 10-inch sewer flowing full at a velocity of 3 feet per second will carry 100 cubic feet per minute, or the run-off from a rainfall at a rate of 2 inches per hour on a totally impervious area of 0.8 acre, or a residential area of double that, or say 200 by 350 feet. A 12-inch sewer with the same velocity of flow would carry the same run-off from an area 50 per cent larger, or from the same area at a 3-inch rate. Consequently these sizes are no more than sufficient for inlet connections or a sewer fed through but one inlet. Moreover, the water, when it enters the sewer, quite generally has a velocity of less than 3 feet per second, acquiring this velocity only after flowing some distance. Methods of overcoming this will be discussed in the next article.

A circular or egg-shaped sewer is sometimes limited in size by the amount of covering necessary and the distance below the street-surface of its invert, where this is fixed by the elevation of the outlet and the necessary grade from that to the point in question. If the whole sewer at this point be lowered, the grade and velocity become less and the size of the sewer must be increased, thus raising the crown. The size can be reduced only by increasing the grade, which means raising the sewer. Under these conditions, the sewer can be built as an "inverted siphon" to flow under a head (Art. 22), two or more parallel smaller sewers can be substituted for the one, or the shape can be modified. In adopting the last alternative engineers have devised many forms which can be generally classified as those flattened on the bottom and those flattened at the top.

ART. 15. SHAPES OF SEWERS

Of all possible shapes of sewers of equal area of cross-section, the circular gives the greatest velocity when flowing full or half full and, having the shortest perimeter, contains the least material. Also, being devoid of angles, it offers little opportunity for deposits. For sewers intended to always flow at least half full it is, therefore, the most desirable shape from this point of view. This is not true, however, of a combined sewer—that is, one which carries both house sewage and storm water—for, as we have seen (Art. 13), the house sewage may occupy only $\frac{1}{140}$ of the capacity of the sewer and have a velocity only about $\frac{1}{6}$ as great if a circular sewer be used. If the sewer, considered as a storm sewer, be given a grade adapted to a velocity of 4 feet per second when flowing full or half full, the velocity of the house sewage would be about $\frac{2}{3}$ of a foot per second. If on the other hand the grade be so increased (which is seldom possible) as to give the minimum house sewage flow a velocity of $1\frac{1}{2}$ feet per second, the depth of this flow would be only about .02 of the sewer diameter. Neither of these conditions is permissible in a good sewerage system.

The result of adopting too flat a grade is shown by the illustration (Fig. 11) of obstructions in the old London sewers which came to be known as "sewers of deposit." These required frequent cleaning, since almost the entire sewage matter was deposited in them, and became very dangerous to the health of the city. The question thus forced upon the attention of engineers was first solved by building in the bottoms of the old sewers channels of much shorter radius of curvature. These, by increasing *R* and consequently *V*, as well as the depth of flow relative to the invert radius, had the same effect upon the flow as the use of smaller sewers, which they in fact were, and answered the purpose, practically the same design being employed in recent years in Washington, D. C., and other

American cities. It will be noticed, however, that there is considerable useless material in this design; also that the bench on either side of the small channel offers opportunity for the deposit of material, which may putrefy there. To meet these objections the egg-shaped sewer was designed and is used extensively for combined, and sometimes for storm-water, sewers. Several proportions have been suggested and used, but that most frequently found in modern American practice is represented here. The diameter of a circular sewer having an equal area is 1.209D. In this sewer

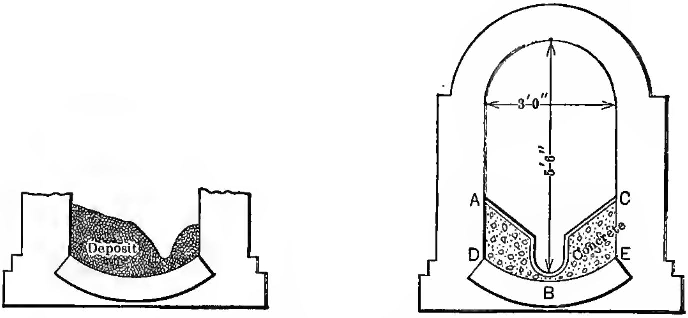
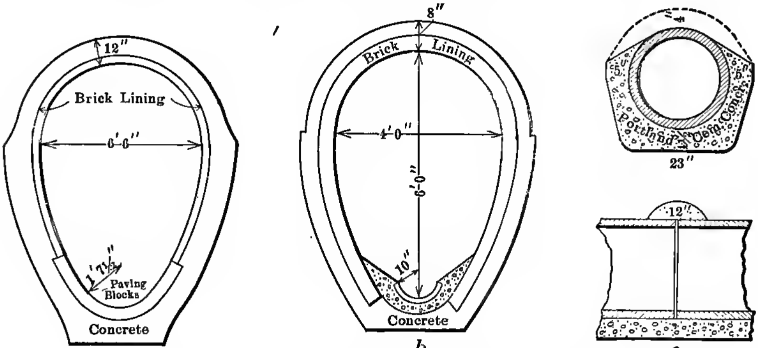


FIG. 11.—LONDON "SEWER OF DEPOSIT," AND SAME WITH MODIFIED INVERT.



a *b* *c*

FIG. 12.—WASHINGTON, D. C., EARLY STANDARDS.

a—Egg-shaped. *b*—same with modified invert. *c*—pipe bedded in concrete, with concrete collar at joint.

$$H = 1.5D, \qquad dc \text{ or } r' = 0.5D,$$

$$ef \text{ or } r = 1.5D, \qquad gh \text{ or } r'' = 0.25D.$$

Reference to Table No. 14 shows that a flow of $\frac{1}{140}$ of the full capacity of this sewer would have a velocity about 0.3 as great as if the sewer flowed full, or 85 per cent greater than the same amount in a circular sewer of equal total capacity; also the depth would be about $0.1D$, or $0.4r''$. If the velocity of the house sewage in the above be $2\frac{1}{2}$ feet per second (as it should be), that when the sewer were full would be 8 feet or more per second. This form does not, therefore, quite meet the requirements of a combined sewer, intended to carry a run-off of 3 inches from the area drained, as to either depth or velocity of house sewage. As we shall see later, this requirement applies to lateral combined sewers only, and this design is suitable for most combined sewer mains, whose maximum flow is only $1\frac{1}{2}$ or 2 inches run-off from the drainage-area. In laterals or other sewers, however, where the proportion of house to storm sewage will be too small, or for some other reason sufficient velocity and depth for the house sewage cannot be thus obtained, the adoption of an egg-shaped sewer with $r''=\frac{1}{6}D$ or $\frac{1}{8}D$, or a form similar to that shown in Fig. 12, is recommended; the purpose being, whatever the form adopted, to get a satisfactorily high value for R for the house sewage flow. Whatever the radius of invert, the grade must not be less than that which would be required by a circular house sewer having a radius $=r''$. The radius r'' should be so chosen, also, that the depth of house sewage will never be less than $\frac{r''}{2}$. A flat bottom should never be used for house or combined sewers unless the sewage will always be sufficient

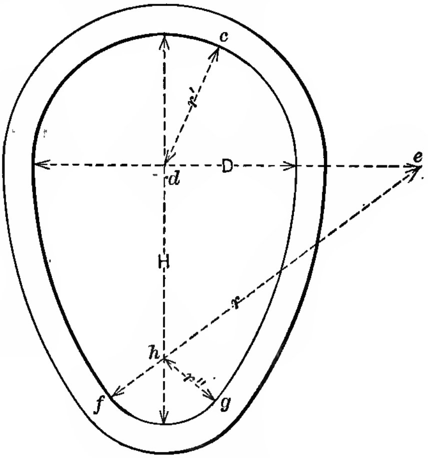


FIG. 13.—EGG-SHAPED SEWER.

to cover it at least 6 inches deep. Angles in the section are to be avoided as favoring deposits. In storm sewers it is advisable that the shape be such as to give good velocity to small amounts of storm-water, but the penalty of not following this rule is not so serious as in the case of house sewers.

Economy of construction will frequently require the use of other designs for sewers, as when built in tunnel, on special foundations, etc. These will be considered under the head of "Designing."

When entering a sewer from a storm-water inlet or a house-connection, the sewage too commonly does not have a smooth flow parallel to the axis of the sewer and of the desired velocity, but must flow for some distance in the sewer before this is attained. Much can be done to improve this condition by proper designing of intakes and junctions. The latter should be so designed that the sewage enters from lateral or connection to main sewer in a direction as nearly parallel to the axis of the main as possible. Inlet connections can be greatly increased in capacity if the upper or intake ends be given a flaring or bell-mouth shape, and if the inlet itself be so designed as to guide the street run-off into it with the least possible amount of agitation. Among other things this means the avoidance of all angles in the structure. In general, it may be said that angles should be eliminated altogether in all parts of a sewer system reached by flowing sewage unless it is desired to retard velocity.

CHAPTER V

FLUSHING AND VENTILATING

ART. 16. DEPOSITS IN SEWERS

IT is seen from Table No. 13 that if at any time the flow in a circular sewer becomes less in volume than $\frac{14}{100}$ of the full capacity of the sewer, the depth becomes less than $\frac{1}{4}$ the diameter and the velocity less than $\frac{2}{3}$ that for a full sewer. If the sewer is small, the former condition is apt to cause deposits by the stranding of floating matter on the edges or even in the center of the stream; if the grade is near the minimum, the velocity becomes less than is desirable and deposits result from this cause. Deposits are therefore apt to form in sewers that are larger than required for the actual flow; consequently the probability of deposits is greater during the early than the later use of a sewer. It is also apparent that, entirely aside from expense, it is unwise to make a sewer larger than is necessary, or to provide for too great a future increase in volume of sewage.

A 6-inch or 8-inch pipe is usually the minimum size employed for sewers, and to maintain a velocity of 2 feet per second in the former would require the average sewage flow from about 500 persons, and in the latter that from 900. Above the points where this volume is received the volume, velocity and depth of sewage are less than is needed for safety from deposits; and at the upper end only one or two houses contribute sewage. The discharge from any individual house comes usually not in a continuous flow, but in spurts of relatively large quantities separated by considerable intervals of time. When the sewage enters an empty sewer from a house-connection, it flows both down the grade and also up it for a short distance. The latter portion at the end of the discharge also flows down grade, but it has probably carried with it, and left at the upper limit of its flow, matter which remains there to putresce and perhaps form the beginning of an obstruction. Beginning in the sewer at practically nothing (since most of the initial velocity is destroyed by foaming), the velocity of such discharge continually increases (and the depth correspondingly decreases) with the distance from the point of entry. This frequently causes the stranding below the house-connection of large floating matter which is introduced from such connection; and although successive discharges may move this matter, each one a little further down the sewer, a long cessation of them may give it an opportunity to become fixed in its position. Discharges from connections higher up the grade will tend to prevent these deposits, two or more discharges occasionally coming simultaneously and uniting their volume; and generally the further any connection is from the upper or dead end of a lateral the less the danger of its causing such deposits. In a thickly settled district this danger in the case of 6- or 8-inch pipe becomes very small at a point to which there is tributary 1000 to 1500 feet of sewer. If the district is sparsely settled, however, the danger may exist for several times this length.

Any house sewer, but particularly a lateral, is liable to partial stoppage at times, due to ashes, sand, or other material introduced through house-connections, manholes, or infiltering through the joints or other defective places. Unless the velocity of flow is sufficient to carry this matter along, it will form deposits in the sewer-invert which must be removed in some way.

There is another class of deposits, composed of mycelial matter, which forms in most house sewers. This contracts the area of cross-section, retards the velocity of flow, and may become the breeding-place of micro-organisms; but it emits little odor and is readily detached and carried away by a strong flush of water.

The surface of flowing sewage lies in a continuously (although not necessarily uniformly) falling plane. Therefore, if there is a drop or sag in a sewer-invert, or a high spot or obstruction, the sewage will be deeper in the former or above the latter than in other places, the cross-section of flow will be correspondingly greater and the velocity correspondingly less. As a result, deposits are apt to form if the velocity is reduced below the critical point. This is especially true if some of the matter carried by the sewage is being rolled along the sewer-invert so long as this slopes downward, but cannot be rolled up the grade out of the sag by the reduced velocity. If a sewer drops entirely below the hydraulic gradient, it is always full of sewage, no matter what the volume of flow; and the velocity of flow through it equals such volume divided by the area of the sewer cross-section. Such a sewer is called an *inverted siphon.*

To *prevent* these deposits the only practicable way known is to lay all sewer-inverts true to grade, keep all sewers constantly flowing with a depth at least ½ the radius of the invert (additional water being introduced for this purpose if necessary), and also maintain a velocity of at least 1½ feet per second. To *remove* them the methods employed are either occasionally to turn through the sewer streams of water of sufficient quantity and velocity to dislodge the deposits and wash them down the sewer, or to employ shovels, hoes, "pills," scrapers, or other appliances designed especially for the purpose.

Prevention, if applied near a dead end, even in the case of a sewer laid at minimum grade, would require about 47,000 gallons per day for each line of 6-inch pipe and 83,000 gallons for each 8-inch line. For larger sewers the amount needed is correspondingly greater. These quantities it will usually be impracticable to supply; and were it practicable, the addition to the sewage of this amount in each of several laterals would compel a large increase in the size of the sewer mains, and greatly increase the cost of treatment in case this method of disposal was employed, and of pumping where this is necessary. There will occasionally be instances, however, where a convenient stream of water can be utilized to advantage in this way.

In general, a sewer in which there is a continuous flow with a depth of at least ½ the radius of the invert and a velocity exceeding 2 feet will need cleaning seldom, if ever, if legitimate sewage only be admitted. A layer of grease and dirt accumulates on the sides of many separate sewers, between ordinary high- and low-water mark, being deposited by floating grease and soap. It retards the velocity slightly, but otherwise its presence is not particularly objectionable. Scraping is generally necessary to remove it.

In cases of storm sewers where much dirt is washed from the streets by the rain water, it is common practice to attempt to prevent this entering the sewer by placing a depressed well or *catch basin* below the street inlet. In other cases a depression in the sewer-invert for catching matter rolling along the bottom, or an enlargement in section to reduce velocity and cause deposits, is placed at some point along the sewer, usually with provision for removing the deposits at intervals. This is not advisable if domestic sewage flows in the sewer, since deposits of the suspended matter in this will putrefy and cause offensive odors.

ART. 17. FLUSHING SEWERS

As stated, there are two general methods of cleaning sewers —flushing, and by the use of some kind of scraper or similar tool. The latter usually calls for no special provisions in the construction and need not be considered at this point. Flushing, however, is frequently accomplished by appliances built into the system, and hydraulic principles are involved. It is therefore necessary to consider it in designing.

Flushing may be done by hand, by automatic appliances, or by use of rain water. By the first, the sewer can be flushed from any manhole, as well as from flush-tanks; by the second, from fixed points only, usually the heads of laterals; by the third, the flushing-water enters from roofs through all or many house-connections, or in some instances inlets are so constructed as to store the rain water from the street-surfaces or from water-courses and flush with periodic discharges of the same.

The secret of successful flushing lies in compelling a large mass of water to move at considerable speed down the sewer. If the sewer be less than 24 inches or 30 inches in diameter, water should, if possible, fill it at least half full through the entire length needing flushing, in order that it may move with the maximum velocity possible. With the sewer flowing full bore at the upper end, the depth of the water will decrease as the flushing-wave progresses down the sewer and the velocity increases, until at some point below—the distance varying with the size and grade of the sewer, with the head of water at the upper end and the volume of sewage flowing—the depth and velocity of the sewage itself will be but little affected by the flush.

The initial velocity will depend upon the head and upon the facility offered the water for entering the sewer. There should be a free and open orifice at the entrance end, and if possible the angle between the inside of the sewer and that of the manhole or flush-tank should be rounded. Speed is of more value in flushing than quantity, and with a given amount of flushing-water, the more quickly it can be made to pass through the sewer the better. In most cases little if any benefit would result should a faucet be left continuously running in each house in a city, but one one-thousandth of the same amount of water used in a proper way and place would be of great benefit to the system.

Although for creating velocity the head in the flush-tank should generally be as great as possible, it must be limited by the amount of internal pressure which the sewer can stand without rupture. However, a head of 6 or 8 feet should not endanger any sewer, and ordinarily the practicable depth of the flush-tank limits it to less than this. In no case should the head be such as to back the sewage up house-connections and flood cellars or basements.

Flush-tanks are generally placed at the dead ends of sewers. When placed elsewhere, or when other means of flushing are employed, the flushing-water should be so applied that, as far as possible, the flushing-water will move down and not up the sewer, since the effect of the latter would probably be to sweep the intermediate deposits nearly to the upper limit of the wave and leave them there.

The interval which should elapse between flushings will vary under different conditions. In sewers where there is a constant ample flow of water, where stoppages are few and due solely to accident or to design of ignorant or malicious persons, flushing need be resorted to only when such stoppages occur. If it is found from experience that stoppages are frequent or that there is a constant depositing of material in certain sewers, or if it is foreseen that this will occur, frequent flushings of these should be provided for. In the case of a dead end of a separate or combined sewer, or one which has but few house-connections made with it, the flushings should be done once in each twenty-four or at least forty-eight hours.

Both separate and combined systems have been built and satisfactorily maintained without flushing at any point oftener than two or three times a year. It is probable that this is possible only where there is considerable ground water entering the sewers at their upper ends, or where the dead ends occur only in thickly populated districts and on grades a little greater than the minimum herein advocated. There is too little definite information on this subject to justify a positive statement as to when, if ever, flushing at dead ends may be profitably omitted. It is advisable so to arrange every separate or combined sewer, where the conditions will be those given as favoring deposits, that it can be satisfactorily flushed.

Investigations made of the effect of flushing appear to show that 300 gallons is in most cases insufficient to properly flush an 8-inch pipe, at least 400 or 500 being necessary for effective scouring; also that the effect of such a quantity is felt for about 800 to 1000 feet.*

In flushing by hand, the sewer may be stopped at the downgrade side of a manhole or flush-tank and this be filled to the desired height with water or by allowing the sewage to accumulate in and above it, the gate, plug, or other stopper, is

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* See also Transactions Am. Soc. C. E., vol. XL, pp. 1–30.

then removed and the water allowed to enter the sewer under the head due to its height. Where outside water is used for flushing and is limited in quantity, another stopper may be placed at the upper orifice, in the case of manholes, to prevent a flow up the sewer, and be left in until the flushing is over. The stoppers are made of various forms and to act in various ways, and to close the whole sewer or only the lower half or two-thirds if the sewer be large.

Some have advocated admitting roof-water to separate sewers, claiming that it is beneficial in flushing the sewer. If roof-water is admitted to small sewers throughout their length, there is great probability of its gorging the pipes and backing up into connected basements and cellars. In several cities great damage has been caused in this way. If it is admitted only at and near the dead ends it usually will be advantageous, but it should not be thought to take the place of all other flushing, especially where daily flushing is desirable. The sewers are most likely to need flushing at dry seasons, and this must then be done by hand or otherwise, and there is a danger that the presence of these roof connections will give a false idea that the flushing requirements have been entirely met.

In England the separate system, when first constructed, was designed to admit to the separate sewers roof-water and drainage from yards, and this method is still followed there to a considerable extent. But since the danger is so imminent and the benefits contributed at such uncertain intervals, most American engineers do not advise the admission of roof-water to small sewers.

Sewers are sometimes flushed by connecting their upper ends with convenient streams, or artificial channels filled from such streams, the water being admitted periodically by gates.

Tides are sometimes made use of for this purpose, the water being allowed to rise in the sewer at high tide and being held there by gates until the low tide, when it is released. Ordinarily only the lower reach of the outlet sewer can be flushed thus. A better method in some cases is to hold the water after high tide in a basin, from which it is rapidly discharged at low tide into the sewer to be flushed.

As in the case of Milwaukee, Bremen, and a few other large cities, the flushing-water may be pumped from a lake or river directly to the sewer. This is, of course, applicable within the limits of economy to very large sewers only, or to a system where a number of dead ends can be reached by a comparatively short line of force main.

The water for flushing is sometimes taken from the ocean or other body of salt water; but salt water mixed with sewage causes suspended matter to settle more readily and is corroding to any metal-work in the sewers. Hence its use is not advised by most authorities.

Automatic flush-tanks are in use in a large number of separate systems, but are seldom used for flushing combined or storm-water sewers, owing to the enormous quantities of water needed for that purpose. A great number of devices have been invented for flushing, but practically all of those now used are siphons in principle, so arranged that a tank in which they are set may fill gradually up to a certain point, when its contents are discharged rapidly into the sewer by siphon action. The tanks are made to contain at the time of discharge from 250 to 600 or even 1200 gallons for 6- to 10-inch pipe sewers. For larger sewers larger quantities are provided. The smaller quantities are of little use. No tank should discharge less than 250 gallons at a time into a 6-inch pipe, and correspondingly larger amounts into larger sewers. Five hundred to 800 gallons discharged into an 8-inch pipe once in twenty-four hours would be more beneficial than half of that amount at each of three or four discharges during the same time. The tanks should, of course, be watertight. They are usually built of brick or concrete (the latter often reinforced) plastered on the inside. Wood or steel could be used, but would not be so durable. They should be so built and arranged that the water may have the greatest permissible head above the sewer when discharging. (For details see Art. 42.)

The water may conveniently be admitted to the tank through a stopcock connected with the street-main by a supply-pipe passing through the tank-wall. This cock is continually left sufficiently open to cause the tank to fill and discharge at desired intervals. If the water is inclined to be muddy at times, the use of too large a supply-pipe will result in the choking of it by sedimentation; and tuberculation or corrosion may stop it if a metal so affected by the water be used. To secure a velocity of flow through it of 2 feet per second to prevent deposits would require a diameter of less than half an inch if 800 gallons is fed to the tank each twenty-four hours. Some meet the difficulty by using a larger pipe with a stopcock on the end which is kept nearly closed, but which is opened wide at intervals to flush out the pipe. Instead of a cock, a small orifice plate is sometimes placed at the end of the pipe, the size of the orifice determining the flow.

Where automatic flush-tanks are not used, some engineers have built into manholes at dead ends 2-inch to 4-inch pipes connected with adjacent water-mains and provided with gate-valves. This is probably the most convenient method of hand-flushing and the cheapest to operate. The cost at Mount Vernon, N. Y., averaged about $40 for installing each 4-inch branch and connection. In other cases the outlet in the bottom of the tank is provided with a plug or flap valve that is lifted by an attached chain when the tank is to be emptied; the tank being filled from the water main by a small pipe and stopcock, or by hose from a fire-hydrant.

Whether the tank be automatic or hand operated, the discharge pipe should be at least as large as the sewer; and it would be better to have it a few inches larger and bell-mouthed at the end so as to secure the maximum obtainable velocity of flow in the sewer.

Provision for flushing large sewers, and sometimes small ones, may be made by building in any manhole a gate of some kind that closes the sewer opening and allows the sewage to collect behind it, which gate can then be opened by an operator on the ground above.

ART. 18. SEWER AIR

In every sewer there is a space above the sewage filled with air, and this air will generally be far from pure unless kept in motion and frequently renewed. The odor accompanying all sewage, even when there is no decomposition proceeding in the sewer, is communicated to this air, and some gases due to putrefaction may be given off. This air probably is seldom motionless. It is influenced by the sewage to move down the sewer; it is warmer in winter and often cooler in summer than the outside air, which condition occasions motion when there is communication between the two; it is driven out of or along the sewer by sudden inflows of sewage from house-connections or branches and sucked in by decrease in the volume of flow; near the outlet, the direction and force of the wind affect it, driving it up the sewer or sucking it out; last, and most important, it passes into empty or partly empty house-connections and into proximity to, if not into the air of. connected residences. There is no "sewer-gas" which is deadly to human life, but air that has been confined in contact with decomposing sewage may become charged with sulphuretted hydrogen, ammonia and other gases that are objectionable to the smell and may be more or less detrimental to health, although the weight of evidence appears to indicate that no pathogenic bacteria are ever carried into house plumbing pipes by sewer air. In fact, the air in sewers where there is ordinarily good ventilation is generally found to be more pure than that in a theater, church or other room well filled with people.

The most serious pollution of sewer air is that due to gasoline, and next to this, illuminating gas. Gasoline is discharged into sewers by dry cleaning establishments and garages, and there vaporizes. When the vapor is mixed with a certain percentage of air the combination is highly explosive and may be fired by a spark from a horse's hoof on a manhole cover, a smoker's match, or possibly by spontaneous combustion. Hundreds of thousands of dollars' damage and several deaths have been caused by such explosions. The only preventive appears to be to prevent the discharge of gasoline into sewers; and there appears to be no remedy or preventive of explosion once it is in.

Illuminating gas leaks into the ground from most gas mains in greater or less quantities; and from the ground finds its way into sewers through openings in sewer joints, manhole brickwork, etc. It also is explosive, but is more dangerous for its asphyxiating effect on laborers in the sewer.

Sulphuretted hydrogen may combine with moisture on sewer-walls to form sulphuric acid, which will destroy the cement in joints or concrete walls. But the formation of sufficient gas to cause any serious effect is possible only when conditions in the sewer permit considerable deposits of organic matter to remain and putrefy indefinitely. Probably greater amounts of gas-forming deposits are to be found in house-connections and catch-basins than in sewers. (This will be discussed in the next chapter.) In many cases, odors attributed to sewers undoubtedly originated in basins or house-connections.

ART. 19. VENTILATING SEWERS

Aside from illuminating gas and gasoline, most of the objectionable gases in sewers are given off by putrefaction, and the prevention of this in the sewers is therefore most desirable. This is best accomplished by the removal of all sewage to the outlet before putrefaction can begin; and here is seen the advantage of daily flushing, cleaning the upper laterals of deposits before they reach the putrefactive stage. The use of disinfectants in sewage for this purpose is seldom advisable, chiefly on account of the enormous cost and practical difficulties of applying them, but also because the various and changing characters of sewage in different cities and from hour to hour may introduce such matter as will combine with any given disinfectant to produce deposits and gases fully as injurious as those due to sewage alone.

To prevent air from the sewer from entering houses, two general methods are in use: placing barriers in the house-connection or plumbing, and removing the sewer air through other outlets. The former is usually attempted by the use of traps. (In England, where deposits in sewers are much more common than in this country, elaborate flap valves and seals are used in the house-connections in a number of cities.) The latter is effected by natural ventilation or by the use of ventilating devices, in few or none of which has positive action been obtained successfully. A combination of these two methods gives reasonably good results in most cases, a partial obstruction to the air being placed in the house-connection or its branches in the shape of water-sealed traps, and the power of the air to force its way through these being lessened by ventilation.

Where the sewer is a tight conduit with no inlets or outlets except through the house-connections and the main outlet, the sewer air must remain constantly unchanged and stagnant, or must find exit and entrance through the house-connections. The first condition is impossible, for the amount of sewage varies from hour to hour and must displace, and in turn be displaced by, air driven to and derived from some outside source. In case of a sudden discharge of sewage into such a sewer, the air will be driven through the only outlets—the house-connections—unsealing the main traps, and the secondary ones also unless these be amply vented. A strong wind blowing up the sewer from the outlet may produce the same result. In addition to ventilating the sewer it therefore is advisable to insure a continuously free air outlet to every soil pipe.

Attempts have been made to constantly remove the air from sewers by either sucking out the foul air or forcing in fresh; that is, by producing a current through the sewer to a given outlet by either the vacuum or plenum process. Both have proved failures as well as very expensive. In no experimental case has the effect been felt more than 1000 feet from the fans or other apparatus, not only on account of the great amount of air in the sewer mains and laterals to be moved, but also because the traps in the house-connections were unsealed by the pressure and air was sucked from or forced into the buildings, according to the system employed.

The Metropolitan Board of Works, London, concluded, after exhaustive study of the question, "that the method of ventilation adopted in mines, where there are only two openings to be dealt with (an inlet for the air at one end and an outlet for it at the other), is inapplicable to sewers." This characteristic of a sewerage system renders impracticable all methods of ventilation depending upon one or two ventilators to each line of sewers, such as connecting the sewer-end with a chimney, which would afford little more ventilation than an untrapped soil-pipe at the same point or a special ventilating-manhole.

Many expedients for ventilation have been devised and tried —among them connecting the sewers to street-lamps, where a suction is caused by a constant flame, which also burns the sewer gas; placing in the crown of brick sewers small perforated pipes connected with "uptake shafts," expected to cause a continuous removal of the gases; leading pipes from the sewer to special flues constructed in houses, within the body of the walls, adjacent to the chimney, or upon the outside of the house and running up above all windows; leaving the main house drains untrapped and extending them above the roofs; placing flap-doors in the sewers, opening downward for the sewage, but closed to air, which can escape through openings just above such flaps; placing in the street center, at intervals along the sewer, manholes or other ventilating shafts with perforated covers; connecting the sewers by untrapped pipes with street-inlets at the curb line. In connection with these, charcoal and other deodorizers are sometimes placed at the air-outlets.

There seems to be evidence in favor of the conclusion that most odors and gases originate in the house-connections themselves and not in the sewers, although the latter should be prevented from contributing to this danger. Of many analyses of sewer air made, not one to the author's knowledge has shown a greater impurity than that in a crowded auditorium, whether CO_2, oxygen, or bacteria be taken as the basis of comparison. Equally positive proof goes to show that the average house-connection or the adjacent soil near open joints in the same does give rise to objectionable gases. (It is probable that the upper ends of lateral sewers, if not flushed well and often, are open to the same charge.) However, a rush of comparatively pure air from the sewer *forced* through the traps of a foul house-connection is as objectionable as though it itself were polluted, since it forces into the building the impure air existing in such connection. Air outlets to house plumbing should hence be of such capacity and so placed as to give full and immediate passage to all the air necessary to prevent forcing or siphoning of traps.

This fact, that the house-connections themselves are fully as foul as, if not more so than, the sewers, should be more generally recognized and better provision made for ventilating them. This is reasonably well done by placing a vent-shaft just above the main trap, continuing the soil-pipe above the roof and venting each trap throughout the house. But a still better circulation of air is obtained by omitting the main trap altogether and permitting the air from the sewer to pass through the house-connection unobstructed. The danger of this air passing the traps on house fixtures is then no greater than that of the soil-pipe air doing the same, and in the majority of cases the sewer air is the less impure. Such construction is also of great assistance in ventilating the sewer. If only an occasional house-connection be left untrapped, however, the odors from this may be objectionable, the sewer air being but little diluted by the infrequent openings. But the author knows of no city which makes this method compulsory in all connections where it is not perfectly satisfactory, and the leading sanitary engineers of this country advocate it for all cities, although many plumbers oppose it.

The use of street-lamps as outlets may sometimes be advantageous, but in this country the cities which have tried it have not found it of much value. The use of hollow electric-light poles was tried in Columbus, Ohio, in 1898, but was decided to be not worth adopting. The general use of flap-doors in the sewers presupposes a regular flow of air in a fixed direction through the sewer, which investigation has found does not ordinarily exist; but this use may be advantageous on steep grades, where there is a tendency for the air to rise past intermediate ventilating-points to the highest ones. Ventilation through manholes and other ventilating-shafts most, if not all, engineers recommend, although many do not consider these sufficient.

The use of storm-water inlets for ventilation is much opposed by many, who contend that the sewer air should not be discharged so near to passers-by upon the sidewalk. In fact, this same argument is used by a few against ventilation through manholes in the center of the street. It is believed that there can be no danger from this cause, since if there is such danger it is dependent, not upon the gases, which are enormously diluted upon reaching the outer air, but upon the presence of disease-germs in the exhalations, which has been disproven. Moreover, the average catch-basin, even if just cleaned (as this cleaning is ordinarily done), is more offensive than any rightly-designed sewer is at all likely to become; and it is extremely doubtful if, when combined with its odors, any contribution of air from the sewer could be detected. For these reasons it seems to the author desirable to connect the sewer with the street-inlets by untrapped pipes and to place manholes with perforated heads at intervals. Since the latter are apt to be sealed in winter by ice and snow, and in summer by mud, the additional ventilation through the street-inlets would seem to be advisable, particularly if the sewer be not ventilated through the house drains. A small amount of snow will not ordinarily stop the openings in a manhole-cover, owing to the warm air of the sewer, but a heavy storm or frozen mud may easily do so.

Since the proportion of air in a small sewer to the individual discharges into the same is much less than in the case of a large combined sewer, and consequently the effect of a given discharge is a greater compression of, and pressure transmitted by, the air in the smaller sewer, the sewers of the separate system need ventilation or safety-vents even more than do those of the combined. In case there are storm-water inlets to which ventilation pipes from separate sewers may be led, this method may be adopted; but ventilation through untrapped house-connections is probably more efficient.

The aim should be to secure for every sewer by whatever method the greatest possible number and freedom of communications between the sewer and the outer air; and there is little doubt that when this is realized the sewer air becomes so diluted and the organic matter floating in it so oxidized as to remove practically all dangerous and objectionable features. When this is not true, the sewers are probably in great need of cleaning and flushing.

CHAPTER VI

SEWER APPURTENANCES

Art. 20. Manholes, Inlets, and Flush-tanks

Manholes. A theoretically perfect sewer might work uninterruptedly without any attention; but the construction of such a sewer is practically impossible, in addition to which there is more or less misuse of sewers by those whose houses are connected therewith. All of which makes it essential that provision be made for obtaining access to every sewer in order to inspect it and remove obstructions from it if necessary. Such means of access is furnished by manholes.* In addition, manholes are used for other purposes, such as ventilating sewers, flushing by hand, shoveling snow into the sewers, and occasionally others.

Manholes should be placed at sufficiently short intervals to secure these results, but on the other hand should be as few as possible because of their cost and of the objection to the heads in the street surface. They should permit workmen to enter and work in them, but it should be difficult for others to gain access to them. They should offer the least possible obstruction in the roadway or sidewalk surface. They should be impervious against ground water and gases in the ground. They should be strong enough in all their parts to withstand any traffic loads that may come upon them or any pressure of the surrounding ground. They should be unaffected by any ordinary deteriorating influences, such as heat, cold, and moisture, They should have no moving parts to become inoperative by corrosion or rough or ignorant use. They should prevent the entrance of street dirt into the sewer, but should permit air

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* The first separate sewers in this country, those at Memphis, Tenn., were built without manholes, but a year or two demonstrated the necessity of them, and they were introduced in all new sewers and constructed along the lines of the old ones.

to enter into or escape from it. They should not in any way interfere with the continuous, uniform flow of sewage in the sewer which they serve. These features should be obtained at the least possible cost.

Inspection of a sewer requires that it be perfectly straight in line and grade between manholes (unless it be large enough to enter), and that it be possible to place the eye or a mirror in or near its center at every manhole. The smaller the sewer the less the length that can be inspected from one point. Proper inspection generally requires manholes to be not more than 300 feet apart if the sewer be 8 inches in diameter, 400 feet if it be 12 or 15 inches, 500 feet if 18 to 36 inches. A sewer 4 feet or more high can be entered for inspection.

To permit effective flushing by hand for removing occasional deposits, manholes should be not more than 800 feet apart. It is difficult to use rods or other cleaning tools where manholes are more than 400 or 500 feet apart. For sewers that are large enough to be entered, the manholes are used for access and for removing the deposits to the surface. If they are too far apart, the deposits will need to be carried too far in the sewer by the laborers before being raised to the surface, making the work expensive and slow. In these large sewers this consideration would limit the manhole interval to 500 or 600 feet, although even 1000 feet is sometimes employed where the necessity for cleaning is not anticipated.

For ventilation, the more numerous the manholes the better; but this is a secondary consideration in deciding as to spacing, since other ventilating mediums are more effective.

The generally desirable maximum distance between manholes, therefore, is 300 feet for 8-inch pipe, 400 feet for 10- to 15-inch, 500 feet for 18- to 48-inch, and 600 feet for the larger sizes.

The number of manholes can be kept a minimum for a given spacing by placing one at each sewer intersection, where it will serve both lines of sewer. This location is also desirable as facilitating special construction at the junction of the sewer channels. Sewers 36 inches in diameter or larger may have curves in their alignment, when a manhole should be placed at each curve. (Short lengths of sewers of this size can be entered for inspection and cleaning.) In smaller sewers curves should be confined to the bottoms of the manholes themselves, otherwise the curved portion will be inaccessible. Since the line and grade of a sewer between manholes should both be straight, a manhole should be located at every change in direction of either. The general rule, therefore, is to place a manhole at every intersection, at every change of line or of grade; and if there remain any lengths between manholes exceeding those named in the preceding paragraph, to introduce a sufficient number of additional intermediate ones.

Inlets are openings at the street level for removing the storm-water therefrom, which is then led to the sewer by inlet connections. They receive the water from gutters and therefore are placed in the gutter, or in the face of the curb or both, Inlets are also placed between the rails of street railway tracks in many cities, because the rails prevent the water from flowing from the track space to the gutter. Where two gutters both fall toward their intersection, there should be an inlet at such intersection. Where there is a continuous grade in a street across an intersecting street, an inlet should be placed at the upper gutter of the intersection; and, in general, inlets should be so placed as to obviate the necessity of water flowing across a roadway at any point. Street-water can, however, be made to flow around two sides of a block to one inlet placed at the lowest corner of the block, as in Fig. 9. In some small municipalities water is carried across roadways intersecting its course, either on or under the surface, where there is no storm sewer to receive it, but this should be avoided by sewer removal wherever possible.

In districts where the street traffic is considerable, and where any great depth of water in the gutters would inconvenience a large proportion of the population, the inlets should be not more than 200 or 300 feet apart; while in residence districts they may be so situated as to require the run-off to flow for 600 or 700 feet over the surface.

Instead of placing the inlet at the gutter intersection, it may be placed 15 to 30 feet above the intersection, so that the gutter-water need not flow past the cross-walk to the inconvenience of the pedestrians, and also that the vehicle trap caused by the corner inlet may be avoided. This practice is growing in popularity. Where both gutters fall toward their intersection, this requires two inlets, one in each gutter, in place of one at their intersection, but both may be connected with the sewer by a single pipe.

If there is a sag in the street grade between street intersections, there must be an inlet in each gutter at this point.

In general, inlets in the gutter intercept the water more completely than those in the curb face, and are especially desirable on steep hills where the water flows with great velocity and is apt to shoot past a curb inlet. Gutter inlets are more liable to be choked with leaves and trash, however, since they must be covered with a grating at the pavement level to carry vehicle wheels, and have other objectionable features. The curb inlet is therefore the more popular. Many cities use a combination curb and gutter inlet in one as more certainly insuring the withdrawing of water from the street.

In a great many cities a large proportion of the inlets are provided with catch-basins—more than the best practice would warrant, in the author's opinion. The object of using a catch-basin is to retain there the silt and other heavy matter removed from the street by rain water and not permit it to be carried and deposited in the sewer. Catch-basins should be cleaned after every storm, but in many cities several weeks usually elapse between the beginning of a storm and the cleaning of the catch-basin;* and during this time the organic matter which has been washed or thrown into the inlet, including horse droppings, fruit and vegetable refuse, etc., is putrefying and frequently emitting objectionable odors, which are commonly attributed to the sewer. If this organic matter had been carried on into the sewer it would probably have been carried

* The records of a considerable percentage of cities using catch-basins universally, show that the average frequency of cleaning is once in six to thirty-six months.

to the outlet; and even if it settled in the sewer, it would be less offensive there than near the sidewalks. In the latter event the sewer would need to be cleaned to remove the deposit; but it is found impracticable to intercept all suspended matter in catch-basins, and if the sewer grade is flat the matter carried on would be deposited in it and, although less in amount, would still necessitate a cleaning of the sewer. If not cleaned before it is filled with sediment, a catch-basin ceases to act as such; also the contained matter gives off odors and the basin is much worse than useless. Moreover, catch-basins are usually cleaned with shovels only, and sufficient filth is left upon the sides and bottom to become noticeable by its odors.

For these reasons the universal use of catch-basins is, in the author's opinion, not to be advised, but rather the inlet should be so designed that all material shall at once reach the sewer. Also he would make the inlet connection without a trap, that it may assist in the ventilation of the sewer; and if the sewer and its appurtenances are properly designed, constructed, and maintained there will be very few instances where any odor can be detected at the inlet.

There may well be locations where catch-basins are desirable, as where the wash from a steep hillside is intercepted, or for other reason a large amount of coarse soil finds its way to the inlet; and there the catch-basin will need to be large, that only a small proportion of this may reach the sewer, and should be cleaned after every heavy shower. A small catch-basin is worse than useless in most locations. Also catch-basins are often desirable where the sewer grades are very flat, giving a velocity of less than 2.5 feet per second, especially if the sewers are on the combined system.

Several engineers have become so convinced of the objectionable features of catch-basins already existing in systems under their charge that they have filled in such basins, changing them to plain inlets only.

Flush-tanks. A flush-tank consists of a well or underground tank, generally of masonry, placed at the dead end of a sewer, or occasionally at other points. The grades of laterals and the conditions of their use should be examined carefully to determine where frequent flushing will probably be needed. In some cases, such as where a flat grade on a long line of small sewer is unavoidable, it may be desirable to place flush-tanks, either automatic or for hand-flushing, at intervals of 800 to 1000 feet along its length, the tanks being placed at one side of the sewer and discharging into it through a short connecting-pipe. If automatic appliances are not to be employed, however, manholes at intervals along the line can be used for flushing by hand.

All the local conditions should be examined, that advantage may be taken of any opportunities for flushing offered by springs, streams, or any available sources of water; and, in general, decision made as to the places and methods of flushing. But in the great majority of cases the water main will prove the most satisfactory source of water.

Where a dead end is but temporary and the sewer is to be extended later, it may terminate in a manhole, so located as to be permanently serviceable, and this manhole used for flushing the sewer. Where two sewers flow in different directions from a common summit, one flush-tank may be made to serve for both, as a matter of economy in construction; but generally the two sewers can terminate a considerable distance apart, and the cost of laying a sewer across the intervening space will be greater than the cost of the second flush-tank.

ART. 21. SUB-DRAINS

Very frequently storm sewers are placed at such a short distance from the surface that they cannot be utilized for draining damp cellars, particularly since a cellar should be connected with no sewer whose *crown* is above its level, from danger of back-water when the storm sewer flows full. Ordinarily a separate sewer is below the cellar-level; but this should not be utilized as a drain, both because the amount of sewage may thus be too largely increased; and still more on account of the danger from sewer air, which would have free access through the drain should the trap-seal evaporate during a drought, which it is very apt to do, and from the cellar this air might permeate the entire house.

From a sanitary point of view the drainage of wet soils is almost, if not quite, as important as the sewerage and should not be neglected. The mere opening of sewer trenches tends to drain the soil, even after they are refilled. But in many cases it is extremely desirable to provide other and more positive drainage.

It is almost impossible to make a perfectly tight sewer without great expense, and when laid in wet ground, sewer-joints may admit in the aggregate large quantities of water. This could be prevented and the land adjacent drained, to its great improvement and that of the health of residents thereon, if this ground water could be lowered along the line of the sewer by some means.

During construction in wet ground, much trouble will be experienced, even when the pumping facilities are ample, by water rising and flowing over newly laid inverts, to their permanent injury.

These difficulties can each and all be met in most cases by the use of sub-drains—that is, drains laid a little below the sewers. These are ordinarily laid in a narrow trench in the bottom of, and at one side or in the center of, the sewer-trench. When properly designed to faciliate construction, their size will in most cases be sufficient for the continuous drainage of the land and also for cellar-drainage. The instances will be very few, however, in which any approach to an accurate estimate can be made of the amount of sub-drainage which will be required in a system. But provision should always be made for sub-drainage wherever the soil is wet, for permanent drainage if for no other purpose.

The water flowing into such drains must have some outlet, and the most natural course would be, when the sewage is disposed of by dilution, to place the outlets of sewers and sub-drains at the same point. It may happen, however, that the necessity for sub-drains is not foreseen when the sewer-outlet is being built; or the place where they will be necessary may be so far from this outlet that a great length of otherwise useless drain-pipe must be laid to reach it; also the amount of ground water may be so much greater than was anticipated, in spite of all investigations, that the drain-pipe near the outlet will not carry it all. In any of these cases another outlet may be desirable or necessary. This can frequently be found by leading the sub-drain in a special trench to a near storm sewer or natural watercourse. In some cases, however, special means must be resorted to, such as pumping.

If the sub-drain is necessary for construction purposes only, it may, during construction, drain to a sump-well where a pump is stationed; and be broken and sealed at several points after construction is completed. (This last will be necessary, as otherwise the drain would continue to lead the ground water to this point, which might become permanently and dangerously water-soaked.)

Although the sub-drain is in most cases smaller than the sewer, it must be laid at practically the same grade. The objection to flat grades in separate sewers does not apply to these so urgently, however, since the water flowing through them, after construction is completed at least, is usually free from suspended matter likely to cause deposits. The size and position, then, are the only elements of the general design to be decided upon. The size it will not be advisable to make less than 6 inches at the outlet for long stretches, but for stretches of a few hundred feet only and through ground but moderately wet 4- or even 2-inch pipe may be used. Pipe larger than 10 or 12 inches is seldom used in any but exceptional cases. If a larger would be required (and instances can be named where the sub-drainage from a small town would more than fill a 36-inch pipe) special methods may be employed; such as dividing the sub-drainage system into small sub-systems, each having its own outlet, which may, when constructed under a storm sewer, discharge into the sewer immediately above it, or which may be at a nearby watercourse.

ART. 22. INVERTED SIPHONS

"Inverted siphon" is the name given to a stretch of sewer that lies entirely below the hydraulic gradient. It is not really a siphon, and the siphon principle is in no way involved in its operation.

A sewer should fall continuously throughout its length, but sometimes this is impracticable. For instance, if a stream is to be crossed and the hydraulic gradient lies above its bed, this would require that the sewer be supported in the water or above it. The former is generally impracticable, for drift [illegible] stream, or it might obstruct [illegible] Carrying it above a narrow stream is [illegible] wide or navigable it may be too costly or interfere with the water traffic. The only alternative in many cases is to lay it in the bed of the stream, below the hydraulic gradient.

FIG. 14.—OUTFALL SEWER CROSSING VALLEY ON HYDRAULIC GRADIENT.

Where a sewer line is intersected by a large underground structure, such as a transit subway or large storm sewer, and the bottom of this is lower than the lowest practicable hydraulic gradient for this sewer, the sewer must generally be placed below the hydraulic gradient under the obstruction, rising again to the gradient beyond it.

Where a sewer crosses a wide valley (frequently a valley separates a city, or a section of it, from the treatment plant) the use of an inverted siphon across the valley is the common solution.

Since the ordinary sewer seldom flows more than $\frac{1}{2}$ to $\frac{2}{3}$ full, while an inverted siphon, being under a head, will flow full bore, the maximum velocity in the latter will be only $\frac{1}{2}$ to $\frac{2}{3}$ that in the sewer laid to the hydraulic gradient, if they are of the same size. On account of the difficulty of access and repairs, it is especially necessary that the velocity of flow in the siphon should be at least as great as that in the ordinary sewer, that deposits may be prevented. This can be attained only by reducing the size of the siphon-pipe. Moreover, this velocity should be had from the beginning of the use of the system; and therefore this size should be designed to give sufficient velocity to the sewage from the first. This first sewage flow may be doubled or trebled as time passes, and the increase may then be provided for either by giving originally sufficient fall to the hydraulic gradient of the siphon to produce the greater velocity necessary, or by additional siphon-pipes. Usually at least two siphon-pipes are laid at the first, so that while one is being emptied and cleaned the other may be used. The friction-head in the inverted siphon will be greater than if the sewer were laid to the hydraulic gradient, since the length of pipe is greater, and consequently the gradient must be steeper. The difference in elevation of the two ends of the siphon should be not less than the fall required by a sewer of the same size flowing full and of the length of the entire siphon (which is not the horizontal distance between its ends) to pass the given amount of sewage, plus an additional head to provide for that lost in angles, bends, etc. in the siphon.

The velocity of flow in an inverted siphon is entirely independent of the fall therein, but depends upon the quantity of sewage, since all of this must, but no more can, pass through it. If the fall in the inverted siphon itself is not sufficient, the sewage will back up the sewer until sufficient head is obtained to produce the required velocity. Hence, to prevent this, the fall in the siphon itself should be made great enough to create the velocity which will be required by the largest quantity to be passed at any time.

To provide for inspecting and cleaning a siphon, it is necessary to place a manhole at each end of it. In some cases this manhole serves as part of the siphon, the free-flow sewer entering it near the top and the pressure pipe at the bottom. Generally a better plan is to use falling and rising siphon-pipes, built in the manhole when they are vertical, and provide for access to them at the bottom of the manhole. Provision must also be made for shutting off the flow of sewage into any one of the siphons and pumping out the sewage already in it before opening it for inspection or cleaning.

The siphon in some cases does not drop vertically, but slopes down and slopes up again on the further side. In such a case a manhole should be placed at the low points and one at each change of grade or line. When the siphon consists of a vertical drop and vertical rising pipe connected by a comparatively level stretch, the latter should be straight and should slope toward one end to facilitate pumping out, inspecting and cleaning.

In some cases a part of the suspended matter in sewage is removed before it enters a siphon to lessen the danger of deposits in the siphon. For example, before entering a siphon 160 feet deep under Dorchester Bay, Boston's sewage passes slowly through large "deposit sewers," where the low velocity favors sedimentation; from which sewers the sediment is removed to scows and dumped at sea.

ART. 23. INTERCEPTING SEWERS AND OVERFLOWS

It often happens that a town lies in a valley and upon the slope on one or both of its sides, and that, while the valley district is too low to sewer to the outlet by gravity, the upper districts are sufficiently elevated to do so. In such a case it would be useless to carry all the sewage to a main lying in the bottom of the valley and pump it all to a gravity outfall sewer. Instead, a gravity main should be run up each side of the valley at the minimum grade, to receive all the sewage from higher up the hill, leaving only the sewage from below such main to be pumped. Such a main is called an intercepting sewer.

This term is also applied to a long sewer that passes down a valley and receives the sewage from several systems or parts of systems to conduct it all to a common disposal point. A sewer carrying to an outlet the sewage from several communities is called a joint outfall or outlet sewer.

It sometimes happens that, because a system must be extended further in a given direction than was anticipated or for some other reason, the amount of sewage contributed by a district becomes greater than the sewer mains can carry. This can be remedied by running an intercepting sewer across such gorged sewers at mid-length, intercepting the sewage from above and leaving the lower lengths to carry only their local sewage. Such an intercepting sewer is called a relief sewer.

Where storm-water flowing in combined sewers can find near outlets at many points to a stream or other body of water, at which outlets, however, the house sewage should not be discharged, an intercepting sewer may be run along and near the water to intercept the house sewage from all such combined sewers and convey it to a satisfactory outlet or to treatment grounds or works. By a construction of the sewers called an interceptor or by a mechanical contrivance called a regulator, the house sewage and the run-off from light rains (which is the filthiest of storm sewage) may be diverted to the intercepting sewer, while the run-off from heavy storms will reach the nearer outlet.

Another method of obtained similar results is that of putting storm overflows in the combined sewers, a special storm sewer taking the overflow sewage to a convenient outlet. The overflow is, in general, an opening in the sewer with its bottom forming a weir elevated some distance above the sewer-invert. Until the sewage reaches the height of this overflow it remains in the combined sewer and flows to its outlet; when the quantity becomes such that the height of sewage flow is greater than this, the surplus discharges through the overflow into the storm-water outlet. It is usually so arranged that this shall occur only when the dilution of house sewage by storm-water has reached the point where the mixture, when discharged into the stream in question, will not create a nuisance. A mixture with the house sewage of from one to five or more times its volume of storm-water is usually required, depending upon the relative flow of the stream and the sewer and other conditions to be discussed in Art. 68.

With either of these constructions, the overflow or the interceptor should, if possible, be at such an elevation that it cannot be reached by floods or tides backing up the storm-water sewer. The storm overflow method permits discharging both dry-weather flow and storm-water overflow at a higher level than does the interceptor method. The latter is more readily adaptable to modifying existing sewers for diverting dry-weather flow to a new outlet, or for keeping all storm-water from a treatment plant.

Art. 24. Sewer Junctions

Any departure from uniformity of cross-section or straight alignment of a sewer tends to reduce the velocity of flowing sewage; as does also the entrance of additional sewage at an angle to the direction of flow. To compensate for this, if the velocity as reduced would be below the minimum desirable, a slight additional grade may be given the sewer for a short distance. These retarding conditions are found chiefly at curves and at junctions of two or more sewers. To reduce the effect, the radius of each curve should be made as long as practicable. For small sewers, where the curve is confined to a manhole bottom, the radius is limited by the size of such bottom, which is seldom made more than 5 feet wide, which limits the radius of the axis of the sewer to 2½ or 3 feet for a 90 degree bend. If the theoretical velocity of flow in this sewer is less than 3 feet per second, it is desirable to make an additional drop in the invert grade in the manhole of one- or two-tenths of a foot.

The junction of two sewers, where both are less than 3 feet diameter, should be made at a manhole, and this is generally the practice for the larger sizes also. If it is a case of a small lateral, as an 8-inch, discharging into a large main sewer, the effect of the discharge of the smaller into the volume of the larger flow will be slight. But if the lateral joins one of the same size or whose diameter is not more than two or three times as great, the effect may be a considerable disturbance of flow and retarding of velocity. This should be minimized by curving the branch sewer so as to make it, at the junction, as nearly as possible tangent to the main or the sewer whose line is continued through the manhole. At the best there will be some disturbance, and there should be a drop of a tenth or two in the invert between the junction and a point a few feet further down the sewer.

The least disturbance will be occasioned when, in all the sewers at a given junction, the sewage surface is normally at the same level. That is, if a sewer designed to flow half full joins one designed to flow two-thirds full, the center of the former should be at the same elevation at their intersection as a point two-thirds the diameter of the larger above its invert. If the smaller sewer were set at a lower grade, the sewage in it at and for some distance back from the junction would be deeper than half the diameter, and the velocity would be reduced accordingly. Another objection is that this greater depth would interfere with the inspection and cleaning of the smaller sewer.

Where the lateral probably will not flow continuously, it is desirable to keep its invert at the junction entirely above the surface of ordinary flow in the main sewer, as the branch channel below such surface would retard the flow in the large sewer;

but if the lateral will flow continuously it is desirable to have the two surfaces of flow at the junction as nearly at the same level as possible.

When a sewer increases in size or changes its form of cross-section, it should do so gradually so as to minimize the loss of head. If the vertical diameter increases, the top of the sewer should continue at the same gradient and the invert drop on a slope an amount equal to the increase in diameter. If the horizontal diameter increases and the vertical decreases, leaving the area of cross-section the same, theoretically the centers of gravity of the successive cross-sections might continue on a uniform slope, the invert rising; but it is desirable to continue the invert on a uniform slope instead, both to give additional fall to compensate for the loss of head, and especially because, if the sewer should flow less than half full, the rise in the invert would dam back the sewage.

Most of the above statements are based on the assumption that the normal velocity of flow in the main is theoretically not more than 3 or 4 feet per second. If greater than this, and especially if greater than is desirable, these precautions are unnecessary; in fact, obstructing the flow in these and other ways may be advantageous. But the possibility of abrasion or rupture of the sewer by too great agitation of the sewage must not be overlooked. Another objection to agitation is that by it suspended organic matter will be thrown up upon the sewer walls, where it may remain and putrefy.

ART. 25. HOUSE AND INLET CONNECTIONS

The connections between the sewers and houses and storm-water inlets are of an importance second only to the sewer mains. Any defect in one of the connections, while limited in the range of its effect, is fully as detrimental within that range to the proper working of the system as a defect in the main itself. Since the house-connections are subject to extreme fluctuations of discharge and hence to stoppages, as also to the formation of grease deposits, it is desirable that they be equally as accessible as sewer mains for both inspection and cleaning, and also that their grade and alignment be given equal care in both the design and the construction. They should, if possible, be given a uniform grade of not less than 2½ per cent. Where the house sits back from the street, an observation-hole at the property-line is desirable and one should be placed wherever there is a change in the line or grade. There should also be a hand-hole in the pipe just after it enters the cellar. The junction with the sewer should be made by means of branches, either Y or T. It should never be made in pipe sewers by breaking a hole into the shell and inserting a pipe. If the sewer be larger than 24-inch a T is advisable; both because this offers easier inspection of the house-connection from its lower end, which inspection can be made by a person entering the sewer, and because the branch can be placed entirely above the ordinary level of the sewage, which position it should occupy when possible, so as to cause no interference with the sewage flow. When the sewer is too small to admit a man (which size will also not admit of raising the branch entirely above the ordinary sewage flow without giving it too steep a pitch), a Y branch is preferable, because this will retard the flow less than a T, and because the house sewage will enter the sewer at a less angle with its flow. The vertical angle which the branch makes with the horizontal should not ordinarily exceed 45 degrees in small sewers, because of the interference with the flow and of the splashing caused by a vertical drop of sewage into their relatively small stream, and because of the danger that the weight of the house-connection may break in the crown of the sewer.

It is well to so place the branch in masonry sewers that a trickling discharge from it will flow over the surface for the least possible distance, that deposits from such discharge may be avoided. In the case of combined sewers this would call for placing the branch but a short distance above the invert, but it should be given such a grade as to bring it higher than the crown of the sewer when it reaches the cellar.

Some engineers always use T branches, more always use

Y branches, for house-connections; but the practice here recommended seems to best utilize the advantages and avoid the disadvantages of each.

The connections from inlets should never enter the sewer at an angle with its axis greater than 45 degrees, on account of the great disturbance to the flow which would be occasioned. Where possible, and particularly in small sewer mains, a manhole should be placed where each connection enters the sewer, and the connection be continued by a curved invert in the bottom of said manhole.

It is difficult to calculate the proper size for a storm-water connection; but, since there is little disadvantage in having it larger than is actually required except the cost, and these connections are so short that this is not considerable, while the effect of too small a pipe may be disastrous, it is advisable to make the size fully ample to discharge all the run-off from the heaviest storms. A 12-inch pipe is probably the smallest which should ever be used; while a 24-inch may be required if the sewer lies near the surface (thus giving little fall to the connection) and if the tributary area is large. Where considerable undeveloped territory drains into the head of a sewer-main, or a small stream is received there, it may be necessary to continue the sewer to the inlet, not only not diminished in size but even enlarged into a bell mouth.

A bell-mouth construction is advisable for all inlet connections, and the upper few feet must be larger than the remainder of the connection if the latter is to run full, since the velocity of flow into the entrance will seldom be as great as that nearer the sewer. Theoretically the best construction would consist of a bell-mouth entrance and a pipe tapering nearly or all the way to the sewer. But this construction would be difficult and expensive, and is seldom, if ever, adopted. A flaring entrance, however, is practicable, and the entire length of the connection should be of as large a diameter as that required to admit the water to the connection under the pressure due to the head from connection mouth to street surface.

ART. 26. USE OF OLD SEWERS

In many cities, before any general sewerage system has been constructed or even thought of, short conduits, both private and public, have been built, discharging at the point nearest to hand—usually a stream or lake. These are often built in the crudest manner, graded by eye, and generally larger or smaller than necessary. In other cases the sewers are well built and graded and of a size adapted to remove the storm-water, but the outlet is located where house sewage should not be discharged, or the sewer is not sufficiently deep to permit of receiving all house sewage, or it is a pipe sewer and is not provided with sufficient branches for house-connections. Such sewers can frequently be incorporated into the proposed system, and a saving made of the cost and the tearing up of the streets avoided. But a thorough examination of them should first be made to ascertain which ones can be so used and how.

If they are sufficiently large they should be entered and their condition learned as to size, grade, character of workmanship, etc. If the brick-work is very rough it may be desirable to clean it and plaster it with cement mortar. It may be cleaned for this purpose by washing first with dilute muriatic acid, then with a solution of potash, and then with water.

No connection pipes should be allowed to protrude within the sewer. If the junctions are not well designed they should be torn out and rebuilt. If necessary, a sufficient number of manholes should be built to bring the intervals between them within the proper limits. If it is desirable to use an old circular sewer as a combined sewer, the invert can be narrowed as shown in Fig. 33.

If the sewers are too small to be entered, they should be examined thoroughly from the manholes; "pills" (wooden balls a few inches less in diameter than the sewer) should be floated through them to ascertain whether the bore is of uniform size and clear of deposits, or this be ascertained in some other way. Their size, grade, elevation, etc., should be learned by actual measurement. If they are not laid in straight lines, particularly those less than 12 or 15 inches in diameter, it is doubtful if they should be used, unless manholes can be so located as to give straight stretches of the sewer between them.

If a pipe sewer lies too high for efficienct service or at too flat a grade, a trench may be dug down to it and the pipe taken up, cleaned, and the good ones relaid at a lower level or better grade in the same trench. In the majority of cases this probably will be the best disposition that can be made of old pipe sewers. But if it requires much additional excavation to recover the pipes it will be a waste of money to do so.

Owing to the difference in character and volume of house and storm sewage, a sewer not adapted for use as a separate or combined sewer may often be used as a storm sewer. It frequently happens that old combined sewers, or even the larger separate sewers, are admirably adapted to this use, and a separate system can then be built for the house sewage.

If an old combined sewer, or storm sewer modified into a combined sewer as explained above, can be used, except that the house sewage should be discharged at a new and more distant outlet, this sewage can be discharged through an interceptor, or diverted by a mechanical regulator, into an intercepting sewer, and the old outlet used to discharge the storm-water only.

But the efficiency of the system is of greater moment than small economies, or even large ones, and should not be sacrificed to them.

ART. 27. PUMPING SEWAGE

WHEN PUMPING IS NECESSARY

Pumping house sewage is employed continuously where

(1) A section of a city is too low to drain by gravity to any acceptable outlet. This section is then provided with a system of its own, draining to one point, at which it is pumped

through a force main (generally of cast iron) into a main leading by gravity to the outlet.

(2) Where all the sewage of the city is collected at one point near the body of water that is to receive it, but below the level of such water, and is there raised to such level.

(3) Where a ridge separates a part of the city from the outlet. In such case there may be the alternative either to pump the sewage over the ridge, or to carry it through the ridge by tunnel or deep cut construction.

(4) Where, owing to flat land and a long outfall, or other conditions, a continuous grade to the outlet not only would bring this much below the surface of the water that is to receive the sewage, but also would require that a considerable part of the mains or outfall sewer be laid at a too expensive depth below the surface. In such case a number of pumping plants sometimes are located at intervals along the mains, which then consist of a series of lifts (generally vertical) and long, flat inclines, alternating.

(5) Where a treatment plant is required and must be placed higher than the outfall sewer. In such case the pumping plant is commonly placed close to the treatment plant for convenience and economy of operation.

Pumping house sewage is employed intermittently where

(6) Occasional high water in a stream receiving the sewage would back up the sewer and perhaps flood connected properties. A gate (to exclude the high water from the sewer) and pumping plant are then placed at each outlet and the sewage pumped into the stream during such periods, but not at other times. This plan is generally practicable for separate systems only.

(7) Unusually high tides at ocean outlets would have the same effect. Where each high tide backs up the sewer, but the outlet is free at low tide, pumping during the former period is desirable, although the expense may not be considered warranted.

Storm-water is almost never pumped, because of the enormous amount to be handled. (New Orleans is a notable exception to this.)

For Case 1, the only alternative to pumping is omission of the low area from the sewerage program, unless it can all be raised by filling in. It may be omitted from immediate construction, but should always be provided for in the plans; and the main into which the sewage from this area is to be pumped should generally be given capacity for removing the sewage from it whenever in the future pumping may be adopted. The force main should be made as short as possible, since it is much more expensive than a gravity main and house-connections cannot discharge into it.

[illegible] GRADIENT ABOVE STREET SURFACE.

[illegible] pipe in hollow wall along the side of a fill across valley.

may occur because the ground generally is flat, because there is little fall from the head of the outfall to the outlet, or because of a low area at some point along the route of the outfall or of one of the mains. The last case may sometimes be solved without pumping by using an inverted siphon, or better still by carrying the main through on the gradient, letting it come above the surface where necessary. Where so elevated, the grade of the street should ultimately be raised sufficiently to cover it if possible. If not, the main may be carried on a trestle or built into a masonry wall along the side of the street, where there are no intersecting streets or other local conditions to make this impossible.

Case 3 can in some cases be solved by carrying the sewage by gravity to the natural drainage outlet of the land in question; by arranging with an adjoining city to remove it if the outfall enters the borders of such city, or by treating it if necessary to discharge it into a stream so small that the untreated sewage would create a nuisance. But pumping may be cheaper than building and operating a treatment plant or than building a long outfall to another outlet.

Case 4 may be considered as Case 2 with the added feature of considerable and expensive depth of sewer throughout a long distance. The outfall, beginning a few feet (possibly 5 or 6) below the surface at each pumping station, continually falls and reaches a maximum depth that is generally greater the greater the distance to the next pumping station. The less the distance between pumping stations, the less the average depth of the outfall and resulting cost and the less the lift at each station. The number and location of pumping plants are generally decided upon the basis of which will cause the least annual charges (interest and sinking fund, maintenance and repairs). If all the lifting can be done at one or two points, it is usually most economical to so arrange it, even at great expense for excavation. It would be possible in many cases to use only one pumping station, all of the outfall sewer beyond it being laid at a practically uniform depth, regardless of grade, and acting as a force main; but the cost of such a main, since it must withstand pressure, would be several times that of a gravity main, and deposits would be apt to form near the bottom of any rising grade. It is evident that no house, inlet or other gravity connection can be made with a pumping main, inverted siphon, or other sewer under internal pressure.

Case 5 is more or less common because the outlet of a treatment plant should be above the highest water, while there is more or less head lost in the plant itself (10 to 15 feet fall is required for tank treatment followed by sprinkling or contact filter). Even where the topography would permit bringing the sewage to the plant by gravity, it may be that the outfall was built before treatment was considered, and when the treatment plant is built either the sewage must be pumped or the outfall and a part of the system be rebuilt. If the combined system is used and can be laid at such an elevation as to discharge into a stream by gravity, the outlet can be so arranged that the storm sewage will so discharge but the dry-weather flow and light storm run-off will be pumped, the separation being effected by interceptor, regulator, overflows, or other method.

Case 6 also may result from change in conditions, which cause higher water in a stream than was anticipated when the plans were made. Or it may be practically impossible to lay the outfall high enough to discharge above the level of the highest freshets, or more expensive to do so than to install and occasionally use a pumping plant.

In case 7, if pumping is not employed, the high tide backing up the outfall sewer compels it to flow full at the lower end, thus reducing the velocity to $\frac{\text{cubic feet per second}}{\text{area of sewer in square feet}}$, which diminished velocity will probably cause deposits. The length of sewer so flooded may then be made only large enough to carry the sewage for three to five years to come, thus increasing the velocity when flowing full; adding another outfall sewer when the increased amount of sewage demands it.

In case 6, and in case 7 when only occasional tides flood the sewer, efficiency and low cost of operation of pumps are of much less importance than cost of installation, since operation will be so infrequent. It is desirable to locate the plant where power can be obtained from an outside source—electricity from a power or traction company, steam from the boilers of a factory or water-works pumping plant, etc.—which will cost less and be more reliable in an emergency than creating energy in a plant operated at very infrequent intervals.

In all of the above cases an effort should be made to reduce the amount of sewage to be pumped by carrying to the outlet or treatment plant by gravity, generally through an intercepting sewer laid at a minimum grade, sewage from so much of the city as lies at a sufficient elevation to permit this.

In any case where low land causes the necessity for pumping, it is decidedly preferable, for other reasons as well as for sewering (although, of course, more expensive) to raise the streets and sewers generally throughout the low area a sufficient amount to permit gravity discharge. (The city of Chicago, when rebuilding after the fire, raised the streets over its entire area. chiefly to secure better drainage.)

PUMPING PLANTS

Sewage pumps must handle water containing more or less suspended matter, and at constantly varying rates. A pump cannot ordinarily vary its rate to meet instantly every variation in sewage flow, and therefore more or less storage is required at a pumping station to provide for the continuous variations from minute to minute, and in some cases the greater variations from hour to hour. The amount of storage should be the least that is safe, for deposits are liable to form in the storage tank (which is generally an enlarged suction well) unless the sewage therein be kept constantly in motion, and the cost of underground storage is considerable. For this reason, also, pumping is generally continued night as well as day.

Even with storage, there must be a considerable variation in the rate of pumping in most cases; as a general thing, the smaller the amount pumped the greater the variation. This variation may be obtained by varying the speed of the pumps, by varying the number of pumps in action, or by intermittent pumping. In most cases the two latter are combined.

It is desirable to screen sewage before pumping it, to remove sticks and other large substances that might clog or injure the pumps. But the screens should not intercept small matters like pieces of paper and fæces (unless located at and serving as part of a treatment plant), since the presence of these in the screenings makes it difficult to dispose of them without offense. Also it should not be possible for the screen to become so clogged as to prevent free flow of the sewage through it.

In a general way, any kind of plant used for pumping water may be employed for pumping sewage. But pieces of paper, rags, match sticks and the like are likely to interfere with the operation of valves and other moving pump parts, and for this reason reciprocating pumps are seldom employed, although they offer the advantage of permitting considerable variation in speed. Largely for this reason, they are sometimes used for large plants, where attendants are always present, fine screening being employed and special provision made for frequent removal and immediate disposal of the screenings. Centrifugal pumps, however, are most commonly used, since there is little danger that small floating matters will interfere with their continuous action. Another contrivance used for sewage pumping is the pneumatic ejector, in which the sewage is raised intermittently by compressed air acting expansively on the surface of sewage in a pot or tank.

For operating pumps, any of the common steam, gas, gasoline, or kerosene engines, or electric motors may be used. Steam is probably most common for large plants, electric motors for the small ones. The chief advantage of electrical operation for small plants is that they can be made to operate automatically, receiving no attention except a daily visit for inspection and oiling.

A type of plant that has almost become standard consists of a vertical, submerged, centrifugal pump, driven by an electric motor direct connected to the upper end of the vertical pump shaft. The motor is started and stopped by a switch that is operated by a float in the suction well. When the sewage rises in the well above a certain level the pump is started, and continues to operate until the sewage is drawn below a certain lower level, when it is stopped. If the sewage continues to rise during pumping, a second float starts a second pump operating. A third pump started at a still higher level should be provided against a stoppage of either of the other two.

While the pumps are below the low sewage level in the suction well, they are preferably in a dry well, between which and the suction well is a tight wall, through which the suction pipe passes. There should always be two pumps and preferably three or more, one for reserve and as a third-level emergency pump, one or more for peak loads, and one or more others with capacity for all but the peak loads. This throwing in and out of service of supplementary pumps is necessary, since the centrifugal pumps so operated cannot vary their velocity, while the rate of flow of sewage into the suction well varies considerably. To insure that a pump will be "primed" when its motor starts, It is necessary that the sewage flow into it by gravity.

The motors should be of sufficient capacity to operate their pumps continuously at maximum flow and head and be provided with overload stopping devices to shut off the power in case of a clogged impeller. If an operator is always present at the plant, a tell-tale device should be used to show what pumps are operating. If it is not under constant inspection, a float should, by closing an electric circuit, operate a bell or whistle where some one is always present, if the sewage in the suction well should rise above a given level, indicating the failure of a pump to function.

The amount of storage and number and capacity of pumps required for reliable and economical operation depend upon the maximum rate of flow and frequency and amount of variations in rate. It should not be necessary for a pump to stop and start more frequently than two or three times an hour. The greater the storage capacity the less frequent the stops; but on the other hand, the less the storage the less the danger of sedimentation in the well and resulting putrefaction, and the less the cost.

A pneumatic ejector is operated by compressed air. Where there is pumping at more than one point, the air may be piped to all points from a central plant or be furnished by an electrically-driven compressor located near each ejector. The cost of one large compressor plant and the necessary air pipes, together with the cost of operation and loss of energy by transmission, is to be balanced against the cost of several individual plants and their cost of operation. The efficiency of the central plant system is greatest when the lift by all the ejectors is practically the same. The ejector is especially adapted to small quantities of sewage or great variations in quantity. Sewage flows from the sewer directly into the pot or chamber of the ejector, and when it has almost filled this, it opens a valve in the air-pipe, admitting compressed air from above that forces it into the rising or pressure pipe. No storage tank is required, and the ejector, if large enough, adapts itself to any rate by its frequency of operation. The compressor is generally operated by electricity and started and stopped automatically, so as to keep the air in the air reservoir at the proper pressure. A duplicate ejector and compressor should be provided to permit repairs or cleaning of either.

Fig. 16.—New Orleans Pumping Station Superstructure.
Automatic electric plant under ground.

From no pumping station need there be any odor, with good management. The suction well and screen are the only parts of the plant where odors are at all probable. The former should be so designed and operated as to prevent sedimentation or stagnation and consequent putrefying of any part of the sewage. Pumping plants can therefore be placed at any convenient point. The small pumping plants and pneumatic ejectors are usually placed in vaults beneath the surface, the larger plants above ground. The sewage-pumping stations of London, Berlin, New Orleans, and other cities are within the city limits, no odor whatever being perceptible near them.

Eighty plants are described in *Municipal Journal* for March 18, 1915, of which 52 were motor-driven centrifugal pumps, 10 were centrifugal pumps driven by steam engines, 3 centrifugal pumps driven by gasoline or gas engines, 5 were reciprocating pumps, and 10 were pneumatic lifts.

CHAPTER VII

COLLECTING THE DATA

ART. 28. DATA REQUIRED

ANY plans made before the full and complete data are at hand may be shown by further information to be inadvisable, while their very existence may create a prejudice against the substitution of more efficacious ones. Therefore, although the development of the plans may suggest the desirability of further data the necessity for which was unforeseen, all such data should be collected and surveying done preliminary to any designing as would seem to be necessary for completing it.

The first necessity will be for a map of the district under consideration. This will usually include the city or town and all land over which it may spread in the future; also all adjacent areas which shed their water into or across the surface of this territory. This map should show all streets, lanes, etc.; all parks or other areas permanently devoted to vegetation; all rivers, creeks, ponds, or other bodies of water—in fact, all natural and artificial divisions of the area embraced by the corporate limits. It usually happens that this much can be found already mapped for other purposes; but unless it is known that the measurements from which such map was prepared were accurately taken, a sufficient number of check measurements should be made to establish its accuracy or the reverse. On the point of accuracy a question may arise as to how exactly the measurements should be taken. If these should involve an error of no more than .2 per cent they would be sufficiently accurate for the work in hand. For, as sewer grades are ordinarily run from manhole to manhole, and these are about 300 feet apart, an error of .2 per cent would mean that of .6 foot in that distance, which on a grade of .5 per cent (a fairly steep one) would involve an error in grade of .003 foot, which is less than the limit of accuracy practicable in the construction of the sewer.

It will be advisable to obtain also the location of all street-railroads, and of all gas- and water-pipes, their distance from the curb or side lines of the street and the depth of the pipes being noted. Also the location, grade, size, and condition of any existing sewers and appurtenances should be ascertained, by actual inspection if possible.

The data for computing the extent of tributary drainage-areas will ordinarily need to be collected in their entirety, as it is seldom that such information exists in a serviceable form. The topographical surveys which have been made of several of the States, however, may be used to great advantage in this connection. The data desired include the boundaries of the watersheds whose run-off does not reach a confined channel before entering the limits of the territory to be sewered. (Such water as passes through this territory in the form of streams rather than flowing over the ground does not affect the problem, unless these streams are to be walled in, in which case each one will form a problem by itself.) Also the slope of the ground and the character of the soil as to permeability should be ascertained, the location and extent of rock at or near the surface, of woods and of cultivated land. Care should be taken to note and locate any slightly worn channels along which storm-water ordinarily flows to the nearest creek or rivulet across territory not yet built up, as these, if they cross into the sewer district, indicate the points at which the storm-water must be intercepted.

Such levels must be taken as are necessary for the plotting of profiles of each street, alley, or any other surface under which a sewer is to run, including a profile across the bed of each stream crossed, with the elevation of high- and low-water marks; also the elevation of the body of water into which either the crude or purified sewage is to be discharged, the elevation during drought and flood as well as the ordinary elevation being ascertained. The depths must be obtained of all cellars whose bottoms are not evidently above the grade of the proposed sewer, unless all sewers are to be placed at a fixed minimum depth, which is to be increased only by the demands of the necessary sewer grades and not by the depth of any cellar or basement. Also if grades have been adopted for any street, but not yet carried into effect, these as well as the existing surfaces should be obtained.

The method of disposal must be decided upon before planning begins. (This subject requires treatment at such length that a special section is devoted to it—Part II.) If the sewage is to be treated before discharge into a stream or other body of water, a site must be selected for the treatment plant. This should be as low as practicable, to secure the head needed for operating the plant without pumping, if possible; but should also be sufficiently high to avoid flooding by high water. The latter is more important than the former; although if pumping is necessary it is sometimes preferable to place the plant low, protected from floods by dikes, if necessary, and pump the purified effluent rather than the crude sewage.

A treatment plant, no matter how inoffensive, is not desired as a neighbor, and should be located at least 500 to 1000 feet from residences, if possible; although many are entirely surrounded by residences that have been built since the plant was put into operation. Ordinarily the outfall sewer falls more rapidly than the stream into which it discharges, unless there is a rapids or falls in the stream; therefore the nearer to the city the outlet is placed, the greater the head available.

Even treated sewage contains some impurities, and the effect of these on the water receiving it must be considered, and careful search made for the point where the dispersion of the sewage in the water will be most rapid and other conditions as well as elevation be most favorable. The amount of flow, ordinary and during droughts, the height of floods, location of main channel, and chemical and bacterial analyses of the water at and for a few miles below the site of the proposed outlet, are the more important data to be obtained in the case of rivers. If discharge is to be into lake or ocean, the action of currents, tides and prevailing winds should be investigated to learn what course will probably be taken by sewage if discharged at different points along or at some distance from shore; also to what height the water will rise under the combined effect of tide and wind.

If a treatment plant is to be built, borings should be made to determine the nature of the soil and the depth at which solid foundation can be found. If the outlet is to be carried out into the water, the submerged ground in which the pipe must be laid should be investigated, and a profile of the surface along the line of submerged outlet be obtained.

The engineer should in person pass through every street in the district to be sewered, noting the character of each, the location of the business and factory districts, the general character of the pavements and yards, and the average size of lot occupied by each residence. He must also ascertain as nearly as may be the present population and its past rate of increase; the probable direction and extent of the future growth of the business part of the city, as well as of the city as a whole. He should obtain the figures, if they exist, of water consumption in this and neighboring cities; also all possible data concerning the rainfall.

A considerable amount of other information will in many instances be desirable, called for by the peculiarities of each case. Many items, such as cost of materials and labor (for use in the estimate), will suggest themselves as they are needed.

ART. 29. SURVEYING AND PLOTTING

Since extreme accuracy is not necessary in the transit survey, the use of the ordinary stadia methods will be found advantageous for filling in either check or original surveys, although precise lines should be run as a skeleton or outline to be filled in by the less accurate methods. Stadia-hairs in the level, for use in running street-profiles, will be found to expedite this work, and will permit reducing the number in the level party to two. The adjustment of the stadia-hairs should be checked frequently.

The tributary drainage areas will not need to be surveyed in great detail. If the natural features are boldly accentuated it may be sufficient to locate by a transit line the limiting summits and ridges, both main ridges and spurs. If the country is gently rolling or generally flat, contour surveys should be made of the whole drainage-area, or at least of any portion of it the disposal of whose run-off may offer difficulties.

Of such undeveloped areas as may be reached by the city in its future growth and which lie within drainage-areas for which sewers are to be designed at once, accurate contour surveys should be made, contours being located from 1 to 25 feet apart vertically, according to the nature of the country. They should be sufficiently close to show the configuration of the ground in considerable detail, but not so close that the contour-lines will obscure all else upon the map.

Most cities and towns of any size have the street grades established and recorded, with their profiles. An extensive experience in attempts at the adaptation of such information to the requirements of sewer-designing has demonstrated that in nine cases out of ten it is waste of time to attempt to use these records and profiles. For the levels have usually been taken by a succession of surveyors of varying degrees of efficiency; occasionally also the grades have been altered on the ground, but not upon the profile; and the time employed in discovering and rectifying errors and omissions would generally have sufficed for taking entirely new levels.

The levels of the street-surfaces taken for the profile need be to tenths of a foot only, but the bench-marks and back- and fore-sights should be to thousandths. Readings should be taken along each proposed sewer line not more than 100 feet apart, at every pronounced change of grade and at street intersections. The elevations of rails where the line crosses a railway, and at stream-crossings the profile of the bottom and the water-surface, should be obtained.

A convenient scale for a map of a village or borough is 200 feet to 1 inch, but if its size is such that this scale would necessitate the use of paper more than 3 feet wide it may be better to use a scale of 250 or 300 feet to 1 inch. It is inadvisible to use a smaller scale than this, and if the resulting map is still too large for the paper or for convenient use, it may be necessary to spread it over two or more sheets. In such a case it will be found convenient, where conditions permit of it, to so arrange the sheets that each drainage-area shall appear upon one sheet only. Upon this map should be shown the location of the proposed sewers and all appurtenances, when they have finally been decided upon, these being usually in some color other than black. It is convenient to make a tracing of this map, and from this to make black-and-white prints to use as working maps. On one of these the contours will be placed, and it will be used for studying the general subdivision into drainage districts. One may be used for tentative lay-out of separate sewers, another of storm sewers, etc.

A convenient scale for the profiles is 25 feet to 1 inch horizontal and 5 feet to 1 inch vertical. These should show the street surface, the depths of unusually low cellars and of pipes and other structures existing in the street, and of rock and ground water where known. On them will be drawn the sewer at its proper grade and the location of all manholes and other appurtenances. A plan of the street is usually placed under the profile, showing the location therein of the sewer-line and all appurtenances, and of the pipes and other underground structures.

For ascertaining the best location for an outlet into tidal waters the use of floats is desirable, since thus can be learned the ordinary periodic movements of the water into which the sewage is to be discharged, and hence the possibility of the creation of a nuisance thereby. These floats should expose as little surface to the wind as possible. A pine rod or tin tube, weighted at the bottom and with a number flag fastened to the top, is usually employed. They should be started at different stages of the tide from each point which is being

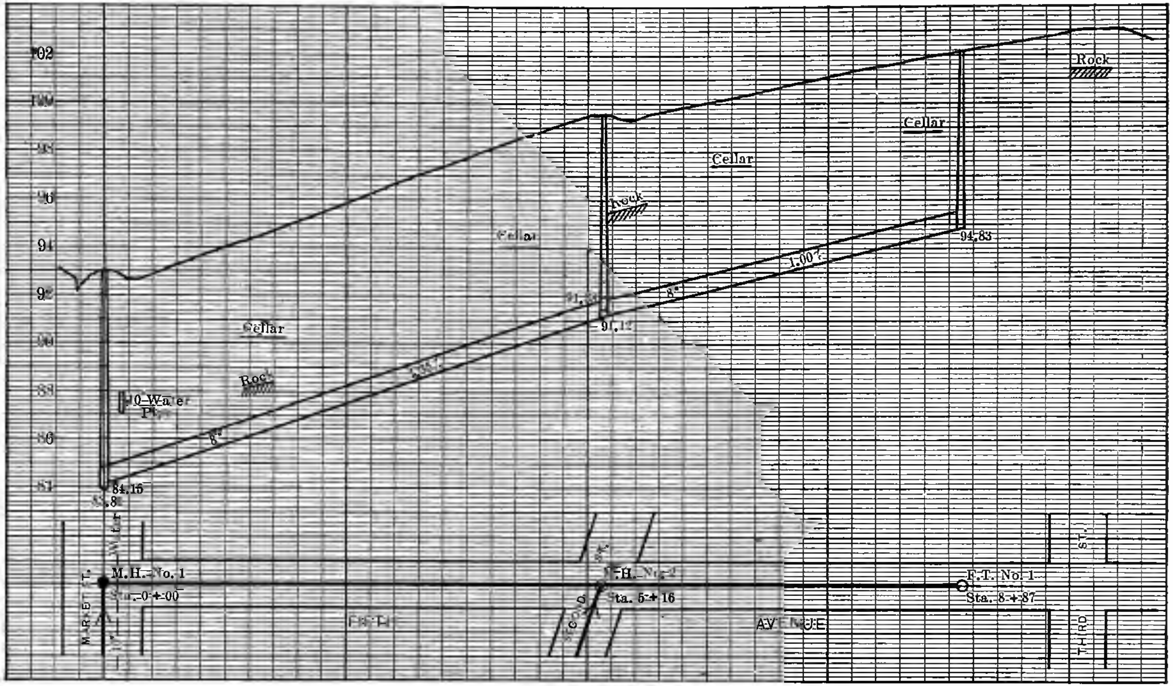


FIG. 17.—PROFILE AND PLAN OF SEWER.

considered as a possible outlet. Account should be kept of and allowance made for winds during the times the floats are in the water. Each float should be numbered and a record kept showing the time and place at which it was put into the water, the state of the tide, wind, etc. By means of one or more boats they should be so traced that the path of each can be plotted upon a map until it strands or passes beyond the point where sewage can create a nuisance. It may at times be necessary to follow a set of floats night and day for three or four days; seldom longer than this, for if they have not in that time passed to a considerable distance from the starting-point, such point is not suitable for an outlet.

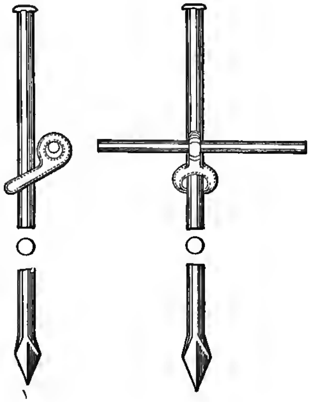


FIG. 18.—ROD FOR SOUNDING FOR ROCK.

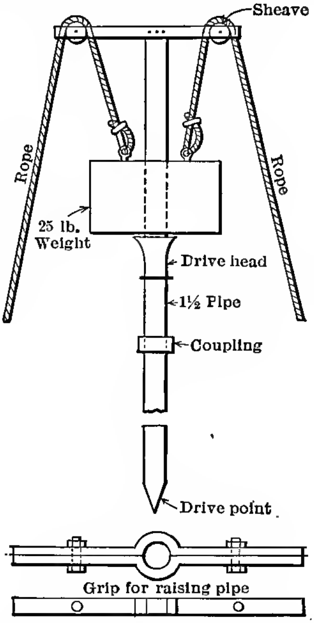


FIG. 19.—MACHINE FOR SOUNDING FOR ROCK.

The quantity of water flowing in a given stream and the resulting dilution can be ascertained by a weir, or by the use of floats or a current-meter, the cross-section of the stream being first obtained. In some cases this flow can be learned from gaugings made by the U. S. Geological Survey and published in its annual report. If possible a gauging of the stream during a drought should be obtained, since it is even more important that there be the necessary dilution at such a time than when the river is high.

It is often desirable to sink test-pits or bore at intervals along the line of each proposed sewer to ascertain the character of the material to be excavated; although when neither rock nor quicksand is anticipated it is seldom of a service commensurate with the cost. In sounding for rock several methods have been used. An iron rod, upset and pointed at one end, may be driven to a depth of 10 or 12 feet through most soils, and may be raised again by a handle, as shown in Fig. 18, which can if necessary be fastened to a lever, a stout wooden horse being used as a fulcrum. It is possible to reach still further by replacing the first heavy rod by a thinner and longer one driven in the same way.

A somewhat more elaborate apparatus is shown in Fig. 19, which has been driven to 18 feet in sand and 10 to 15 feet in stiff clay. In the latter soil the rod should be turned frequently with Stillson wrenches. Care should be taken that boulders are not mistaken for rock.

When there are not many boulders or gravel-stones in the soil, an iron pipe about 1 inch in diameter may be connected by hose with a fire-hydrant and sunk into the ground by the "jet process" to a considerable depth. By connecting the hose to the side of a T screwed to the end of the pipe and capping the top of this, the pipe can in most cases be driven by hammer past any small stones or other hard obstacles.

A modified post-hole auger can be used for the same purpose, with the advantage that by it samples of the soils passed through may be obtained.

For deep borings, as where tunnelling may be necessary, a more elaborate outfit is used, comprising derrick and winding drum for handling a pipe for wash boring. When depth and nature of rock must be known, a core may be obtained by diamond drill, but this is very expensive.

The only certain method of detecting the presence of running sand is by sinking a test-pit, though the absence of sand from the materials removed by other methods would of course be proof of its absence. The washings from a jet pipe may be caught and from the sediment some idea be had of the materials encountered, though not of their consistency.

The presence of ground water in any quantity is fully as important a matter in designing as the presence of rock, and should be thoroughly investigated. Ground water is frequently found in porous soils just at the base of a hill. It is usually found in gravelly soils near hills or mountain streams whose waters percolate into the porous ground. Usually (although there are exceptions) little water reaches the soil from rivers, whose beds are in most cases impervious. The presence and amount of ground water can be known only by excavating or from existing wells or pipe wells driven for the purpose.

CHAPTER VIII

DESIGNING

No general directions for designing a sewerage system can be given that will cover all the conditions met with in every case. But it is believed that this chapter will furnish such as are necessary for all conditions commonly found, and upon the principles already stated may be based any special designs, care being taken to violate none of the requirements of sanitary sewerage. For solving unusual problems or fundamental ones where several alternatives are presented, it may frequently be necessary, as it is always desirable, to call upon the services of an experienced consulting engineer.

Art. 30. General Principles

The first matter to be decided upon in preparing the design is, How much and what kinds of sewage must be provided for? the second, What disposal shall be made of it? the third, What system—separate, combined, or mixed—shall be employed?

Plans should be made for the removal of house sewage from all areas that are or will become urban in character. Local circumstances, financial, topographical, and meteorological, will usually decide whether or not storm-water also shall be removed by the sewers. In small cities there are usually a few places the removal of storm-water from which is almost imperative. These places must be ascertained, the area draining to them measured on the contour-map, and an estimate made of the run-off based upon the principles already given.

In the business centers, where there is much pedestrian traffic, the storm-water should not flow in the gutters more than one block—or say 300 feet—before finding a sewer inlet or some natural stream or channel into which it can discharge. In residence or suburban districts the same rule applies when the streets have impervious pavements and the yards are small. As the pavements become more pervious and the houses more scattered this distance can be increased considerably and the extent of the storm-sewer system proportionately reduced. The judgment as to how many localities (from a lack of watercourses or other reasons) need storm sewers must be balanced against the funds available for such sewers. If possible, however, the storm sewers should serve as wide a territory as the separate sewerage system.

In most small cities, natural watercourses are retained to carry away the run-off, and if the service rendered by these is not already adequate, it may be made so by enlarging, straightening, and walling them. (If the money necessary for substituting a storm sewer for such a drain is available, this should of course be done.) The residents along such a watercourse should be prohibited from depositing any excreta, garbage, or other refuse therein; and if this is enforced and the stream so enlarged as to prevent overflowing, it will become a good substitute for a storm sewer, and much less objectionable than such small streams ordinarily are to the occupants of the property it traverses. For the amount of water to be provided for from given areas see Art. 11.

A short summary of some of the principles previously stated may be given here to advantage, with applications of the same.

The amount of domestic sewage depends, first, upon the population to be provided for. This must be the population some years in the future, ordinarily between thirty and fifty years. The first seems preferable in most cases, since the larger sewers called for by the second will be less suited to the needs of the present, deposits more probable, and consequently cost of maintenance greater; also in most cases the difference in cost at compound interest for thirty years would amount to sufficient at the end of that time to pay for additions adequate for the increased needs. Moreover, it is impossible to predict with any great accuracy for thirty, and still less fifty, years ahead the amount and direction of growth of the city. From the estimate of Baltimore's growth made by the sewerage commission it was calculated that to provide for a population for thirty years ahead would call for sewer mains of twice the capacity at present required; while if that for fifty years ahead were adopted as the number to be provided for, the mains would need to be more than three times such capacity.

For making this prediction it is customary to plot all known past populations, each year and its corresponding population being made coordinates of as many points, and pass a curve as nearly through these points as possible. This curve is then extended by one (or preferably all) of the methods described in Art. 6. As a general rule, the smaller the city or town the greater the probability of sudden and great unforeseen changes in the rate of growth.

There is no necessity for per capita water-consumption exceeding 50 or 60 gallons daily, and yet we cannot be sure that it will not reach 200 or even 300. Since it can be confined well within the 100 mark by the use of meters and thorough inspection, it seems wasteful of capacity and capital to provide for more. The probability is that the near future will see the consumption almost universally reduced below this limit.

The population decided upon times the per capita water-consumption may be taken as the average amount of domestic sewage to be provided for. Industrial sewage should be estimated for the business district, and seepage for all sewers.

The character of the sewage, involving the proportionate amount of house wastes and diluting water, the character of the water supplied, and the presence of acids or other manufacturing wastes, will have a bearing upon the method of disposal.

In deciding upon the disposal to be adopted, if that by dilution is physically practicable, the laws of the state should be investigated to determine its legality; the direction and velocity of tides and currents should be known to be such as to remove the sewage continuously from rather than toward all shores or other places where it may be deposited and create a nuisance; the number of gallons of unpolluted water passing the outlet each day should be equivalent to at least 1500 times the population; the velocity of the water past the outlet must be sufficient to prevent the deposit of sewage matter at or near said outlet. The effect of the discharge upon bathing beaches, upon fish, oysters, or other food matter, upon the water-supply of towns below, or upon manufacturing interests—these must all be studied, on both their scientific and commercial sides.

If from these investigations dilution is found inadvisable, the method of treatment best adapted to the circumstances must be sought. Search should be made for a spot or spots which are low and flat, but not boggy, not less than 500 feet from a residential section and as little more than 1000 feet as is possible, and whose value is low (although land which possesses none of these qualities can be used for sewage disposal), and whose extent is sufficient for years to come. Part II should be studied carefully before deciding upon any scheme of treatment. It will usually be well to make preliminary plans based upon each of two or three methods of disposal and compare them from both sanitary and financial points of view.

Decision as to the system to be employed will ordinarily be influenced considerably by the method of disposal, importance of storm sewerage, and funds available. If treatment of the sewage is necessary or will probably become so in the course of twenty or thirty years, or if the house sewage is to be discharged at some distance from the center of the city, or must be pumped, the separate system will usually be advisable.

If there are a number of convenient points along a water front at each of which house sewage can be discharged without nuisance, the combined system may be the cheapest and most desirable. If there already exist large sewers discharging at various points where the discharge of house sewage creates a nuisance, or of a character not adapted to carrying house sewage (because of poor grades, flat bottoms or rough interior), the separate system will usually be advisable, the old sewers being used in the storm-sewer system. If such large sewers are adapted in grade, interior surface, and form to carrying house sewage, however, they may be retained for this purpose, but an intercepting sewer built to receive from them the dry-weather flow and convey it to a suitable outlet, the storm-water discharging through the previous outlets.

In all these matters, however, engineering experience and judgment, and not fixed rules, should be the basis of decision.

The general rule in sewerage, as in other engineering work, is: obtain the best results and at the least cost. Certainty of attaining this will frequently require the preparation and comparison of alternative plans, both of the system as a whole and of its separate parts.

ART. 31. COMBINED AND SEPARATE SYSTEMS

One of the first questions arising in designing a sewerage system is whether it should be a combined or a separate system. The amount of storm-water to be provided for in either storm or combined sewers is very much greater than the amount of house sewage from the same district. Consequently either storm or combined sewers must be given sizes much greater than those required for separate sewers. The conditions under which each of these is most advisable and the relative advantages and disadvantages of each may be stated briefly as follows:

The small sewers of the separate system give a greater velocity to ordinary dry-weather flow than do the combined sewers, with the result that the sewers are generally kept cleaner. The smaller size, however, renders more difficult the removal of any obstructions or sediment which may collect.

Where complete systems of both storm sewers and separate sewers are provided, the total cost is greater than that of a single system of combined sewers of capacity adequate for carrying both classes of sewage. This additional cost, however, is to a certain extent offset by the fact that the storm sewers frequently can be placed at less depth than that at which combined sewers must be placed to receive the house sewage, which decrease in depth reduces the cost of construction. The fact that towns which do not require complete storm sewerage or which are too poor to afford a complete system of combined sewers can obtain the more necessary removal of house wastes at much less expense by the construction of a system of separate sewers only, is a most important advantage.

The objection has been made that large quantities of water are used for flushing house sewers of the separate system. But if the sewers of the combined system are kept equally as clean, much larger quantities of water are required for the same purpose except during the occasional seasons when rain storms are frequent.

The claim sometimes made that large sewers possess the advantage that they can be laid at flatter grades than small ones is based upon ignorance of hydraulic principles since, as a matter of fact, the larger sewers must be given steeper grades to secure equal velocity in the ordinary dry-weather flow.

While surface water is frequently allowed to run for longer distances in the gutters where the separate system is used than where the combined, this is not a fault but is rather an advantage of the former system, for substituting such gutter flow for an equal length of large sewer permits a considerable saving in expenditure, or deferring of the same until the necessity for more complete storm-water removal justifies the additional expenditure.

In the separate system the small sewers reach every house to remove the house sewage, but the large storm sewers need be carried only where removal of surface water is most necessary. Also the house sewage must generally be carried to a distant outlet or treatment plant, but storm sewage can be discharged at numerous points at near outlets. A combined sewer must be as large as a storm sewer, must have a total length as great as that of the separate sewer system, and must be carried full size to the distant outlet selected for house sewage at great expense, or else discharge diluted house sewage at outlets where it may be most objectionable.

It has been claimed that traps in house connections are more likely to be forced with the separate system than with the combined, which forcing would be due to inadequate ventilation. If any such danger exists it is a result of poor design.

On the contrary, it may be said that the removal of foul air can be effected more completely in the smaller sewer; while deposits, which are the cause of foul air in sewers, are less likely to form in the small sewers than in the large ones.

A very important argument in favor of the separate system, and one which is becoming more so every year, is the fact that the use of the separate system is a practical necessity where house sewage must be treated. So true is this, that several cities sewered on the combined system have spent large sums of money in changing the entire system over to the separate one. The reason for this is that it is the pollution in the house sewage which occasions the necessity for treatment, and the presence of storm-water mixed with the house sewage greatly increases the difficulty of such treatment. It is true that the storm sewage for the first few minutes after the beginning of a storm may contain street washings which render it quite as foul as house sewage, but this pollution is not very objectionable when discharged into streams of considerable volume and such condition lasts for only a few minutes. There are few, if any, cities in this country which purify water discharged by storm sewers, although there are several which treat the run-off from light storms when discharged by combined sewers.

In the author's opinion, the separate system is always preferable, except where storm-water removal is essential, the house sewage can be discharged at numerous outlets without long outfalls, and funds cannot be obtained for both separate and storm sewers. New Orleans and Baltimore, the only large cities that have built complete sewerage systems during the past twenty-five years, are both sewered on the separate system; the sewerage for the new parts of New York City is planned to be a separate system; and it is doubtful if one per cent of the systems begun within a quarter century are combined, most combined sewers built recently being extensions of existing combined systems.

ART. 32. SUBDIVISION INTO DISTRICTS

For the purpose of designing, the territory under consideration is ordinarily divided into two sets of districts, one based upon the density of population, the other upon the topography.

The former division should take as a basis the probable density of population per acre of different sections at some time—say thirty years—in the future, since the system must be adequate to serve the population at that time. It will be convenient to base the division upon estimated populations per acre of 20, 30, and other factors of 10, 20 being the minimum assumed for habitable districts in most cities. The maximum may run up to 150 or more per acre. This division is for the purpose of design only and is not ususally shown upon the finished map, but may be designated by bounding lines or by tints upon a working map. Having made the above subdivision, the total resident population of each area should be calculated from the assumed density of population, and the sum of all these populations compared with the estimated future total population. It may exceed this by a small amount —say 10 per cent—to allow for incorrect apportioning of densities. If it does not at least equal it, changes in the extent or density of the different areas should be made, at such points as the engineer's best judgment dictates, sufficient to give this total. In the business districts an additional allowance is made for commercial occupants, to be used in estimating the amount of commercial sewage.

The second subdivision is that into drainage districts. For this purpose a carefully prepared contour map of the city or area to be sewered is necessary. Each district is to contain all the territory draining into one main sewer, together with that main down to its outlet or its junction with the intercepting or outfall sewer. (Under some plans of sewer assessments this subdivision is necessary for assessing as well as engineering purposes.) For separate sewers it can usually be made best after the designing of the sewers is completed. For storm sewers, however, it should be made after the lines are located, but before the sizes are determined upon, to facilitate calculation of the latter. This refers to the exact boundary lines. A general outline of the sewerage scheme—the number of districts, approximate location of the main sewer for each and of intercepting sewers and outfall—is approximately determined by a careful study of the map as a whole before any definite sewer locations are made.

ART. 33. OUTLINING THE SYSTEM

Where an area to be sewered slopes uniformly toward and extends to a body of water into which the sewage can be discharged at any point, the problem is to so locate outlets and mains leading to them as to give the minimum cost. This may be met by a sewer carried to an outlet down each street that extends to the body of water; or by such a sewer in each second or third street with laterals sewering the district in between. If the country is rolling, the mains will lie at the bottoms of the valleys sloping toward the body of water, the laterals extending up their sides. If a railroad right-of-way lies along the water front it may be cheaper to run an intercepting sewer parallel to this to receive the sewage from all the mains, the intercepting sewer crossing under the tracks to an outlet at one or more points.

If all the sewage of the city or of a considerable area of it must be carried to one outlet (the most common case), the interceptor or outfall sewer is carried from the outlet to and through the city along the lowest stretch of land (usually along the water front), so that all other sewers can discharge into it, if this is possible, without giving it too flat a grade. If it is not possible, then the outfall sewer is started at the lowest outlet that will give free discharge at all stages of water, and carried along the lowest route that will permit giving it the minimum acceptable grade. The territory above it can drain to it as an interceptor; the sewage from that below it must be pumped, and is led to a pumping station by a low-level main.

This sewage may be pumped into the body of water directly, or into the interceptor at the nearest point.

If all of the land is too low to drain to the outlet by gravity, but slopes with grades acceptable for sewers toward one or more points, the system may be laid out as though such points were outlets, and from such points of concentration the sewage may be removed to the outlet or outlets by a combination of pumping stations and outfall lines. For such outfall, that line will be chosen that gives a minimum value for the combined cost of outfall (giving due consideration to effect of depth of sewer on cost of construction), pumping plant and capitalized cost of operating such plant. A comparison of several routes and of different numbers of pumping plants on each route may be necessary to determine this. If all the land is a level plain, it may be divided into small areas, each area with a pumping plant in its center to which it all drains. The outfall sewer may then pass from one pumping station to the next, being a gravity sewer between stations, each successive pumping plant lifting the accumulated sewage as well as that of its own district; or the outfall may be laid practically level near the surface and act as a force main.

The above cases are a few of those that may arise, but each design presents conditions and problems of its own. Correct solving of these requires a thorough knowledge of principles, experience and ingenuity. The general outlining of the system is the most important and difficult part of the designing and that in which the services of an expert is most likely to be desirable.

ART. 34. LOCATING THE SEWER LINES

Unless this location is already occupied by gas- or water-pipes or a street-railroad, separate and combined sewers are in most cases located in the centers of streets or alleys, the cost to the householders on each side for house-connections being thus made equal. This also permits the minimum depth of sewer if the houses generally are at equal elevations on both sides of the street. In some cities the sewers are located under the sidewalks, there being a line on each side of the street. This plan, which is used in Washington, D. C., quite extensively, is usually adopted in the case of wide streets, since there the cost of the duplicate line is less than that of the additional lengths of house-connections required by a single sewer. From a financial standpoint the double line is cheaper when the cost of a minimum-sized sewer (generally 8-inch) of a length equal to the average house-lot frontage is less than the cost of a house-connection of a length equal to the distance between the two sewer lines. Another advantage of side sewers is that the street pavement need not be torn up in making house-connections. A serious disadvantage is that the distance from the upper end of each line to the point where the sewage flow is self-cleansing in volume and velocity will be double that when but a single line is laid. Also the roots of shade-trees are apt to cause serious trouble by entering the pipe-joints or breaking the pipe.

Where a city has alleys intermediate between the streets, it may be advisable to carry the sewers through these rather than through the streets, the principal argument for this being that less valuable pavement is destroyed and less obstruction caused to traffic by the work of construction. On the other hand, the house-connection will be longer, resulting in both increased cost and decreased grade in such connection, if the distance from the house to the street center is less than that to the alley center, as is generally the case. Moreover, the pavement in an alley *should* be equally as good as that in a street, and the uneven surface often left after sewer construction is exceedingly apt to contribute to the disease-breeding slovenliness in what is often at its best an elongated Gehenna. Again, in a narrow alley the space available for piling the excavated dirt is so contracted that the cost of construction is frequently increased by a very appreciable amount on this account. On a hillside, however, it may often be advisable or even necessary to locate sewers in the alleys for the drainage of houses on the lower sides of streets above.

Sewers should be laid in continuous straight lines, as far as possible.

No turn greater than a right angle should be made at any one point by any sewer less than 24 inches in diameter, and any turn whatever made by such a sewer should be in a manhole, by means of a curved channel. For sewers larger than 12 or 15 inches it is advisable to use two manholes in making a bend greater than 45 degrees (see Fig. 20). Brick or concrete sewers more than 30 inches in diameter may be laid on curves, since they can be entered for inspection or cleaning.

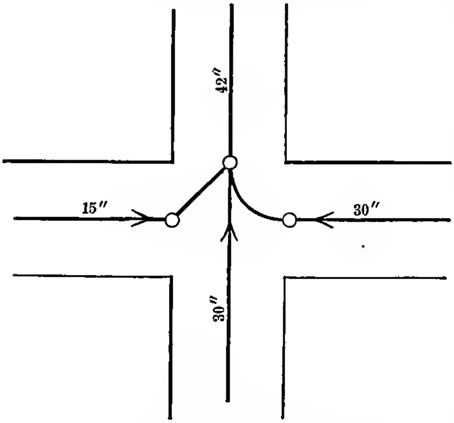


Fig. 20.—Alignment of Sewer Junctions.

Each lateral sewer should take the most direct course to its main, each main the most direct course to its outlet, and the number of mains should be as few as possible. This serves both economy and sanitary efficiency.

An exception to the last rule is made where this would cause velocities of more than 6 or 8 feet per second, as in draining a steep hillside. Here the main should follow a diagonal course down the hill to prevent the high velocities with their disadvantages.

Dead ends should be made as few as possible, even at some expense of additional excavation, but not by reducing mean velocities below 2.5 feet per second; nor is it ordinarily serviceable to unite the upper ends of sewers flowing in opposite directions.

Separate sewers should be carried within reach, as regards both horizontal distance and grade, of every lot in the sewered district.

Storm sewers should have as few branches as can be made to reach all the street-inlets; to better insure which, such inlets should be located previous to the location of the sewer lines.

Keep large or very deep sewers out of narrow business or high-value streets if possible, because of construction difficulties.

It is generally advisable to avoid crossing private property where possible, since legal complications and delays might result from such crossing. This will frequently be impossible, however, particularly near outlets.

The sewer lines can usually be laid cut directly upon a contoured working map, an approximate rough estimate of the necessary size and consequent minimum slope of each sewer being made, that deep or shallow cutting may be avoided. The direction of flow may be indicated by arrows.

In laying out sewer lines, the outfall sewer, interceptors and mains should be located first. Attention should then be given to low areas which promise to offer difficulties. Laterals in other areas may be left until all other lines have been determined.

In the separate system the storm-water sewers should usually be placed on one side of the street centers, the separate sewers being placed in the centers. The two should never be placed one above the other in the same trench unless in contact with each other or connected by masonry.

ART. 35. VOLUME OF HOUSE SEWAGE

Since the minimum grade of a sewer is limited by its size, and the size is determined by the grade and consequent velocity, but to even a greater extent by the maximum volume of sewage to be carried, this last must be determined before either the limiting grade or size can be decided upon. If the maximum rate of water-consumption be taken at 175 gallons per day per capita, the maximum volume per second to be carried by a sewer (in cubic feet) is $\frac{175DA}{7.48 \times 86{,}400}$, in which D = density of population and A = the area in acres. As previously described, a factor of safety of 2 is generally used for laterals, $1\frac{3}{4}$ for sub-mains and $1\frac{1}{2}$ for mains.

Beginning at the summit of each lateral, it is clear that it is unnecessary to calculate the capacity required for any section of sewer until the point is reached where the volume of sewage to be carried exceeds the capacity of the smallest sewer used at the given grade. For an 8-inch pipe flowing full with an average velocity of 2.5 feet per second, this volume is about $\left(\frac{3.1416\times16\times2.5}{144}=\right)0.8726$ cubic feet per second, which, allowing a factor of safety of 2, would be contributed as a maximum domestic flow by a population of $\left(\frac{0.8726\times7.48\times86{,}400}{2\times175}=\right)1611$. Dividing 1611 by the density of population, assumed for the area served by this lateral, gives the number of acres to be sewered before the size is increased. Below this point the size must be enlarged to the next market size of pipe or the next size of masonry sewer convenient for construction.

The amount of commercial and industrial sewage is determined in the same way, but using the units given in Art. 7. If the same district is expected to be at one time residential and at another industrial or commercial, the condition that would yield the maximum amount is made the basis of design.

The allowance for leakage into the sewer of ground water, which should be small compared to the sewage proper, may be added at intervals, according to the engineer's judgment, based on such data as he is able to obtained. In the Cincinnati plans 75,000 gallons per day per mile of sewers was used. The amount depends upon the local rainfall and character of soil as well as upon the tightness of the sewer.

In calculating the volumes of sewage, it is advisable to begin with the furthermost lateral sewer first; where this joins another the contributions of both are to be added to determine the flow below that point; and in tracing down this line, as each lateral or branch is encountered its contribution must be calculated and added. Decision having been made, after a study of the topographical map, as to the line of sewer into which each section of undeveloped territory will drain when sewered, the sewage which this area will ultimately con-

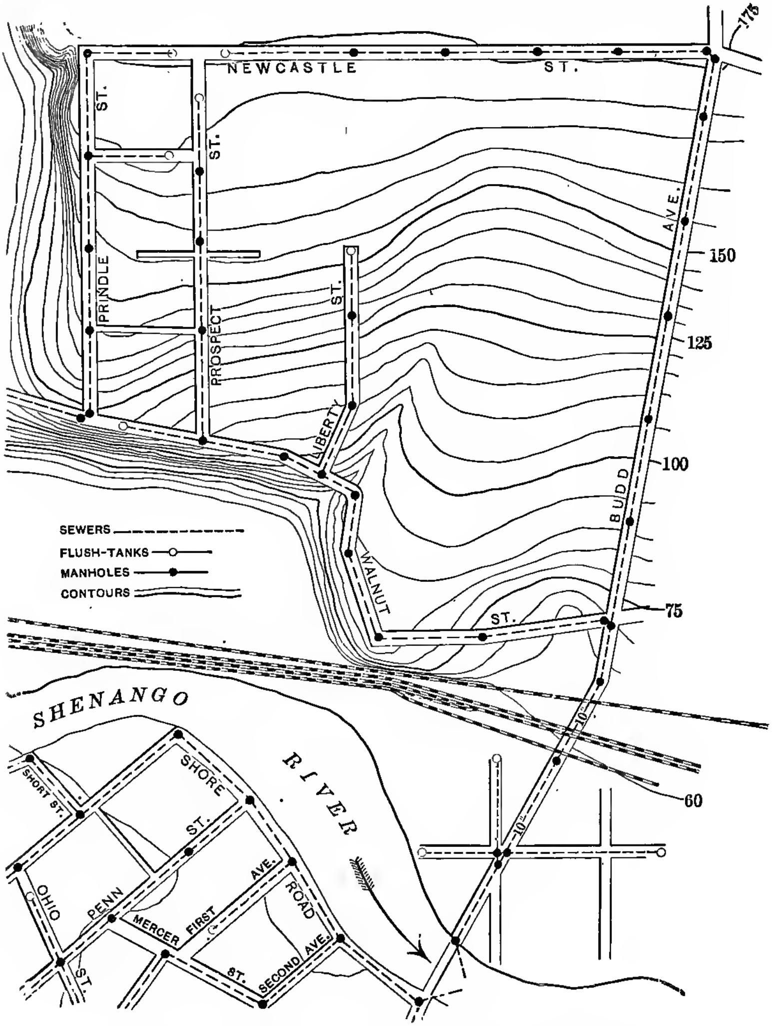


Fig. 21.—Map Used in Calculating Separate Sewer System.

tribute should be placed at the heads of the volumes of flow in this line.

An excellent method of making these calculations is as follows, the sewerage-map, Fig. 21, being used for this table.

In this case it is seen that the capacity of an 8-inch pipe at the minimum grade was reached at the junction of the Newcastle and Budd street sewers, but the line down Budd has 1 : 50 as its grade, and no increase of size is yet necessary.

CALCULATION OF SEWAGE QUANTITIES AND SEWER SIZES

Street.	From	To	Area Acres.	Density	Population.	Sewage. Gallons per Day.	Total Sewage.	Grade.	Size.
Prospect	Newcastle	Walnut	10.4	20	208	36400	......	1 : 30 1 : 11	8 in. "
Walnut	Prindle	Prospect	1.7	20	34	5950	......	1 : 20	"
Walnut	Prospect	Liberty	1.9	20	38	6750	......	1 : 20	"
Liberty (extended)	Newcastle	Walnut	12.7	20	254	44450	......	....	"
Walnut	Liberty	Budd	8.2	20	164	28700	122250	1 : 300	"
Newcastle	Prospect	Liberty	1.5	20	30	5250	......	1 : 300	"
Undeveloped terri	tory tributary	to Newcastle	27.3	20	546	95550	......	....	.....
Newcastle	Liberty	Budd	7.5	20	150	26250	......	1 : 300	8 in.
Undeveloped terri	tory tributary	to Budd	44.0	20	880	154000	281050	....	.....
Budd	Newcastle	Walnut	11.0	20	220	58500	319550	1 : 50	8 in.
Budd	Walnut	River	3.0	20	60	10500	452500	minimum	10 in.
Budd	Walnut	River	Ground-water			......	......	....	.....

At the junction of Budd and Walnut the sewage amounts to 452,300 gallons, or 42 cubic feet per minute, and the sewer from there to the river must have the minimum grade allowable. The size must therefore be increased, and as the next market size, 10-inch, has a capacity at that grade, with a factor of safety of $1\frac{1}{2}$, of about 590,000 gallons, it is therefore sufficiently large for the rest of the line, including sewage contributed along its length and ground water. No ground water was anticipated on the hillside, but it was considered probable that on Budd below Walnut this would leak into the sewer at the rate of 2 gallons per day per foot of sewer.

Art. 36. Volume of Storm Sewage

The rational method of calculating the run-off to storm sewers has already been described in some detail in Chapter III. In making such calculation, the inlets are located so as to intercept the rain water flowing in the gutters without necessitating too long a surface flow. Storm-sewer lines are located so as to serve all the inlets. Inlets and sewers must be planned for the entire area draining to any sewer for which calculation is made, tentative locations for both being made where street plans have not yet been laid out.

Profiles are prepared of the surfaces of all streets, and the sewer-inverts are located on them in pencil, since the final calculation will probably result in minor changes in the sewer grades. The location of the inlet connections are indicated on the profiles.

The rainfall records of the place in question are consulted to determine the rates of precipitation to be used in the calculation, and decision made as to what class of storms to provide for—the maximum ever probable, the maximum omitting those not occurring oftener than once in ten years on an average, or storms of annual occurrence only. (Provision for the second class is believed to be advisable in most cases.) If such records are not available, use may be made of the rainfall curves in Fig. 7 or Fig. 22, or preferably of similar curves prepared from data for the region of the place in question secured from long-time records of the U. S. Weather Bureau.

An imperviousness factor for each part of the area draining to each inlet is then decided on. In making this decision, the condition during the following thirty to fifty years should be considered. In general the tendency is for the imperviousness to increase, due to the changing character of street and sidewalk construction and the increasing number of houses with their impervious roofs. A plan commonly followed is to select a block fully developed as a business block, others as dense residence, medium residence and suburban blocks, and determine the actual conditions in such blocks. Then forecast which of these conditions each of the areas will attain within the time assumed. The safest course is to assume every street surface (both roadway and sidewalk) as wholly impervious, also all roofs. In business districts, the yards and courts should probably be given factors of .60 to .80. In residence districts, for lawns and gardens the factor would probably lie between 25 and 75, depending upon the porosity of the soil, assuming a rainfall of at least an hour preceding the maximum precipitation.

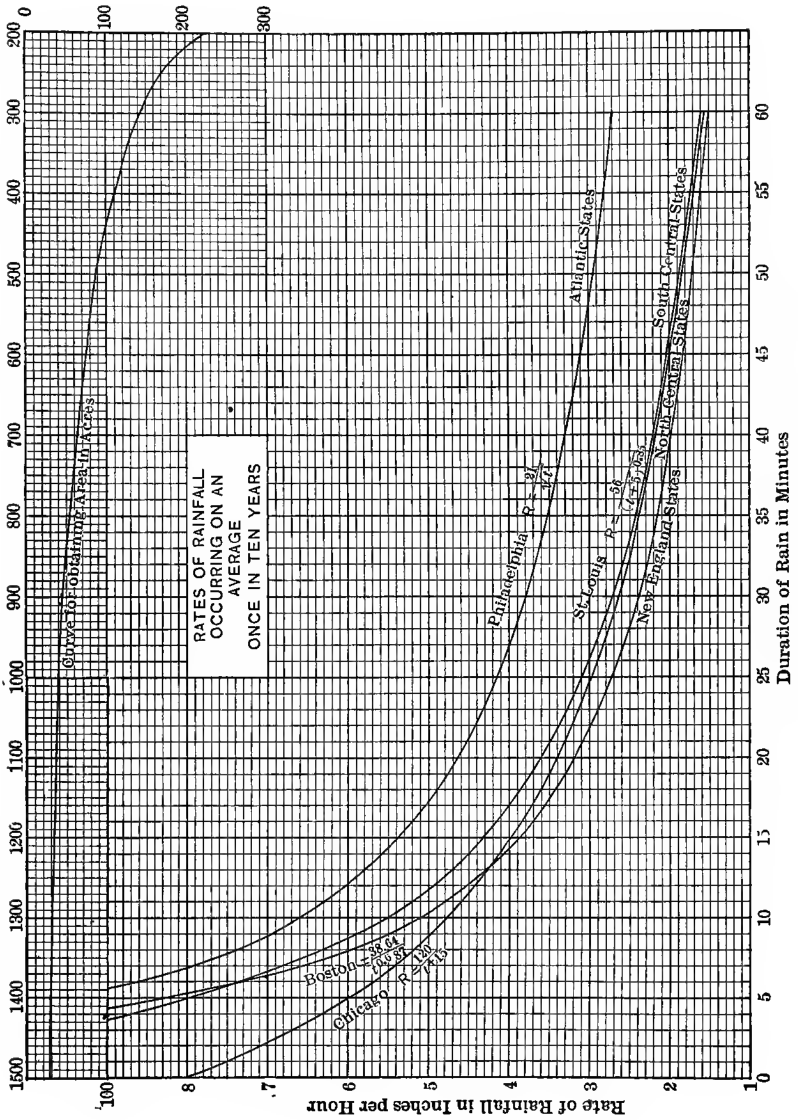


Fig. 22.—Rainfall Curves and Acre-Calculating Curve.

The imperviousness factor for a given area may be calculated thus:

Let l = the average length of a city block;
b = breadth of a city block;
f = number of front feet to a building lot;
d = depth of a building lot;
w = width of street
i = percentage of imperviousness of yards, courts, etc., expressed as a decimal;
I = percentage of imperviousness of the entire area, expressed as a decimal.

Then

$$I=\frac{\frac{alb}{fd}+w(l+b+w)+i\left(lb-\frac{alb}{fd}\right)}{lb+w(l+b+w)}=\frac{lb(a+ifd-ia)wfd(l+b+w)}{fd[lb+w(l+b+w)]}.$$

As an example, let $l=450$, $b=250$, $f=50$, $d=125$, $a=1200$ square feet, $w=66$, $i=.60$; then $I=.777$, or say .78.

When most of the above factors must be estimated by judgment only, as for areas not yet opened up or fully developed, it may be as well to estimate I at once.

A map is used on which are indicated the locations of all inlets and sewers, and on each area its imperviousness factor I and its area a. The run-off from each area to its inlet is then calculated as in Art. 11. Since we are assuming future conditions, all of the blocks in a given district will be similar except as to dimensions and grades of the bounding streets; and if the street lay-out is at all regular, the blocks may be arranged in a few groups so nearly alike in these respects that one calculation will suffice for each group.

The areas draining to inlets do not ordinarily differ in their run-off times nearly so much as do the areas between successive run-off contours of a single block; consequently there will be much less error in assuming that the precipitation rate remains constant during the run-off time assumed for a district including a group of blocks. The method employed in calculating sewer capacity for a number of blocks may therefore be simpler. The following calculation illustrates a method of making and tabulating a typical problem, reference being made to the map, Fig. 23.

a is the size of each sub-area;
I is its imperviousness;
AI is in each case the sum of all the preceding aI's;
s is the surface-slope of the sub-area;
l is the greatest distance traversed by the run-off in crossing each sub-area;
t is the time occupied by the run-off in travelling the distance l;
r is the rate of rainfall for the time t;
$q=aIr$;
S is the slope of the sewer removing the run-off from the point in question;
L its length to the point next considered (usually the next inlet connection or sewer-junction);
T is the time occupied by the run-off in flowing from the extreme limit of the drainage-area A, over the surface and through the sewers to the point under consideration;
R is the rate of rainfall for the time T;
Q is the total amount of run-off from all drainage-areas above $=AIR$.

The quantity $q(=aIr)$ as well as Q should be calculated for each sub-area, and if the Q for any stretch of sewer is at any place less than the q immediately tributary to the same, the latter should determine the size.

Fig. 22 will be found convenient for determining a, and also R when the rates of rainfall of the place in question can be represented by any of the curves there given, these being for rains at ten-year intervals. To find a in acres from the diagram, use one dimension (in feet) of the area (or of an equivalent rectangle if it is not rectangular) as an ordinate and find the corresponding abscissa of the acre-curve in the diagram; divide this into the other dimension of the area and the quotient will be a in acres.

By the table, the run-off from the undeveloped territory is placed at 60.0 cubic feet per second, which is carried by a 42-inch sewer on a .6 per cent grade for 360 feet, where it receives still more sewage; the maximum amount to be received there, both over the surface and through the sewer, being 62.4 cubic feet, although q for the block No. 1 alone is 7.6 cubic feet. But Q is not equal to $60.0+7.6$, because the latter quantity was due to a rainfall of 3.9 minutes' duration, or rather to the maximum rate for that time, during which only

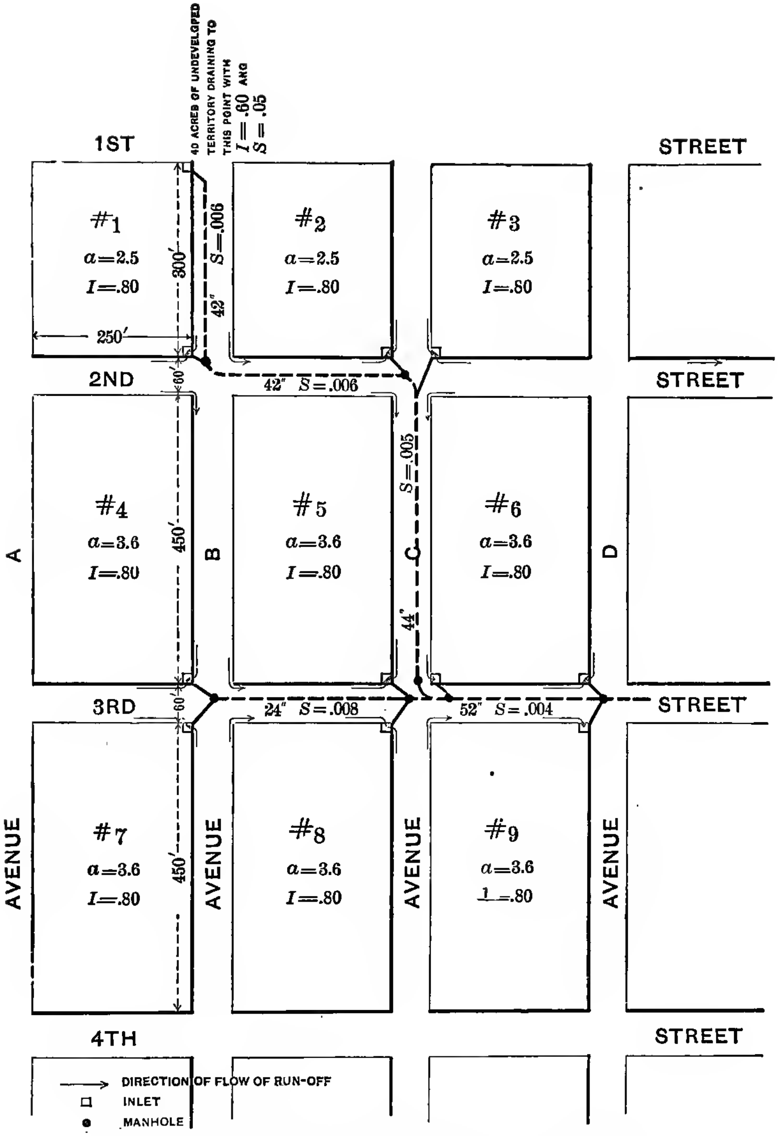


FIG. 23.—MAP FOR CALCULATING STORM SEWER SYSTEM.

Location of Area.	a	I	aI	AI	s	l	t	r*	q	S	T	R*	Q	Size of Sewer.	Velocity of Flow, Feet per Minute.	L	Location of Sewer.
Undeveloped territory	40	.60	24	24	.05	3600	13.4	2.5	60.0	.006	13.4	2.5	60.0	42″	420	360	Ave. B, 1st St. to 2d St.
No 1	2.5	.80	2.0	26	.01	625	3.9	3.8	7.6	.006	14.3	2.4	62.4	42″	422	310	2d St., Ave. B to Ave. C.
2	2.5	.80	2.0	28	.01	615	3.8	3.8	7.6								
3	2.5	.80	2.0	30	.01	625	3.9	3.8	7.6	.005	15.1	2.4	72.0	44″	396	510	Ave. C, 2d St. to 3d St.
4	3.6	.80	2.88	32.88	.013	830	4.6	3.7	10.6	.008	6.2	3.4	19.6	24″	388	830	3d St., Ave. B to Ave. C.
7	3.6	.80	2.88	35.76	.007	830	6.2	3.3	9.5								
5	3.6	.80	2.88	38.64	.005	800	7.1	3.2	9.2								
8	3.6	.80	2.88	41.52	.007	800	6.0	3.4	9.8								
6 (one-half)	1.8	.80	1.44	42.96	.005	630	5.6	3.5	5.0								
9 (one-half)	1.8	.80	1.44	44.40	.007	630	4.7	3.7	5.3	.004	16.4	2.2	97.7	52″	400		3d St., Ave. C to Ave. D.

* r and R taken from the rainfall-curve (Fig. 23) for the New England States.

such water would have arrived from the upper end of the drainage-area as was due to a lower rate of rainfall; but the time of 14.3 minutes is that for which the run-off is calculated from both the undeveloped territory and block No. 1. Blocks No. 2 and No. 3 both reach the sewer at the same point, and, taking the rate of rainfall for 15.1 minutes, we have a total run-off from all the territory above of 72.0 cubic feet per second and, the grade being .5 per cent, a 44-inch sewer is found to be necessary.

Blocks No. 4 and No. 7 discharge first into a branch sewer which it is found should be 24 inches in diameter. Where this joins the main the run-off from blocks No. 5 and No. 8 and from half of No. 6 and No. 9 also reaches it, and it must consequently be increased in size. The time *T* at this point is 13.4+0.9 (in the Ave. B sewer)+0.8 (in the Second Street sewer)+1.3 (in the Ave. C sewer), or 16.4 minutes, and the rate of rainfall for this time is used for the run-off from the entire area.

In case the value assumed at first for the *S* of any length of sewer is less than that required for minimum velocity in the size of sewer called for by this calculation, the *S* must be increased. This will involve a change in the grade of the length of sewer immediately above or immediately below this, and possibly in several lengths above and below. Not until the calculation has been completed to the outlet, including all the branches, can the grade of any sewer be considered to be finally established.

ART. 37. GRADE, SIZE, AND DEPTH OF SEWERS

For both determining and recording the grades of the proposed sewers, use is usually made of the profiles of the streets, plotted from the level notes. Upon these a vertical longitudinal section of the proposed sewer through its center line is placed, thus showing the size, grade, and depth of the sewer. While designing, however, it will be found convenient to pencil in the line of the invert only, since then changes in its vertical location can be made more readily.

Some engineers plot first, in pencil, the surface of the sewage at ordinary maximum flow, since then no allowance need be made for drop in invert where size changes (as explained later in this article). But this is not common practice.

A short experience in sewer-designing will demonstrate how mutually involved are *Q*, *S*, the diameter and the depth of the sewer. In many cases it will be necessary to alter and re-alter the grade and diameter before obtaining for each reach of sewer the best obtainable depth and velocity. *Q* is a fixed quantity for any given case, *S* may vary between fixed limits, the size also has its limits in some cases, but the depth of the sewer may vary from any distance below to any distance above ground. A depth of 25 or 30 feet is obtained in many sewerage systems, and even 50 feet or more has been reached in open cut, while sewers have been laid in tunnel at still greater depths. Where possible, deep sewers should run through wide streets, that the danger to building-foundations may be kept as small as possible; and they should avoid the busiest thoroughfares unless these are also the widest streets and the soil is treacherous. The sewer may in some cases be carried on bridges or trestles, as in crossing a stream or ground lower than the hydraulic gradient. In many such locations, however, this position will be impossible, owing to traffic on the river, to danger from floods, to blocking of streets, or to prohibitive cost of construction. In such cases the pipe may be placed under the surface of the ground or in the bed of the stream, as an inverted siphon. It will not be possible, or at least advisable, to connect any buildings to an inverted siphon, since the sewage will continually stand in the connections up to the level of the hydraulic gradient of the siphon.

The depth of storm sewers is usually fixed by grade requirements only; the covering over them, however, should be not less than 2 feet and would better be 3 or 4 feet. The minimum depth to which separate or combined sewers should be laid will usually be decided by local circumstances or customs. It is generally desirable to lay them somewhat deeper than the gas- or water-pipes, that these may not interfere with them. The city of Brooklyn some years ago fixed 12 feet as the depth to which all (combined) sewers are to be laid, unless the maintenance of proper velocity requires a less or greater one. In Philadelphia, 14 feet is the standard depth, in Washington, D. C., 10 feet. In residence districts in the smaller cities, 7 to 10 feet is usually sufficient, although in a street running along a hillside a much greater depth may be called for by the depth of basements upon the lower side of the street. In streets which are already built up, the sewer should be deep enough to drain all basements and cellars, with the exception, perhaps, of an occasional one of unusual depth. To insure this, the cellar depths taken during the survey should be indicated in their proper positions upon the profiles of their respective streets. In many Southern cities where there are no cellars under the dwellings, and other conditions do not interfere, the sewers may be given a depth of covering of only 3 or 4 feet. In the North, 6 feet is probably the least depth which should be given to the flow-line save under exceptional circumstances. The maximum depth should be kept at 14 to 16 feet, if possible, since below this the cost of construction increases rapidly. When the depth is considerable the expense of making house-connections may become excessive. It may in such cases be found cheaper to lay a small sewer about 7 or 8 feet below the surface and following the surface grade, which may be with or against the grade of the deep sewer, to a manhole in the deep sewer into which this shallow one can discharge.

If the depth of sewer is less than 1.5 or 2 times the width of trench in which it is laid, there may be considerable pressure exerted upon it by vehicles or other surface loads, and shallow location may call for additional strength of sewer wall. (See Art. 38.)

Before fixing the grade it is well to prepare tables similar to those given in Articles 35 and 36, and also to calculate as closely as possible the total amount of sewage reaching each outlet.

Very often the main sewer for a long distance from the outlet must be laid at a minimum grade if pumping is to be avoided or the lift kept as small as possible. In such a case the grade of this main will be the first to be located upon the profile, the outlet being placed as low as is permissible. This should never be below ordinary high water unless absolutely necessary, and under no consideration should it be below or even as low as ordinary low water; or rather this should be true for the hydraulic gradient, although the last few feet of the sewer may be given a steeper grade to bring the outlet below the water-surface or into the channel.

There may be other lines also where the surface elevations demand the flattest possible grades; that is, the grades which will give the minimum permissible velocity. This grade will depend upon the size of the sewer, and this again upon the quantity of sewage. To ascertain this size, reduce the maximum sewage flow to cubic feet per second, divide by the desired velocity of flow in feet per second, multiply the quotient by a factor of safety of 1.5 for mains or 2 for laterals, and find the dimensions of the sewer having this product for its area. Or, divide the gallons of sewage per day times 1.5 or 2, as the case may be, by the required velocity in feet per second, and take the size corresponding to the next highest quantity in the following table:

TABLE No. 16

Size of sewer	8″	10″	12″	15″
$\frac{\text{Gallons of sewage per day}}{v}$	225,500	352,500	507,600	792,800

Size of sewer	18″	20″	24″
$\frac{\text{Gallons of sewage per day}}{v}$	1,141,700	1,410,300	2,030,500

Where possible, the grades of sewers should be such as to give a velocity of from 3 to 5 feet per second. The demands of economical construction and the necessity for sufficient fall in house-connections should not, however, be sacrificed to reduce velocities to less than 10 or 12 feet or increase them above $2\frac{1}{2}$ feet, which, however, should be the limits allowed.

If it is possible, the grades of the various sewers should be so proportioned that the velocity of the sewage shall increase as the outlet is approached, or at least it should not decrease, since a decrease in velocity may cause a deposit of suspended matter. Frequently, however, it is impossible to attain this in the design, since the flattest surface slopes are usually nearest to the outlet and the sewer grades are largely controlled by these.

Still more important than obtaining a constant or constantly increasing velocity is the keeping of the velocity within the limits given in Art. 13. If the ground surface is too flat to permit of obtaining this velocity by gravity, pumping must be resorted to. If the surface is steeper than is permissible for the sewer, the sewer grades can be broken by a drop made at each manhole, or by "flight sewers." (See Art. 38.)

A slight drop in the grade should be made at each manhole on flat grades to compensate for the obstruction offered by curves, etc., at this point, and for slight errors in measurement; 0.02 or 0.03 foot is usually sufficient. This is generally unnecessary in the case of masonry sewers or others with continuous inverts and straight alignment.

Of the above principles, the most important is that the velocity of the sewage shall be within the proper limits; then, that all basements and cellars to a reasonable depth shall be drained by separate sewers; also the depth of excavation should be kept as light as possible, and the principles outlined in Art. 34 should be regarded. The obtaining of the nearest possible approach to an ideal design will usually require many changes in, and rearrangement of, both lines and grades, since a change in those of one lateral may in some way affect the entire system.

The preliminary grades having been fixed according to the desirable depths and velocities of flow, the size of the sewer for each reach should be calculated or taken from the diagram and the velocities checked by accurate calculation. Additional changes, usually slight, will probably be required to obtain the best values for each interdependent velocity, size, and depth. The junctions and crossings of the sewer lines must be carefully examined and adapted to each other. It is a good plan to make a list of all the manholes, showing for each the elevation at which each sewer enters and leaves it. Two sewer lines should never intersect each other, each having a continuous grade across the intersection; either one should discharge from both directions into the other or they should cross, the one above the other.

At junctions, the surface of the sewage in the contributing sewer should never be designed to be lower than that in the other; that is, the center of the tributary should not be below the center of the intercepting sewer if a factor of safety of 2 be used for both; if the larger is a main, the center of the tributary lateral should not be lower than a point two-thirds the diameter of the larger above its invert. It would be still better to place the invert of the tributary above the ordinary sewage-surface in the main when the former drains but a small district; but where the total available fall is slight, none of it need be utilized for this purpose.

Difficulty will sometimes be found in so arranging the comparative depths of storm and separate sewers that the house-connections can pass under or over the former. In some cases this may be impossible, and it may be necessary to place a separate sewer on each side of the storm sewer, in which case the nearer both of these are to the building lines, the shorter and less costly will be the house-connections.

Reference to the data of locations and depths of gas- and water-pipes and other existing sub-surface systems should be made constantly and the sewers so designed as to interfere with them as little as possible.

On the profile of each sewer line the elevation of all sewers that cross such line should be indicated and a cross-section of the sewer shown. On the finished profile it is well to indicate the top as well as the bottom of the sewer and the thickness and material of the sewer-walls and of all manholes and other appurtenances. The materials may be indicated by colors, as red for brick, brown for sewer-pipe, etc. The size, grade and length of the sewer between each two manholes should be given in figures, and the exact elevation of the invert at each manhole and change of grade. (See Fig. 17.)

CHAPTER IX

DETAIL PLANS

ART. 38. THE SEWER BARREL

A SEWER may consist of a series of pipes joined together to form a continuous conduit, or may be built in place of bricks or blocks of different shapes, of stone masonry, or of concrete poured into forms in place in the trench. Sewers are built of hard-burned clay, stone, concrete, iron, and wood. The material should be practically indestructible under the conditions found in sewers. The construction should be such as to afford sufficient strength to resist all outside and inside pressures. The completed structure should be watertight and the inner surface free from unevenness and uniform in cross-section. The cross-section and grade should be designed with careful observance of the requirements of hydraulics and flow as previously outlined. Local conditions as to foundation afforded by the soil or by artificial support, the shape or dimensions of trench or tunnel that can be constructed most economically to receive the sewer, the head-room available, etc., should be carefully considered, and also the materials most readily available of which to construct the sewer. Large sewers are very expensive, and every effort should be made to keep the cost at the minimum that will give satisfactory service.

Pipes are used in practically all cases where the diameter of the sewer does not exceed 30 inches, and have been used up to 72 inches and possibly larger. For the sizes up to 24 to 36 inches, salt-glazed vitrified clay is the material most commonly used; the shape being cylindrical. Concrete pipe (also called cement pipe) also is used for these sizes, either round or egg-shaped in cross-section. Cast iron is used where the pipe is to be under internal pressure, where water-tightness is of special importance or where for other reason unusual strength is required, as in unstable ground or outlets under water. Wood is seldom used for underground sewers, but is sometimes used for outlets, either entirely below low water, where there is little decay, or supported on piles, where some flexibility without leaking is desired; its absorption of sewage and liability to rapid decay are objections to its use, but both of these can be much lessened by creosoting.

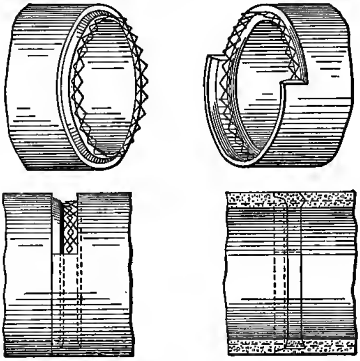


Fig. 24.—Joint of a Reinforced Concrete Pipe.

For sizes larger than 24 or 30 inches, reinforced concrete is the material most commonly used for pipes. There are several patented methods of reinforcing, some involving special methods of securing tight joints between pipes. With few exceptions these pipes are made cylindrical.

The chief advantages of pipes are that they can be made outside the trench, by which more perfect construction can be insured; they can be laid (at least in the smaller sizes) more rapidly than a sewer built of blocks or other small units or of concrete poured in place and with less plant and at less cost; and they can be given a more exact shape than is practicable with construction in place. The chief objections are the difficulties of avoiding breaks in continuity of surface at the joints, and of securing water-tightness at joints. Also, if very large sizes are used, the great weight makes the handling of the pipes difficult and expensive.

Fifty years ago practically all large sewers were made of brick. Present practice uses concrete very largely for such sewers; also large circular sewers are built of specially shaped interlocking blocks of vitrified clay, so designed that all joints lap and there are no joints continuous through the sewer to cause leaks. These are called segmental block sewers. In some special cases large sewers are built with vertical side walls of brick or stone masonry and roofs of reinforced concrete flat slab construction, or concrete or brick arches between steel beams. The arch is the cheaper and more common form of roof, however. The invert or bottom may be made of any form desired. Various forms will be discussed later.

—Forty-eight-inch Segmental Block Sewer at Wausau, Wis.

ART. 39. VITRIFIED PIPE SEWERS

Salt-glazed vitrified clay sewer-pipes that meet standard specifications are non-porous, not attacked by acids, smooth of surface, and have sufficient strength to resist crushing under ordinary conditions. The so-called "double-strength" pipes are somewhat thicker than the standard and are recommended where there is any probability of heavy pressure. (The double-strength pipe have a thickness of shell $\frac{1}{12}$ the diameter.) Some engineers, however, question whether pipe more than 30 or 36 inches in diameter have sufficient strength against crushing. But the best quality of double-strength pipe of any size made is probably amply strong for ordinary circumstances.

In many instances where vitrified clay pipe has been crushed in the ground it has been found that this was probably due to the fact that the pipe had a bearing on the bottom at only one or two points instead of along its entire length, or that stones or frozen earth were thrown upon it in back-filling. If earth is well tamped under and around a vitrified clay pipe it will not usually collapse, even when broken, although it may leak. Such pipe ordinarily breaks along four lines—at top, bottom, and each side—into pieces of almost equal size. For this reason fire-cracks and slight imperfections which do not cause the rejection of a pipe should be placed at a point about 45 degrees below the horizontal in laying, and not at the top.

Tests made by the Brooklyn, N. Y., Bureau of Sewers on several hundred pipes gave an average breaking load of about 350 pounds per foot of length for each inch diameter, the minimum ranging from about 200 to 300 for the different sizes. In these, the pipes were bedded carefully in a box of sand and the pressure applied through a strip of wood placed along the top.

The exact amount of pressure brought to bear upon a sewer by back-filling is uncertain. For a few feet of depth it probably bears the entire weight of the earth immediately above it. With granular material the proportion of pressure to weight of back-filling probably decreases but little, while with other soils it decreases more or less rapidly after the depth equals the width of the trench. But it is probable that, while clayey material gives an almost vertical pressure, sand acts more as a fluid, pressing normally to the surface of the sewer, and is not so liable to crush it. Little, however, is known on this point. If the depth of covering is small, there is danger that outside weight from road-rollers or even heavy wagons may crush it. But this danger appears to be very slight when the depth of covering equals or somewhat exceeds double the width of trench.

After several years of experimental research on this subject, the Engineering Experiment Station of Iowa State College developed a theory of the pressure received by a sewer in a trench from the back-filling, which is expressed by the formula $W = CFB^2$, in which W is load on pipe in trench, in pounds per lineal foot; C is a coefficient; F is weight of trench-filling material, in pounds per cubic foot, and B is breadth of ditch, in feet, measured $\frac{1}{7}$ the diameter of the sewer below its top. C varies with the ratio $\frac{H}{B}$, in which H is the height of fill above top of pipe. Values of C for the most commonly used values of $\frac{H}{B}$ can be taken from the diagram, Fig. 26.

The maximum load, using clay at 130 pounds per cubic foot, trench 2 feet wide at the pipe and 8 feet deep above the pipe, would be 1380 pounds per lineal foot. Of twenty 12-inch standard-thickness vitrified clay pipe tested, the weakest cracked under a load of 2230 pounds per lineal foot, and the average cracking load was 2890 pounds. A factor of safety of $1\frac{1}{2}$ is recommended, which would give a safe load for such pipe of 1927 pounds, which is the calculated load from the heaviest back-fill in a trench 2 feet wide and 15 feet deep. If the trench is deeper or wider, double-strength pipe should be used. Similar tests of standard-thickness 18-inch pipe gave a safe load for such pipe of 2050 pounds per lineal foot, and for 24-inch pipe, 2100 pounds. The last would be sufficient for only 8 feet depth (above the pipe) of a 3-foot trench; while double-strength pipe would suffice for about 13 feet depth, both assuming the heaviest saturated clay back-filling.

If sheeting is left in the trench, but not the rangers and braces, the pressure on the pipe may be increased 8 to 15 per cent.

Additional pressure upon the pipe is caused by loads upon the surface of the back-filling, as of vehicles. The greatest proportions of such loads that reach the pipes are estimated, from the Iowa State College experiments, to be about as follows:

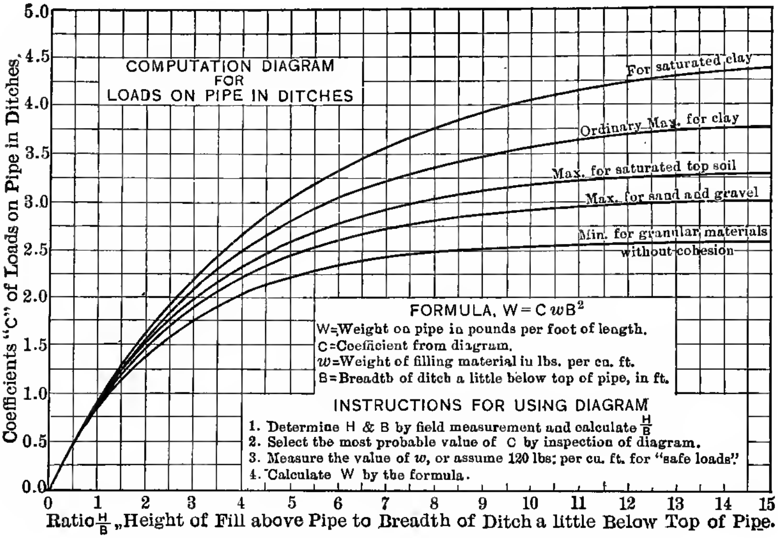
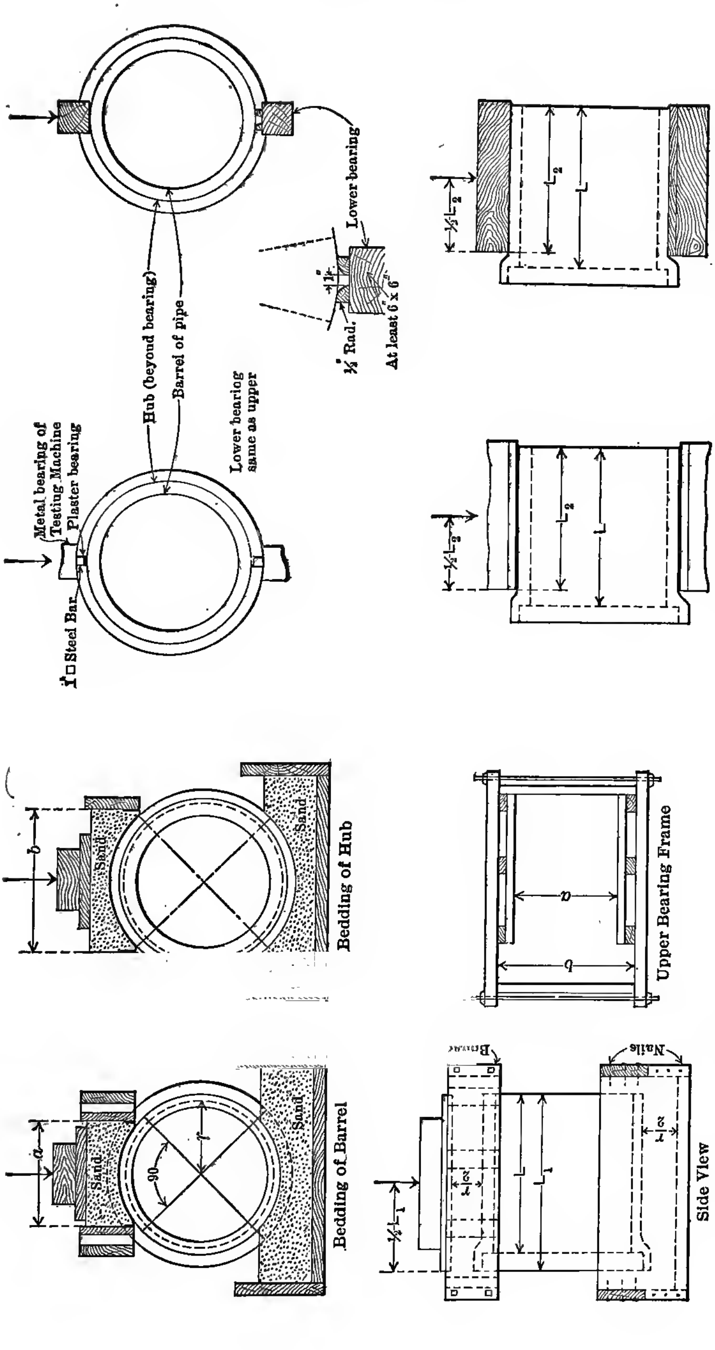


FIG. 26.—DIAGRAM FOR COEFFICIENT IN LOAD FORMULA.

GREATEST PROPORTIONS OF SURFACE LOADS ON BACK-FILLING THAT REACHES PIPE IN TRENCHES

Ratio of Depth to Width.	Sand and Damp Top Soil.	Saturated Top Soil.	Damp Yellow Clay.	Saturated Yellow Clay.	Ratio of Depth to Width.	Sand and Damp Top Soil.	Saturated Top Soil.	Damp Yellow Clay.	Saturated Yellow Clay.
0.0	1.00	1.00	1.00	1.00	3	0.21	0.23	0.25	0.29
0.5	0.77	0.78	0.79	0.81	4	0.12	0.14	0.16	0.19
1.0	0.59	0.61	0.63	0.66	5	0.07	0.09	0.10	0.13
1.5	0.46	0.48	0.51	0.54	6	0.04	0.05	0.06	0.08
2.0	0.35	0.38	0.40	0.44	8	0.02	0.02	0.03	0.04
2.5	0.27	0.29	0.32	0.35	10	0.01	0.01	0.01	0.02



Sand Bearings

"Two-point" Bearings

"Three-point" Bearings

FIG. 27.—BEARINGS RECOMMENDED FOR USE IN TESTING "ORDINARY SUPPORTING STRENGTH" OF SEWER-PIPE.

Thus, for a trench 2 feet wide and 8 feet deep, a wheel carrying a load of 1 ton would transmit to the buried pipe about 240 to 280 pounds, depending upon the nature of the soil. (A pavement, especially one with a concrete base, would presumably relieve the back-filling of much or all of this pressure.)

The joints of vitrified clay pipe sewers are generally made of the bell-and-spigot pattern, as shown in Fig. 28. Other joints, including the ring joint, have been used, but none during recent years to the author's knowledge. The bell-and-spigot joint is made by filling the annular space between bell and spigot with a material that should be durable, watertight and not too expensive nor too difficult to apply properly. Cement mortar is most commonly used, generally one part Portland cement to one part (sometimes two parts) of sand. This is applied by hand, rubber gloves being used, or with trowels. The latter is not recommended, as it is difficult to obtain a perfectly filled joint by troweling. A twisted strand of oakum or similar material is generally placed at the back of the joint (often soaked in cream of cement before use) to hold the spigot so elevated above the bell as to bring the inverts of the two pipes to the same grade, and to completely fill the joint space and prevent the mortar from being squeezed into the inside of the pipe. Joint makers are apt to slight the bottoms of joints—the most important part—because they are out of sight and sometimes difficult to get at. Water rising in the trench before the mortar has set will soften the mortar, causing it to slide out of the joint. Sand, mud or other dirt is apt to find its way into the joint after the pipe is set but before the joint is made. These must all be guarded against by careful inspection and use of experienced and conscientious joint makers.

Some engineers have practiced tying a band of cheesecloth around each mortar joint to prevent it from sliding out of the bell. Special forms have been used that permit pouring cement grout into the joint, thus insuring that it is completely filled at the bottom. More common is the use of material other than cement, with the aim of more surely obtaining watertight joints. Pitch pine tar and cement kneaded together has been used at Atlantic City, N. J., and a few other places. A mixture of sulphur and sand, melted and poured into place, and compounds consisting largely of asphalt or linseed oil that are poured in hot have been used with success during the past few years and the use of the asphalt and linseed oil compounds is becoming quite common, especially in the East. All of these are more expensive than cement joints and use of them is generally confined largely to locations where there is considerable ground water.

Even if there is no ground water, if much sewage leaks out through a joint there is danger that the remaining fluid will not be sufficient to keep the sewer clean of deposits. After a short period of use, however, a fairly good cement joint will become so stopped with matter strained from outfiltering sewage as to be practically watertight. But if the head of ground water is greater than that of sewage, the flow will be inward and the joint will probably not become tighter than it was at construction. Under such conditions special precautions may be taken, such as surrounding each joint with concrete.

The amount of ground water that may leak through a cement joint depends very largely upon the shape of the bell and the manner in which the joint is made. If the annular cement-space in the bell is too small, the cement is likely to be improperly compacted therein or not enter at all at some points. Experiments seem to show that the deeper the ring of cement in the joint the less the leakage. If for any reason the cement draws away from either bell or spigot, a leak is caused. Hence it seems best, particularly in wet soils, to use extra wide and deep sockets. The standard specifications of the American Society of Municipal Improvements call for a width of annular space of $\frac{5}{8}$ inch for 6-inch to 24-inch pipe, $\frac{3}{4}$ inch for 27-inch and 30-inch, and $1\frac{1}{4}$ inches for 33-inch to 42-inch. Also depth of socket or bell of $2\frac{1}{2}$ inches for 6-inch, $2\frac{3}{4}$ inches for 8- and 10-inch, 3 inches for 12- and 15-inch, $3\frac{1}{4}$ inches for 18-inch, $3\frac{1}{2}$ inches for 20-inch, $3\frac{3}{4}$ inches for 22-inch, 4 inches for 24-inch to 30-inch, and 5 inches for 33-inch to 42-inch. Pipes with shallower bells and less annular space are manufactured but are not recommended. Those described are known as " deep and wide socket " pipe. (For fuller description of pipe and laying, all specifications, Art. 48.)

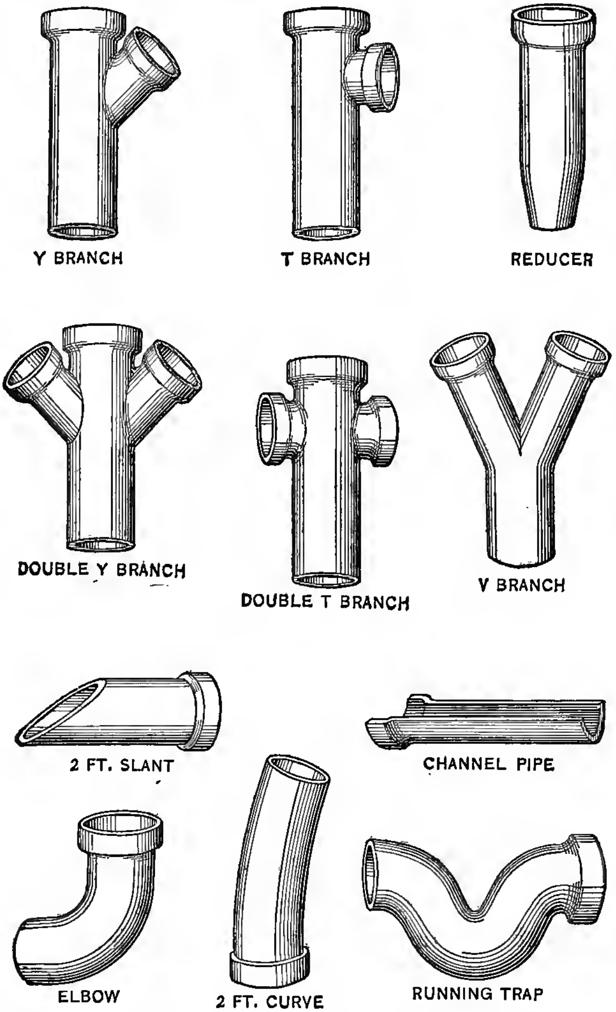


FIG. 28.—SPECIAL FORMS OF VITRIFIED SALT-GLAZED SEWER-PIPE.

With poor joints, the amount of leakage may be limited only by the amount of ground water, but with the best of cement joints in very wet ground, the leakage may be limited to from

5000 to 20,000 gallons per day per mile of sewer. In very many systems it is more than ten times this amount; in a few it is less. Where there is no ground water, the only leakage is outward, which is objectionable because of the possibility that it may so reduce the amount of water as to cause deposits in the sewer, may undermine the joints and cause settlement of the pipe, or the escaping sewage may reach wells, cellars or other places where it would endanger lives or give offense.

Since the joint is the weak place in a pipe, the fewer joints there are the better. The expense of laying, also, is decreased by decreasing the number of joints. For these reasons the use of 3-foot rather than 2-foot lengths of pipe is advised. Vitrified clay pipes more than 3 feet long have not yet been manufactured with success, but 3-foot lengths can be furnished by most pipe manufacturers at the same price per foot as the 2-foot lengths. Pipes larger than 24-inch are generally made in $2\frac{1}{2}$-foot lengths. (The length is that of the pipe exclusive of the bell—the length it will occupy when laid.)

The dimensions, weights and list prices of vitrified sewer-pipe furnished by most manufacturers east of the Mississippi River are given in Table No. 17. Figures used by the western and southern companies differ materially from these. Slants two feet long or less are charged the price of four feet of plain pipe. Double-strength pipe is generally allowed 10 per cent less discount than standard pipe. Increasers and reducers cost double the price of 2 feet of pipe of the size of the larger end. Channel or split pipe (halves or thirds of pipe made by splitting the pipe lengthwise) cost three-fifths the price of whole pipe of the size from which they are split. Discounts from the list prices generally range between 65 per cent and 75 per cent for car-load lots.

ART. 40. CONCRETE PIPE SEWERS

Small concrete pipe sewers (generally made with fine broken stone or gravel) are often called cement sewers. They are generally made round, but egg-shaped sections have been used in

TABLE No. 17

LIST PRICES, WEIGHTS, AND DIMENSIONS OF VITRIFIED, SALT-GLAZED SEWER-PIPE

Diameter.	List Prices.									Thickness of Shell.		Weight per Foot.		Depth of Socket.	Annular Space.
	Straight Pipe.	Elbows.	Curves.	Branches.											
				1 or 2 Ft. Long, with Inlets up to and including 12 In.	$2\frac{1}{2}$ or 3 Ft. Long, with Inlets up to and including 12 In.	$2\frac{1}{2}$ or 3 Ft. Long, with Inlets 15 In. or Larger.	Double, 2 Ft. Long, with Inlets up to and including 12 In.	Double. $2\frac{1}{2}$ or 3 Ft. Long, with Inlets up to and including 12 In.	Double. $2\frac{1}{2}$ or 3 Ft. Long, with Inlets 15 In. or Larger.	Standard.	Double Strength.	Standard.	Double Strength.		
In.	Per Ft.	Each.	Each.	Each.	Each.	Each.	Each.	Each.	Each.	In.	In.	Lb.	Lh.	In.	In.
3	$0.30	$1.20	$1.20	$1.20	$1.50	$2.10	$1.50	$1.80	$2.40	$\frac{1}{2}$	......	7	......	$1\frac{1}{2}$	$\frac{1}{4}$
4	.30	1.20	1.20	1.20	1.50	2.10	1.50	1.80	2.40	$\frac{1}{2}$	......	9	......	$1\frac{5}{8}$	$\frac{3}{8}$
5	.45	1.80	1.80	1.80	2.25	3.15	2.25	2.70	3.60	$\frac{5}{8}$	......	12	......	$1\frac{3}{4}$	$\frac{3}{8}$
6	.45	1.80	1.80	1.80	2.25	3.15	2.25	2.70	3.60	$\frac{5}{8}$	......	15	......	$1\frac{7}{8}$	$\frac{3}{8}$
8	.70	2.80	2.80	2.80	3.50	4.90	3.50	4.20	5.60	$\frac{3}{4}$	......	23	......	2	$\frac{3}{8}$
9	1.05	4.20	4.20	4.20	5.25	7.35	5.25	6.30	8.40	$\frac{13}{16}$	......	28	......	2	$\frac{3}{8}$
10	1.05	4.20	4.20	4.20	5.25	7.35	5.25	6.30	8.40	$\frac{7}{8}$	......	35	......	$2\frac{1}{8}$	$\frac{3}{8}$
12	1.35	5.40	5.40	5.40	6.75	9.45	6.75	8.10	10.80	1	......	45	......	$2\frac{1}{4}$	$\frac{1}{2}$
15	1.80	14.40	7.20	7.20	9.00	12.60	9.00	10.80	14.40	$1\frac{1}{8}$	$1\frac{1}{4}$	60	75	$2\frac{1}{2}$	$\frac{1}{2}$
18	2.50	20.00	10.00	10.00	12.50	17.50	12.50	15.00	20.00	$1\frac{1}{4}$	$1\frac{1}{2}$	85	118	$2\frac{3}{4}$	$\frac{1}{2}$
20	3.00	24.00	12.00	12.00	15.00	21.00	15.00	18.00	24.00	$1\frac{3}{8}$	$1\frac{2}{3}$	100	138	3	$\frac{1}{2}$
22	4.00	32.00	16.00	16.00	20.00	28.00	20.00	24.00	32.00	$1\frac{1}{2}$	$1\frac{5}{8}$	120	157	3	$\frac{1}{2}$
24	4.50	36.00	18.00	18.00	22.50	31.50	22.50	27.00	36.00	$1\frac{5}{8}$	2	140	190	$3\frac{1}{4}$	$\frac{1}{2}$
27	6.50	52.00	26.00	....	32.50	39.00	32.50	39.00	52.00	2	$2\frac{1}{4}$	224	265	4	$\frac{3}{4}$
30	7.20	57.60	28.80	....	36.00	43.20	36.00	43.20	57.60	$2\frac{1}{8}$	$2\frac{1}{2}$	252	290	4	$\frac{3}{4}$
33	9.00	72.00	36.00	....	45.00	54.00	45.00	54.00	72.00	$2\frac{1}{4}$	$2\frac{5}{8}$	310	335	5	$1\frac{1}{4}$
36	10.25	82.00	41.00	....	51.25	61.50	51.25	61.50	82.00	$2\frac{1}{2}$	$2\frac{3}{4}$	350	375	5	$1\frac{1}{8}$

NOTE. The prices of 3-, 5- and 9-inch pipe are made as great as those of the next larger sizes because these sizes are seldom used and the manufacturers desire to discourage their use altogether.

Brooklyn, N. Y., and elsewhere for sizes from 12-inch to 20-inch, these latter generally having flat bottoms. They are sometimes made with a bevel or taper joint, but commonly with a bell-and-spigot joint, similar to vitrified clay pipe. The thickness, depth of socket and annular space for the several sizes required by the specifications of the American Society of Municipal Improvements for non-reinforced concrete pipe are given in Sec. 202 of said specifications, page 245. The thickness is made about 25 per cent greater than that of vitrified pipe. To secure imperviousness, the concrete must be mixed of just the right consistency and thoroughly rammed or otherwise compacted. One process of manufacture comprises a revolving core that gives a smooth, dense inner surface to the pipe.

Cement adheres firmly and readily to concrete pipes, and probably is somewhat less liable to produce leaky joints than with vitrified pipe, although there is little definite information on this point. There would seem to be no reason why the bituminous jointing materials used with vitrified clay pipes should not be equally effective with concrete.

For sizes larger than 36-inch, and even down to 24-inch, reinforcement is used in concrete sewers to increase the strength. Reinforced pipe is commonly made in 4-foot lengths, in moulds, either along the trench or at a point convenient thereto. It generally is made with a mixture of 1 part cement to 2½ or 3 of sand and grit, and about 3 of ¾-inch stone. There are three or four styles of patented reinforced pipe, the joint of one of which is illustrated in Fig. 24.

The ease with which concrete pipe can be manufactured has led to the production, by unreliable manufacturers, of much that is weak, porous or otherwise undesirable, and care in inspecting and testing is even more necessary in accepting these than in the case of vitrified pipe.

Art. 41. Sewers Built in Place

Sewers more than 5 feet in diameter are generally built in the trench; concrete, brick, stone or special forms of clay-block being the materials commonly used; although pipes (made outside the trench) have been used of diameters up to 7 feet, and sewers have been built in place that were smaller than 5 feet. (Sewers as small as 10 or 12 inches have been built in place by means of a movable inner and outer form, but this system has never come into commercial use.)

During the past twenty years concrete has been used more than any other material for construction in place, replacing brick, which had been used generally before that time. Concrete possesses the advantages over brick that it does not require so much skilled labor, and is generally cheaper. Also, it can be made to any desired form. When well made it is equal if not superior to the best hard-burned sewer brick in resistance to abrasion in inverts. Concrete inverts twenty years old and more can be cited that show no appreciable wear under conditions that made it necessary to renew brick inverts in six or seven years. Carelessness in constructing concrete, however, can easily produce inferior work, causing infiltration of ground water and occasionally collapse. Concrete should consist of such proportions of aggregate as to secure maximum density and strength, the materials being thoroughly mixed and placed in the forms with the thickest consistency that will permit the concrete to fill them completely. The invert, especially, should be well mixed and troweled down smooth. In perhaps the majority of cases, concrete sewers are strengthened by the use of steel reinforcement.

Large sewers have been made of almost every conceivable shape. A few of the shapes that have been used are adapted to peculiar circumstances only, and some have been freaks of invention adapted to no circumstance.

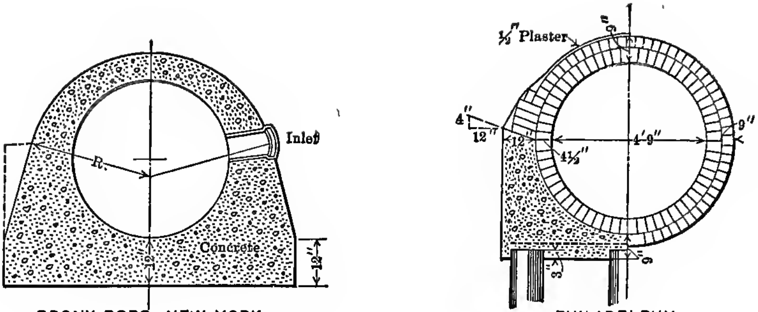
For a given perimeter of cross-section, the circle gives a larger area than any other form; consequently if the thickness of shell be fixed, a sewer of a given capacity requires for construction the least material if circular. Brick sewers were generally made circular, or sometimes egg-shaped or oval. Some conditions or features of construction, however, may make it more economical to employ a different shape, the saving in labor, in foundation material, etc., more than offsetting the additional amount of material in the sewer barrel. For example, in some cases limited head-room necessitates a flatter shape than a circle. In designing a section, full consideration should be given to the requirements of minimum flow (dry-weather or house-sewage flow, if a combined sewer), and the invert so made as to insure ample velocity.

Where the soil is not stable, the circular shape is generally not practicable, since neither the horizontal nor the vertical thrust of the arch can be sufficiently resisted by the ground. In such a case, the bottom may be made flat or approximately so, and side-walls vertical on the inside and battering on the outside may be used to take the thrust of the arch; or vertical side-walls may be covered with a flat roof of reinforced concrete slab construction, or of steel-beam and arch construction.

Where the head-room is limited, the sewer may be divided into two or three circular sewers, or may change its section to a wide and shallow sewer with a flat roof. In some cases, one or two longitudinal walls in a wide sewer practically divide it into two or three sewers having a continuous flat roof. Such construction may be used under railroad tracks or other places where considerable weight is applied to a sewer, heavy side-walls and a heavy roof securing an adequate strength of construction at less cost than would be practicable using a circular sewer.

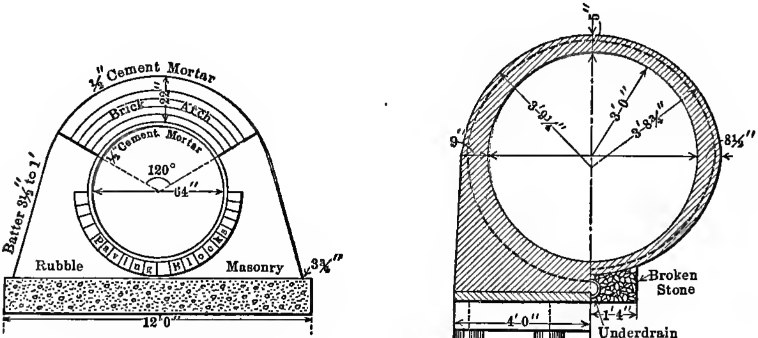
Where the sewer is built in tunnel, economy is generally effected by making the shape of the sewer as nearly as practicable that of the tunnel. This may give a section approximately rectangular in form where the sewer is through ground requiring the use of poling-boards or other tunneling methods giving a flat roof.

Where the sewer must be supported on piles and a timber platform, owing to the poor support offered by the soil, the most economical construction would be one with a flat invert.



BRONX BORO, NEW YORK

PHILADELPHIA



SPECIAL SECTION BENEATH RAILWAYS
SALT LAKE CITY, OUTLET SEWER

WILMINGTON, DEL.

FIG. 29.—CIRCULAR SEWER SECTIONS.

Those at the left are for poor foundations and heavy loads. The left-hand sides of the right-hand sections are for pile foundations; the right-hand sides for firm soil.

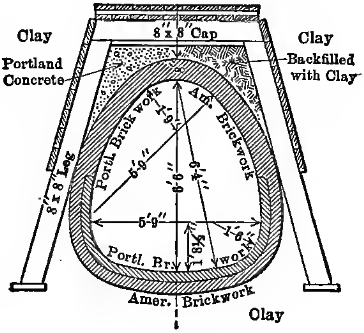
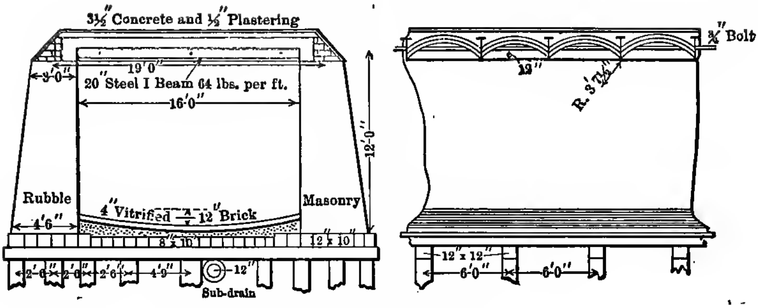
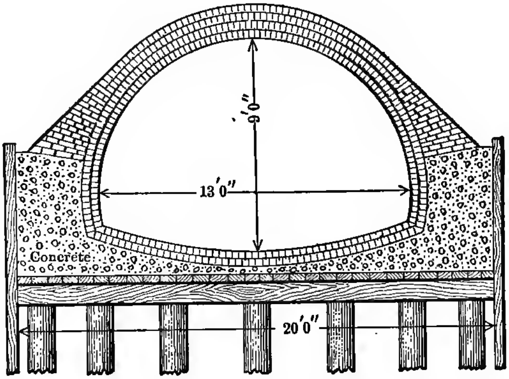


FIG. 30.—CATENARY SECTION IN TUNNEL.

Note that shape is designed to fit tunnel bracing.



Canal Street Sewer, St. Paul, Minn.



Large Boston Sewer

FIG. 31.—SEWER SECTIONS IN UNSTABLE SOIL.

Flat inverts to minimize amount of material on flat base. Upper one had limited headroom.

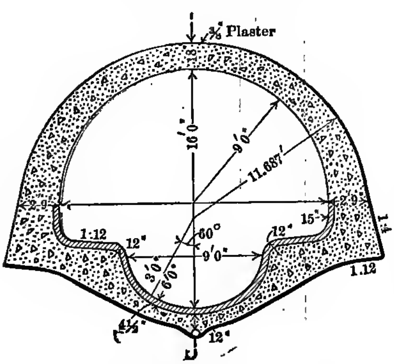


FIG. 32.—CUNETTE SECTION, WASHINGTON, D. C.

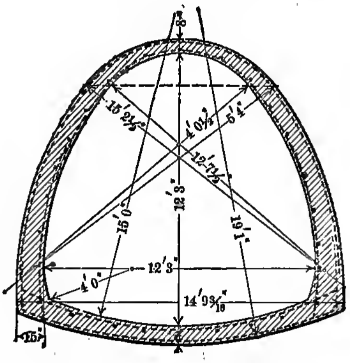
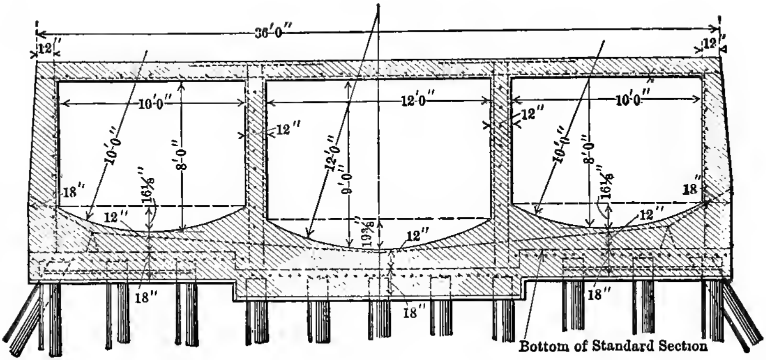


FIG. 33.—SEMI-ELLIPTICAL SECTION, LOUISVILLE.



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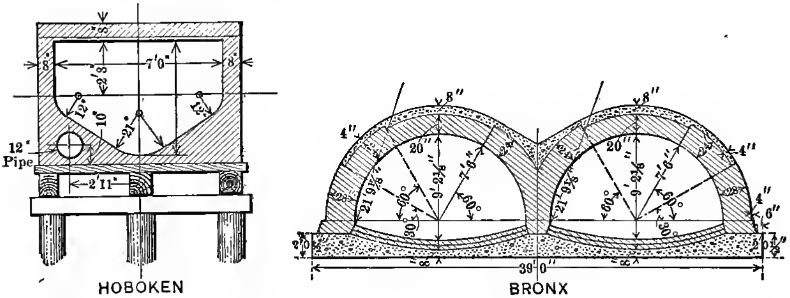


HOBOKEN

BRONX

FIG. 34.—SECTIONS FOR LOW HEAD.

Illustrations of flat top, multiple sewer, and both combined.

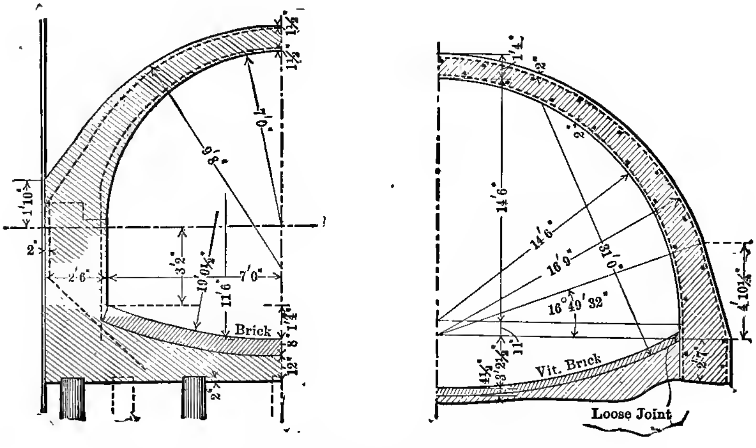
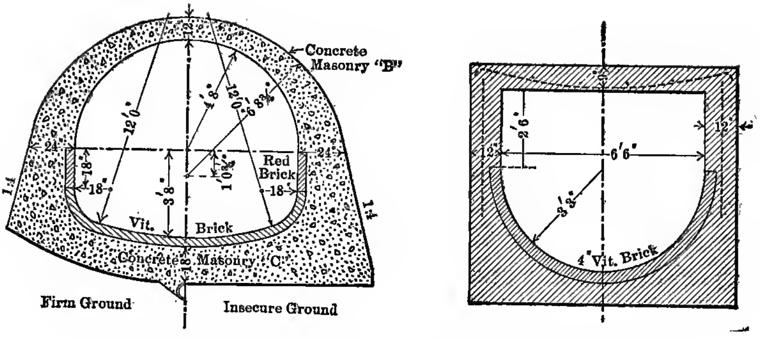
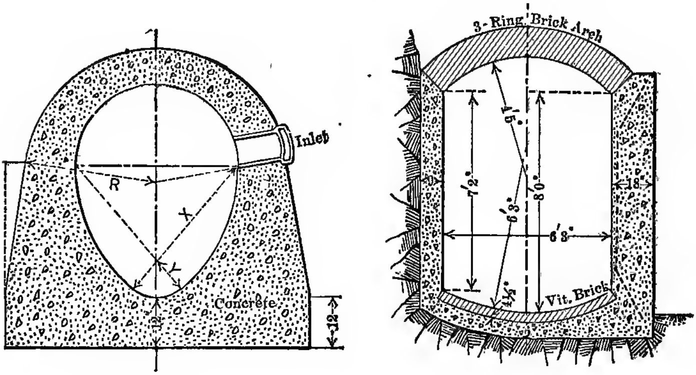


FIG. 35.—HORSE-SHOE; BOSTON. SEMICIRCULAR; ST. LOUIS.



Washington Richmond

FIG. 36.—BASKET-HANDLE AND U-SHAPED SECTIONS.



Bronx Boro. St. Louis

FIG. 37.—EGG-SHAPED AND RECTANGULAR SEWERS.

This illustrates the large amount of material used in placing an egg-shaped sewer on a flat foundation in unstable soil. In the rectangular sewer, the left side is designed for rock cut, the right for earth.

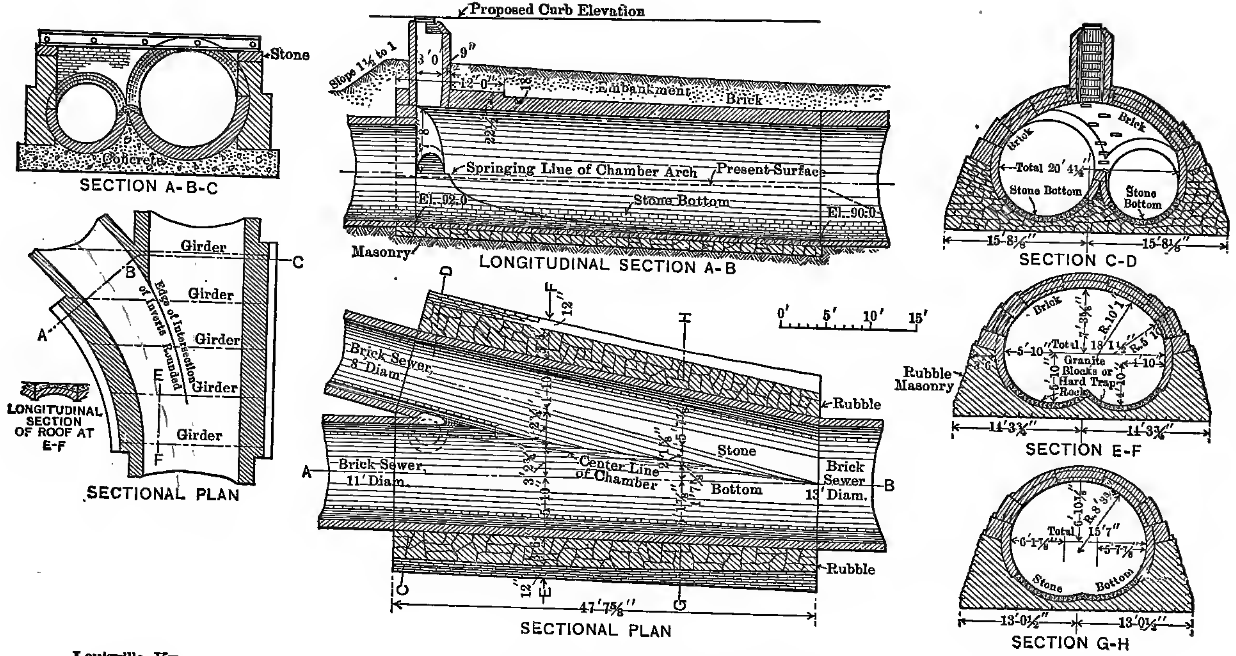
The above are a few of the forms which have been designed to meet special construction conditions. In the case of a combined sewer, the invert should be such that the dry-weather flow will be carried in a channel narrow enough to give a desirable depth of flow and velocity. This eliminates the flat bottom, although a bottom approximately flat but with a depressed channel for the dry-weather flow may be employed. In such case the channel should have sufficient depth so that the maximum amount of dry-weather flow will not overflow onto the benches. The most serious objection to this form from an operating standpoint is the probability that after a rain-storm, as the amount of combined sewage decreases to the dry-weather flow, suspended organic matters will be left stranded on the side benches. To prevent this, it is desirable to make these benches as steep as practicable. The dry-weather channel should be made as smooth and uniform in section and as straight in line as possible, an excellent plan being to line the bottom with split vitrified pipe embedded in the concrete, the walls of the channel being carried up from this channel pipe a distance equal to at least the radius of the pipe; a batter of as much as 45 degrees in these walls offering several advantages.

In the case of outfall sewers, intercepting sewers and others where there is at all times a considerable volume of flow, there is no serious objection to making the bottom of the sewer approximately flat, although such form gives a somewhat lower velocity than the circular.

Where the sewer is built on yielding soil, the bottom is generally given the form of a flat inverted arch to resist the upward thrust of the soil.

In all forms, angles should be avoided in the bottom or between the bottom and the side-walls, since angles greatly reduce velocity of flow and so encourage deposits; also because it is more difficult to remove deposits from angles than if the surfaces be joined by a cove or short-radius curve. Where the sewer is built of concrete, such curve also lessen the probability of cracking at the angles.

The inside surface of the sewer should be made as smooth as possible, to prevent the adhering thereto of suspended matters and also to afford as little retardation of velocity as possible on the flat grades. For this reason, forms for the inside of concrete sewers should be made of steel plates or, if of wood, of tongue-and-groove material closely driven together and greased. In addition to this, on the removal of the forms the interior of the sewer should be finished off by hand, removing all fins or other projections, filling the cavities with cement mortar, etc. In some cases, the walls have been rubbed down shortly after the removal of the forms to insure a perfectly smooth surface.



Louisville, Ky.

Philadelphia, Pa.

FIG. 38.—INTERSECTIONS OF LARGE SEWERS.
The left-hand illustration shows a flat-roofed junction chamber; the right-hand one, an arch-roofed junction chamber.

Where egg-shaped sewers are constructed, a smooth invert is sometimes obtained by embedding in the concrete, vitrified sewer-pipe split into thirds, this giving approximately the arc of the small invert-circle of egg-shaped sewers. There would seem to be no advantage in this over monolithic concrete construction, however, with careful setting of invert forms and hand-finishing of inverts, combined with care in proportioning and mixing the concrete.

Where a large sewer changes direction, such change should be made by a curve and never by an angle, and the longer the radius of the curve the better. When two sewers join, one or both should be curved in the direction of flow of the other. In general, when a branch sewer joins a larger one, it is desirable to make the inner wall of the former tangent to the corresponding wall of the latter. If the branch is very much smaller than the sewer that it enters, however, the curve may be omitted and the branch make an angle of 45 degrees with the main sewer. Each junction of large sewers will generally require special careful designing. The sewer below a junction will ordinarily have an area approximately equal to the sum of the areas of all the sewers uniting at that point, and efforts should be made to have the sewage from all of these enter the sewer receiving their combined flow in a direction as nearly as possible parallel to the axis of such sewer. Also, it is desirable to so adjust the invert elevations and horizontal diameters as to have the surface of flow in all sewers at the junction point stand at the same elevation at all conditions of flow. Perfect attainment of this is generally impracticable, but the desirability of it should be borne in mind. Great improvement in this respect would have been possible in a great many sewer junctions that have been constructed.

Illustrations of the above points are shown herewith, accompanied by suggestions as to the reasons for the special form in each case.

The thickness that should be given the walls of a brick or concrete sewer should theoretically depend upon its shape, size, material, the pressure to be sustained contributed by or through the surrounding soil, etc. Brick sewers have frequently been made one ring (4 inches) thick up to 30 inches diameter, two rings up to 60 inches, and three rings up to 120 inches. In the case of flat inverts on yielding soils, the invert should be designed to resist, as arch or beam, the vertical pressure exerted by the side-walls, unless these have bases sufficiently broad to prevent settlement independent of any support by the invert. The side-walls, or side arches, must be able to withstand the pressure of soil without; and if the soil can not carry the thrust of the arch without appreciable yielding, the side-walls should be able to carry this also.

Several formulas have been proposed for giving the thickness of arch of concrete sewers. Wm. B. Fuller's rule is: For crown, $\frac{d}{12}+1$ inch; for invert, 1 inch thicker; for haunches, $2\frac{1}{2}$ times the crown; 4 inches being the minimum for the crown, 5 inches for invert and 6 inches for haunches (d being the diameter). C. D. Hill (chief engineer of sewer construction of Chicago) used the formula $0.28\sqrt{R}+0.1$ foot, which gives approximately $\frac{d}{12}+1$ inch up to 6 feet, $\frac{d}{12}$ for 8 feet, and $\frac{d}{12}-2$ for 11 feet.

For spans under 20 feet, the *American Civil Engineers' Pocketbook* gives, for thickness of arch at crown $0.04(6+S)$ for plain concrete, and $0.03(6+S)$ for reinforced concrete, S being the span of the arch. At the springing line, the thickness should be 50 per cent greater for circular, parabolic and catenary arches having a ratio of rise to span less than 1 : 4; and 100 per cent, if the ratio of rise to span exceeds this.

Buel & Hill, in "Reinforced Concrete," suggest a thickness at the crown of a concrete arch $0.0075\ (S+10R)$, in which S is the span and R is the rise of the intrados.

Walter C. Parmley recommends a thickness of brick arch on a horizontal line through the center of a sewer equal to $\frac{S}{\frac{S}{14}+2.572}$.

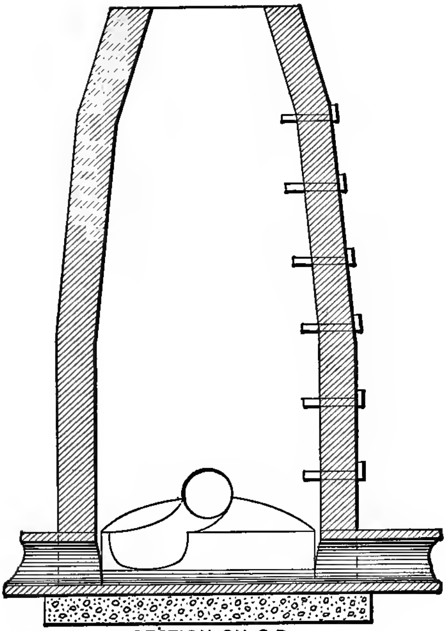
In general, reinforced concrete sewers, especially those approximately circular in section, have been made as thick as those not reinforced. The reinforcement, however, tends to prevent rupture if cracking occurs; and with flat slab roof or side-wall construction, or flat inverts on yielding soil, reinforcement is necessary unless excessive thickness of concrete be used. In concrete arches, it is considered good practice to use transverse reinforcing bars to the extent of 0.2 per cent to 1.5 per cent as much cross-section of steel as of concrete, depending upon the factor of safety desired against unforeseen stresses or poor workmanship.

In any concrete sewer there is likely to be contraction and expansion due to temperature changes. The former is apt to form transverse cracks. If longitudinal reinforcement be used, it tends to prevent wide cracks, distributing the contraction into a great number of cracks too fine to cause leaks. Reinforcement to the extent of about 0.2 per cent to 0.4 per cent of the concrete area is common practice. In some sewers, in place of or supplementary to reinforcement, expansion joints are used in the concrete at intervals of 25 to 50 feet, generally of the tongue-and-groove type. Even if these are provided, it is best to use about 0.2 per cent of reinforcement, especially if the joints are more than 25 feet apart.

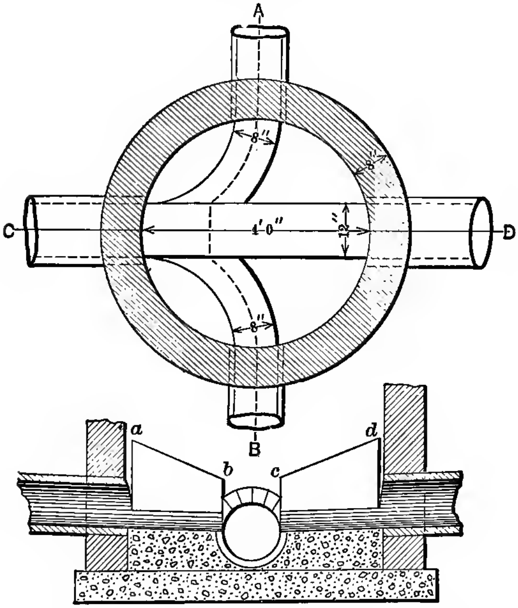
ART. 42. MANHOLES, FLUSH-TANKS, AND INLETS

The purpose of manholes, as the name implies, is to give admittance to the sewers, which is necessary for the purpose of inspection and cleaning. They should therefore be sufficiently large to permit a man of average size to enter and work in them. They are also utilized for ventilation.

Manholes are in general built immediately above a sewer and leading from it to the ground surface. In the case of some large sewers in Europe, they are built at one side of the sewer and connected with it by an underground passage, the chief advantages of which construction are the greater convenience for entering and the avoiding of manhole-heads in the street-pavement. But this construction is very expensive, and the passage is liable to be a collector of filth.



SECTION ON C-D



SECTION ON A-B

FIG. 39.—BOTTOM OF JUNCTION MANHOLE.

The size of vertical manholes is usually 24 inches diameter at the top, although sometimes only 22 or even 20 inches, increasing towards the bottom to a size in which a man can work. The least size advisable for the bottom on lines of pipe sewers is 4 feet circular or 3 feet by 4 feet 6 inches oval. In manholes of this size, the ordinary operations of inspection and cleaning of pipe sewers can be carried on. There is no particular advantage in having an ordinary manhole of more than 5 feet interior diameter.

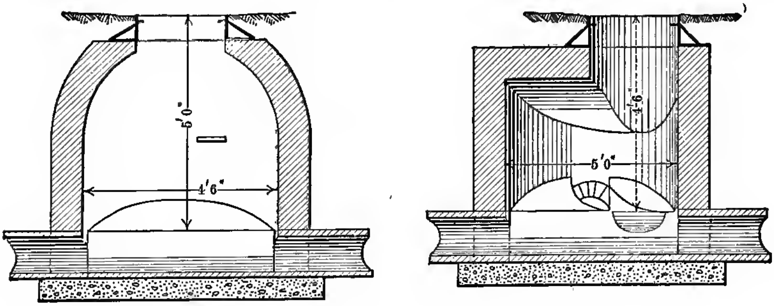


Fig. 40.—Shallow Manholes.

Manholes oval at the bottom are well adapted to locations where there are no intersecting sewers; those circular, to points of intersection.

Wherever possible, the sides of the manhole should be built vertical from the side benches of the bottom, *ab*, *cd*, Fig. 39, to a point 3 feet above, from which point they may be brought in with a batter or corbells to the smaller top, which is usually circular. Where the depth of the top of a pipe sewer below the surface is less than 7 feet, this construction becomes difficult, owing to the considerable batter that must be given to the upper walls, since the slope cannot well begin at a lower point than that stated and leave working room at the bottom. If the depth of sewer is more than 5 feet, this difficulty can be met by arching the walls (see Fig. 40), which construction requires careful workmanship.

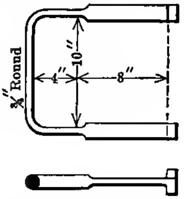


Fig. 41.—Manhole Step.

An alternative method, especially adapted to a depth of less than 6 feet, is to reduce the area of the manhole near the top by an offset, using either a brick arch or an iron beam to span the offset (see Fig. 40). If the manhole is more than 10 feet deep, the diameter should increase more rapidly for the first 3 feet down from the top, being at least 2 feet 9 inches at that depth, as otherwise descent through the shaft will be difficult.

Descent through the manhole can be made by means of a ladder, but it is customary to build steps into the wall for this purpose. These may consist of protruding bricks or stones, but preferably and commonly are of cast or wrought iron. Iron steps are made of various shapes. The simplest and probably as good as any is one made of a round wrought-iron bar bent and the ends flattened as shown in Fig. 41. The steps should be placed about 14 inches (6 bricks) apart vertically, and either directly under each other or alternating on opposite sides of a vertical line, the former in narrow shafts.

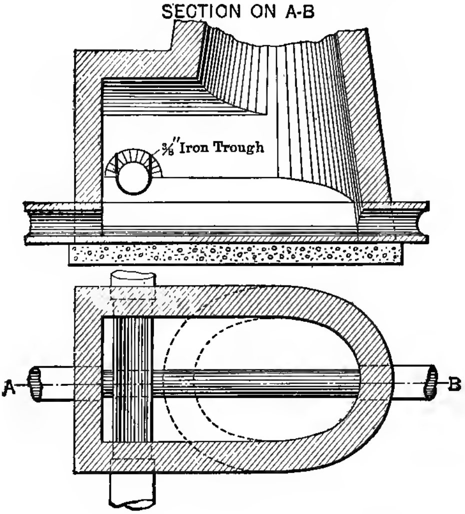


FIG. 42.—CROSSING MANHOLE.

Where one sewer crosses another without intersecting it, a manhole of special construction, permitting of inspecting each sewer, is desirable. Such a one is shown in Fig. 42, in which the upper sewer is continued through the manhole by an iron trough.

While, at the junction of a pipe-sewer main and lateral, the latter should be at a somewhat higher elevation than the former, it is desirable that the difference in elevation of the crowns of the two do not exceed 6 inches. To obtain this result the lateral may, if necessary, be lowered a sufficient amount at the junction by increasing the grade from the previous manhole. If this would increase the depth of excavation by more than 3 or 4 feet, a drop between the sewers may be made at the manhole. This should be so arranged that each sewer will be accessible for cleaning. The drop should not be made through the shaft of the manhole, but through a small, smooth channel. A good design is shown in Fig. 43.

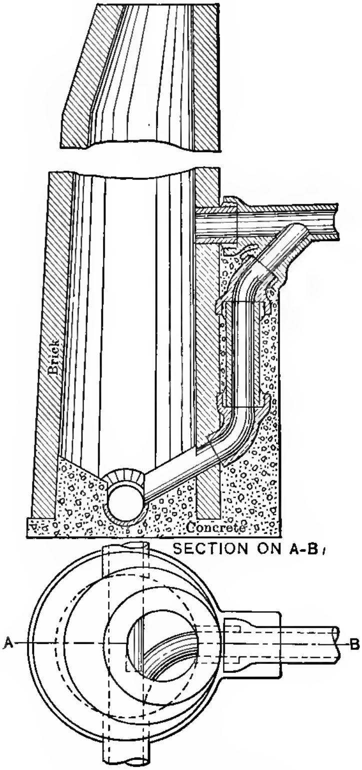


Fig. 43.—Drop Manhole.

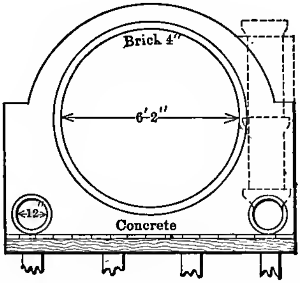
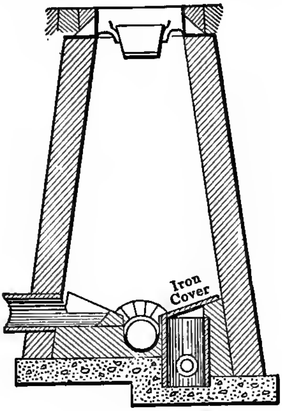


Fig. 44.—Sub-drain Inspection Shaft, Baltimore.

When sub-drains are laid under large sewers, arrangements for cleaning them may be made as shown in Fig. 44, by a vertical branch opening into a manhole; or, if they are under the center of the sewer, such a pipe may open into the sewer-invert, the opening being ordinarily tightly closed by a cap or plug. When the sub-drain is under a small sewer, the vertical branch should lead into a manhole, opening either in the sewer-invert or, better, in the bench. In either case the opening should be plugged so that absolutely no sewage can enter it (see Fig. 45).



SECTION ON A-B.

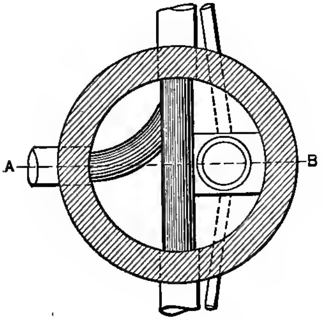
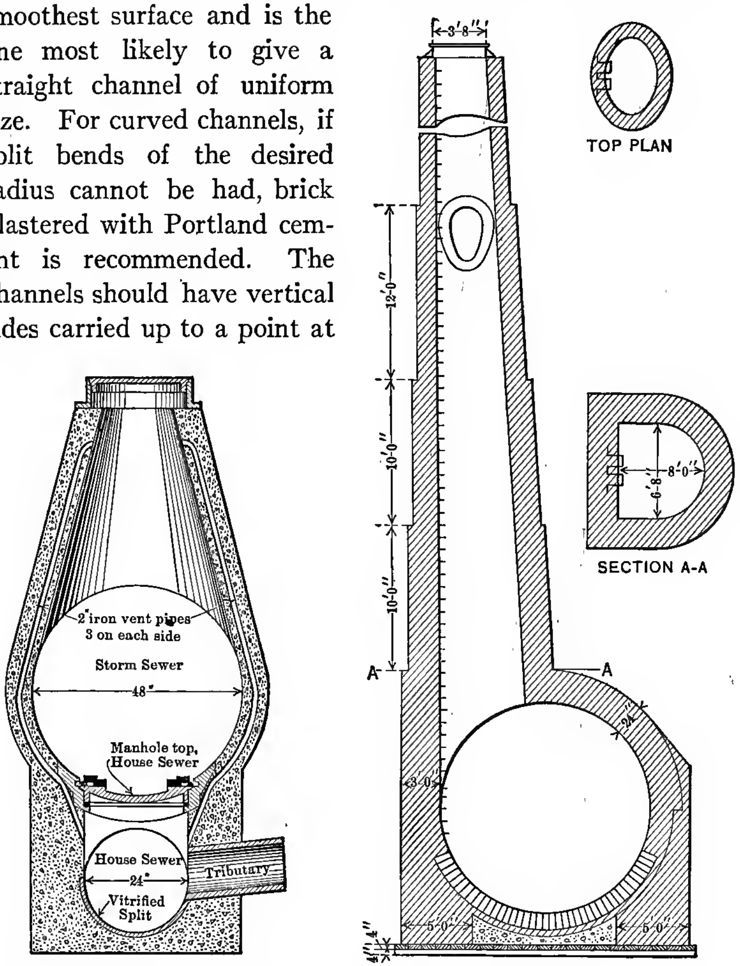


FIG. 45.—MANHOLE WITH SUB-DRAIN INSPECTION HOLE.

Manholes of special design will be required by unusual conditions, but in every design the three principal requirements of a manhole should be met: it should offer easy access for inspection and for cleaning of the sewer, and should assist in ventilation of the same; it should also be impervious to seepage of ground water, and be so proportioned as to resist the pressure of the surrounding earth. For this last purpose the curved form is better than the polygonal.

Manholes for sewers larger than 30 to 36 inches are usually built up from the sewer-arch and have no special bottom construction. The sewer-invert under the manhole should be reinforced, however, and a large foundation area provided, if the ground is at all yielding. The manhole shaft is sometimes placed on one side of the sewer, both for strength and for facility of access (see Fig. 46).

The foundation of a manhole should be perfectly solid. If the soil is soft, a plank platform may be used. Owing to the irregular shape of the bottom, concrete usually gives better results as to strength, shape, and imperviousness than does brick-work. The bore of each sewer should be continued through the bottom by a smooth channel of uniform section and slope, either straight or with a continuous curve. This channel can be plastered with Portland cement, lined with brick or with split vitrified pipe. The last method gives the smoothest surface and is the one most likely to give a straight channel of uniform size. For curved channels, if split bends of the desired radius cannot be had, brick plastered with Portland cement is recommended. The channels should have vertical sides carried up to a point at least $\frac{2}{3}$ as high above the invert as the top of the sewer-pipe, and benches should slope up to the sides of the manhole at an angle of at least 10 or 15 degrees with the horizontal.



Combination Storm and Separate Sewer. Off-center Manhole

FIG. 46.—SPECIAL MANHOLES.

The manhole walls are usually built of brick, 8 inches thick from the top to a point 10 or 12 feet below the surface, and increasing in thickness with the depth. If the bottom is a circle or a well-designed oval with no radius greater than 6 feet, a 12-inch wall should be strong enough at any depth, unless the ground is a quicksand or similar material, or is very wet. The outside of the manhole should be plastered with cement mortar to keep out ground water or water used in settling the trenches, and to prevent the lifting of the top foot or two by freezing ground.

In several cities manholes have been built entirely of concrete. These are generally more watertight than brick ones, and stronger. Special forms are required for their construction, and the providing, placing and removing of them add to the cost and inconvenience of concrete manhole construction.

The top of the manhole is generally capped with an iron casting sufficiently deep to permit the laying close to it of brick or stone paving materials. This will be about 8 or 10 inches, except where the pavement is made for heavy or city traffic, where it may need to be 12 to 16 inches.

Where the street is not paved, each manhole-head should be surrounded for a distance of at least 2 feet by cobble, rubble or stone block pavement, to protect both the head and passing vehicles. In some cases the head is provided with inside flange or lugs to hold it in place on the manhole; but this is undesirable, for it is better that the head should slide out of place than that it should rupture the top of the manhole masonry, as would probably occur if the pavement around the head should move. Where the pavement has a concrete base, this holds the head more firmly than a flange could.

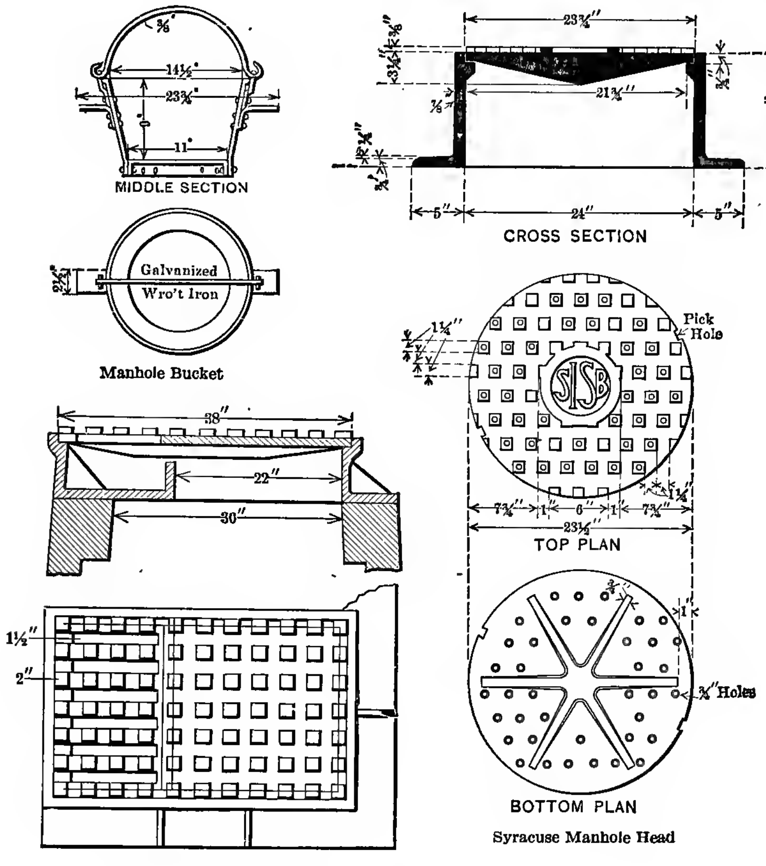
The cover should be sufficiently strong to support the heaviest wheel pressure. It should be provided with ventilation-holes giving as much area of opening as possible. Its upper surface should be roughened to provide foothold for horses. It should offer as little obstruction as possible to traffic, and be practically noiseless. The ventilation-holes should be through the elevated rather than through the depressed parts of the cover;

since by this construction the stoppage of the holes by dirt and snow and the entrance of dirt into the sewer are considerably lessened. Such a manhole-head and cover, as used in Syracuse, N. Y., is shown in Fig. 47. Covers are sometimes provided with locks to prevent the opening of the manhole by unauthorized persons, but these locks cause much trouble in some instances, particularly in freezing weather. A better plan probably is to make the covers so heavy that they cannot readily be raised without the use of some strong implement adapted to this purpose.

On roads and streets not paved with hard, permanent pavement, more or less dirt will be sure to enter through the ventilation-holes and if allowed to reach the bottom of the manhole may sometimes form stoppages, particularly in small sewers. To prevent this some cities provide a bucket of some kind suspended under the holes, smaller than the manhole-opening that the air may pass up between the bucket and the walls; or a special construction of some kind is designed for this purpose. (see Fig. 47). These receptacles should be cleaned before they become filled with dirt. The bucket supports must be so strong that the bucket cannot drop into the sewer, even when filled with dirt or ice.

A *flush-tank* or flushing-manhole should be watertight. It should be so proportioned as to hold the required amount of water without increasing the head on the sewer beyond the limit set (Art. 17). The flush-tank is usually set at the upper end of a sewer line, toward which much sewer air rises, and the sewer should therefore be provided at that point with ample ventilation. In spite of this, many automatic flush-tanks are so built as to afford the sewer absolutely no ventilation, forcing the adjacent houses to unwillingly, and usually unknowingly, provide it. Since flushing-siphons cannot permit of ventilation through their passages, a vent should be furnished the sewer just below the flush-tank. In some cases a manhole is placed just below, even in contact with, the flush-tank, which serves for both ventilation and for inspection and cleaning. Or the sewer may be continued straight into the flush-tank and provided with a removable stopper, while the flushing water enters the side of the sewer just below the tank.

Flush-tanks may be built of brick with concrete bottoms, the whole being made watertight, but concrete reinforced with steel rods is preferable in most cases, as this construction is more watertight and stronger than brick.



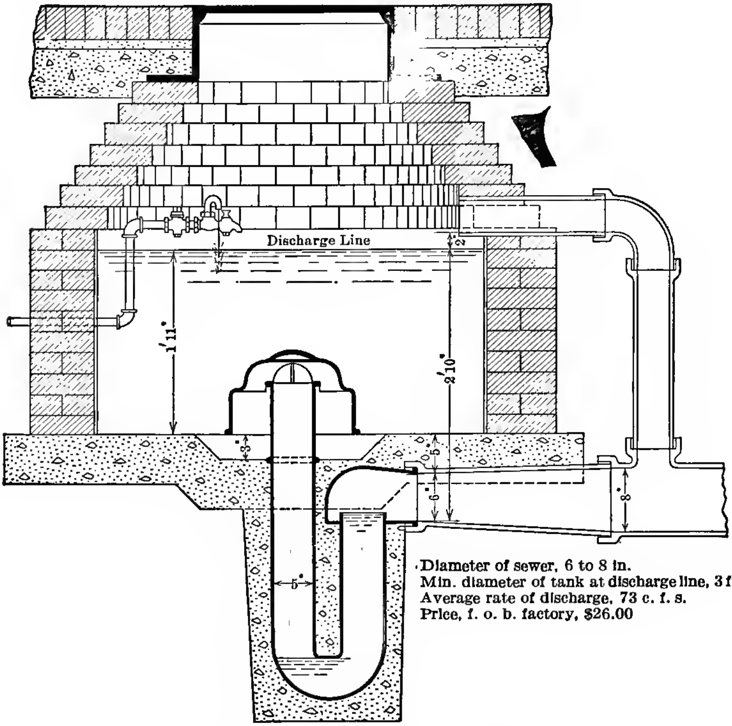
Manhole Bucket

Ventilation Manhole Head

Syracuse Manhole Head

FIG. 47.—MANHOLF HEADS AND BUCKET.

The automatic flushing appliances in common use act on the principle of the siphon, the variations being in the method of starting the flow. Most of those now used have no moving parts whatever. A number of other ideas have been used for flush-tanks, such as a tank on trunnions, which tips when full and returns to its original position when empty, but experience seems to have demonstrated the inadvisability of any moving parts.



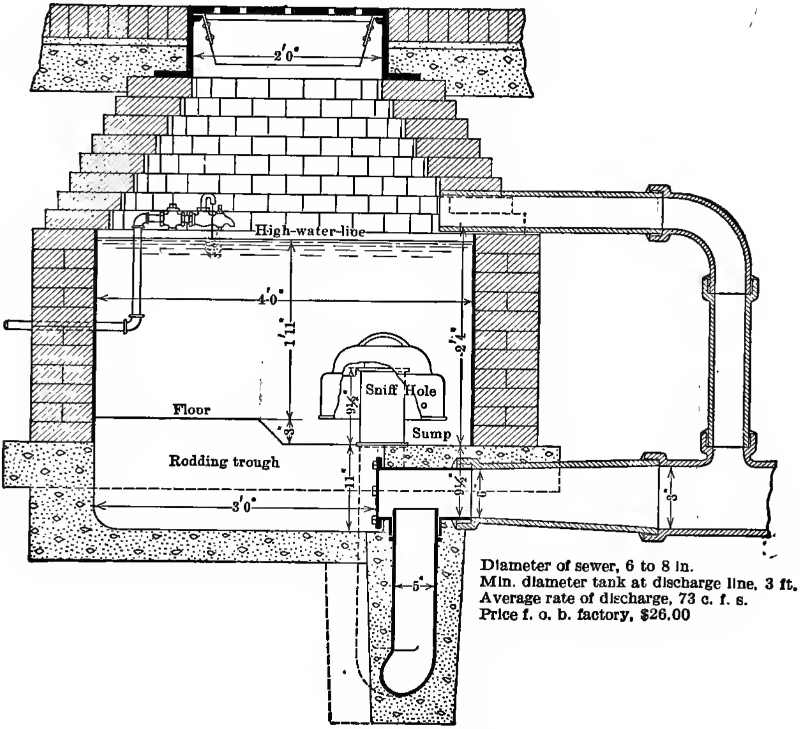
Diameter of sewer, 6 to 8 in.
Min. diameter of tank at discharge line, 3 ft.
Average rate of discharge, 73 c. f. s.
Price, f. o. b. factory, $26.00

FIG. 48*a*.—MILLER SIPHON FLUSHTANK.

The outlet of the flush-tank should be at some elevation, the more the better, above the sewer. If no automatic appliance is used, the opening of the flush-tank may be in the bottom, stopped by a plug or cap, which is raised by an attached chain when the tank is full; or it may be in the side and be opened and closed by a valve, either sliding or hinged.

If water is led to the flush-tank by a pipe, this should be kept below the effect of frost, turning and rising to a higher level inside the flush-tank if necessary.

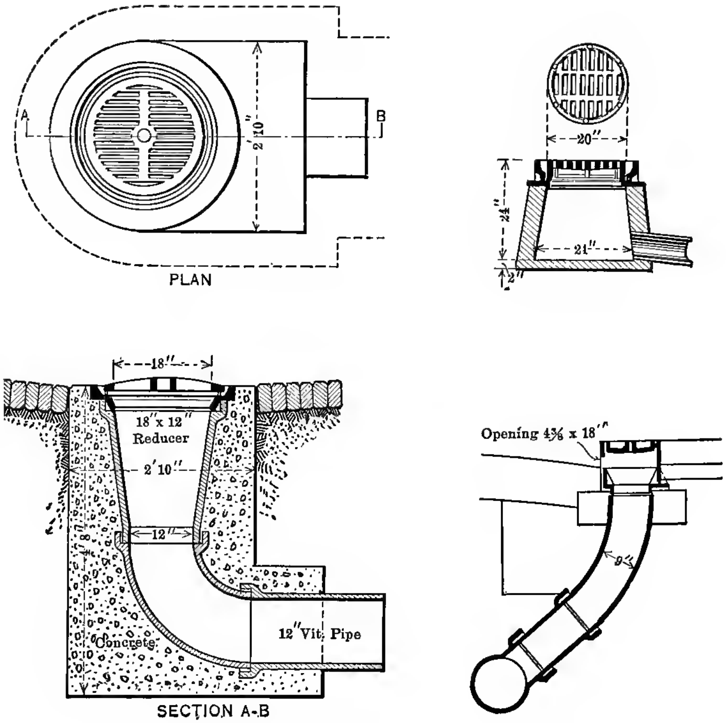
Inlets are made with and without catch-basins (see Art. 20), and the openings are sometimes vertical (in the curb), sometimes horizontal (in the gutter), and sometimes inclined. Their purpose being to admit water from the roadway to the sewer, the opening of each inlet should be sufficiently large to admit all the water which can reach it from the heaviest rain whose run-off the sewer is designed to carry. It may be so designed that the smaller of two openings, leading to a house sewer, shall pass the water from light rains or the first washings of a rain, while another larger one leads to a storm sewer. The opening should be at



Diameter of sewer, 6 to 8 in.
Min. diameter tank at discharge line, 3 ft.
Average rate of discharge, 73 c. f. s.
Price f. o. b. factory, $26.00

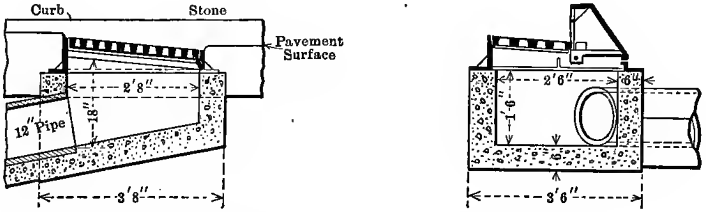
FIG. 48*b*.—MILLER-MACKINTOSH FLUSHTANK AND MANHOLE.

By shutting off water and removing cap in rodding trough, sewer becomes accessible.



METCALF & EDDY INLET

SPRINGFIELD, MASS.



BRONX BOROUGH, NEW YORK

FIG. 49.—SOME STANDARD FORMS OF INLETS.

the gutter where the water flows, and which should be slightly depressed at this point. If horizontal in the bottom of the gutter, one large opening is not permissible, but smaller ones, into which neither carriage-wheels nor feet of horses nor pedestrians can enter, must be used. The plate through which these holes are made must be able to support the most heavily loaded wheels that are likely to come upon it.

FIG. 50.—GUTTER TREATMENT AT STORM WATER INLET.

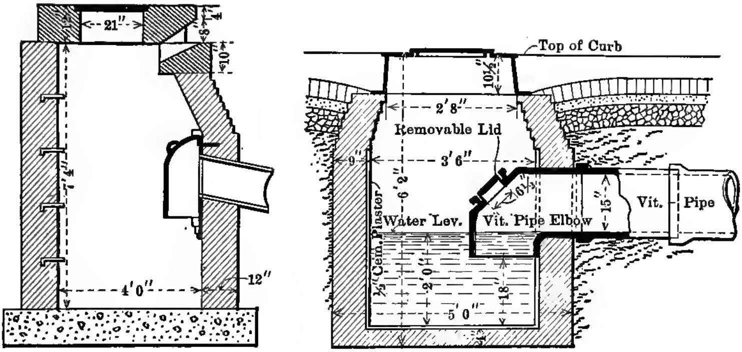
If the opening is through the face of the curb, in a plane either vertical or slightly inclined, it may be much larger. In some cases one large opening is used, entirely unprotected, through which children could and sometimes do fall. Except for this danger, such a clear waterway is an excellent arrangement. But it is advisable to so place one or more bars across the opening as to remove the danger referred to.

The total area of opening required may be found approximately by the hydraulic formulas for flow through horizontal [illegible] he case may be. In the [illegible] cross in any direction, an [illegible] or the occasional stoppage of some of them by leaves, paper, etc. The vertical openings, being larger, are less liable to stoppage. If horizontal openings in the gutter are in the shape of slots, they should run across the line of the gutter. Large gutter inlets are preferable where the water approaches with considerable velocity. Otherwise the author prefers curb inlets.

Between the inlet opening and the sewer, the channel should be straight or have as easy bends as possible, that the run-off may have an uninterrupted flow. The use of a catch-basin greatly interferes with this, the water seething and whirling in it during storms; consequently the channel connecting it with the sewer should be larger than if a simple inlet were used. In some instances a pipe leads directly from the opening to the sewer, either with or without a water-seal trap. It is better, however, to obtain a more substantial structure by setting under the opening a small basin with a curved bottom from which the pipe leads directly to the sewer. There is much room for improvement in the designing of inlets, with a view to reducing to a minimum the head lost in passing through them. The channel, from inlet opening to connection pipe, should contain no offsets or abrupt changes in size or shape, as few bends as possible, and these with long radii. Where the opening is horizontal, the basin is desirable to support the weight which may come upon the grating and, where a trap is used, to enable it to be placed below danger of freezing. It also facilitates inspection and cleaning of the connection-pipe.

A catch-basin usually consists of a well under the inlet-opening and below the connection-pipe to catch the heavier matters. It is sometimes placed between the inlet and the sewer on the line of the connection-pipe, and sometimes at the sewer in connection with a manhole. To be at all effective it should extend more than 18 inches below the connection-pipe, since a heavy rain will keep the water in it so stirred up as to wash out any deposits above that point. The bottom of the catch-basin should be covered with a flag-stone or the most substantial of concrete to receive the impact of the water, and be smooth to make cleaning easy,

Inlet and catch-basin wells may be built of concrete or of stone, but are usually of brick. Catch-basin wells are usually watertight, that water may constantly cover the contents and lessen their odors. An objection to this is the possibility that mosquitoes will breed in the water. (This may be prevented by pouring a little oil into each basin after every rain.) Some



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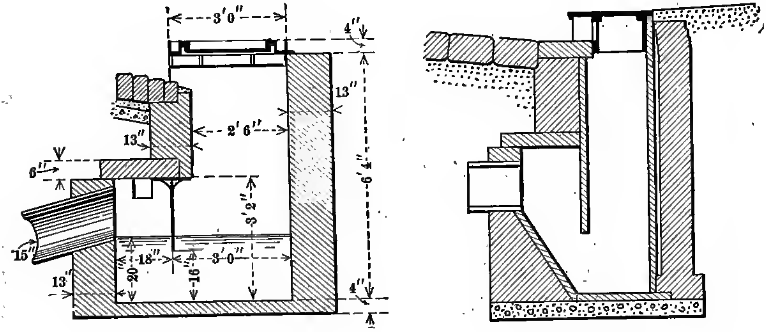

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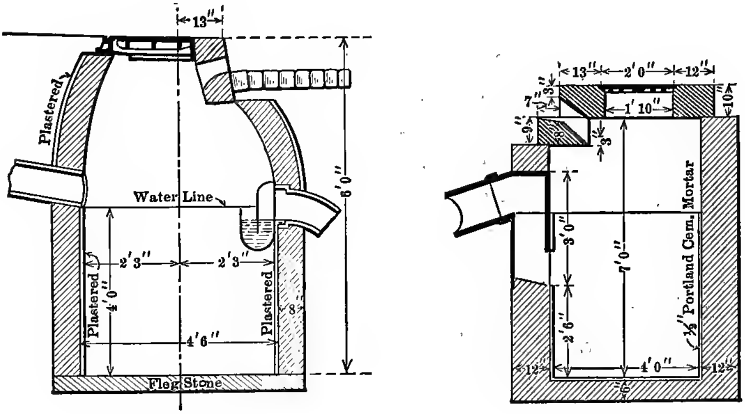


PROVIDENCE, R. I. NEWARK, N. J.

FIG. 51.—SOME STANDARD FORMS OF CATCH BASINS.

drain out the basin by means of a pipe at the bottom connected with the sewer. The gratings of catch-basins should be removable or the basins should be provided with manhole-openings, and the wells be sufficiently large to be entered for the inspection and cleaning of the connection-pipes.

When the inlet-opening is in the curb, the well with its catch basin (if one is provided) is generally placed under the sidewalk, and access to it is through a manhole-opening in the sidewalk. There is a great variety of inlet-tops for such construction, both cast iron and stone being used. The latter, where not too expensive, is usually preferable, being neater, more durable, and usually more like the contiguous sidewalk material than is cast iron. In some cities reinforced concrete is used instead of stone.

Traps are placed in many catch-basins or the connecting-pipes to prevent the exit of sewer air through the inlet; unwisely, the author thinks (see Art. 19). The outside trap is usually a running or P pipe trap. Many varieties of inside trap have been designed, both fixed and movable. The former should not prevent access to the connection-pipe and hence should be at least 15 inches from its opening. Traps with movable parts should be as simple as possible in construction and any trap should compel the outflowing water to make the least possible number of angular changes of direction.

Instead of placing a catch-basin at each inlet, it is sometimes preferable to place silt-basins along the line of the sewer at intervals of 1000 feet or more, with a manhole over each for ventilation and cleaning. These are particularly applicable to flat grades of storm sewers in the separate system. They consist of an enlargement of the sewer, and a depression of a foot or more in its invert, into which the heavier silt is washed and from which it can be removed more easily than when deposited along a stretch of sewer. These, however, should not be used to encourage deposit, but only when deposits would occur along the sewer beyond them if they were not provided. Their advantage over inlet catch-basins is that one takes the place of several such basins, and the difficulty and cost of cleaning is not so great.

Only in exceptional cases should they be used in sewers which carry house sewage. Inlet catch basins are preferable on lines of combined sewers, or on storm sewers where heavy dirt is washed in in very large quantities.

ART 43. OTHER STRUCTURAL DETAILS

Interceptors. The best form of interceptor to be employed is determined largely by the character of the system at the point of interception. If the house sewage is to be intercepted from sewers that originally discharged into a near body of water, the "leaping weir" interceptor, Fig. 52, may be used. The exact length of opening required in the invert can be only approximately determined. It may be made smaller than is thought necessary and cut to the right size, which is ascertained by trial, after the sewer is in use. It will also probably be desirable to increase the length from time to time as the amount of house sewage increases. The principal objection to this form of interceptor is that, although the storm-water may leap the opening, much of the sand and other heavy matter carried along the invert of the combined sewer will fall into the small intercepting sewer and may be deposited there.

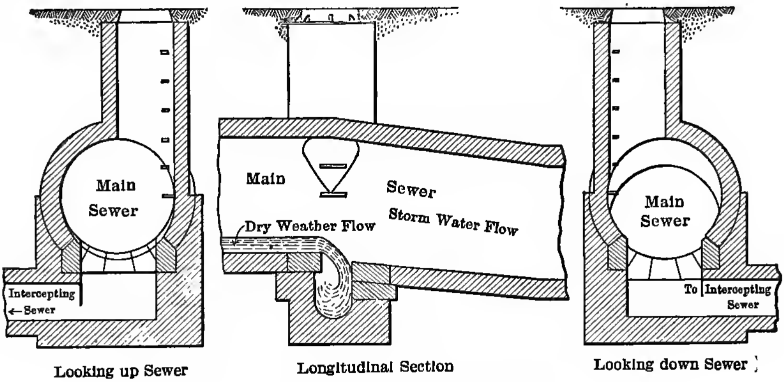


FIG. 52.—LEAPING-WEIR INTERCEPTOR.

An interceptor which meets this objection, which is called a regulator, is shown in Fig. 53. The valve shown is closed by the rising of the float, which occurs when the amount of sewage reaching the intercepting sewer becomes greater than it is desired that it should carry. The joints of the mechanism should be of bronze. A sewer does not offer the best conditions for the continued proper working of any mechanism therein, but one so simple as this should give little trouble in its maintenance. Several other designs of automatic mechanism for accomplishing this purpose have been employed.

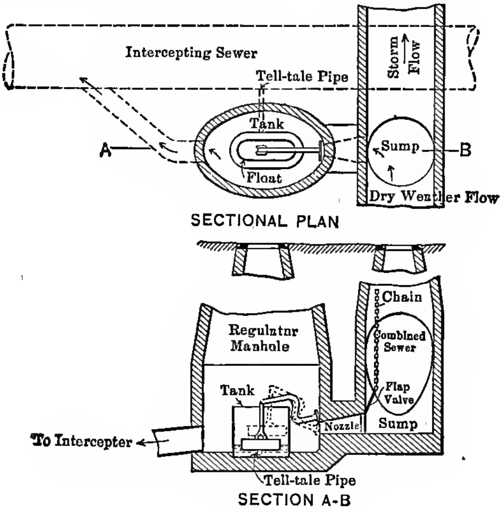


FIG. 53.—BOSTON REGULATOR.

Relief Sewers. When a sewer, because of improper designing or of changed conditions, becomes too small to carry all the sewage coming to it, the excess above its capacity may be diverted to and carried by a relief-sewer or -sewers. A relief-sewer may cross under and receive the excess from several gorged sewers, or a single sewer may overflow into several relief-sewers placed at intervals along its length and leading to nearby outlets.

An outfall sewer main to combined sewers is sometimes provided with overflow outlets at several points, to avoid increasing the size of the main beyond the smallest necessary dimension, or to limit the amount reaching a treatment plant to from two to five times the dry-weather flow. The diversion into such a relief-sewer or relief-outlet is ordinarily made by means of an overflow, as in Fig. 54, where the relief-sewer was constructed after the smaller sewers had long been in use.

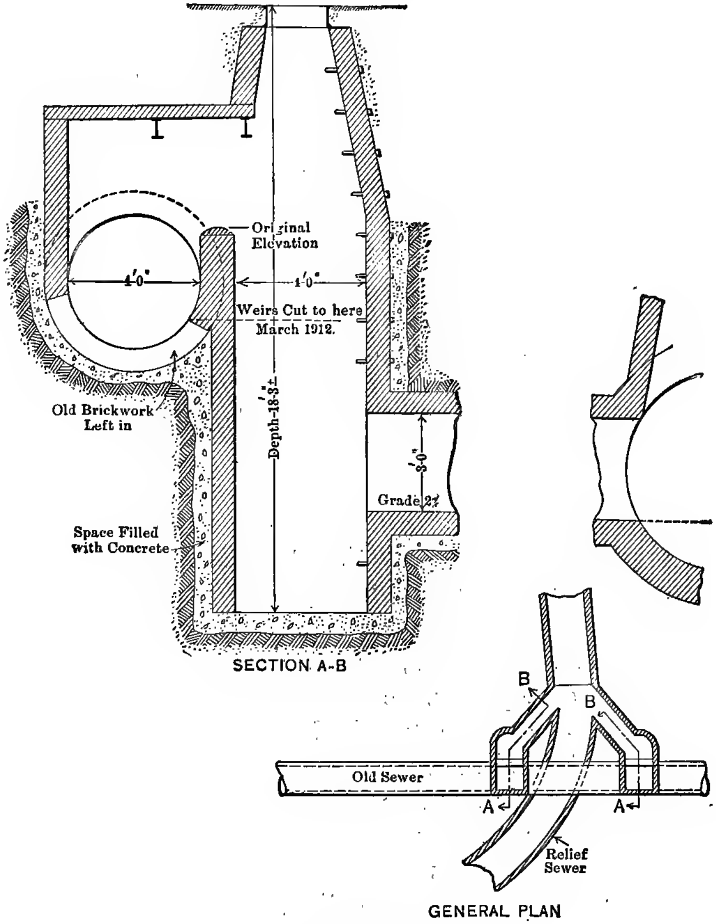


Fig. 54.—Storm Water Overflow.

Inverted siphons are usually circular in section, since always flowing full; usually of metal, since always under pressure. The size required has already been referred to. When laid under water, they should be so weighted or covered with concrete or stone as to prevent their floating when pumped empty for inspection or cleaning, and should be absolutely tight. The inverted siphon is made sometimes to slope from both ends to a point near mid-length, sometimes with a vertical drop at one end, sometimes at both ends. The first should be adopted only when the siphon is sufficiently large to permit the entrance of a man. When not of such a size, it should be straight from end to end. This will usually require a shaft at one end, sometimes at each, which may also serve as a manhole. It is in most cases advisable to place a catch-basin at the foot of such a shaft, although in place of this a basin in the bottom of an enlargement of the sewer just above the siphon is sometimes employed.

Unless a siphon under water is of large size and in tunnel or laid in a trench in a rocky bottom, it should be protected from undermining by currents, or movement by shifting bottoms or channels. This protection is usually afforded by driving a row of sheet-piling on each side of the pipe, the space between these being in most cases excavated and filled with concrete. The softer the material in the bottom and the stronger the currents the deeper the sheeting should be driven. If the bottom is too hard to permit of driving sheeting, large stone rip-rap may be placed on both sides and over the siphon.

A sewer must sometimes pass either under or over an obstruction—such as a water-main, another sewer, etc.—and if under, this must generally be done by an inverted siphon. Such a siphon is usually a few feet in length only and under but little head. A manhole should be placed over or near it when the sewer is 24 inches or more in diameter, since it will probably need more frequent cleaning than the other parts of the line. If the sewer is less than 24 inches diameter, a manhole should be placed at each end of the siphon (which is preferably straight from end to end).

Sub-drains are placed either directly beneath the sewer or at one side of the trench. When there are no artificial foundations under the sewer the latter position is to be preferred, but is in some instances much more difficult and expensive, particularly in quicksand. The sub-drain should be surrounded with

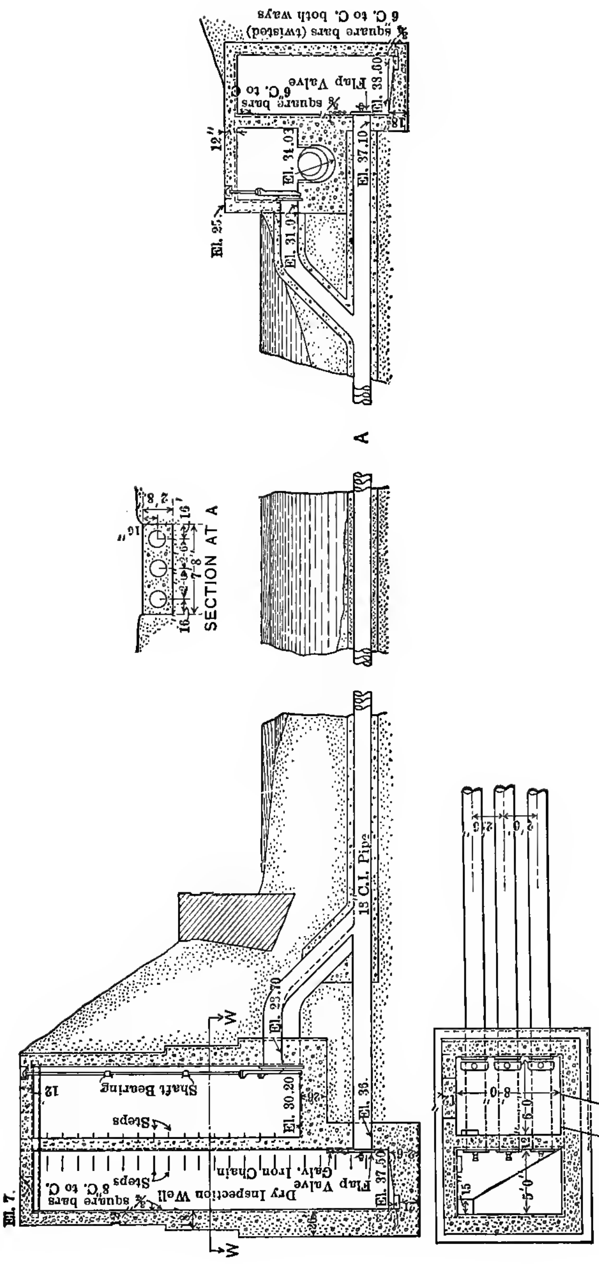


FIG. 55.—INVERTED SIPHON UNDER RIVER.

broken stone or clean gravel, varying preferably from the size of a hickory-nut to that of a pea. There should be at least 3 inches of this under the drain and 6 inches at its sides and top. In quicksand or similar material these dimensions should be increased 50 to 100 per cent. This stone should be well compacted to prevent future settlement. The joints of the drain should be slightly open and a 5- or 6-inch strip of cheese-cloth or burlap wrapped around the pipe at the joint to keep out the dirt. Or, if bell-and-spigot pipe is used, a piece of jute may be calked loosely into the joint for this purpose.

When the sewer is laid directly over this there may be danger of a settlement of the same and of leakage resulting. For this reason the sub-drain may be laid at one side of the trench when the soil is firm. In quick or running sand this is practically impossible unless the trench is very wide or unless close sheathing be driven on each side of the sub-trench and carried below its bottom; such sheathing not to be removed after the sub-drain is laid. It would usually be better and cheaper than this to lay the sub-drain in the center of the trench (which must of course be close-sheathed in quicksand), and on the stone filling, when levelled off, to place a continuous platform on which to lay the sewer. A still better construction in any but firm soils is to lay a pipe sewer in concrete. Such construction is shown in Fig. 57. Where a foundation is necessary for the sewer, the sub-drain construction is easily arranged.

The sub-drain should be laid to grade as carefully as the sewer itself. It is seldom that a sub-drain can be so arranged that inspection can be made of it, and therefore perfectly straight alignment is not necessary; but there should be no sharp angles in its line, which might cause obstructions or interfere with the future cleaning of it. If cellars and basements are to be connected with this drain, Y branches should be inserted to permit of such connections, and should be covered similarly to the separate-sewer branches.

Rising House-connections. When separate or combined sewers are placed with their tops more than 4 or 5 feet lower than the average cellar depth in that locality, it is advisable to place a

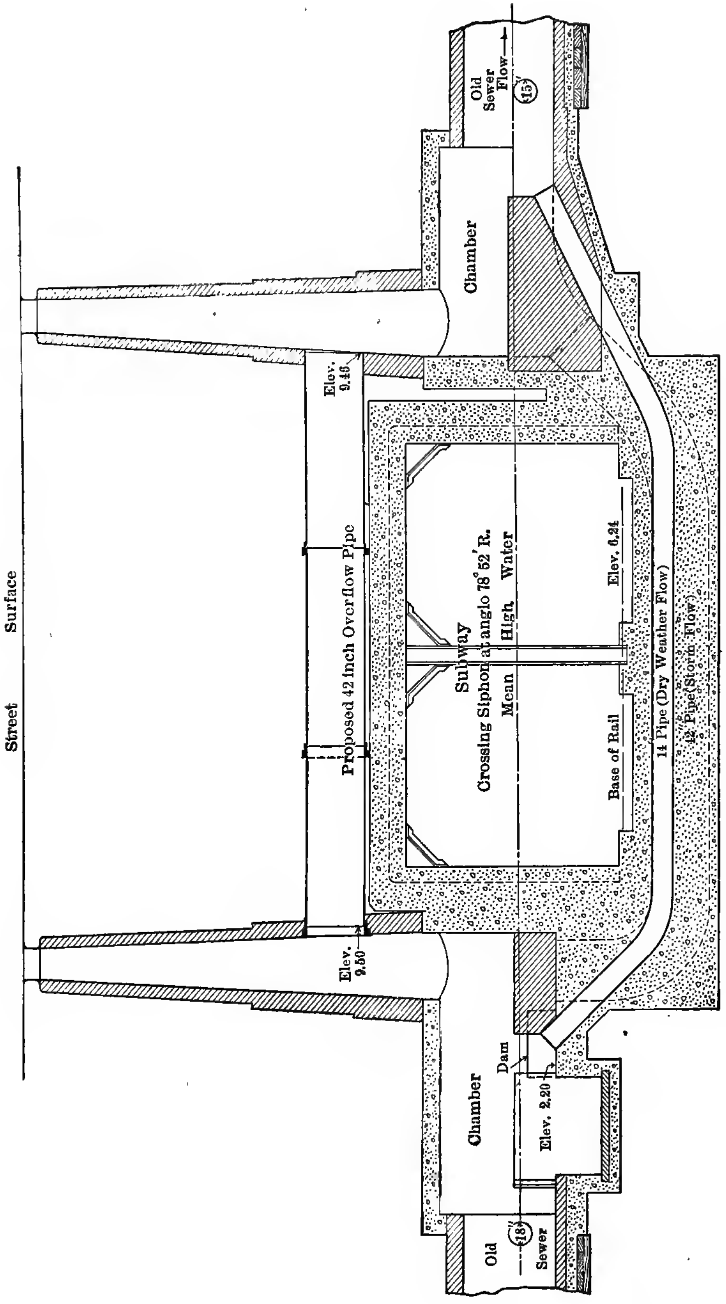


FIG. 56.—INVERTED SIPHON UNDER SUBWAY AT 149TH STREET, NEW YORK.

rising house-connection above each branch, bringing it to within 3 to 5 feet of the average levels of the cellar bottoms, but stopping at least 7 or 8 feet from the surface. This is to avoid compelling each householder along the line to dig down to a deep sewer branch in order to make a connection. These rising connections are built while the sewer-trench is open, and are covered at the top with a cap or cover similar to house-branches. They should not merely rest in the branch, but a foundation of concrete or brick masonry should support each. The vertical pipes should be held in place during back-filling, as by stakes driven into the bank. In the case of a rock cut, or where the banks are not firm, the rising connection may be inclosed by a vertical trough of planks, between which and the pipe earth is packed, this trough being held firmly in place until the trench is filled and tamped. If the banks are liable to cave, sheathing should be driven at each such connection, and neither it nor the braces removed when the trench is filled.

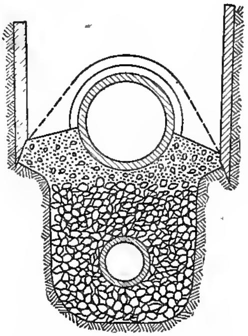


FIG. 57.—SUBDRAIN; SEWER ON CONCRETE SADDLE.

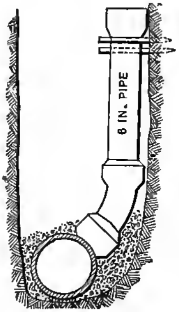


FIG. 58.—RISING HOUSE CONNECTION.

Foundations. A sewer in soft soil, like any other structure, requires a foundation. Since the weight is not comparatively great, the service of the foundation is more often to distribute the pressure and prevent local settling or heaving than to prevent the subsidence of the sewer as a whole. This purpose is usually achieved by use of a cradle, or a platform of plank, the former in comparatively firm soils like damp sand or loam, the latter in swamp-muck, quicksand, etc. Where muck or other soft, water-sogged soil is encountered it may be necessary to drive piles and rest a timber platform upon these. Such a foundation is shown in Figs. 31 and 34. Where a platform is used it is necessary to fill the sub-invert spaces of the sewer with masonry. All sewers in soft soils should have their inverts arching downward to resist the upward thrust of the ground between the side-walls, since the weight of the masonry is largely concentrated in these walls. Care should be taken to insure that manholes can not settle, since this would break the bond with the sewer or else cause a sag in the sewer grade at the manhole.

In rock excavations, no part of a pipe sewer should come within 6 inches of the rock bottom, and the space between this and the sewer should be filled with sand or other soil which compacts readily, which should be thoroughly tamped to prevent settlements of the invert; or the pipes should be bedded in concrete, in which case the rock may be taken out only to the under side of the pipe. If the sewers are built of concrete or brick masonry, this should be carried to rock everywhere under the invert.

CHAPTER X

SPECIFICATIONS AND CONTRACT

ART. 44. DEFINITIONS

PUBLIC work is frequently, if not in the majority of cases, done by contract by a "party of the second part" who is paid for this work by the city, the "party of the first part." That the contractor shall do the work as the city desires, it is necessary that he be instructed what is desired and that he bind himself to follow the instructions. This should all be recorded in writing for the protection of both the city and the contractor. The agreement to perform the work on the one hand and to pay for the same on the other is called a contract and is generally accompanied by a bond under which the contractor places himself to perform the work as directed.

The directions, called "specifications," "consist of a series of specific provisions, each one of which defines and fixes some one element of the contract. These clauses relate, in general: first, to the work to be done; second, to the business relations of the two parties to the contract" (Johnson's "Engineering Contracts and Specifications.")

The clauses in specifications for sewer construction referring to the work to be done may be classified as those: first, defining the character of the material to be employed; second, giving directions, dimensions, etc., for excavating and back-filling; third, setting forth the methods to be employed in the construction of the sewer barrel and appurtenances, including foundations; fourth, stating the requirements as to the completed work, tests to be made, etc.; fifth, giving general directions for the conduct and maintenance of the work, employment of labor, etc. Disposal plants will require separate specifications, varying with the character of the disposal employed. No general form for such can be given. Other special features of a system will call for special clauses.

The clauses relating to the business relations of the two parties to the contract may be classified as relating to: first, time of commencement and of completion and rate of progress of the work; second, character of labor and appliances to be employed; third, measurement of and payments for the work; fourth, contractor's protection of and responsibility for lives and property; fifth, abandonment, cancellation, assignment of contract, etc.; sixth, definition of names and terms employed.

The specifications are generally accompanied by a set of plans which form a part of the specifications and contract. These together should set forth the work to be done so clearly as to leave no point for future dispute. Care should be taken that contradictory instructions are not given, but that all parts of both plans and specifications mutually agree. Too great profuseness should be avoided as confusing to contractor, inspector, and engineer. Many engineers insert provisions which they have no intention of enforcing under ordinary conditions, merely to be on the safe side, or which aim at theoretic perfection of details which cannot be attained in practice (of which fact their inexperience may make them ignorant). The fact that some clauses in a specification cannot be enforced is apt to detract from the effectiveness of the others. It is better to make only such requirements as experience shows are desirable and practicable and give the contractor to understand that these will be rigidly enforced.

No foresight can predict all the emergencies which may arise in sewer construction. To provide for these it must be agreed that the engineer can modify plans or methods of work during construction, as well as increase or decrease quantities, provision being made to secure the contractor against loss due to such changes in plan. The contract itself can not be changed. Work not at first specifically provided for may be made the subject of a separate contract, or if but small in quantity, may be done under the original contract as extra work, to be paid for at its cost plus such a percentage for profit (generally 10 or 15 per cent) as is fixed in the contract.

Art. 45. Specifications for Sewer Construction

The specifications given on the following pages are those adopted by the American Society of Municipal Improvements. They were prepared by E. J. Fort, Chief Engineer of Sewers of Brooklyn, N. Y., Rudolph Hering and A. J. Provost as a committee of that society, and were adopted after two years of discussion by the society. They have been copyrighted by the society to prevent their use for advertising purposes, but any municipality which is represented in the membership of that society will be given free permission to use them upon application to the secretary of the society. Some alterations may be required to adapt them to particular cases, and for most cases many of the paragraphs may be omitted as inapplicable to the work in question.

TRENCHES

1. Length of Trench.—Unless otherwise directed or permitted, not more than .... feet of any trench in advance of the end of the built sewer shall be open at any time; and unless written permission to the contrary is given, the trench shall be excavated to its full depth for a distance of at least .... feet more than the minimum length of sewer permitted to be laid in it (see sections 152 and 158). Trenches for house-connection drains shall not be open on both sides of the street at the same time, unless permission has previously been given to close the street. Unless otherwise directed, each trench for basin connections and house-connection drains shall be fully excavated for its entire length before any pipes are laid therein.

2. **Sheeting and Bracing.**—Where necessary, the sides of the trenches and excavations shall be supported by adequate sheeting and bracing. Steel sheeting may be used only where shown on the plan or directed. Sheeting and bracing will be paid for only when left in place by written order, in which event the amount left in place will be paid for at the contract price for such material. Unless specially permitted, sheeting against which concrete is placed shall not be removed, but such sheeting will not be paid for unless ordered to be left in place to protect the sides of the trenches and excavations. The Contractor will be held accountable and responsible for the sufficiency of all sheeting and bracing used, and for all damage to persons or property resulting from the improper quality, strength, placing, maintaining or removing of the same.

3. **Sheeting in Soft Material.**—Where the material to be excavated is of such a character or other conditions are such as to render it necessary, the sheeting shall be closely driven and to such depth below the bottom of the sewer as may be directed.

4. **Tunneling.**—All work shall be done in open trenches or excavations, no tunneling shall be done except with the consent of the Engineer.

5. **Trees and Stumps.**—The Contractor shall grub and clear the surface over the trenches and other excavations of all trees, stumps, stones and any other incumbrances affecting the prosecution of the work, and shall remove them from the site.

6. **Material to be Disinfected.**—If required by the Engineer, any or all of the excavated material shall be satisfactorily disinfected or deodorized or immediately removed from the work.

7. **Roadway, Sidewalks, etc., to be Kept Clear.**—Unless permission is given to the contrary, the excavated material and materials of construction shall be so deposited, and the work shall be so conducted as to leave open and free for pedestrian traffic all crosswalks, a space on each sidewalk not less than one-third the width of the sidewalk and not less than 3 feet in width, and for vehicular traffic a roadway not less than 8 feet in width. All street hydrants, water gates, fire alarm boxes and letter boxes shall be kept accessible for use. Not more than .... linear feet of sidewalk shall be used at any time for storage of materials from any one trench. During the progress of the work the Contractor shall maintain such crosswalks, sidewalks and roadways in satisfactory condition, and the work shall at all times be so conducted as to cause a minimum of inconvenience to public travel, and to permit safe and convenient access to private and public property along the line of the work.

8. **Surplus Material.**—If all of the excavated material cannot be stored on the street in such a manner as to maintain the traffic conditions hereinbefore specified, the surplus shall be removed from the work and stored. After the construction of the sewer, so much of this material as is of satisfactory quality and necessary for the purpose shall be brought back and used for backfilling the trench.

9. Where directed, in built-up districts and in streets where traffic conditions render it necessary, the material excavated from the first . . . feet of trenches

shall be removed by the Contractor as soon as excavated, and the material subsequently excavated, if suitable for the purpose, shall be used to backfill the trenches in which the sewers have been built and neither the excavated material nor materials of construction shall be stored on the roadways or sidewalks.

10. **Fence.**—Where required by the Engineer, suitable fences shall be placed along the sides of the trenches to keep the streets safe for traffic.

11. **Temporary Bridges.**—Crosswalks, where intersected by trenches, shall if required be temporarily replaced by substantial timber bridges not less than 3 feet wide, with side railings. Where required, suitable temporary bridges for vehicles shall be provided and maintained across trenches.

12. **Disposal of Water from Trenches.**—The Contractor shall at all times during the progress of the work keep the trenches and excavations free from water. Water from the trenches and excavations shall be disposed of in such a manner as will neither cause injury to the public health, nor to public or private property, nor to the work completed or in progress, nor to the surface of the streets, nor cause any interference with the use of the same by the public.

13. **Cost to be Covered.**—The cost of all labor required to be done and all materials required to be furnished in the performance of all of the work specified in paragraphs 1 to 12, inclusive, except as otherwise provided, shall be covered by all the contract prices for all the items for which there are contract prices.

EARTH EXCAVATION.

14. Earth excavation shall include the removal of all material other than rock as defined in sections 21 and 22.

15. **Width of Trench for Sewers, etc.**—The minimum widths of trenches in earth for pipe sewers, basin connections, house connection and other drains not over 18 inches in diameter, shall be such as to give a clearance of 8 inches on each side of the barrel of the pipe, and for those of larger diameters, of 10 inches on each side of the barrel of the pipe, and all such trenches shall have a clear width equal to the maximum widths of the cradles of the sewers to be laid in them, when such cradles are wider than the minimum widths hereinbefore specified. The minimum clear widths of trenches in earth for other sewers shall be the greatest external width of the structures, including the necessary forms, to be built therein.

16. **Excavation for Manholes, etc.**—Where a riser, manhole or other appurtenance or the foundation therefor extends beyond the exterior lines of the sewer or its foundation, the minimum excavation in earth required for the same shall be that contained in a prism with vertical sides and a horizontal section equal to the smallest rectangle which will enclose such appurtenance and its foundation.

17. **Excavation for Receiving Basins, etc.**—The minimum dimensions of the excavation in earth for brick receiving basins, catchbasins and flush tanks shall be such as to give a clearance inside the sheeting of 1 foot on all sides above the foundation, but in all such cases the excavation shall be large enough to

include the foundation for the structures shown on the plan. The excavation for concrete catchbasins and flush tanks shall be of such dimensions as to permit the proper placing and removal of the necessary forms.

18. **Depth of Trenches.**—Trenches shall be excavated to the depths required for the foundations of the sewers and appurtenances shown on the plan, and where conditions are such as to make it necessary, to such additional depths as may be directed. Where pipe is laid without a cradle, the bottoms of trenches shall be excavated to fit the lower third of the pipe, and excavations shall be made to receive the hubs. All irregularities in the bottoms of trenches shall be filled up to the required grade with suitable material.

19. (*Same as paragraph* 13, *except paragraph numbers.*)

20. **Additional Earth Excavations.**—When there is a contract price for additional earth excavation, it shall cover the cost of excavating all material (other than rock) ordered to be excavated beyond the lines and depths herein specified in sections 15 to 18, inclusive, and also the cost of excavating all material within the lines of the trenches above the surface of the ground as shown on the plan, when such material has not been placed there by the Contractor. This contract price shall also cover the cost of filling such excavations with approved material. Where no price is named in the contract for additional earth excavation, the cost of the several items enumerated above shall be covered by all the contract prices for all the items for which there are contract prices.

ROCK EXCAVATION.

21. **Definition.**—Rock excavation shall include the excavation and removal of the following materials:

a. Rock which shall be determined to be of such a character as to warrant its removal by blasting, in order to insure the prompt and proper prosecution of the work.

b. Boulders and pieces of rock, masonry in mortar, and concrete, each of which contains one-third cubic yard or more, except the masonry and concrete of old sewers and their appurtenances.

22. Pieces of rock, masonry, concrete or boulders which fall or slide into the trench from beyond the lines thereof as herein defined, will not be measured, and the cost of the removal of the same shall be covered by all the contract prices for all the items for which there are contract prices.

23. **Width of Trench.**—The required width of trench in rock for pipe sewers, basin connections, house connections and other pipes will be such as to give a clearance of 1 foot on each side of the pipe, exclusive of spurs and hubs; the required width of trench in rock for other sewers and drains will be such as to give a clearance of one foot on each side of the structure to be built therein at its greatest external width. Where a riser, manhole or other appurtenance, or the foundation therefor, extends beyond the exterior lines of the sewer or its foundation, the excavation in rock required for the same will be that contained in a prism with vertical sides and a horizontal section 1 foot wider on each

side than the smallest rectangle which will enclose such appurtenance and its foundation. The required dimensions of the excavation in rock for receiving basins, catch basins and flush tanks will be such as to give a clearance of 1 foot on all sides above their foundations.

24. **Depth of Trench.**—The rock shall be excavated to the depths required for the cradles and foundations of the structures as shown on the plan, and not less than 4 inches below the outside of the barrel for the pipe sewers.

25. **Measurement.**—The volume of rock to be paid for will be that contained in prisms with vertical sides and of such dimensions as to give the widths and clearances hereinbefore specified from the bottoms of the trenches, as specified and as shown on the plan, to the surface of the rock.

26. **Rock Stripped.**—Rock shall be stripped in sections, which, unless otherwise permitted, shall be not less than 50 feet in length, and the Engineer shall then be notified in order that he may measure the same. Rock excavated or blasted before such measurement is made will not be paid for.

27. **Excavation for Branches.**—Wherever a branch for a proposed sewer or extension of a sewer is built in the rock, the required trench shall be excavated for a distance of not less than 5 feet beyond the end of such branch, in the direction of the proposed sewer or extension.

28. **Blasting.**—All blasting operations shall be conducted in strict accordance with existing ordinances and regulations relative to rock blasting and the storage and use of explosives. Any rock excavation within 5 feet of a water main less than 36 inches in diameter, and within 10 feet of a water main 36 inches or more in diameter, shall be done with very light charges of explosives, or, if directed, without blasting, and the utmost care shall be used to avoid breaking or disturbing the main.

29. **Exposed Structure to be Protected.**—All exposed sewers, manholes, receiving basins and other structures shall be carefully protected from the effects of blasts. Any damage done to such structures shall be promptly repaired by the Contractor at his own expense.

30. **Price to Cover.**—The contract price for rock excavation shall cover the cost of all labor and materials required to excavate and remove all rock as specified, and without regard to its subsequent use. When there is no contract price for rock excavation the cost of excavating and removing rock shall be covered by all the contract prices for all the items for which there are contract prices.

BACKFILLING.

31. **Backfilling around Sewers, etc.**—Unless otherwise specified or directed, all trenches and excavations shall be backfilled immediately after the structures are built therein. For a depth of at least 2 feet over the top of sewers, basins, basin connections, house connections and other drains, the material used for backfilling trenches as excavated shall be clean earth, sand or rock dust. It shall be carefully deposited in uniform layers not exceeding 6 inches in depth, and unless otherwise permitted each layer shall be carefully and solidly tamped

with appropriate tools in such a manner as to avoid injuring or disturbing the completed work.

32. **Backfilling for Remainder of Trench.**—Backfilling for the remainder of the trenches as excavated shall be approved material free from organic matter and containing no stones over 10 inches in their largest dimensions. Stones which are used in backfilling shall be so distributed through the mass that all interstices are filled with fine material. Backfilling shall be deposited as directed, and unless otherwise permitted shall be spread in layers and solidly tamped.

33. **Backfilling around Manholes, Receiving Basins, etc.** — Backfilling within 2 feet of manholes, house connection drains, receiving basins, inlet basins, flush tanks and other structures shall be of the same quality as that specified in sections 31 and 32. It shall be uniformly deposited on all sides, and unless otherwise permitted solidly tamped in such a manner as to avoid injuring the structures or producing unequal pressures thereon.

34. **Puddling.** — Backfilling shall, if required, be flooded or puddled with water as the work progresses, instead of being tamped.

35. **Cavities Filled.**—When sheeting is drawn, all cavities remaining in or adjoining the trench shall be solidly filled. When sheeting is left in place, all cavities behind such sheeting shall be solidly filled as directed.

36. **Deficiency of Filling.**—Unless otherwise shown on the plan, trenches shall be backfilled to the height of the surface of the ground as it existed at the commencement of the work. Should there be a deficiency of proper material for the purpose, the Contractor shall furnish and place such additional material as may be required.

37. **Temporary Bulkheads.**—For retaining backfilling only temporary bulkheads will be allowed. Such bulkheads shall not be of stone, and they shall be removed as the trenches are backfilled.

38. **Curves, Branches, etc., not to be Covered.**—Sewers built on curves, also drains, basin connections, house and sewer connections, and intersections, ends of sewers and branches shall not be covered until the Engineer shall have inspected, measured and located the same, and given permission to backfill the trenches over them.

39. **Removal of Surplus Material.**—As trenches are backfilled, the Contractor shall remove all surplus material and regrade and leave free, clear and in good order all roadways and sidewalks to within .... feet of the end of the completed work. During the progress of, and until the final payment for and acceptance of, the work, he shall maintain in good and safe condition the surface of the street over all trenches, and promptly fill all depressions over and adjacent to trenches caused by the settlement of backfilling. In case of failure or neglect on the part of the Contractor to comply with the requirements of this paragraph within 24 hours after the service upon him of a written notice so to do, the .... may furnish all materials and do all work required, and the cost thereof will be charged to the Contractor and deducted from any moneys due or to become due him under this contract. All surplus material or any part thereof shall, if required, be deposited as directed on the streets and avenues

within the limits of this contract where surfaces are below grade, and in such a manner as to leave the surfaces of the filled material even.

40. (*Same as paragraph* 13, *except paragraph numbers.*)

ART. 46. MASONRY AND MATERIALS THEREFOR.

CEMENT.

41. **Quality.**—All cement used in the work shall be high-grade Portland cement of well-established and approved brands.

42. **Specific Gravity; Weight.**—The cement shall have a specific gravity of not less than 3.10 after being thoroughly dried at 212° F. It shall weigh not less than 376 pounds net, to the barrel, 4 bags of 94 pounds each being considered equivalent to a barrel. For the purpose of measurement one bag shall be considered the equivalent of 1 cubic foot.

43. **Fineness.**—The cement shall be dry, finely ground, of uniform color and free from lumps. It shall leave a residue of not more than 8 per cent by weight when passed through a No. 100 sieve, and not more than 25 per cent when passed through a No. 200 sieve.

44. **Tensile Strength.**—Standard briquettes shall develop, within the periods specified, tensile strength not less than that shown in the following table:

Neat Cement.	Lbs. per sq. in.
24 hours in moist air	175
7 days (1 day in moist air, 6 days in water)	500
28 days (1 day in moist air, 27 days in water)	600
Mortar consisting of 1 part cement and 3 parts standard Ottawa sand, by weight.	
7 days (1 day in moist air, 6 days in water)	180
28 days (1 day in moist air, 27 days in water)	225

The average of the tensile strength developed at each age by the briquettes in any set from one sample will be considered the strength of the sample at that age, excluding any results that are manifestly faulty. The average strength of briquettes at 28 days shall be greater than the average strength at 7 days, and if tests are made after 28 days the strength shall be not less than that at 28 days.

45. **Soundness.**—Pats of neat cement, when tested for constancy of volume or soundness, shall remain firm and hard and show no sign of checking, cracking, distortion or disintegration.

46. **Setting.**—Unless otherwise required, cement shall not develop initial set in less than 30 minutes, and shall develop final set in not less than one hour nor more than 10 hours. Quick-setting cement of an approved brand shall,

if required, be kept on the work in sufficient quantity to provide for any contingency requiring the use of the same.

47. **Testing.**—Cement will be subjected to such tests as the Engineer may deem necessary, and such tests will be made in accordance with the methods recommended by the Committee on Uniform Tests of Cement of the American Society of Civil Engineers.

48. **Re-testing.**—Any cement which shall have been kept in storage after testing for a sufficient time to warrant it, shall be re-tested. Any prior acceptance shall be considered void and the acceptance or rejection of the cement shall depend upon the results of the later tests.

49. **Approval of Brand May be Rescinded.**—The engineer may at any time rescind the approval of any brand of cement that develops qualitites which in his opinion unfit it for use in the work.

50. **Samples.**—The Contractor shall notify the Engineer of the arrival of cement on the work, and furnish such facilities as may be required for obtaining samples for testing. Samples will be taken so as to fairly represent the material. The number of packages sampled and the quantity to be taken from each will depend upon the importance of the work and the number of tests to be made.

51. **Delivery and Storing.**—Cement shall be delivered on the work in barrels or approved bags of uniform size with the brand and the name of the manufacturer plainly marked thereon, and shall be immediately stored in a dry place and carefully protected from the weather. A sufficient stock of cement shall be kept on the work in advance of the necessity for its use to permit of the making of the required seven-day tests. Except by written permission, no cement shall be used before it has been tested and accepted, and any concrete or masonry which may have been made under such permission with cement that is subsequently rejected, shall be removed and replaced with concrete or masonry made of accepted cement. All cement found to be of improper or inferior quality shall be immediately removed from the site of the work.

52. **Cost to be Covered.**—The cost of furnishing, storing, and incorporating cement in the work, and the cost of samples required for testing, shall be covered by the contract prices for the structures or classes of work in connection with which the cement is used.

SAND.

53. The sand shall be clean and sharp, free from dirt, loam, mica and organic matter, and shall contain not more than 8 per cent by volume of clay, and no clay shall be artificially added.

MORTAR.

54. **Composition.**— All mortar used in the work, unless otherwise specified, shall be composed of 1 volume of cement, as in the original package, and 2 volumes of sand. Mortar used in the haunch walls of brick sewers shall be composed of 1 volume cement and 3 volumes of sand.

55. **Mixing.**—Mortar shall be mixed in a suitable box or on a tight platform, and never upon the ground. The cement and sand shall be thoroughly

mixed dry, until the mixture has a uniform color. Clean, fresh water shall then be added and the mass worked until a mortar which is uniform and of the required consistency is produced. Mortar shall be mixed in no greater quantity than is required for the work in hand, and any that has set sufficiently to require retempering shall not be used.

56. **Freezing Weather.**—The mixing and use of mortar in freezing weather shall be subject to the same requirements as hereinafter specified for mixing and placing concrete under similar conditions.

57. **Cost Covered.**—The cost of all labor and materials required to furnish and place mortar in the work, as specified, shall be covered by the contract price for the structure or class of work in connection with which the mortar is used.

CONCRETE.

58. **Class A Concrete.**—Class A concrete shall be made of 1 part of cement, 2 parts of sand and 4 parts of broken stone or gravel.

Broken stone for Class A concrete shall be hard, sound and durable and shall not contain loam, clay, organic matter, objectionable quantities of dust or other improper material. Broken stone for Class A concrete shall be the run of the crusher that will pass through a screen with circular openings 1 inch, 1½ inch and 2 inches in diameter and be retained on a screen with openings ⅛ inch in diameter. Gravel shall be of hard, sound, durable material equal in quality to that specified for broken stone. It shall be clean and of the sizes herein specified for broken stone.

59. **Class B Concrete.**—Class B concrete shall be made of 1 part of cement, 2½ parts of sand and 5 parts of broken stone or gravel.

Broken stone, gravel and sand for Class B concrete shall in all respects comply with the requirements specified for the same materials for Class A concrete.

60. **Class C Concrete.**—Class C concrete shall be made of 1 part of cement, 3 parts of sand and 6 parts of broken stone or gravel. Broken stone for Class C concrete shall be the run of the crusher that will pass through a screen with circular openings 1 inch, 1½ inch and 2 inches in diameter and be retained on a screen with circular openings ⅛ inch in diameter. Gravel for Class C concrete shall be as specified for Class A concrete.

Broken stone, gravel and sand for Class C concrete shall in all respects comply with the requirements for similar materials for Class A concrete, except as to sizes as above specified.

61. **Rubble Concrete.**—Rubble concrete shall consist of Class B concrete with large stones embedded therein.

The embedded stones shall be hard, sound and durable, roughly cubical in shape and of such sizes as may be deemed suitable for the mass in which they are to be used. They shall be laid on their largest beds and be so placed in the work that they will not be nearer than 9 inches to the bottom of a footing, to an expansion joint, to any surface or to each other. The stones after having been thoroughly cleaned and wetted shall be firmly bedded in the concrete. The joints shall then be filled and the stones covered with concrete to such a depth that the spacing specified will be obtained. The stones shall not be placed directly on any concrete which has acquired its initial set.

62. **Measuring Ingredients.**—For the purpose of determining the proportions of the materials for concrete, each bag of cement will be considered as containing 1 cubic foot and the other ingredients shall be measured by an approved method.

63. **Water.**—Only clean, fresh water shall be used for concrete.

64. **Mixing.**—Unless permitted to be mixed by hand, concrete shall be mixed in approved mechanical batch mixers, so constructed and operated that the ingredients of the concrete may be accurately measured and will be thoroughly mixed. Enough water shall be added during the mixing to bring the concrete to the required consistency, which for concrete laid in place shall generally be such that the concrete may be poured into place without causing the separation of the stones from the mortar. When concrete is mixed by hand the broken stone or gavel shall be thoroughly wet before it is used. The cement and sand shall be mixed in the proper proportions dry until the mixture has a uniform color. It shall then be made into mortar of the desired consistency. The broken stone shall be added and the entire mass turned until each stone is entirely coated with mortar.

65. **Placing Concrete.**—Concrete shall be mixed only in such quantity as is required for the work in hand, and any that has set sufficiently to require re-tempering shall not be used. Any concrete in which the water has separated from the solid matter shall be satisfactorily remixed before being placed. The concrete shall be so deposited in the work as to prevent the separation of the stone from the mortar. It shall be deposited in as nearly a continuous operation as practicable and shall be worked, tamped, spaded or rammed with suitable tools to produce a dense and compact mass. When the operation of placing concrete is interrupted, the concrete in work shall, if required, be confined by suitable temporary forms or bulkheads. When concrete is to surround reinforcing rods, structural steel or wire netting, it shall be so deposited as to work closely around such material. When a comparatively dry concrete is used it shall be deposited in horizontal layers not exceeding 6 inches in depth and solidly tamped.

66. **Joining Old and New Concrete.**—When fresh concrete is to be laid on or adjoining concrete already set, the surface of the latter shall be thoroughly cleaned, washed and roughened, and coated with a grout of neat cement before the fresh concrete is deposited.

67. **Forms and Centers.**—The Contractor shall provide all necessary forms and centers for shaping concrete. They shall be true to the required shapes and sizes, strong enough and so secured in place as to withstand all operations incidental to placing the concrete, and watertight, and the faces against which the concrete is to be placed shall be satsifactorily smooth and clean. When lumber is used in forms and centers for exposed faces it shall be of seasoned stock and shall be coated as directed with an approved lubricant.

68. **Removal of Forms and Centers.**—Forms and centers shall be left in place until the concrete has set sufficiently to permit their removal without danger

to the structure, and until so much of the backfilling or embankment as may be directed has been put in place. No forms or centers shall be struck or removed until permission to do so has been given by the Engineer.

69. **Exposed Surfaces.**—Special care shall be used to secure smooth and uniform finish to the surfaces of concrete which will be exposed in the completed structure. Immediately after the removal of the forms such surfaces if uneven shall be rubbed smooth to a uniform and satisfactory finish. All exposed edges of concrete shall be neatly rounded as directed, and if any voids, projections or other imperfections be found, such defects shall at once be corrected by tooling, cutting out and filling with mortar, or otherwise, as directed.

70. **Expansion Joints.**—Expansion joints shall be provided in such manner and at such places as are shown on the plan or as may be directed. All unavoidable joints shall be made as shown on the plan or as directed.

71. **Depositing Concrete under Water.**—Whenever it becomes necessary to place concrete under water, it shall be deposited by means of drop-bottom buckets, closed chutes or other approved method. Concrete so deposited shall be carefully spread without tamping.

72. **Freezing Weather.**—In freezing weather, until the temperature falls to 24° F. the water used for concrete shall, if directed, be heated to an approved temperature, and if directed, 1 per cent by weight of salt shall be added to the water for each degree Fahrenheit that the temperature of the air is below 32° F. Other materials for concrete shall be heated sufficiently to remove all frost and ice. No concrete shall be laid when the temperature of the air is below 24° F.

73. **Protection.**— Concrete shall be allowed to set for such time as may be directed before it is worked or walked upon, or before backfilling or other material is placed upon or against it. It shall not be flooded with water until it has sufficiently set. Concrete shall be carefully protected from injury by freezing and from the drying effects of the sun and wind by covering it with canvas, bagging, hay or other suitable and approved materials. Such protection shall be placed as soon as the concrete is in condition to receive it, and except in freezing weather, the covering as well as the concrete shall be kept wet for such time as may be directed.

74. **Measurement.**—The amount of concrete to be paid for as such will be all concrete put in place as shown on the plan or as directed, except such concrete shown on the plan as parts of structures for which there are contract prices and cost of which is hereinafter specified as covered by the contract prices for such structures.

75. **Prices to Cover.**—The contract prices for the various classes of concrete shall cover the cost of all labor and materials required to furnish, place and remove all necessary forms and centers, and to make, place, furnish and protect the concrete as specified.

BRICK MASONRY.

76. **Quality of Bricks.**—All bricks used in the work shall be sound and hard burned throughout and of uniform size and quality. If required, the bricks

shall be culled immediately after they are brought on the work and all bricks which are warped, cracked or of improper size, shape or quality shall be at once removed. The proportion of bats permitted will be determined according to the character and location of the work in which they are to be used. When bricks are used for lining inverts and in neat arch courses of sewers they shall be specially selected and no bats shall be used except for closers.

77. **Vitrified Bricks.**—Where shown on the plan, vitrified bricks of approved size and quality shall be furnished and laid. After having been thoroughly dried and then immersed in water for 24 hours they shall not absorb more than 4 per cent of their weight of water.

78. **How Laid.**—Bricks shall be satisfactorily wet when being laid and each brick shall be laid in mortar so as to form full bed, end and side joints in one operation. The joints shall not be wider than $\frac{3}{8}$ inch, except when the bricks are laid radially, in which case the narrowest part of the joint shall not exceed $\frac{1}{4}$ inch. The bricks shall be laid in a workmanlike manner, true to line, and wherever practicable the joints shall be carefully struck and pointed on the inside. Brickwork shall be laid with a satisfactory bond, and as it progresses shall be racked back in courses, unless otherwise permitted.

79. **Protection.**—All fresh brickwork shall be carefully protected from freezing and from the drying effects of the sun and wind, and if required, it shall be sprinkled with water at such intervals and for such a time as may be directed. Brickwork shall be protected from injuries of all sorts, and all portions which may become damaged or may be found defective shall be repaired, or if directed, removed and rebuilt. In freezing weather bricks shall be heated when directed, sufficiently to remove all ice and frost.

80. **Measurement.**—The amount of brick masonry to be paid for as such will be all brick masonry built, as shown on the plan or as directed, except such brick masonry shown on the plan as parts of structures for which there are contract prices and the cost of which is hereinafter specified to be covered by the contract prices for such structures.

81. **Price to Cover.**—The contract price for brick masonry shall cover the cost of all labor and materials required to build and protect the same as specified.

Cut Stones.

82. **Materials.**—Where shown on the plan, cut stones of the required kind, form, dimensions and finish, shall be furnished and accurately set in full beds of mortar. The stones shall be sound, durable and free from rifts, seams and laminations, and other imperfections.

83. **Cost Covered.**—The cost of all labor and materials required to furnish and set cut stones as specified shall be covered by the contract price for the structure or class of work in connection with which they are used.

Cemented Rubble Masonry.

84. **Materials.**—Stones for rubble masonry shall be hard, sound, free from checks and shakes, as nearly rectangular as practicable, and unless used for

trimming or closers, not less than 6 inches thick. The stones shall be cleaned and wetted immediately before being placed in the work; they shall be laid on their natural beds, in full beds and joints of mortar, with spalls firmly embedded therein. In walls, one-third of the stones shall be headers extending through the walls where the same do not exceed 3 feet in thickness.

85. **How Laid.**—All rubble masonry laid in mortar shall be laid to line, thoroughly and satisfactorily bonded, and in courses roughly leveled up. When the laying of rubble masonry in mortar is interrupted the tops of the courses shall be left unplastered. No dressing or tooling shall be done on or upon any stone after it is in place. Immediately before any rubble masonry in mortar is laid on or against any such masonry in which the mortar has set, the surface of such masonry shall be thoroughly cleaned and wetted. Rubble masonry laid in mortar shall not be laid in freezing weather.

86. **Pointing.**—When the faces of rubble masonry laid in mortar will be exposed to view in the finished work, the joints in such faces shall be raked out to a depth of not less than 1 inch and neatly pointed with mortar composed of 1 part cement and 2 parts sand.

87. **Measurement.**—The amount of rubble masonry laid in mortar to be paid for as such will be all cemented rubble masonry built as shown on the plan or as directed, except such shown on the plan as being part of structures for which there are contract prices, and the cost of which is hereinafter specified to be covered by the contract prices for such structures.

88. **Price to Cover.**—The contract price for cemented rubble masonry shall cover the cost of all labor and materials required to construct the same, as specified.

DRY RUBBLE MASONRY.

89. **How Laid.**—Dry rubble masonry shall conform to the requirements specified in sections 85 and 87, except those that relate to the use of mortar. All joints shall be thoroughly pinned and wedged with suitable spalls.

90. **Price to Cover.**—The contract price for dry rubble masonry shall cover the cost of all labor and materials required to construct the same, as specified.

STONE BALLAST.

91. **Quality.**—Stone ballast shall be broken stone, clean, sound, hard and roughly cubical in shape and unless otherwise shown on the plan or directed, of sizes ranging from 1 inch to 4 inches. Cobbles, if satisfactory, may be used.

92. **Price to Cover.**—The contract price for stone ballast shall cover the cost of all labor and materials required to furnish and place the same as specified.

ART. 47. STEEL, IRON, AND LUMBER.

STRUCTURAL STEEL.

93. **Quality.**—All structural steel used shall be medium steel for members and rivet steel for rivets made by the open hearth process and shall conform

to the latest revised Standard Specifications for Structural Steel for Buildings adopted by the American Society for Testing Materials, and such tests as may be required shall be made in accordance therewith and at the places hereinafter specified. The chemical and physical properties of the steel shall be as follows:

Properties Considered.	Medium Steel.	Rivet Steel.
Phosphorus (maximum)	0.06 per cent	0.06 per cent
Ultimate tensile strength, pounds per sq.in.	55,000–65,000	48,000–58,000
Yield point	½ ult. tens. str.	½ ult. tens. str.
Elongation, per cent in 8 inches (minimum)=	$\frac{1,400,000}{\text{ult. tens. str.}}$	$\frac{1,400,000}{\text{ult. tens. str.}}$
Character of fracture	Silky	Silky
Cold bend without fracture	180° to diameter of one thickness	180° flat.

94. **Finish.**—All finished material shall be free from injurious seams, flaws and cracks, and have a workmanlike finish.

95. **Variation in Weight.**—When steel is inspected at the mill or shop all pieces (except plates), which vary in weight more than 2½ per cent from that specified, shall be rejected; when steel is not inspected until it is delivered on the work such variation in weight will be sufficient cause for rejection when in the judgment of the Engineer the safety of the work will be impaired thereby.

96. **Workmanship.**—All structural steel shall be in accordance with the plan and approved shop drawings. All details not shown on the plan, and all workmanship and finish shall be equal to the best current practice in similar work for buildings.

97. **Anchor Bolts.**—Anchor bolts and expansion bolts shall be furnished where required and set in place as directed. When holes are drilled in masonry or concrete for such bolts, the holes shall be washed clean and the bolts shall be firmly embedded in a mortar composed of equal parts of cement and sand, unless other material is shown on the plan.

98. **Melt Numbers.**—Test specimens and every finished piece of steel shall be stamped with melt or blow number, except that small pieces may be shipped in bundles securely wired together, with the melt or blow number on a metal tag attached.

99. **Tests and Inspections.**—The required tests and inspections of structural steel shall, if directed, be made at the mills and shops by the city's authorized inspector. The Contractor shall notify the Engineer as to the mills and shops which are to supply the steel, sufficiently in advance to enable the Engineer to arrange for such tests and inspections and the mills and shops shall afford every facility for making the same.

100. **Mill Certificates.**—If it is decided not to make the tests and inspections at the mills, then mill certificates showing the properties of each melt of which the steel is made will be accepted for consideration.

101. Shipping Invoices.—The Contractor will be required to furnish complete copies of shipping invoices with each shipment of steel.

102. Certificates, etc., for Information only.—Steel will not be accepted until the required inspector's reports or mill certificates are received. All tests, inspection, reports and certificates are for the information of the Engineer, and he shall not be precluded on account thereof from requiring or making any further tests which he may deem necessary.

103. Shop Drawings.—The Contractor shall prepare complete and accurate shop drawings of all steel work, and no shop work shall be done until such drawings shall have been approved. The Contractor shall furnish to the Engineer 3 complete sets of prints of the approved shop drawings.

104. Painting.—All steel shall be thoroughly cleaned of scale, rust, oil and dirt, and unless otherwise directed, those parts which are not to be bedded in concrete shall be painted with a priming coat of the best red lead and linseed oil or such other paint of equivalent value as may be directed. After erection, the metal which will be exposed in the finished work shall be evenly painted with 2 coats of approved paint. No painting shall be done on wet surfaces.

105. Measurement.—The amount of structural steel paid for as such will be all structural steel placed in the work in accordance with the plan or directions, except any excess greater than 2½ per cent above the weight required, and except such structural steel shown on the plan as part or parts of structures for which there are contract prices, and the cost of which is hereinafter specified to be covered by the contract prices for such structures.

106. Price to Cover.—The contract price for structural steel shall cover the cost of all labor and materials required to furnish, fabricate, erect and paint the same, to furnish all test pieces, to prepare and furnish prints of shop drawings, and to drill holes for and set anchor and expansion bolts, where required, all as specified.

STEEL REINFORCEMENT BARS.

107. Shape.—Steel bars for reinforcing concrete shall be of such shape as to afford an approved mechanical bond with the concrete and to insure intimate contact between the steel and concrete. Plain bars may be used only when shown on the plan.

108. Samples.—The Contractor shall indicate the type of bars proposed to be used and if required shall furnish samples thereof, and he is cautioned not to place the order for bars until the type has been approved.

109. Size.—Each bar shall have a net cross-sectional area equivalent to that designated on the plan or required, or it shall be the commercial size of the approved type of bar having a net cross-sectional area next larger than that designated or required.

110. Variation in Weight.—Reinforcement bars will be rejected if the actual weight varies more than 5 per cent from their theoretical weight, as shown by the manufacturer's tables. For weighing reinforcement bars the Contractor shall, whenever required, provide an accurate scale of an approved type, with a capacity of not less than 500 pounds.

111. **Quality.**—All steel for reinforcement bars shall be made by the open hearth process, and shall conform to the latest revised Standard Specifications for Steel Reinforcement Bars adopted by the American Society for Testing Materials.

The chemical and physical properties of the steel shall be as follows:

Properies Considered.	Structural Steel Grade.		Hard Grade.*		
	Plain bars.	Deformed bars.	Plain bars.	Deformed bars.	Cold twisted bars.
Phosphorus, maximum:					
Bessemer..........	0.10	0.10	0.10	0.10	0.10
Open Hearth........	0.05	0.05	0.05	0.05	0.05
Ultimate tensile strength pounds per sq. inch.	55,000 to 70,000	55,000 to 70,000	80,000 min.	80,000 min.	Recorded only.
Yield point, minimum pounds per sq. in.....	33,000	33,000	50,000	50,000	55,000
Elongation, minimum, per cent in 8 inches..	$\frac{1{,}400{,}000}{\text{tens. str.}}$	$\frac{1{,}250{,}000}{\text{tens. str.}}$	$\frac{1{,}200{,}000}{\text{tens. str.}}$	$\frac{1{,}000{,}000}{\text{tens. str.}}$	5 per cent
Cold bend without fracture:					
Bars under ¾-in. in diameter or thickness............	180°d = 1t	180°d = 1t	180°d = 3t	180°d = 4t	180°d = t
Bars ¾-in. in diameter or thickness and over............	180°d = 1t	180°d = 2t	90°d = 3t	90°d = 4t	180°d = 3t

* The hard grade will be used only when specified.

t = Nominal thickness or diameter of bar.

112. Reinforcement bars shall be rolled from billets of new steel; they shall be straight and free from seams, flaws, cracks and imperfections of all kinds.

113. **Tests and Inspections.**—The provisions of sections 95, 98, 99, 100 and 102 relating to tests and inspections of structural steel shall also apply to tests and inspections of steel reinforcement bars.

114. Test pieces 18 inches long may be cut from any of the bars delivered on the work, and the failure of any test piece to meet the specified requirements, or the failure of any bar when being tested or handled shall be deemed sufficient cause for the rejection of all steel from the melt from which the test piece or bar was made.

115. **Protection.**—Bars shall be protected at all times from mechanical injury and from the weather, and when placed in the work they shall be free from dirt,

scale-rust, paint and oil. Bars which are to be imbedded in concrete, but which remain exposed for some time after being placed in the work, shall, if directed, be immediately coated with a thin grout of equal parts of cement and sand.

116. **Cutting and Bending.**—Bars shall be bent to the shapes shown on the plan and in conformity with approved templets. When bars are cut and bent on the work, the Contractor shall employ competent men and shall provide the necessary appliances for the purpose.

117. **Placing.**—All bars shall be as long as can be conveniently used, accurately bent, placed, spaced and jointed as shown or directed, and they shall be securely held in their positions by approved devices until the concrete has been placed around them.

118. **Joints.**—Where more than one bar is necessary to complete a required length the joints shall be made by means of approved clamps which will develop the full strength of the bars or by lopping the ends of the bars around each other in such a manner as to produce and maintain tension on the joint during construction or by lapping the ends of the bars, as directed, and wiring them together in an approved manner, or by lapping the ends of the bars for a distance of 21 times their normal diameters for deformed bars, and 40 times their nominal diameters for plain bars, and with a space not less than 2 inches between them. Joints in longitudinal bars shall be staggered as directed.

119. **Measurement.**—The weight of steel reinforcement bars paid for as such will be the weight computed from the lengths and theoretical net sections of the steel reinforcement bars placed in the work in accordance with the plan or directions, except such steel reinforcement bars shown on the plan as part or parts of structures for which there are contract prices, and the cost of which is hereinafter specified to be covered by the contract prices for such structures. The weight paid for will not include the lengths of bars used for laps or wires, clamps and other devices used for spacing, jointing and securing the bars in place, or lugs, corrugations and irregularities which increase the weight of the bars above the weight of plain steel bars of the same net cross-sectional areas, the cost of all of which shall be covered by the price bid for steel reinforcement bars. In computing the weight of bars, 1 cubic foot of steel will be considered to weigh 489.6 pounds.

120. **Price to Cover.**—The concrete price for steel reinforcement bars shall cover the cost of all labor and materials required to furnish, clean, cut, bend, place, join, secure and protect the same, to furnish all test pieces and samples, all as specified.

WIRE NETTING.

121. **Type, Quality, etc.**—Wire netting of approved type and quality, and of the mesh and gauge of wire shown on the plan shall be furnished and placed where shown or directed. The netting shall be of steel wire. When placed in the work, wire netting shall be free from dirt, paint, oil and rust-scale. It shall be securely held in place by an approved method until the concrete has been placed around it.

122. **Price to Cover.**—The cost of all labor and materials required to furnish and place wire netting as specified shall be covered by the contract price for the structure or class of work in connection with which it is used.

EXPANDED METAL.

123. **Type, Quality, etc.**—Expanded metal of approved type and quality and of the weight and size of mesh shown on the plan shall be furnished and placed where shown or directed. When placed in the work, it shall be free from dirt, scale, rust, paint and oil. It shall be placed in position with adjoining sheets lapped 1 mesh, and secured by an approved method until the concrete has been placed around it.

124. **Measurement.**—The amount of expanded metal paid for as such will be all expanded metal placed in the work in accordance with the plan or directions, except such expanded metal shown on the plan as part or parts of structures for which there are contract prices for such structures, and which is hereinafter specified to be covered by contract prices for such structures. The amount paid for will not include waste material cut from sheets, not the material used for laps, nor wires, clamps and other devices used in joining and securing the expanded metal in place, the cost of all of which shall be covered by the contract price for expanded metal.

125. **Price to Cover.**—The contract price for expanded metal shall cover the cost of all labor and materials required to furnish, clean, cut, bend, place, join and secure the same as specified.

WROUGHT IRON.

126. **Quality.**—Wrought iron shall be double-rolled, tough, fibrous and uniform in quality. It shall be thoroughly welded in rolling and be free from surface defects. It shall have an ultimate tensile strength of at least 48,000 pounds per square inch, a yield point of 25,000 pounds per square inch, an elongation of at least 20 per cent in 8 inches, and a fracture wholly fibrous. Specimens shall bend cold, with the fiber, through 180 degrees around a diameter equal to the thickness of the piece tested. When nicked and bent the fracture shall be at least 90 per cent fibrous.

127. **Galvanizing, Painting.**—When required by the plan exposed wrought iron shall be thoroughly and uniformly galvanized. When not required to be galvanized exposed wrought iron shall be pinted as specified in paragraph 104.

128. **Measurement.**—The amount of wrought iron paid for as such will be all wrought iron placed in the work in accordance with the plan or directions, except any excess greater than 2½ per cent above the weight required, and except such wrought iron shown on the plan as part or parts of structures for which there are contract prices, and the cost of which is hereinafter specified to be covered by the contract prices for such structures.

129. **Price to Cover.**—The contract price for wrought iron shall cover the cost of all labor and materials required to furnish, fabricate, erect and galvanize or paint the same, as specified, and to furnish all test pieces required.

IRON CASTINGS.

130. **Quality.**—Iron castings shall be of the best foundry pig iron, gray, tough and free from cold shuts, blow holes and other imperfections. (The weight shall be conspicuously painted by the manufacturer with white oil paint on each casting.) The castings shall be sound, true to form and thickness, clean and neatly finished. Where required castings shall be thoroughly coated with coal tar pitch varnish.

131. **Price to Cover.**—The cost of all labor and materials required to furnish, place and coat the castings as specified, shall be covered by the contract price for the structure or class of work in connection with which they are used.

TIMBER.

132. **Quality.**—All timber shall be ...... as specified, and shall be sound and free from shakes, cracks, large or loose knots, and other defects impairing its strength or durability. It shall be squared to the required dimensions throughout its entire length.

133. **Placing.**—Timber shall be placed as shown on the plan or directed, and where necessary shall be firmly spiked or bolted with approved nails, spikes, or bolts of such sizes and lengths and at such places and in such numbers as shown on the plan, or as directed.

134. **Measurement.**—The amount of timber to be paid for as such will be all timber placed in the work in accordance with the plan or directions, except piles and timber sheeting and except such timber shown on the plan as part or parts of structures for which there are contract prices, and the cost of which is hereinafter specified to be covered by the contract prices for such structures. The amount paid for will not include timber used for forms, templets, centers, scaffolds, bridges (unless otherwise specified), fences, guard rails or other temporary structures, the cost of all of which shall be covered by all the contract prices for all the items for which there are contract prices. No deduction will be made in the measurement of timber on account of the spaces occupied by the piles.

135. **Price to Cover.**—The contract price for timber shall cover the cost of all labor and materials required to furnish, work, place and secure the same as specified.

TIMBER SHEETING.

136. **Quality, Placing, etc.**—Timber sheeting and the rangers and braces for the same shall be of a satisfactory quality of timber and of sufficient size and strength to adequately support the sides of the trenches and excavations. Sheeting shall be driven in such a manner as to avoid cracking and splitting, and if required, for the proper prosecution of the work, shall be tongued and grooved.

137. **When Paid for.**—Timber sheeting will be paid for as such only when left in place by written order. When sheeting is left in, so much of it below the surface of the ground as may be directed shall be cut off.

138. **Measurement.**—The amount of timber sheeting to be paid for as such will be all timber sheeting, rangers and braces left in by written order, and will not include sheeting, rangers and braces left in place without such order, nor

sheeting left in place because concrete is placed against it, nor that part of the sheeting that extended above the uppermost ranger after having been driven, the cost of all of which shall be covered by all the contract prices for all the items for which there are contract prices.

139. **Price to Cover.**—The contract price for timber sheeting shall cover the cost of all labor and materials to furnish, place and cut off the sheeting, rangers and braces as specified, and shall also cover the cost of all excavation necessary to place the same.

PILES.

140. **Quality.**—Piles shall be of yellow pine or . . . . ., as specified, sound and free from splits, shakes and other imperfections impairing their strength or durability. They shall be straight, taper uniformly from butt to point, and if so specified shall be barked. Unless otherwise shown on the plan, they shall conform to the following dimensions:

Length below cut-off.	Minimum diameter at point, inches.	Minimum diameter at cut-off, inches.
Less than 20 feet	6	10
20 feet to 25 feet	6	11
26 feet to 35 feet	6	12
36 feet to 45 feet	6	13
46 feet and over	6	14

To determine the necessary length of piles to be used in the work, the Contractor may be required to drive test piles.

141. Each pile less than 60 feet long shall be in one piece; piles longer than 60 feet may be spliced in an approved manner. The small ends of piles shall be pointed, and, if required, shall be shod with approved iron shoes. The butt ends shall be cut off square and protected while driving with iron bands or caps.

142. **How Driven.**—Piles shall be driven without the use of a follower, unless specially permitted. Pile heads that become split or broomed shall be cut off and the driving continued. Any pile which splits, breaks or drives unsatisfactorily will not be paid for, and it shall be withdrawn or abandoned and another driven in place of it. After being driven, all piles shall be accurately cut off at the required elevation.

143. **Bearing Piles.**—Bearing piles shall be driven vertically and shall be spaced as shown on the plan or as directed. They shall be driven to a satisfactory refusal by a hammer having a concave face and weighing not less than 2000 pounds. Refusal in general will be indicated by a penetration not exceeding 1 inch per blow under the last 6 blows of a 2000-pound hammer falling 15 feet. If steam-hammer pile-drivers are used, the piles shall be driven so that their bearing power shall be not less than that of piles driven as herein specified. When it is shown on the plan or specified that piles are to be driven to a certain required depth, they shall be driven by the use of a water jet, hammer, or by any other approved method as may be necessary to reach this depth.

144. Brace Piles.—Where shown on the plan, brace, batter or spur piles shall be driven at the inclination shown or directed, and the tops shall be framed, bolted, or strapped to adjoining piles or to each other as shown on the plan.

145. Measurement.—The amount of piles to be paid for will be the total length below cut-off of all piles remaining in the work in accordance with the plan or directions, and the total length of all piles used only as test piles. Piles driven for temporary use will not be paid for.

146. Price to Cover.—The contract price for piles shall cover the cost of all labor and materials required to furnish, drive and cut off the same as specified, of fastening brace piles, and of furnishing and placing all shoes, bands, bars, straps, bolts and other fastenings required.

ART. 48. CONSTRUCTING SEWERS.

CONCRETE SEWERS.

147. Inverts.—Inverts of concrete sewers shall be formed between transverse templets and shall be screeded, unless other material is used for lining. The templets shall be placed at such intervals as to divide the invert into sections of suitable size for convenient construction, and unless otherwise permitted, the concrete shall be deposited in alternate sections and allowed to set before the remaining sections are built. Unless otherwise shown on the plan, a layer of mortar not less than ½ inch thick shall be spread evenly and to a smoothly finished surface upon the concrete of the invert as soon as such concrete is in place. Where the radii of inverts are too short to permit screeding between templets, the inverts shall be shaped by means of suitable forms, which shall be removed as soon as the concrete has a sufficient set, and if required, the surfaces of inverts shall be floated or troweled to a smooth finish. The concrete for inverts shall be deposited continuously for their entire cross-sections, and for such longitudinal distances as may be convenient. Where shown on the plan, inverts shall be lined with brick masonry, tile or other material, which shall be laid at such times and in such manner as may be directed. Inverts shall be carefully protected from all injury during progress of the work.

148. Side Walls.—Concrete in the side walls of sewers shall be deposited continuously to the height directed and for such longitudinal distances as may be convenient.

149. Roof.—Concrete in the roofs of sewers shall be deposited continuously for the full depths and widths of the roofs and for such longitudinal distances as may be convenient. The outer surfaces of roofs shall be finished with an excess of mortar and left true and smooth. They shall be covered and protected as specified in section 73, and such covering shall remain thereon until the backfilling or embankment is placed.

150. Bulkheads.—While being deposited concrete for sewers shall be confined by temporary vertical bulkheads placed at such intervals longitudinally as may be required for convenient working. The bulkheads shall be so designed as to give an approved shape to the end of the section of concrete under construction, shall be satisfactorily secured in place before the concrete is deposited, and shall remain in place until the concrete has set sufficiently to hold its shape.

151. **Reinforcement.**—Where shown on the plan concrete sewers shall be reinforced with metal of the dimensions and shapes shown, and of the quality and in the manner hereinbefore specified.

152. **Minimum Length of Invert.**—Unless otherwise permitted or ordered, not less than 16 feet of foundation or invert for concrete sewer shall be built at one operation.

153. **Connections.**—Connections and branches for lateral sewers and receiving basins shall be built in where shown on the plan or where directed. Such connections and branches shall be closed with bulkheads of brick masonry 8 inches thick unless otherwise shown on the plan. All necessary openings and bulkheads for branch sewers shall be built in concrete sewers where shown on the plan or where directed.

154. **Measurement.**—The lengths of concrete sewers will be determined by measurements along their inverts parallel to their center lines. No deductions will be made on account of openings at branches and manholes. The measurement of a branch concrete sewer will be made from the inner surface of the wall of the main sewer to which it connects. A reducer will be paid for at the contract price for the sewer at the larger end thereof.

155. **Prices to Cover.**—The contract prices for concrete sewers shall cover the cost of all necessary excavation (except rock, when there is a contract price for rock excavation); of furnishing, maintaining and removing all forms, centers, templets, and temporary bulkheads; of all openings and bulkheads; also the removal of all bulkheads in the ends of sewers to which connection is made by the sewers in this contract; of all backfilling; of all embankments required; and of all labor and materials required to construct concrete sewers as shown by the normal sections on the plan and as specified.

BRICK SEWERS.

156. **Inverts.**—Inverts of brick sewers shall conform to lines drawn between transverse templets, and shall be lined with specially selected bricks, unless vitrified bricks are called for on the plan; no bats shall be used except for closers.

157. **Arches.**—The arches of brick sewers shall be built on substantial centers and shall be keyed with stretchers in full joints of mortar. No bats shall be used in the neat courses except for closers. The centers shall be true to the required shapes and sizes and shall be strong enough and so secured in place as to withstand all operations incidental to the construction of the arches. The extrados of the arches shall be smoothly and evenly plastered with a layer of mortar ½ inch thick. The centers shall be left in place until the mortar has set sufficiently to permit their removal without danger to the arches, and until the trench is backfilled for its full width to a height of at least 1 foot above the crown of the extrados of the arches. No centers shall be struck or removed until permission to do so has been given.

158. Minimum Length of Cradle.—Unless otherwise permitted or ordered, not less than 16 feet of foundation or cradle for brick sewer shall be built at one operation.

159. Branches, Measurement, etc.—The construction of connections and branches for lateral sewers and receiving basins, and of openings and bulkheads and the measurement of brick sewers shall in all respects conform with the requirements hereinbefore specified for concrete sewers in sections 153 and 154.

160. (*Same as paragraph* 155, *substituting " brick sewers " for " concrete sewers."*)

VITRIFIED PIPE SEWERS.

161. Vitrified Pipe.—Vitrified pipe sewers and house connections shall be built of shale or clay hub and spigot pipes with deep and wide sockets. The pipes shall be manufactured at a suitable temperature, to secure a tough, vitreous material, without warps, cracks or other imperfections, and shall be fully and smoothly salt-glazed over the entire inner and outer surfaces, except that the inside of the hub and the outside of the spigot may be unglazed for two-thirds of the depth of the hub. On all other portions of the pipe the glazing shall completely cover and form an integral part of the pipe body. If not left unglazed the inside of the hub and the outside of the spigot shall be scored in 3 parallel lines extending completely around the circumference.

When it is broken, vitrified pipe shall show dense and solid material, without detrimental cracks or lamination; it shall be of such toughness that it can be worked with a chisel and hammer, and when struck with a hammer, it shall have a metallic ring.

162. Identification Marks.—Each pipe shall have clearly impressed on its outer surface the name of the manufacturer and of the factory in which it was made.

163. Shape and Dimensions.—The sizes of the pipes are designated by their interior diameters. Each pipe shall be a cylinder with a circular section, and shall have a uniform thickness.

164. The minimum lengths, thicknesses, depths of hubs and annular spaces for the respective sizes of vitrified pipes shall be as follows:

Size, inches.	Length, feet.	Thickness, inch.	Depth of socket, inches.	Annular space, inch.
6	not less than 2	⅝	2½	⅝
8	not less than 2	¾	2¾	⅝
10	not less than 2	⅞	2¾	⅝
12	not less than 2	1	3	⅝
15	not less than 2	1¼	3	⅝
18	not less than 2	1½	3¼	⅝
20	not less than 2	1⅔	3½	⅝
22	not less than 2	1⅚	3¾	⅝
24	not less than 2	2	4	⅝
27	not less than 2½	2¼	4	¾
30	not less than 2½	2½	4	¾

Size, inches.	Length, feet.	Thickness, inch.	Depth of socket, inches.	Annular space, inch.
33	not less than 2½	2⅝	5	1¼
36	not less than 2½	2 2/4	5	1¼
42	not less than 2½	3½	5	1¼

165. Curves, Bends, etc.—Where curved pipes are required they shall be furnished in either one-eighth or one-quarter bends of their respective sizes. Curved pipes, bends, siphons, and special pipe of the sizes and forms shown on the plan shall be furnished and laid, and unless otherwise provided they will be paid for at the contract prices for the corresponding sizes of vitrified pipe sewers.

166. Samples for Testing.—Any or all of the following tests may be applied to samples selected by the Engineer from the pipe delivered on the work. For the purpose of making such tests as may be required the Contractor shall furnish and deliver, when directed, and at the place required, one length of pipe for each 200 feet of pipe sewer to be laid.

167. Crushing Tests.—When supported at the bottom upon a knife edge one inch in width in such manner that an even bearing is provided throughout the whole length, exclusive of the bell, and pressure is applied at the crown uniformly through a similar knife edge, the various sizes of pipe shall withstand the following pressures:

Diameter, inches.	Pressure, lbs. per lin. ft.	Diameter. inches.	Pressure, lbs. per lin. ft.
6	900	22	1750
8	900	24	1950
10	1000	27	2150
12	1050	30	2350
15	1250	33	2500
18	1400	36	2800
20	1550	42	3200

168. Drop Weight Test.—When supported on a dry sand bed 2 inches deep, all pipe shall withstand without cracking the impact from two blows of a cast iron ball weighing 8 pounds falling 18 inches. Spurs shall resist without fracture the impact from two blows of such a ball falling 6 inches and striking on the extreme end of the hub of the spur.

169. Hydrostatic Test.—When subjected to an internal hydrostatic pressure of 10 pounds per square inch, vitrified pipe shall show no percolation.

170. Absorption Test.—After having been thoroughly dried and then immersed in water for 24 hours, sample pieces of vitrified pipe about 10 square inches superficial area with all broken edges shall not absorb more than 5½ per cent of their weight of water.

171. Factory Rejection.—The entire product of any pipe factory may be rejected when, in the judgment of the Engineer, the methods of manufacture fail to guarantee uniform results, or where the materials used are such as produce inferior pipe, as indicated by repeated failure to comply with the tests herein specified.

172. **Cradles.**—In earth trenches pipe sewers shall be laid in concrete cradles when required by the plan. In rock trenches pipe sewers shall be laid in cradles of concrete, gravel or broken stone or sand as shown on the plan.

173. **Without Cradle.**—When the sewer is to be laid without a cradle the trench shall be excavated as specified in paragraph 15, and the earth forming the bed carefully freed of stones. The pipe shall then be evenly bedded therein, the joint properly made and the backfilling placed firmly tamped in such a manner as to avoid disturbing the sewer.

174. **Concrete Cradle.**—When the sewer is to be laid in a concrete cradle, the method of procedure, otherwise directed or permitted, shall be as follows, viz., the concrete for the full width of the cradle shall be deposited continuously to the height of the outside bottom of the pipe. Before the concrete has set the pipe shall be evenly bedded therein and the remainder of the concrete immediately deposited and carefully tamped in such a manner as to avoid disturbing the sewer.

175. **Gravel or Broken Stone Cradle.**—When the sewer is to be laid in a gravel or broken stone cradle, the latter shall consist of clean gravel or sound broken stone, all of which will pass through a 1-inch mesh, and be retained on a $\frac{1}{8}$-inch mesh screen. The gravel or broken stone shall be deposited and tamped for the full width of the trench to the height of the outside bottom of the pipe. The pipe shall then be bedded therein and the remainder of the gravel or broken stone deposited and carefully tamped in such a manner as to avoid disturbing the sewer.

176. **How Laid.**—All pipes shall be laid with ends abutting and true to line and grade. The pipes shall be fitted together and matched so that when laid in the work they will form a sewer with a smooth and uniform invert. Unless otherwise permitted or directed, not less than . . . . feet of pipe sewer shall be laid in one operation.

177. Unless otherwise shown on the plan, the joints of vitrified pipe sewers shall be made as hereinafter specified in section 179.

178. **Plain Mortar Joints.**—Plain mortar joints shall be made in the following manner: Before a pipe is laid, the lower half of the hub of the preceding pipe shall be plastered on the inside with stiff mortar mixed 1 to 1, and of sufficient thickness to bring the inner bottoms of the abutting pipes flush and even. After the pipe is laid, the remainder of the hub shall be thoroughly filled with similar mortar and the joint wiped inside and finished to a smooth bevel outside.

179. **Gasket and Mortar Joints.**—Gasket and mortar joints shall be made in the following manner: A closely twisted hemp or oakum gasket of suitable diameter, in no case less than $\frac{3}{4}$ inch, and in one piece of sufficient length to pass around the pipe and lap at the top, shall be solidly rammed into the annular space between the pipes with a suitable calking tool. Before being placed, the gasket shall be saturated with neat cement grout. The remainder of the space shall then be completely filled with plastic mortar mixed 1 to 1 and the joint wiped inside and finished to a smooth bevel outside.

180. Joints for Sanitary Sewers and Bituminous Compound for Same.—Joints of sanitary pipe sewers below the normal water table shall be made with a compound approved by the Chief Engineer. The compound shall preferably have a bituminous base, shall adhere firmly to the glazed surfaces of the pipes, shall melt and run freely at a temperature as low as 250° F. and when set shall be sufficiently elastic to permit of a slight movenent of the pipes without injury to the joints or breaking the adhesion of the compound to the pipes. The compound shall not deteriorate when submerged in fresh or salt water or normal domestic sewage. It shall show no deterioration of any kind when immersed for a period of five days in a 1 per cent solution of hydrochloric acid or a 5 per cent solution of caustic potash.

All sanitary pipe sewers below the normal water table shall be laid in concrete cradles as shown on the plans; the joints shall be carefully centered and calked as specified in article 179. After a joint is properly calked, a suitable runner shall be placed and the compound, heated to a temperature of approximately 400° F., shall be poured into it in such a manner that the annular space shall be completely filled to within $\frac{1}{2}$ inch of the outer rim of the bell of the pipe.

After the joints are run and the concrete cradle is placed those portions of the joints not imbedded in the cradle shall be encased in cement mortar, which shall extend at least 2 inches from the face and outside of the bell. The cement mortar shall be mixed in the proportions of one part of cement to one of sand.

181. Inspection of Joints.—Unless otherwise permitted, at least four finished joints shall be left exposed for inspection throughout the working day, and the necessary staging for the protection of the exposed sewers and for the handling of excavated material shall be provided. A suitable ladder affording easy access for such inspection shall be furnished at every trench open for the proposed sewer. The joints on the inside of all pipe sewers larger than 15 inches in diameter, shall be carefully filled with mortar and wiped smooth and flush with the surface of the pipe.

182. Sub-grade to be Tested.—No pipe or the cradle therefor shall be laid or placed until the subgrade of the trench shall have been tested and found correct.

183. Sewer to be Kept Clean.—The interior of the sewer shall, as the work progresses, be cleared of all dirt, cement and superfluous materials of every description.

184. Backfilling.—Immediately after the sewer is laid the trench shall be backfilled as provided in sections 31, 32, 34, 35, 36, 37, 38 and 39. No walking on or working upon the completed sewer (except as may be necessary in tamping the backfilling) will be permitted until the trench has been backfilled to a height of at least 2 feet over the top of the sewer.

185. The exposed ends of pipe sewers shall be provided with approved temporary covers fitted to the pipe so as to exclude earth and other materials.

186. Branch Pipes.—Branch pipes and connection pipes shall be of the same quality and dimensions and laid in the same manner as specified for pipe sewers; Dead ends of pipes shall be closed with bulkheads of brick masonry 8 inches in thickness.

187. **Connection with Existing Work.**—Wherever the proposed sewer is to connect with an existing manhole in which there is a branch pipe which is damaged or of unsuitable size or in improper position, such pipe shall be removed and be replaced with a pipe of suitable size or be reset in the proper position. The pipe so substituted or reset will be paid for at the contract price for the corresponding size of pipe sewer.

188. **Pipes Cut to Fit Masonry.**—The ends of pipes which enter masonry shall be neatly cut to fit the face of the masonry. When directed, such cutting shall be done before the pipes are built in.

189. **Measurement.**—The length of pipe sewers to be paid for will be determined by measurements along their invert lines, and no deductions will be made on account of openings at manholes.

190. **Prices to Cover.**—The contract prices for pipe sewers shall cover the cost of all necessary excavation (except rock when there is a contract price for rock excavation); of all sand, gravel, broken stone or concrete cradles required; of the making of all joints as specified; of all necessary trimming, fitting and building into masonry; of all bulkheads, also the removal of all bulkheads in the ends of sewers to which connection is made by the sewers in the contract; of all backfilling; of all embankments required; of all samples furnished; and of all labor and materials required to furnish and lay the sewers complete in place, as shown on the plan and as specified.

CEMENT CONCRETE PIPE SEWERS, WITHOUT REINFORCEMENT.

191. **Shape and Dimensions.**—Cement concrete pipes without reinforcement, used in the construction of sewers, shall be hub and spigot pipes conforming in dimensions to the standard plan on file in the office of the Engineer. Variations not greater than one-half (½) per cent from such dimensions will be permitted.

192. Egg-shaped sections for 12-inch and larger sizes shall have flat bases and shall be equal in quality to samples marked standard on exhibition at the Engineer's office.

193. **Quality of Pipe.**—When cement concrete pipe is broken it shall appear homogeneous, be entirely free from cracks or voids and generally uniform, showing pieces of fractured stone, firmly imbedded in the mortar.

194. **Proportions.**—The concrete used in the manufacture of cement concrete pipe shall be composed of a mixture of the best quality of Portland cement, clean, sharp sand and clean, broken stone or gravel suitably graded and equal in quality to similar materials specified herein for concrete, and properly proportioned to produce a pipe that will comply with all the requirements specified in sections 195 to 202, inclusive.

195. **Method of Making.**—Methods of molding, trimming and seasoning cement concrete pipe are left to the discretion of the manufacturer; as furnished, it shall be without warps, cracks or imperfections and shall present smooth inner and outer surfaces with no stones visible.

196. **Delivery.**—No pipe shall be delivered on the work or used within .... days after manufacture.

197. Inspection.—The materials used in the manufacture, the process of manufacture and the marking and dating of pipe shall be subject to inspection at the factory by inspectors designated by the Engineer.

198. Date of Molding.—All pipe shall have manufacturer's name and the date of molding clearly impressed on the outer surface as identification marks.

199. Tests.—Sections 165, 166, 168, 169, 171, 172, 173, 174, relating to "curves, bends, etc.," "samples for testing," "drop-weight tests," "hydrostatic pressure tests," "factory rejection," "cradles," "without cradles," "concrete cradles," and all sections 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188. 189 and 190, relating to manner of laying, jointing, inspection, etc., etc., of vitrified pipe sewers shall govern in the manufacture of cement concrete pipe and the construction of cement concrete pipe sewers, wherever applicable. Crushing tests shall be applied as in section 167, except that flat base of pipe shall rest on sand bed not less than 2 inches thick, and pressure through a knife edge 1 inch thick shall be applied at the crown.

200. Spurs and Branches.—The manner of forming and joining spurs and branches with hubs of standard dimensions to cement concrete pipe shall be such as to insure a tight union, of ample strength to meet the requirements of the work and of the tests heretofore specified for spurs and branches on vitrified pipe.

201. Absorption Tests.—After having been thoroughly dried and then immersed in water for 24 hours, sample pieces of cement concrete pipe of about 10 square inches superficial area, with broken edges, shall not absorb more than ten (10) per cent of their weight of water.

202. Dimensions.—The minimum lengths, thicknesses, depths of hubs and annular spaces for the respective sizes of cement concrete pipes shall be as follows:

Diameter, inches.	Length, feet.	Thickness, inches.	Depth of socket, inches.	Annular space.	
6	2	¾	2½	Not less than ⅝ inch.	
8	3	⅞	2½	Not less than ⅝ inch.	
10	3	1	2⅝	Not less than ⅝ inch.	
12	3	1¼	2¾	Not less than ⅝ inch.	And as shown on Standard Plan.
15	3	1½	2¾	Not less than ⅝ inch.	
18	3	1¾	3	Not less than ¾ inch.	
20	3	2	3	Not less than ¾ inch.	
22	3	2¼	3¼	Not less than ¾ inch.	
24	3	2½	3¼	Not less than 1 inch.	

CEMENT CONCRETE PIPE SEWERS WITH REINFORCEMENT.

203. Shape and Dimension.—Reinforced cement concrete pipes used in the construction of sewers shall be either circular in section without flat base, or egg-shaped in section with flat base, and shall conform in dimensions to the standard plan on file in the office of the Engineer. Variations not greater than one-half (½) per cent from such dimensions will be permitted.

204. Ends of Pipes.—The ends of such pipes shall be molded with hubs and spigots or with any other shapes which are satisfactory to the Engineer, and which will permit the making of tight, smooth and permanent joints. The shapes of the pipe ends shall be such as to require and permit the making and finishing of the joints both on the inside and outside of the sewer.

205. The pipes shall conform to the requirements in section 193 and shall be equal in quality to samples marked "Standard" on exhibition at the Engineer's office.

206. Dimensions, etc.—The minimum lengths, thicknesses and depths of hubs for the respective sizes of reinforced concrete pipes shall be as follows:

Size, inches.	Lengths, feet.	Thickness, inches.
24	4	3
30	4	3½
36	4	4
42	4	4½
48	4	5
54	4	5½
60	4	6
66	4	6½
72	4	7
78	4	8
84	4	8

207. Type of Reinforcement.—The steel used for reinforcement of cement concrete pipe shall conform to the requirements for such material specified in section No. 111.

a. It shall either be expanded metal, rods or wire mesh, equal in quality and design to that manufactured by the American Steel and Wire Company.

b. Where reinforcement in pipes is exposed, it shall be thoroughly painted with cement grout so as to prevent deterioration by exposure to the weather, unless the reinforcement be galvanized.

208. Reinforcement for Circular Pipes.—In all sizes of circular reinforced cement concrete pipe from 24 inches to 48 inches in diameter, inclusive, reinforcement shall be placed at distances varying from 1 inch to 1½ inches from the inner surfaces according to diameter of pipes, as shown on the plan.

a. Either one or two lines of reinforcement may be used in the above sizes of pipes.

b. In all circular pipes whose diameters exceed 48 inches two lines of reinforcement shall be used, unless otherwise shown on the plan.

c. The inner line of reinforcement shall be placed 2 inches from the inner surface. The outer line of reinforcement shall be placed 1¾ inches from the outer surfaces.

209. Reinforcement for Egg-shape Pipe.—In all sizes of egg-shaped reinforced cement concrete pipes, reinforcement shall be placed in such manner as to best resist stresses induced by external loads, and in a manner satisfactory to the Engineer. In all cases the shapes to which reinforcement shall be bent in the finished pipe shall be smooth and true, so that its position in the pipe shall conform at all points to that shown on the standard plan.

210. Samples for Testing.—Any or all of the following tests may be applied to samples selected by the Engineer from the pipe delivered on the work. For the purpose of making such tests as may be required, the Contractor shall furnish and deliver, when directed, and at the place required, three lengths of each size of pipes used in the work.

211. Crushing Tests.—When tested in the manner described in Section No. 167, the various sizes of pipes between 24-inch and 42-inch in diameter, inclusive, shall withstand, without collapse, the following pressures:

When supported upon a saddle which extends the full length of the pipe exclusive of the bell and whose upper surface fits accurately the outer curved surface of the pipe, and whose width is equal to an arc of 15 degrees, in such a manner that an even bearing is provided throughout the whole length, and pressure is applied to the crown uniformly through a knife edge 1 inch in width, the various sizes of pipes with diameters greater than 42 inches shall withstand, without collapse, the following pressures:

Diameter, inches.	Pressure, lbs. per lin. ft.	Diameter, inches.	Pressure, lbs. per lin. ft.
24	1950	60	5000
30	2350	66	5500
36	2800	72	6000
42	3200	78	6500
48	3800	84	7000
54	4400		

212. Reinforced concrete pipe in which the reinforcement is not placed symmetrically about the circumference of the shell or in which only one concentric line of reinforcement is used, shall be tested in such a manner as to develop the same bending moments at the extremities of the vertical and horizontal diameters as will be developed at the crown by the tests specified above.

213. Hydrostatic. and Absorption Tests.—When subjected to an internal hydrostatic pressure of ten (10) pounds per square inch, reinforced cement concrete pipe shall show no percolation.

Reinforced cement concrete pipe shall meet the requirements of the absorption test specified in Section 201.

214. Spurs and Branches.—Reinforced cement concrete pipes having openings to receive spur and branch connections shall be furnished and laid at such points as the Engineer may designate and as called for by the plan. The openings in pipes shall be made in accordance with a plan approved by the Chief Engineer, and the openings shall be such that connection may be made with the sewer in as effective a manner as is possible with pipes with molded spur connections.

215. General.—All the sections relating to vitrified pipe sewers and to cement concrete pipe sewers without reinforcement which are pertinent and applicable to reinforced cement concrete pipe sewers unless otherwise specified herein shall govern in all respects and details.

CAST-IRON PIPE SEWERS.

216. Cast-iron Pipe.—Cast-iron pipe for sewers shall conform with the requirements of the latest revised Standard Specifications for Cast-iron Pipe adopted for the American Society for Testing Materials, and all tests required shall be made in accordance therewith.

217. The thickness of shell and weight of the several classes of pipe, and the allowable variations of diameter and weight shall be as follows:

Nominal Inside Diam., inches.	Class A, 100-foot Head, 43 pounds Pressure.		Class B, 200-foot Head, 80 pounds Pressure.		Class C, 300-foot Head, 130 pounds Pressure.		Allowable Variations.	
	Thickness, inches.	Weight, pounds.	Thickness, inches.	Weight, pounds.	Thickness, inches.	Weight, pounds.	Diam., inches.	Weight, per cent.
4	0.42	240	0.45	260	0.48	280	0.06	5
6	0.44	370	0.48	400	0.51	430	0.06	5
8	0.46	515	0.51	570	0.56	625	0.06	5
10	0.50	685	0.57	765	0.62	850	0.06	5
12	0.54	870	0.62	985	0.68	1,100	0.06	5
14	0.57	1,075	0.66	1,230	0.74	1,400	0.06	5
16	0.60	1,300	0.70	1,500	0.80	1,725	0.06	5
18	0.64	1,550	0.75	1,800	0.87	2,100	0.08	4
20	0.67	1,800	0.80	2,100	0.92	2,500	0.08	4
24	0.76	2,450	0.89	2,800	1.04	3,350	0.08	4
30	0.88	3,500	1.03	4,000	1.20	4,800	0.10	4
36	0.99	4,700	1.15	5,450	1.36	6,550	0.10	4
42	1.10	6,150	1.28	7,100	1.54	8,600	0.10	4
48	1.26	8,000	1.42	9,000	1.71	10,900	0.12	4
54	1.35	9,600	1.55	11,200	1.90	13,700	0.15	4
60	1.39	11,000	1.67	13,250	2.00	16,100	0.15	4

The above weights are for 12 feet laying lengths and standard sockets; proportionate allowance will be made for any variation therefrom.

218. Variation in Thickness.—For pipes whose standard thickness is less than 1 inch, the thickness of metal in the body of the pipe shall not be more than 0.08 inch less than the standard thickness; and for pipes whose standard thickness is 1 inch or more, the variation shall not exceed 0.10 inch, except that for areas not exceeding 8 inches in any direction, variations from the standard thickness of 0.02 inch in excess of the allowance above given will be permitted.

219. Coating.—All cast-iron pipes shall be thoroughly and evenly coated inside and outside with coal-tar pitch varnish. The coating shall be smooth, tough and tenacious when cold and shall not brittle or have any tendency to scale off.

220. Marking.—The weight and class letter shall be conspicuously painted by the manufacturer with white oil paint on the inside of each pipe after the coating is hard.

221. Joints of cast-iron pipe sewers shall be of the kinds shown on the plan.

222. Lead Joints.—When lead joints are required, the inner portion of the annular space between the pipes shall be packed with clean, sound jute packing yarn and the remaining portions shall be run full of pure, soft lead and calked with suitable tools. Unless otherwise shown on the plan, the depths of the lead joints shall be 2½ inches for 6-inch to 8-inch pipe; 3 inches for 12-inch to 24-inch pipe, and 3½ inches for 30-inch to 48-inch pipe.

223. Mortar Joints.—When gasket and mortar joints or plain mortar joints are required they shall be made as specified in sections 178 and 179.

224. General.—All the requirements as hereinbefore specified, relating to excavation, laying, backfilling and measurements of vitrified pipe sewers shall apply, as far as they are applicable, to cast-iron pipe sewers.

225. Prices to Cover.—The contract prices for cast-iron pipe sewers shall cover the cost of all necessary excavation (except rock when there is a contract price for rock excavation); of all sand, gravel, broken stone, or concrete cradles required; of the making of all joints; of all bulkheads; of all backfilling; of all embankments required and of all labor and materials required to furnish and lay the sewers complete in place, as shown on the plan and as specified.

BASIN CONNECTIONS.

226. The connections between receiving basins or inlet basins and sewers or manholes shall be 12-inch vitrified pipe, unless otherwise shown on the plan. The pipes shall be of the same quality and dimensions and laid in the same manner as hereinbefore specified for vitrified pipe sewers.

227. Measurement.—The lengths of basin connections to be paid for will be determined by measurements along their inverts.

228. Price to Cover.—The contract price for basin connections shall cover the cost of all necessary excavation (except rock, when there is a contract price for rock excavation); of all sand, gravel, broken stone, or concrete cradles required; of all necessary trimming, fitting and building into masonry; of all backfilling; of all embankments required; and of all labor and materials required to furnish and lay the basin connections complete in place, as specified.

PIPE DRAINS.

229. Pipe drains shall be built of vitrified or cement concrete pipe of the same quality and dimensions and laid in the same manner as hereinbefore specified for pipe sewers.

230. Old Drains Restored or Extended.—Any existing drain encountered, disturbed or removed on account of the work under this contract shall, if required, be restored or connected with the new work as directed. The portions of such drain restored or the extensions thereof will be paid for at the contract prices for pipe drains of the same size.

231. Measurement.—The lengths of pipe drains to be paid for will be determined by measurements along their inverts.

232. **Prices to Cover.**—The contract prices for pipe drains shall cover the cost of all necessary excavations (except rock, when there is a contract price for rock excavation); of all necessary trimming, fitting and building into masonry; of all backfilling; of all embankments required; and of all labor and materials required to furnish and lay the drains complete in place, as specified.

SPURS FOR HOUSE CONNECTIONS.

233. Spurs for house connections shall be of vitrified or cement concrete pipe 6 inches in diameter, equal in quality and dimensions to that specified for pipe sewers.

234. **In Brick and Concrete Sewers.**—In brick and concrete sewers spurs shall be built in as shown on the plan or as directed. They shall be hub-and-spigot pipes with the spigot end moulded or cut to fit flush with the inner surface of the sewer, and of sufficient length to reach the exterior of the sewer.

235. **In Pipe Sewers.**—Pipes having 6-inch spurs with hubs moulded thereon shall be furnished and laid in pipe sewers where shown on the plan or directed. The cost of such pipes shall be included in the contract prices for pipe sewers.

236. **Covers.**—The ends of all spurs not connected with drains shall be closed with approved covers of the same material as the pipe. If required, such covers shall be cemented in place, and when directed the covers shall be so cemented before the pipes are lowered into the trench.

237. **Price to Cover.**—The cost of spurs and all labor and materials required to furnish and place the same as specified, and furnishing and cementing the covers for the same, shall be included in the contract price of the sewers to which they connect. They shall be furnished and laid as above specified without extra cost to the city.

DRAINS FOR HOUSE CONNECTIONS.

238. Where shown on the plan or where directed, drains for house connections shall be built from the spurs in such a manner and for such distance as may be shown or directed.

239. **Depth at Curb.**—Generally house-connection drains shall be laid with such a gradient as to secure a depth at the curb line of 9½ feet or at a gradient of ¼ inch per foot. Where this is not possible or advisable, the depth at the curb line shall be as shown on the plan.

240. **Material.**—Unless otherwise shown on the plan, drains for house connections shall be of pipe of the quality and dimensions specified for pipe sewers. The ends of the drains shall be closed with approved covers of the same material as the pipe.

241. **How Laid.**—All the requirements, as hereinbefore specified, relating to excavation,. laying and backfilling of pipe sewers shall apply, as far as they are applicable, to drains for house connections.

242. **Measurement.**—The lengths of pipe drains for house connections to be paid for will be determined by measurement along their inverts.

They shall be measured from the hub of the spur attached to the drain, sewer or riser.

243. Price to Cover.—The contract price for drains for house connections shall cover the cost of all necessary excavation (except rock, when there is a contract price for rock excavation); the cost of all backfilling; the cost of all covers, bends and specials required; of all sand, gravel, broken stone or concrete cradles; and the cost of all labor and materials required to furnish and lay the drains for house connections complete in place, as specified and as shown on the plan.

244. Risers.—Where shown on the plan or where directed, risers for house connections shall be built from the spurs in such a manner and to such height as may be shown on the plan or directed. Unless otherwise shown on the plan, they shall be of pipe of the quality and dimensions hereinbefore specified for pipe sewers. They shall be supported and surrounded by concrete as shown, and each shall be closed with an approved cover of the same material as the pipe.

245. Measurement.—The lengths of risers to be paid for will be determined by measurements along their axes. They shall be measured from the hub of the spur attached to the main sewer.

246. Price to Cover.—The contract price for risers shall cover the cost of all necesssary excavation (except rock, when there is a contract price for rock excavation); the cost of all concrete used in connection with the risers; the cost of all backfilling; the cost of all covers, bends, and specials required; and the cost of all labor and materials required to construct the risers complete in place, as specified.

MANHOLES.

247. The masonry or concrete for manholes shall be built to within. . . .inches of the established grade of the street or to within. . . .inches of the existing surface of the ground, as directed. When not built up to within. . . . .inches of the established grade of the street, the masonry or concrete shall, if directed, be covered with stone slabs not less than 5 inches thick or with an approved reinforced concrete slab to support the head.

248. Brick Manholes.—Brick manholes shall be formed by means of templets placed at top and bottom with not less than 8 lines drawn between them if directed by the Engineer, and they shall be smoothly and evenly plastered on the outside with a layer of mortar ½ inch thick.

249. Concrete Manholes.—Concrete manholes shall be built of the materials, sizes and dimensions shown on the plan.

250. Steps.—Galvanized wrought-iron steps of the size and shape shown on the plan shall be firmly built into the manholes at vertical intervals of about 16 inches.

251. Head and Cover.—Manhole heads and covers shall be of cast iron, and unless otherwise shown on the plan, each head, exclusive of cover, shall weigh not less than 475 pounds and each cover shall weigh not less than 135 pounds. The weight of each head and cover shall be conspicuously painted thereon by the manufacturer with white oil paint. The head shall be set on the masonry or concrete in a full bed of stiff mortar.

252. Dust Pans, etc.—Where shown on the plan, dust pans and protective gratings of the materials, forms and dimensions shown shall be furnished and fitted in the manholes.

253. **Price to Cover.**—The contract price for manholes shall cover the cost of all necessary excavation (except rock, when there is a contract price for rock excavation); of all backfilling; of all plastering; of all stone and concrete slabs; of all steps; of heads and covers; of dust pans and protectives gratings, when required; and of all labor and materials required to construct the same complete, in place, as shown on the plan and specified.

Receiving Basins.

254. **Brick Basins.**—Brick receiving basins shall be built in the manner and of the dimensions shown on the plan. They shall be equipped with heads and hoods or traps corresponding with the standard plan on file in the office of the Engineer. They shall be formed by means of templets placed at top and bottom with not less than 10 vertical lines drawn between them, if directed by the Engineer. If required, the outlets of receiving basins shall be closed with bulkheads of brick masonry and such bulkheads shall be removed when directed. The outside of the brickwork shall be smoothly and evenly plastered with a layer of mortar ½ inch thick.

255. **Concrete Basins.**—Concrete receiving basins shall be built in the manner and of the dimensions shown on the plan. Class A concrete shall be used throughout and shall be placed for both bottom and side walls at one operation.

256. **Concrete Heads.**—Where concrete heads or cover slabs of receiving basins or their inlets are built in or adjoin concrete sidewalks, the new work shall be made to correspond in pattern and color with the existing sidewalk.

257. **Pavement at Inlets to Receiving Basins.**—The pavements adjoining the inlets to receiving basins shall be restored and adjusted to the extent and in the manner directed, and in accordance with paragraphs....and....in unpaved streets and in macadamized streets, where the inlets to the receiving basins are approximately at the surface of the street, a space of 2½ feet adjoining such inlets shall, if required, be paved with approved paving blocks.

258. **Price to Cover.**—The contract price for receiving basins shall cover the cost of all necessary excavation (except rock, when there is a contract price for rock excavation); of heads and inlets, traps and fittings; of the outlet culvert connecting with the sewer; of all backfilling; of all pavement required at the inlets to the basins; of the temporary brick bulkheads in the outlets of the basins or outlet culverts when required; and of all labor and materials required to construct the receiving basins complete in place, as shown on the plan and specified.

Storm-water Inlets.

259. Storm-water inlets and the heads and covers therefor shall be of the materials, forms and dimensions shown on the plan. If required, the mouth of inlets shall be closed with bulkheads of brick masonry and such bulkheads shall be removed when directed.

260. **Price to Cover.**—The contract price for inlets shall cover the cost of all necessary excavation (except rock, when there is a contract price for rock excavation); of all backfilling; of connections with sewers or basins; of the temporary brick hulkheads in the mouths of the inlets when required; and of all

labor and materials required to construct the inlets complete, in place, as shown on the plan and specified.

FLUSH TANKS.

261. Flush tanks shall be of the materials, form and dimensions shown on the plan. Unless otherwise directed, they shall be connected with the water main and with the sewer. The connection with the water main shall be made under a permit from the proper authorities, and under their rules and inspection.

262. **Price to Cover.**—The contract price for flush tanks shall cover the cost all necessary excavation (except rock, when there is a contract price for rock excavation); of all backfilling; and of all labor and materials required to construct the flush tanks complete, in place, as shown on the plan, and to connect the same with the water main and the sewer.

EMBANKMENT.

263. **Quality.**—Where indicated on the plan, embankment shall be made of the form and dimensions shown. It shall consist of clean steam ashes, or filling of the quality specified in sections 31, 32 and 34, which shall contain no stone over 6 inches in its largest dimension. When the material forming the embankment contains stones, the latter shall be so distributed through the mass that all interstices are filled with fine material, and the material within 2 feet of the sewer shall be free of stones. When embankment is used as foundation it shall consist entirely of filling of the quality specified in sections 31 and 32.

264. **How Made.**—The embankment shall be deposited and spread in horizontal layers to such an extent and at such times as may be directed. When embankment is used as a foundation, the ground on which it is to be made shall be prepared by grubbing and clearing, and removing all improper material. Embankment used as foundation shall be deposited in uniform horizontal layers not exceeding 1 foot in depth, and each layer shall be thoroughly compacted by rolling or tamping, or both; such embankment shall not be built upon until the expiration of....days after its completion.

265. **Approaches.**—Where the embankment obstructs or interferes in any way with any public or private roadway, the Contractor shall furnish and place all material necessary to provide suitable approaches of such widths and to such extent as shown on the plan, or as directed.

266. All embankments and approaches shall be maintained at their full dimensions until the completion of this contract.

267. **Price to Cover.**—The cost of all labor and materials required to prepare the ground, to make the embankment and approaches as specified, to make all necessary excavations and backfilling therein, and to maintain the embankments and approaches at their designated dimensions until the completion of this contract, shall be covered by the contract prices for the structures over or in connection with which they are made.

SLOPE PAVEMENT.

268. **How Laid.**—Slope pavement shall be not less than 18 inches in depth and shall be composed of sound quarried or split stones. Except when used for pinning or wedging, the stones shall be not less than 6 inches thick and from 12

to 18 inches long. They shall be placed by hand so as to present a fairly even surface, and have their longest dimensions approximately perpendicular to the side of the embankment. At least one-third of the stones shall extend through the pavement. Slope pavement will be measured by its superficial area.

269. **Price to Cover.**—The contract price for slope pavement shall cover the cost of all labor and materials required to lay the same complete, in place, as specified.

ART. 49. RESTORATION OF SURFACE AND CLEANING UP.

270. **Restoration of Unpaved Roadways, Sidewalks, etc.**—At such time as may be directed, all unpaved roadways, gutters, and sidewalks affected by the work done under this contract shall be restored by the Contractor to the same condition in which they were at the time of the opening of bids for this contract.

271. **Pavements, etc., Restored by City.**—Unless otherwise required by the plan, all roadway and sidewalk pavements, cross-walks, curbs, etc., along the line of the work (except those under guarantee for maintenance by the paving Contractor), which are removed, destroyed, lost or injured on account of, or during the construction of the work under this contract, or which are injured by traffic on account of any act or omission on the part of the Contractor, his agents, servants or employees, in the prosecution of the work, will be restored and adjusted by the city at the expense of the Contractor. For this purpose, before the completion of the contract, and when directed, the Contractor shall pay to the city a sum of money sufficient to cover the cost of restoring and adjusting the pavements, cross-walks, curbs, etc., the amount of the work to be done being determined by the Engineer, and the cost being computed at the following prices:

Granite block with concrete foundation, tar and gravel (or cement grout) joints...$....per sq. yd.
Granite block pavement, with sand foundation.................
Medina block pavement, with concrete foundation (grouted joints)
Brick pavement with concrete foundation....................
Brick pavement, with sand foundation.......................
Belgian block pavement..................................
Cobblestone pavement...................................
Macadam pavement......................................
Iron slag pavement.......................................
Wood block pavement....................................
Asphalt block pavement over 10 yds.........................
Asphalt block pavement under 10 yds........................
Sheet asphalt pavement, with concrete foundation, over 10 yds...
Sheet asphalt pavement, with concrete foundation, under 10 yds..
Asphalt pavement, without concrete foundation, over 10 yds.....
Asphalt pavement, without concrete foundation, under 10 yds....
Cement sidewalk relaid....................................$....per sq. ft.
New flagging...
Flagging relaid...

Curbstone reset, sand foundation............................$....per lin. ft.
Curbstone reset, concrete foundation..........................
New curbstone furnished and set, sand foundation..............
New curbstone furnished and set, concrete foundation...........
Bridgestone reset, sand foundation...........................$....per sq. ft.
Bridgestone reset, concrete foundation........................
New bridgestone furnished and set, sand foundation............
New bridgestone furnished and set, concrete foundation.........

272. **Pavements, etc., Restored by Contractor.**—If required by the plan, roadway and sidewalk, pavements, cross-walks, curbs, etc., except those under guarantee for maintenance, shall be satisfactorily restored and adjusted by the Contractor at such times as may be directed. Sidewalk pavements shall be restored in whole flags, squares or sections which shall correspond in quality and appearance with the original or adjoining flags, squares or sections. All work and materials used in such restoration and adjustment shall conform in all respect. to the standard specifications now in use by the city for similar work and materialss.

273. **Pavements, etc., under Guarantee.**—All pavements, sidewalks, cross-walks, curbs, etc., existing at the time of the opening of the bids for this contract, and under guarantee for maintenance, shall be restored and adjusted by the parties responsible under such guarantee, and at the expense of the Contractor. If not so restored and adjusted during the progress of the work, the Contractor shall, when directed, pay to the city, before the completion of the contract, a sum of money sufficient to cover the cost of having the same restored and adjusted by the parties responsible under such guarantee, and at the charges for the restoration of the same, as set forth in their contracts relating thereto. Such sum shall be accompanied by certificates from the parties responsible for the maintenance of the pavements, sidewalks, cross-walks, curbs, etc., to the effect that such sum will be accepted by them as covering the entire quantity of pavement, etc., to be restored and adjusted.

274. **Temporary Restoration.**—At such times as may be directed roadway and sidewalk pavements, cross-walks, curbs, etc., which have been removed, whether under guarantee or not, shall be temporarily restored by the Contractor to the satisfaction of the Engineer.

275. **Change of Pavement, etc.**—When the kinds of pavements, sidewalks, cross-walks, curbs, etc., in any street affected by this contract, are changed after the bids are opened and before work is commenced, the Contractor will not be required to make permanent restoration of the new pavement, sidewalks, cross-walks, curbs, etc., disturbed, but a sum of money sufficient to pay the cost of replacing the kinds of pavements, sidewalks, cross-walks, curbs, etc., which were there at the time of the opening of the bids for this contract, will be deducted from the amount which would have been payable to the Contractor upon the completion of the contract, had the character of pavements etc., not been changed, and such cost will be computed at the prices stated in section 269.

276. **When New Pavement is Laid.**—If pavement, sidewalks, cross-walks, curbs, etc., are laid where none existed at the time the bids for this contract were

opened, the Contractor shall excavate and remove such portions of the pavements, sidewalks, cross-walks, curbs, etc., and their foundations as may be necessary for the prosecution of the work, but he will not be required to make a permanent restoration of them.

277. **Trenches Flooded.**—Before laying any pavements, sidewalks, cross-walks, curbs, etc., the trenches shall, if required, be flooded with water, as directed, and all resulting holes or depressions shall be filled and tamped solid.

278. **Unnecessary Cross Gutters.**—All cross gutters rendered unnecessary by the work under this contract shall be removed and the entire street intersection or so much thereof as may be necessary shall be re-graded and re-paved as herein specified.

279. **Cleaning Up.**—At such times as may be directed, the Contractor shall remove from the streets all materials which were placed thereon by him as a consequence of performing this work, and which are not required by the contract to be left as part of the finished work. The entire work and portions of the street affected thereby shall be left in a satisfactory condition. The sidewalks and cross-walks shall be swept clean of all material which may have accumulated thereon by reason of the work performed under this contract, and if required, they shall be sprinkled with water during the sweeping.

280. **Prices to Cover.**—The cost of all the labor required to be done and all the materials required to be furnished in the performance of all the work specified in sections. . . ., inclusive, shall be covered by all the contract prices for all the items for which there are contract prices.

ART. 50. THE CONTRACT

Accompanying the specifications and bound with them should be the contract proper. A form is given which has proved satisfactory in many cases; but any form, before being used, should be passed upon by the city's legal consultant to insure that it meets all requirements of city, state and federal laws.

THIS AGREEMENT, made and concluded the. . . . . day of. . . . . .in the year One Thousand Nine Hundred and. . . . ., by and between the City of. . . . . of the first part, and. . . . . Contractor, of the second part,

WITNESSETH, That the said party of the second part (has) (have) agreed, and by these presents (does) (do) agree with the said party of the first part, for the considerations herein mentioned and contained, and under the penalty expressed in a bond bearing even date with these presents and hereto attached, to furnish at (his) (their) own proper cost and expense all the necessary material and labor, except as herein specially provided, and to excavate for and build, in a good, firm, and substantial manner, the sewers indicated on the plans now on file in the office of the city engineer, and the connections and appurtenances of every kind complete, of the dimensions, in the manner, and under the conditions herein specified; and (has) (have) further agreed that the engineer in charge of the work shall be and is hereby authorized to inspect or cause to be inspected the materials to be furnished and the work to be done under this agreement, and to see that the same correspond with the specifications.

The party of the second part hereby further agrees that (he) (they) will furnish the city with satisfactory evidence that all persons who have done work or furnished material under this agreement, and are entitled to a lien therefore under any law of the State of .... have been fully paid or are no longer entitled to such lien, and in case such evidence be not furnished as aforesaid, such amount as the party of the first part may consider necessary to meet the lawful claims of the persons aforesaid shall be retained from the moneys due the said party of the second part, under this agreement, until the liabilities aforesaid may be fully discharged and the evidence thereof furnished.

The said party of the second part further agrees that (he) (they) will execute a bond in a sum equal to ......per cent of the contract price, secured by a responsible Indemnity or Guarantee Company of, or authorized by law to do business in, the State of ....and satisfactory to the city, or by at least three responsible freeholders of..........County satisfactory to the city, for the faithful performance of this contract, conditioned to indemnify and save harmless the said city, its officers or agents, from all suits or actions of every name or description brought against any of them for or on account of any injuries or damages received or sustained by any party or parties, by or from the said party of the second part, (his) (their) servants or agents, in the construction of said work, or by or in consequence of any negligence in guarding the same or any improper materials used in its construction, or by or on account of any act or omission of the said party of the second part, or (his) (their) agents, in the performance of this agreement, and for the faithful performance of this contract in all respects by the party of the second part; and the said party of the second part hereby further agrees that so much of the moneys due to (him) (them), under and by virtue of this agreement, as shall be considered necessary by the said city may be retained by the said party of the first part, until all such suits or claims for damages as aforesaid shall have been settled and evidence to that effect furnished to the satisfaction of said city.

The said party of the first part hereby agrees to pay, and the said party of the second part agrees to receive, the following prices as full compensation for furnishing all materials, labor, and tools used in building and constructing, excavating and back-filling, and in all respects completing the aforesaid work and appurtenances, in the manner and under the conditions before specified, and as full compensation for all loss or damages arising out of the nature of the work aforesaid, or from the action of the elements or from any unforeseen obstructions or difficulties which may be encountered in the prosecution of the same, and for all expenses incurred by or in consequence of the suspension or discontinuance of the said work, and for well and faithfully completing the same and the whole thereof according to the specifications and requirements of the engineer under them, to wit:

(*Insert here spaces for making bids, being careful to include every item for which bids are invited. As an example:*)

For all 36-inch brick sewers, trenches from 6 to 8 feet deep	$——	per lineal foot
For water-tamping	——	per cubic yard
For each manhole 8 feet deep, complete	——	
For each vertical foot of manhole more than 8 feet deep, 8-inch wall	——	
For each vertical foot of manhole more than 8 feet deep, 12-inch wall	——	
For timber foundations	——	per M. B. M.

etc., etc.

IN WITNESS WHEREOF the said party of the second part (has) (have) hereunto set (his) (their) hand and seal and the said party of the first part has caused these presents to be sealed with its common seal and to be signed by the...................... on the day and year above written.

It is recommended that the engineer refer to Johnson's "Contracts and Specifications," Wait's "Law of Contracts," or Allen's "Business Law for Engineers," where will be found a full discussion of the subject from both the legal and engineering standpoint.

ART. 51. ESTIMATING COST

It is always desirable, and frequently required by law, that a careful estimate be made of the cost of the work to be done. For this purpose map, plans, specifications, and profile should be carefully studied to obtain quantities, and the amount of rock to be excavated, locations of quicksand and ground water should be ascertained, and in general as careful a study made of the conditions as a contractor would make before bidding. Also the prices of materials should be obtained, including the cost of getting them upon the ground, and from these as close an estimate made as possible of the actual cost of constructing the system. To this should be added 10 to 100 per cent for profit and contingencies, the latter amount when the work is to be done under great risks and subject to possible losses.

The cost of any piece of work consists of the cost of the labor and materials of all kinds entering into it; an allowance for plant sufficient to pay interest, repairs and depreciation or obsolescence on all tools and appliances used—picks, shovels, wheelbarrows, engines, etc., and on the power for operating, whether horse, gasoline or steam; cost of foremen and all other supervision, timekeeper, office expenses, labor insurance or an allowance in lieu thereof to cover damages recoverable by injured workmen; interest on the money put into the work up to the time payment is made for it; demurrage, and possibly other items also; and finally a fair profit.

Of these, rate of interest on plant cost and other money advanced, and labor insurance are fairly constant; some materials like pipe, cement, etc., change in price slowly in ordinary times, and can be calculated very closely for a given piece of work; while other materials such as broken stone, sand, and other local products vary several hundred per cent in different localities. Wages also change slowly, but vary considerably in different sections, and the amount of actual work that is obtained for a dollar varies with the character of local labor, the ability of the foreman to get work out of the men, and that of the contractor to plan the work to the best advantage.

The engineer's estimate should not be too low, as this often gives rise to suspicion of intentional deception by the city, and if made the basis of an appropriation of funds for construction, may lead to a forced curtailment of the amount of work done. On the other hand, an unduly high estimate may discourage any appropriation whatever.

In the figures for cost that follow, the cost given does not include superintendence, use of tools, profits, or any of the general expenses of management, but is thought to be liberal and sufficient to include them under good management.

Sewer-pipe. The list prices of vitrified clay sewer-pipe and specials were given in Table 17, page 178.

Concrete Materials. According to figures collected by "Municipal Journal" in 1916 in nearly 1000 municipalities, the cost of sand varied from $.20 to $3 per cubic yard, averaging $1; that of broken stone varied from $.40 to $3.75 per cubic yard, averaging $1.00. Cement cost about $1.25 per barrel. Labor for feeding mixers by wheelbarrow, mixing and delivering concrete direct from mixer by chute or beam and bucket, cost from $3 to $4 per cubic yard. The cost of forms will vary with their elaborateness, convenience of handling and size of sewer, but may run as high as $2 or more per cubic yard.

Trenching for pipe by hand, sheathing if necessary, and backfilling cost about as given in Table No. 18, for easy digging—

loam, sandy clay, etc. Sand and gravel are included as " easy," but must be sheathed. Hardpan may cost about double these figures. Rock excavated in the trench will cost from $2 to $10 per cubic yard—the latter when only 2 or 3 inches depth are to be removed, and the rock does not shatter readily.

TABLE NO. 18

COST OF EXCAVATING AND BACK-FILLING, AND OF SHEATHING TRENCHES, CENTS PER LINEAL FOOT

Most favorable conditions: Compact loam, no ground water, no obstructions.

Depth of trench, feet	6	8	10	12	14	16	18	20
4-inch to 10-inch sewer	16	22	32	45	55	75	90	1.20
15-inch sewer	19	27	39	54	70	90	1.15	1.50
20-inch sewer	22	33	48	66	85	1.05	1.32	1.80
24-inch sewer	26	39	54	75	1.00	1.20	1.50	2.00
30-inch sewer	30	45	63	87	1.15	1.35	1.70	2.25
Close sheathing used once: lumber	.85	1.05	1.25	1.60	2.00	2.30	2.65	3.00
labor setting	18	21	24	30	45	50	55	60
Close sheathing used 2½ times *	52	63	74	94	1.25	1.42	1.60	1.80
Skeleton sheathing, planks 4 ft. apart	24	28	35	42	56	65	75	85

Labor taken at $2.25 a day, lumber at $25 a M.

* Three-fourths used the second time, one-half the third time, one-fourth the fourth time. With care good sheathing may be used an average of three to five times where driving is easy.

Quicksand may cost from two to ten times the above. No estimate can be given for it.

TABLE NO. 19

COST OF LAYING SEWER-PIPE. CENTS PER LINEAL FOOT

	2-ft. Lengths			3-foot Lengths										
Size, inches	4	5	6	7	8	10	12	15	18	20	24	27	30	36
Unloading, hauling, and distributing*	1.0	1.2	1.5	2.2	2.5	3.0	3.7	5.2	6.7	8.2	10.5	13.5	16.5	23.0
Laying and calking, and cost of jute	2.2	2.2	2.2	2.2	2.5	2.8	3.7	4.5	5.2	6.0	7.0	8.0	9.0	12.0
Cement mortar for joints	0.8	0.9	1.0	1.0	1.1	1.2	1.6	2.0	2.4	2.7	3.6	4.2	5.0	8.3
Total	4.0	4.3	4.7	5.4	6.1	7.0	9.0	11.7	14.3	16.9	21.1	25.7	30.5	43.3

*Teams hauling 2500 to 3000 pounds per load, average haul one mile. Labor taken at $2.25 a day; teams at $5.00.

Concrete Sewers, if designed according to the formula $t=1+\frac{d}{12}$ (all dimension in inches), will require a theoretical amount of concrete represented by the formula,

$$Q=0.007295d^2+0.09427d+0.0808,$$

in which Q is the cubic yards of concrete required for 100 feet of sewer, and d is the inside diameter, in inches. From 5 to 10 per cent should be added for waste, expanding of forms, etc. In estimating cost, be sure to allow sufficient for setting up and taking down forms. Where collapsible sheet steel forms are used, this cost is about 5 to 10 cents per lineal foot for diameters up to 5 feet.

Manholes. The approximate cost of manholes, 3 feet by 4 feet 6 inches on the bottom, is given in the following table. A 4-foot circular manhole will cost about 4 per cent more. The brickwork is taken as 8 inches thick down to a depth of 12 feet, and below this as 12 inches thick. This table does not include the cost of excavation, moving of materials from one manhole to another, or overhead charges.

TABLE NO. 20

COST OF MANHOLES, 3 FEET BY 4 FEET 6 INCHES

Depth, top of brickwork to sewer-invert, feet	8	10	12	14	16	18	20
Brick, at $10 per M	$12.95	$15.88	$18.80	$23.75	$29.05	$33.45	$37.70
Mortar, mixed 1 : 3:							
Cement at $1.50 per bbl.	1.85	2.27	2.70	3.40	4.15	4.75	5.40
Sand at $1.00 per yd.	.50	.60	.75	.95	1.15	1.35	1.50
Mason at $5.00 per day	4.00	4.65	5.30	6.55	7.80	9.05	10.30
2 helpers at $2.25 per day	3.60	4.20	4.80	5.90	7.05	8.15	9.30
Total	$22.90	$27.60	$32.35	$40.55	$49.20	$56.75	$64.20

Add to the above:

Foundation of concrete 6 inches thick, with benches	$6.00
Cast-iron top and cover, 450 to 800 pounds, at 3 cents	$13.50 to 24.00
Steps, wrought iron, one for each 15 inches height, each	$0.40

CHAPTER XI

SUPERVISION OF CONSTRUCTION

ART. 52. WORK PRELIMINARY TO CONSTRUCTION

As soon as possible after the signing of the contract the contractor should submit samples of the material he wishes to use, and these should be carefully examined by the engineer, and if accepted should be retained and marked for future identification and compared from time to time with the material actually furnished.

The contractor should be notified some days in advance of the point or points at which he is to begin work. Reasonable deference should be made to his wishes in this matter, since it is his privilege and duty to so organize the work as to secure the greatest efficiency at the least cost to himself. If, for instance, part of the work lies through wet ground and sub-drains are to be used it is ordinarily to his interest, and indirectly to the city's also, that the work begin at an outlet to which all ground water will drain, or at a point at which a pump, once set up, can drain the work for long distances without moving its location, as at the junction of two mains. It is also usually desired by the contractor that, if two or three small gangs are to work at as many places, they may be within a few blocks of each other for convenience of oversight. It will ordinarily be to the interests of both contractor and city to work in as dry ground as possible, and hence to leave until summer droughts construction through low, soggy land. Construction across or near streams should not be carried on when there is a possibility of floods or freshets, if it can be avoided. Both trench- and masonry-work should be avoided in winter weather, if possible, for it is then costly to the contractor, and it is impossible to be sure that the mortar is uninjured, or to restore the streets to good condition with frozen earth.

Ordinarily the contractor will desire to place upon the street, along the line of the work, pipe, brick, sand, lumber, etc. This cannot be denied him, but he should be compelled to place and pile this material so as to interfere with travel as little as possible, and along only those stretches of street in which construction is to be begun within a week, or ten days at the outside. This material should be inspected as it is delivered, and that condemned removed at once.

Just before the work begins it is well to run levels carefully over all bench marks to see that they have not been disturbed and to check previous levelling; also to establish new ones if necessary. It is desirable to so place these that one of them can be seen from the instrument when set up for giving grades to any part of the work. They should be accurate within at least .003 of a foot.

Final arrangements should now be made for the oversight of the work, the proper instruments obtained, engineering and inspecting assistants engaged, an office or other headquarters arranged for, notebooks and blanks obtained for making and preserving records, final arrangements made as to right-of-way across private property and along county roads or others not controlled by the city or village. Arrangements should be made also for locating the branches for house-connections at the points desired by the property owners. For this purpose it is well to publish in the paper or otherwise make known to the citizens that each is desired to drive, at his fence-line or curb, a stake indicating the point at which he wishes his house-connection to enter his property, and that in case no such stake is driven the engineer or inspector will use his judgment in locating such branches.

Counsel for the city should pass upon the sufficiency and correctness of the contracts signed, of the bonds given and of their signers, and all other legal matters in connection therewith, before the contractor is permitted to begin work.

ART. 53. WORK DURING CONSTRUCTION

Giving Line. Since a sewer-trench is seldom more than 12 inches wider at the bottom than the sewer to be placed in it, it is necessary that the trench itself be carefully aligned. For giving alignment, the method recommended is to drive stakes or spikes along the center line of the proposed trench at intervals of about 50 feet. (Spikes may be used in joints of block pavements.) These spikes or stakes should be a uniform distance apart to facilitate finding them.

Giving Grade. For laying pipe sewer, the best method is by means of a cord stretched vertically over the center line of the proposed sewer and parallel to its grade. The preferred plan for supporting a cord in this position is to fasten it to a standard or strip of wood that is nailed in a vertical position to a plank which stands upon edge with one end resting upon the ground upon each side of the trench. This plank should extend at least 18 to 24 inches beyond the trench on each side and should be firmly bedded in solid ground so that it cannot possibly settle, and be held upright by a stake driven at each side of it at each end, or by stones and earth banked solidly around the ends. When excavating machinery is used, these planks cannot ordinarily extend above the surface, but can be sunk into the ground entirely below the surface; or the vertical strips that carry the cord can be nailed to the trench bracing. The cord should be strong fish-line or a similar material whose light weight will

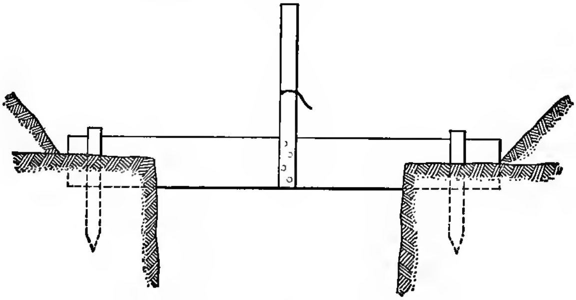


FIG. 59.—METHOD OF SETTING GRADE PLANK.

prevent unnecessary sagging. If stretched tightly between the grade planks, the amount of sag will be inappreciable unless these planks are too far apart. To minimize the sag, the grade planks should be not more than $33\frac{1}{3}$ feet apart, and 25 feet would be better. After the planks on a given stretch of sewer have been set firmly in place, the center line of the sewer is marked on the top edge of each plank, and a standard (a strip of wood about 1 inch by 2 inches by 24 inches) is nailed to each plank so that one edge is just at the center line mark and is truly vertical, the latter being determined by means of a plumb-bob. On this edge is placed a mark exactly a whole number of feet above the sewer-invert immediately beneath it, and a slight notch is cut here to receive the cord. All the notches in each stretch of sewer are placed at the same distance above the sewer-invert and the cord is stretched from one to the other, and is therefore at every point the same distance above the sewer-invert and vertically over it. If it is desired to change this distance above the sewer-invert, such change is made by cutting in the edge of one of the grade standards two notches to receive the grade cord which are exactly 1 or 2 feet apart in elevation, as may be desired. A grade plank must of course be placed at every change of line or grade.

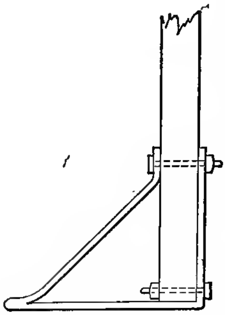


FIG. 60.—GRADE ROD.

In measuring from the cord to the sewer-invert, a grade rod is used, consisting of a rod of white pine or other light wood, to the bottom of which is attached an offset piece which can rest on the inside of the end of the pipe. Such an offset is preferably made of a piece of wrought iron about $\frac{3}{16}$ or $\frac{1}{4}$ of an inch thick, and stiffened by being bent back upon the rod as shown in the illustration.

Another method employed for giving grade is to drive stakes to grade along the center line in the bottom of the trench. A third method is to drive stakes in the ground surface near the edge of the trench, their tops a uniform or stated distance above the sewer grade, such distance being measured down to the sewer by means of rod and spirit level. Neither of these is recommended for pipe sewer, but the former may be used to advantage in setting templets for constructing concrete or brick sewers. If the grade board method is used for sewers built in place, the cord may be stretched only when the templets or forms are being set, being removed at other times so as to be out of the way.

Grade planks should be tested for grade and line at least once a day, and the inspector should keep close watch to see that they are not disturbed and that the cord is kept taut. Where running sand is found in the trench, the banks may settle several inches during construction, carrying the grade planks with them; and where this occurs it may be necessary to keep a level constantly on the ground and check the grade planks every few minutes during the time pipe is being laid.

Inlet- and house-connections should be laid as truly to line and grade and in the same way, as the sewer itself.

Keep careful notes of all instrumental work connected with giving line and grades. (See Art. 54.)

It is convenient to keep in the level notebook a list of all bench marks in the sewer district in which it is to be used.

Passing Obstructions. Inspector, engineer and contractor should watch for the first indication of the existence in the trench of an obstruction to the sewer, so that preparation may be begun immediately for a change in line and grade, if necessary, to pass the obstruction. Such change, if in line, may necessitate inserting one or two additional manholes; if in grade, it may sometimes be made by a flattening of grade in one stretch and an increase of grade in the next, or by an inverted siphon. If possible, the change should be made in the obstruction and not in the sewer.

Locating Branches. The inspector should see that branches for house-connections and inlet connections are inserted at the proper points and the exact locations noted; which locations the engineer must make note of and reference to some fixed point, usually the center of the nearest manhole, to make possible the ready finding of the branches in the future. This is very important, and should be faithfully attended to. In addition, some engineers bury in the trench a stake or steel rod standing vertical above each branch and rising to the surface or a few inches below it, which can be found by a plumber soon after he begins to excavate for a connection.

Inspector's Duties. Among these are the following:

Be on hand before work is begun, at morning or noon, to see that no partly set mortar is worked over, and that the new mortar is properly proportioned and mixed.

See that grade boards are not disturbed and that grade lines are taut.

See that no dirt enters or remains in the sewer while being laid.

Examine each pipe before it is lowered into the trench, and each load of brick, sand, cement or other material as it is delivered on the work, to see that they meet the specification requirements.

See that each pipe or each templet is set to grade, using grade rod and plumb-bob for this purpose.

Mark the position of each branch for house- or inlet-connection by a stake driven in the bank directly opposite it, indicating the side of the street toward which the branch points. See that covers are cemented in each branch (to prevent dirt or ground water from entering the sewer).

See that arch centers and concrete forms are set solidly to proper line and grade and do not spring or settle, and are not removed before the concrete is sufficiently set.

See that backfilling is placed and tamped as required by the specifications.

Keep a record of all extra work, of foundations and of sheathing left in trench or similar work that cannot be measured after the completion of the sewer.

See that no ground water flows over concrete or brick-work or through the pipe laid, except as may be ordered by the engineer.

Engineer's Duties. The engineer or his assistant should visit each part of the work at least once a day and give necessary instructions to inspector and contractor, as well as giving and testing line and grade.

See that each inspector makes a daily written report of the work done in his section, preferably upon blanks furnished for the purpose.

Decide where and how much sheathing shall be left in the trench.

Classify materials excavated, measuring promptly any classified as rock.

Measure each stretch of sewer and the depth of each manhole as soon as completed.

See that the contractor keeps streets and sidewalks open where possible, places such shoring and sheathing as may be necessary to prevent accidents to property or lives, provides pumps adequate for handling all ground water encountered, uses laborers in sufficient number and of the requisite skill, uses excavating machinery where necessary; and in general, that he conforms to all requirements of the specifications.

ART. 54. NOTES AND RECORDS

Each manhole, lamp-hole, flush-tank, and inlet should be designated by a number. It is almost impossible otherwise to correctly count and keep track of these, especially the manholes, so many of which are each common to two lines of sewers.

A final-estimate book should be kept, in which is entered an exact statement of each piece of work as it is completed, but not before then. The measurements should be classified under the items for which bids were received, and the location of each given; thus:

8-INCH SEWER, 8 TO 10 FEET DEEP

Location.	Length.
From manhole No. 7 to manhole No. 8	327.3 feet
Between manhole No. 8 and manhole No. 9	39.0 feet

8-INCH×4-INCH Y BRANCHES

Location.	Number.
Between manhole No. 7 and manhole No. 8	13
" " " 8 " " " 9	11

MANHOLES

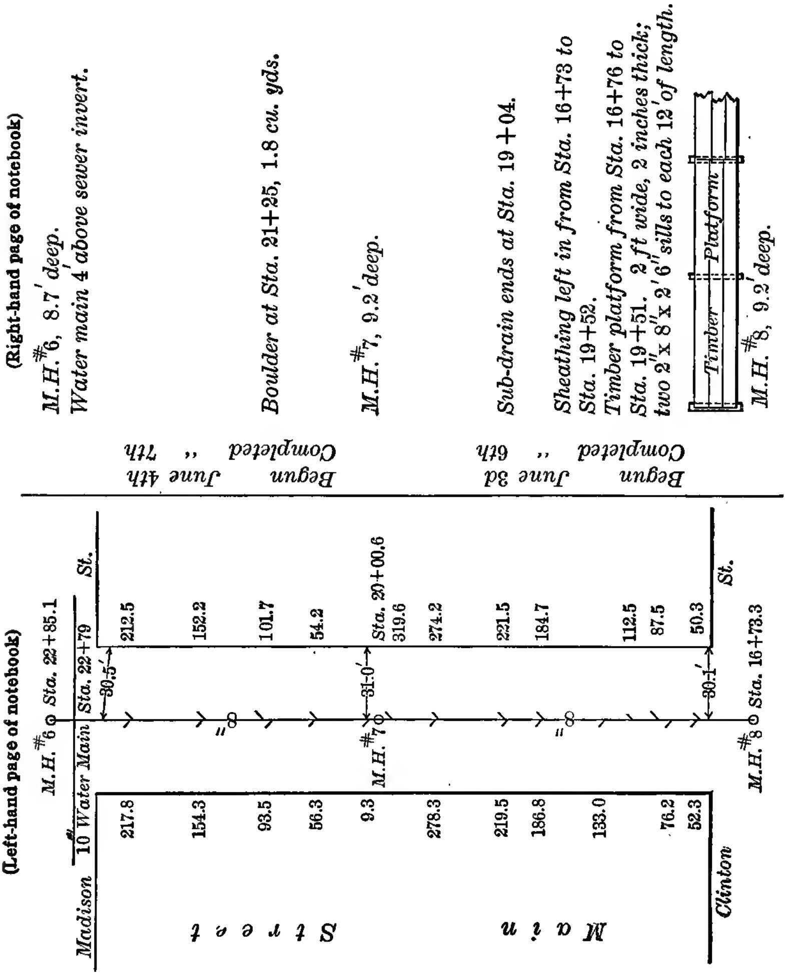
No. of Manhole.	Location.	Depth
7	Main Street, between Clinton and Madison	9.2
8	Corner Clinton and Main Streets	9.2

A pocket field-book should be constantly at hand, in which are entered all measurements taken, the points of the beginning and ending of " sheathing left in trench," of sub-drains, of foundations, the location of all Y's, the details and quantities of " extras," the location of underground structures for future reference, and the date of beginning and ending of construction on each stretch of sewer. These notes should be copied every evening into an office-book, since a loss of these data would be serious and irreparable. The general appearance of such notes is shown on page 271.

It is well also to have a pocket copy of the profile of each street, showing the sewer as designed, with size, grade, elevation, location of manholes, flush-tanks, and other appurtenances. This method of taking these data to the field for use seems to be more complete and convenient than copying them down into a notebook. Photographic reproductions of profiles and detail plans at about one-fourth or one-fifth full size have been found convenient for field use by a number of engineers.

ART. 55. FINAL INSPECTION

The final inspection of the work before its acceptance from the contractor should be thorough, and made by the engineer in person or by an experienced, trustworthy assistant. He should enter every flush-tank, manhole, inlet, or other appurtenance sufficiently large for this, taking its dimensions, noticing whether the head or grating is at the proper level and substantially set, the brick-work and concrete smooth and no ground water leaking through it, the form regular, the steps properly set at the prescribed intervals, that pipes passing through the walls are properly built in with surrounding "bull's-eyes"; that the bottoms of manholes are formed according to instructions, the invert channel being straight or with a uniform curve, of the proper width, and its grade uniform through the manhole and of the proper elevation, and that the benches have the specified slope; also, if there are sub-drains, the handholes should be


(Left-hand page of notebook)

(Right-hand page of notebook)

Begun June 4th
Completed " 7th

Begun June 3d
Completed " 6th

M.H. #6, 8.7' deep.
Water main 4' above sewer invert.

Boulder at Sta. 21+25, 1.8 cu. yds.

M.H. #7, 9.2' deep.

Sub-drain ends at Sta. 19+04.

Sheathing left in from Sta. 16+73 to Sta. 19+52.
Timber platform from Sta. 16+76 to Sta. 19+51. 2 ft wide, 2 inches thick; two 2"x 8"x 2'6" sills to each 12' of length.

M.H. #8, 9.2' deep.

inspected, and these as well as the manholes should be free from dirt. Flush-tanks should be filled with water and tested for tightness for at least twenty-four hours, during which time the water-level in them should not lower more than 1 or 2 inches. If automatic flushing apparatus is set, it should be tested with a stream sufficiently small to fill it in not less than twenty-four hours. To expedite the test it can be rapidly filled and discharged once to test its proper working, then rapidly filled three-quarters way to the discharging point and the inflowing stream cut down to the rate above mentioned, to see that the siphon does not " trickle," but holds the water until the height is reached calculated to cause a complete siphoning of the water in the tank.

Every foot of sewer and inlet connection should be inspected. Sewers 24 inches or over in diameter should be entered and each joint inspected, if they are pipe sewers, to see that no jute or cement protrudes into the sewer and that there is no leakage. In case of the former the protruding cement or jute should be removed; and if there is leakage this should be stopped, for which purpose there may be calked into the joint from the inside dry cement immediately followed by jute, cloth, or similar material to hold it in place until set; or wooden wedges, or lead wool may be used. If these or similar methods fail, it may be necessary to uncover the pipe and apply additional cement on the outside, backed and supported by concrete if necessary. Any cracked or broken pipe should be dug up and replaced. The branches should be examined also to see that a watertight cover is in each one which is not already connected with a house connection.

If the sewer is of concrete or brick the inner surface should be smooth and without any stone pockets or cracks. To determine whether the form and dimensions are as specified, a skeleton templet may be used. If the sewer is circular, this may consist of two light rods, each of a length equal to the nominal interior diameter, and connected by a bolt passing loosely through holes at the exact center of each. One of these rods is to be held stationary across the sewer and the other revolved upon the bolt, when each end of the latter should just touch the sewer through the entire revolution. For an egg-shaped sewer, a half-templet may be used. Slants or other branches should be examined as stated for pipe branches. Special attention should be paid to junctions of sewers to see that the curves are easy and uniform in plan, and that the arches are strong and well built. All spalls, bats, plank, and other refuse and dirt should be removed from the sewers. All appreciable leaks should be stopped. For such inspections, a lantern with a reflector is desirable, or a large dry battery electric lamp.

Inspection of small pipe sewers can be made from manholes only. As a test for straightness, a light held at the opening of the pipe in a manhole should be distinctly visible from the next manhole. Further inspection can be made by the use of mirrors from which sunlight is reflected into the sewer or of dry battery lamps. The simplest plan is to reflect the sunlight from a mirror held by an assistant on the surface to another mirror held by the inspector in the manhole, who so manipulates his mirror as to throw a spot of light onto each length of the sewer in succession, meantime inspecting the same by looking past the mirror into the sewer. Apparatus has been devised for removing some of the inconveniences of this method by so placing an additional mirror that the interior of the sewer is reflected therein, and the inspector is relieved of the necessity of assuming an uncomfortable position. Such an apparatus is described in "Municipal Journal," Vol. XXIX, page 572.

The imperfections most commonly found in pipe sewers are: Loops or ends of oakum or ridges of cement protruding into the sewer at the joints; dirt, stones, etc., in the sewer; uneven grade (which can be detected by allowing a small amount of water to flow through the sewer, which stream will be wider at the depressed and narrower at the elevated points); groundwater leaking in through the joints; broken pipe; breaks, at joints, in the continuity of the invert surface.

Broken pipe and leaking joints can be repaired only by digging down to the sewer. Dirt, stones, and protruding cement may be removed by drawing a scraper through the sewer by means of a rope, or by pushing it through by a rod formed by jointing together several shorter rods of a size which can be introduced through a manhole—about 5 feet. A stream of water from a fire-hose nozzle under a good head can be used to remove from a stretch of sewer not more than 300 feet long almost anything less in size and weight than a brick. The hose while water is passing through it is so stiff that it can be pushed for a long distance into the sewer. Jute ends or loops are sometimes difficult to remove, but can usually be cut off by a sharp-edged hook fastened to a long rod (a pruning hook may be used), or burned off by putting under them (they generally hang from the top of the sewer) a small lamp or candle similarly fastened. Or if there is water flowing through the pipe, the candle may be fastened to a piece of wood to which a string is attached and floated down to the desired point. The exact distance from the manhole of any defect can be ascertained by counting the number of pipe joints intervening.

Sub-drains should be inspected by turning into each stretch for a short time all the water it can carry (if they are not already running full) and watching for indications of stoppages. The apparatus for inspecting sewers above referred to may in some instances be used for sub-drains, being lowered into the sub-drain handhole. If any drain is entirely stopped, this may be remedied by the use of garden-hose, "pills," etc.; or it may be necessary to locate the obstruction and dig down to it.

As far as possible, assurance should be had by examination that all the conditions of the contract have been carried out, those having reference both to the construction and to the more strictly business relations between city and contractor.

CHAPTER XII

CONSTRUCTION

ART. 56. TRENCHING

THE engineer must have some knowledge of construction if he is to co-operate with the contractor to secure the most effective results; in addition to which, an engineer in charge of an existing system will probably be required to personally supervise the making of repairs and even the laying of extensions.

An effort has been made to outline the more common features of sewer construction in this chapter.

The more common practice is to lay sewers up-grade. This is almost necessary with pipe sewers, since Y branches are so made that the pipe bell must point up-grade; and if laying proceeds down a steep grade, a pipe, after being placed in position and before the next is laid, tends to slide away from the one next above it and cause a bad joint. The only reason advanced for laying a sewer downhill is that, the lower end of the trench being ahead of the pipe, any ground water will be kept drained away from the sewer to the end of the trench, where it can be pumped out. On the other hand, in laying up-grade, a sub-drain can be used (or the completed sewer itself) for removing ground water without pumping; and the trench serves to drain out the ground ahead of it and so reduce the amount to be handled during excavation.

The width of trench at the bottom should be at least 12 inches wider than the outside of the bell of the pipe to be laid, plus an allowance for sheathing, if this is to be used; and the top is generally made a little wider to allow for more or less batter to the sides of the trench. Two feet is the narrowest trench that men can work in, and 30 inches is a common minimum. For brick or concrete sewers the bottom need be no wider than the outside width of sewer, plus sheathing. In some cases where the trench is to be comparatively shallow and dug by machinery and the banks would not stand without sheathing (as in sand or uncemented gravel), the sides of the trench are allowed to assume a natural slope, often approximating 1 to 1.

Trenches may be excavated by hand (pick and shovel) or by machinery. The former is generally preferable when only a few hundred feet of small sewer is to be laid at a stretch, or where there are boulders, rock, or frequent pipes or other obstructions lying across or in the path of the trench; also, when the ground caves badly, unless the sides are to be allowed to slope, as described above.

Machinery is especially effective and economical where wide or deep trenches are to be dug; where the ground will stand up without bracing for a depth of 8 feet or more and contains few large stones or roots, and there are no house-connection, water- or gas-pipes crossing the trench; where it is desirable to avoid piling the excavated dirt along the street; or when labor is exceedingly scarce or high priced. Machinery has been used advantageously where none of these conditions was present, but only when special local conditions outweighed other unfavorable ones.

The machinery used may be divided into five classes: (1) Simple lifting appliances, like derricks, either stationary or mounted on travellers. (2) A wire cable suspended above the center line of the trench, on which run one or more travellers carrying buckets that are first raised from the trench and then carried to one end of the cable. (3) A trestle spanning the trench, on which is supported either a track from which depend a number of travellers, each carrying a bucket, or two rails on which runs a large traveller that carries a large bucket and a man to operate it. These three are really dirt handlers rather than excavators. In each, the cable moving the carriers is operated by a stationary engine placed at the end of the trench, the whole equipment being moved ahead every few days. (4) The fourth type consists of an excavator that both digs and elevates the dirt, one variety working on the general principle of the ladder dredge, another employing a wheel that carries upon its periphery a number of buckets provided with cutting teeth or edges. Either ladder or wheel can be raised or lowered by the operator at will so as to give the required depth of trench. These have been used for excavating trenches up to 20 feet in depth. A steam shovel with elongated dipper handle has been used for trench excavating in a few cases. (5) The fifth class is the drag-line scraper

Fig. 61.—Ladder-dredge Type of Trench Excavator.

where there is no sheathing or
banks are allowed to assume a
nery is economical when the
cost of running (including all labor) and of repairs, plus the rental or interest and depreciation on first cost of the machine, is less than the cost of " staging " it out (as the use of platforms is called) plus that of back-filling. If the back-filling is to be hand-tamped, this last item should not be included, since if a machine is used the material must be spread by hand after

dumping. Where the excavation can, for some reason, proceed but slowly, the use of a trenching machine is not generally economical, although it may be advisable for other reasons.

In some cases, especially where the sewer is to be laid in an important street that must be kept open for traffic, it may be advisable to require the contractor to use trenching machinery of a type that will effect this.

Obstructions in Trench. If a water- or gas-pipe or other conduit run diagonally across a trench, or run in it, or cross one more than 8 or 10 feet wide, it should be supported in position before the earth is removed from under it. This can be done by placing across the trench, at intervals of 12 feet, sufficiently strong timbers or old rails, and suspending the conduit from these by chains drawn tight by driving wedges between them and the beams. Rope should not be used for this purpose, as rain causes it to contract or to break in the attempt to do so. If such a pipe lies in the bank, close to or slightly protruding into the trench, the bank should be thoroughly braced just under the pipe and the pipe itself be held in place by braces. These braces should not be removed when the trench is back-filled; and if the pipe is suspended, the trench should be filled and thoroughly tamped under and around the pipe before the chains are removed. The breaking of a water-main in or near a sewer-trench is one of the most disastrous accidents which can happen to it. Small house-connection pipes crossing the trench are apt to be broken by workmen climbing over them and should be protected, as by a piece of plank or of a 2×4 placed across the trench just above such pipe, the ends extending 6 inches or more into the banks for support. In all cases where there is danger of a water-main breaking along the trench, such and so many gates should be temporarily closed that the closing of only one more will entirely shut off the pressure from the threatening line of pipe, and a wrench be kept at hand for closing this.

If a drain crosses the trench, the pipe should be removed and saved and a trough substituted during construction, its ends supported in the banks. The back-filling should be carefully tamped under this and the pipe relaid in the trough.

The soil where a trench has previously been dug, although it were years before, is more liable to cave than that which has never been disturbed, and in laying out a sewer-trench it should be kept several feet from any old trench, if possible.

Sheathing. The use of sheathing is generally for the advantage of the contractor, but in some cases it is desirable that the city require its use, and in many such cases that it be left in when the trench is back-filled. The most common of such conditions is where the caving of the trench would endanger water or gas mains or other portions of public utility systems, or would undermine street railway tracks or pavement over which traffic must be maintained. In some cases tongue-and-groove sheathing should be used to prevent sand running through it and thus forming cavities behind it which would threaten the safety of other underground structures, of the pavement, or even of adjacent buildings.

In many instances it is desirable to leave the sheathing in the trench, sometimes with and sometimes without the rangers and braces. The conditions calling for leaving in sheathing are: that drawing it may endanger the sewer, or water- or gas-pipes in the street near the trench, or adjacent buildings, or that the street-paving will be injured thereby. The danger to buildings usually exists only in connection with deep trenches in unstable soil or where a building is quite near a sewer which lies below its foundation. Water- or gas-mains would be endangered if within 2 or 3 feet of, and more than that distance above the bottom of, a sewer-trench in fairly good soil. If the soil has shown a tendency to crack along the banks near the trench, the sheathing should not be drawn if the street is well paved; and if water- or gas-pipe or other sewers are laid in such street, the judgment of the engineer must decide at what distance they may be considered safe from disturbance if the sheathing be drawn. If the sheathing has been driven below the center of a sewer, as must be done under some conditions, its removal would disturb the foundation of the sewer and should not be attempted. But if two or more courses of sheathing have been driven, all but the lowest course may be removed if the sewer only be would affected. The rangers and braces as well as the plank should usually be left in. If the banks are liable to cave with the drawing of the sheathing, the trench should be filled to a distance above the sewer at least equal to its width before the top braces are knocked out or any sheathing plank is entirely drawn.

Before drawing sheathing the back-filling, if it is not to be rammed, should be carried to a point at least 3 feet above the bottom of the plank. The bottom set of braces and rangers may then be removed. If this gives less than 2 feet of back-filling above the top of the sewer this amount should be thrown in and properly tamped. When the sewer has been properly covered, the remaining braces and rangers may be removed and the sheathing entirely drawn.

Ground Water. The contractor should be required to keep the water in the trench below any green concrete or brick-work, or pipe-sewer joints. If this necessitates pumping, he must be required to so discharge the water that it will cause the least inconvenience to the public and will not soak back through the ground into the open trench.

Railroad Crossings. If a sewer is to pass under a railroad in open cut, each rail should first be supported by bridge timbers, beams, or iron rails placed under the ties lengthwise of the track and extending at least 10 feet beyond each side of the proposed trench. After the completion of the work with thoroughly tamped back-filling, the trench should be wet down every two or three days for several weeks, the bridge timbers or rails being left under the ties meantime. Just before each wetting, earth should be placed and tamped on the filled trench to 2 or 3 inches above the ties. When the trench shows no settlement after a wetting down, the supporting timbers or rails may be removed.

For small sewers it will be well to use iron pipe with lead joints for railroad crossings, and for large sewers, the arch and side-walls should be made of such strength as to provide a large factor of safety against the heavy loads and jarring transmitted by the track above through the earth to the sewer.

Art. 57. Construction

Pipe Sewers. Except in the case of quicksand or other unusually difficult conditions, the contractor should be required to have the bottom of the trench as nearly as possible at grade for at least 25 feet ahead before he is allowed to begin laying pipe. This can be tested by passing a special grade rod through the trench, a mark for excavation depth being kept at the level of the grade cord. Bell-holes should be dug at least 9 or 10 feet in advance of pipe laying, and it should be insisted that each be of such size that, when the pipe is in position, the jointer can pass his hand entirely under and around the front of the bell.

The inspector must see that each pipe is set accurately to grade and line. For the former, the grade rod is used, the inspector preferably standing on a board that spans the trench and is moved ahead as each pipe is laid. For line, the inspector may lower a plumb-bob onto the forward end of each pipe, bringing the plumb-bob string into contact with the grade cord; or the plumb-bob may be suspended from the forward grade board immediately under the grade cord, and when the inspector's eye is so placed that the cord and the plumb-bob string coincide, the former is projected vertically into the trench and should cut the center of the pipe, which will be indicated by a band of light reflected from the sky (unless the pipe is so poorly formed that it should not be used in the sewer). As soon as a pipe is in position, a little earth may be placed and rammed on each side of it just back of the bell, to prevent its moving. After a joint is finished, the inside of the pipe should be cleaned of any cement (or other jointing material) that may have entered through the joint; for which purpose a bag stuffed with straw may be pulled through the sewer, or a disk of heavy rubber packing fastened between two wooden ones of slightly less diameter. The rubber disk should be slightly larger than the sewer.

Water should never be allowed to stand in bell-holes after a pipe is cemented. If liable to, the bell-hole should be filled with cement or concrete, or at least with sand or gravel well tamped. No water should be allowed to run through a sewer until the cement is fully set. Particular attention should be paid to branches and slants in wet trenches to see that they are tightly sealed. It is an excellent plan to build a dam at each end of a stretch of sewer in a wet trench, after the sewer has been completed and cement set but before back-filling above the pipe, and allow the water to stand upon it. Leaks thus discovered are then readily accessible for repairs.

When a manhole or other break in the sewer is reached in the pipe-laying, the last pipe before reaching and the first after leaving it should be omitted or left with uncemented joint, to be laid while the manhole or other appurtenance is being built. This is on account of the probability of such pipe being disturbed or broken during the construction of the masonry before it has been walled in. In this or any case where a stretch of pipe ends, or when the laying is temporarily stopped, a plug should be inserted in the end of the last pipe, and a bar or stake driven against it into the ground or nailed to the sheathing to hold it in position. The last joint should be left uncemented until laying is renewed.

In setting branch specials, the earth where the special will come should be so excavated as to permit the branch to rest upon it firmly when in the desired position. If necessary, earth should be placed and tamped under the branch for this purpose. The inspector must not forget to examine each branch to see that a cover is cemented in it, unless the house-connection is to be built at once, and also to mark its location. In wet soil particularly, uncovered branches may give rise to serious difficulty, and an unlocated branch is worse than none at all.

If work must be done in the winter-time, great care should be taken to prevent the mortar from freezing and to keep ice and frozen dirt out of the joints. In pipe joints this is not very difficult if the trenches are at all deep, since in these the temperature seldom falls below 40 degrees. But the sand for mortar should be heated, and the pipe also, to insure the removal of all frost from the bells and spigots. In shallow trenches, the joints should be covered as soon as possible with at least 2 feet of unfrozen earth. Care should be taken, particularly when back-filling is dumped from excavator buckets, that no frozen lumps fall upon the sewer.

When back-filling is thrown in without ramming, particular care should be taken that all pipe be first well covered with earth, for stones and frozen lumps invariably roll to the foot of the slope of the back-filling and might break the pipe if unprotected.

Brick Sewers. A simple ring invert can be used only where the soil is firm and compact enough to stand when given the shape of the outside of the invert; such as clay, pure or mixed with sand or loam. If it will not retain this shape while the sewer is being built, but is solid enough to offer good foundation, as damp sand, the bottom of the trench may be given a flatter curve and lined with a board or plank cradle, upon which concrete or stone masonry is placed for the invert-backing, to be lined with 4 inches of brick-work. In rock cuts, the same plan may be adoped, since it is usually impracticable to bring the rock to the exact shape of the sewer.

Concrete Sewers. It is most important that the forms for concrete sewers be of the desired size and shape, and be stiff and strong enough to retain that shape under the considerable pressure exerted by concrete of semi-fluid consistency. Also that they be set exactly to line and grade and so firmly fixed in place as not to be moved therefrom by either the upward hydrostatic pressure of the invert, the weight on the arch form, the horizontal hydrostatic pressure against the sides, or the use of facing spades or rammers. All forms should be tight, so that escaping water will not carry away any of the cement. It is important that, especially in the invert, there be no fins or other irregularities in the concrete surface caused by joints or depressions in the forms, for which reason steel plates are preferable to wooden lagging.

If reinforcement is used, it should be spaced carefully as specified, including the distance from the face of the concrete, and held in this position until the concrete has taken an initial set. The concrete must entirely surround and be in contact with every part of the reinforcement; to insure which it should be thoroughly mixed, of the consistency of soft mush, and be thoroughly spaded to eliminate all air pockets.

The more thoroughly mixed a given concrete is, the stronger and more impervious it will be and the more easily will it flow down chutes and the more completely will it fill forms, without any air or stone pockets. It is strongly urged that each batch be revolved in the mixer for at least two and preferably three minutes. It should have the minimum amount of mixing-water that will give the consistency required for flowing down a steep chute. When it is placed in an invert having the form of a flat curve and no invert form is used, it must be stiffer than this, so that it requires some ramming to compact it, otherwise it will settle out of shape before solidifying. Gravel is believed to make a concrete more impervious and fluid than does broken stone, but not quite so strong. Great pains must be taken to insure the perfect cleanness of every gravel stone. No stone should be used whose longest diameter is more than one-fourth the thickness of the sewer wall; and in no case, probably, should the maximum diameter exceed 1½ inches when reinforcement is used.

The sooner after it is mixed that concrete can be placed, the better. While placing the concrete, spades or other instruments with flat blades should be continually pushed down between the inside form and the cement just placed, and moved slightly back and forth so as to press the larger stones away from the form, leaving the finer material there and thus securing a smoother surface without pockets or air holes.

Concrete sewers are generally built in sections, the end of which is determined by a vertical wall or stop of planks. The concrete should never be allowed to assume a natural slope at the end of the section, but should always be built up with a vertical face. This face should have a groove formed in it about in the middle of the sewer barrel and continuous around the entire perimeter, to furnish a tongue-and-groove bond between this and the following section. If an entire section is not finished in one day, a similar groove should be made in the top surface of each wall to provide a bond between old and new work. Great pains should be taken, before placing new concrete in contact with an old surface, to remove from the latter all dust, loose stone, laitance, or scale, wet it thoroughly, and wash or thinly plaster it with cement grout first before placing the new concrete.

Foundations. Piles are ordinarily used for sewer foundations in soft soil. They usually support a timber platform, but in some instances concrete is placed directly upon and around their heads. For driving them, the ordinary pile-drivers are used, or they are sunk by the water-jet. If they are to support platform timbers they must be driven carefully to line and sawed off accurately to grade. It will sometimes be advisable to drive the piles before the excavation has proceeded very far, using piles considerably longer than actually required, as the jarring of the banks of the trench may thus be avoided, as well as the inconvenience of moving the driver through or over a trench full of braces. The objection to this plan, aside from the cost

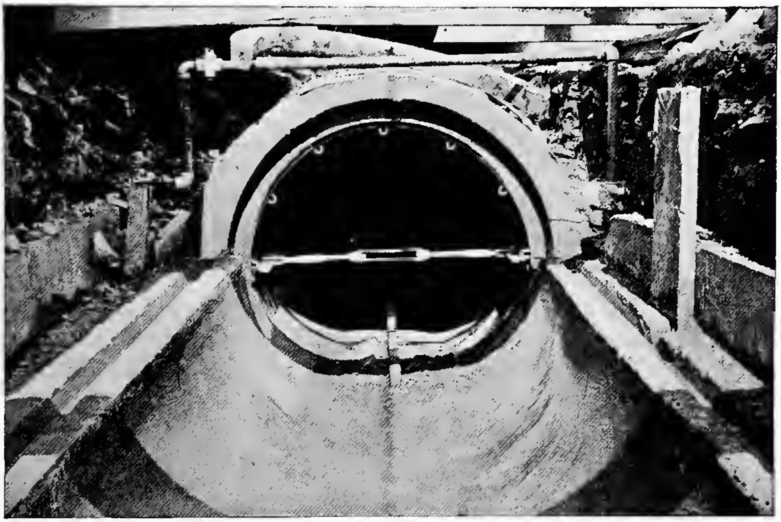


FIG. 62.—FIFTY-TWO-INCH CONCRETE SEWER.
Shows grooves for connecting new work to old; also collapsible steel form.

of the additional length of the piles, is that they interfere with the excavation.

If a platform is used without piles, sills should be placed under the planking, although in the case of small sewers these may consist of 2-inch plank only. Such platforms may serve to distribute the load and prevent local settlement and motion of the soil during construction, while the loading due to the sewer is non-uniform and continually changing, even though they are of little service in furnishing support to the completed structure.

Manholes and Flush-tanks. When laying a pipe sewer, the manholes are not usually constructed until the sewer has been completed beyond them, pipes being omitted from the line where the manhole comes, including the length of pipe that enters and the one that leaves the manhole, these last being laid when the manhole is built.

Manhole bottoms are most conveniently made of concrete. If the soil be soft or wet, it is well to place a plank platform under the concrete. If the soil is not such as to assure the support of the manhole walls without any settlement, special precautions against settlement should be taken, as by using piles, providing a wide footing for the walls, or building steel beams into the bottom that extend across the manhole and under and possibly beyond the walls.

The channel through a pipe-sewer manhole is sometimes built of brick, but a split pipe is better. If brick be used, the inside of the channel should be plastered with a coat of neat Portland cement. (If any branch channel in a manhole is not to be used at once, it should be closed temporarily to prevent deposits forming in it.) The bench may be built up of brick plastered on top with cement, or of concrete. The author prefers to make the whole manhole bottom of concrete, a wooden or sheet-metal core being slipped into the opposite pipes and spanning the manhole to give the shape to the channel; or the split-pipe invert being put into exact position and held there by braces until the concrete sets under and around it.

In leaving the manhole opening in a brick sewer, the end brick in every alternate course of the outside ring may be laid radially, thus presenting toothing protruding at right angles to the sewer barrel. In this, steps with horizontal treads can be built of brick trimmed to the necessary shape, from which the manhole can be carried up without danger of its sliding off the sewer.

The brick in a manhole may be laid as all headers, all stretchers, all on end with their edges exposed or a combination of these. Bats may be used in large or small proportion, or not at all. A strong manhole can be built by using three courses of stretchers to one of headers, all whole brick, until a diameter of about 3 feet is reached, and from there to the top using three courses of square bats to one of headers. The outside of the manhole should be plastered as the wall is built, since it may be impossible to reach it afterward. The head should be set and the opening back-filled as soon as the brick-work is completed.

Flush-tanks are built in a manner similar to the above. These, except at the very top, and catch-basins and inlets, are usually larger in diameter than manholes, and are built throughout of whole brick. Extra care should be taken to have all joints filled with cement and tight, and the work well bonded. After the cement in flush-tanks and catch-basins has fully set, they should be given on the inside two or three washes of neat-cement grout, laid on with a whitewash or similar brush, care being taken to cover the entire surface with each coat, which should be allowed to dry before the next is applied. This will seldom fail to give a tight wall.

Concrete would seem to be especially adapted to flush-tanks, as it can be made watertight more readily than can brick. The concrete should be made of a rich mixture, with an aggregate especially porportioned for securing imperviousness. Gravel will generally give more impervious concrete than stone. It should be mixed just wet enough to flow into place in the form when joggled with a shovel.

No water should be turned into the trench for flushing or other purposes before the cement in these appurtenances, as well as in the sewer, has set.

CHAPTER XIII

MAINTENANCE

ART. 57. NECESSITY FOR MAINTENANCE

IT is the too general rule that when a city has constructed a system of sewers it considers its duty done, and permits any kind of connection to be made with them, by anybody and in any way, and takes no more thought of its sewers until compelled to do so by some obnoxious conditions therein. This is all totally wrong, and even criminal. While it is not probable that any well-designed and constructed sewerage system will ever become worse than no system at all, it will not work at its best efficiency and free from objectionable conditions if unattended to, any more than would any mechanism.

Moreover, a considerable expense has been incurred to provide sanitary sewerage for the citizens, but if careless or penurious landlords or plumbers or ignorant householders are permitted to construct between the sewer and the house, or in the latter, cheap and unsanitary house-connections and plumbing fixtures, the health of the citizens is endangered and complete return for the outlay for sewers is not received. No dread of paternalism should interfere with the proper performance by the city of its manifest duty to require that all " sanitary " piping and fixtures throughout the city *are* sanitary, and the sewers should be in the charge of an experienced officer who is held responsible for their cleanliness and efficiency.

The first necessity for this oversight will come with the connection of the dwellings to the sewers.

ART. 59. MAKING HOUSE-CONNECTIONS

No house-connections should be attached to a sewer except in the presence and under the direction of a city inspector and by a party who is under bond to follow the city's regulations for such work.

No house should be allowed to connect with the sewer until its construction is entirely completed, including plastering and sanitary fixtures, owing to the danger that mortar and rubbish may otherwise be admitted to the sewer.

No connection should be made with a sewer except at a branch provided for that purpose. If there should be no branch within a short distance, one may be inserted in a brick sewer by cutting through its wall and building a slant firmly in place or, in a pipe sewer, by removing a pipe and inserting a branch pipe in its place. If 3-foot lengths of pipe were laid in the sewer a few 3-foot lengths of branch pipes may be kept on hand for this purpose. (Branch pipes are generally used in 2-foot lengths.) To remove a pipe from a sewer it may be broken to pieces with a hammer, care being taken not to crack the adjacent pipe. Then, with a cold-chisel used with some care, the upper half of the bell facing this opening is broken away and likewise the upper half of the bell of the branch pipe to be inserted. This is then dropped into place with the branch on the wrong side and revolved, thus bringing to the top of the sewer that part of both pipes where the bell is wanting. The joint is then made, Portland cement being substituted for the missing portions of the bells.

In breaking the cap or plug out of a sealed branch, care must be taken not to break any part of the pipe. If broken, the pipe should be replaced by a new one, as above. If the branch is cracked, it may be left in, but should be surrounded with rich cement concrete well compacted.

It is absolutely not permissible to cut a hole into a pipe sewer and insert the house-connection therein, as it is almost impossible to obtain a junction that will not leak or to prevent the connection-pipe from protruding into the sewer.

The house-connection should never be larger than the branch which it enters, but should preferably be smaller. A 4-inch pipe is large enough for any residence or small hotel or, in general, for 90 per cent of all the buildings in most cities. On a grade of 1 : 40 it can carry the simultaneous discharge of ten or more water-closet flushes, or that of two large bath-tubs when emptying themselves in two minutes. This connection may be of vitrified clay pipe from the sewer to a point 5 or 6 feet outside of the cellar wall. It should be laid to as perfect line and grade as was the sewer itself, the fall of 1 : 40 being the minimum allowed under any but exceptional circumstances. If a uniform grade from the sewer to inside the cellar is not obtainable or desirable, or if this distance be more than 100 feet, it is advisable to place an inspection-hole at the fence-line or at some other convenient point, the grade and line being straight each way from this to both sewer and house. If the pipe branches before reaching the house, an inspection-hole should be placed at the junction. The joints of the house-connection should be of cement, and it should be of equally as good material as, and laid in every way according to the methods used for the sewer. In made ground or quicksand or where trees are near the pipe or the latter passes near a well or cistern, the connection should be of cast-iron pipe with lead joints.

ART. 60. MAINTENANCE REQUIREMENTS

The requirements for keeping a sewerage system in good running order can be concisely stated as—preventing and removing deposits and maintaining ample and safe ventilation.

As previously stated the main dependence for *preventing* deposits is flushing. If a deposit remains for any time, it is apt to continually increase and become more difficult of removal, and deposits should therefore be removed as soon as possible after forming. This the automatic flush-tank is supposed to do for 800 to 1000 feet below it, but any forming below this limit will probably need to be removed by hand-flushing from a manhole or by the use of special appliances. If deposits continually form in any one place and are not apparently occasioned by articles which should not be introduced into the sewer it may be advisable to place a flush-tank just above where such deposits form, at one side of the sewer but connected with it at a manhole or by a Y branch. If obstructions are frequently formed at any one place by the introduction of improper matters, such as ashes, bones, etc., the source of these should be ascertained and the parties responsible therefor punished.

It should not be taken for granted that a sewer is working properly, but the system should be inspected once a week or at least once a month. This may require merely a look into each flush-tank to see that it works properly, into each inlet or catch-basin to see that it is clean and the grating unobstructed, and into each manhole (the dirt-pan being at the same time removed and emptied) to see that the sewage is flowing with sufficient velocity and is apparently not dammed back by any deposit below. But during the first few months of his service the inspector should enter each manhole and look through the sewer at each inspection until he becomes familiar with its condition of depth and velocity of flow when in good order If there are any considerable odors observed about any appurtenance the cause should be discovered and removed. This will usually be a large deposit or imperfect ventilation, except in the case of catch-basins, where it probably means improper or infrequent cleaning.

The catch-basins should be cleaned after every rainfall. There is danger of putrefaction and objectionable odor from these if this is not done within two or three days after each rain, but this is almost impracticable in large cities, where there are one or two on every corner, without the use of an enormous number of men and carts, since each cart with three men will clean but five to fifteen catch-basins a day

A record should be kept of all sewer-inspections, each line of sewer and each appurtenance having a record of its own showing when it was inspected, its condition, when cleaned, what repairs were made to it, with their nature and cost; of the frequency of flushing or of the discharge of each automatic flush-tank; of the location and date of making each house-connection, with all details as to route, size, and grade of connection-pipe, cost, by whom ordered, by whom put in (if by private contractor).

Extensions of the system should, of course, be made with as much care as were the original sewers, and no alterations should be made in the original plans without a careful consideration of their effect upon the sytem as a whole.

ART. 61. FLUSHING

When automatic flush-tanks are used, they should be inspected at intervals to insure their regular discharging. The most common failing with siphon-tanks is the trickling over of the water into the sewer as fast as it enters the tank after it has once reached the level of the top of the bend. Under this condition the siphon will never flush. This trickling may be due to faulty designing, but is usually caused by a leaking joint or blow-hole in the iron siphon at some point, which must be corrected. The frequency of discharge is regulated by the cock admitting the water. This can be adjusted only by actual trial with each tank. It is a good plan to have one or more registering reservoir-gauges for occasional use in the flush-tanks which will indicate the times of discharge. A simple one, but sufficient for this purpose, can be made with a clock-works actuating a vertical cylinder on which the height of water is constantly registered by a pen whose motion is caused by the rise and fall of a float, a cord carrying the pen and one from the float both passing over connected wheels of such relative diameters that the path of the pen is but 4 or 5 inches long. Such an apparatus left for a day or two in a flush-tank will serve in place of frequent visits to it, and can be moved from one to another as each is adjusted to the desired frequency of discharge. The waste of water caused by flushing oftener than once in eighteen to twenty-four hours is not justified by any proportionate advantages.

In flushing directly from 2- or 4-inch branches led from the water-main into the flush-tank, the valve is ordinarily opened to its full extent, or so much as is necessary to maintain the height of water in the flush-tank as great as is safe for the tank or sewer. It may be left open until such time as the water flowing through the manholes below is perfectly clear. It will be necessary to use the most solid construction in the flush-tank to resist the considerable force with which the water leaves the water-pipe.

Instead of connecting the flush-tank with the water-main by a large pipe, a small one is sometimes used, and the tank filled from this after closing the sewer end, which is then opened and the contained water allowed to flush the sewer. This method takes much longer than the previous one and is consequently more expensive. In some cases the flush-tank is filled by hose from the nearest fire-hydrant.

In some cities the water is conveyed to the flush-tanks in carts, and either the tanks filled from these and discharged by hand as above, or from the bottom of the cart a large pipe or canvas hose is lowered into the flush-tank and connected with the end of the sewer, into which the water is discharged under a head equal to the elevation of the cart above the sewer. These carts are ordinarily used at manholes along the line of the sewer rather than at flush-tanks proper.

As flushing is seldom effective for more than 800 to 1000 feet below the point of entrance of the flushing-water, when automatic tanks are not used at the head of every section of such length which requires flushing, this is performed at manholes wherever necessary. For this purpose, outside water may be introduced by carts as just described; or all the openings in a manhole may be stopped and the manhole filled by hose, when the plug to the down-stream opening is removed and the sewer below flushed; or only this opening is closed, and the sewage is permitted to back up in the sewer above, when the plug is removed and the sewage performs the flushing. The last method is not particularly satisfactory with pipe sewers in most instances, since there is thus obtainable only a small head and resulting low velocity of flush, and if the house-connection pipes are on a flat grade the sewage may back up these to an undesirable height. Deposits also may form while the sewage is accumulating, which will not be removed by the flush if near the upper end of the dammed sewage, and the time required for a sufficient volume of sewage to collect will often be considerable and is longest in those cases where the necessity for flushing is greatest.

The plugs used for stopping pipe and other small sewers may have any of a variety of forms. One design is a simple conical cork-shaped piece of wood with heavy rubber so fastened around it as to come between it and the inside of the sewer when the plug is pushed into place and make a watertight joint. Another consists of a solid center of plank, around the edge of which is placed a pneumatic tube similar to a bicycle tire, which is inserted just inside the sewer and the tire inflated by a bicycle pump. These have ropes attached by which to draw them out of the sewer when the manhole or flush-tank is full, the air being first released from the tube of the one last described.

Another plan, that of bracing a loose frame or hinged gate against the end of the sewer in a manhole, is hardly applicable to properly constructed systems, where the manhole-channel and sewer are continuous, but may be used in a flush-tank designed for the purpose. The cover, whether loose or hinged, may be held in place by a brace hinged at the middle and extending from the cover across the flush-tank to the opposite wall. A rope is attached to the hinge of the brace and by pulling this when the tank is full the brace folds up and releases the cover.

In large sewers it is generally impracticable and unnecessary to dam back the sewage higher than, or even as high as, the crown of the sewer, and a dam one-half or two-thirds the height of the sewer is sufficient. This may be made similar to those already described, but not filling the entire bore of the sewer. Or a "pocket dam" may be used. This consists of a bag of tarred canvas having rings around its mouth and a rope passing through these long enough to reach from the sewer to the surface. Another rope is fastened to the bottom of the bag. This bag is filled with water and placed in the sewer-invert, being held upright by the rope through the rings, and serves as a dam to the sewage. When the sewage has risen sufficiently, this rope is released, the bag collapses and is removed by the rope attached to its bottom.

In very large sewers, flushing, if practised at all, must generally be done with sewage, on account of the enormous quantity of water required for this purpose. But this practice is not recommended where sufficient water can be obtained. In the case of storm or combined sewers advantage should be taken of light rains by damming up the run-off from them in the sewers and flushing with this comparatively clean water. Heavy storms, of course, need no assistance in their flushing effect.

One argument in favor of hand-flushing is that it renders more probable frequent inspection of the system, which will be made at the time of flushing; but on the other hand, pressure of other duties or carelessness may cause longer intervals between flushings than is desirable. In the case of large brick sewers, it is probably best to resort to one of the methods of hand-flushing. For pipe-sewer dead-ends, automatic appliances are desirable in all cases, in the author's opinion. When any flushing is done elsewhere than at dead-ends, hand-flushing is generally resorted to.

ART. 62. CLEANING SEWERS

The purpose of flushing is to prevent deposits, or rather to prevent the accumulation and solidifying of deposits. But if, because of insufficiency or infrequency of flushing, or of the presence of sticks, stones, or other matter which flushing is not adequate to remove, obstructions form, these must be removed by hand or some other method. Catch-basins must be cleaned by hand, and this should be done frequently. The manhole dirt-buckets, also, should be cleaned at intervals. These last are merely removed from the manholes and dumped into a cart.

The catch-basins are generally cleaned by ordinary shovels, the dirt being taken to the surface by a bucket and emptied into a cart. Several cities use, for raising the bucket, a block and fall hung on a crane or other support attached to the wagon. In some cities the dirt is mixed with water and pumped out by an " Eductor " into a tank-like wagon body, the dirt settling out and the water being used over again repeatedly. In other cities, and especially when the catch-basins are small, the dirt is removed with long- and heavy-handled hoes, the blade of the hoe being at right angles to the handle and about 8 by 10 inches in size. These are used from the surface through the manhole opening or that left by removing the grating. Catch-basin walls should be thoroughly cleaned with a hose and broom and washed with a solution of chloride of lime or some deodorizer, but this is seldom done. The cost of cleaning a catch-basin varies from about $1.50 to $6 each, depending upon their size, the frequency of cleaning, and other special circumstances or conditions, $3 seeming to be about the average for large cities.

Small sewers are cleaned by flushing when this is possible, but in many cases other means must be resorted to. The use of "pills" is convenient where there are no stones, sticks, or other hard materials in the sewer. These are round balls, usually of wood, which are floated through the sewer either in the sewage or, if there is not enough of this, by flushing water. A set of these 2, 3, 4, 5, 7, 9, etc., inches in diameter should be kept on hand. When a sewer is to be cleaned the smallest pill is floated through from one manhole to the next, where it is caught by an assistant; the others are then sent through in the order of their sizes until all have passed through up to the size 1 inch smaller than the sewer. When any ball reaches a point where the opening is contracted by sediment to less than its diameter, the ball, which has floated and rolled along the top of the sewer, dams up the water until it has sufficient head to force its way under the ball and scour out the sediment. The ball rolls slowly ahead, the current washing away the sediment for an inch or two under it. If a stone or stick is among the deposit, the ball may be stopped by it, in which case both stone and ball must be removed by another method. The pill cannot be used when the sewer is stopped entirely so that there is no flow through it. No cord should be fastened to any of these round balls, as it is liable to be rolled about them and wedge them in the sewer, catch in obstructions, and generally give trouble. Ovoid balls, however, are sometimes used with cords attached. These do not roll along the top of the sewer, and may need to be weighted to prevent the friction between them and the sewer top interfering with their motion ahead.

These methods all depend upon the scouring action of the water and presuppose a passage through the sewer. Other contrivances for cleaning a small sewer under such circumstances are based upon the use of main strength to haul the material out. Probably the simplest is in the shape of a heavy plank disk to which a rope is attached by three short light chains fastened to as many bolts through the disk. One of these chains is attached at each side and one at the bottom of the disk, and their relative lengths are so arranged that when all are taut the top of the disk will incline a little away from the rope. Upon the other side of the disk, at its top, is fastened another rope. By the latter it is pulled a short distance into the sewer, lying flat; the other rope is then pulled, when the disk rises into an upright position and scrapes along the deposit in front of it. It is well not to draw this too far into the sewer at once, but to clean only a few feet at each trip. The dirt can be scraped to a manhole and there removed by buckets. It is awkward pulling in a manhole bottom, and it is well to arrange a pulley in a frame, around which the rope passes, as also around another pulley at the top to permit of a horizontal pull. The lower frame may consist of two 4×6 or 4×8 timbers fastened to each other parallel and a short distance apart, between which the pulley turns in journals fastened to their under sides, these timbers being braced against the inside arch of the sewer and the pulley being in the center of the manhole. This method can be used where the material is too heavy to be scoured out by pills or similar contrivances, and also as a substitute for these.

In some cases the sewer will be found entirely stopped, so that no cord can be got through it, and an opening must be forced through. A rod of some kind is used for this purpose. Since none longer than 5 feet can be got into the sewer through the manhole (unless it be too flexible for efficient service) rods of this length made to join together are generally used. These are sometimes lengths of gas-pipe with screw-couplings, but wooden rods 3 to 5 feet long, with a peculiar hook or other patent coupling are furnished by several firms. These are forced through the obstruction by working them back and forth or even by driving with a hammer. When an opening is once made, it is well to leave the rod in it and work it a little back and forth as the sewage flows through until the hole is too large to be in danger of immediately stopping again, when a pill or cord may be floated through and the cleaning completed by one of the above methods.

A small sewer or sub-drain may also be cleaned by the use of hose, pushed into the sewer while kept stiff by the water flowing through it.

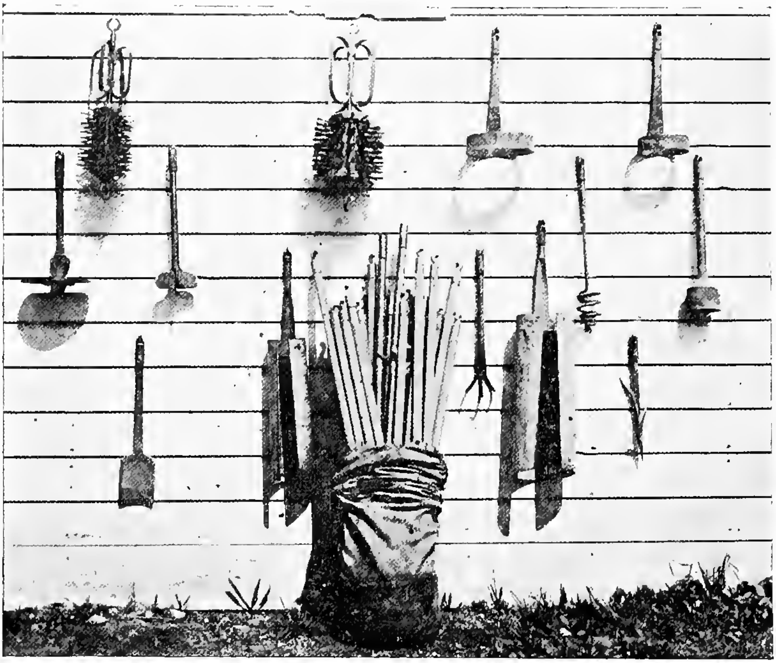


Fig. 63.—Sewer Cleaning Tools Used in Richmond Borough, New York.
Sewer cleaning brushes, root cutters, clay cutters, claw, and other applicanes. These can be fastened to jointed rods shown in bag.

In some cases the obstruction may be so obstinate as to necessitate the digging up of the sewer. Before doing this, its exact location should be ascertained by pushing a rod to it through the sewer and measuring its length, or by the use of mirrors, as previously described.

For cleaning house-connections, sub-drains, and other small pipe which cannot be reached readily, garden hose is excellent, sufficient water being turned through it to make it stiff enough to be pushed through the pipe; or rods may be used, as just described. Instead of a rod, the city of Waltham, Mass., has used for these cases a length of steam-hose filled with sand, a wooden plug being fastened in the end of it. This is flexible, but stiff enough for use in a pipe only 3 to 5 inches in diameter.

Even pipe sewers as small as 18 inches diameter can be entered for inspection and cleaning by hand. A large stone or a stick wedged across the sewer can frequently be removed in this way and the necessity for digging up the pipe avoided.

If the sewer is found to be broken in any place, there is generally but one thing to do—to dig down to and replace it. A sewer which is only cracked or is leaking badly has been repaired by inserting inside of it a line of screw-joint pipe as large as can be slipped into it, and sealing the space between the two at the ends with cement. The substitution of new pipe would probably be cheaper in most cases, however.

When small pipe is only coated or contains but little deposit, it is sometimes cleaned by the use of a wire brush, just the size of the sewer, fixed upon the end of a rod similar to those already described. Small sticks, jute, etc., can be cut by tree-pruning shears. Cloth or similar matter can be withdrawn by a contrivance like a large corkscrew on the end of the rod. These and other special contrivances are shown in Fig. 63.

The cleaning of sewers large enough to permit a man to work in them needs no special discussion. If they are large enough, the dirt may be carried to the manhole in a low car running on the sewer bottom. In smaller sewers it may be shovelled or hoed into a pile at each of two manholes from a point midway between them, and removed in buckets.

An inverted siphon may be cleaned as an ordinary sewer, after the sewage flow has been diverted to the other siphon-pipe or dammed up, and the sewage contained in it pumped out.

PART II. SEWAGE DISPOSAL

CHAPTER XIV

DISPOSAL BY DILUTION

ART. 63. "DISPOSAL" AND "SEWAGE" DEFINED

THE word *disposal* is often used where *treatment* would more properly be employed. As a matter of fact all sewage, dry or water-carried, must be disposed of in some way after having been collected by a sewerage system. But if this disposal consists of anything other than throwing away the sewage this may be properly called a treatment thereof. These words will be used thus in this work—*disposal* as a general term, *treatment* as a more specific one.

For a proper consideration of the various methods of disposal it will be necessary to understand the results aimed at and the principles involved. And first we must understand what is implied by the word sewage. Sewage may be found to contain almost every description of waste matter: fæces, house-"slops," manufacturing waste-waters and acids, drainage of stables, piggeries and slaughter-houses, waste paper and rags, and frequently garbage, and numberless matters which should never reach the sewer. This is ordinarily called house sewage. Into combined and storm sewers, besides rainwater, not only horse-droppings and vegetable refuse but sand, clay, gravel, and other heavy matters find admission through the street inlets. These go to make what is called storm sewage. The common impression is that, of these, human excrements alone are dangerous; and this is to a large extent true so far as concerns dissemination of the germs of disease. But it is known that, aside from this, kitchen-wastes are fully as objectionable, since they contain practically the same putrescible matter, and in a state less easily rendered innocuous by either natural or artificial means. Where storm-water is admitted to the sewers, the large quantities of horse-droppings which are washed in during the first few minutes of each rainstorm render the water during that time nearly as offensive, if not so dangerous, as do human excreta.

Owing to diversity of manufacturing industries, to differences in the characters of the water used by different towns, and to other local peculiarities, the sewage of each town varies from that of almost every other. Therefore the question of the proper disposal of this compound is seen to be a problem of no easy solution. The difficulty of treatment is increased by the exceeding dilution of the sewage, since the sewage of an average American town will contain less than 1 part in 1000 of organic matter, 1 part of mineral matter, and 998 to 999 parts of water.

ART. 64. AIMS OF DISPOSAL

The first aim is the getting rid of the sewage; the disposing of it in such a way and such a place that it will not create a nuisance. Communities, being even more selfish than individuals, seldom regard the well-being of other communities, but are satisfied if no nuisance is created within their own limits. It is here that the State, by its laws and through its Board of Health, should interfere for the protection of each community against all others. In England this protection is afforded by national laws and a national board. In this country a number of States within the past few years have enacted laws affording a certain amount of such protection. The first of these was Massachusetts, but Pennsylvania, New Jersey, New York, and Ohio now have excellent laws and most of the other States are falling into line. It is a duty which the engineer owes to humanity to educate the people to the importance of this matter; though he will often be compelled to yield, in part at least, to the selfish demands of those for whom he acts that they be put to no expense for protection of other communities that is not required by State or national laws.

When this protection is afforded through adequate laws properly enforced, the disposal of the sewage must be such that it will "lose permanently its power for evil." How this can best and most economically be done is the question to be solved.

Many attempts have been made at a solution of this question of disposal that shall not only meet the sanitary requirements, but that shall also be financially remunerative. Some reports of success have been heard of, but when investigated the details are found to be disappointing, and the author knows of no case where the disposal of sewage is accomplished at a profit to the city or town. This is not to be wondered at, since the value of the manure contained in one ton of Boston's sewage, for instance, is estimated to be but one cent.

The sewage of several of our Western cities situated in the "desert" region is disposed of for irrigation at a considerable profit. But in general few, if any, farms in districts where irrigation is not necessary, and on which sewage must be turned in rainy as well as in dry weather, will bring any considerable rental; and no other system of treatment is known which will return any net profit above running expenses, although there is a possibility of such result being obtained by the "activated sludge" process. Until a financially profitable process is available, the endeavor should be to find for each place that method of disposal which, under the existing conditions of location, character of sewage, etc., will best meet the requirements both of the State laws and of the laws of sanitary science, and which will be least expensive, both first cost and maintenance being considered.

ART. 65. PRINCIPLES INVOLVED

For an exposition of the principles involved we must call upon chemistry, biology, bacteriology, medicine, and kindred sciences. Their teachings, stated generally, are:

That matter in a state of putrescence is harmful to human life if taken into the system.

That volatile emanations from such matter, when breathed continually into the lungs, probably lower the tone of the constitution but do not directly occasion disease.

That many diseases may be contracted by taking into the stomach certain germs which are found to be excreted by those already sick of such a disease, and these germs will exist for days in sewage having any amount of dilution.

That ordinarily excreta do not putresce until from twenty-four to sixty hours after their discharge, or even longer under certain circumstances, such as absence of moisture.

That the only true destruction of the dangerous characteristics of sewage is that effected by oxidation, which transforms the putrescible organic matter into harmless mineral compounds, and by removal of the disease germs.

The legal principles involved vary in different localities and with different interpreters of the law, frequently depending upon the ruling as to what creates a nuisance. A recent ruling in the United States has included in the " creating of a nuisance " the rendering unfit for drinking purposes of water which would otherwise be used thus. Under properly prepared State laws, interference with the health and rights of others should be preventable by injunction, or, in the case of injury to private interests, should subject the city to forfeiture of damages. The Supreme Court of Connecticut has held that: " The discharge of sewage and other noxious matters into an inland stream to the injury of a riparian proprietor below has been held to be an unlawful invasion of the rights of said proprietor, remediable by injunction, by the courts of nearly every State, by the federal courts, and by the courts of England." (Morgan *et al. vs.* City of Danbury, Conn.)

Most of the states now have laws, more or less rigidly enforced, requiring sewage to be partially purified before being discharged into any stream, provided such treatment is ordered by the State Board of Health or similar state authority; the degree of purification to be satisfactory to such authority. Therefore, in each case the State laws on this point must be learned, and, when these require it, the state health authority consulted to learn whether treatment will be required.

From a sanitary and engineering, rather than a legal standpoint, it is a mooted question, concerning which sanitarians as well as city officials and engineers disagree, as to how much purification it is proper to require of cities and of private individuals who discharge sewage and other polluted water into streams. It is theoretically possible, but hardly practicably so, for sewage to be transformed into clear and practically harmless drinking water, but this would be very expensive in the majority of cases. At very much less expense sewage can be so freed of organic matters that there will be little or no danger of its creating a nuisance after being discharged into a stream on tidal water; the amount of purification required depending to a considerable degree upon the amount and character of the water which receives the effluent. It is also possible to almost entirely sterilize a sewage effluent after removing the grosser impurities. In the great majority of cases the effluent should be such as will, after discharge into the steam which receives it, create no nuisance. Where it is discharged into a large body of salt water where tides and currents will remove it from the neighborhood of the land, it may be that no purification whatever will be needed. (But in this case the possibility of shoaling of channels by deposits should be borne in mind.) Where there are shellfish reached by the effluent, it is generally considered that practical sterilization is desirable.

In the case of fresh-water streams, even those which may be drawn upon for water supplies lower down, there is considerable difference of opinion. Some maintain that effluents reaching these should be freed from all putrescible organic matter and also be practically sterile. Others, however, claim that cities or private companies desiring to use the water for drinking supplies can make such supplies safe only by purification, even though it receive no sewage, since other sources of pollution remain which it is almost impracticable to eliminate; and that this being the case, it would cost little if any more to effect the purification if the stream received sewage effluents more or less high in sewage bacteria. Moreover, the cost of removing the bacteria from comparatively clear river water is much less than that of removing them from sewage or even from an effluent previous to dilution in the river; and therefore the minimum cost to both communities considered together would result from the sewage filter removing the greater part of the suspended organic matter only, and the water filter removing the bacteria.

It is seen that, whichever of the above arguments be accepted, some purification must be given to sewage which is discharged into a fresh-water stream, unless this be of great volume of flow.

In most of the States, sewerage systems must be so designed before meeting the approval of the State Boards of Health (which is by law made a necessary prerequisite to construction), as to permit and provide for a treatment of the house sewage at some future time, even if they are allowed temporarily to discharge into adjacent streams. But in any event, where the discharge is into a stream or lake, the possibility of the necessity arising in the future for treatment of the sewage should be foreseen and provided for in the design of the system.

In addition to sanitation, decency and comfort demand consideration. The discharge of crude sewage or a foul effluent from a purification plant into a stream used for boating or so as to reach the bathing beach of a pleasure resort may cause the abandonment of these desirable uses of the water and a loss of patronage of the resort representing a much larger sum than the cost of complete clarification.

The financial question is a very important one. It involves the first cost of constructing a plant; the cost of keeping it in repair and of making extensions when necessary; and that of operation, including chemicals or other materials, labor and supervision. The actual annual cost of a proposed project includes cost of supervision, labor, materials, repairs, and interest and depreciation on the first cost. If several different plans should be under consideration, either of which would be satisfactory, the choice would generally lie with that which showed the lowest total of the above items.

The cost of construction of a given type might easily vary several hundred per cent in different localities. Sand for a sand filter might be found on the spot in Massachusetts, but have to be brought a long distance in a clay country. Suitable broken stone for a coarse-grain filter would vary in cost according to nearness of quarries and facilities for hauling. The amount of grading necessary to secure level beds or practicable elevation of the same will vary with topography. One type of plant might require to be located at a greater distance from the city than others. For these and other reasons, what is least expensive in one city may be most expensive in another.

The capacity of a plant should be made greater than the immediate demands; how much greater is a matter of judgment. All capacity beyond present requirements involves the payment of interest and sinking fund on unemployed capital. Moreover, improvements are constantly being made in methods of disposal, and the less the excess capacity of the plant, the sooner these may be taken advantage of. On the other hand, sewage disposal plants, if operated beyond their capacity, become nuisances and may be almost ruined; and it is generally difficult to obtain funds for enlarging a plant until several years after its completion.

ART. 66. COMPOSITION OF SEWAGE

Being composed of house-wastes and wastes from manufacturing processes carried in suspension and solution by water, sewage is found to contain all the matters contained in these, either in their original forms, or combined according to their affinities into new compounds, or partly decomposed into their elements. In either the combination or decomposition, gases may be formed, and in these and in vapors a small percentage of certain elements in the sewage may escape to form the "sewer air."

Of the various constituents of sewage, a large proportion are harmless; some, while in themselves harmless, may form compounds which are noxious, or may interfere with the purification; others—the organic matters—are offensive and dangerous to animal life while undergoing decomposition, in which state they are always found in sewage; and of the bacteria, many are harmless, but an indefinite number are dangerous to human life. Purely mineral elements and compounds are seldom found in sewage in such quantities as to be injurious if taken into the stomach.

Table No. 21 shows the weight in pounds per day of the solid and liquid excrements of a mixed population of 100,000, and also the same divided by the weight of 100 gallons (the assumed per capita water consumption), giving the parts by weight per 100,000 which the excrements would contribute to the sewage. If the consumption is not 100 gallons, multiply by 100 and divide by the consumption.

TABLE NO. 21

AMOUNT OF EXCREMENTAL ORGANIC MATTER IN SEWAGE FROM A POPULATION OF 100,000

(From Wolff & Lehmann)

	Fæces.			Urine.			Total.		
	Total.	Organic Nitrogen.	Phosphates.	Total.	Organic Nitrogen.	Phosphates.	Total.	Organic Nitrogen.	Phosphates.
Pounds per day	20,000	294	413	257,920	2311	1037	277,920	2605	1450
Parts per 100,000 parts of sewage (water consumption 100 gallons per day)	24.09	0.35	0.50	309.5	2.77	1.24	333.60	3.12	1.74

TABLE NO. 22

POUNDS OF ORGANIC MATTER PER CAPITA PER DAY

Average of Several Massachusetts Plants

Residue on Evaporation.				Ammonia.		Chlorine.	Total Nitrogen.	Bacteria, Billions per capita per day.
Loss of Ignition.		Fixed.						
Dissolved.	Suspended.	Dissolved.	Suspended.	Free.	Albuminoid.			
.0594	.0836	.1276	.0242	.0110	.0031	.0352	.0213	300

These matters will constitute most of the organic pollution found in the sewage, excepting such as may come from tanneries, breweries, slaughter-houses, and markets. The principal constituents of organic matter are carbon, oxygen, nitrogen, and hydrogen. All contain carbon, but all do not contain nitrogen. Those containing nitrogen are in general the more liable to putrefy, and are regarded as the more objectionable. For this reason the quantity of nitrogen and its compounds in sewage is that most carefully determined as an indication of the quantity of harmful organic matter present.

The pollution from manufacturing establishments may consist of almost any acids, alkalis, or organic matters. A carpet, blanket, and cloth mill on the Schuylkill used daily, a few years ago, 48,700 pounds of organic matter, including 18 different substances, 2520 pounds of 21 different acids, and 950 pounds of 6 different alkalis. Brass-works discharge considerable sulphate of copper, cyanide of potash, and oils; the chief waste from iron-works is sulphate of iron; from paper-mills come filaments of jute, cotton, and other organic matters, caustic soda, chloride of lime and sulphite; in woollen factories the washing of the wool produces large amounts of organic wastes, and there are also discharged soda alkalis, logwood, fustic, madder, copperas, potash, alum, blue vitriol, muriate of tin, and other dye-wastes; from cotton factories come sulphuric, nitric, and muriatic acids, chloride of lime, soda, potash, alum, copperas, blue vitriol, lime, pearl-ash, stannate of soda, sugar of lead, indigo, cutch, sumac, alkali, soda, and various aniline dyes; from silk factories, sericine, or silk gum, soda, and a small amount of dyestuffs. Many of the acids and alkalis from factories neutralize each other, and the principal objection to these in sewage is that they may form insoluble compounds or foul gases, or that the acidity of the sewage may interfere with the later treatment. In some instances acids discharged from brass-works and iron-mills are sufficient in quantity to kill the fish in a river, and of course to render it unfit for drinking-water. An occasional advantage experienced from acid sewage is the destruction by the acid of considerable percentages of the contained bacteria.

The water itself before pollution generally contains little organic but some mineral matter. Lime, chlorine, and iron are the minerals most commonly found in solution. Sand and clay are generally found in suspension in varying quantities. Copper, zinc, lead, and other metals are sometimes found in small quantities. Lime causes the " hardness " of water which is classified as either " permanent " or " temporary." The former is caused by calcium sulphate and other soluble salts of calcium and magnesium, not carbonates, held in solution; such water cannot be materially softened by boiling. Temporary hardness is due to carbonates of calcium and magnesium; by boiling such water the carbonic acid is expelled and the salts become insoluble.

Chlorine is found in most waters, being washed from the soil, or from the air where it has been carried by ocean vapors. It is unobjectionable in the quantities ordinarily found, but is significant in sewage for two reasons: First, if more than normal in quantity, it is an almost sure indication of sewage contamination, and if not more than normal, that there has been no sewage contamination; second, it cannot be removed from solution and hence remains constant through all filtration and other purification processes, thus serving as an index of the strength of domestic sewage, whether purified or not. The amount of chlorine in a sample of purified effluent and in the sewage from which it was derived must be practically the same.* To determine pollution from the amount of chlorine present it is necessary to know the normal amount in the district in question. This ordinarily varies with the distance from the ocean, being least in those localities which the ocean winds must travel farthest to reach; excepting, of course, those places where the ground waters are rich in salt, as in west-central New York. Fig. 64 shows the distribution of chlorine in the normal waters of New England and New York. It is seen to reach a maximum of 24.2 parts per 1,000,000 on Cape Cod.

Iron is to be found in small quantities in most waters, but this and other metallic substances have no significance in sewage except as they may affect purification.

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* For some reason not understood the chlorine in effluents from purification processes is generally a very little lower than that in the crude sewage.

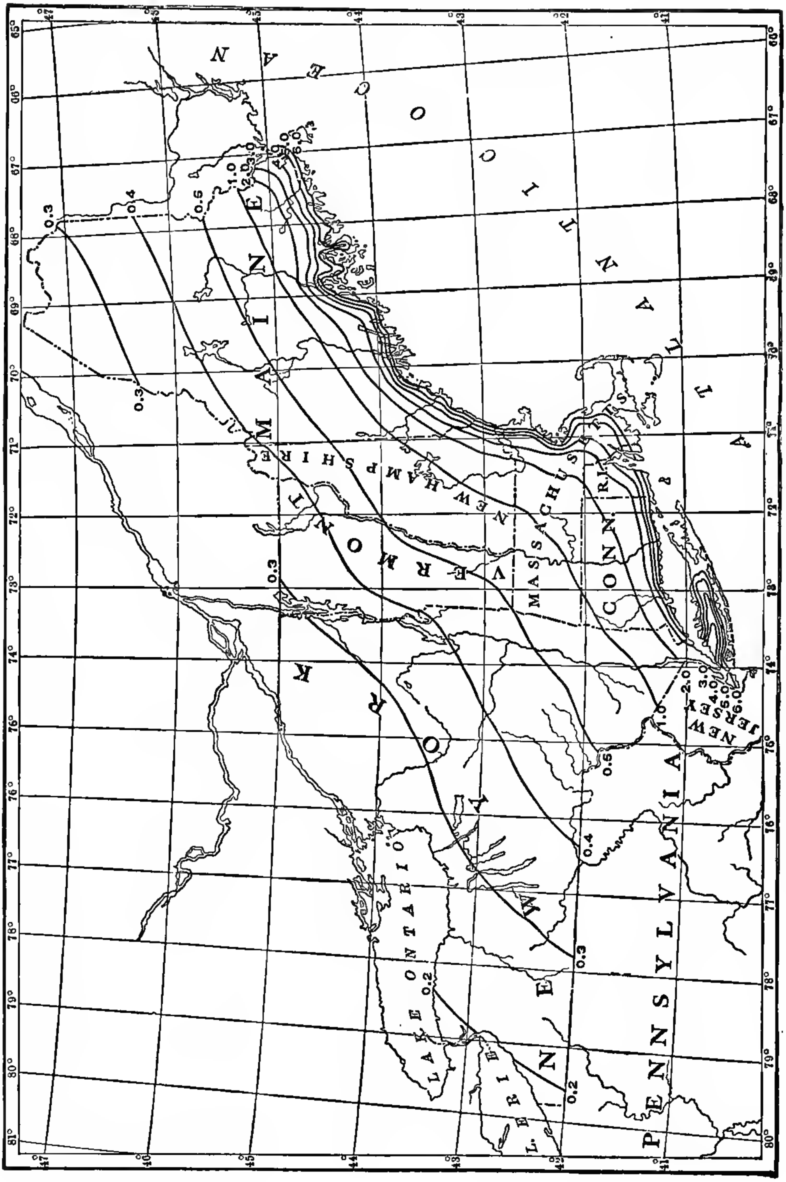

FIG. 64.—NORMAL CHLORINE CURVES (ISOCHLORS) OF NEW ENGLAND AND NEW YORK.
From map prepared by U. S. Geological Survey.

The organic and mineral matter in suspension and solution in the water before the addition of sewage matters will of course be included in that found in the resultant sewage, and it is desirable to learn what this amount is. The Naugatuck River at Union City, Conn., contained, as extremes, in September, 1897, 60.5 parts per 1,000,000 of mineral and 22.0 of organic matter, 20.0 parts being lime and 4.2 chlorine; and in April, 1896, but 16.0 of mineral and 15.5 of organic matter; these being fairly average results for New England in a thickly populated district.

The above illustrates in a general way the constitution of sewage; but to understand the methods and processes involved in the purification of sewage, it is necessary to study the chemical conditions and forms in which these matters exist in sewage, as well as those in which they generally appear in chemical analyses. Average American sewage contains about 400 to 700 parts per million of solids when the water consumption is 60 to 80 gallons per capita. Of these about 250 to 450 will be in suspension and the remainder in solution. The older the sewage and the more it has been agitated, the greater will be the proportion of solid matter in solution. Of those in suspension 100 to 150 parts are mineral and 150 to 300 are organic; of those in solution 80 to 150 are mineral, 70 to 100 are organic. Owing to causes already mentioned, as well as to the great variations in per capita water consumption in different places, any individual sewage may vary greatly from the above figures; but they serve to give a general idea of the relative proportions. The average amounts of these constituents per capita in a number of American cities is given in Table No. 22.

The above figures are from New England cities. In cities where the water consumption is much greater the sewage will be proportionately weaker. In comparatively strong sewage the amount of solid and organic matter is fully twice as great in the day flow as in the night flow.

The proportions of the various constituents are stated by some chemists in parts per hundred thousand; but the standard method at present is in parts per million, or, which is practically the same thing, in milligrams per liter. In this work, parts per million will be used unless otherwise stated.

About 40 ounces per day of human urine is excreted per capita, on an average, and 3 ounces of wet fæces (see Table No. 21). Of the urine, about 0.337 grain is common salt, 0.2 being chlorine. In the excrements occurs the great bulk of the nitrogen found in sewage, mostly as albuminous compounds. This leaves the body in the form of urea, of which the composition is $CO\begin{cases}NH_2\\NH_2\end{cases}$. It is quickly attacked by either the bacillus ureæ or micrococcus ureæ, or both. Each of these, breaking down the urea, convert it into carbonate of ammonia thus:

$$\underset{\text{Urea.}}{CO\begin{cases}NH_2\\NH_2\end{cases}}+\underset{\text{Water.}}{2(H_2O)}=\underset{\text{Carbonate of ammonia.}}{(NH_4)_2CO_3}.$$

"If the sewage is kept without undergoing purification for a day or so, it undergoes putrefaction and begins to give off foul emanations; in the course of two or three days the albuminous matters begin to split up, and the sewage, particularly when the water contains sulphates, yields sulphuretted hydrogen, which is known by its characteristic odor of rotten eggs. When this gas is formed the sewage becomes black. As the above changes take place, more and more of the solid matter enters into solution." (Barwise, "Purification of Sewage.")

Vegetable refuse occasions much of the foulness of stale sewage, largely because of the sulphur it contains. Putrefaction is preceded by the combination of part of the nitrogen and carbon with all the free oxygen and with part of that contained in the nitrates.

It is evident that the form under which the nitrogen is found will depend to a considerable degree upon the amount of decomposition which the organic matter has undergone. This decomposition is facilitated by comminution of the particles in suspension, such as occurs in pumping, and increases with time, and its character is determined by the amount of oxygen contained in the sewage water. In a short time after entering the sewers, sewage ordinarily contains very little dissolved oxygen and nitrogen in the form of nitrates; although when fresh it contains some free oxygen and generally nitrates and nitrites.

Sewage contains countless numbers of bacteria of many varieties, as many as 30,000,000 in a cubic centimeter having been estimated, of 200 or more varieties. One of the most important is the Bacillus coli communis, which originates in the animal intestine. Most of these bacteria are harmless; many are beneficial in breaking down complex organic compounds and assisting in the oxidation of the sewage; but a few are the cause of disease if taken into the human system. Among the last are the bacterium of cholera (Spirillum choleræ asiaticæ) and that of typhoid fever (Bacillus typhosus). B. coli communis and B. enteritidis sporogenes are the bacteria most easily identified as directly derived from excrement. The former is most abundant in sewage-polluted water; the latter is not so abundant, but is much more probably pathogenic, being a possible cause of acute diarrhœa. There are also present in sewage large numbers of enzymes, lifeless organic substances which exert chemical action in breaking down complicated organic molecules. Such are pepsin, pancreatin, and other digestive ferments. Their mode of action is not well understood, but they play a very important part in sewage treatment.

ART. 67. ANALYSES OF SEWAGE AND EFFLUENTS

In the majority of cases the purpose of analyzing sewage is to determine the amount and condition of the putrescible matter therein and of other substances that may affect purification processes; and the analyses of sewage effluents are for the purpose of determining the degree to which putrescible matter and bacteria have been removed and the amount of these that remain in the effluent.

If sewage be heated in a platinum dish until evaporated, a solid residue is left consisting of mineral and organic matter. If this be heated to a low red heat, the organic matter will be almost entirely burned off while the mineral will be changed little if at all. The loss in weight caused by burning will be the amount of organic matter in the quantity of sewage analyzed. The amount after evaporation is called " total solids " or " residue on evaporation "; the part removed by burning is called " loss by ignition " or " volatile " or " organic residue," and the part remaining after burning is the " fixed solids " or " mineral residue." If a sample of raw sewage be filtered through a Gooch crucible, the matter in suspension will be intercepted, and the difference between this and the total solids determined as above will be the amount of solids in solution. If the suspended solids be burned as above, thus removing the organic matter, the amount remaining will be the fixed solids in suspension, and the difference between that and the total fixed solids will be the fixed solids in the solution.*

As organic matter decays, it gives off carbonic acid, part of which remains in the solution and part escapes. Ammonia also results from the decay and is taken into solution. Other organic matter which is about ready to decay gives up ammonia if the sewage be boiled. The ammonia in solution and that set free by boiling are known as " free ammonia," which, being the product of decay, is the most characteristic ingredient of stale sewage. " Free ammonia " is not chemically free but is generally in combination with carbonic and organic acids, or even appears as chloride or sulphate of ammonia.

In addition to the nitrogen contained in the ammonia, there is a quantity of combined nitrogen in the organic matter called " organic nitrogen," a part of which can be made to pass off as ammonia by use of permanganate of potash. The ammonia thus obtained is called " albuminoid ammonia." Albuminoid ammonia is being constantly changed by decomposition into free ammonia, and hence the older the sewage is the greater the proportion of free to albuminoid ammonia. When comparing two samples of sewage by their ammonias, we must remember that free ammonia is largely the result of decomposition of that previously, but not now, existing as organic matter. A number

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* For laboratory methods of making these and the other determinations described on the following pages, see Appendix, "Testing Sewage and Effluents."

of analysts determine the organic nitrogen and not the albuminoid ammonia, but others consider the latter as giving the more valuable information of the two. Organic nitrogen determination gives a fair approximation of the total nitrogenous matter in the sewage, but gives no indication as to how much of this is readily putrefied; while albuminoid ammonia does give an idea of the amount of nitrogen easily putrefied.

In oxidation, upon which sewage purification largely depends, nitric acid is formed from the nitrogen of the ammonia and of the organic matter and the oxygen of the air. This strong acid immediately combines with the potash, soda, lime, or other base in the sewage, forming nitrates of potash, soda, etc., which are entirely harmless in the quantities found in the strongest sewage effluent. The nitrogen contained in these salts is called " nitrogen as nitrates " or " as nitrites," or simply " nitrates " and " nitrites "; the nitrites being nitrous acid salts in which the oxidation is carried less far than in the nitrates owing to lack of oxygen. (Nitrites are also formed by the combination of nitrates and unoxidized matter, the former sharing its oxygen with the latter.) This is probably the most important chemical determination made of sewage. The organic matter may vary from 30 to 1000 parts of sewage. It would be unusual to find as much as 0.1 part of nitrogen as nitrates or nitrites in sewage; but in the effluent or purified sewage as much as 50 or 60 parts may be found. Some analysts determine the " total nitrogen," generally by the Kjeldahl process. This is a most important test, but one difficult to make.

If a portion of sewage, made slightly acid with sulphuric acid (if necessary), is digested with a solution of permanganate of potash, the carbon in the organic matter will be oxidized. This test gives an approximate idea of the amount of carbonaceous organic matter present, this being expressed in terms of " oxygen consumed," " absorbed " or " required." While this is not the total amount of oxygen necessary to oxidize completely all of the organic matter, the information is valuable in determining the degree of purification effected.

Where partial purification preliminary to dilution of the effluent is the aim of a treatment plant, as is the case with the majority of such plants, a determination of the putrescibility of the effluent is necessary. The test most commonly used for making this determination is the methylene blue test, which consists in adding a solution of methylene blue dye to a sample of the sewage effluent in a glass-stoppered bottle and incubating this at 20° C. The blue color remains practically unchanged until the available oxygen contained in the effluent (both free and in the nitrates and nitrites) has been used up and its condition becomes putrefactive, when decolorization begins. The time required for this decolorization is the measure of the degree of putrescibility. Retention of color for four days at 20° C. indicates good stability.

It is desirable to know what amount of the contents of sewage can be removed by sedimentation, or the " settling " suspended matter. This is commonly determined by placing one liter of sewage in a glass vessel of conical shape with the apex of the cone at the bottom, the glass being graduated in cubic centimeters. The amount of sediment, read by the graduations, that collects in a given number of hours (usually two) indicates the amount that will settle out in that time. Turbidity of effluents is sometimes determined, the method employed ordinarily being the turbidimeter employed in water analyses. A figure for sedimentation may be determined by taking the difference between the turbidity reading of a settled sample and the reading of the same sample after shaking.

A form of matter called colloids is found in water that seems to be neither fully in solution nor fully in suspension. The term is not very exactly defined and in connection with sewage is commonly used to mean suspended matters in a state of very fine division which can not be removed practically by sedimentation. They are included in but do not necessarily constitute all of the non-settleable solids as determined by the above method.

The fat content of sewage is important as to its effect on the working of treatment processes; and this, or more specifically the ether-soluble matter, in crude sewage is sometimes determined.

TABLE NO. 23

ANALYSES OF SEWAGE OF SEVERAL CITIES

	Nitrogen as					Oxygen Consumed.	Chlorine.	Suspended Solids			Solids in Solution.			Gals. of Sewage per Capita.	Population (1910).
	Free Ammonia.	Albuminoid Ammonia.	Organic Nitrogen.	Nitrites.	Nitrates.			Total.	Lost on Ignition.	Fixed.	Total.	Lost on Ignition.	Fixed.		
Concord, Mass.†	21.4	5.6	..	...	..	43.2	38.8	..	..	..	..	..	..	102	6,421
Concord, Mass.§	2.5	0.12	..	0.02	5.86	1.9	34.8								
Chicago	8.8	...	7.6	0.11	0.35	38.0	40.0	141	81	60	..	..	..	289	2,185,283
Boston	13.9	...	9.1	0.0	0.2	56.0	2300.0	135	91	44	..	..	..	200	670,585
Milwaukee, Wis.	12.0	...	9.0	...	..	100.0	59.0	131	78	52	457	248	209	197	375,857
Columbus, O.	11.0	...	9.0	0.09	0.20	51.0	65.0	209	79	130	787	106	681	121	181,548
Gloversville, N. Y.	12.0	...	23.0	0.38	0.87	95.0	158.0	406	229	176	..	..	..	154	20,542
Stockbridge, Mass.	12.4	3.7	7.1	...	..	26.8	18.3	99	84	15	199	93	106	94	1,933
Meriden, Conn.	8.51	4.50	..	0.12	0.49	...	45.8	..	..	..	..	..	..	..	27,265
Meriden, Conn.‡	0.02	0.07	..	0.005	5.15	...	31.7								
Large American cities *	10.6	7.0	8.0	0.11	0.44	59.0	48.0	303	211	92	1052	242	811		
American manufacturing cities *	26.5	11.9	24.1	0.26	1.19	133	109	450	365	85	608	270	338		
Small American manufacturing cities *	38.9	11.3	23.8	...	..	107	83	242	203	39	488	245	243		
American residential and rural communities *	27.2	7.8	18.0	...	..	71	47	342	260	82	261	133	128		
Passaic river	0.47	1.02	..	0.10	0.00	...	16.33	121	42	79					

* From Metcalf & Eddy, "American Sewerage Practice."

† Sewage applied to sand filter.

‡ Effluent from filtration grounds. Probably 30 per cent of this is ground water.

§ Filter effluent.

Table No. 23 gives the analyses of the sewage of several cities. As an illustration of the chemical effect of purification by sand filtration, the Concord sewage is seen to lose by filtration 97 per cent of the carbonaceous matter ("oxygen consumed"). The free and albuminoid ammonia are reduced 89 per cent and 98 per cent, respectively, most of that lost appearing as nitrates in the effluent. The chlorine is changed but little, as it should be.

In the Meriden sewage is seen the effect of dilution in the decreased chlorine. If the ground water contained 0.2 part of chlorine (the normal chlorine at Meriden), and the sewage 45.8, there would appear to be in the effluent analyzed about 45 per cent as much ground-water as true sewage effluent. The true amount of purification would therefore probably be shown if each quantitative determination for the effluent, diminished by 30 per cent of the amount of the same substance found in normal ground water, be multiplied by about 1.45.

The result of a bacterial analysis is stated as a certain number of bacteria per cubic centimeter. This number frequently runs up into the millions, of which it is evident that no direct count could have been made. To obtain practicable conditions, a small amount of sewage is diluted with 1000 to 100,000 times its volume of sterile water, and the number of bacteria found in this mixture per cubic centimeter is multiplied by the proportion of dilution. How many of the bacteria are pathogenic it is impossible to say with our present knowledge of bacteriology and methods of analyzing; for the finding of the bacterium of typhoid fever or cholera in sewage is an unusual occurrence, so few are they in comparison with the total number present. If there was one such bacterium in each cubic centimeter of a given sewage, and this was diluted 10,000 times for analysis, the chance of this bacterium being present in the analyzed sample would be but one in ten thousand; but if this sewage be discharged into 50 times its volume of water, each glassful of this would be likely to contain five or six typhoid bacilli. It is therefore apparent that the absence of pathogenic bacteria from an analyzed sample by no means indicates that they are not present in the sewage in great numbers. This is of little importance in an analysis of sewage, since it should be assumed that the excreta of a typhoid patient containing millions of these may at any time enter the sewer. It is desirable, however, to learn to what extent such bacteria are removed by purification or otherwise, and on this point there is still great uncertainty. But it is in general assumed that any reduction in the total number of bacteria is at least no greater than that in the number of pathogenic ones in proportion to the number originally present. It is now thought that typhoid bacilli increase in number in sewage but slowly, if at all; consequently that they disappear even more rapidly than a general analysis would indicate.

It is desirable to distinguish between aerobic, anaerobic, and facultative bacteria, and between the liquefying and nonliquefying; largely because of the effect of these in the decomposition and purification of sewage. Also to ascertain the presence or absence of B. coli communis, especially in the case of an effluent from a purification plant where a high percentage of bacterial removal is attempted or desirable.

ART. 68. POLLUTION OF STREAMS AND TIDAL WATERS

The simplest solution of the problem, where it is permissible, and the one most frequently employed in this country, is to discharge the sewage directly into some flowing stream or large body of fresh water, the ocean or one of its estuaries. This is called "disposal by dilution." So far as cheapness is concerned this stands easily first among the methods of disposal, since it requires the purchase of no land and needs no care to regulate its working, excepting where the discharge is into tidal waters, when some expense is sometimes gone to, both of first cost and of maintenance, to regulate the time of discharge. It is usually efficient also in removing the sewage beyond the limits of the area contributing to its volume. Looked at in a less selfish way, and considering the good of the State and country as well as of the locality sewered, other and adverse arguments present themselves in some cases. Although the sewage is removed to a distance from the contributing territory by tides or currents, it may be deposited in proximity to other communities, on banks or shores or retained by dams, thus creating a nuisance; or may render unfit for drinking, household, or manufacturing purposes water which would otherwise be so used.

The effects of sewage pollution of a stream in creating a nuisance are well illustrated by the Passaic river.

" The great extent of the pollution of the lower Passaic may be illustrated in several ways. It is apparent to the eye in the condition of the river during the summer; in the foulness of the shores where sewage-laden mud, when exposed to the sun, gives out foul odors; and it is demonstrated by every practical test. The cities of Newark and Jersey City have been compelled to seek water-supplies elsewhere at large expense, and the immediate decrease in zymotic disease in these places which has followed the change has shown how necessary it is. Fish life, excepting of a few hardy kinds, has disappeared from the river, and fifteen years ago shad, which formerly frequented the stream, abandoned it. The manufacturers have reported that the acid of the sewage-laden water affected boilers so as to make its use inadvisable. The use of the river for pleasure purposes, which at one time made it a delight to thousands, has become comparatively infrequent, and the attractiveness of the river may be said to have disappeared." (Report of the Passaic Valley Sewerage Commission, 1897.) While this is an extreme case, there are many others in this country almost as bad; and as the country becomes more thickly populated other streams are becoming similarly polluted.

Deposits. In addition to pollution, the formation of deposits may become a serious matter. In the case of storm waters, more or less sand and heavy silt will be deposited at or near the outlet of each sewer and it may even become necessary to remove such deposits by dredging at intervals; but much can be done to avoid this by discharging into rapid currents. In the case of house sewage, a large part of the suspended matter, especially the soaps and greasy matter, float upon the surface, but a considerable part of the remainder settles to the lower strata and is deposited at a greater or less distance from the outlet. Havana harbor is an instance of deposit of this kind, there being several feet of such deposit over a considerable portion of its bottom. Investigations which have been made recently have shown New York harbor to contain in some places as much as 10 or 15 feet of similar sewage deposits. Mr. John R. Freeman, in reporting upon the Charles River dam, cited experiments made during his investigation to show that sewage matter settles much more quickly in salt water than in fresh, and consequently that deposits are more apt to occur near the outlet when sewage is discharged into the ocean or tidal waters than when into rivers.

The amount of deposits depends to a considerable degree upon the amount and rapidity of dispersion of the sewage in the water, and it therefore seems desirable, especially where discharge is into salt water, to locate the outlet near the line of maximum motion of tide or current, and to employ several outlets distributed over a considerable area when the amount of sewage is great.

Typhoid Fever. The mortality due to sewage-polluted water may occur through almost any enteric disease, but the greatest is probably from typhoid fever. Illustrations of the mortality from this disease due to sewage in drinking water are given by the following table, which shows the typhoid death rates, per 100,000 population, for the five years immediately preceding and the five years immediately succeeding the introduction of filtration of the water supply:

City.	Years Prior to Beginning Filtration.					Years Subsequent to Beginning Filtration.				
	5	4	3	2	1	1	2	3	4	5
Albany, N. Y.	170	102	88	100	87	21	32	20	18	19
Paterson, N. J.	33	46	23	23	34	7	14	4	11	10
Pittsburgh, Pa.	136	130	108	141	135	13	12	10	6	10
Lawrence, Mass.	127	134	119	105	80	19	16	14	34	18

(See also Art. 11 of the author's work on "Water-supply Engineering.")

Another illustration was the epidemic of typhoid fever which, in the winter of 1898–99, visited two or three cities on the Passaic river which, for a few days when the supply of pure water ran low, pumped from this river into their mains.

In this connection reference should be made to the danger of spreading certain diseases through the agency of oysters, and that of the destruction of fish by disposing of sewage by dilution. There seems to be little doubt that typhoid and probably other fevers have been so conveyed by oysters, as at Wesleyan University, Middletown, Conn., in 1894, and again in 1906 under almost exactly identical circumstances. These were exposed, however, to contact for hours at a time, at low tide, with sewage but little diluted. In view of this and of similar cases both in this country and abroad, Baltimore decided to take every precaution in the way of sterilizing its sewage in order to protect the important oyster industry in its harbor, and New York prohibits the sale of oysters grown or fattened in sewage-polluted water.

It is probable that germs of enteric diseases are conveyed on the outside rather than the inside of the body of the oyster, and that there is little danger in eating sewage-fed fish or cooked shellfish, since the organic matter is digested by them and converted into healthy tissue, and such bacteria as enter the digestive organs are either destroyed or leave at once in the excrement. A moderate amount of fresh organic matter attracts most kinds of fish, which live upon it or upon the minute animal and vegetable life of which it forms the food; but the gases produced by putrefactive decomposition and the reduction thereby of oxygen in the water makes impossible therein the existence of the higher forms of animal life.

Art. 69. Aims of Treatment

The aim of any treatment of sewage may be either to prevent the creation of a nuisance, or to produce an effluent which, if discharged into a river, will not render it unsuitable for city water supplies. The former case may exist where the sewage is discharged into a stream, a lake or salt water; the latter where into potable fresh water only. A third case is found in many coast cities where shellfish are raised or fattened for the market; which shellfish might serve as carriers of disease germs.

The purification must be considered from both the chemical and the bacteriological sides. For either of these a standard of purity for either the first or the second aim is most difficult to decide upon; and although a number of standards have been advanced and some are still used in other countries, it does not seem probable that a general chemical standard will ever be adopted. It is possible, however, that a bacteriological one may be reached, applicable to cases where potability or oyster contamination is an important consideration. The Royal Commission of England in 1909 stated, as a chemical standard, that an effluent would generally be satisfactory for discharge into a stream, if it complied with the following conditions:

> (1) That it should not contain more than three parts per 100,000 of suspended matter; and (2) that after being filtered through filter paper it should not absorb more than (*a*) 0.5 part by weight per 100,000 of dissolved or atmospheric oxygen in twenty-four hours; (*b*) 1.0 part by weight per 100,000 of dissolved or atmospheric oxygen in forty-eight hours; or (*c*) 1.5 parts by weight per 100,000 of dissolved or atmospheric oxygen in five days.

Where it is desired only to prevent a nuisance, the bacteriological condition need hardly be considered. In such a case the purification need be carried to such a point only that a large percentage of all matters in suspension are removed or so modified that the danger of future putrefaction is averted.

The maintaining of a river water potable, however, calls for a much higher standard. To be absolutely safe it would seem, from our present knowledge, that all bacteria should be removed, since we are not certain that some of those escaping are not pathogenic. The removal of 99.98 per cent of the bacteria, however, probably reduces the chance of infection by at least that amount; and if the effluent be then diluted with ten times its volume of pure water, the chance of infection by drinking such dilution would be about $\frac{1}{50,000}$ of that by drinking the sewage. Where this is the aim, the standard for the number of bacteria permissible in the effluent should be—the least which the state of the art renders possible.

It is now possible to almost completely sterilize sewage, and thus to deliver an effluent of a very high bacterial standard. Except for reasons to be referred to later, such disinfection (incomplete sterilization) should follow rather than precede any biological treatment, since a considerable percentage of the contained bacteria are necessary for the liquefying and oxidation of the organic matter in the sewage. Even complete sterilization will not prevent such liquefying and oxidation, but will delay it and will probably result in later putrefaction if other treatment has not effected sufficient removal of the organic matter. Consequently, sterilizing to avoid decomposition should not be attempted, since decomposition must precede any purification, and in most cases the sooner it occurs the better. Disinfection to remove pathogenic bacteria is especially appropriate where the effluent is discharged near shellfish beds, or under other conditions where bacteriological purification is more important than organic.

The question of the degree of purification demanded in any specific case is one more of State law or the policy of State Health Boards than of engineering; but it deserves some mention at this point. The question is being debated whether it is desirable to compel cities to so purify their sewage that those below can use the streams receiving the same for drinking water without further treatment; or whether the mere prevention of a nuisance by sewage effluents should be the extent of requirement. The former idea is based largely on the hypothesis that morally the city has no right to pollute a stream and thus put another city to the expense of purifying it for public use. On the other hand, it is claimed that the occasional lapses in efficiency of the sewage purification plants which are probable, and especially the existence of other sources of pollution which are well-nigh unpreventable, make it necessary for a city to purify any river water used as a public supply; and this being the case, it deducts very little, if anything, from the expense of water purification to secure high bacterial purity in sewage effluents. Consequently there seems to be little question that the combined expense of sewage and water purification, to all cities located upon a river into which all discharge sewage and from which all obtain their water supplies, would be less with partial sewage purification than if this were made complete; and at this writing (1918) the general tendency is towards the prevention of nuisance only; but on the other hand, persistent and intelligent efforts are being made to actually obtain a general enforcement of such treatment of all sewage. This means that the number of sewage purification plants is being greatly increased, but that the efficiency demanded has been placed much lower than it was some years ago.

The difficulty of setting a general standard to be met by all sewage-disposal plants lies not only in the various requirements to be met, but also in the varying characteristics of both the sewage and the stream which receives it. Where the stream is small, a much higher degree of purification is necessary to prevent a nuisance than where it is large. Moreover, the amount of free oxygen in the stream is an important consideration. The scientific method would be to ascertain the amount of free oxygen in the diluting stream passing the effluent outlet per second, and to permit no more unoxidized organic matter to reach such stream per second than can be fully oxidized by $\frac{1}{3}$ or $\frac{1}{2}$ of this amount of oxygen (since the intermingling of sewage and stream probably will not be complete, and a part of the free oxygen must be left in the water). So far as all organic matter except bacteria is concerned, the above standard would also insure a safe potable water if time and opportunity for complete intermingling and oxidation be afforded.

In examining a stream for sewage pollution, it should be remembered that the presence of chlorine in excess of the local normal is generally an indication of sewage pollution; nitrates indicate the amount of organic matter rendered innocuous; and albuminoid ammonia is taken as an index of the polluting organic matters still present. The presence of numerous bacteria is not necessarily indicative of sewage pollution, but B. coli are generally assumed to be (although small numbers may have been voided by animals other than man). The character of an effluent should not be judged by its appearance alone, by its chemical or bacteriological analyses, but by the three combined; since it may be clear, but contain many pathogenic bacteria or dissolved matter which may be precipitated or putrefy and create a nuisance; also a turbid effluent may contain only mineral matters or such organic ones as are harmless and will undergo no change but oxidation.

Art. 70. Disposal by Dilution

There are undoubtedly conditions under which disposal by dilution is much less objectionable than any other available method. And in considering this, it must be borne in mind that the liquid must ultimately be discharged into some stream or body of water; the question being therefore to what extent, if at all, it must be purified or modified before being so discharged. Under what conditions and to what extent a water receiving sewage will purify itself is a question which has received less attention than have methods of treating sewage, although it is much the most common method of disposal. The self-purification may be considered as to the organic matter and as to the bacteria. (Sand and other mineral suspended solids cause shoaling near the mouth of a sewer, unless this be in a swift current. But the treatment of this problem has already been considered; catch-basins or occasional dredging being the most common solutions.)

Considering first the organic matter, the agents of purification are sedimentation and dilution, accompanied and followed by liquefaction and oxidation; and the agency of animal and vegetable life. Any considerable amount of sedimentation is objectionable, especially if concentrated in a limited area; because the matter deposited undergoes putrefaction, and the products of this are disagreeable and render the water above unsuitable for a public supply if they do not even create a nuisance. If the deposit is thin, however, the products of putrefaction, both liquid and gaseous, may be so small in quantity that they are rapidly oxidized by the water above. This will depend upon the relative amounts of putrefaction products and of oxygen available per day or hour in the water above.

By dilution, or intermingling of the sewage with large quantities of water, the ratio of available oxygen in the water to organic matter may be made sufficient to cause the rapid oxidation of all the nitrogenous matter before sedimentation occurs. Such dilution prevents putrefaction; but total reduction to nitrates by oxidation is in general slower than by combined anaerobic and aerobic action. It is the opinion of many experts that still water purifies itself more rapidly than flowing, because of the liquefaction taking place in sediment, which is deposited more abundantly in still water. The chief advantage possessed by running water is that the constant delivery of fresh water insures a constant mixture and completeness of diffusion not secured by discharge at one point in quiet water. But, as Mr. X. H. Goodnough has said in a report to the Charles River Dam Committee: " The sewage discharged into a pond or stream may be objectionable or not, in the neighborhood of the outlet, depending upon the location of the outlet with reference to the stream or pond, and the conditions in the neighborhood. Observations upon the discharge of sewage into water at many places show that there is much advantage in discharging it at several outlets, since the sewage then mingles much more rapidly with the water, and is subjected more quickly to those actions which tend to remove its effect." " Experience at places at which sewage is discharged into a pond or slowly moving stream indicates that sewage discharged into such bodies of water has a less noticeable effect upon their waters than an equal quantity of sewage has upon a rapidly moving stream of equivalent volume."

The above does not refer to stagnant water, since there must be fresh quantities of oxygen continually available in the water of dilution. This may be supplied in a large body of water by absorption of oxygen from the air into the surface layers of water, combined with a continual vertical circulation of water due to differences in temperature or to winds. But these causes are less reliable than a constant but slow translation, as by stream flow or tidal currents. Whatever the condition, the organic matter must come in contact with sufficient oxygen to permit mineralization before putrefaction products reach the surface of the stream, if a nuisance is to be avoided.

No matter how large the volume of diluting water, unless the current at the immediate outlet be sufficiently swift to effect rapid and thorough diffusion and mixing, the discharge of large volumes of sewage at one point will cause a local nuisance which might be entirely avoided by providing several outlets some distance apart. A large volume of sewage discharged from a single outlet into a stream or lake can frequently be traced by its color for a long distance, only slowly mixing at its edges with the purer water.

While rapid diffusion and intimate intermingling are necessary, the degree of rapidity depends partly upon the putrescibility of the sewage; a corollary to which is that the amount of sewage which a given volume of flow will receive without nuisance is similarly dependent. Certain processes of sewage treatment produce, as their chief effect, reduced or delayed putrescibility; the most important being the sprinkling or trickling filter.

From what has been said, it is apparent that the amount of flow of a diluting stream required to inoffensively dispose of a given volume of sewage depends upon the strength and putrescibility of the sewage, the available oxygen in the water, conditions favoring sedimentation or rapid intermingling, diversity of outlets and other conditions. The limits are placed by most authorities at between 1500 gallons and 4000 gallons of diluting water per day per capita contributing sewage. (The proportion is sometimes stated in terms of cubic feet or gallons of sewage, but since the amount of impurity is not increased by greater per capita consumption or waste of water, the former method seems preferable. Investigations now being made by the U. S. Public Health Service promise to develop a more scientific method of estimating required dilution. See page 332.) This means that this amount of water must not only be flowing past the sewer outlet, but must be mixed with the sewage. It is quite possible to have a local nuisance created, in the form of nauseous gases and floating matter, by failure to effect rapid mixing, but to have a rapid reduction to inoffensive and harmless conditions after the mixing has taken place. This reduction by oxidation is a function of time rather than of distance traveled by the stream, and this furnishes an additional advantage for discharge into slowly moving streams, in that the effect of the unoxidized sewage does not extend so far. Two to three hours after thorough intermingling are frequently sufficient for the reduction of much of the nitrogenous matter into nitrates.

It should be remembered that the water of dilution has been considered in the above discussion to be unpolluted; and that the same water, swinging back and forth with the tide past a sewer outlet, will soon become grossly polluted. The actual dilution will be closely indicated by multiplying the actual cross-sectional area of the channel by the distance separating the positions occupied by a given float at two successive ebb-tides, as compared with the sewage discharged in the same time. There will, however, be a somewhat greater reduction of the sewage than is indicated by such a calculation, since the water will continually absorb fresh oxygen from the air above and sedimentation will continue to remove sewage matter, and more complete intermingling will assist in oxidation and diminish the possible nuisance by mere physical dilution. Thus the same volume of water, moving back and forth with the tide and receiving no fresh pollution, will continually improve in character.

Sedimentation is most active when clay, sand or other heavy matter is carried in the sewage; this, in sinking, carrying with it other finer and lighter matter, including bacteria. A rough bottom, shallow water and high velocity, each and especially all combined, interfere with sedimentation, but assist in intermingling. It is found that sedimentation is much more rapid in salt water than in fresh; consequently more attention should be paid to the location of outlets in the former, to insure their discharging into rapid currents or in small quantities through numerous outlets. Mr. H. W. Clark, Chemist to the Massachusetts State Board of Health, found that " temperatures and other conditions being equal, salt water apparently holds less oxygen in solution than fresh water. This being so, it is evident that, volume for volume, fresh water can receive the greater amount of pollution without the exhaustion of its oxygen, if bacterial life is of equal vigor in each case." Also the odors given off by putrefying sewage in salt water are greater than when in fresh.

Investigations of New York Harbor made by the Metropolitan Sewerage Commission showed that at all points at all distant from sewer outlets most of the sewage was either floating in the top 6 inches or had settled to the bottom; which indicates that surface area is more important than depth in salt-water dilution. From experiments conducted by the Metropolitan Sewerage Commission in 1896 in Boston Harbor, where sewage is stored and discharged on the ebb-tide and in addition about the same amount is discharged continuously, it was found that the arca covered by a reservoir-discharge in three-quarters of an hour of 22,000,000 gallons is approximately 750 acres; but when but 11,000,000 gallons is discharged at once, this area is not more than 250 acres. In calm weather the sewage is offensively visible over two-thirds of this area, but the odors are confined to a relatively small portion. By far the greatest amount of sewage is found in the upper 2 or 3 inches of the polluted area, and this largely disappears in two or more hours after the discharge, depending chiefly upon the force of the waves. A thin film of grease some times covers large areas, but is not accompanied by enough sewage to be detected. Within the polluted area, sewage cannot be detected at a greater depth than 5 feet at the outlet and 2 feet near the edges of the area. When 35,000,000 to 40,000,000 gallons daily was continuously discharged, the dilution was such that, fifteen minutes after leaving the outlet, sewage constituted but 20 per cent of the surface water; thirty minutes after, 15 per cent; forty-five minutes after, 5 per cent; and sixty minutes from the outlet but 4 per cent of the surface-water was sewage. The discoloration was evident for about 1$\frac{1}{8}$ miles, and covered about 350 acres during ebb-tide and 300 acres during flood-tide. The observations indicate that, the greater the quantity of sewage that is discharged the greater is the area covered, the area increasing in more than direct proportion to the sewage discharged. This is additional reason for discharging at a number of outlets.

The two outlets in Boston offer an illustration of the comparative merits of continuous and ebb-tide discharge. "The great advantage of discharging sewage continuously and in comparatively small quantities into a large volume of tide water, as compared with discharging it in large quantities from reservoirs in a limited time, is well illustrated by a comparison of the conditions at the present outlets at Moon Island and at Deer Island. At Moon Island (discharge during two hours of ebb-tide) a large area is covered densely with sewage during a period of several hours at each tide, while at Deer Island (continuous discharge) the sewage flows in different directions at different parts of the day, covers a much smaller area and becomes more readily broken up and mingled with the sea water." (Report of Mass. State Board of Health on Boston Harbor.)

In the case of discharge into large lakes, there are no tides to assist in diffusion, and currents and winds are the chief agents. Sedimentation is less active than in salt water, and sewage pollution has often been traced for 5 to 10 miles from an outlet. As in the case of salt water, the distance reached by unoxidized sewage seems to increase more rapidly than the amount discharged. In general the same principles hold; that numerous outlets at some distance from shore are desirable to prevent a nuisance.

Organic matter in water forms the food of filth infusoria, hydra, rotifera, entomostracan crustacea, fresh-water shrimp, and the larvæ of a number of water insects. Entomostraca seem to be the most efficient in the purification of streams, and thrive on human excrement. A sewage-polluted river may contain 25 to 50 or more per gallon; but when the pollution becomes intense they seem to disappear, probably because of lack of oxygen, but their place is taken by larvæ. Diatoms, desmids, confervoid algæ and other vegetable organisms, together with bacteria, act largely upon the dissolved impurities; although the last-named seem to attack organic matter also. These all serve as food for fish; and fish, in turn, for man; and sewage matter disposed of by dilution is therefore not wasted, although it does not serve as fertilizer for plant life.

Seaweed plays an important part in the purification of tidal water. The Royal Commission (England) found that the green seaweeds assimilate nitrogenous compounds such as ammonia and nitrates, and also evolve large quantities of oxygen. They are thus of great value in the purifying of sewage-laden waters. When thrown upon the shore by storms they give off, in decomposing, quantities of sulphuretted hydrogen, which can be avoided by gathering up, drying and burning them.

Certain fish eat organic matters in sewage when this is discharged fresh into running water, which water is not therefore deprived of oxygen at the sewer mouth. But as intermingling takes place and oxygen is taken up by the sewage, conditions become unfavorable to fish life; and few fish can live in highly polluted waters. This is generally because of lack of oxygen; but some trade wastes contain acids and others gelatinous or colloidal matters which collect around the gills and prevent breathing.

The U. S. Public Health Service in 1914 began exhaustive investigations into the pollution and self-purification of the Ohio river, and is still working upon it. Its conclusions up to September, 1915, were stated by Prof. Earle B. Phelps, of the Hygienic Laboratory of the Service, in a paper before the American Society of Municipal Improvements. In substance these were: That reaëration of a polluted water plays a large part in self-purification. Average American sewage (assumed at 100 gallons per capita per day) has a biological oxygen demand of from 200 to 400 parts per million. Assuming a water at 68° F. and oxygen-saturated, and that 33 per cent of the oxygen is to be left in the water (an extreme minimum if nuisance is to be prevented), the 67 per cent of oxygen would be exhausted by the sewage if the dilution be 7.56 cubic feet per second per 1000 population (equivalent to about 5000 gals. per day per capita). If less dilution suffices, it must be because of continuous absorption of oxygen from the air by the sewage-laden water as rapidly as the sewage depletes it. Reaëration increases as depth of water decreases and as velocity of flow and degree of turbulence increase. Efforts are being made to determine in definite terms the effect of these and other conditions upon rate of reaëration.

CHAPTER XV

REMOVING SUSPENDED MATTER

ART. 71. GENERAL PRINCIPLES

THE methods of treating sewage may, in conformity with the ideas previously stated, be classified as those for effecting physical removal of suspended matter, chemical change in organic matter, physical removal of bacteria, destruction of bacteria by chemicals, and the biological destruction of both organic and bacterial matter.

Physical removal of suspended matter is effected by straining out the coarser matters by screens, by sedimentation, by surface adhesion, and by precipitating by adding a coagulant. Some chemical change generally accompanies coagulation; but such change is not the chief aim of any process which has been adopted in practice; although some have been suggested, such as oxidation of organic matter by permanganates. There is a change which might perhaps be called structural rather than chemical, and which has been termed " modification " of organic matter, which renders this less subject to putrefaction, although little chemical change can be detected except by the most delicate tests. The change may make it possible to discharge the matter into a stream without creating a nuisance (other than such as would be created by an equal amount of surface soil from a field), where otherwise a nuisance would be inevitable.

More or less physical removal of bacteria is effected by any removal of suspended matter, since the bacteria exist largely in and on such matter. Filters also remove bacteria directly by surface adhesion, and partly by straining when covered with a dense " schmutzdecke." Sterilizing agents destroy the life of bacteria; and heat might theoretically be used for this purpose, but no method has been devised for making this commercially practicable. Bacteria removed from their habitat or deprived of sustenance will in time die; although some spores can retain the germ of life indefinitely under adverse conditions. However, disease germs do not assume the spore condition.

In all lifeless organic matter there exist countless bacteria whose function it is to break down the organic structure and resolve the matter into simpler forms. One class changes the nitrogenous matter into readily oxidizable forms, and the resulting mineral compounds are the final stage of thorough purification; the next stage of which, in nature's cycle, would be their absorption by plant life as food. " Biological disposal " methods are efforts to intensify this action as to both time and space. Such destruction of objectionable bacteria as is effected by biological action is probably due largely to the creation of adverse conditions.

There is probably no method of sewage treatment in use to-day which does not combine two or more of the above processes. But each is best adapted to most economically or effectively maintain one of them, the others being in a measure incidental, or carried on uneconomically. The effort should be to determine just what method or combination of methods would most economically produce the desired results, consideration being had of local conditions and possibilities and the character of the sewage.

In studying the subject, thought must be given to the *ultimate* disposal of *all* the objectionable matter. Every method (except mere disinfection) results in an accumulation in the plant of more or less of the suspended matter, which is of varying degrees of offensiveness depending upon the process; and this must be in some way disposed of. Moreover, the oxidized organic matter (nitrates and nitrites) are rich plant food, and although they are harmless they may lead to an undesirable growth of vegetable matter in the water which receives them.

Certain methods and apparatus are best adapted to the coarse work of removal of gross suspended matters; others to the modification of organic matters; others to biological liquefaction, still others to biological oxidation. The last are uneconomical contrivances for effecting the purposes of the first; and, theoretically at least, the greatest efficiency in the plant as a whole is obtained by performing the rough work by some rapid clarification process, and the finishing purification (when necessary) by the more sensitive aerobic filter. But the available area and materials, character of sewage, fall available, etc., may outweigh these purely theoretical conditions. Moreover, the combining of the two general functions in one appliance, although one of them may be effected uneconomically, may produce an economy of combined action greater than would be possible by two appliances or operations, because of the complication of operations thus introduced.

The general structures and appliances for treating sewage consist of strainers for removing coarse suspended matters; tanks for sedimentation; septic tanks for developing septic action in sediment; the treatment of sewage with coagulants to hasten and increase precipitation; " hydrolytic " and Imhoff tanks for utilizing surface adhesion in clarifying sewage and for securing more advantageous septic action; filters of coarse material—contact filters—for removing suspended matter by surface adhesion and incidentally by straining, together with bacterial action upon the organic matter so removed; other coarse-grain filters in which suspended organic matter removed by surface adhesion is so modified as to be less putrescible—sprinkling or trickling filters; fine-grain filters in which straining and surface adhesion remove a large part of the suspended organic matter and also bacteria, and effect a large amount of purification by oxidation; the irrigation of cultivated land with sewage; treatment with disinfectants to kill off most of the bacteria; together with some other contrivances and processes advocated for various purposes but not in common use.

ART. 72. STRAINING

All processes of purification involve the removal from sewage of suspended matter. Screens, coarse and fine, are used for removing all grades of such matter, from sticks, rags, etc., to that passing a $\frac{1}{20}$ of an inch opening. Coke and other coarse-grain filters are sometimes used for the same purpose. Sedimentation in tanks may remove a large part of all but colloidal matters, and more or less of these, the use of coagulants increasing this amount. By introducing suitable surfaces, part of the colloidal matters is removed by " surface adhesion " to these, the matter so collecting falling off from time to time in large flakes. Tanks have been built containing large numbers of horizontal surfaces, placed a few inches apart vertically, on which suspended matters collect. Other tanks are filled with stones or sand which remove suspended matter partly by straining and partly by surface adhesion. In each kind of tank other processes are undergone by the sewage, which will be discussed under the head of " tank treatment."

When the sewage is to be treated on any kind of filter, the previous removal of coarse suspended matter is more important than is generally appreciated. " The volume of sewage which may be successfully purified upon a given filter area is inversely proportional to the amount of suspended matters in the sewage applied. In other words, if the whole or a part of the suspended matters are removed from the sewage by some treatment preliminary to filtration, the filters can be operated at much greater rates and a smaller area will be required for treatment of a given volume of sewage." (Report of Mass. State Board of Health, 1908.)

The simplest strainers are of rods or wire screens of galvanized iron, copper, etc. These are generally placed vertically between the sewer outlet and the tank or filter, or the pump suction. The iron rods used in this country are generally $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter and spaced with $\frac{1}{2}$- to $\frac{3}{4}$-inch clear opening, although the spacing has been as great as 6 inches. Rod strainers are placed either vertical or inclined as much as 45 degrees from the vertical. Material can be removed from them with rakes, and they are cleaned more easily than are screens, but are not so effective.

In some installations, the rods are bent and joined to form a cage or basket. At Glasgow, Scotland, a screen of rod links, passing over two wheels like a link belt and inclined 45 degrees, its lower loop being in the sewage, removes the larger matters and raises them to an elevated platform. According to the late Emil Kuichling, coarse screens remove from 3 to 10 cubic feet of material per million gallons of sewage, equivalent to about 104 pounds of dried matter, or 12½ parts per million of suspended solids.

Strainers of coarse particles such as coke or buckwheat coal have been used but little in this country. Coke and coal are used partly because of the possibility of burning the organic matter removed by the strainer, by using the strainer material as fuel when it is removed. Tests by the Massachusetts State Board showed that coke breeze (including pulverized coke) in a bed 12 inches thick (gradually reduced to 3 inches by removing clogged material) removed 57 per cent of the bacteria and 74 per cent of the suspended albuminoid ammonia. Screened coke removed 72 per cent of the bacteria and 59 per cent of the suspended albuminoid ammonia. Fine bituminous coal removed 70 per cent of bacteria and 65 per cent of suspended albuminoid ammonia. Buckwheat anthracite (between ½-inch and ⅛-inch mesh) removed 56 per cent of bacteria and 56 per cent of albuminoid ammonia. All were operated at a general rate of 1,000,000 gallons per acre daily. From the breeze bed were removed 8 cubic yards of coke per 1,000,000 gallons of sewage strained; from the screened coke 0.4 cubic yard; from the bituminous coal 0.8 cubic yard; and from the anthracite 0.8 cubic yard.

At Columbus screened ¼-inch coke was used to strain sewage at the rate of 1,500,000 to 3,000,000 gallons per acre per day. The results were fully as good as those just described, but there was considerable putrefaction with objectionable odor; and 5.5 cubic yards of coke were removed per 1,000,000 gallons strained. They were cleaned at from two- to eight-week intervals. Drying the coke for burning required from two to four weeks when it was spread upon land, and an objectionable odor was given off. The results obtainable do not seem to warrant the general use of this method, with its objectionable features; although improvements in structure or operation may perhaps be devised to meet the objections.

Fine screens of modern design are comparable to sedimentation tanks in the amounts and fineness of suspended matter removed. There is no accepted limit between fine and coarse screens. Kenneth Allen would make it $\frac{5}{8}$ of an inch, but others would place it as low as $\frac{1}{16}$ of an inch. The finer the screen the greater the percentage of removal of suspended matters, of course. The following is greatly condensed from a paper by Mr. Allen before the Am. Soc. of Civil Engineers and a discussion thereof, this being the most exhaustive compilation on the subject up to the year 1918. The use of fine screens is just beginning to be seriously considered in this country, but will probably increase in the near future.

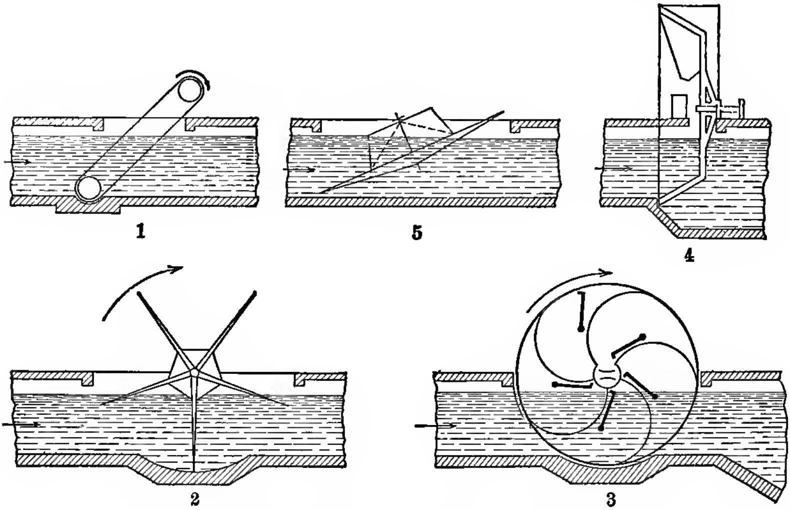

Fig. 65.—Diagrams of Various Types of Screens.

Fine screens may be divided into five general types:

1. The band screen, consisting of an endless flexible band, of either wire mesh or links, which passes over upper and lower rollers like a belt.

2. The wing screen, formed of vanes, as in a paddle wheel, which are composed of radial bars at uniform distances apart.

3. The shovel-vane screen, similar to the wing screen, but with semicircular wings and a different method of removing the screenings.

4. The drum screen, consisting of a cylinder or truncated cone of perforated plates or wire mesh, which rotates on a horizontal axis.

5. The Riensch-Wurl screen, which consists of a perforated disk surmounted by a truncated cone, also perforated, both mounted on an inclined shaft.

The first type is represented in this country by the Jennings screen, which has been in service at the Chicago stock yards since July, 1913. It consists of separate sections of removable screens of Monel metal, 40 meshes per inch. The screen is cleaned by blowing off the matter adhering to it by use of air under 1½ pounds pressure. Screen and blower together are operated by a 10 H.P. motor at a cost of 12 to 15 cents per hour, 1¼ to 1½ million gallons a day being screened. A band screen of parallel links in Hamburg, Germany, is cleaned by a comb scraper. One of wire mesh in Göttingen is cleaned by a brush and water jets.

Wing screens are not used in this country, but are found at three German installations and one English one. Each wing or vane is 5 to 10 feet long and is formed of parallel bars set ¼ to ½ inch apart. The vanes revolve against the current. Each vane is cleaned by a hard rubber scraper which, as the vane rises, travels from its inner to its outer end, and is followed by a brush. One screening, 21 to 26 million gallons a day, requires 2.3 H.P. to operate and cost 11 cents per year per capita of population served.

The shovel-vane screen is a modification of the wing. The vanes are semicircular in section and the stationary axle is hollow and quite large, with its top third open. As each vane rises it scoops up the suspended matter, which slides slowly toward and finally drops into the hollow axle. In this axle is a belt conveyor, which receives and removes the screenings. An arm carrying a brush at its end swings about a pin at the center of the arc of each vane and automatically brushes off adhering matter as the vanes revolve. The screen is about 12 feet diameter.

DATA RELATING TO SEWAGE

Type of screen.	Name of inventor or manufacturer.	Location.	Clear opening, in inches.	Screenings.	
				Per million gallons.	Per 1,000 population daily.
Band...	..Brunotte......	Hamburg..	0.6	0.34 cu. yd.	0.018 cu. yd.
	Hertzberg.....	Göttingen .	0.4	0.35 cu. yd.	0.026 cu. yd.
	John Smith & Co......	Sutton....	0.375 meshes per inch	0.6 ton	....
	Jennings....	Chicago Stock Yards	....	2.4-3.1 tons	....
Wing...	..J. S. Fries Sohn	Frankfort .	0.40	0.7 cu. yd.	0.040 cu. yd.
	J. S. Fries Sohn	Elberfeld..	0.40	1.15 cu. yd.	0.053 cu. yd.
		Stralsund..	0.20	....	0.079 cu. yd.
		Wiesbaden.	0.60	1.1 cu. yd.	0.033 cu. yd.
Shovel-vane.	Geiger Mach. Wks........	Strassburg	0.10	1.6 cu. yd.	0.043 cu. yd.
	Geiger Mach. Wks.........	Gleiwitz...	0.12	....	0.192 cu. yd.
Drum...	..Geiger Mach. Wks.........	Temesvar .	0.12	0.9-1.7 cu. yd.	0.067-0.133 cu. yd.
	Windschild....	Bromberg .	0.08	4¾ tons	....
	Windschild....	Mainz....	0.12 0.04-0.08	0.52 cu. yd.	....
	Windschild....	Trier......	0.10	0.39-0.42 cu. yd.	0.13 cu. yd.
	Windschild....	Osnabruck	0.08	3.2-4.0 cu. yd.	0.08-0.10 cu. yd.
	Weand........	Reading, Pa.......	36 meshes per inch	1.0 cu. yd.	....
	Weand........	Brockton, Mass.....		1.4 tons	....
Riensch-Wurl..	Riensch-Wurl..	Dresden...	0.08	0.97 ton	0.09 cu. yd.

*The figures in this column should be used with caution. More complete data ferent screens.

The drum screen consists of a revolving drum, of either cylindrical or truncated cone shape, the outside being a screen. The sewage enters at one end and flows out through the perforations in the screen, material tending to clog these being blown into the

SCREENS. Compiled by Kenneth Allen.

Screenings.	Percentage of efficiency.	Horse-power per screen.	Cost of operation.		Remarks.
Percentage of moisture.*			Per million gallons.	Per cubic yard of screenings.	
87	....	2.5	....	....	After removal of half this volume of grit.
....	90(?)	2.0	....	....	
....	....	....	....	....	
79	63	....	....	....	
....	10	5.0	....	$0.18	After removal of 16 per cent by grit chamber.
75	....	....	....	....	Including 0.6 cu. yd. grit per million gals.
....	....	4.5	....	....	
....	....	Hand power	$1.64†	....	After passing 1.6-in. bar screen.
89.3	10-12	3.35	....	0.054	After removal of 0.132 cu. yd. grit and coarse screenings per 1,000 population.
....	63	....	0.90	0.125	
60-70	....	....	Small	....	
40-60	....	....	2.45	....	Experimental.
75	53.5	5.2-6.8	0.89-3.42	....	
50-60	....	....	2.41	....	Experimental.
....	....	9.00	....	....	Before removal of 0.4 cu. yd. grit per million gallons.
89.5	42	2.0	1.00 ±	....	
....	71.3	....	....	....	
84	33.6	2.5	0.325-1.76	....	

drum by air or water. A number of these are in use in Germany. At Reading, Pa., Atlanta, Ga., Baltimore, Md., and Brockton, Mass., is used a drum screen known as the Weand screen. This is constructed with a fine wire mesh protected by

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should be secured, in order to furnish a reliable comparison between the efficiencies of dif-

† Including coarse screening, settling and subsequent screening.

an outer coarse mesh. The intercepted material is worked toward one end by an interior spiral flange, and at that end is raised by short radial plates and dropped into the end of a chute which projects into the drum. The Reading screen is 12 feet long and 6 feet in diameter. The screen, of Monel metal, has 36 meshes per inch, the protecting screen being of No. 12 copper wire, $\frac{5}{8}$ inch mesh. It is cleaned by jets of screened sewage directed against the outside of the drum.

The Riensch-Wurl screen is used in several German cities and in Daytona, Fla., and Brooklyn, and Rochester, N. Y., and is proposed for some other cities. The general shape is that of a hat with a flat brim, both composed of slotted plates, about three-fourths of the brim being submerged; the axis being set at 10 to 30 degrees with the vertical. This revolves, and as the intercepted matter is carried above the sewage surface on the surface of the plates, it is brushed off by revolving brushes and falls into cans or onto a conveyor. Each screen in the Dresden, Germany, plant contains 230,000 openings, each .087 by 1.2 inch.

Perforated plates intercept finer matters than do bars. Wire-mesh screens may be made still finer. Compressed air gives drier screenings than water jets, and both clean more thoroughly than do brushes or scrapers, but apparently cause more spattering and diffusion of odor.

The disposal of the screenings from plants such as these is a difficult problem. They quickly become offensive and must be buried, burned or treated in some way within a few hours after removal from the screens.

ART. 73. TANK TREATMENT. SEDIMENTATION

The general object of tank treatment is clarification. By clarification is meant the physical removing of matters in suspension, as is done in the laboratory by the use of filter paper. These matters are of varying size and consistency, some being so fine as to be microscopic; and there are matters known as colloids which are so minute as to sometimes render it a matter of debate whether they are in solution or suspension. Some of the matters are heavier than water, the sand and other mineral substances from the street surface especially; some are lighter than water and float to the surface, such as fats, pieces of wood, etc.; and others have a specific gravity of practically one and only gradually move either downward or upward. Some of the suspended matters are more or less soluble and would be taken into solution if sufficient time be allowed; in fact, the amounts of matters in solution and those in suspension in a given sewage will ordinarily vary with the age of the sewage, the former increasing and the latter decreasing. Bacteria are in suspension, attached to or embedded in particles of organic matter; so that removal of such matter by clarification or otherwise will at the same time remove large numbers of the bacteria.

By running sewage slowly through a tank or basin much of the suspended matter will settle out by gravity, forming a sludge or thick liquid at the bottom. If run through more rapidly, only sand and other coarse mineral solids will be deposited. When the flow is slow, fats, pieces of wood and other light particles, including organic matter which is gasifying, will float upon the surface. The slower the flow the larger the percentage of matter which will settle out; but this percentage increases much less rapidly than the reduction in velocity, and such reduction becomes uneconomical beyond a certain point.

The simplest plan would be to discharge the sewage into the tank from a pipe at one end and remove it at the other by a pipe at the level of the contained sewage. This, however, would cause a current more or less direct from one pipe to the other, giving too great velocity to the flowing sewage and leaving much of the tank contents practically stagnant. This is avoided by admitting the sewage through several inlets across the end, or better still through an orifice or over a weir extending entirely across the end; the effluent being removed through a similar orifice or weir at the outlet end. If a weir be used for the latter, the floating scum will pass off with the effluent. This is generally not desired, and is prevented by use of a submerged orifice, or more commonly by a " scum board " which extends across the tank a short distance from the outlet and the lower edge of which is 6 to 18 inches below the surface of contained sewage. If the submerged orifice is used, the pipe or channel which serves as outlet for this is brought up to the desired level of the tank, thus fixing this. The form of inlet and outlet and their approaches should be so designed as to distribute the flow across the entire width of the tank and also reduce the velocity of entrance as much as possible. Present practice is by no means satisfactory in this respect.

If the sediment and scum remain long in the tank, bacterial action begins and becomes more and more active, especially in the former. As there is little if any available oxygen in the tank, the action is anaerobic or putrefactive. This results in liquefying and gasifying much of the organic matter, a large part of the remainder being finely comminuted. As the gases form they rise to the surface, generally carrying organic matter with them, sometimes in masses of several inches area. This action and the vertical currents set up tend to prevent sedimentation and also carry into re-suspension matter which had already settled to the bottom. Some part, also, of the gases is probably taken into solution in the sewage. The escaping gases may be offensive, but generally are not seriously objectionable unless the tank be very large and the air motionless, and not always then.

Several modifications of construction have been used to meet or avail of these and other conditions. One aims to permit sedimentation and also the gasifying action without any interference of the latter with the former. Another takes advantage of the fact that fine suspended matter is observed to adhere to surfaces, by introducing a great number of surfaces. The latest idea is to prevent anaerobic putrefaction by continuously forcing air into the sediment. These will be described later.

In such a tank as is described above, the sewage flows continuously, though slowly, leaving at a level only slightly lower than that of entrance. This is called a constant-flow tank. Another style of tank, called intermittent-flow, is filled and allowed to stand full for some time, when the liquid is withdrawn. This requires the outlet pipe to be as much below the inlet as the fall of sewage level when the tank is emptied, or else that pumping be resorted to for filling or emptying the tank. The sewage is not perfectly quiet in most cases, but continues, with constantly diminishing velocity, a circulating motion or eddying caused by the comparatively rapid filling. The structural difficulties and details of liquid-withdrawing appliances, combined with the loss of head, cause this form of tank to be but little used.

When the velocity is so great that only the heaviest, mineral matters are deposited it is called a grit chamber. These are sometimes desirable where the combined system is used; but in the separate system so little sand or grit is carried that they are considered by experts to be unnecessary. They are generally objectionable because of the organic matter which is apt to deposit in them and putrefy, a velocity of even 135 feet per hour being insufficient to prevent this in Columbus. Such grit as finds its way to a tank might better settle with the remaining sludge; or a bottom baffle wall in the tank near the inlet end may serve to collect the grit and its accompanying organic matter.

In a plain sedimentation tank there are to be considered, besides the inlet and outlet, the length, width, depth and general form. Except for special forms to be described, tanks are generally made rectangular. Experiments at Columbus indicated that a velocity of 50 feet per hour would permit an amount of precipitation which could be increased very little by reducing the rate. Also that prolonging the stay in the tank beyond four hours did not materially increase the deposit. These figures might vary somewhat with differences in the nature of the sewage, but agree almost exactly with the ideas of some English authorities. Accepting them, we would have a tank 200 feet long, and with an area of cross-section obtained by dividing the flow in cubic feet per hour by 50. In addition to this, allowance should be made for 1 or 2 feet of quiescent sludge in the bottom of the tank. From 6 to 8 feet depth, allowing 3½ to 6 feet for depth of actual cross-section of moving sewage, is generally considered most desirable.

The width obtained by such a calculation might be taken as that of the tank, and in a small plant probably would be. But to permit of putting a tank out of service when cleaning without intermitting the treatment, several tanks may be provided; and this is also made desirable by the tendency to the formation of cross-currents and other causes of non-uniform flow in a wide tank. Several tanks placed side by side are therefore desirable if the volume of flow exceeds say 1,000,000 gallons a day.

Such a tank will remove from 40 to 60 per cent of the suspended organic matter, and a higher per cent of suspended inorganic matter. The sludge must be removed at intervals of three to six days in summer and two to four weeks in winter, if active putrefaction is to be avoided. The sludge deposited will be 80 to 95 per cent water, and disposing of it presents serious difficulties in many cases. This will be considered in another article. While large numbers of bacteria are removed by sedimentation, the number leaving in the effluent is still so large that subsequent treatment to remove them is necessary if bacterial purification is considered.

The removal of the sludge may be facilitated by special construction or apparatus, the simplest of which is the sloping of the bottom of each tank toward a central gutter, which itself slopes toward an outlet at one end or in the middle. This outlet may lead by a pipe to a sludge pit or sludge bed. The supernatant liquid may be drawn off with the sludge, may be pumped to an adjacent tank, or may remain in the tank after the sludge has flowed out. A scraper, of the nature of a squeegee, is sometimes used to force the sludge to the outlet, but this is generally unnecessary. In intermittent-flow tanks the effluent is generally drawn off by a hinged pipe, its free end being maintained, by a float, about 3 to 6 inches below the surface, the lower end being connected to an outlet pipe. When the effluent begins to run cloudy the remaining contents of the tank, or sludge, is drawn off into a sludge well.

Sedimentation tanks should be practically watertight to prevent pollution of the soil and undermining of the foundation. They should have a hard and smooth surface to facilitate removal of sludge. Steel plates might be used to met these requirements but would be unnecessarily expensive and subject to rapid deterioration by rust. Brick or concrete is ordinarily employed, the latter being more common at the present time. The interior of a concrete tank should ordinarily be floated down to a smooth sidewalk finish. Brick-work should be smooth, with the joints pointed. Enameled brick are sometimes used because adhering matter can so easily be removed from them. The tanks are underground in the majority of cases, since the surface of sewage in them is practically at the level of the flow line of the sewer, except when it is necessary to pump the sewage,

Sedimentation tanks are sometimes roofed over, in other cases they are left uncovered. Roofing is somewhat expensive, especially where the tank is large. It offers the advantage of protecting the tank from winds, which would create eddies and currents in a large tank, which would interfere with sedimentation; they maintain a more uniform temperature, preventing the surface of the sewage from freezing (although this is likely to occur only in very cold climates); and conceal the tanks from view and prevent the diffusion of odors, thus palliating imaginary or real offenses to sight and smell. For small tanks an ordinary frame roof, with the gables closed in, will ordinarily serve the purpose, although a more durable and ornamental structure may be obtained by the use of masonry and a slate roof. For larger tanks a more common construction is a concrete or brick roof of groined arches supported by masonry pillars resting at regular intervals upon the floor of the tank. If, as is desirable, a large tank is divided by longitudinal walls into a series of narrow tanks, pillars are unnecessary and either frame or masonry roofs may be supported on the partition walls. Given the dimensions calculated as indicated above, the remainder of the design and construction of a sedimentation tank would be similar to that of any like structure for containing water; except for the special inlet and outlet constructions, as already described.

On account of popular prejudice, as well as to reduce the cost of the considerable area occupied by horizontal tanks, they will generally be placed as far as possible from built-up sections.

Where this cannot be done, the area required can be reduced by use of a vertical tank.

In a vertical tank the sewage flows vertically downward to nearly the bottom of the tank, then outward under a suspended wall and upward to the outlet, the area of the upward flow being much greater, and consequently the velocity much less, than of the downward. This assists the precipitation of suspended matter. The " Dortmund " tank is of this type. The upward velocity is at the rate of .005 to .01 foot per second. Experience shows that these remove less organic matter than do horizontal-flow tanks, and few are used.

ART. 74. TANK TREATMENT. PRECIPITATION

To hasten the sedimentation and render it more thorough, as well as to remove a part of the matters in solution, chemicals are sometimes added to the sewage. It was at first thought that by chemical treatment a large part of the organic matter in solution could be rendered insoluble and precipitated, and Slater cites over 450 patents granted in England for chemicals to be so used. It is now generally recognized, however, that practically only the solids in suspension and 5 per cent to 15 per cent of those in solution can be removed by this method. As only about one-fourth of the total solids are in suspension, it is evident that but a small percentage of them is removed, although these may include half of the organic matter.

Precipitation is largely or entirely a physical process. When lime, for instance, is added to sewage it unites with the carbonic acids to form carbonate of lime, and with sulphuric acid, if any be present, to form sulphate of lime or gypsum; both of which are insoluble in water and settle to the bottom of the tank, entangling and carrying down with them flocculent matters in suspension. If a large amount of lime be used, calcium hydrate instead of carbonate is formed, clarifying the sewage. Sufficient lime generally remains in solution in the carbonic and other acids to render the sewage alkaline. If iron sulphate or aluminum sulphate be added to sewage thus made alkaline, a flocculent precipitant of hydrate of iron or hydrate of aluminum is formed which seems to precipitate slightly more of the soluble matter than does lime. Ferrous sulphate seems to be useless without the addition of lime to combine with the excess of carbonic acid and with the sulphuric acid of the ferrous sulphate. Ferric sulphate is more readily precipitated and more completely insoluble than the ferrous salt, and the use of lime with it is not so necessary; as is also the case with aluminum sulphate or crude alum, ordinary sewage containing enough alkali to decompose these salts. It is found that if more lime is used than will combine with the carbonic acid in the sewage, no benefits result from the additional lime; and the free lime is objectionable because of the danger that it will kill fish in the water reached by the effluent, and that it will cause a secondary precipitation in the effluent or stream which receives it. With ferric and alum salts, however, the precipitation increases with the amount used, though at a less rate after a certain point is reached. Some sewage containing industrial wastes, such as that of Worcester, Mass., contains so much ferric sulphate that it is useless to add more.

Of the great number of materials (not necessarily "chemicals" in the popular use of the word) proposed, only a few have been found practicable, many being too expensive. Lime, ferrous and ferric sulphate and sulphate of alumina are believed to be the only ones used in this country. A few patented preparations are used in England. From tests made by the Massachusetts State Board of Health certain conclusions were reached as to relative effectiveness and cost, which are given in Table No. 24. In each case, the time allowed for sedimentation was one hour. The calculations of cost were based upon the following unit costs in the year 1908: Lime (70 per cent available CaO), $6 per ton. Copperas (55 per cent available $FeSO_4$), $10 per ton. (Sugar sulphate of iron, containing 64 per cent available $FeSO_4$, can be used, reducing the cost about 15 per cent). Crude alum (58 per cent available $Al_2(SO_4)_3$), $20 per ton. Ferric sulphate, $27 per ton.

Worcester, Mass., and Providence, R. I., are believed to be the only cities in this country now using precipitation. Owing to the cost of the chemicals and the increased amount of sludge to be disposed of (the chemicals added equal about 30 per cent of the total sludge), and certain other objectionable features, the process is now considered advisable for use only when certain unusual sewage characteristics are involved.

TABLE NO. 24

RESULTS OF PRECIPITATION OF SEWAGE WITH VARIOUS CHEMICALS

From Laboratory Experiments of the Mass. State Board of Health.

Precipitant.	Pounds per Million Gallons.		Per Cent. Removed.			Cost of Chemicals.
	A.	B.	Loss on Ignition.	Albuminoid Ammonia.	Bacteria.	
Plain sedimentation...	......	......	23	24	19	......
Lime..............	......	800	35	43	67	$2.40
	......	1200	38	44	78	3.60
	......	1600†	49	56	98	4.80
	......	2000	48	56	98	6.00
Copperas..........	500	......	26	21	10	2.15
	1000	......	2	18	......	4.30
Copperas (A) and lime (B)..........	200	580‡	21	37	95	2.60
	400	630‡	26	41	98	3.61
	500	400	33	20	34	3.35
	500	700‡	47	50	95	4.25
	500	1200	43	65	99+	5.75
	500	2000	47	56	99+	8.15
	1000	800‡	56	61	98	6.70
	2000	1100‡	45	59	99+	11.90
Sulphate alumina...	500	......	37	38	97	2.75
	650	......	55	51	86	3.60
	870	......	49	56	91	4.80
	1000	......	52	66	91	5.50
Sulphate alumina (A) and lime (B).....	500	400	44	31	74	3.95
	500	800	39	47	91	5.15
	1000	500	64	68	95	7.00
	1000	1000	60	67	99	8.50
	2000	1000	71	78	99+	11.50
Ferric sulphate.....	500	......	29	48	86	6.80
	750	......	40	64	91	10.20
	1000	......	61	67	97	13.60
Ferric sulphate (A) and lime (B)...	500	400	42	60	78	8.00
	500	800	47	61	90	9.20
	1000	500	62	70	96	15.10
	1000	1000	58	70	96	16.60

† Amount adjusted to CO_2 in sewage. ‡ Amount adjusted to copperas.

ART. 75. TANK TREATMENT. SEPTIC TANKS

The fact that sludge in the bottom of a sedimentation tank will in time begin to putrefy and give off gases has been referred to; also that this action interferes somewhat with sedimentation. Study of putrefactive action, however, showed that by it much of the organic matter in sewage is liquefied or gasified; and it had been learned that liquefaction precedes oxidation in the reduction of organic matter. Owing largely to the study of the subject by Donald Cameron, of Exeter, England, there was developed a method of utilizing this putrefactive or septic action in tanks. Cameron believed the tanks must be covered to exclude light and air, because the septic action was performed by anaerobic bacteria. To such tanks he gave the name *septic tanks.*

" The essential difference between settling tanks and septic tanks is that the solid matters deposited in the former are removed at frequent intervals and otherwise disposed of, while with the latter the sludge is allowed to remain for longer periods in the tank, where it is subjected to hydrolytic or bacteriolytic action. By these means a portion of the organic matter is converted into unoffensive gases or into soluble compounds which pass off with the outflowing sewage. When septic tanks first came into use it was stated by many that all of the sludge would be destroyed ultimately, and that mechanical handling of the sludge would be necessary but rarely. That this view was largely erroneous has been proved by experience, but it is still a fact that a very considerable portion of the deposited matter may be destroyed. Ultimately, however, the space occupied by the deposit increases to such an extent that, if the quantity of sewage for which the tank was designed is passed through daily, the rate of flow becomes so great that the sedimentation of suspended matter is greatly impaired, and under such a condition it is necessary to remove the sludge mechanically. But as sludge destruction is dependent on slow bacterial action, and as that action may not become operative immediately, it is essential, to get the best results, that septic tanks be cleaned only when absolutely necessary." (Report of Mass. State Board of Health for 1908.)

Reference has also been made to floating matter in sedimentation tanks. The action of the gases in a septic tank increase the amount of this scum, and under favorable conditions (which are not thoroughly understood) this coheres into a continuous covering which becomes dense and leathery and several inches in thickness. Little septic action, or bacterial action of any kind, takes place in the scum. In many tanks no scum at all forms, but its absence does not seem to interfere with the action of the tank. The scum is in many cases the home of great quantities of maggots, earthworms and similar low forms of animal life, and also gives growth to plant life of various kinds. It may become a foot or more thick and undesirably contract the free flow area of the tank. This has been avoided in Birmingham, Ala., by flooding sewage over the scum and breaking this up, when much of it will settle to the bottom and be added to the sludge. Where water under pressure is available, it can be used advantageously to break up and settle the scum by applying it by hose, or from stationary nozzles connected with the water

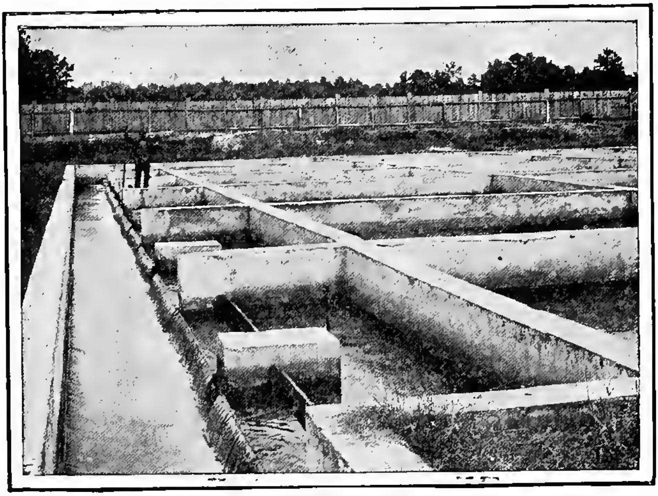


FIG. 66.—DISCHARGE WEIRS OF SEPTIC TANKS, BIRMINGHAM, ALA.
Effluent is seen flowing in channel at extreme left.

main. Some amount of scum is perhaps desirable, however, to protect the sewage from temperature changes and agitation by winds, which interfere with sedimentation and septic action.

In the sludge, anaerobic bacteria gradually develop and liquefy and gasify the organic matter. A period of from two weeks to several months is required for the full development of septic action in the sludge; this time being required for the requisite number of bacteria to multiply. If the sewage is fresh and not well broken up and commingled, the time required is generally longer than if it be stale. Some classes of organic matter are easily decomposed, others resist decomposition for months; but in time a point is reached where the volume of sludge remains nearly constant, the additions balancing the amount leaving as liquid, gas and finely comminuted matter. But even then there is some matter which decomposes so slowly (if at all) that it is not practicable to retain it until it decomposes; but this matter is removed at intervals of from once in six months to once in six years. No method has been devised of removing this resistant matter without removing the remaining sludge also; and the tank is emptied and the process begun anew, some of the fresher sludge being sometimes left in the tank to " seed " it.

The effluent from a septic tank generally has a more objectionable appearance than the crude sewage, being dark and turbid. But it really contains less suspended matter by 25 to 50 per cent, most of which has gone into solution but some of which has disappeared as gas. The suspended matter left is more finely divided. The bacterial content is sometimes reduced, but at other times (generally in warm weather) the number is increased. The sludge from a septic tank is more thoroughly worked over and dries more readily than that from a sedimentation tank.

Tests made by the Massachusetts State Board of Health gave the composition of dry septic sludge as follows: Mineral matter, 45 to 71 per cent; total organic matter, 29 to 54 per cent; organic nitrogen, 1.1 to 2.9 per cent; fats, 8.8 to 11.9 per cent; carbon, 25.1 to 29.8 per cent.

The gas from septic tanks has as its principal ingredients methane, carbon dioxide and nitrogen, the proportions varying widely with different tanks. Sulphuretted hydrogen and other hydrogen gases are sometimes present. The quantities given off vary widely, measurements showing from 1.5 to 7 or 8 cubic feet of gas per 100 cubic feet of sewage. The amount apparently depends more upon the temperature and putrescibility of the sludge than upon the amount of organic matter present. The gas is highly inflammable, and suggestions have been made that it might be used for illumination or gas engines. But its variableness as to volume and composition are apparently insuperable obstacles to this.

The sewage should not stay too long in a septic tank, from 6 to 12 hours being found best—the latter for fresh sewage. Longer than this increases little, if any, the amount of sedimentation, and may result in undesirable action upon the matter in solution. The true function of the septic tank is to remove and hydrolyze the suspended matter. It was once believed that the effluent contained gases and products of anaerobic activity which would inhibit later oxidation; but this does not seem to be the case. Consequently aeration of septic effluents, which was formerly more or less common, is unnecessary; and as it involves loss of head, and the creation of a nuisance by odors, it is undesirable. There may also be "a needless loss of temperature which may seriously interfere with the finishing devices during winter weather. Odors have not been especially pronounced near septic tanks; and, at distances greater than from 100 to 200 feet, in none of the plants studied has there been any cause for criticism in this regard." (Report of Ohio State Board of Health for 1908.) The effluent from many of the Ohio tanks contains dissolved oxygen, this reaching as high as 50 or 60 per cent of complete saturation at times; although generally it did not exceed one-half to one-fourth of the amount found in the crude sewage.

The septic tank removes in some cases more, in some less, suspended matter than does a sedimentation tank. But the matter removed is in general that which putrefies readily and that which resists reduction. The effluent of the septic tank is therefore in better condition for disposal by dilution than merely settled effluent. Moreover the grosser matters which cause surface clogging of filters are removed. It is a question, however, whether septic effluent is better adapted for disposal on fine-grain filters, as the fineness of the suspended matter and absence of the surface mat which is formed on a filter when coarser matters are present result in a deeper penetration of the deposits.

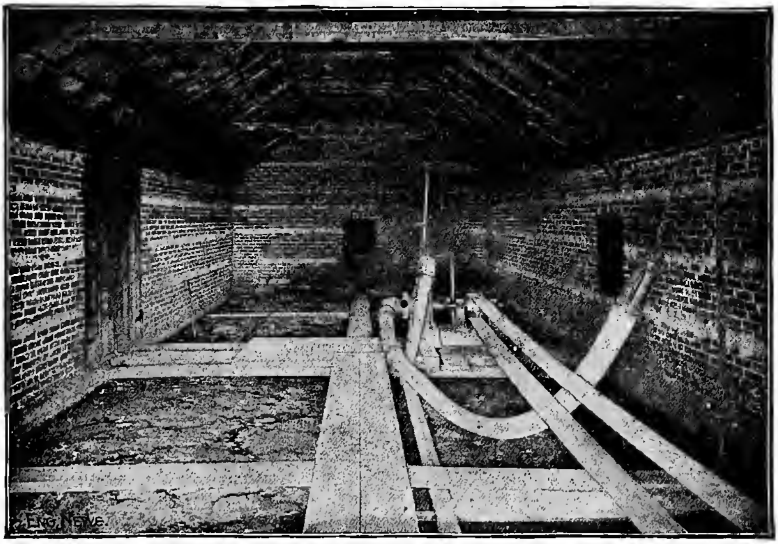


Fig. 67.—Interior of Covered Septic Tank.
Hand pump and suction for emptying tank shown in center of tank.

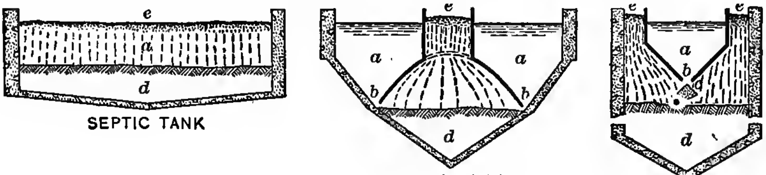
A septic tank, being essentially a sedimentation tank, is constructed in much the same way. Its cubical contents should be that of from six to twelve hours flow of sewage. If larger, the effluent may be subject to undesirable anaerobic action, and it has been found also that the amount of sludge which resists reduction is increased. As the volume of sewage flow varies from day to day, and generally increases continually as the population increases, two or more tanks should be provided, and provision made for adding others as needed. With this, arrangements should be made by which, when the flow through the tank or tanks in service becomes greater than desired, another shall come into service; and when the flow diminishes, one shall be put out of service. In perhaps the majority of plants, especially of small ones, this flexibility is not provided, but only one tank is used; but the results from many of those are far from satisfactory.

Efforts have been made in some plants to minimize the taking of sludge into resuspension. At Worcester two low baffle walls divide the bottom of the tank into three equal parts, and above these are suspended baffles of scum boards, submerged a few inches. These tend to confine the most vigorous action to the first third of the tank and permit resedimentation in the last third.

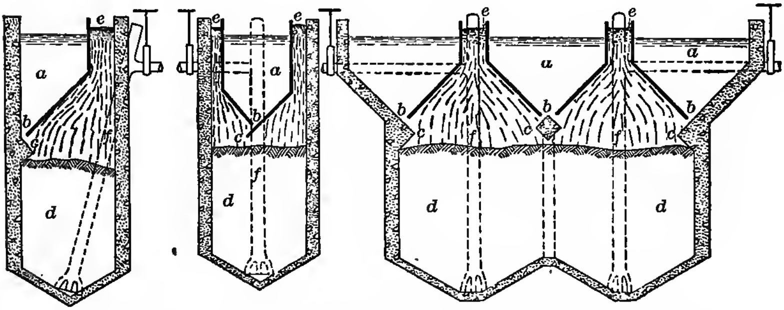
The largest septic tank plant that has been built in the country was that at Columbus, O., where provision was made for treating 20,000,000 gallons a day, by four tanks $56\frac{1}{2}\times 150$ feet, and two tanks $115\frac{1}{2}\times 262$ feet, each about 12 feet deep, uncovered. The tanks were divided into three sections by transverse walls. These tanks, of concrete throughout, cost $4070 for masonry, $3640 for earth work, $12,530 for sluice gates, and $2490 for other details; or about $3336 per million gallons. These tanks were changed, in 1915, to Imhoff tanks, described further on in this article. Previous to the completion of the Columbus plant, the one at Birmingham, Ala., was probably the largest septic tank plant in the country, comprising six tanks each 100×20 feet by 10 feet deep, treating about 5,000,000 gallons a day.

A tank at Lake Forest, Ill., capacity 200,000 gallons per day, cost $8000. One at Delaware, O., of 100,000 gallons capacity, cost, including coke filters, $12,000. One at Lakewood, O., 300,000 gallons capacity, cost, including 625 acres of contact filters, $24,175. One at Mansfield, O., 1,000,000 gallons capacity, with $1\frac{1}{4}$ acres of contact filters, cost $65,547. One at Wauwatosa, Wis., handling 100,000 gallons a day, cost $5370.

A tank treatment was devised several years ago by Mr. Travis, of England, known as the " hydrolytic " or Travis tank. This aims to separate the sludge from the flowing sewage, to prevent the objectionable effects upon the latter caused by gases and particles of deposited matter rising from the former, and also to take advantage of the principle of surface adhesion of colloids for removing these minute matters from the sewage. The tank, the bottom of which has the form of a flat V, is divided into three compartments by a longitudinal arch-shaped wall enclosing a lower compartment, on top of which is a vertical double wall enclosing a narrow channel and dividing the upper portion into two compartments. The arch has openings along the line of its junction with the V-shaped bottom and also in its crown. The outlet end of the tank has a level weir which is divided by the arch so as to apportion a definite width of weir to each of the compartments. The compartment under the arch receives the sludge through the openings in the arch, the sedimentation occurring in the other two compartments. Sewage enters the upper or sedimentation chambers only, the other compartments receiving sewage and sludge from them. There is, however, some flow through this bottom compartment and over the weir



SEPTIC TANK TRAVIS TANK IMHOFF TANK



IMHOFF TANKS

a, channel through which sewage flows; *b*, slot through which sediment slides into chamber below; *c*, gas deflector to prevent gas rising through *b* into *a*: *d*, sludge digesting chamber; *e*, scum in gas outlets or scum chambers; *f*, sludge pipe, for withdrawing sludge. Irregular dashes indicate gas rising from decomposing sludge.

FIG. 68.—TYPICAL SECTIONS OF TANKS FOR SEWAGE TREATMENT.

at the end, the amount being determined, as before stated, by the relative length of the weir at the end of this compartment. At Hampton, England, this section of the weir is 20 per cent of the total length. It is believed that tank and weir proportions which will cause the sewage to remain four hours in the sedimentation chambers and twelve hours in the sludge or reduction chamber give the best results. The gases formed in the sludge compartment will not reach the sedimentation chambers to interfere with the sedimentation. There is some flow through the sludge tank; probably because this was thought necessary to maintain maximum septic action. In addition to this construction, the sedimentation chambers, except in the first one-fourth of their length, contain a number of vertical or practically vertical surfaces or curtain walls, on which the colloids collect by surface adhesion, to slide off in patches as the accumulation becomes sufficiently dense and weighty to detach itself from the surfaces. The V-shaped bottom of the sludge tank facilitates withdrawing of sludge through a pipe placed at the angle of the V.

ART. 76. TANK TREATMENT. IMHOFF TANKS

About 1909, a new kind of tank was introduced into this country, which had been developed in Germany by Dr. Karl Imhoff for treating sewage in the Emscher district, for which reason it is called the Emscher, or more commonly the Imhoff tank. In some respects it resembles the Hampton tank. Its aim is primarily to prevent gas, scum and regurgitated particles from reaching the flowing sewage from the sludge; but perhaps a more important effect is the production of a sludge less offensive and much more easily dried than that of a septic tank. The latter characteristic has been the chief cause of its popularity in this country, where it is receiving general acceptance. The tank consists of a channel through which the sewage flows, which has a sloping bottom down which the sediment slides to a slot through which it drops into a sludge-digesting chamber beneath. The slot is so arranged that gases and sludge rising from the bottom cannot pass up through the slot, but are furnished with an outlet outside the channel, where the scum collects. There is very little motion of translation in the bottom chamber. A little liquid rises through the slot as it is displaced by the falling sludge; but except for this, the effluent is practically as fresh as the entering sewage. As most of the sediment collects near the inlet end, it is customary to reverse the direction of flow every few days or weeks, so that the entire length of the tank may be occupied by sludge.

The cross-section of the channel should be such as to give a velocity sufficiently low to permit of as complete sedimentation as is practicable, say about 1 foot per minute, and the length of channel such as to give a flowing-through period of two to four hours. The slope of the channel bottoms should be at least as steep as 45 degrees and the surface smooth, so that all sediment will slide at once into the chamber below. To prevent gas rising through the slot, either the channel bottom is made V-shaped and one side is carried beyond the other until its lower end is 6 to 9 inches horizontally beyond that of the other side; or a beam with an inverted V-shaped top is placed under the slot; or the slot is at the side-wall, on which is a projection extending across the slot and a few inches below it.

In an Imhoff tank that is functioning properly, the sludge is digested into an inodorous humus mass, with a fairly uniform liberation of the gases caused by the splitting up of the complex molecules of the suspended organic substances into carbon, hydrogen, nitrogen and sulphur atoms. This digestion is probably effected by enzymes or liquid ferments excreted by certain kinds of bacteria. When first put into action, ordinary bacterial decomposition predominates over enzyme digestion; but as the tank "ripens," the latter becomes more effective.

The sludge-digesting chamber must have a capacity for holding all the sludge that will accumulate during the period required for sludge digestion or, in cold or moist climates, that during which sludge can not be withdrawn to advantage, generally three to six months. The volume of thoroughly digested sludge (75 per cent moisture) from a system of separate sewers is about 5 cubic feet per 1000 persons per day; but in the tank it may average several times this volume because more liquid, or 12 to 15 cubic feet. The sludge-holding capacity in most American cities should be about 14 cubic feet per 1000 population for each day's retention, or say (180×14=)2500 cubic feet per 1000 population. This should be the capacity measured up to a level 12 inches below the slots. The greater the depth of the digesting chamber the smaller the volume of digested sludge, owing to the greater compression of entrained gases and the smaller water content. On the other hand, great depth generally adds very considerably to the cost.

The sludge is removed by the static pressure of the sewage in the tank, a pipe being placed inside the tank with its open foot 8 to 12 inches above the bottom of the tank and its outlet 3 to 6 feet below the level of the sewage in the channel, giving this head to force out the sludge. The tank should be so planned that the gas outlets are accessible for breaking up scum, and the channel bottom and slot accessible for scraping through the slot any sediment which may adhere to the channel bottom. There should be no unvented or inaccessible arches in which gas and scum may collect.

The sludge is dried on beds, onto which it is discharged. They should have an area of 325 to 350 square feet per 1000 population—double this in moist climates. Also the deeper the tank the less the area of bed required.

The royalty charged for use of the Imhoff tank varies from about $80 for one serving 1000 persons to $2500 for 100,000 population.

ART. 77. TANK TREATMENT. ACTIVATED SLUDGE.

In 1913 and 1914 Dr. Gilbert Fowler, of Manchester, England, developed the so-called "activated sludge" process, which was at once taken up with enthusiasm in this country, and within a year ten or more experimental plants were in operation. Leslie C. Frank, of the United States Public Health Service, has taken out a patent on the process and dedicated it to the citizens of the United States. The largest experimental plant has been operated at Milwaukee under the direction of T. Chalkley Hatton since 1915, and the process has been adopted for a permanent plant of 100,000,000 gallons daily capacity by that city. Plants were put in operation in San Marcos, Texas, in 1916 and in Houston in 1917; and a few other small ones have been built. As yet, however, there are almost no reliable data from plants under ordinary service conditions.

The process consists of " the agitation of a mixture of sewage with about 15 per cent or more of its volume of biologically active liquid sludge in the presence of ample atmospheric oxygen, for a sufficient period of time at least to coagulate a large proportion of the colloidal substances, followed by sedimentation adequate for the subsidence of the sludge flocculi; the activated sludge having been previously produced by aëration of successive portions of sewage and maintained in its active condition by adequate aëration by itself or in contact with sewage." (Report of Committee of American Public Health Association.)

The method commonly employed is to pass the sewage through a tank in which about 25 per cent of its volume of sludge is supplied continuously and the whole thoroughly mixed and aërated by air entering at the bottom through fine porous plates of artificial stone (" filtros ") or wood, or small orifices in a pipe manifold. The mixed and aërated liquid is then allowed to settle in a sedimentation tank and the proper amount of sludge so settling is withdrawn continuously and pumped into the aërating tank, as described.

The aërating tank that gave best results at Milwaukee has 1 square foot of air-diffusing surface for each 5.5 square feet of tank surface and has 9 feet average depth of liquor. It is necessary to remove from the sewage, before it enters the aërating tank, all grit or other heavy matter that would settle upon the diffusing surface and block the air supply. The amount of air used varies considerably in different plants, but seems generally to be from four to ten times as much (in volume of free air) as the sewage. From ten to thirty days of aëration is required before a sludge is obtained that causes a plant to function at its best.

Concerning the process as tested at Milwaukee, the chief chemist of this plant, William R. Copeland, describes the action as follows:

" The sludge contained in sewage and consisting for the most part of organic matter, when agitated with air for a sufficient period, assumes a flocculent appearance very similar to little pieces of sponge. Bacteria gather in these flocculi in immense numbers, some of them having been strained out of the sewage and others developed by natural growth. Among the latter are species which possess the power of decomposing organic matter, especially of an albuminoid or nitrogenous nature, setting the nitrogen free; and others, of absorbing this nitrogen, converting it into nitrites and nitrates.

" These biological processes require time, air and a favorable environment, such as suitable temperature, food supply and sufficient agitation to distribute them through all parts of the sewage."

By this process at Milwaukee there was obtained a removal of 99 per cent of the bacteria and suspended matter, the effluent contained 12 to 14 parts per million of nitrites, was as clear as lake water and stable after five days. The air supplied cost $4.43 per million gallons of sewage treated, and the total cost was less than $6. A lower degree of purification could be secured at less cost. It is believed that the sludge can be sold for fertilizer to net $6 per million gallons treated, or about the cost of treatment. On this point there is not yet satisfactory evidence, some engineers doubting whether the sludge can be treated to yield a sum approximating this in a plant in actual service.

An activated sludge plant, with its air compressors and distribution system, pumps for returning continuously to the tank a fourth of the sewage treated, and machinery for dewatering the sludge, is an expensive one; and the operation also is costly unless cheap electric current or other low-cost power is available. On the other hand, the tanks need not cost so much as Imhoff tanks.

CHAPTER XVI

OXIDATION METHODS

ART. 78. CHEMISTRY AND BIOLOGY OF OXIDATION

SEDIMENTATION and precipitation, as described, remove 40 to 60 per cent of the organic impurities, but leave most of those in solution unchanged, the effluent of the septic tank even containing a greater amount of soluble organic matter than the original sewage. Moreover the matter removed forms a considerable amount of sludge which must be disposed of in some way. For both reasons they can be considered but preliminary processes in treatment. Final disposal of the sludge is imperative, and there are few cases where the effluent also does not require further treatment. A change of the putrescible matter of either into permanently non-putrescible, harmless compounds or elements can be attained only by changing it into mineral forms by oxidation. When complete oxidation has taken place the carbon has taken the form of carbonic acid and the nitrogen the form of nitric acid, both probably combining at once with some mineral base in the sewage. While this change is described in chemical terms, it has been found that no mere mixing of chemicals with sewage will produce it, but it is in part a biological process.

This complete process is a true purification of sewage. The organic matter may, however, be partially purified, or "modified," and left in such condition that it will not readily putrefy, but can be discharged into a stream or onto land with no more danger of giving offense than if composed of so much leaves or straw; the amount approximating 500 to 1000 pounds per million gallons.

Stated briefly, investigation to date seems to prove the following as facts: Lifeless organic matter is stable in the absence of moisture, but in its presence a large proportion of such matter is readily broken down in structure and is resolved into minerals appearing generally as mineral compounds. Albuminous matter is particularly unstable; while woody fiber, bones, and similar matters are quite stable, and cause most of the difficulty experienced in sewage purification. Organic matter is decomposed not so much by chemical action as by certain classes of bacteria, some of which exist in all soils, and probably in water and air as well. Certain of these seem to require the presence of free oxygen for their action if not for their life, and are called aerobic; others, the anaerobic, live and work best in the absence of light and air; and still others are facultative, i.e., can live and act under either condition.

When sewage enters a sewer it generally contains a small amount of free oxygen and a few nitrates. By the action of aerobic bacteria the free oxygen is taken up by the urea, ammonia, and easily decomposable matter present, and nitrates are formed. At the same time anaerobic or facultative bacteria, together with a few aerobic ones, are at work breaking down the albuminous matters into soluble nitrogenous compounds; which operation is carried on with increased activity after the disappearance of all free oxygen, the anaerobic bacteria being the more effective in liquefying sewage. It is during this stage,—in some cases at its beginning, in others when it is well advanced,—that the sewage is generally received at the treatment works or discharged into the river or ocean.

If it should now be left stagnant, as in a cesspool or septic tank, the anaerobic bacteria would continue the breaking down of the organic matters, even the cellulose and fibrous matter being finally liquefied. During this anaerobic action much of the organic matter is changed into hydrogen gases (since no free oxygen is present), such as marsh gas, and sulphuretted hydrogen, and nitrogen, much of which escapes into the air; the sewage meantime becoming offensive to sight and smell. In this condition it is called septic sewage. Liquefaction, either septic or aerobic, must generally precede oxidation.

If oxygen be admitted to the sewage as soon as it becomes well liquefied, oxidation will begin quickly, and the dissolved and finely comminuted organic matter will be changed to innocuous and inoffensive nitrates and carbonates.

Previous to oxidation, most of the decomposed nitrogenous matter which has not escaped as gas has taken the form of ammonia. By oxidation and the action of the aerobic bacteria the ammonia becomes changed largely into nitric or nitrous compounds with some base, such us potassium or sodium, present in the sewage. Probably none of these changes is the effect of only one class of bacteria, but several classes work both together and successively, These processes are summarized by Dr. Rideal as shown in the following table:

	Substances dealt with.	Characteristic Products.
INITIAL. Transient aerobic changes by the oxygen of the water-supply, rapidly passing to:	Urea, ammonia, and easily decomposable matters.	
FIRST STAGE. Anaerobic liquefaction and preparation by hydrolysis.	Albuminous matters. Cellulose and fibre. Fats.	Soluble nitrogenous compounds. Fatty acids. Phenol derivatives. Gases. Ammonia.
SECOND STAGE. Semi-anaerobic breaking down of the intermediate dissolved bodies.	Amido-compounds. Fatty acids. Dissolved residues. Phenolic bodies.	Ammonia. Nitrites. Gases.
THIRD STAGE. Complete aeration; nitrification.	Ammonia and carbonaceous residues.	Carbonic acid, water, and nitrate.

The process above outlined is, so far as we know, the only one other than burning (rapid oxidation) by which organic matter can be permanently deprived of its noxious properties.

It is important to note that liquefaction must precede bacterial nitrification, and that the anaerobes are the most effective liquefying agents; also that any attempt to reverse the order of these processes will merely retard final purification.

One of the difficulties of stimulating these processes in the purification of sewage is that the various components of this resist liquefaction so unequally that it seems impossible to make the conditions at all times most favorable to each of the contained organic matters. If light and air are excluded to encourage the anaerobic action until all the fats and fibers are liquefied, the albumens will meantime reach the last stages of offensive putrefaction. By making the conditions alternately favorable to aerobic and anaerobic action at short intervals, each particle of matter may be oxidized as soon as it has become prepared for this action and objectionable odors be largely avoided; but under these conditions neither class of bacteria will develop and act to the best advantage.

The bacteria necessary for the above process exist in the sewage, but their numbers and the celerity of their action can be greatly increased by collecting and retaining them in a permanent lodging-place with favorable environment and supplying a constant amount of pabulum in successive doses or in a continuous stream of sewage. Most plans for the destruction of sewage have for their aim the supplying of these conditions. In some, but one lodging-place is afforded, and either both the liquefying and nitrifying organisms exist and act side by side (possibly only aerobic liquefiers acting) or in separate parts of the plant, or no liquefaction takes place after the sewage enters the plant. Other plants are divided into two or three, or even more, separate parts, each devoted to a different class of bacteria. In many instances sewage is flowed over and settles down through porous soil, in passing through the interstices of which it comes into intimate contact with the contained air and with the bacteria which adhere to the soil particles; and if the passage of the sewage be sufficiently slow and the number of nitrifying bacteria sufficiently large, the oxidizable liquefied organic matter will all be transformed into nitrates. If the number of bacteria is not originally sufficient, they will increase with great rapidity; and if a constant amount of sewage be applied continually to a given plot of ground, and sufficient oxygen be furnished, the number of bacteria will in a few days become sufficient to effect complete nitrification. If the sewage be simply turned continuously upon this land, the interstitial air will soon yield up all its oxygen, and nitrification will cease. But if the land be allowed to drain out, the interstices will again fill with air and the operation can be repeated; and this can go on indefinitely, or until the filter becomes clogged with unliquefied matter. This is the principle upon which purification by land and by filter-beds acts. If the land be too open and porous, the sewage will pass through too rapidly to permit of thorough bacterial action. If it be composed of too fine grains, capillary attraction will be so great that it will drain out and be reaërated but slowly. The time required for draining out a bed is in some plants reduced by making the bed very porous and holding the sewage in it during fixed periods of time by closing the outlet. In other cases the beds are not drained out at all, but air is continuously forced in under a few ounces pressure. In still others the sewage is sprinkled over a very porous bed and trickles through, at no time filling the pores and driving out the air.

These methods, depending upon the aerobic bacteria only. must use sewage in which are no matters in suspension not easily liquefied by aerobes, or else be subject to clogging, the fine-grain filters mainly upon the surface, the coarse-grain ones in all their interstices. For this reason some preliminary process for removing or liquefying the suspended matter must generally be provided. Sedimentation and septic action are those most commonly used for this purpose.

ART. 79. INTERMITTENT FILTRATION AND IRRIGATION

In sewage and water purification, the word " filter " is generally applied to a collection of particles of any size, through which the liquid is passed. The individual particles may be as fine as the finest sand or as large as cobble stones. Evidently, straining out impurities can be no part of the function of the latter; and the straining effect of the fine sand filter is considered but incidental.

In any filter " the essential conditions are very slow motion of very thin films of liquid over the surface of the particles that have spaces between them sufficient to allow air to be in contact with the films of liquid. With these conditions it is essential that certain bacteria be present to aid in the process of nitrification." (Mass. State Board of Health, 1890.) During this slow motion in contact with air and in the presence of aerobic bacteria, the dissolved organic matter is largely oxidized. The colloids and fine suspended matters which have not been previously removed adhere to the surfaces of the filter particles or grains, where they are retained and worked over more slowly, probably being liquefied by aerobic or facultative bacteria. Nitrogenous matters have been found to be retained in a filter for several years before final oxidation. The percentage of suspended matter so retained depends partly upon the slowness of flow through the filter, partly upon the area of surfaces offered for adhesion; and this last increases with the fineness of the particles.

The requisite number of bacteria will develop in the filter if favorable conditions be offered, but this will require some days, and meantime the oxidation effected will be less than the maximum efficiency of the plant. The establishing of these most favorable conditions involves the application at constant or constantly increasing rates of a sewage of uniform character, and the continuous presence of oxygen, or frequent renewals of the supply; and fairly high temperature is helpful.

Theoretically the results from using filters of different sizes of grains should differ in degree rather than in kind; but it is found that the effluents obtained are quite different in their nature; a partial reason for which may lie in the different methods of operation made necessary by the different structures. The general classes of filters in common use are fine-grain (sand), contact, and sprinkling or trickling. Slate beds, wave beds and one or two others also are used, the principles of which differ somewhat from those just outlined.

As explained, the organic matters are oxidized to nitrates, which compounds are assimilated by plant life of all grades. In some cases vegetation is grown directly on the filters, when the treatment is called " broad irrigation." Natural soil is almost invariably used for this purpose. Filters proper may be built of sand, gravel or broken stone, or may simply utilize natural soil when this is suitable.

"Broad irrigation means the distribution of sewage over a large surface of ordinary agricultural ground, having in view a maximum growth of vegetation (consistently with due purification) for the amount 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 clean it, not excluding vegetation, but making the produce of secondary importance." (Royal Commissioners on Metropolitan Sewage Discharge.) No more definite line could be drawn between irrigation and filtration than is indicated by these definitions. In many plants the same land is used alternately for both methods. The nitrates which would pass off with the effluent in filtration are to a certain extent (10 per cent to 20 per cent probably) absorbed by vegetation.

Irrigation. In broad irrigation much of the sewage must at times be diverted from the crops—as in rainy weather or after the fruit has matured. If this is not done, the crops cannot be raised to advantage. In some locations it will not be seriously objectionable to turn the sewage at these times into the streams, particularly in rainy weather when these will be in flood; but where this is not permissible provision must be made to treat the sewage otherwise, as on filtration beds. If this plan is adopted, sewage should be turned upon the filtration beds two or three times a week to keep alive in them the nitrifying bacteria.

Irrigation-fields are ordinarily odorless, but on close, humid days in summer the moist deposit on the surface gives off an appreciable dish-water smell, which, however, is seldom noticeable more than 100 yards from the field. The intensity of the odor seems to increase not directly with but as the square or some higher power of the area irrigated. It is not advisable to place such grounds in the midst of a settled community, but a quarter of a mile should be sufficient intervening space.

Sewage is used in irrigation much as water is, except that it should not come into direct contact with berries, celery, cabbage, or the edible portions of any plant. In some cases, generally where grass of some kind is grown, the sewage flows slowly all over the land in a thin layer. Where corn or vegetables are grown they are usually planted on the narrow ridges between plowed furrows into which the sewage flows, and where it stands, soaking downward and sideways into the soil. The roots of vegetation and the vegetable mould which forms on the surface of the ground prevent the rapid absorption of the sewage and unless the subsurface soil be clayey or quite non-porous sub-drains are not often necessary, but ditches are carried through the farm at intervals to receive the drainage. If the sewage is not clarified before being applied to the soil, an impervious skin shortly forms, composed of filaments of paper, rags, and similar matters, together with grease and the more stable organic matter; and this must be removed frequently if the ground is to be reaërated and kept absorptive. This matter, which has little odor, can be piled in a dry spot and burned occasionally.

There are few, if any, places in this country where irrigation is used for its fertilizing value only. Where used, it is because water of any kind has a value for irrigation. In general it is applied like any irrigating water, subject to the qualifications just stated. The sewage of from 50 to 200 persons can be used for irrigating one acre, depending upon the quality of the soil.

Crops of all kinds are grown on sewage farms, but corn, English walnuts, alfalfa, Italian rye-grass, and timothy and other grasses are most common.

Filtration may be effected through natural soil if porous, or through specially prepared beds of sand, gravel, or other substances.

If natural soil is used, care must be taken to keep it as free and open on top as possible. The beds are made level, and generally surrounded with high banks and flooded, but are sometimes plowed into ridges and furrows. If the soil is very porous, there is a tendency for all the sewage to enter it near the carrier outlets. Under such conditions numerous secondary carriers may be used, composed of boards formed into shallow troughs. Uniform distribution may also be assisted by giving considerable slope to the surface of the beds. Great care must be used to prevent the formation of puddles in which the sewage will stand and putrefy. The surface of the ground in furrows will shortly become clogged with organic matter which resists immediate decomposition, but would be broken down and oxidized if given time. Furrows should then be opened in the ridges where the soil is probably unclogged, the earth being thrown into the old furrows. In time a considerable amount of undecomposed organic matter will collect throughout the interstices of the filter, and this should then be given a rest for several days or weeks, for which purpose the filtration area should be divided into three or more beds, one of which is always resting. Those in use should be allowed to drain out after each dose, that they may be reaërated; the

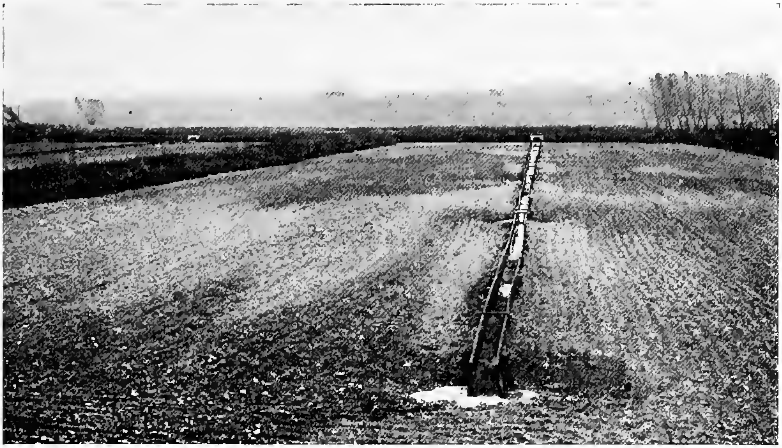


FIG. 69.—ARTIFICIAL SAND FILTER WITH WOODEN DISTRIBUTOR.

FIG. 70.—WOODEN TROUGH DISTRIBUTOR IN ACTION.

sewage generally flowing onto drained beds while the ones previously used are draining. In some small plants, however, the sewage is received in settling tanks and the effluent discharged upon all the beds at intervals of several hours, or even only once a day.

On such natural filters the sewage of from 800 to 2000 people may be treated and 85 to 99 per cent of the albuminoid ammonia removed. If it is desired to further economize space, artificial filters may be constructed. These are generally of sand, of an "effective size"* of about .01 inch, over coarse sand or fine gravel, which in turn rests upon a layer of medium-sized gravel, at the bottom of which the drains are placed. The greater part of the purification appears to be done in the upper layer, since 1,118,000 bacteria have been found per gram of sand in the upper inch, while at 4 inches depth but 125,000 were found.† The purpose of the finer top layer is to regulate the velocity of flow, to insure a more minute subdivision of the water and thorough oxidation, and to support the gelatinous top coating which materially assists in the straining and probably in the removal of bacteria. Care must be used to insure that in no place does the sewage pass from a coarse to a fine sand, since organic matter would be deposited here and clog the filter. By having the finest sand on top all clogging is at the surface, where it can be reached.

By intermittent filtration through clean, coarse sand 50,000 to 75,000 gallons per day of American sewage can be treated on one acre, and 97 per cent to 99 per cent of the organic matter therein removed. With fine sand or sedimentary deposit the same result can be obtained with 30,000 gallons or less per day if care is taken to allow thorough drainage between doses.

Low rates are obtained with very fine soil because capillary attraction not only prevents the actual passing of liquid at a high

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* The effective size of a material "is such that 10 per cent of the material is of smaller grains and 90 per cent is of larger grains than the size given. The results obtained at Lawrence indicate that the finer 10 per cent have as much influence upon the action of a material in filtration as the coarser 90 per cent." (24th Annual Report State Board of Health of Mass.).

† It is probable that a large percentage of the great number of bacteria found in the upper inch are those strained out of the sewage, only a few of which are nitrifying.

rate, but it retains a part in the lower portion and prevents complete reaëration and hence full oxidation.

It is probable that if sewage is applied without preliminary clarification, there will be strained out on the surface as much suspended matter as though it were collected in a settling tank; in other words, the same amount of solids remains to be disposed of. And collection on the surface interferes with aëration of the filter and even lessens the amount of sewage which can be passed through it. If too much accumulates it will even waterproof the surface in places and cause pools of sewage to collect and putrefy. It is therefore generally advisable to remove as much suspended matter as possible before filtration; and the greater the amount removed the higher the rate of filtration possible. Perhaps double the rate can be maintained with septic sewage as with crude; but the clogging of the body of the filter will be more rapid, requiring frequent renewal of the sand, because of the fine division of the matter.

The amount of oxygen introduced by each aëration of the bed can nitrify only a given amount of sewage, and if more be applied before reaëration an unsatisfactory effluent must result. For example, to oxidize five parts of nitrogen per 100,000 requires a volume of air one-half as great as that of the sewage treated.

Nitrification is favored by certain constituents of soil, such as carbonate of lime, and impeded by others.

Polarite (magnetic oxide of iron 54 per cent, silica 25 per cent, lime, alum, magnesia, carbonaceous matter and moisture 21 per cent) is a (patented) granular substance used for filtration, but there seems to be little evidence that it is more efficient than sand of a similar size of grain, or finely broken coke breeze. Polarite is generally placed in a thin layer between an upper and a lower bed of sand.

On the care of filtration areas or beds Mr. Geo. W. Fuller has given the following suggestions:

"(1) Systematic raking, with occasional harrowing or plowing, is very satisfactory, particularly for coarse materials.

"(2) Systematic scraping (*removal of clogged material*) at regular intervals (followed by raking to loosen the material) gives very good results, especially for fine materials.

" (3) Systematic scraping when necessary, without raking or harrowing, is not advisable.

" (4) The efficiency of very fine material (clogged or not clogged) is much increased by trenching with coarse material. (*Digging trenches through the bed and filling them with other material, generally coarse sand.*)

" (5) Such trenches should contain carefully graded materials at the bottom to prevent clogging at the junction of the coarse and fine sand.

" (6) When new material is put onto old to replace clogged material removed by scraping, it is always advisable to mix the old and the new together in order to prevent clogging at the junction of layers of unlike capillary attraction.

" (7) The removal of stored organic matter by resting for a limited period is sufficiently great to render this simple and inexpensive method worthy of careful consideration in cases of clogging where the available area is not too limited.

" (8) It is important that the treatment of filters be such that the condition of operation be as favorable as possible during the cold winter weather.

" (9) Great care should be taken, especially in the case of filters of fine material, that the capacity of the filter be not taxed during the winter months to such an extent that more organic matter is stored throughout the sand that can be removed during the spring and early summer, which is the period of highest nitrification."

" Qualitative deterioration is a serious matter in winter, because when a period of biological reconstruction is necessary, nitrification cannot be promptly re-established, as is the case in summer, but requires a period of several weeks and possibly months." (Report Massachusetts State Board of Health, 1894.)

With reference to the effect of cold and snow upon irrigation or filtration beds, it is found that if snow falls before the ground is frozen, there is generally little trouble; but if the ground becomes frozen, the sewage usually freezes also if flowed over a flat surface in a thin stream. If, however, the land be deeply furrowed, there is little danger of the sewage freezing. If the land is only slightly porous, flooding to a depth of a foot or two will give satisfactory results. The sewage should be kept as warm as possible before discharging onto beds. There is little bacterial action when the temperature of the sewage is below 40 degrees; the temperature most favorable for rapid oxidation appearing to be 90 degrees; at about 130 degrees it entirely ceases.

Worms and burrowing animals occasionally give trouble by opening passages in the soil by which unpurified sewage reaches the drains. These have been driven out by flooding the land once or twice with very strong or septic sewage.

The sludge from the settling tanks is generally pumped or flowed upon beds set apart for this purpose, and each application is raked off after it has dried, and the deposit is left piled upon the surface to be burned. In a few plants the sludge is taken by farmers for fertilizer.

The cost of land for irrigation or filtration plants will of course vary with every city. To a certain extent the cost of preparing the plant also will vary, depending upon the character of the soil and the nature of its surface. Of several plants in this country, the cost of construction of those using natural soil was from $700 to $1500 per acre; and the cost of those constructed artificially of sand and gravel was from $1500 to $6000 per acre. Operating these plants cost from $75 to $100 per acre per year, or from $5.50 to $9.00 per million gallons.

ART. 80. CONTACT FILTERS. SLATE BEDS

An intermittent filter produces the purest effluent practically obtainable from sewage. But the rates are low; and in some cases a less pure effluent would be satisfactory if less area of land could be used. This is found to be impracticable with a fine-grain filter, but should theoretically be with a coarse-grain one. The latter, however, presents the practical difficulty of obtaining a uniform distribution of the sewage throughout the filter. If flowed on, as in the case of a fine-grain filter, the sewage passes through a small section only, near the point of application. To meet this difficulty, the contact filter was devised. In this, the sewage is allowed to fill slowly a bed composed of stones (generally of a size varying from pea to walnut), to stand in it while the suspended matter settles onto the stones or collects on them by surface adhesion, and is then withdrawn slowly; after which the bed is allowed to remain empty for a few hours to become reaërated and permit oxidation to take place. In many cases two hours is allowed for each step, or eight hours for a cycle.

The theory of action of these filters is as follows: " When the effluent flows from a filter, air is drawn into the filter again and fills the open space. Consequently a partial oxidation of the organic matter left within the filtering material proceeds until this oxygen is exhausted, when the open space is completely filled with the chief products of this oxidation,—namely, carbonic acid gas, marsh-gas, nitrogen of the air primarily present and nitrogen liberated during decomposition,—and the filter will remain with its open space filled with these gases until they are removed by the introduction of sewage or air. This condition reached, the activity of the oxidizing and nitrifying bacteria within the filter ceases and anaerobic actions begin, which change a considerable portion of the organic matter adhering to the filtering material into forms easily soluble and oxidized by the air introduced when the filter is again flooded." (Mass. State Board of Health, 1899.) If these filters are used in pairs, the effluent from the " first-contact filter " passing to the " second-contact filter," the action in the latter becomes almost wholly aerobic.

A contact filter consists of a pit, generally about 4 to 8 feet deep. The pits have generally been made watertight, but this does not seem to be essential; and experimental ones at Manchester were simply excavated from the soil, with side slopes of 2 to 1. On the bottom of the pit is laid a series of drains leading to a main outlet pipe, which is provided with a valve for regulating the flow of sewage from the filter. The pit is then filled with coke, coal, slag, cinders, gravel, burnt clay, glass, or other clean, insoluble material of fairly uniform size. Coke breeze gives excellent results, although it is liable to slow disintegration. The Manchester experts obtained their best results from clinkers passing through 1½-inch mesh and rejected by ⅛-inch; and this material is recommended by the Massachusetts Board of Health. Both of these bodies of investigators found that the contact beds had at first a water capacity of about 50 per cent, but that this was quickly reduced to about 33 per cent, at which it remained constant; the reduction being due partly to the growth of bacterial jelly on the surfaces of the filter material, partly to chaff, straw, and wood and cloth fibers. To prevent the filling of the filter by sand or other solid mineral matter, a pit or catch-basin should be placed above the filter, through which the sewage should flow at such velocity as to carry on all but heavy insoluble matter.

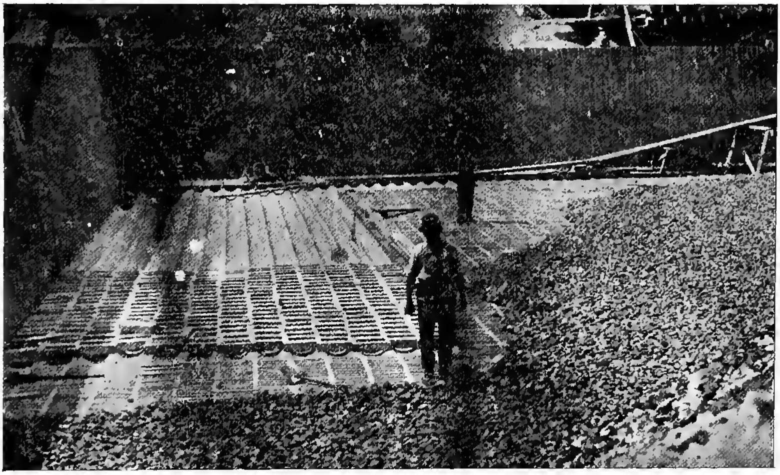

Fig. 71.—Floor Construction and Stone Filter Material. Contact Filter at Fitchburg, Mass.

As already stated, the operation of a contact filter consists in filling the filter, allowing it to remain full for a fixed time, emptying, and allowing it to stand empty; two hours being allowed for each operation in many cases. It was found at Lawrence that if the sewage stood but two hours in a single-contact bed which was filled once daily, the action during this time was anaerobic only, the aerobic action taking place while the tank stood empty. The rests between doses should not be long enough to permit the bacteria to die from lack of pabulum, but these should be preserved in the filter to work over successive doses. For this reason also the sewage should not be allowed to enter or leave the bed with so great velocity as to wash the bacteria out of the filter.

FIG. 72.—CONTACT BEDS WITH TILE PIPE DISTRIBUTORS AND HAND GATES.

In order to secure this rotation, it is necessary to hold the sewage in a tank between dosing periods, or else to have four or more beds to be closed alternately. In either case, the flow of sewage to the beds and of effluent from them must be controlled at intervals. This may be done by hand, or by automatic dosing appliances, of which there are several on the market.

If a contact bed is filled three times a day, and its interstices have a volume one-third that of the entire filter, it is evident that the daily capacity of the filter is its cubical contents. A filter 5 feet deep could therefore treat 37 gallons per square foot per day. Allowing for walls or embankments between filters and occasional resting or cleaning of beds, it is thought that 25 gallons per square foot per day, or, say, 1,000,000 gallons per acre, can be purified. If double contact is employed, as it should generally be, double the area will be required; or 500,000 gallons per acre per day can be rendered unputrescible; which was the conclusion reached by the Manchester Commission.

Double-contact filters, 6 feet deep, in London have removed practically all the suspended matter and 51 per cent of the dissolved putrescible organic matter, when receiving 600,000 gallons of crude sewage per acre per day. Dibdin in 1895 filtered through 3 feet of coke breeze the effluent from a lime-precipitation plant at the rate of 1,000,000 gallons per acre per day, the effluent from the contact filter containing 71 per cent less albuminoid ammonia and absorbing 77 per cent less oxygen than the precipitation effluent which was applied to it.

In tests at Columbus with both single and double contact, the effluents from the primary contact beds were putrescible for about one-third of the time; and those from the secondary contact filters were found putrescible about 25 per cent of the time; the rates being from 100 to 300 gallons per cubic yard per day, which was considerably reduced by periods of rest which were allowed at intervals. The tanks were 5 feet deep and the net rates of treatment varied from 0.5 to 2.38 millions of gallons per acre per day; averaging about 1¼ millions. No odor was noticed around the filters, and when the material was removed for cleaning the only odor noticed was that characteristic of garden soil. The percentage of suspended matter removed varied considerably, but averaged about 40 to 50 from crude sewage, and 60 to 70 from settled or septic sewage. Of the organic nitrogen the average removal was about 35 to 40 per cent. Of the bacteria the percentage of removal varied all the way from 0 to 60, averaging about 40. Of the applied nitrogen, there appeared in the nitrified form in the effluent of the primary filters from 4 to 11 per cent and in the effluents of the secondary filters from 17 to 21 per cent. An important feature was the uniformity of removal and the absence of any such unloading of stored material as is characteristic of sprinkling filters.

These filters had voids amounting to from 43.1 to 54 per cent of their volume at the beginning, which was reduced to from 31.9 to 45.8 at the end, these voids being somewhat greater than had been found in other cases. Both limestone and coke were found to suffer no disintegration or loss in weight during nine months of operation.

It was concluded that a safe daily rate to produce a non-putrescible effluent from Columbus sewage would be in the neighborhood of 600,000 to 700,000 gallons per acre per day of 5-foot bed. Aside from the benefits to be derived from a removal of the suspended matters, septic treatment offered practically no advantage as an adjunct to contact filter treatment; on the other hand no disadvantages appeared. It appeared to be virtually necessary in the successful operation of contact filters not only to encourage aerobic action at the expense of a diminished anaerobic and consequently reducing action, but to discharge the effluent from the filter before the nitrates previously formed should have been entirely reduced. Thereby through the nitrates there is obtained an active and efficient agent in the protection against ultimate putrefaction of the effluent.

Thorough drainage of a contact bed is of the first importance, both in order that time may be saved in removing the liquid contents and in order that the period of aëration may be as long as possible. For this reason also it has been found preferable to diminish the time of emptying and filling from the two hours originally proposed. At Columbus it was concluded that the rate of emptying should be as high as possible without creating undue mechanical disturbance within the filter, from one-half hour to an hour being considered sufficient for a filter 5 feet deep. So far as nitrification is concerned, the oxidation or resting empty stage is the most important. On the other hand, however, the resting full stage should be sufficiently long to secure as high a degree of clarification as is consistent with proper operation otherwise; but should not be so long as to foster anaerobic conditions.

When the filling up of the pores of a bed results from overworking and the consequent accumulation of organic matter and bacterial jelly, and not from silt and other mineral matters, it is generally preferable to restore the bed by resting empty or working at a very low rate rather than by removing the material and washing the same, since the latter will remove the bacterial jelly which is the agent of oxidation, and it will require several days or weeks to restore the bed to conditions of full activity. Practically all of these conclusions, reached at Columbus, are confirmed by actual experience with municipal plants in Ohio and elsewhere.

If no insoluble mineral matter reaches a contact filter and if the material of which it is composed does not disintegrate, it should act indefinitely, any lessening of capacity caused by overworking being remedied by resting or operating at low rates or with longer resting periods. Such resting periods should not take place in winter, however, if it can be avoided, on account of the lowering of the efficiency or even possible freezing caused by the entrance of cold air. To prevent this, methods have been adopted in some small plants of artificially heating the air, but the expense of this would seem to be greater than the advantage derived warrants.

Contact filters equipped with suitable appurtenances will average about $30,000 per acre for a bed 4 feet deep, and a slightly less cost per cubic yard for deeper beds.

Instead of double contact, a septic tank and contact filter are frequently used in series. Or a contact filter or double contact filtration may be followed by a fine-grain filter. The former combination was adopted at Plainfield, N. J.,* Lakewood, O., and other places. At Marion, O., were combined a septic tank, contact filter and sand filter operating in the way named.

Similar in many respects to contact beds, and yet differing from them in both construction and principles of operation are the slate beds which have been experimented with by Dibden and others since 1907. In these the basin or tank is filled with superposed layers of slate, the layers separated 1 to 3 inches by means of slate blocks; the whole thus forming an indestructible series of shelves on which the suspended matters of the sewage are deposited while the beds are standing full. The operation is practically the same as that of a contact bed, but the deposited material collects in more considerable masses, forming comparatively thick layers on the slate shelves, where it undergoes bio-

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* Plainfield changed to Imhoff tank and sprinkling filter in 1916.

logical action which is carried on not by bacteria only, but also by worms or other low forms of animal life. In addition to the sedimentation which takes place on the shelves, the finer suspended and colloidal matter is removed by surface adhesion as in contact filters. In an experimental bed at Belfast 95½ per cent of the suspended matter was removed. When the beds were filled once daily the albumenoid ammonia was reduced 47 per cent, and 34 per cent when filled three times daily. In these, as in the regular contact beds, the material collecting on the slate is worked over slowly, although the bacterial jelly of the latter is not in evidence in the slate bed and there seems to be a tendency to the formation of insoluble humus-like matter somewhat similar to that discharged from the sprinkling filter, a substance which gives off no offensive odor and is not putrescible. Owing to the construction of the slate bed it is a comparatively simple matter to remove practically all this matter from the slates or shelves by flushing water through it.

ART. 81. SPRINKLING FILTERS

As stated in the previous article, one of the chief reasons for intermittently filling and emptying the contact filter is the necessity of distributing the sewage matter uniformly throughout the filter. It is seen that in the contact filter, however, the conditions are alternately favorable to aerobic and to anaerobic bacteria, and consequently at intervals unfavorable to both; unless we assume that both liquefaction and oxidation are performed by facultative bacteria. Experiments with other kinds of filters indicate that better results would be obtained could the conditions be maintained uniformly favorable to one kind of bacteria; and since the filter as an appliance is better adapted to aerobic than anaerobic conditions, continuous operation under the former is desirable. To secure this in coarse-grain filters and at the same time obtain a uniform distribution of the sewage, two general methods have been adopted; one, to cover a porous filter with a mat or layer of fine material which can be kept covered with an inch or two of sewage and will allow it to trickle through at the desired rate; the other, by spraying the sewage or distributing it as a film from moving distributors over the entire surface. Experiments with the former have not often been satisfactory, although it is not certain that this method may not yet be developed along some more effective lines. The scattering of the sewage uniformly over the surface has been attempted by the use of a number of appliances with greater or less success. Among the earlier were numerous parallel troughs with notches along their edges, through which notches the sewage ran in minute streams or drops. One of the obstacles to proper distribution by this method is the difficulty of maintaining the troughs absolutely and continuously level, and another is the collection of filamentary and other fine suspended matter in the overflow notches, or the gradual accumulation thereon of mycelial growths. Somewhat better success was had with distributing the sewage in level wooden troughs, protruding vertically from the bottom of which were nails driven at regular intervals; the sewage overflowing the edges of the troughs in a thin sheet and following the outer surface to the nails, from which it dropped onto the bed below. Uniform and continuous distribution seems almost impossible by this method also, for much the same reasons as those just mentioned.

Believing the advantages of the system warranted the cost, a number of English managers have adopted methods of distributing the sewage over coarse-grain filters by moving appliances of various kinds. Some of these are in the form of troughs over which the sewage pours in a thin sheet, the troughs being moved slowly over the surface of the bed, either revolving around a central pin, the bed being circular, or travelling back and forth from one end of a rectangular bed to the other. In the latter case the distributing trough is moved by outside motive power; the revolving distributor may be moved by outside power or by the action of the sewage itself acting under a hydrostatic head. Among the revolving distributors the more common is one which sprays the sewage from one side of the arm, the reaction causing revolution as in a Barker's mill. There seems to be a general agreement that the moving distributors would not operate satisfactorily in the winter climates of the northern part of the United States, and we believe that only one moving distributor has been used in this country, that at Springfield, Mo.

Instead of these, in this country and in some English plants stationary sprinkler heads are used which spray the sewage through nozzles of various forms. At the Massachusetts Institute of Technology Experimental Station there was developed an additional kind of distributor in which the sewage flowed in a small stream from a pipe or trough onto a splashing disk or concave plate which scattered the sewage in a spray similar to that from a nozzle.

In all of these the aim is uniform distribution. The material of which a coarse-grain filter is composed is ordinarily 1 or 2 inches in diameter and there is little capillary attraction to distribute the sewage horizontally, experiments at Waterbury, Conn., having indicated that such horizontal distribution seldom exceeds 12 inches. If one-fourth the surface of the bed should be receiving no sewage, and one-half the remainder should receive it at double the average rate—which would be a condition by no means unusual—the last-named portion of the filter would be working at a rate $2\frac{2}{3}$ times as great as the nominal; and if it could do so satisfactorily, then the entire area could operate at the same rate and a correspondingly greater amount of sewage be treated per acre, if uniform distribution could be secured. This is the principal problem remaining to be solved in connection with the sprinkling filter.

The term just used, sprinkling filter, is that most commonly employed, because sprinkling has so far seemed to offer the best solution of this problem of distribution. Probably, however, trickling or percolating would be a more correct term, since the essential characteristic is not the method of distribution, but the fact that the distribution should be uniform at such low rates that the sewage will pass slowly in thin films over the filtering material, so that the pores within it shall always contain air for the oxidation of the organic matter. "As the sewage percolates through the filter, much of the suspended matter is deposited upon the surface of the particles of filtering material and thin

Fig. 73.—Sewage Being Sprayed onto Sprinkling Filter, Cleburne, Texas.

gelatinous films are formed about the grains of material. As in contact filters, it is these films which play an important part in the purification effected by the filter, due to their power of removing by absorption a certain proportion of the dissolved organic matters contained in the sewage and of acting as oxygen carriers.

" Largely due to the predominance of aerobic conditions within sprinkling filters, the deposited organic matter is gradually oxidized to a condition in which it has lost the power in a large measure of adhesion to the particles of filtering material. During periods of rest the oxidation of deposited matters is very rapid and coincident with the efficient drying out which is afforded the filter under favorable weather conditions. Due to these causes, when operation is again resumed, the films of stable suspended matter crack, peel, and are washed from the filters to the temporary detriment of the appearance of the effluent, but to the ultimate benefit of the filter. The removal from the filter in this manner of the deposited suspended matter means a less frequent removal of filtering material on account of clogging, as compared with contact filters, in which no such unloading takes place. As the sewage passes through the filter, constant contact of the sewage with the air is conducive to the highest degree of aerobic bacterial activity. During the active period of operation nitrates and nitrites are constantly being formed in the filters and washed out in the effluent, and serve in this way as a protecting agent against the ultimate putrefaction of the effluent, as do the considerable quantities of dissolved atmospheric oxygen which regularly escape absorption in passing through the filter. During periods of rest nitrification increases in intensity as in the case in contact filters, and the unstable organic matters which have accumulated in the filter are more or less thoroughly oxidized, depending upon the length of the resting period." (From " Report on Sewage Purification at Columbus, Ohio," by George A. Johnson.)

In the above quotation reference has been made to periods of rest. In order to bring about the unloading of the filter, or removal of suspended matter, which is one of the characteristics of the sprinkling filter, it has seemed best to those at Columbus to occasionally rest each filter bed from use for a few days, as explained. In experiments conducted at the Massachusetts Institute of Technology, however, it has been found best not to rest the bed; but that the same unloading takes place voluntarily each spring, apparently with the warmer weather which induces a more vigorous bacterial growth and action.

Rates as high as two or even three million gallons per acre per day have been satisfactorily treated on sprinkling filters in this country, both at Columbus and at Reading, Pa. If seems probable, however, as in the case of sand filters, that the rate should more correctly be expressed in terms of nitrogen to be oxidized than in mere gallons of fluid. Sewage from a population of 15,000 to 19,000 is treated satisfactorily on one acre of American sprinkling filters 7 feet deep.

Concerning the results obtained by a sprinkling filter, the following conclusions were derived from the Massachusetts Institute of Technology experiments: "It removes about one-half the soluble organic matter, yielding an effluent which is somewhat turbid, stable, and well oxygenated. The organic matter present has been so worked over and purified by the bacteria in the filter as to be non-putrescible. Judged by the methylene blue reduction test, 93 per cent of the samples of the effluent are of such stability as to undergo no putrefactive change when kept closed up from the air for four days. Under ordinary conditions of discharge into open water such an effluent would be entirely unobjectionable.

"With good distribution the trickling beds show no appreciable tendency to clog. During the greater part of the year solid matter accumulates on the surfaces of the stones throughout the bed, but when this storage reaches a certain point, usually in the early spring, the solids break away and come off in the effluent in a stable condition. In a period covering two years the total amount of solid matter coming off balanced that going on. The filtering material at the end of the experiments was in excellent condition and showed no storage of nitrogen."

It is to be noticed that the removal of suspended matter from sewage by a sprinkling filter is largely nominal, as there is no permanent storing of this and very little if any liquefaction; but the material removed, after being modified to a non-putrefactive form, is carried away with the effluent in flakes or patches which can either pass out with the effluent or be intercepted by a settling basin. Owing to this feature of the sprinkling filter it is necessary that the underdrainage be free and open in order that these large particles may find ready exit. In recent large plants, the drainage system has been so designed that it may be flushed out by a stream from a hose without removing the filtering material.

FIG. 74.—SPRINKLING FILTER DRAINAGE SYSTEM.

Distributor main in background. Distributor branches rest on the concrete posts shown. Broken stone is filled in up to level of tops of posts.

In several plants, arrangement is made for intercepting the suspended matter which leaves the filter in a settling-tank before discharging the effluent into a stream. Owing to the large particles a comparatively small tank with rapid flow will serve this purpose, one having a capacity of one hour's flow being used at Columbus. The matter here collected is not readily putrescible; but it is still organic, and if allowed to remain too long in the bottom of the tank it will begin to putrefy. It should therefore be removed at frequent intervals and may be used for filling in land. At Columbus advantage is taken of high water in the river to discharge this sediment directly into the stream at such periods. The amount of this deposit was found at the Massachusetts Institute of Technology Experimental Station to vary from 1.5 to 5.7 cubic yards per million gallons.

One of the objectionable features of the sprinkling filter is the rapid lowering of temperature of the sewage when sprayed through cold air. The effect of winter weather is therefore greater than in the case of other filters. The Columbus filters, for instance, were started in the winter, but it was not until June or July of the following year that normal oxidation became established; whereas four to six weeks should be sufficient time for the attainment of this. In spite of this, however, no greater difficulty has been experienced in operating stationary sprinkler filters through the coldest winter weather than is found with other filters; probably because the continuous operation prevents a thorough chilling of the filter surface, which chilling is possible during the rest periods of intermittent sand and contact filters.

In the construction of a sprinkling filter, the filtering material may be placed in a tank or pit or may be erected in a pile upon the surface of the ground, the material being retained within walls of concrete or masonry of open dry stone-work. The last has the advantage of affording additional opportunity for aëration and is ordinarily cheaper than the other. As the sewage simply percolates downward, there is no necessity for water-tight walls. A size of particles between ½ inch and 3 inches is believed to give the best results with sewage which has previously been well clarified. The finer the material the greater the surface area, but also the greater the tendency to clog with sediment. Some European authorities believe that uniformity of size throughout a bed is of more importance than the actual size of grain, as this gives the maximum interstitial space for the circulation of air.

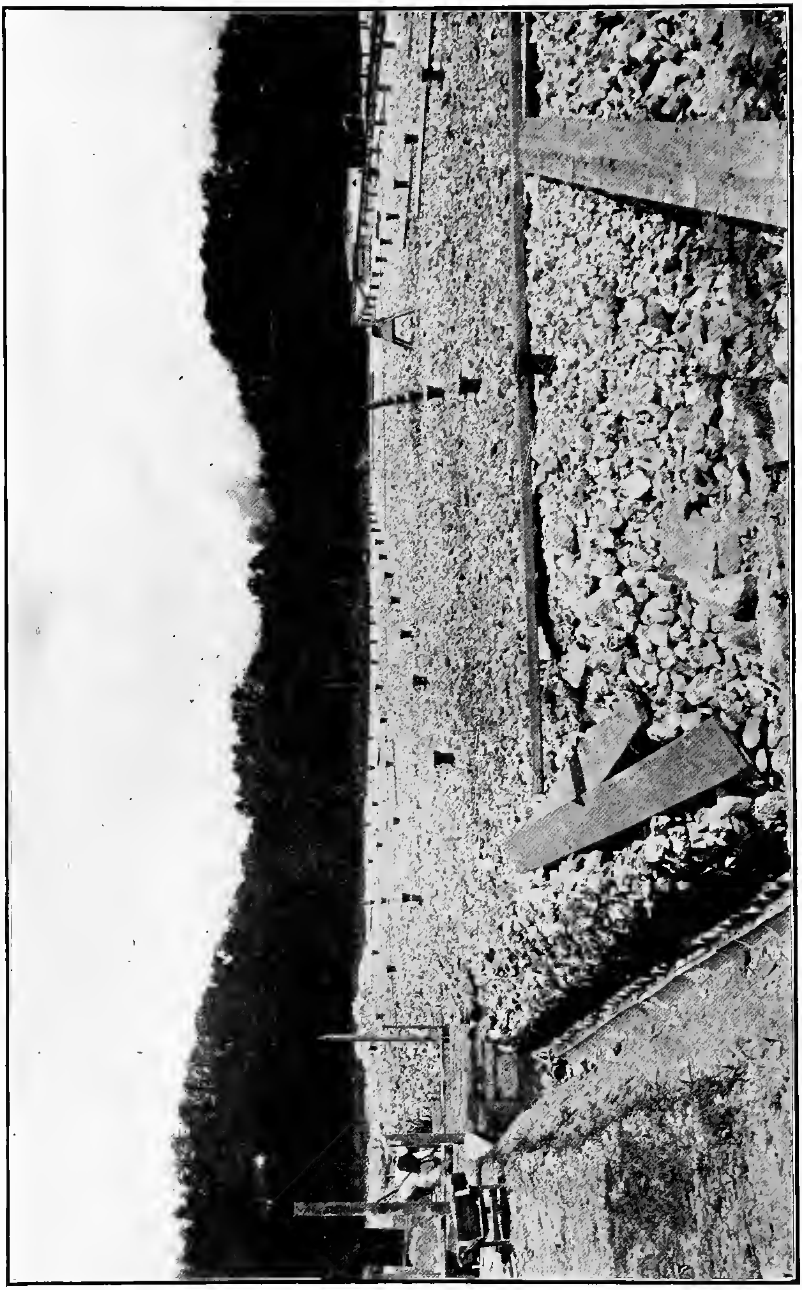

Fig. 75.—Sprinkling Filter at Reading, Pa.

Built above the ground, with dry-laid stone walls to retain filtering material. Risers show above stone, to which nozzles are to be attached.

The very important problem of uniform distribution is largely a mechanical and hydraulic one, and considerable advance has been made in its solution; but entirely satisfactory results have not yet been obtained. An ordinary nozzle directing spray vertically upward covers an area of bed which is circular in shape; and no combination of circles can be made to cover a square bed without overlapping, or leaving uncovered triangular spaces, or both. The same is true of the splashing disks previously referred to. In 1908 a patent was obtained for a nozzle which, owing to its peculiar shape, covers a square area with its jet.

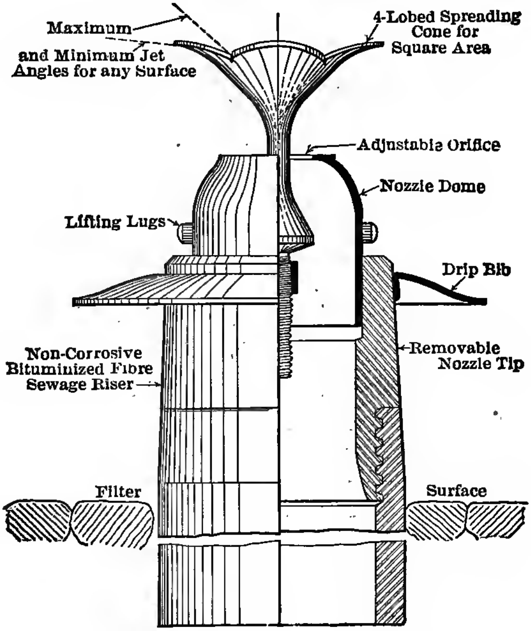

Fig. 76.—Nozzle for Covering a Square Area.

It is not only the shape of the wetted area, however, which prevents uniform distribution, but the fact that jets tend to concentrate the discharge in one or more rings concentric around the nozzle. This also can probably be overcome to a large extent by mechanical construction of the nozzle. Most recent plants, however, employ a varying head of the sewage applied, which causes the radius of the ring of spray to vary from a few inches to from 3 to 5 feet at regular intervals of time. This is brought about either by a butterfly valve worked by a cam, or more commonly by a dosing tank of the shape of an inverted truncated pyramid which is discharged by an automatic siphon. With the latter, the nozzles rest while the dosing tank is filling, begin to discharge at maximum radius and the ring of spray contracts as the tank empties.

The nozzles used consist in the majority of cases of a vertical opening above which is an inverted cone or similar surface which sprays the sewage in a more or less horizontal direction, as in the Columbus, Waterbury, and Birmingham nozzles; or one in which the jets issue from several openings placed at an angle with the vertical, as in the Salford. One of the chief difficulties in designing a satisfactory nozzle is obtaining a sufficiently small opening to furnish a discharge at the desired low rate, and at the same time to have it of such size and shape that it will not clog with fine suspended matter.

Probably the most exhaustive tests of nozzles and other distributors which have been made in this country were those conducted at the Massachusetts Institute of Technology Experimental Station. As before stated, there was devised at this station a method of distributing by splashing disks or saucer-shaped plates into which sewage was allowed to fall in a continuous small stream. Experiments were made with numerous styles and sizes of these, and the following conclusions concerning them were derived therefrom:

1. The discharge on each sprinkler should be in the neighborhood of four gallons per minute; this means, for a two-million gallon rate, 340 sprinklers per acre, with a distance between sprinklers of about 11 feet.
2. The head between the distributing trough or pipe and the filters should be as great as possible; 2 feet is inadequate, 4 feet gives fair results, and 6 feet is better.
3. The head on the sprinklers should be from 2 to 4 feet. The best subdivision of available total head can probably best be determined by experiments with the disks to be used in each individual case.
4. A simple concave disk of metal seems to produce the best efficiency.
5. The best diameter for the disks appears to be 3 inches. For low rates cf discharge smaller disks are better, and for very high rates or very high heads larger ones may be more suitable.

6. Unless the disk be too large it is of advantage to increase its concavity as much as possible. Of 3-inch disks, that having a concavity corresponding to a radius of 2 inches proved most satisfactory. The radius of curvature might profitably be increased toward the limiting value of $1\frac{1}{2}$ inches, which would make the disk a hemisphere. With larger disks larger radii of curvatures are necessary.

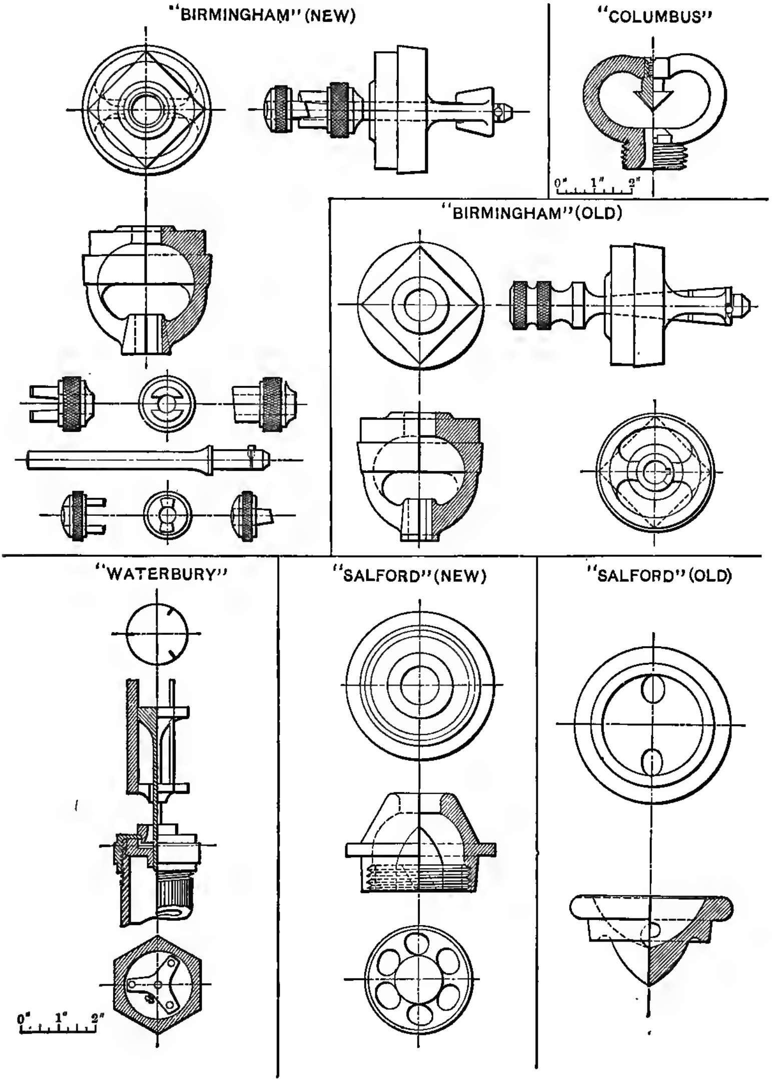

FIG. 77.—TYPES OF SEWAGE SPRINKLER NOZZLES.

A method of expressing efficiency of sprinklers was found necessary, and the one devised by Mr. Earle B. Phelps is suggested for general use for this purpose. In this method the area covered by the jet is divided into small collecting tanks, in which is collected the falling sewage. In this way the amounts falling at various known distances from the center or nozzle may be determined. If the quantity Q, collected in each small collecting tank be multiplied by the distance D, of its center from the center of the nozzle, the products will be proportional to the total amounts distributed in annular spaces entirely surrounding the nozzle and at the distance D from it. Plotting quantities Q as ordinates and the corresponding D values as abscissas, we obtain

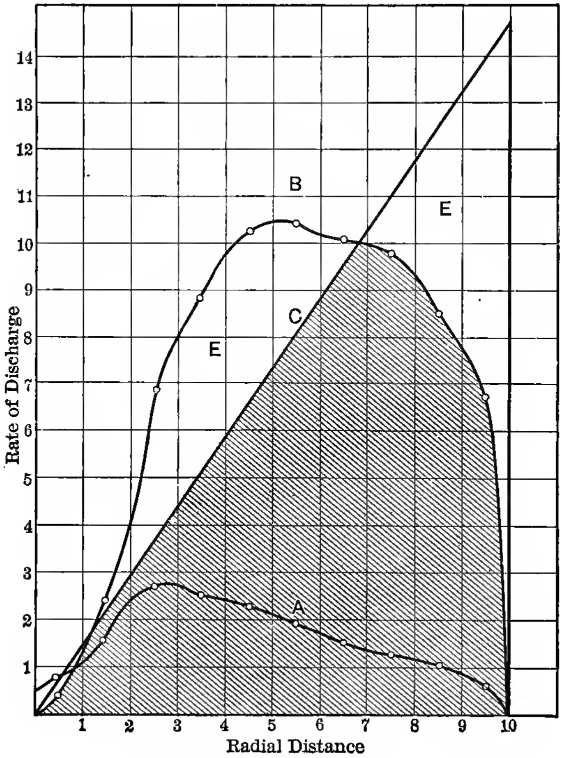

FIG. 78.—SPRINKLING FILTER DISTRIBUTION CURVES.

a curve showing the relative distribution of the sewage along the radius. This curve is shown at A in the diagram. It shows the rate of discharge per unit area at any point whose distance from the center is known, and is called the "curve of radial distribution"; and an ordinate to this at any distance from the center or point of origin shows the rate of discharge at all points on a circumference at that distance from the center. The products $D \times Q$ are also plotted as ordinates with the corresponding D values as abscissas and the curve B is obtained, called the "curve of distribution." The total area under this curve represents the total discharge from the sprinkler. Perfect distribution, being that at a uniform rate throughout the wetted area, would be represented by a straight line; and this line would enclose below it an area representing the total discharge from the sprinkler, or the same as that below B. The departure of the triangle last formed from the curve B shows the variation of the nozzle from perfect distribution. The area between these two is therefore the measure of that variation. This is called the "excessive discharge" E. The coefficient is then represented by the ratio between total discharge and total discharge minus excessive discharge; or by $\frac{T-E}{T}$. If E becomes zero the coefficient is one, or perfection. This coefficient Mr. Phelps calls the "distributor coefficient."

This gives a measure of uniformity of distribution within a circular area. This, however, must be modified to express the relation of the actual distribution to perfect distribution over the entire area of the filter. If each nozzle discharges a certain amount, and a certain quantity per area has been determined upon, the number of nozzles per acre and their distance apart are fixed. The most effective arrangement of these is to place them alternating rather than directly opposite each other; and if so arranged, with the circular wetted areas exactly tangent, there still remains about 10 per cent of the area which is not wetted. (With special nozzles covering a square area the whole bed may theoretically be wetted.) It may also be that the spread of the nozzle is not sufficient or is too great to produce exact tangency. Correcting the distribution coefficient for these various conditions, we obtain a corrected coefficient.

The best results of the Birmingham nozzle, as determined by the tests above referred to, gave corrected coefficients from 0.7 to 0.8. The Columbus nozzle gave corrected coefficients of 0.26 to 0.30. The Waterbury nozzle gave a maximum corrected coefficient of about 0.22. The new Salford gave 0.67 as the best corrected coefficient and the old Salford 0.41. The best splashing disk (also called gravity distributor) gave 0.62. These results were obtained by tests with clear water. Actual service has apparently indicated that the Birmingham nozzle, which gave the highest efficiency, is more liable to clog and act irregularly than is the Columbus nozzle. This matter of continuous action is fully as important as distribution coefficient. A nozzle should be not liable to clog or to become detached from its riser, should be sufficiently stout to retain its shape under rather rough handling and should be easily cleaned of mycelial growth, lint and other matters adhering to it.

Sprinkling filters are made from 6 to 10 feet deep, but the majority of engineers at present seem to consider from 6 to 7½ feet as the most effective and economical depth. The cost of a filter 7 feet deep will average about $45,000 per acre.

CHAPTER XVII

OTHER TREATMENT METHODS

Art. 82. Disinfection

Disinfection, or the direct destruction of bacteria, may theoretically be accomplished by one of several methods. Those proposed include heat, lime, acids, ozone, chlorine and its compounds, copper and its compounds, and a number of other substances, including permanganates. Heat is used for sterilizing or disinfecting small amounts of liquids, but would be entirely too expensive for sterilizing the enormous quantities of sewage which must be treated; at least by any method yet suggested. The amount of coal required to raise a million gallons of sewage from 60 degrees to the boiling-point would be about 40 tons, worth, say, $100. It has been proposed to recover a part of the cost by the sale of free ammonia distilled while boiling the sewage. The total amount of free ammonia in a million gallons will probably average from 50 to 100 pounds, and this, if concentrated to commercial strength of 28 per cent, would bring about 40 cents per pound. It would, however, probably be impossible to recover all of this. The net cost would therefore probably be at least $75 per million gallons.

Lime is apparently too weak a germicide for the purpose, the large quantities used in chemical precipitation seeming to have little effect upon bacteria except to precipitate them with the sludge. The use of acid promises better than that of alkalies, since bacteria, especially those of typhoid and cholera, are more sensitive to acids. Different investigators have found from 0.04 to 0.08 per cent of sulphuric acid to be fatal to pathogenic bacteria. The cost of the smaller amount of sulphuric acid, however, would be between $150 and $175 per million gallons. It is possible that with favorable conditions even smaller amounts would be sufficient to produce a very high rate of sterilization, but on the other hand any alkali in the sewage must first be neutralized before any effect could be obtained from the acid. Here again the expense is prohibitive. Ozone has been used with more or less success for sterilizing drinking water and could undoubtedly be used with sewage also; although it is probable that it would not be effective should the sewage carry large particles of suspended matter. Here again the expense, however, would seem to be prohibitive, as it has not yet been found possible to sterilize water economically by this method, and the amount of ozone required for sterilizing sewage would be much greater than in the case of water.

The substances which promise most favorably, both as to effectiveness and cheapness, are the compounds of chlorine and copper. The latter has been used successfully as an algicide for clearing reservoirs and lakes of vegetable growths; and it is known that copper salts and especially copper sulphate are highly disinfectant in comparatively small quantities. Probably the most exhaustive experiments which have been made with copper sulphate are those conducted by the Ohio State Board of Health at Marion, Lancaster, Westerville, and other cities. At the same time experiments were conducted with the use of chloride of lime or bleaching powder. Summarizing these experiments the State Board reported: "Very satisfactory results were obtained with both copper sulphate and chloride of lime. Copper sulphate appeared the more limited as regards its adaptability to practical conditions in that its efficiency is perhaps more dependent upon a high-grade sewage effluent, together with a required storage point of at least three hours. Chlorine as bleaching powder, on the other hand, requires less storage and is less susceptible to organic matter.

"The indications drawn from these studies were, briefly that a sewage effluent of a purity equal to that from efficiently operated intermittent sand filters may be disinfected as regards B. coli by the use of thirteen parts per million of copper sulphate (108 pounds per million gallons) with a storage of treated effluent of about three hours and at a cost for chemicals of about $6.48 per million gallons. Similar results with chloride of lime required about four parts per million of available chlorine (133 pounds per million gallons of bleaching powder containing 25 per cent available chlorine), under one hour's storage at a cost of $3.32 per million gallons.

"With less highly purified effluents, greater quantities of sulphate were required, 40 parts per million (334 pounds per million gallons) applied to the Westerville continuous contact filter effluent removing, however, about 99.3 per cent of the acid-forming colonies under about one hour's storage and at a cost for chemicals of about $20 per million gallons. Chloride of lime, on the other hand, under the application of lesser quantities appeared to be quite efficient for effluents of less stability than those from sand filters, results from the putrescible Marion contact filters showing a removal of 100 per cent of fermenting organisms with the use of five parts per million of applied chlorine at a cost for chemicals of $4.15 per million gallons."

Larger amounts were required for septic tank effluents, as high as 25 parts of available chlorine per million gallons removing 99.3 per cent of fermenting organisms. There were, however, indications that more thorough settling of the septic effluent or the addition of larger amounts of chlorine or both would have raised the percentage to practically 100. The prices given above were for chemicals only. The Board of Health has prepared an estimate based upon the cost of both chemicals and labor, but not including interest, depreciation, etc. This gives the annual cost of quite thoroughly disinfecting crude sewage at $18.55 per 1000 gallons per day; that of the effluent from contact filters at $11.77 per day for copper sulphate or $2.73 for chloride of lime; the effluent from sand filters at from $4.86 to $6.93 with copper sulphate and from $2.43 to $5.78 for chloride of lime; and the effluent from septic tanks at $8.83 with chloride of lime.

Still more extensive experiments have been conducted with chloride of lime by Mr. Earle B. Phelps, at the Experimental Station of the Massachusetts Institute of Technology, at Red Bank, N. J., and at Baltimore, Md.; the Red Bank experiments being conducted on 250,000 gallons per day of septic effluent and those at Baltimore on the effluent from a sewage previously treated by a septic tank and trickling filter. It was found that the Baltimore effluent could be satisfactorily disinfected by the use of about 75 pounds of bleaching powder per million gallons, the bacterial efficiency of this being 95 per cent, and the combined bacterial efficiency of sprinkling filter and bleaching powder being between 98 and 99 per cent. This amount of bleaching powder represents three parts per million of available chlorine. The cost of such treatment is estimated at $1.00 to $1.50 per million gallons. To remove 98 per cent of total bacteria from crude sewage, it was determined, would require from five to ten parts per million of available chlorine and cost from $1.50 to $3.50 per million gallons. It was also found from these experiments that the disinfection of septic sewage required from ten to fifteen parts of available chlorine. However, it would appear that it would be very advantageous to disinfect the sewage before septic treatment rather than after; this requiring less chlorine and being equally effective in destroying the pathogenic bacteria, but leaving in the effluent the liquefying and nitrifying bacteria to continue the purification after discharge into the stream.

Mr. Phelps has prepared a table of estimated costs of treating sewage and effluents of various kinds with bleaching powder, these figures being based upon a plant having a capacity of five million gallons per day, the cost given being that per million gallons. The treatment is classified according to amounts of available chlorine used, and these are considered to apply as above stated, namely, from two to five parts for filter effluents of varying quality; from five to ten parts for sewages, and from ten to fifteen parts or more for septic sewages.

It is seen that the costs of disinfecting by bleaching powder given by Phelps are only about one-third to one-fifth of those given by the Ohio Board of Health. A considerable part of this difference is probably due to the difference in size of the plants—five million gallons per day in one case as compared to from 40,000 to 160,000 gallons per day in the Ohio plants. Moreover, the bleaching powder is assumed in the Ohio report to contain but 25 per cent available chlorine, and to cost 2½ cents per pound. An estimate of the cost of a plant for one of these towns, with an assumed flow of 600,000 gallons per day, is given as $151 exclusive of arrangements for supplying water to dissolve the chloride of lime.

TABLE NO. 25

DISINFECTION OF SEWAGE AND EFFLUENTS

Average Chlorine, Parts per Million.	Bleach, Pounds per Million Gallons (Approximate).	Time of Contact, Hours.	Cost per Million Gallons.					
			Fixed.		Operating.			
			Storage Tanks.	Other Fixed Charges.	Bleaching Powder.	Labor.	Power.	Total.
1	25	5.0	$0.10	$0.02	$0.30	$0.10	.....	$0.52
2	50	2.5	.05	.04	.60	.10	.....	.79
3	75	1.6	.04	.05	.90	.10	$0.02	1.11
4	100	1.2	.03	.07	1.20	.10	.02	1.42
5	125	0.8	.03	.08	1.50	.10	.03	1.74
10	250	0.5	.02	.16	3.00	.15	.06	3.39
15	375	0.5	.02	.24	4.50	.20	.09	5.05

In applying chloride of lime or other disinfectant, time and thorough mixing are necessary. Heat also plays some part in the effectiveness of action. Certain experiments seem to indicate that it is better that the mixing of the disinfectant with the sewage should take place somewhat slowly and should continue throughout a period of an hour or more before the effluent is diluted by discharge into a stream.

The action of the chlorine is probably through the free nascent oxygen which it liberates from the water in which it is dissolved, the oxygen destroying the bacteria in the same manner as ozone would. It is for this reason that organic impurities in the sewage increase the amount of chlorine required, since a considerable part of the oxygen would be taken up by these rather than be used in destroying the bacteria. Chlorine is also obtainable as chlorine gas, and as oxychlorides, these existing in three forms, Cl_2O, Cl_2O_3, and ClO_2. Any of these could be used as a disinfectant, but the cost is greater than that of bleaching powder. Potassium and sodium permanganate have been used for the oxidation of organic matter in streams and in sewage as laboratory experiments. Apparently the only objection to their use is that either is more expensive than the chlorine compounds, without any greater efficiency.

Bleaching powder is manufactured chiefly by the electrolytic process at Niagara Falls and can be purchased at about one cent per pound guaranteed 40 per cent available chlorine.* This cost of 2½ cents per pound of available chlorine is equivalent to 21 cents per million gallons for each part of available chlorine. It has been suggested, and indeed some small plants have been operated upon the principle, that the chlorine might be manufactured from caustic lime by the application of electric current. As this is practically the method employed in the manufacture of bleaching powder at Niagara Falls, where current is unusually cheap, the process conducted on an enormous scale, and the bleaching powder merely a by-product, it does not seem at all probable that it will be possible to create chlorine electrolytically in the comparatively small quantities required in sewage disposal plants as cheaply as it can be purchased. There is an advantage in the chlorine gas generated in the sewage itself, however, in that it is more powerful and more fully available than the chlorine in bleaching powder, and it is possible that some method may be devised for the use of electricity for generating chlorine in the sewage itself.

During 1913 and 1914 apparatus was perfected for applying chlorine gas directly to water and sewage, the gas being purchased compressed into liquid form in steel containers similar to those used for charging soda water. The cost of material for a given amount of chlorine is somewhat greater than by the use of bleaching powder, but there is less waste and less storage room required. It seems probable that, to secure equal disinfection, the suspended matters in the sewage must be more thoroughly removed or comminuted when gas is used.

The use of electricity to decompose sea water, or a solution of

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* The European war has caused an increase of this price.

magnesium and sodium chlorides, has been used in this country under the name of the Woolf process at Brewsters, N. Y., and at Danbury, Conn., but in 1895 the latter place was enjoined from discharging the effluent from this treatment into the Still river, and adopted filtration in its place. At Brewsters 1000 gallons of water containing 160 pounds of salt was subjected to an electric current of about 700 amperes and five volts, the positive electrode being of copper plated with platinum and the negative of carbon, a 4-H.P. dynamo being used. One part of this solution was used in 100 parts of sewage, or $3.20 of salt to each one million gallons. Practically the same process was used in Bombay in 1897, but abandoned after four months' trial, it being found that the same amount of free chlorine could be obtained with chloride of lime at one-half the cost. (Recent use of electricity in sewage treatment will be referred to in the next article.)

It is noticed that Phelps refers to the destruction of only 98 to 99 per cent of the bacteria. It is found that, whatever method of disinfection or sterilization be employed, the use of comparatively small amounts will effect bacterial removal up to, say, 95 per cent; that double this amount would be required to increase this to 98 or 99 per cent; and that two or three times this latter quantity would be required for complete sterilization, if indeed this last would be possible with any practicable amount. This phenomenon was termed by George C. Whipple as that of a "resistant minority," there apparently being a certain very small percentage of bacteria in all sewages which are destroyed very much less readily than any of the others. Further investigation is necessary to determine whether or not this small resistant minority contains any pathogenic bacteria. There are some reasons for thinking that it does not. At any rate, the great addition to the cost required for destroying this last one per cent would not ordinarily be justified by the results obtained.

ART. 83. MISCELLANEOUS METHODS

Wave Filters

Special conditions or special ideas concerning sewage purification have naturally led to the designing and in some cases constructing of a number of variations on the methods and devices described in the previous articles. One of these is the "wave filter," which has been used in at least three or four plants in this country. At Kenton, Ohio, are three wave filters, each 10 feet wide and 100 feet long, filled with broken stone and pea coke, the stone being from 1 to 3 inches in diameter; the depth of the filtering material decreasing gradually from 2 feet at the upper end of the filter to 6 inches at the toe. Dosing devices discharge the sewage at the upper end of these filters into each, in rotation, and the sewage passes in waves or sudden flushes through the filter to the toe, where it flows through a number of 2×8¼-inch openings into an effluent channel. The dosing intervals were approximately five minutes. The filters are supposed to serve to aërate the sewage passing through them and to remove by straining and surface adhesion a large part of the suspended matter, which is oxidized after the draining of the filter at the termination of each dose. It was believed that the wave action would displace the carbcnic acid and nitrogen gases which would be formed in the pores during the periods of rest. The material was removed from each filter twice a year and spread on adjacent land in thin layers where exposure to sun, wind, and rain sufficed to restore it to such condition that, after screening, it was suitable for use again. The general experience here and in other plants appears to have been that these filters have not developed the efficiency expected, and their use has been quite limited.

Cultivation Filters

In the Scott-Moncrieff "cultivation filter" the sewage passes upward through the gravel or broken stone, leaving the solid matter behind, but carrying with it all matter liquefied from sludge previously deposited. Here the aim is to combine both liquefaction and nitrification in the same filter, the liquefying anaerobes being segregated in the lower part, the nitrifying bacteria in the upper, although the former class of bacteria sometimes occupies the entire filter.

A somewhat similar idea was used in an experimental septic tank by the Massachusetts State Board of Health; a septic tank being filled with coarse stone with the idea that these would assist in retaining permanently a larger proportion of the liquefying bacteria, and that less intermingling of the sludge with the effluent would take place. While there are some advantages found both in this and the Scott-Moncrieff tank, the cost and difficulty of removing and cleaning all the filtering material at the more or less frequent intervals when the sludge requires removal seems a serious objection.

Aëration of Filters

The idea of forcing air into a filter to secure more rapid and thorough oxidation has been made the basis of a number of types of filters. Colonel Ducat in England constructed a number of filter beds with porous walls and bottom, with the idea of supplying more oxygen for nitrification. The same idea is found in the sprinkling filters contained within dry stone walls, as previously described. One objection found to this is that the large amount of outer air which enters the filter in winter cools the sewage below the temperature most favorable to bacterial action. Lowcock, an Englishman, placed in a sand filter a layer of coarse gravel at about one-third of its depth from the top, and through this gravel laid a number of perforated pipes, through which a blower forced air continuously, the mingled air and sewage passing downward through 4 feet of coke or gravel to sub-drains; only a slight pressure being required in the blower. The object of this construction was to render unnecessary the rest and aërating of sand filters. The same result was the aim of Colonel Waring, who established at Willow Grove Park, Philadelphia, and at Homewood, Brooklyn, filters in which air was forced through porous tile laid in the bottoms of the filters; the former plant treating strained sewage at the rate of 640,000 to 800,000 gallons per acre per day; the latter treating 245,000 gallons per acre of strainer and filter combined.

Another and cheaper method, although less positive in action, is the use of ventilating hoods, held towards the wind by vanes, the hoods being fastened to the top of vertical pipes which connect with and discharge the air into the under drains; the under drains being trapped so that the air will be forced to rise upward through the filter, rather than escape through the outlet. A calculation based on Dr. Rideal's experiments indicates that even from slight winds there is a material benefit to be gained when air is forced with little pressure into the under drains. In none of these forced-air plants would much benefit be derived unless the filter grains be quite coarse and the pores correspondingly large, as the friction opposed to the air by fine-grain sand beds would require considerable pressure and probably result in the formation of blow holes. However, actual experiments along this line are too few to permit of definite conclusions; except that where the air is pumped in the cost of operating the air pump or fan is too great in proportion to the benefit derived; also the retarding of bacterial action when the air introduced has a low temperature is a serious objection. (Ventilating hoods for admitting air to the bottom of a sprinkling filter are seen in Fig. 73.)

To overcome this objection of low temperature, Whittaker and Bryant in 1898 constructed in Accrington, England, a "thermal aerobic filter," somewhat similar to Ducat's in construction, but in which jets of steam sprayed into the sewage raised the temperature in both summer and winter to that most favorable to bacterial action.

Electrolytic Treatment

Several so-called electrolytic plants have been built in this country; two, at Santa Monica, Cal., and Oklahoma City, respectively, about the year 1910. None of these was thoroughly tested by experts and their value was doubted by most. A new process was tried in 1914 and 1915 in Brooklyn, N. Y., and reported on by three experts, including Prof. Wm. P. Mason, who found that it reduced the turbidity from 41 to 7 and the color from 47 to 19, reduced the oxygen consumed by 50 per cent and the bacteria by 99.8 per cent. The effluent looked like water and was without odor. The sludge was large in amount, but remained non-putrescent for four days or more by the methylene blue test. The plant consists of a tight box 23¼ feet long, 3 feet wide and 2¾ feet deep, and a sedimentation tank. In the box or enclosed flume are 1100 iron plates $\frac{3}{16}$ of an inch thick, hung vertically parallel to the sides of the box, assembled in sets like the plates for a storage battery. The sewage passes between these plates, which serve as electrodes, the electric current passing from one to the next through the sewage. Between each two consecutive plates is a pair of paddles which are revolved about 18 times per minute to reduce polarization, keep the active surfaces of the electrodes clear of deposits and mix the sewage and lime rapidly and thoroughly. Lime was added at the rate of 1300 pounds per 1,000,000 gallons, or nearly as great an amount as the sludge contained in the sewage. The effect of the electricity is apparently to accelerate and intensify the action of the lime. The sewage occupied about one minute in passing through the electrodes and four hours in the sedimentation tank (which time could probably be shortened by better-designed tanks). The removal of bacteria is much greater than by lime alone. There is an appreciable amount of oxidation, probably due to the nascent oxygen created by the electricity. It was suggested by the experimenters that the current caused an agglutination of colloidal particles. The cost was estimated to be at the rate of $25.08 per million gallons for a one-million-gallon unit and $17.17 for a three-million-gallon; electricity costing 4 cents per kw.h., lime $7.90 per ton, and labor $75 a month. The sludge in Brooklyn is pressed, but could be used for filling low land.

Mills Acid Treatment

Experiments in the use of sulphur dioxide have been made on Boston sewage by E. S. Dorr and R. Spurr Weston, with particular reference to the recovery of grease and fertilizer. The method of treatment is patented and is known as the "Mills" process. It was found that one ton of sulphur dioxide per million gallons of sewage produced, after settling 8 hours, 6.7 tons of sludge, 85.8 per cent moisture. By further settling for 26 hours there can be obtained 4 tons of concentrated sludge, 80 per cent moisture, in a condition suitable for pressing. The advantage claimed for the use of sulphur dioxide is the thorough separation of the grease from the sewage and the low moisture in the sludge. Up to the present (1918) this process has not been adopted for any operating plant.

Rapid Sand Filters

The success obtained with the use of rapid sand filters in the purification of river water quite high in sediment has led to the suggestion of their use for purifying sewage, or at least the effluents from tank processes. The only actual experiments along this line which are known of are those conducted by the Massachusetts State Board of Health in 1906 and 1907. The effluents from six experimental trickling filters were treated with copperas and lime in varying amounts, also with sulphate of alumina, sugar sulphate of iron (a new form of ferrous sulphate), and some other substances. "The experiments indicated clearly that satisfactory removal of color, turbidity, and a considerable proportion of the organic matter may be accomplished by coagulation with sulphate of alumina, or with one of the three forms of ferrous sulphate mentioned, combined with lime; this to be followed by filtration at rates of 25 million gallons per day or somewhat higher in filters of the mechanical type. The removal of from 90 to 99 per cent of the bacteria occurred only when the removal of suspended matter was practically complete. The cost of coagulants necessary to produce an effluent free from suspended matter was so large when iron salt and lime were used and the volume of water filtered between washings was so small as to make the process apparently impracticable. The results obtained during the early portion of the experiments indicated, however, that clarification might be produced at less cost with sulphate of alumina than with either of the iron salts tested, for the reason that much larger amounts of the cheaper iron salts must be used; they require, furthermore, the addition of lime."

Clarification Tanks

Some modifications of the ordinary sedimentation tanks other than the Dortmund tanks have been designed from time to time, but we believe none of these have come into general use other than those already referred to. One of the most promising of the new inventions removes the effluent not through an orifice or weir at the end, but by placing across the tank at close intervals a series of parallel troughs whose edges are all at the same level and which connect with the outlet channel. The sewage thus, instead of all flowing over one weir, flows over the edges of these troughs, each edge of which has a length equal to the entire width of the tank. This produces a very gradual motion of the sewage distributed uniformly over the entire tank. This, of course, could not be used for retaining any scum or floating material, but would only serve for retaining the sediment or sludge. The only plant of this kind known of on this continent was built in Chilliwack, British Columbia, in 1914, with a nominal capacity of 600,000 gallons per day. (*Municipal Journal*, May 20, 1915.)

One or two small plants in Germany have used a clarification tank which is placed above the level of the sewer, the sewage being raised into it by the siphoning action of the departing sewage leaving it on its way to the outlet. The necessity for having the tank absolutely watertight and the other expenses of construction would, it would appear, more than compensate for the saving in not having to excavate for the tank in order to place it underground where the flow could be by gravity. This style of tank is known as the Kessel.

ART. 84. DISPOSAL OF SLUDGE

It is shown in the preceding articles that all tank methods of treatment, and other treatment which is not preceded by a pretty thorough removal of suspended matter, produces a sludge or other accumulation of organic matter. In fine-sand filters most of this is strained out upon the surface or within the top inch or two. In coarse-grain filters it collects within the body of the filter, but is generally so modified as to lose its putrescibility to a large degree. This suspended matter offers really the most serious problem connected with sewage disposal, and one of which no satisfactory solution has yet been found.

The sludge from precipitation tanks is merely concentrated sewage matter which has undergone little change. That from septic tanks has been worked over by bacteria to a considerable extent and a large part of the more putrescible matter has been liquefied and discharged with the effluent; so that the remaining matter is high in carbons and in the more resistant nitrogenous matter. It is therefore less offensive and more easily disposed of. Moreover, a large proportion of the pathogenic bacteria have died out. The matter strained out by fine-grain sand filters is generally in a fairly dry state and frequently contains considerable quantities of fibrous matter such as cloth, paper, wood fibers, etc.; and this matter forms a thin, more or less continuous sheet over the filter, frequently resembling a felt or papier maché. This matter can be removed easily with rakes or spades, but putrefies readily if again subjected to moisture. The solid matters from sprinkling filters, and to a less extent from contact filters, have been so modified as to have lost considerable of their tendency to putrefy, and are considerably more stable than septic effluent.

There is manurial matter of value in the sludge of precipitation tanks and to a less extent in other sludges, but no process has yet been found by which its value can be utilized at a profit. One of the difficulties is that sludge, although concentrated sewage, still contains a very large percentage of water. Glasgow sludge was found to contain 4.63 per cent of organic matter, 5.60 per cent of mineral matter, and 89.77 per cent of water. Septic sludge contains somewhat less water and also yields up its water content more readily. The addition of lime to sludge to "cut the slime" permits the more ready exclusion of water.

One of the principal advantages claimed for the Imhoff tank is that the sludge is more easily disposed of and less offensive than that from plain sedimentation or septic tanks. If care is taken to withdraw only the thoroughly digested sludge, it gives off a little odor similar to that of damp loam containing freshly decayed leaves and woody matter; and it dries out in a few days if spread not more than a foot deep on a drained sludge bed, owing chiefly to the creation of drainage pores by the escape of gases, which gases the sludge absorbs in considerable quantities while in the tank because of the pressure created by the depth of the sewage above it.

Activated sludge gives promise of having more value than any other, but no operating plant has yet (March, 1918) actually marketed any. The Milwaukee plant received offers from two firms manufacturing fertilizer to pay $9 to $12 per ton of dry sludge for such sludge as the experimental plant was turning out; an analysis of which showed it to contain 4.48 per cent. of nitrogen; 7.60 per cent of fat; 0.50 per cent of insoluble phosphoric acid and 1.34 per cent of available phosphoric acid; 5.45 per cent of ammonia, and 0.23 per cent of potash. If the sludge contains 50 per cent moisture, the cost of drying would be about $3 per dry ton (there is apparently about one dry ton per million gallons of sewage treated), the sludge being dewatered much more easily than Imhoff sludge.

Several German plants and at least one in this country (Baltimore) pump the sludge from a sedimentation tank into separate sludge tanks, where it is allowed to remain and digest. A scum forms on the surface, beneath which there is more or less active fermentation and decomposition. From time to time new sludge is added and digested sludge withdrawn onto sludge beds, where it dries rapidly, like Imhoff sludge. Part at least of the Baltimore sludge so treated is sold to farmers. It is inoffensive and may be used for filling low land.

London maintains a number of sludge ships, each carrying 1000 tons, which each day carry more than 300 million gallons of sludge 50 miles to sea and dump it there. Some cities discharge septic sludge into rivers during high water, Columbus finding that a dilution of 800 volumes of water to one of sludge prevents a nuisance. Probably the most common method of disposal, however, is to drain the sludge off onto sludge beds, these being beds of sand or other porous soil, of ashes or other porous artificial material, the bed being surrounded by a low bank for retaining the liquid sludge. Here the water is allowed to drain away and the solid material when comparatively dry is raked up and either burned, used for filling in low lands, buried in pits and covered over with soil, or in some cases has been used as fertilizer. The drying sludge, especially when from plain precipitation, may give off considerable odor, and in some cases a better plan has been found to be to furrow the land quite deeply, run the sludge into these deep furrows, and return the earth to the furrows as soon as the sludge has partially drained. Much of the odor may be avoided by sprinkling chloride of lime over the drying sludge.

The quantity of sludge which would accumulate from a large plant is enormous, and the amount of land which is required for sludge beds is considerable. Instead of sludge beds for removing the water, filter presses are used in a number of cases, especially in connection with chemical precipitation. The filter press is composed of a number of circular or square iron plates, each face of which is grooved and recessed, which rest vertically face to face in a simple frame and slide away from each other on horizontal guides. Between each two plates is a canvas bag. Through these plates passes a central feed passage through which the sludge is forced into the canvas-lined cells thus formed, the water being expelled through the canvas by a pressure in the feed-pipe of about 100 pounds per square inch. It is seen that this is really a method of extracting the water by forcing it out through a canvas bag which retains the suspended matter within it. By this method the amount of contained water is reduced from 90 to 95 per cent to from 45 to 65 per cent. The cakes thus formed are sufficiently solid to be handled, although when dumped into cars or likewise treated in bulk they generally break into masses of several cubic inches each. In Worcester the cakes thus formed are 36 inches in diameter and 2 inches thick. They give off little odor and will burn in a crematory without other fuel. In most cities of this country the cakes are dumped on low land, where they undergo more or less slow putrefaction, but give little offense. The fluid forced out by the press is very foul and is generally removed to the sewer for treatment with the crude sewage.

There are few figures showing the cost of pressing sludge into cakes separate from the other costs connected with chemical disposal. Such as there are seem to indicate that the cost of pressing is about 50 to 75 cents per ton of cake containing 50 per cent moisture.

The Dickson process (first employed on a large scale in Dublin) consists essentially in adding 0.5 per cent of yeast to liquid sludge, allowing it to ferment for 20 to 24 hours at a temperature of 90 degrees to 94 degrees F. and then, when the sludge floats, drawing off the underlying liquor. This reduces the sludge to a consistency suitable for handling, although still containing 80 per cent of moisture.

In a report published in 1908 by the Ohio State Board of Health, the disposal of septic sludge in that state is described, and may be summarized as follows: The removal and disposal of well-digested sludge from a septic tank is not an objectionable undertaking and does not possess so many disagreeable features as might at first be supposed. Provided sufficient time is allowed for a partial digestion of the sludge, there appears to be no particular difficulty or odor connected with the operation. The sludge is inky black in color, homogeneous, and granular, and when allowed to dry oxidizes rapidly and takes a form closely allied to humus matter. In some plants it is pumped by a centrifugal or dredge pump; in others it is thicker and is shoveled into buckets. Where it is thinnest a contractor's diaphragm pump has been used for raising it from the tank. There is usually a considerable saving in expense if a sludge drain is provided for draining it off by gravity onto a sludge bed; but in some cases there is no ground sufficiently low available for this purpose. At one plant the mixed sludge and supernatant sewage is removed by a steam siphon comprising a one-half inch steam pipe and four-inch discharge pipe. At Shelby, Ohio, a plant is used which is considered very satisfactory for small plants. It comprises a bucket conveyor which is placed over the tank on a platform erected for that purpose, by which the sludge is raised by hand power and discharged through a trough into a tank wagon from which it is sprinkled onto the surface of grassed land. The entire contents of the tank, about 7700 gallons, is previously stirred with a pole, and the liquid flows readily both into and from the wagon.

The amount of sludge varies considerably in the different Ohio plants, largely owing to the differences in the amount of suspended matter which is carried over with the effluent. It is probable, however, that the amount will average about three cubic yards of accumulated sludge per million gallons. In most plants the sludge is discharged by drain, bucket, or otherwise upon beds of coarse sand, fine cinders, coke or ashes. It seems desirable to underdrain such beds so that the liquid portion may be drained off as soon as possible and thus hasten the oxidation of the solid residue. Where the sludge required to be removed by hand, the cost in the Ohio plants was found to be about 50 cents to $1.00 per cubic yard. Where regular arrangements are made for draining it off or otherwise removing it by special fixed appliances, the cost in large plants elsewhere has been as low as 5 cents per cubic yard.

In practically all chemical precipitation plants, where machinery is required for the daily processes, pumps are provided for removing the sludge, which is drawn off into a suction well or sludge pit by means of pipes from the sedimentation tanks furnished with valves for regulating their use.

The material removed, largely by screening, from the sewage of the Metropolitan system of Boston before pumping is compressed into blocks which are burned as fuel under the boilers. This was found to burn out the brick-work very rapidly in the externally-fired boilers but to have no effect upon the steel plates;

in consequence of which, internally-fired Scotch boilers have been adopted, the combustion chambers being made of steel plates with water spaces, and with no brick-work except in the bridge walls and around the fire doors.

The amount of sludge removed by the various processes has been referred to in the previous articles. Average raw sewage contains about 200 parts per million of suspended matter, or, say, one cubic yard per million gallons, and double this of compressed sludge or ten to twenty times that amount of wet sludge. A very large percentage of this remains to be disposed of, whatever the treatment, unless it be carried away with the effluent. In Worcester, Mass., one part of sludge is obtained from 90 parts of sewage, there being one ton of solid matter to 750,000 gallons of sewage, 34 per cent of this being organic matter. With a lime precipitant there would be about 0.4 of a pound of sludge per capita daily. The experiments with Columbus sewage gave 5.75 cubic yards of wet sludge (87 per cent water) per million gallons removed by plain sedimentation; and about the same deposited in septic tanks, which was reduced to 2.68 cubic yards by hydrolysis. By chemical precipitation 11.4 cubic yards of sludge, 92 per cent of water, was obtained, or about the same amount of solid matter.

ART. 85. SUMMARY

The methods of treatment described produce effluents differing widely in quality. They use materials of construction of various kinds; some require areas many times larger than others. Some involve a fall or loss of head of only a few inches, others of several feet. Some are best adapted to fresh sewage, some to stale, and others to sewage containing large amounts of trade wastes. (Special methods are required in many instances for the treatment of trade wastes, especially those high in fats, fibrous or other carbonaceous matter.) Where anything approaching complete purification is necessary, a combination of two or even three methods is generally most effective and economical. Which methods should be employed can be properly decided only after a careful study of the conditions.

For a high degree of purification, only one practicable method is known—intermittent sand filtration. For high bacterial purification, either intermittent filtration or disinfection following clarification may be used. For producing non-putrescible effluents, the sprinkling filter seems to be the most effective and economical of area, although double-contact filters give excellent results and are probably cheaper in construction.

In connection with any of the above except intermittent filtration, some preliminary treatment is necessary to remove the coarser suspended matter; and this is advisable with fine-grain filters also, although the sand which composes these strains out upon the surface most of the suspended matter. For such preliminary treatment, screens followed by sedimentation are generally best. The sedimentation tank may be operated as a septic tank, by which the sludge is reduced in volume, and that remaining is less offensive and contains much fewer pathogenic bacteria. Fine-grain filters used for final treatment, however, seem to clog up more rapidly and deeply with septic than with plain sedimentation effluent.

The structural features require engineering skill combined with knowledge of the principles of the physical and bacterial actions taking place. The best arrangement of the several parts will usually be determined to some extent by the topography of the site. The fact that the preliminary processes require less area than the final has suggested a general circular form, the sewage progressing radially from the center outward through concentric tanks or beds; but in most cases the arrangement is such that the sewage advances in parallel lines from one end of the plant to the other.

The matter of applying the sewage to filters is a detail which varies in different plants. In the case of sprinkling filters, pipes may be laid on the bottom, with a riser to carry each nozzle set vertically in a T; or the distributing pipes are sometimes laid on the surface of the bed, with the sprinkler heads screwed directly into them; but the more common practice in this country is to set them on concrete posts of such height that the pipe is just below or at the surface of the bed, and attach the sprinkler nozzles

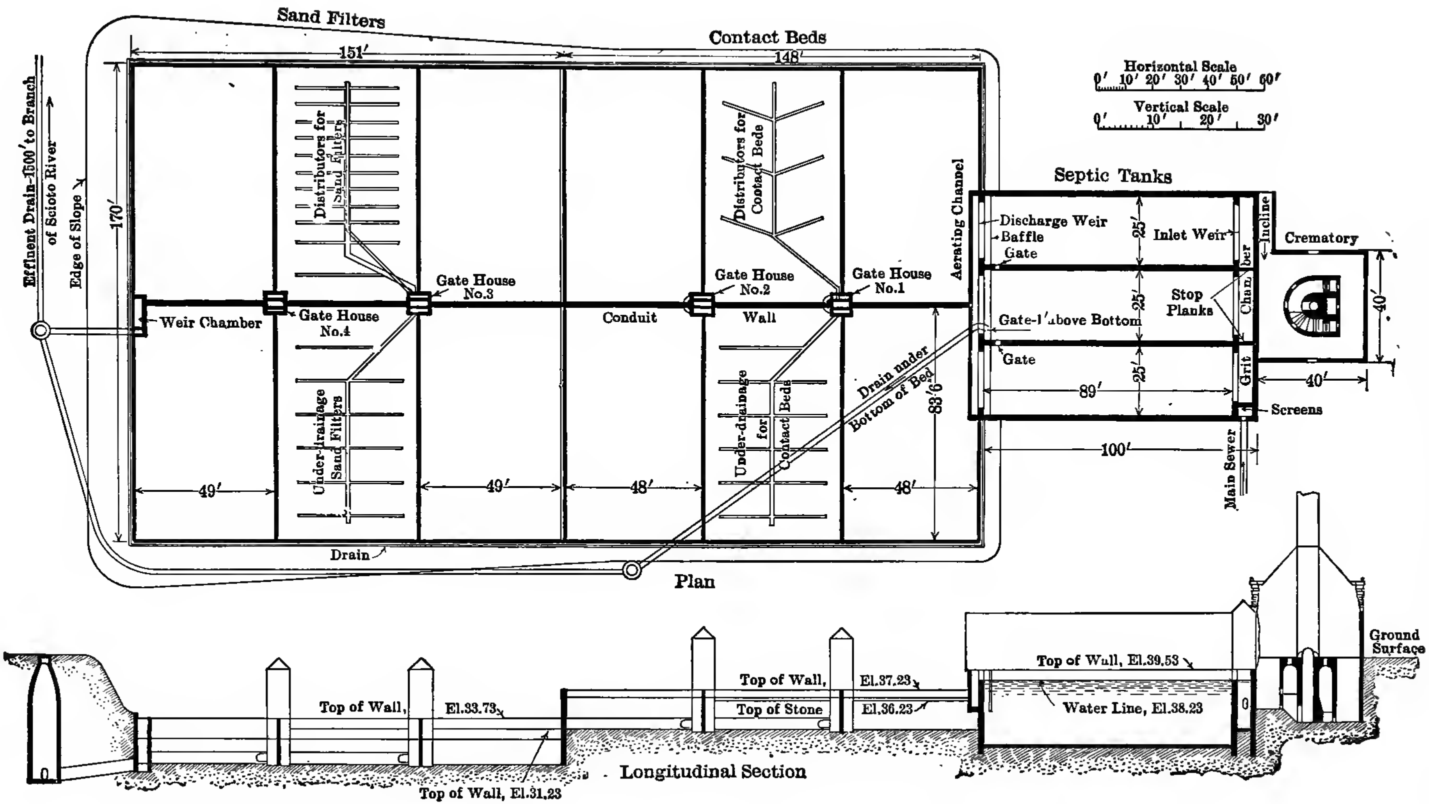

FIG. 79.—PLAN AND SECTION OF SEWAGE TREATMENT PLANT AT MARION, O.

either directly or by means of short nipples. The pipes should be arranged in straight lines with removable plugs at each end so that they can be cleaned out if necessary.

Contact beds are not always provided with arrangements for distributing the sewage; but fine-grain filters, if filled by a slow stream from one point only, would be apt to pass most of the sewage through the bed near that point. For this reason distributors, generally in the form of troughs, are laid across the bed. Wooden troughs are most common, and last four or five years. Split sewer pipe are used, also. These must be laid practically level so that the sewage will flow over their edges for their entire length. These troughs sometimes radiate from the inlet, or may be parallel and provided with outlets or branches at intervals so as to reach all parts of the bed, the troughs being spaced 10 to 25 feet apart.

Where the sewage is flushed on in doses, distributors are not often necessary, but a slab or apron is placed extending for 2 to 5 feet around the outlet to prevent wash. Dosing devices of various kinds have been used, perhaps the most common being siphons similar in action to automatic flush tanks. Also various arrangements of tipping tanks are used, air compressed by the rising sewage, and other contrivances for alternating the flow from one bed to another. Generally a dosing tank or chamber is provided which, as it fills each time, is discharged to different beds in succession. This necessarily involves a loss of head equal to the depth of the dosing tank.

Constant-flow tanks involve a loss of head of only an inch or two; intermittent flow, the depth of the tank. All filters require a loss of head equal to their depth, which should generally be at least four or five feet. Sludge beds must be at least two or three feet lower than the surface of the sewage in the tanks if the sludge is to be drawn out by hydrostatic pressure, and lower than the bottom of the tanks if it is to be drawn off by gravity.

Securing a uniform rate of flow at all points in each cross-section of a tank is very important, is never secured perfectly but deserves the most careful consideration. Any construction which reduces available area (such as a baffle extending above the sludge or a scum board extending below the scum, or a slotted inlet) increases velocity, and this velocity, in slowing down again, produces eddies and cross and vertical currents which prevent sedimentation and stir up sludge. In most tanks there are currents, straight or winding, having several times the theoretical velocity of flow through the tank. Narrow tanks help to remedy this, but the perfect solution remains to be found.

After leaving the sewer of approach, the sewage should flow in open channels at all points, or in channels whose tops can be removed; or at least, if pipes are used, they should be so arranged that every point is accessible for cleaning out.

A fault in most tanks is that the channels are rough, with square angles, and discharge over weirs; each of which encourages deposits, which in turn help to make the plant offensive. Smooth channels with rounded bottoms, like a good sewer, should be provided, and the outlet should be through several branches whose bottoms are no higher than the bottom of the channel, or through a slot in the bottom, or of some other form which will prevent deposits in the channel.

Arrange all parts of the plant so that they can be flushed off and kept clean; avoid wood or other absorbent material in contact with sewage and keep all woodwork painted white or varnished; plant shrubbery around the grounds, especially to conceal unsightly parts of the plant, sod all banks, and in general try to make the plant and surroundings attractive. See that all sewage matters are confined to the insides of the tanks and filters. Water piped to the plant under pressure is desirable to assist in keeping it clean, and for breaking up and settling scum on Imhoff and other tanks.

Sewage treatment plants need not be particularly offensive in any feature except the sludge disposal, but this can hardly help but offend the senses. Fine-grain filters, however, if intelligently operated, create only dry sludge which can be burned or otherwise disposed of inoffensively; and many of these are operated near residences without creating a nuisance. But in general it will be necessary to arrange for the treatment and disposal of wet sludge at a distance from any built-up section.

In most cases such a location would be chosen in any event, because of the necessity for obtaining cheap land, since considerable areas are required.

The cost of filtration plants cannot be estimated very closely without definite knowledge of the amount of grading necessary, and of the local cost of sand, gravel, broken stone, coke and similar materials. Each acre of filter five feet deep contains 8067 cubic yards of filter material, and this has in most plants cost from \$1 to \$2 in place. In a considerable number of plants fine sand filters are made by stripping the top soil from natural sand beds and placing under-drains by trenching. In coarse-grain filters, however, this is not possible; unless a bed of coarse and perfectly clean gravel be available for a sprinkling filter—a formation which is very rare. The distributing pipes and nozzles for 10 acres of sprinkling filter at Columbus, O., cost \$27,700, and the filtering material in place (80,120 cubic yards) cost \$125,800. Six septic tanks in the same plant having a combined capacity of 8,020,000 gallons cost \$66,730, of which \$48,070 was for reinforced concrete, \$12,530 for sluice gates, and the balance for earth work, scum boards and miscellaneous. The total cost of septic tanks, sprinkling filters and settling

FIG. 80.—NEAT SEWAGE TREATMENT HOUSE
Screening and disinfecting plant at Atlantic City.

basins, with gate house, piping and all appurtenances, for purifying 20,000,000 gallons in 24 hours cost $456,350 or $22,820 per million gallons per day. The following table, compiled from data collected by the Ohio State Board of Health, gives the cost and other data of the plants in that State:

TABLE No. 26

DESCRIPTION AND COST OF MUNICIPAL PURIFICATION PLANTS IN OHIO

(From Report of Ohio State Board of Health, 1908)

Place.	Population		Rate of Sewage Flow, Gallons per 24 hours.		Preparatory Treatment.			
							Tank Treatment.	
	Total.	Tributary to Sewers	Average.	Maximum.	Screening.	Grit Chambers. Capacity, Gallons.	Kind.	Capacity, Gallons.
Alliance.....	14,000	6,500	1,600,000	2,170,000	Iron bars.	....	Chemical.	120,000
Ashland	7,500	3,000	340,000	1,000,000	....	3,780	Septic.	39,000
Canton	50,000	23,500	2,500,000	3,100,000	Iron strips.	....	Chemical.	700,000
Clyde.......	2,800	1,050	172,000	360,000	....	....	Sludge boxes.	
Columbus ...	190,000	......	12,670,000	21,400,000	Cage and vertical.	....	Septic tanks.	 8,020,000
Delaware ...	10,000	4,000	433,000	1,000,000	Iron bars.	3,300	Septic.	100,000
E. Cleveland.	8,000	7,000	365,000	2,000,000	None.	64,000	Septic.	170,000
Fostoria.....	10,000	5,000	277,000	489,000	Iron strips.	None.	None.	....
Geneva	2,500	1,200	181,000	450,000	None.	7,500	Septic.	39,000
Glenville....	9,000	6,500	1,200,000	3,000,000	Iron strips.	None.	Chemical.	184,000
Kenton	400	400	18,000	260,000	None.	None.	Septic.	18,800
Lakewood...	10,000	7,000	500,000	3,540,000	None.	None.	Septic.	300,000
London.....	4,000	500	50,000	....	None.	3,500	Septic.	34,700
Mansfield ...	24,000	12,000	1,000,000	3,000,000	W. I. bars.	6,000	Septic.	1,000,000
Marion	19,000	8,000	650,000	2,000,000	None.	19,300	Septic.	414,000
Oberlin	5,200	3,400	250,000	1,000,000	None.	None.	Sludge pits.	6,700
Plain City...	1,800	725	175,000	720,000	None.	None.	Septic. Sludge pits...	12,500 7,700
Shelby......	6,000	1,600	238,000	1,000,000	None.	None.	Reservoirs.	1,660,000
Westerville..	1,500	300	36,000	200,000	None.	None.	Septic.	22,000
Xenia.......	10,000	......	375,000	....	None.	None.	Sludge pits.	9,500

TABLE No. 26—*Continued*

Place.	Purification Devices.								Construction Cost Exclusive of Land or Pumps.	Cost of Operation (not Including Pumping) Annual.
	Primary.					Secondary.				
	Kind.	Filtering Material.			Population Tributary per Acre.	Filtering Material.				
		Kind.	Depth, Inches.	Area, Acres.		Kind.	Depth, Inches.	Area, Acres.		
Alliance	....	....	....	.....	......	....	.....	.....	$22,000	$3,600
Ashland	Sand.	Sandy gravel.	26	4.99	600	None.	.....	.....	*5,000	300
Canton	....	....	....	.....	......	....	.....	.....	26,545	3,375
Clyde	Sand.	Clayey sand.	48	2.70	390	None.	.....	.....	1,000	135
Columbus	Sprinkling filters.	Broken stone.	64	10	19,000	Settling basins.	52	3	456,350	.....
Delaware	Contact.	Coke.	36	0.66	6,000	None.	.....	.....	12,000	Nothing.‡
E. Cleveland	Strainers.	Slag.	30	0.168	42,000	Sand, coke, broken stone.	60 to 66	0.248	23,092	.....
Fostoria	Sand, sand trenches and land.	Sand and clay soil.	36	20	250	None.	.....	.....	†21,300	1,000
Geneva	Sand.	Sand and gravel.	48	0.62	1,940	None.	.....	.....	13,500	700
Glenville	Strainers.	Gravel, coke.	36	0.372	17,500	Sand.	36	1.0	10,000	3,000
Kenton	Strainers.	Stone.	24	.....	......	Coke, stone.	6 to 24	0.069	4,000	111
Lakewood	Contact.	Gravel, cinders.	60	0.625	11,200	None.	.....	.....	24,175	250
London	Contact	Coke.	36	0.25	2,000	None.	.....	.....	15,000	Nothing.‡
Mansfield	Contact.	Cinders.	57	1.25	9,600	None.	.....	.....	35,720	2,750
Marion	Contact.	Stone.	33	0.55	14,500	Sand and fine stone.	36	0.55	43,000	1,125
Oberlin	Land.	Loam.	36	5.25	650	None.	.....	.....	990	500
Plain City	Contact.	Cinders.	36	0.07	10,400	None.	.....	.....	†19,000	190
Shelby	Cinders.	Cinders.	18	0.57	2,800	None.	.....	.....	4,000	700
Westerville	Contact.	Coke.	36	0.126	2,400	Cinders.	72	0.022	2,900	Small.
Xenia	Gravel.	Gravel.	36	1.47	......	None.	.....	.....	6,000	.....

* Including cost of land. † Includes sewerage system.

‡ Attention of regular sewer superintendent not charged.

ART. 86. SEWAGE TREATMENT PLANTS IN THE UNITED STATES

The table given herewith, prepared by the Author, is believed to be the only one ever compiled which gives anything like a complete list of the sewage disposal plants in the United States. The information was obtained from State boards of health when possible. Where obtained from other sources, this is indicated by an asterisk.

TABLE NO. 27

SEWAGE TREATMENT PLANTS IN THE UNITED STATES

Municipal Plants

Cities Operating Sewage Treatment Plants.	General Description of Plant.	Population Served.
ALABAMA		
Birmingham*........	Septic tanks..............................	....
ARIZONA		
Douglas*...........	Septic tank..............................	....
Phœnix*...........	Septic tank..............................	....
Tucson.............	Broad irrigation..........................	....
ARKANSAS		
Camden............	Septic tank..............................	....
Eldorado...........	Three septic tanks........................	....
Eureka Springs.......	Septic tank and filter beds.................	....
Fayetteville..........	Septic tank and filter bed..................	....
Little Rock*.........	Septic tank..............................	....
Russellville..........	Septic tank..............................	....
Stuttgart............	Septic tank..............................	....
Texarkana...........	Septic tank and filter beds.................	....
Texarkana...........	Septic tank..............................	....
CALIFORNIA		
Anaheim............	Imhoff tanks, public and private sewer farms..	2,628
Auburn.............	Septic tanks..............................	2,376
Bakersfield*.........	Septic tank..............................	....
Bishop..............	Septic tanks and sewer farm................	1,190
Boulder Creek.......	Septic tanks..............................	544
Chico..............	Imhoff tank; public sewer farm............	3,750
Clovis..............	Septic tanks..............................	1,000
Coalinga...........	Septic tanks..............................	4,199
Colfax.............	Septic tanks..............................	621
College Park Sanitary District B.........	Septic tanks, chemical disinfection..........	2,500
Colusa.............	Septic tanks..............................	1,582
Concord............	Septic tanks..............................	703

TABLE NO. 27—*Continued*

Municipal Plants—Continued

Cities Operating Sewage Treatment Plants.	General Description of Plant.	Population Served.
CALIFORNIA—*Cont'd.*		
Corning	Septic tanks and sewer farm	972
Corona	Septic tanks, public sewer farm	3,540
Dinuba	Septic tanks, sub-surface irrigation	970
Dixon	Septic tanks and contact beds	827
East San Diego	Septic tanks	500
East San Jose	Septic tanks	1,661
El Centro	Septic tanks, public sewer farm	1,610
Eldridge*	Tank	....
Elsinore	Septic tanks and sewer farm	488
Escondido	Septic tanks	1,334
Fortuna	Septic tanks	833
Fresno*	Settling tanks	....
Fullerton	Imhoff tanks and public sewer farm	1,725
Gilroy	Septic tanks	2,437
Hanford	Septic tanks, public and private sewer farms	4,829
Healdsburg	Septic tanks	2,011
Hemet	Septic tanks and sewer farm	992
Hermosa Beach	Septic tanks	679
Imperial	Septic tanks and public sewer farm	1,257
Lakeport	Septic tanks	870
Larkspur	Septic tanks (part only)	594
Lemoore	Septic tanks and public sewer farm	1,000
Lincoln	Septic tanks	1,402
Lindsay	Septic tanks, public sewer farm	1,814
Livermore	Septic tanks	2,030
Lodi	Septic tanks, contact beds, and sand filters	2,697
Long Beach	Septic tanks	17,809
Los Banos	Septic tanks	745
Los Gatos	Septic tanks	2,232
Madera	Septic tanks and public sewer farm	2,404
Marysville*	Sewage farm	....
Merced	Septic tanks	3,102
Mill Valley	Imhoff tanks	2,551
Modesto	Septic tanks	4,034
Monrovia	Septic tanks	3,576
Monterey*	Septic tank	....
Mountain View	Septic tanks	1,161
Napa	Septic tanks	5,791
Newport Beach	Septic tanks	445
Newman	Septic tanks	892
Orange	Septic tanks and private sewer farm	2,920
Orland	Septic tanks and public sewer farm	836
Oroville	Septic tanks	3,859
Oxnard	Septic tanks	2,555
Pasadena*	Septic tank and sewage farm	....
Petaluma*	Septic tank	....
Pleasanton	Septic tanks and sand filters	1,254
Porterville	Septic tanks and sewer farm	2,696
Redondo Beach	Septic tanks	2,935

TABLE NO. 27—*Continued*

Municipal Plants—Continued

Cities Operating Sewage Treatment Plants.	General Description of Plant.	Population Served.
CALIFORNIA—*Cont'd.*		
Rio Vista	Septic tanks	884
Riverside	Septic tanks	15,212
Roseville	Septic tanks	2,608
St. Helena	Septic tanks	1,603
San Jose*	Septic tank and contact beds	....
San Luis Obispo	Septic tanks	5,157
Santa Ana	Septic tanks	8,429
Santa Clara*	Septic tank and sewage farm	....
Santa Cruz	Septic tanks	11,146
Santa Maria	Imhoff tanks and public sewer farm	2,260
Santa Monica	Electric treatment	7,847
Santa Paula	Septic tanks	2,216
Santa Rosa*	Septic tank and sewage farm	....
Saratoga Sanitary District No. 1	Septic tanks and private sewer farm	400
Sebastapol	Septic tanks	1,233
Selma	Septic tanks and public sewer farm	1,750
Sisson	Septic tanks	636
Sonoma	Septic tanks	957
Susanville	Septic tanks	668
Taft	Septic tanks	2,000
Tracy	Septic tanks and private sewer farm	1,200
Tulare	Septic tanks and public sewer farm	2,758
Turlock	Septic tanks and public sewer farm	1,573
Ukiah	Septic tanks	2,136
Vacaville	Septic tanks and public sewer farm	1,177
Venice	Septic tanks	3,119
Willits	Septic tanks	1,153
Willow	Septic tanks and public sewer farm	1,139
Winters	Imhoff tanks	910
Whittier	Septic tanks and public sewer farm	4,550
Yreka	Septic tanks and contact filters	....
COLORADO	No disposal plants known of.	
CONNECTICUT		Gallons Treated per Day.
Bristol*	Filters	....
Danbury*	Sand filters and broad irrigation	1,500,000
Litchfield	Sand filters and broad irrigation	....
Manchester	Intermittent filters and broad irrigation	....
Meriden*	Sand filtration	....
New Britain*	Sand filtration	7,000,000
Norfolk	Intermittent sand filters	....
Ridgefield	Sand filters	....
Rockville	Septic tanks and contact beds	....
Simsbury	Sand filters	....
So. Manchester	Sand filters	....

TABLE NO. 27—*Continued*

Municipal Plants—Continued

Cities Operating Sewage Treatment Plants.	General Description of Plant.	Gallons Treated per Day.
DELAWARE	No disposal plants known of	
DIST. OF COLUMBIA*	Settling basin, screens and skimming tank	....
FLORIDA		
De Funiak Springs		....
Fort Meyers		....
Gainesville*	Septic tank	....
Jacksonville		....
Key West		....
Lake City		....
Live Oak		....
Ocala		....
Orlando		....
Pensacola		....
St. Petersburg		....
Tallahassee*	Septic tank	....
Tampa		....
GEORGIA		
Atlanta*	Imhoff tanks and sprinkling filters	....
Decatur*		....
ILLINOIS		
Aledo	Sedimentation and percolating filters	....
Arlington Heights	Sedimentation and intermittent sand filters	200,000
Barrington		....
Belleville*	Septic tank	....
Bushnell*	Septic tank	....
Canton*	Septic tanks	....
Carthage	Two-story sedimentation and percolating filters	100,000
Champaign*	Septic tank	....
Charleston*	Septic tank	....
Collinsville	Septic tanks, two plants	....
De Kalb*	Septic tanks	....
Dixon*	Septic tank	....
Downers Grove*	Settling tank and sand filters	....
Du Quoin*	Septic tanks	....
Edwardsville	Septic tanks	....
Galva	Two plants, sedimentation and trickling filter; two-story sedimentation, trickling filter and sludge bed	70,000
Glencoe*	Septic tank	....
Harvard	Sedimentation tanks and intermittent sand filters	200,000
Herrin*	Septic tanks	....
Highland Park*	Septic tank	....
Hoopeston	Septic tank	5,000 p
Jerseyville*	Settling tank	....
Kewanee*	Septic tank	....

p = Population served.

TABLE No. 27—*Continued*

Municipal Plants—Continued

Cities Operating Sewage Treatment Plants.	General Description of Plant.	Gallons Treated per Day.
ILLINOIS—*Continued.*		
La Grange	Septic tanks and sprinkling filters	6,000*p*
Lake Forest*	Septic tank	....
Libertyville	Septic tanks	150,000
Macomb	Septic tank	....
McLeansboro*	Septic tank	....
Monmouth*	Settling tank	....
Mt. Vernon*	Septic tank	....
Napierville*	Settling tank	....
Newton*	Septic tank	....
Paris*	Septic tank	....
Polo*	Septic tank and contact beds	....
Princeton*	Septic tank	....
Upper Alton*	Septic tank	....
Urbana*	Septic tank	....
Wheaton	Septic tank	3,500*p*
Winnetka*	Septic tank	....
Woodstock*	Septic tank and filters	....
INDIANA		
Angola*	Tank, contact beds and sand filters	....
Bedford*	Tank discharging into a cave	....
Bloomington*	Tanks, beds, sprinkling filters and settling basin	....
Gary*	Septic tanks and filter beds	....
Richmond	Tanks and filter	....
IOWA		
Albia*	Imhoff tank and filters	....
Belle Plaine*	Septic tanks and sand filters	....
Carroll*	Septic tank and sand filters	....
Cascade*	Septic tanks and sand filters	....
Centerville*	Septic tank	....
Clear Lake*	Septic tank and sand filters	....
Corydon*	Tanks	....
Des Moines*	Septic tank and sand filters; two plants	....
Dewitt*	Septic tanks and sand filters	....
Fairchild*	Imhoff tank and filters	....
Guthrie Center*	Septic tanks and sand filters	....
Knoxville*	Septic tank and filter	....
Marion*	Septic tank and sand filters	....
Mason City	Imhoff tanks and sprinkling filters; two plants	....
Mt. Vernon*	Tank and sand filters	....
New Hampton*	Septic tank and sand filters	....
Oelwein*	Septic tank and sand filters	....
Oscaloosa*	Septic tank	.....
Osceola*	Septic tank	....
Pella*	Tank	....
Perry*	Septic tank	....
Reinbeck*	Septic tanks and sand filters	....

p = Population Served.

TABLE NO. 27—*Continued*

Municipal Plants—Continued

Cities Operating Sewage Treatment Plants.	General Description of Plant	Gallons Treated per Day.
IOWA—*Continued.*		
Sheldon*	Septic tank and sand filters	....
Storm Lake*	Septic tank and sand filters	....
Tipton*	Septic tanks and sand filters	....
Traer*	Tank	....
Valley Junction*	Tank	....
Waukon*	Tank	....
West Liberty*	Tank and sand filtters	....
KANSAS		Population Served.
Baldwin	Two plants, septic tanks and contact filters	....
Burlingame	Imhoff tank and contact filter	1,422
Burlington	Septic tank	2,180
Caldwell	Septic tank	2,205
Cherryvale	Septic tank and contact filters	4,304
Coffeyville	Two septic tanks	3,064
Columbus	Two plants, septic tank and contact filter	2,545
Council Grove	Imhoff tank and contact filter	1,300
Erie	Septic tank	2,333
Eureka	Septic tank	....
Fort Scott	Septic tank	10,463
Fort Leavenworth*	Septic tank	....
Fredonia	Septic tank	3,040
Garnett	Two plants, septic tank and contact filter	2,334
Girard	Septic tank and contact filter	2,446
Great Bend	Septic tank	4,622
Halstead	Septic tank	1,004
Harper	Septic tank and contact filter	1,638
Hays	Septic tank	1,961
Herington	Septic tank	3,273
Hiawatha	Septic tank and sub-irrigation	2,974
Hoisington	Septic tank	1,975
Holton	Septic tank and contact filter	2,842
Horton	Septic tank and contact filter	3,600
Humboldt	Septic tank	2,548
Independence	Septic tank and contact filters	10,480
Iola	Septic tank	9,032
Le Hunt*	Septic tank	....
Lyndon	Septic tank and contact filter	763
McPherson	Septic tank and Imhoff tank	3,546
Marion	Septic tank	1,841
Newton	Septic tank	7,862
Osage City	Septic tank and contact filters	2,432
Osborne	Septic tank	1,566
Oswego	Septic tank and contact filters	2,317
Overland Park*	Septic tank and filter (not in operation)	....
Parsons	Two septic tanks	12,463
Peabody	Septic tank	1,416
Pratt	Septic tank	3,302

TABLE NO. 27—*Continued*

Municipal Plants—Continued

Cities Operating Sewage Treatment Plants.	General Description of Plant.	Population Served.
KANSAS—*Continued.*		
Sabetha	Two plants, septic tanks and contact filters	1,768
St. John*	Septic tank	....
Sedan	Septic tank, not in use	1,211
Seneca	Septic tank and contact filter	1,806
Stafford	Septic tank and contact filter	1,927
Valley Falls	Imhoff tank	1,129
Washington	Septic tank	1,547
Wellington	Two septic tanks	7,034
Yates Center	Septic tank and contact filter	2,024
KENTUCKY		
Berea	Septic tank	....
Danville	Septic tank	....
Franklin	Septic tank	....
Hopkinsville	Septic tank	....
Mt. Sterling*	Septic tank	....
Murray	Septic tank	....
Nazareth	Imhoff tank and sprinkling filter	....
Shelbyville	Septic tank	....
Silver Grove	Septic tank	....
Versailles*	Septic tank	....
Winchester	Septic tank	....
LOUISIANA		
Lake Charles	Septic tanks	....
Opelousas	Screens, grit chamber, Imhoff tanks, percolating filters, sludge beds	....
MAINE	No purification plants known of	....
MARYLAND		
Baltimore	Main plant: screen chamber, hydrolytic and sludge digesting tanks, revolving screens, sprinkling filters and final settling basins. Imhoff tanks now being added and capacity otherwise increased. May be disinfected	....
	Forest Park Plant: Hydrolytic and sludge digesting tanks, sprinkling filters and final settling basins	....
	Walbrook Plant: Imhoff tanks, sprinkling filters and final settling basins	....
Easton	Two plants, settling tanks and hypochlorite disinfection	....
Ridgely	Septic tank and hypochlorite disinfection	....
Roland Park	Jones Falls Plant: Intermittent sand filters	....
	Stony Run Plant: Imhoff tank	....

TABLE NO. 27—*Continued*

Municipal Plants—Continued

Cities Operating Sewage Treatment Plants.	General Description of Plant.	Gallons Treated per Day
MASSACHUSETTS		
Amherst	Sand filters, settling basins	....
Andover	Sand filters, settling basins	210,000
Attleboro	Sand filters	300,000
Billerica	Sedimentation and sand filters	....
Brockton	Revolving screen, trickling filters (for part of sewage only), humus tank and sand filters	1,752,000
Clinton	Sand filters, settling basins	1,057,000
Concord	Sand filters	395,000
Easthampton	Sedimentation and sand filters	360,000
Fitchburg	Five Imhoff tanks, trickling filters and secondary settling tanks	....
Framingham	Sand filters	637,000
Franklin	Sedimentation and sand filters	90,000
Gardner	Sand filters, two plants, one with settling tank.	705,000
Hopedale	Settling tank and sand filter	90,000
Hudson	Settling tank and sand filter	245,000
Leicester	Settling tank and sand filter	....
Lenox	Settling tank and sand filter	....
Longmeadow	Settling tank and sand filter, two plants	80,000
Marion	Sand filter	95,000
Marlborough	Settling tank and sand filter	880,000
Maynard	Sand filters	16,800
Medfield	Settling tanks and sand filters	....
Milford	Settling tanks and sand filters	433,000
Natick	Sand filters	666,000
No. Attleboro	Settling tanks and sand filters	640,000
Northbridge	Settling tanks and sand filters	260,000
North Brookfield*	Broad irrigation	....
Norwood	Settling tanks and sand filters	450,000
Pittsfield	Sand filters	1,921,000
Southbridge	Settling tanks and sand filters	840,000
Spencer	Sand filters	410,000
Stockbridge	Sand filters	....
Westborough	Sand filters	400,000
Worcester	16 chemical precipitation tanks for night sewage only, sand filters for day sewage	11,480,000
MICHIGAN		
Cadillac	Septic tanks (new plant contemplated)	700,000
Caro	Septic tanks and sand filters	72,000
Coldwater	Septic tanks	2,000,000
Charlevoix	Septic tank	....
Durand	Septic tanks and sand filters	....
Harbor Springs*	Septic tank	....
Holland*	Septic tank	....
Ithaca	Septic tank and sand filters	....
Jackson	Septic tank and sand filters	....
Petoskey	Septic tank	....
St. Johns	Natural sand filters	....
Sturgis	Septic tank and horizontal flow contact filters.	....
Tremont	Septic tank	4,600

TABLE NO. 27—*Continued*

Municipal Plants—Continued

Cities Operating Sewage Treatment Plants.	General Description of Plant.	Population Served.†
MINNESOTA		
Ada	Septic tank	1,432
Alexandria	Septic tank	3,001
Anoka	Imhoff tank	3,972
Baudette	Septic tank	897
Bemidji	Septic tank	5,099
Blackduck	Imhoff tank	942
Blooming Prairie	Imhoff tanks (2) and sand filter	854
Bovey	Septic tank	1,377
Canby	Septic tank	1,528
Chatfield	Imhoff tank	1,228
Chisholm	Imhoff tank, trickling filter and resetting tank.	7,684
Claremont	Imhoff tank	275
Coleraine	Septic tank	1,613
Crosby	Septic tank	....
Deer Wood	Imhoff tank	586
Detroit	Septic tank	2,807
Elbow Lake	Septic tank	776
Ely	Imhoff tank	3,752
Eveleth	Imhoff tank	7,036
Fairmont	Septic tank and sand filter	2,958
Farmington	Imhoff tank	1,024
Gaylord	Imhoff tank	610
Gilbert	Imhoff tank and trickling filter	1,700
Glencoe	Imhoff tank	1,788
Glenwood	Septic tank	2,161
Hallock	Septic tank	910
Janesville	Imhoff tank	1,173
Kasson	Imhoff tank	932
Kelliher	Imhoff tank	294
Lake Crystal	Imhoff tank	1,055
Litchfield	Imhoff tank	2,333
Madison	Imhoff tank	1,811
Maple Lake	Imhoff tank	522
Mapleton	Imhoff tank	809
Morris (Agricultural College)	Septic tank	1,685
Pipestone	Imhoff tank and trickling filter	2,475
Proctor	Imhoff tank, trickling filter, resettling tank	2,243
Sleepy Eye	Imhoff tank	2,247
Staples	Imhoff tank	2,558
Tracy	Imhoff tank	1,876
Two Harbors	Septic tank, not in use	4,990
Virginia	Imhoff tank and trickling filter	10,473
Wadena	Imhoff tank	1,820
Warren	Imhoff tank	1,613

† 1910 Census.

TABLE NO. 27—*Continued*

Municipal Plants—Continued

Cities Operating Sewage Treatment of Plants.	General Description of Plant.	Population Served.†
MINNESOTA—*Cont'd.*		
Warroad	Imhoff tank	927
Waseca	Septic tanks (2)	3,054
Willmar	Imhoff tank	4,135
Worthington	Imhoff tank	2,385
MISSOURI		
Columbia *	Septic tank	....
St. Louis *	Septic tank	....
Sedalia *	Septic tank and filters	....
Springfield*	Imhoff tank and sprinkling filter	....
MONTANA		
Hamilton*	Contact beds	....
Helena*	Broad irrigation	....
Laurel*	Contact beds	....
Miles City*	Intermittent filtration	....
Red Lodge*	Broad irrigation	....
NEBRASKA		
Hastings*	Septic tank	....
NEVADA	No disposal plants known of.	
NEW JERSEY		Gallons Treated per Day.
Allenhurst	Sedimentation	100,000
Asbury Park	Sedimentation	1,700,000
Atlantic City	Sedimentation and disinfection	160,000
Audubon	Sedimentation, contact bed and sand filters	....
Avon	Sedimentation	200,000
Beach Haven	Sedimentation	70,000
Belmar	Sedimentation	150,000
Beverly	Sedimentation and disinfection	200,000
Bivalve	Pail system	....
Bordentown	Sedimentation, double contact and sand filters	260,000
Bradley Beach	Sedimentation, two plants	140,000
Bridgeton	Sedimentation, disinfection and two hours' storage, two plants	290,000
Browns Mills	Sedimentation, contact beds and disinfection	10,000
Burlington	Sedimentation and broad irrigation	700,000
Caldwell	Sedimentation	....

Table No. 27—*Continued*

Municipal Plants—Continued

Cities Operating Sewage Treatment Plants.	General Description of Plant.	Gallons Treated per Day.
New Jresey—*Cont'd.*		
Cape May	Sedimentation	1,000,000
Carlstadt	Sedimentation	125,000
Changewater	Sedimentation and sand filtration	2,000
Chatham and Madison	Sedimentation, double contact and sand filters.	400,000
Cliffside Park	Sedimentation	....
Collingswood	Sedimentation and contact beds	300,000
Cresskill	Sedimentation and broad irrigation	2,500
Deal Beach	Sedimentation	150,000
Delford	Sedimentation	80,000
E. Rutherford	Sedimentation	210,000
Englewood	Sedimentation	560,000
Essex Fells	Sedimentation, contact beds and sand filters	40,000
Fairview	Sedimentation and contact beds	....
Flemington	Screens and land filtration	200,000
Freehold	Screens and land filtration	400,000
Gibbsborough	Two plants, sedimentation and subsurface irrigation; also sedimentation	....
Gibbstown	Sand seepage	....
Haddonfield	Sedimentation, sprinkling filters and secondary sedimentation	225,000
Haddon Heights	Sedimentation and sand filters	70,000
Hammonton	Sedimentation, sprinkling filters and settling	....
Haworth	Sedimentation and subsurface irrigation	6,000
Helmetta	Sedimentation and contact beds	....
Hightstown	Sedimentation and land filtration	....
Interlaken	Sedimentation	10,000
Island Heights	Screens and sand filters	60,000
Keyport	Sedimentation and disinfection	250,000
Lakehurst	Sedimentation and sand filtration	10,000
Lakewood	Sedimentation and sand filtration	300,000
Leonia	Sedimentation	....
Loch Arbor	Sedimentation	....
Long Branch	Screens	800,000
Longport	Sedimentation and disinfection	80,000
Manasquan	Sedimentation	40,000
Margate City	Sedimentation and disinfection, two plants	40,000
Medford	Sedimentation and sand filters	6,000
Merchantville	Sedimentation, trickling filters and sand filters	260,000
Millville	Sedimentation, contact beds and disinfection	1,100,000
Moorestown	Sedimentation and trickling filters	435,000
Morristown	Sedimentation, contact bed and sand filters	630,000
Neptune Township	Sedimentation	350,000
Newton	Sedimentation and sand filters, two plants	500,000
Ocean City	Sedimentation and disinfection	250,000
Ocean Grove	Sedimentation, two plants	600,000
Pemberton	Sedimentation	30,000
Plainfield	Sedimentation and double contact	1,400,000
Point Pleasant	Sedimentation	100,000
Princeton	Two plants, sedimentation and sand filters and broad irrigation	275,000

TABLE NO. 27—*Continued*

Municipal Plants—Continued

Cities Operating Sewage Treatment Plants.	General Description of Plant.	Gallons Treated per Day.
NEW JERSEY—*Cont'd.*		
Red Bank	Sedimentation and disinfection	220,000
Ridgewood	Sedimentation and contact beds	900,000
Riverside	Sedimentation, contact beds and sand filters	250,000
Roebling	Sedimentation, contact beds and sand filters	130,000
Rumson	Sedimentation	......
Rutherford	Sedimentation	800,000
Salem	Sedimentation and disinfection	40,000
Sea Girt	Sedimentation	30,000
Sea Isle City	Sedimentation and disinfection	50,000
Smithville	Sedimentation and sub-surface irrigation	10,000
South River		....
Spring Lake	Sedimentation, two plants	58,000
Stone Harbor	Sedimentation and disinfection	....
Ventnor City	Sedimentation and disinfection	150,000
Vineland	Natural sand filters and disinfection	500,000
Washington	Sedimentation, contact beds and sand filters	200,000
Waterwitch	Sedimentation	10,000
Wenonah	Sedimentation and sand filters, two plants	7,700
Westfield	Sedimentation and sand filters	600,000
Wildwood Crest	Sedimentation and disinfection	....
Woodbridge	Sedimentation, four plants	....
Woodbury	Sedimentation	320,000
Woodstown	Sedimentation and sand filters	90,000
NEW YORK		Population Served.
Auburn	Septic tank and contact beds	22,184
Avon	Settling tanks	2,050
Ballston Spa	Septic tank and contact beds	4,138
Batavia	Settling tank and sprinkling filters	11,600
Brewster	Chemical disinfection and filtration	1,296
Briarcliff Manor	Septic tank and sand filters	980
Brockport	Septic tank and contact beds	3,579
Colonie School District No. 19	Settling tank	....
Corinth	Septic tank	2,166
Dansville	Septic tank and contact beds	3,936
Depew	Septic tank and contact beds	3,921
Dolgeville	Septic tank	2,685
East Aurora	Septic tanks, contact bed and sludge bed	2,781
East Rochester	Screening and grit chamber	2,398
E. Syracuse	Septic tank	3,274
Frankfort	Screen, Imhoff tank and sludge beds	3,303
Franklinville	Settling tank, broad irrigation and sludge beds.	1,568
Fulton	Septic tank	2,500
Fultonville	Septic tank	812
Gloversville	Settling tanks, sprinkling filters and sand filters	20,600
Hempstead	Septic tank and sand filters	5,000
Hobart	Settling tank, sand filters and sludge beds	544
Ithaca	Septic tank	14,802

TABLE No. 27—*Continued*

Municipal Plants—Continued

Cities Operating Sewage Treatment Plants.	General Description of Plant.	Population Served.
NEW YORK—*Cont'd.*		
Kingston	Septic tank and contact beds	3,939
Lackawanna	Septic tank and contact bed	14,549
Lake Placid	Septic tank and sand filters	1,682
Lancaster	Septic tank and contact bed	4,364
Liberty	Septic tank and contact beds	2,072
Matteawan	Septic tank and contact beds	6,727
Middleport	Imhoff tank, sprinkling filter and sludge bed	1,530
Monticello	Septic tank, contact beds and sand filters	1,941
Mt. Kisco	Septic tanks, contact beds and sand filters	2,800
Mt. Vernon	Septic tanks and sprinkling filters	30,919
New Hartford	Settling tanks and sludge beds	2,900
New Rochelle	Chemical precipitation	....
New York City	Coney Island: Three plants, chemical precipitation	....
	Elmhurst: Chemical precipitation	....
	Septic tank and sand filters	....
	Far Rockaway: Chemical precipitation	....
	Jamaica: Chemical precipitation	....
	New Lots: Chemical precipitation	....
North Olean	Septic tanks and sprinkling filters	....
Pelham	Settling tanks and sprinkling filters	5,000
Penn Yan	Settling tank and contact bed	4,579
Saratoga Springs	Septic tank and sand filters	12,683
Saugerties	Septic tank and sand filters	3,929
Scotia	Septic tank and sand filters	3,000
Seneca Falls	Settling tank and sludge bed	6,588
Sharon Springs	Septic tank	2,500
Skaneateles	Septic tank	1,615
Stamford	Chemical precipitation	973
Tuxedo Park	Septic tanks and percolating filter	3,000
Westfield	Septic tanks, contact beds and sludge beds	2,985
Windsor Beach	Septic tanks and sprinkling filter	1,000
NORTH CAROLINA		
Burlington	Septic tank and contact beds	....
Charlotte	Septic tank and contact beds	....
Durham	Septic tank and contact beds	....
Greensboro	Septic tank	....
High Point	Septic tank and contact beds	....
Rocky Mount	Hypochlorite treatment	....
Tarboro	Septic tank and contact beds	....
Thomasville	Imhoff tank	....
NORTH DAKOTA		
Dickinson	Septic tank	....
Ellendale	Septic tank	....
Grafton	Septic tank	....
Jamestown	Septic tank	....
Mandan*	Septic tank	....

TABLE NO. 27—*Continued*

Municipal Plants—Continued

Cities Operating Sewage Treatment Plants.	General Description of Plant.	Population Served.
NO. DAKOTA—*Cont'd.*		
Minot*	Septic tank	....
Rugby*	Septic tank	....
OHIO		
Alliance	Two plants; chemical precipitation, sedimentation, contact and intermittent sand filtration	16,900
Amherst	Sedimentation and intermittent sand filtration.	....
Andover	Sedimentation and intermittent sand filtration.	....
Ashland	Sedimentation and intermittent sand filtration.	7,600
Bedford	Sedimentation and contact filters	....
Bellefontaine	Sedimentation and contact filters	8,700
Canton	Chemical precipitation	56,000
Chagrin Falls	Sedimentation, contact and intermittent sand filtration	....
Clyde	Intermittent sand filtration on natural soil	....
College Hill	Sedimentation, sprinkling filters and final settling tanks	....
Columbus and Grandview	Sedimentation, sprinkling filters and final settling tanks	200,000
Delaware	Sedimentation and contact filtration	9,500
Delphos	Sedimentation	....
Eaton	Sedimentation and intermittent sand filtration.	....
Fostoria	Sedimentation and intermittent sand filtration	....
Galion	Sedimentation and contact filtration	7,200
Geneva	Sedimentation and intermittent sand filtration.	....
Hudson	Sedimentation, contact and sand filtration	....
Jackson	Sedimentation and contact filtration	5,700
Jefferson	Sedimentation and intermittent sand filtration.	....
Kenton	Sedimentation and coarse grain filtration	7,300
Lakewood	Sedimentation and contact filtration	....
Lockland	Sedimentation	....
London	Sedimentation and contact filtration	....
Louisville	Sedimentation and intermittent sand filtration.	....
Mansfield	Sedimentation and contact filtration	21,700
Marble Cliff	Sedimentation and contact filtration	....
Marion	Sedimentation, contact and intermittent sand filtration	20,000
Marysville	Sedimentation, contact and intermittent sand filtration	....
Medina	Two plants, sedimentation and sprinkling filters	....
Mt. Gilead	Sedimentation and intermittent sand filtration.	....
New Berlin	Sedimentation and intermittent sand filtration.	....
New Bremen	Sedimentation and disinfection	....
Oberlin	Sedimentation and intermittent sand filtration.	....
Orrville	Sedimentation and intermittent sand filtration.	....
Oxford	Sedimentation and intermittent sand filtration.	....
Plain City	Sedimentation and contact filtration	....
Ravenna	Sedimentation and intermittent sand filtration.	....

TABLE NO. 27—*Continued*

Municipal Plants—Continued

Cities Operating Sewage Treatment Plants.	General Description of Plant	Population Served.
OHIO—*Continued.*		
Salem	Sedimentation and intermittent sand filtration.	9,300
Sebring	Sedimentation and intermittent sand filtration.	....
St. Marys	Sedimentation and intermittent sand filtration.	....
Shelby	Sedimentation and intermittent sand filtration.	.. ..
Shreve	Sedimentation and contact filtration	....
Sylvania	Sedimentation, contact and intermittent filtration	....
Urbana	Sedimentation and contact filtration (under construction)	8,000
Wadsworth	Sedimentation, contact and intermittent sand filtration	....
Westerville	Sedimentation and contact filtration	....
Wyoming	Sedimentation and intermittent sand filtration.	....
Xenia	Sedimentation and intermittent sand filtration.	....
OREGON		
Ashland	Septic tanks	....
Forest Grove	Septic tanks	....
Hillsboro	Septic tanks and irrigation	....
Klamath Falls	Septic tanks and filter bed	....
La Grande	Septic tanks and irrigation	....
Medford*	Septic tank and filters	....
PENNSYLVANIA		Gallons Treated per Day.
Altoona	Screens and irrigation	1,500,000
Bryn Athyn (Village Association)	Septic tank, primary contact beds, secondary beds, final sand filters and sludge bed	80,000
Carlisle	Imhoff tank, sprinkling filters, secondary settling tanks and sludge bed	50,000
Chambersburg	Imhoff tank, sprinkling filters, secondary settling tanks and sludge bed	700,000
Derry	Septic tanks, contact beds and sludge bed	500,000
Devon (Drainage Co.)	Settling tank and irrigation	25,000
Dormont	Septic tank and contact beds	170,000
Doylestown (Sewerage Company)	Settling tanks, contact beds, chlorinated lime treatment and secondary settling basin	100,000
East Stroudsburg (A. R. Brittian, owner)	Septic tanks and contact filters	30,000
Enola (Realty Co.)	Septic tanks and contact beds	35,000
Hanover (Sewer Co.)	Septic tank, contact beds and chlorinated lime treatment	250,000
Indiana	Settling tanks, sprinkling filters, secondary tanks and sludge bed	900,000
Lebanon	Imhoff tank, sprinkling filters, secondary tank and sludge bed	250,000

TABLE NO. 27—*Continued*

Municipal Plants—Continued

Cities Operating Sewage Treatment Plants.	General Description of Plant.	Gallons Treated per Day.
PENNSYLVANIA—*Cont.*		
Nazareth (Sewerage Company)	Settling tanks, contact bed and chlorinated lime treatment	18,000
New Wilmington	Septic tank, sand filters and sand bed	40,000
Perkasie (Philip Cressman, owner)	Settling tanks, contact beds and chlorinated lime treatment	150,000
Pleasantville	Imhoff tank, trickling filter, sand filter and sludge bed	50,000
Philadelphia (Pennypack District)	Imhoff tank, sprinkling filter, secondary settling tanks, chlorinated lime treatment sludge beds	3,000,000
Reading	Settling tank, sprinkling filters and secondary settling tanks	6,500,000
Washington	Septic tanks, sprinkling filters and secondary settling tanks	2,200,000
Wayne (Sewerage Co.)	Settling tank, primary and secondary contact beds, sand beds and chlorinated lime	700,000
West Chester	Septic tanks, contact beds, secondary settling and sludge bed	1,000,000
RHODE ISLAND		
Central Falls	Septic tank and sand filtration	....
Narragansett Pier	Septic tank	....
Pawtucket	Sedimentation and sand filters	....
Providence*	Chemical precipitation	....
Woonsocket	Septic tank and sprinkling filter	....
SOUTH CAROLINA		
Aiken*	Intermittent sand filtration	....
Greenwood*		....
Newberry*	Septic tank and four sprinkling filters	....
Rock Hill*		....
Sumter*	Septic tanks and contact beds	....
SOUTH DAKOTA		
Mitchell*	Septic tank	....
TEXAS		
Corsicana*	Chemical precipitation	....
Houston*	Coke filter beds	....
UTAH		
Beaver City	Septic tank	....
Murray	Septic tank	....
Olinstead	Septic tank	....
Price	Septic tank	....

TABLE NO. 27—*Continued*

Municipal Plants—Continued

Cities Operating Sewage Treatment Plants.	General Description of Plant.	Gallons Treated per Day.
VIRGINIA		
Blacksburg	Sedimentation and contact beds	....
Chase City	Septic tank and broad irrigation	60,000
Colonial Beach	Septic tanks	....
Culpeper	Broad irrigation	100,000
Manassas	Imhoff tank and trickling filter	....
Winchester*	Settling tanks and contact beds	1,000,000
WASHINGTON		
Seattle*	Septic tanks	....
WEST VIRGINIA	No disposal plants known of.	
WISCONSIN		
Antigo*	Septic tanks and filters	....
Athens*	Septic tank	....
Elk Horn*	Residential septic tanks	....
Fond du Lac*	Septic tank and contact beds	....
Lancaster*	Septic tank and filters	....
Madison*	Septic tank and trickling filter	....
Marshfield*	Septic tank and filters	....
Marinette*	Filters	....
Menomonee Falls	Sedimentation	....
Monroe*	Septic tank and filters	....
No. Milwaukee*	Sedimentation tanks, aeration and filters	....
Ripon*	Filters	....
Tomah*	Septic tanks	....
Waupaca*	Septic tanks	....
Wauwatosa	Septic tank and sand filters	....
Waukesha*	Septic tank	....
West Ellis*	Septic tank and slag filters	....
West Bend*	Septic tank	....
West Salem*	Settling tank	....
WYOMING		
Sheridan*	Septic tank and gravel beds	....

TABLE NO. 27—*Continued*

Institutional and Private Plants

Institutions or Private Parties Operating Sewage Treatment Plants.	General Description of Plant.	Gallons Treated per Day.
GEORGIA		
Peachtree Heights, sanatorium*	....	....
State tuberculosis sanatorium*	....	....
KANSAS		
Fort Leavenworth	Septic tank and sprinkling filter	....
Quindaro	Septic tank and sub-irrigation	....
Soldiers' Orphans' Home	Septic tank and contact filters	....
State Home for Feeble-minded	Imhoff tank, contact filter and sand filter	....
Topeka Industrial Institute	Septic tank and sub-irrigation	....
University of Kansas	Septic tank and contact beds	....
KENTUCKY		
Bethel College	Septic tank	....
Logan Female College	Septic tank	....
Waverly Hills, sanatorium	Imhoff tank, sprinkling filter and intermittent sand filtration	....
MASSACHUSETTS		
Barnstable Normal School	Sedimentation and sub-surface filters	6,000
Canton, Mass., hospital school	Sand filters	6,000
Concord, Mass., reformatory	Sedimentation and sand filters	150,000
Danvers, insane hospital	Sedimentation	150,000
Foxboro, state hospital	Sedimentation and sand filters	450*p*
Framingham, normal school	Sedimentation and sub-surface filter	310*p*
Gardner, state colony	Sedimentation and sand filters	12,000
Lancaster, girls' school	Sedimentation and sand filters	....
Medfield, state hospital	Sedimentation and sand filters	1,700*p*
Monson, state hospital	Sedimentation and sand filters	90,000
North Reading, sanatorium	Sedimentation and sand filters	16,000
Rutland, prison camp	Sedimentation and sand filters	10,000
Rutland, state sanatorium	Sedimentation and sand filters	350*p*
Tewksbury, almshouse	Sedimentation and sand filters	250,000
Wellesley College	Sedimentation and sub-surface filter	50,000
Westboro, state hospital	Sedimentation and sand filters	1,250*p*
Worcester, Grafton colony	Sand filters (under construction)	300,000
NEW JERSEY		
Aldene, factory	Sedimentation and trickling bed	5,500
Ancora, institution	Sedimentation and sub-surface irrigation	....
Asyla, institution	Sedimentation, contact bed and trickling filter	50,000
Burlington, factory	Sedimentation, sprinkling filter and sand filter	40,000
Bryam, private	Sedimentation and sub-surface irrigation	300

p = Population Served.

TABLE NO. 27—*Continued*

Institutional and Private Plants—Continued

Institutions or Private Parties Operating Sewage Treatment Plants.	General Description of Plant.	Gallons Treated per Day.
NEW JERSEY—*Continued.*		
Caldwell, penitentiary	Sedimentation and sub-surface irrigation	40,000
Cape May, real estate company	Sedimentation and disinfection	18,000
Clinton, creamery	Chemical precipitation	300
Colt's Neck, creamery	Chemical precipitation	500
Deal Golf Club	Sedimentation and sand filters	1,200
Gibbsborough, factory	Sedimentation and sub-surface irrigation	....
Glen Gardner, institution	Sedimentation, sprinkling filters and cinder filters	50,000
Grenloch, factory	Sedimentation, contact filters and sand filters	....
Hackettstown, leather company	....	....
High Bridge, private	Sedimentation and broad irrigation	....
Hilliards' Island, private	Sedimentation and sand filters	1,500
Hopatcong, hotel	Sedimentation and sub-surface irrigation	....
Hopewell, institution	Sedimentation and contact beds	....
Jamesburg, institution	Screens and land filtration	60,000
Lawrenceville, school	Sedimentation and broad irrigation	50,000
Madison, private	Sedimentation and sand filters	1,800
Mahwah, factory	Sedimentation and sand filters	....
Metuchen, creamery	Precipitation and sprinkling filters	800
Montague, creamery	Chemical precipitation	400
Morris Plains, institution	Two plants, sedimentation and sand filters and land filtration	670,000
Mullica Hill, private	Sedimentation and sand seepage	....
Neshanic, creamery	Chemical precipitation	250
New Lisbon, institution	Two plants, sedimentation, contact bed, sand filters, and sub-surface irrigation	55,000
New Providence, institution	Sedimentation, contact beds, and absorption	....
Overbrook, institution	Sedimentation, contact beds and sand filters	....
Pleasantville, hotel	Sedimentation and trickling filters	4,000
Powerville, factory	Sedimentation, contact beds and cinders	....
Princeton College	Sedimentation, sprinkling filters and sand filters	....
Quarryville, creamery	Sedimentation and lime precipitation.	250
Rahway, reformatory	Sedimentation and disinfection	50,000
Ralston, institution	Sedimentation and sub-surface irrigation	....
Rockaway, factory	Sedimentation and disinfection	....
Ross Fenton, farm	Sedimentation and sand filters	1,500
Sea Girt, state camp	Sedimentation	20,000
Skillman, institution	Sedimentation, contact beds and land filtration	50,000

TABLE NO. 27—*Continued*

Institutional and Private Plants—Continued

Institutions or Private Parties Operating Sewage Treatment Plants.	General Description of Plant.	Gallons Treated per Day.
NEW JERSEY.—*Continued.*		
Smith's Landing, institution...	Sedimentation and disinfection......	8,000
Sunnyside, creamery..........	Chemical precipitation..............	....
Three Bridges, creamery......	Chemical precipitation..............	....
Trenton, factory.............	Sedimentation, contact beds and sand filters..........................	....
Trenton, factory.............	Sedimentation and contact beds.....	7,000
Trenton, R. R. Shops.........	....	25,000
Trenton, I. O. O. F. home.....	Sedimentation and sand filters......	10,000
Trenton, city hospital.........	Sedimentation....................	....
Trenton, institution...........	Sedimentation and sub-surface irrigation.........................	....
Verona, institution...........	Sedimentation and sub-surface irrigation..........................	7,500
Vineland, institution..........	Sedimentation and broad irrigation...	....
Woodstown, creamery.........	Sedimentation and sprinkling filters..	700
Wortendyke, factory..........	Sand filters.......................	40,000
NEW YORK		
Alfred, university.............	Cesspools.........................	....
Albion, house of refuge........	Coke strainer and precolating filter...	....
Bath, Soldiers' and Sailors' home	Chemical precipitation..............	....
Bedford Hills................	Imhoff tank and sub-surface irrigation	....
Bedford, reformatory for women	Septic tank, sand filter and sterilization	....
Bedford, sanatorium..........	Septic tank and sprinkling filter.....	....
Blauvelt, rifle range...........	Settling tank and sand filter.........	....
Carmel, Gleneida hotel........	Septic tank, trickling filter and sterilization.........................	....
Central Islip, state hospital....	Natural sand filtration..............	....
Chappaqua, assembly.........	Chemical precipitation..............	....
Chappaqua, convalescents' home	Screen chamber, settling tank, contact beds and sand filters.........	....
Clifton Springs, sanatorium....	Screen chamber, settling tank, sprinkling filter and sludge bed..........	....
Colonie, private..............	Septic tank, dosing chabmer and contact beds.....................	....
Comstock, prison.............	Settling tank and sand filters........	....
Dannemora, State prison......	Settling tank.....................	....
Deerfield, private.............	Septic tank.......................	....
East View, almshouse.........	Septic tank and contact beds........	....
East View, convalescents' home	Septic tank and soil filtration........	....
Elka Park..................	Settling tank and contact beds......	....
Fair Haven, hotel............	Septic tank and sub-surface irrigation	....
Fire Island, state park........	Cesspools and sub-surface irrigation..	....
Fourth Lake, camp...........	Settling tanks....................	....
Fulton, county tuberculosis hospital	Settling tank and sub-surface irrigation	....
Granville, factory............	Settling tank, and sub-surface irrigation.........................	....
Great Neck.................	Sedimentation tanks and sand filters.	....

TABLE NO. 27—*Continued*

Institutional and Private Plants—Continued

Institutions or Private Parties Operating Sewage Treatment Plants.	General Description of Plant.	Gallons Treated per Day.
NEW YORK—*Continued.*		
Greenburg, farm	Settling tank and sub-surface irrigation	....
Garden City	Septic tank and sand filtration	....
Glen Haven, hotel	Settling tanks, primary and secondary contact	....
Hawthorne, Jewish A. & P. Society	Primary and secondary contact beds.	....
Hudson, girls' school	Septic tank and contact beds	....
Industry, agricultural school	Six plants, sedimentation and sand filters	....
Jamesville, penitentiary	Sedimentation and contact beds	....
King's Park, hospital	Imhoff tank and sprinkling filter	....
Lebanon Springs, hotel	Septic tank and soil filtration	....
Letchworth, State institution	Settling tanks, sprinkling filters, settling basin, sludge tank and sludge bed	....
Lilly Vale, association	Sedimentation	....
Lima, seminary	Settling tank and sub-surface irrigation	....
Long Beach, realty company	Settling tank and disinfection	....
Loomis, sanatorium	Septic tank, contact beds and sand filters	....
Madeline Lake, private	Siphon chamber and two sand filters.	....
Manhattan Beach, hotel	Settling tanks	....
Monroe County Hospital	Settling tank, sand filters, and sludge bed	....
Montgomery County Hospital	Settling tank and sub-surface irrigation	....
Morrisville, school	Septic tank, dosing tank and sub-surface irrigation	....
Nanuet, school	Septic tank and soil filtration	....
Napanoch, reformatory	Sedimentation tanks and sand filters.	....
Onondaga Co., house	Cesspools	....
Owasco, country club	Septic tank and sand filters	....
Pine Bush, milk company	Cesspools	....
Piermont-on-Hudson, hotel	Septic tank and coke bed	....
Pine Plains, farm	Settling tank and sand filters	....
Pleasantville, benevolent home	Sedimentation, sprinkling filter, sand filter and sterilization	....
Pocantico Hills, college	Sedimentation tanks, broad and sub-surface irrigation	....
Point o' Woods, association*	Sub-surface irrigation	....
Poughkeepsie, hospital	Settling tank, dosing chamber and sub-surface irrigation	....
Poughkeepsie, college	Natural sand filtration or broad irrigation	....
Ray Brook, hospital	Septic tank and sand filtration	....
Rockaway Beach, real estate Co.	Settling tanks	....
Round Lake, resort	Chemical precipitation	....
Rye, benevolent home	Primary and secondary contact	....
Rye, school	Primary and secondary contact	....

TABLE No. 27—*Continued*

Institutional and Private Plants—Continued

Institutions or Private Parties Operating Sewage Treatment Plants.	General Description of Plant.	Gallons Treated per Day.
NEW YORK—*Continued.*		
Saratoga County tuberculosis hospital	Septic tank, sprinkling filter, final settling tank and sludge bed	....
Saratoga Springs, private	Septic tank and contact beds	....
Schenectady, hospital	Settling tank and sub-surface irrigation	....
Silver Bay	Septic tank, sprinkling filter and subsurface irrigation	....
Silver Lake, sanatorium	Septic tank, sprinkling filter and broad irrigation	....
Smithtown, hotel	Settling tank	....
Sonyea, benevolent home	Septic tank and sand filters	....
South Nyack, private	Sedimentation tank and siphon chamber	....
Spring Valley, orphanage	Broad irrigation	....
Tompkins County tuberculosis hospital	Septic tank and sub-surface irrigation	....
Thompson's Ridge, ice cream company	Broad filtration	....
Upper Nyack, benvolent home	Settling tank, sterilization, dosing tank and sand filters	....
Valatie, reformatory	Cesspool and sub-surface irrigation	....
Valhalla, benevolent home	Septic tank, contact bed and sand filters	....
Wampsville, jail	Septic tank and sand filter	....
Webb, hotel	Settling tank	....
White Plains, hotel	Sedimentation tanks, sand filters and sterilization	....
Willard, hospital	Settling tank dosing chamber, sprinkling filters, supplementary settling tanks, sterilization plants and sludge bed	....
Williamsville, benevolent home	Sedimentation and sub-surface irrigation	....
Yonkers	Settling tanks and coarse grain filters	....
Yorkville	Septic tank	....
OHIO		
Alliance, benevolent home	Intermittent sand filtration	....
Amherst, quarry company	Sedimentation and coarse grain filtration	....
Bucyrus, hospital	Intermittent sand filtration	....
Camp Perry	Intermittent sand filtration	....
Circleville, hospital	Sedimentation and intermittent sand filtration	....
Cleveland, Camp Wise	Sedimentation and intermittent sand filtration	....
College Hill, benvolent home	Sedimentation, sprinkling filters and intermittent sand filtration	....
Collinwood, railway	Sedimentation and contact filtration	....
Dayton, hospital	Intermittent sand filtration	....

TABLE NO. 27—*Continued*

Institutional and Private Plants—Continued

Institutions or Private Parties Operating Sewage Treatment Plants.	General Description of Plant.	Gallons Treated per Day.
OHIO—*Continued.*		
Delaware, benevolent home	Sedimentation, sprinkling filters, secondary sedimentation and intermittent sand filtration	....
Gallipolis, hospitals	Three plants, intermittent sand filtration and sedimentation with intermittent sand filtration	....
Granville, college	Natural land filtration	....
Hudson, boys' farm	Sedimentation and intermittent sand filtration	....
Lancaster, industrial school	Intermittent sand filtration	....
Lima, hospital	Sedimentation, contact and intermittent sand filtration	....
Madison, benevolent home	Sedimentation and intermittent sand filtration	....
Mansfield, reformatory	Sedimentation and intermittent sand filtration	....
Marietta, hospital	Sedimentation	....
Massillon, hospital	Intermittent sand filtration	....
Morgans, institution	Sedimentation and intermittent sand filtration	....
Mt. Vernon, sanatorium	Sedimentation and intermittent sand filtration	....
Reynoldsburg, institution	Sedimentation and intermittent sand filtration	....
Sandusky, benevolent home	Sedimentation and intermittent sand filtration	....
Toledo, institution	Intermittent sand filtration	....
Wapakoneta, hospital	Sedimentation and intermittent sand fitlration	....
Warren, hospital	Sedimentation and coarse grain filtration	....
Warrensville, tuberculosis colony	Sedimentation and intermittent sand filtration	....
Westerville, benevolent home	Sedimentation and intermittent sand filtration	....
Wilberforce, college	Sedimentation and intermittent sand filtration	....
Wooster, hospital	Sedimentation and intermittent sand filtration	....
Xenia, benevolent homes	Sedimentation and intermittent sand filtration	....
Xenia, hospital	Sedimentation and intermittent sand filtration	....
Zanesville, benevolent home	Sedimentation	....
OREGON		
Chemawa, Indian school	Septic tanks and filter beds	....
East District Insane Asylum	Septic tanks and filter beds	....
State Mute School	Septic tanks and filter beds	....
State Tuberculosis Sanatorium	Septic tanks and irrigation	....

TABLE NO. 27—*Continued*

Institutional and Private Plants—Continued

Institutions or Private Parties Operating Sewage Treatment Plants.	General Description of Plant.	Gallons Treated per Day.
PENNSYLVANIA		
Allegheny County Work House, Hoboken Station, Allegheny Co.	Septic tank, sprinkling filter, secondary settling tank and sludge bed	40,000
Blaw Steel Construction Co., O'Hara Twp., Allegheny Co.	Septic tanks, contact beds and sludge bed	15,000
Buck Hill Falls Co., Buck Hill Falls, Barrett Twp., Monroe Co.	Septic tank, sand filters and sludge bed	50,000
Carnegie Steel Co., West Salem Twp., Mercer Co.	Septic tank, contact beds and sludge bed	12,000
Children's Village of the Seybert Institute, Abbington Twp., Montgomery Co.	Imhoff tank, sprinkling filter, chlorinated lime treatment, final settling basin and sludge bed	15,000
Dermandy Sanatorium, Morton, Delaware Co.	Septic tank and sprinkling filter	4,000
Eastern Pennsylvania State Institution for Feeble Minded and Epileptic, Spring City, Chester Co.	Septic tanks, sand filters and sludge bed	160,000
Flannery Bolt & American Vanadium Co., Collier Twp., Allegheny Co.	Settling tanks and chlorinated lime treatment	50,000
Glen Mills School, Girls' Dept., Darling, Middletown Twp., Delaware Co.	Septic tank, contact beds and sand filters, and chlorinated lime treatment	50,000
Glen Mills School, Boys' Dept., Glen Mills, Thormbury Twp., Delaware Co.	Settling tanks, contact beds and chlorinated lime treatment	75,000
Haverford College, Haverford Twp., Delaware Co.	Septic tanks, contact beds and sand filters	12,000
Home and Hospital of the Good Shepherd, Radnor Twp., Delaware Co.	Settling tank, trickling filter, chlorinated lime treatment and sludge bed	4,000
Homœopathic State Hospital for the Insane, Haver Twp., Lehigh Co.	Septic tanks, sand beds and sludge beds	200,000
Inwood Sanatorium, Lower Merion Twp., Montgomery Co.	Septic tank, sprinkling filter, secondary tank and chlorinated lime treatment	10,000
Lehigh County Home and Alms House, South Whitehall Twp.	Septic tank, contact bed, secondary tank and chlorinated lime treatment, sludge bed	35,000
Masonic Home, Elizabethtown, West Donegal Twp., Lancaster Co.	Settling tanks, mechanical drier and chlorinated lime treatment	17,000
Montgomery County Poor Farm, Upper Providence Twp.	Settling tank, sprinkling filters and sludge bed	20,000
Morrisville Rubber Works, Morrisville, Bucks Co.	Settling tank, sand filter and sludge bed	5,000

TABLE NO. 27—*Continued*

Institutional and Private Plants—Continued

Institutions or Private Parties Operating Sewage Treatment Plants.	General Description of Plant.	Gallons Treated per Day.
PENNSYLVANIA—*Continued.*		
Mt. Gretna Park, Mt. Gretna, Lebanon Co.	Settling tank (modified Imhoff), sprinkling filters, sand filters, secondary settling tank and sludge bed	60,000
Nelson Valve Co., Springfield, Twp., Montgomery Co.	Septic tank, trickling filter and sludge bed	20,000
N. J. Zinc Co., Palmerton Village, Carbon Co.	Septic tank, contact beds and sand beds	65,000
Northwestern Anti-Tuberculosis League, Bells Camp, Foster Twp., McKean Co.	Septic tank and contact bed.........	8,000
Norwich Lumber Co., Norwich, McKean Co.	Septic tank and sand filters.........	75,000
Palmer Land Co., Palmerton Village, Carbon Co.	Septic tank and sand filters.........	75,000
Pennsylvania Glue Co., Springdale, Allegheny Co.	Settling tanks.....................	20,000
Pennsylvania State College, State College, Center Co.	Imhoff tank, sprinkling filters, chlorinated lime treatment and sludge bed	400,000†
Pennsylvania State Lunatic Hospital, Harrisburg, Dauphin Co.	Settling tanks, sprinkling filters, secondary settling tanks and chlorinated lime treatment	150,000
Pennsylvania State Sanatorium for Tuberculosis No. 2, Cresson, Cambria Co.	Imhoff tanks, sprinkling filters, secondary tank, sludge bed and chlorinated lime treatment	50,000
Pennsylvania State So. Mountain Sanatorium, MountAlto, Franklin Co.	Septic tanks, sprinkling filters, sludge bed and chlorinated lime treatment	130,000
Pennsylvania Training School, Morganza, Washington Co.	Septic tanks, sprinkling filters, secondary settling tanks, sand filters, and sludge bed	55,000
Perkiomen Seminary, Pennsburg, Montgomery Co.	Septic tank, contact bed, chlorinated lime treatment and secondary settling tank	18,000
Pittsburgh Municipal Water Works plant, near Aspinwall, Allegheny Co.	Septic tanks and sand filters.........	6,000
Pittsburgh North Side City Home, Warner's Station, Allegheny Co.	Septic tanks, sprinkling filters, final settling tank and sludge bed	160,000
Philadelphia Jewish Sanatorium for Consumptives, Eagleville, Lower Providence Twp., Montgomery Co.	Septic tank, contact bed and broad irrigation	3,000
Rumpft's Sons, Frederick, Middletown Twp., Bucks Co.	Chemical precipitation and sludge bed	60,000

† Gallons capacity. Plant just completed and not yet in operation.

TABLE NO. 27—*Continued*

Institutional and Private Plants—Continued

Institutions or Private Parties Operating Sewage Treatment Plants.	General Description of Plant.	Gallons Treated per Day.
PENNSYLVANIA—*Continued.*		
Rush Hospital for Consumption and Allied Diseases, Country branch near Malvern, Willistown Twp., Chester Co.	Settling tank, contact bed, sand filter and chlorinated lime treatment	5,000
St. Francis Industrial Home, Eddington, Montgomery Co.	Modified Imhoff tank, sand filters and sludge bed	25,000
Schuylkill County Poor Farm and Hospital for Insane, Schuylkill Haven, North Manheim Twp.	Settling tanks, contact beds, sand filters, sludge bed and chlorinated lime treatment	160,000
Soldiers' Orphans' Industrial School, Scotland, Franklin Co.	Settling tank and irrigation.........	50,000
Somerset County Home and Hospital, Somerset.........	Settling tank and contact beds......	16,000
State Asylum for Chronic Insane of Pennsylvania, Wernersville, South Mountain, Berks Co.	Septic tanks, sprinkling filters, secondary settling tanks, sludge bed and chlorinated lime treatment	100,000
State Hospital for Criminal Insane, Farview, Wayne Co.	Settling tank and chlorinated lime treatment	20,000
State Hospital for the Insane, Danville, Montour Co.	Settling tanks, sprinkling filters, secondary settling tank, chlorinated lime treatment and sludge beds	425,000
State Hospital for the Insane of the Southeastern District, Norristown, Montgomery Co.	Settling tanks, sprinkling filters, secondary settling tanks, sludge beds and chlorinated lime treatment	200,000
State Institution for the Feeble Minded of Western Pennsylvania, Polk, Venango Co.	Settling tanks, sprinkling filters and sludge bed, chlorinated lime treatment	225,000
State Hospital for the Insane, Warren, Warren Co........	Imhoff tank, sprinkling filters, secondary settling basin, and chlorinated lime treatment	250,000
State Police Barracks, Hempfield Twp., Westmoreland Co.	Septic tank and trickling filter	60,000
Tressler Orphans' Home, Loysville, Perry Co.............	Irrigation.........................	20,000
Universal Portland Cement Co., Pennsylvania Twp., Allegheny Co.................	Septic tank and contact beds........	5,000
Valley Camp Association, Lower Burrel Twp., Westmoreland Co.	Settling tanks and chlorinated lime treatment	5,000
Villanova College, Villanova, Delaware Co..............	Settling tank and contact beds......	45,000
Warren Water Co., filtration plant, Warren, Warren Co..	Settling tank and sand filter.........	. 100
Western Pennsylvania State Hospital for the Insane, Dixmont, Kilbuck Twp., Allegheny Co.	Settling basin, contact beds, sprinkling filters and sludge bed	85,000

TABLE NO. 27—*Continued*

Institutional and Private Plants—Continued

Institutions or Private Parties Operating Sewage Treatment Plants.	General Description of Plant.	Gallons Treated per Day.
PENNSYLVANIA—*Continued.*		
White Haven Sanatorium of the Free Hospital for Poor Consumptives, White Haven, Luzerne Co.	Septic tanks, primary and secondary contact beds and sludge beds	18,000
Williamson Free School for Mechanical Trades, Middletown Twp., Delaware Co.	Septic tanks, trickling filters and sand filters	30,000
Willow Grove Park, Moreland Twp., Montgomery Co.	Septic tanks, roughing filters, sand filters, chlorinated lime treatment and final settling tank	200,000
Willow Grove Park, Parkside Hotel, Moreland Twp., Montgomery Co.	Septic tank, sprinkling filter, chlorinated lime treatment and final settling basin	500,000
Wood, Allen Iron & Steel Co., Ivyrock Station, Montgomery Co.	....	....
RHODE ISLAND		
State Sanatorium............	Septic tank, sprinkling filters and settling tank....................	....
UTAH		
Saltair, resort................	Septic tank......................	....
Salt Lake, penitentiary........	Septic tank......................	....
Wandamere, resort...........	Septic tank......................	....
VIRGINIA		
Catawba, sanatorium.........	Imhoff tank and trickling filter......	20,000
Laurel, industrial school.......	Imhoff tank and sand filters.........	300*p*
State Farm..................	Sedimentation tank and sand filters..	10,000
WISCONSIN		
Dane County Poor Farm*.....	Septic tank and filter...............	....
Mendota, hospital*...........	Septic tank and filter...............	....
Milwaukee County institutions*	Septic tank and filter...............	....
Northern Hospital...........	Septic tanks and filters.............	....
Soldiers' Home..............	Filters...........................	....
Wales, sanatorium...........	Septic tank and sub-surface irrigation	....

p = Population served.

APPENDIX

TESTING SEWAGE AND EFFLUENTS

The determining of the chemical composition, physical characteristics and bacterial content of sewage and sewage effluents can be made reliably and comparably only by the careful, intelligent and practiced following of standard methods. The methods now generally followed by testing laboratories and private investigators in this country are the "Standard Methods of Water Analysis" developed and published by the American Public Health Association. These apply primarily to less polluted waters than sewage; some of them are applicable without change to such foul waters, others after slight modifications; a few have no place in sewage analyses, while two additional ones are suggested, as stated below.

The instructions given herewith for making tests are, for the most part, those of the "Standard Methods," but they contain some modifications as recommended by F. E. Daniels in his book "Operation of Sewage Disposal Plants."

A committee on Sewage Works Operation and Analytical Methods of the American Public Health Association recommends the use of two other tests, which it calls X and Y, but for which no standard procedure has yet been adopted; X being "a test for measuring by incubation the avidity of the sample of sewage or effluent for dissolved oxygen or its equivalent," which test is considered to be of prime importance; and Y being "a test for measuring not only the amount, but also the condition and physical characteristics of the suspended matter in sewage."

This committee recommended particular tests as specially useful in connection with each of several types of works or processes, as indicated by the table given herewith.

Concerning taking samples, the committee reported:

> Due to its heterogeneous nature, the composition of crude sewage is very variable and chance samples taken at short intervals of time will, upon analysis, yield very different results; but when the sewage is submitted to increasing refinements of treatment, this variability in composition is lessened. It is, therefore, advisable for all tests in which the samples can be properly kept for a time before analysis, to obtain a composite sample made up of a number of small portions and thus automatically obtain an average sample for analysis. To do this properly, the size of the individual portions should be proportional to the rate of flow of sewage at the time of sampling, but it is recognized that with the class of labor usually available at sewage treatment works, this ideal cannot be realized. The frequency of sampling will largely depend upon the available force at the plant. Crude sewage should be sampled at more frequent intervals than effluents of refined processes of treatment.
>
> It is of great importance for the proper interpretation of published data, that in connection with reported analyses a statement be made of the frequency of sampling and whether the figures given are, for instance, the average of certain chance samples or the averages of continuous composite sampling.

The methods of making analyses referred to are as follows:

TOTAL SOLIDS.

Procedure.—Ignite and weigh a clean platinum dish and into it measure 100 c.c. of the liquid. Evaporate to dryness on a water bath, dry in an oven, cool in a desiccator and weigh. The increase in weight gives the total solids.

LOSS ON IGNITION.

Procedure.—Heat the platinum dish containing the residue in a " radiator " which consists of another platinum dish large enough to allow an air space of about half an inch between the inner and outer dishes, the inner dish being supported by a triangle of platinum wire laid on the bottom of the outer dish. Over the inner dish is suspended a disc of platinum foil large enough to cover the outer dish, to radiate the heat into it. The larger dish is heated to bright redness, until the residue is white or nearly so. Allow the dish to cool in a desiccator and weigh. This weight gives the fixed solids and the difference between it and the total solids gives the loss on ignition. An electric muffle furnace may be used for the ignition. Care must be used and the temperature not allowed to get too high or else some of the mineral salts will be volatilized.

TOTAL SUSPENDED MATTER.

Procedure.—Filter a definite quantity of the liquid, depending upon the amount of suspended matter contained, through a tared Gooch crucible by means of a suction apparatus. Dry in an oven and cool in a desiccator and weigh. This gives the total suspended solids.

Carefully ignite, cool in desiccator and weigh. This weight gives the fixed solids and the difference between it and that of the total suspended solids gives the volatile suspended solids.

TESTS FOR DETERMINING THE COMPOSITION OF CRUDE SEWAGE FOR COMPARISON.

	Works Primarily Designed to Prevent Nuisance.		Works Primarily Designed to Protect Sources of Water Supply.	
	Works consisting of preliminary processes only. such as fine screens or sedimentation.	Works consisting of preliminary and oxidation processes such as contact beds or percolating filters.	Works consisting of preliminary processes and disinfection.	Works consisting of preliminary and oxidation processes and disinfection.
Tests for operating control and determination of efficiency:				
Influent and effluent of preliminary processes..........	(1) Test for the avidity of oxygen, called X. (2) Test for suspended matter, called Y.			
Sludge drawn from one-story tanks. Sludge drawn from two-story tanks.	(1) Specific gravity. (2) Percentage moisture in wet sludge. (3) Percentage of dry residue that is volatile. (4) Reaction of wet sludge (two-story tanks only).			
Effluent of oxidation process.	....	(1) Nitrogen as nitrates. (2) Test for avidity for oxygen, called X. (3) Dissolved oxygen. (4) Relative stability.*	....	(1) Nitrogen as nitrates. (2) Test for avidity for oxygen, called X. (3) Dissolved oxygen. (4) Relative stability.*
Final effluent as discharged into the receiving body of water.	(1) Test for avidity for oxygen, called X. (2) Test for suspended matter, called Y.	(1) Test for avidity for oxygen, called X. (2) Nitrogen as nitrates. (3) Dissolved oxygen. (4) Test for suspended matter, called Y. (5) Relative stability.*	(1) Presumptive test for B. Coli. (2) Test for avidity for oxygen, called X. (3) Test for suspended matter, called Y.	(1) Presumptive Test for B. Coli. (2) Test for avidity for oxygen, called X (3) Nitrogen as nitrates. (4) Test for suspended matter, called Y. (5) Relative stability.* (6) Dissolved oxygen.
Tests to determine sufficiency of treatment:				
Receiving body of water.	(1) Dissolved oxygen. (2) Test for avidity for oxygen, called X.		(1) Presumptive test for B. Coli. (2) Dissolved oxygen. (3) Test for avidity for oxygen, called X.	

* In small plants not provided with a laboratory relative stability may take first place.

Note.—Occasional composite samples to be analyzed for nitrogen as organic or as free ammonia. Test for suspended matter (Y) and for chlorine. At same time examine samples for avidity for oxygen (X).

SUSPENDED MATTER WHICH WILL SETTLE. (BY VOLUME.)

Apparatus.—Tall straight-sided or conical glass vessels of 1 liter capacity, having a tapering interior at the bottom which is graduated in cubic centimeters.

Procedure.—Fill the glass to the liter mark with the sewage or effluent. After the specified time read the volume of the sediment by means of the c.c. graduation at the tapering bottom. During the settling carefully dislodge by means of a wire or glass rod any particles caught on the sides of the vessel.

For comparison of tank influent and effluent, take a representative sample of influent and, after the "flowing through" time has elapsed, a sample of the effluent should be taken. The results of the two samples may be compared to show the tank removal of suspended matter. The physical characteristics of the sediment should be observed as carefully as possible and recorded so that there may be less chance for errors in drawing conclusions.

CHLORINE.

Reagents.—1. Standard salt solution. Dissolve 16.48 grams of fused sodium chloride in distilled water and make up to one liter. Dilute 100 c.c. of this stock solution to one liter in order to obtain a standard solution, each c.c. of which will contain .001 gram of chlorine.

2. Silver nitrate standard. Dissolve about 2.40 grams of silver nitrate crystals in one liter of distilled water. One c.c. of this will contain approximately .0005 gram of chlorine. Standardize this against the standard salt solution.

3. Potassium chromate. Dissolve 50 grams of neutral potassium chromate in a little distilled water. Add enough silver nitrate to produce a slight red precipitate. Filter and make up the filtrate to one liter with distilled water.

Procedure.—Use 10 c.c. of the sample in a white 6-inch porcelain evaporating dish when the chlorine content is not excessively high or low. Dilute to 50 c.c. with distilled water and add a definite quantity of the potassium chromate solution as indicator. Titrate with the silver nitrate solution, under similar conditions as to light, volume, temperature and indicator as were used in standardizing the silver nitrate solution.

TOTAL ORGANIC NITROGEN.

Reagents.—1. A 30 per cent solution of copper sulphate.

2. A 5 per cent solution of potassium hydrate.

3. Concentrated C. P. sulphuric acid.

Procedure.—Take 50 c.c. of the sample and add 5 c.c. concentrated C. P. sulphuric acid and 3 or 4 drops of a 30 per cent solution of copper sulphate. Digest in a Kjeldahl flask over a flame under a hood until colorless. While hot add a few crystals of potassium permanganate until a heavy green precipitate persists in the liquid. Cool. Dilute to 250 c.c. and mix. Allow to stand until the manganese compounds have well settled out, otherwise a greenish solution will result upon the addition of potassium hydrate. Pipette out 20 c.c. of the diluted mixture and add an equal amount of 5 per cent potassium hydrate. Filter and pipette out an aliquot portion into a Nessler tube. Make up to the mark, mix and Nesslerize in ten minutes. Read by comparison with Nessler standards and calculate in parts per million (see "Standard Methods"). Should the solution be turbid upon the addition of the 5 per cent potassium hydrate, use an 8 or 10 per cent solution. The 5 per cent solution is not strong enough for some sewages.

It is advisable to run a blank and apply the proper corrections if necessary.

NITROGEN AS FREE AMMONIA.

Reagents.—1. A 10 per cent solution of copper sulphate.

2. A 10 per cent solution of lead acetate.

3. A 50 per cent solution of potassium hydrate.

Procedure.—Fifty c.c. of the sample are mixed with an equal volume of water, and a few drops of the copper sulphate solution are added. After a thorough mixing, 1 c.c. of the potassium hydrate solution is added and the contents are again thoroughly mixed by shaking. The solution is then allowed to stand for a few minutes, when a heavy precipitate should fall to the bottom, leaving a colorless supernatant liquid. Neslerize an aliquot portion of this clear liquid. Usually 4 c.c. of the mixture will be sufficient to fall within the range of the Nessler standards.

Many samples containing hydrogen sulphide require the use of lead acetate in addition to the copper and with others a little magnesium chloride is said to be of service..

NITROGEN AS NITRATES.

Sulphanilic Acid Method.

Reagents.—1. Sulphanilic acid solution. Dissolve 3.3 grams of sulphanilic acid in 750 c.c. of water by the aid of heat. Add 250 c.c. of glacial acetic acid and make up to 1 liter.

2. A-naphthylamine acetate solution. Boil 0.5 gram of solid a-naphthylamine in 100 c.c. of water for 5 minutes. Filter through a plug of washed absorbent cotton. Add 250 c.c. of glacial acetic acid and dilute to 1 liter.

3. Sodium nitrite stock solution. Dissolve 1.1 gram silver nitrite in nitrite-free water; precipitate the silver with sodium chloride solution and dilute the whole to 1 liter.

4. Standard sodium nitrite solution. Dilute 100 c.c. of solution (3) to one liter, then dilute 10 c.c. of this solution to one liter with sterilized nitrate-free water, add 1 c.c. of chloroform and preserve in a sterilized bottle. One c.c. = 0.0001 mg. nitrogen.

Procedure.—Take 10 c.c. of the sample and 90 c.c. of water in a low-form 100 c.c. Nessler tube and add 2 c.c. of each of reagents Nos. 1 and 2 and mix. Let stand and read in 10 or 15 minutes by comparing with temporary standards made from reagent No. 4 or permanent standards made as follows:

Cobalt Solution.—Weigh out 24 grams of cobaltous chloride ($CoCl_2 \cdot 6H_2O$) and dissolve it in distilled water. Add 100 c.c. strong HCl and make up to one liter with distilled water.

Copper Solution.—Weigh out 12 grams of dry cupric chloride ($CuCl_2 \cdot 2H_2O$) and dissolve it in distilled water. Add 100 c.c. of strong HCl and make up to one liter with distilled water.

Make up standards in 100 c.c. tubes by running in the amounts of cobalt and copper solutions given in the table and filling up to the mark with water. Label each tube with its corresponding nitrate number.

C.C. Cobalt Sol.	C.C. Copper Sol.	Standard Nitrate Number.
1.1	1.1	1
3.5	3.0	3
6.0	5.0	5
8.7	6.9	7
12.5	8.0	10
20.0	8.0	15

Phenolsulphonic Acid Method.

Reagents.—1. Phenolsulphonic acid. Mix 30 grams of synthetic phenol with 370 grams of C.P. concentrated sulphuric acid in a round-bottom flask. Put this flask in a water bath and support it in such a way that it shall be completely immersed in the water. Heat for six hours.

2. A 25 per cent solution of potassium hydrate.

3. Standard nitrate solution. Dissolve 0.72 gram of pure recrystallized potassium nitrate in one liter of distilled water. Evaporate cautiously 10 c.c.

of this strong solution on the water bath. Moisten quickly and thoroughly with 2 c.c. of phenolsulphonic acid and dilute to one liter for the standard solution, 1 c.c. of which will equal 0.001 mg. of nitrogen.

Procedure.—Evaporate 10 c.c. of the sample in a small porcelain evaporating dish on the water bath; removing it from the bath just before it has come to dryness. Let the last few drops evaporate at room temperature in a place protected from dust. Add one c.c. of phenolsulphonic acid and rub this quickly and thoroughly over the residue with a glass rod. Add about 10 c.c. of distilled water and stir with a glass rod until mixed. Add enough of the potassium hydrate solution to render the liquid alkaline. Transfer the liquid to a 100 c.c. Nessler tube and fill to the mark with distilled water.

If nitrates are present there will be formed a yellow color. This may be compared with permanent standards made for the purpose, by putting the following quantities of the standard nitrate solution into 100 c.c. tubes and making up to the 100 c.c. mark with distilled water, adding 5 c.c. of strong ammonia or potassium hydrate to each tube; namely, 0, 1, 2, 4, 7, 10, 15, 20, 25, 30, 35 and 40 c.c. These standards may be kept for several weeks.

Compare the sample treated as above described with these standards by looking down vertically through the tubes at a white surface so placed in front of a window that it will reflect the light upward through them. If the figures obtained by this comparison be divided by the number of c.c. of the samples which were evaporated, the quotient gives the number of parts per million of nitrogen in the form of nitrate.

If the color is too high to fit the standards, take an aliquot portion, dilute to 100 c.c. and compare.

NOTE.—As all permanent standards in tubes should be protected against dust and evaporation, covers made of discs of clear glass cemented on the tops of the tubes with a mixture of paraffin and bee's-wax are a great convenience. If desired, the tubes may be made with a small flat flange at the top to permit of a stronger seal.

When the chlorine content is above 30 the reduction method is recommended.

REDUCTION METHOD FOR NITRATES.

Reagents.—1. Potassium hydrate solution. Dissolve 250 grams of the hydrate in 1.25 liters of distilled water. Add several strips of aluminum foil and allow the action to proceed over night. Boil down to one liter.

2. Aluminum foil. Use strips of pure aluminum about 10 c.m. long, 6 mm. wide and .33 mm. thick, and weighing about 0.5 g.

Procedure.—Put 100 c.c. of the sample of water in a 300 c.c. casserole. Add 2 c.c. of the hydrate solution and boil down to about 20 c.c. Pour the contents of the casserole into a test-tube about 6 cm. long and 3 cm. in diameter and of approximately 100 c.c. capacity. Rinse the casserole several times with nitrogen-free water and add the rinse water to that already in the tube, thus making the contents of the tube approximately 75 c.c. Add a strip of aluminum foil. Close the tube by means of a rubber stopper through which passes a V-shaped glass tube about 5 mm. in diameter. Make the short end of the tube flush with the lower side of the rubber stopper, while the other end extends below the surface of distilled water contained in another test-tube. This apparatus serves as a trap through which the evolved hydrogen escapes freely. The amount of ammonia escaping into the trap is slight and may be neglected. Allow the action to proceed for a minimum period of four hours, or over night. Pour the contents of the tube into a distilling flask, dilute with 250 c.c. of ammonia-free water, distill and collect in Nessler tubes and Nesslerize. When the nitrate content is high, collect the distillate in a 200 c.c. flask and Nesslerize an aliquot portion. If the supernatant liquid in the reduction tube is clear and colorless, the solution may be diluted to a definite volume and an aliquot part Nesslerized without distillation.

OXYGEN CONSUMED.

Reagents.—1. Concentrated C. P. sulphuric acid.

2. Standard potassium permanganate solution. Dissolve 0.3952 gram of the crystallized chemical in freshly boiled distilled water, and make up to one liter. Check against an ammonium oxalate solution. One c.c. is equivalent to 0.1 mg. of available oxygen.

3. Ammonium oxalate solution. Dissolve 0.888 gram of the substance in distilled water and make up to one liter. One c.c. is equivalent to 0.1 mg. of oxygen. Preserve with chloroform.

Procedure.—Measure into a flask 10 c.c. of the sewage and 90 c.c. of distilled water. Add 2 c.c. of the sulphuric acid and 10 c.c. of the permanganate solution. Place immediately in a bath of boiling water and digest for 30 minutes to the exact second. A few seconds before the expiration of the time remove the flask from the bath and exactly on the expiration of the 30 minutes run in 10 c.c. of the oxalate solution. Then titrate back with the permanganate solution to a faint but permanent pink color.

Run a blank on 90 c.c. of distilled water under precisely the same conditions and make the necessary corrections.

The amount of the permanganate used in the determination minus the blank, is the amount actually consumed by the organic matter.

If the volume of the permanganate is insufficient for complete oxidation, use a larger quantity, as it should always be in excess.

DISSOLVED OXYGEN.

Winkler Method.

Reagents.—1. Manganous sulphate solution. Dissolve 48 grams of manganous sulphate in 100 cc. of distilled water.

2. Sodium hydrate and potassium iodide solution. Dissolve 36 grams of sodium hydrate and 10 grams of potassium iodide in 100 c.c. of water.

3. Sulphuric acid. Specific gravity 1.4 (dilution 1 : 1).

4. Sodium thiosulphate solution. Dissolve 6.2 grams of chemically pure recrystallized sodium thiosulphate in distilled water and make up to one liter. This gives a $\frac{N}{40}$ solution, each c.c. of which is equivalent to 0.2 mg. of oxygen or 0.1395 c.c. of oxygen at 0° C. 760 mm. pressure. Inasmuch as this solution is not permanent, it should be standardized occasionally against an $\frac{N}{40}$ solution of potassium bichromate as described in almost any work on volumetric analysis. The keeping qualities of the thiosulphate solution are improved by adding to each liter 5 c.c. of chloroform and 1.5 grams of ammonium carbonate before making up to the prescribed volume.

5. Starch solution. Mix a small amount of cornstarch with cold water until it becomes a thin paste. Stir this into 150 to 200 times its weight of boiling water. Boil for a few minutes and preserve by adding a few drops of chloroform.

The product known as soluble starch is more convenient to use, being more easily dissolved and made up into a clear solution.

Collection of the sample.—The sample should be collected with the usual precaution against the entrainment or absorption of any oxygen from the atmosphere. Aspirator bottle apparatus are sometimes used, although the sample bottle may be filled with a light mineral oil and lowered beneath the surface with the stopper in place. The stopper is then removed and the sewage allowed to fill the bottle by displacing the oil. From a running effluent a satisfactory sample may be obtained by allowing the bottle to be filled by means of a rubber tube. One end of the tube is held in the stream and the other inserted into the bottle to the bottom. The flow of liquid through the tube quickly fills the bottle and after the bottle has been allowed to overflow a few minutes the tube is slowly withdrawn' care being used to prevent any bubbles of air being caught and passed into the bottle during the filling. The bottles should hold about 250 c.c. and should have solid glass stoppers.

Procedure.—Remove the stopper from the bottle and add 2 c.c. or less of the manganous sulphate and an equal amount of the sodium hydrate-potassium iodide solution, delivering both of these solutions beneath the surface of the liquid by means of pipettes. Replace the stopper and mix the contents of the bottle by rapidly turning the bottle upside down several times. Allow the precipitate to settle. Remove the stopper and add about 2 c.c. of the sulphuric acid and mix thoroughly. After the precipitate is completely dissolved pipette out 200 c.c. into a flask and titrate with the $\frac{N}{40}$ sodium thiosulphate solution using a few c.c. of the starch solution toward the end of the titration. Titrate until the first disappearance of the blue color. Some analysts titrate 100 c.c., in which case an $\frac{N}{80}$ solution of sodium thiosulphate is used.

In each case the number of c.c. used gives directly the dissolved oxygen in parts per million. For accurate work, however, there are a number of corrections to be applied. (See Standard Methods.)

It is usually best to make the complete determination in the field unless the laboratory is near by, because the titration of some sewages will not permit of being delayed even after the addition of the sulphuric acid.

TURBIDITY.

The simplest form of apparatus for this work is the candle turbidimeter (see Standard Methods, page 7). An incandescent electric lamp may be compared with and substituted for the candle. This is more convenient and does not heat the turbidimeter tube.

The sewage is poured into the tube until the outline of the light is indistinct. The turbidity is read directly from the graduation at the top of the liquid.

SEDIMENT.

A figure for sediment may be obtained by taking the difference between the turbidimeter reading of a settled sample and the reading of the same sample after shaking.

PUTRESCIBILITY.

Samples should be collected in well-fitting glass-stoppered bottles of about 4 to 8 oz. capacity. No special precautions are necessary in collecting samples of ordinarily good effluents that are fairly high in dissolved oxygen. If the dissolved oxygen be low, precautions similar to those used in collecting dissolved oxygen samples should be observed.

A one-tenth per cent solution of methylene blue, Merck's double zinc salt, BX, is used as an indicator. One-half cubic centimeter of this solution is added to the sample and the stopper is inserted by means of a twisting motion, so as to make it tight without any bubble of air remaining in the bottle. The sample is incubated at 20° C. for fourteen days, and observations made at least once a day. As soon as the sample has become decolorized the number of days standing blue are recorded and the sample discarded. (For relative stability table see "Standard Methods.")

For convenience a 1 per cent solution of the blue may be used, in which case only one or two drops, depending on the size of the bottle, are necessary.

The medicinal form of blue may be employed, although it is not so strong in color as the dye.

AVAILABLE CHLORINE IN BLEACHING POWDER.

Titration by Sodium Arsenite (Penot).

Reagents.—1. Sodium Arsenite Solution. Dissolve 4.948 grams of the purest sublimed arsenious oxide in a few c.c. of strong caustic soda, acidulate slightly with HCl and add 30 grams of sodium bicarbonate and make up to a liter. This gives a tenth normal solution.

NOTE.—Sutton in his new edition on Volumetric Analysis, p. 139, gives the following new method to which the reader is referred: Dissolve 4.948 grams of the purest sublimed arsenious oxide in about 250 c.c. of distilled water in a flask with about 20 gm. of pure sodium carbonate. The mixture needs warming and shaking for some time in order to complete the solution; when this is accomplished the mixture is diluted somewhat, cooled, then made up to a liter.

This gives a tenth normal solution and may be checked with a tenth normal solution of iodine.

2. Iodized Starch Paper. This is made by moistening a piece of filter paper with a starch solution in which a few crystals of potassium iodide have been dissolved.

Procedure.—The sample is well and quickly mixed, and 7.09 grams weighed out from a stoppered test-tube into a porcelain mortar, and the powder ground with successive portions of water until it is well triturated and washed into a liter flask without loss, and the mortar washed quite clean. The flask is then filled to the mark with water, well shaken and 50 c.c. of the milky liquid (=0.3456 gm. bleaching powder), are taken out with a pipette, observing the precaution that it shall contain its proportion of the suspended matter.

This is titrated in a beaker with the tenth normal arsenious solution, until a drop of the mixture, taken out with a glass rod and brought in contact with the iodized starch paper, gives no blue stain.

Each c.c. of the arsenite used gives the percentage of available chlorine in the bleaching powder.

Bunsen's Method.

The chloride of lime solution prepared as above is measured into a beaker and an excess of a solution of potassium iodide added. The mixture is then diluted somewhat, acidified with acetic acid and the liberated iodine titrated with $\frac{N}{10}$ thiosulphate and starch; 1 eq. iodine so formed represents 1 eq. chlorine.

Solutions for Field Work.

For titrating solutions of bleach at disinfecting plants, it is more convenient to have the solutions of arsenite or thiosulphate of such a strength that 1 cc. will be exactly equivalent to a definite number of milligrams of chlorine. For example: if 1.3944 gm. of As_2O_3 per liter are made up according to the method given above, 1 c.c. of the solution will be equal to 1 milligram of chlorine. With such a solution the calculations are simpler and more quickly made.

In place of the iodized starch paper, large drops of the iodized starch solution may be placed separately upon a piece of clean porcelain or white glass. These are touched in succession with the stirring rod as the titration proceeds. As soon as a spot fails to turn blue the end-point has been reached.

If preferred, toward the end of the titration, which may be done in a porcelain dish, a drop or two of the iodized starch solution may be added to the contents, causing a pale blue color, which disappears as soon as the end-point is reached.

Bacterial Tests.

Bacterial tests on sewage and effluents are not of great importance except at those plants where disinfection is carried on. In some cases, however, it is very useful to know how the effluents are running and what the several units are doing in the bacterial reduction.

Of the tests usually performed, the total count on agar at 20 degrees C., the total count on litmus-lactose-agar at 37 degrees C., the number of red colonies on the same plate, and the presumptive test for B. coli are the ones most generally made.

The details in regard to the apparatus, collection and care of samples, the preparation, handling and storage of various culture media, conditions of incubation and expression of results, are all carefully laid down in the "Standard Methods of Water Analysis" to which the reader is referred because all details of standard technique must be closely followed if results for comparison are to be obtained.

In general the technique for making plates is as follows:

The sample collected in a sterilized bottle is thoroughly shaken and 1 c.c. is withdrawn with a sterilized pipette and delivered into a sterilized Petri dish. If there be reason to suspect that the number of bacteria is more than 200 per c.c., mix 1 c.c. of the sample with 9 c.c. of sterilized tap or distilled water. Shake thoroughly, and with another sterilized pipette transfer 1 c.c. of this mixture to another 9 c.c. of sterile water and so on until the proper dilution has been obtained. The first dilution will be 1 : 10, the second 1 : 100 and so on. In case of an unknown sewage or effluent it is advisable to use several different dilutions of the same sample. To the liquid in the Petri dish add 10 c.c. of standard agar at a temperature of about 40 degrees C. Mix the medium and water by tipping the dish back and forth, and spread the contents uniformly over the bottom of the dish. Allow the agar to cool rapidly on a horizontal surface and transfer to the 20 degrees C. incubator. Incubate the culture for 48 hours at a temperature of 20 degrees C. in a dark well-ventilated incubator where the atmosphere is practically saturated with moisture. After the period of incubation place the Petri dish on a glass plate suitably ruled, and count the colonies with the aid of a lens which magnifies at least five diameters. So far as practicable the number of colonies on a plate shall not be allowed to exceed 200.

As sewages and tank effluents usually have to be plated at a dilution of one to one hundred thousand and other effluents at one to a thousand or ten thousand, it is convenient to indicate the dilution by a sub-figure instead of a fraction or sign of ratio. Thus S_5 would indicate that a sewage sample was plated at a hundred thousand dilution and if 75 colonies were found, the addition of five ciphers to the 75 would give 7,500,000, the number of bacteria per c.c. Likewise E_3 would indicate an effluent at one thousand dilution and three ciphers are to be added to the count obtained on the plate.

For the 37 degrees count the same procedure is followed except that the medium is litmus-lactose-agar, the temperature is 37 degrees C., and the time of incubation is 24 hours. In addition to the total count on this plate, the number of red colonies also is recorded.

For the presumptive test for B. coli, standard lactose-peptone bile is used in test-tubes containing a small inverted test-tube about 3 inches long. This tube is dropped in on the bile before being plugged with cotton and in the process of sterilizing becomes filled with the bile in its inverted position. One tube is inoculated with 1 c.c. of each of three or more dilutions, so selected that at least the highest dilution will be negative. The tubes are incubated at 37 degrees C. for 48 hours and all tubes showing 20 per cent or more gas in the small inverted tube are called positive.

If desired, the number per c.c. may be estimated by taking as the number the factor of the highest dilution which is positive. Thus of three tubes, if E_2 and E_3 are positive while E_4 is negative, then the B. coli figure per c.c. would be 1000.

In inoculating the tubes, care should be used to see that the inner tube is not stuck and that the bile under it is inoculated also.

If desired, after fermentation begins in an enrichment medium such as lactose broth or lactose bile, some of the liquid may be tested out on Endo medium plates. The Endo plates confirm the gas formation in the tubes and the B. coli can be estimated as above.

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