# SEWERS AND DRAINS

MARSTON-FLEMING

# SEWERS AND DRAINS

A COMPREHENSIVE DISCUSSION OF MODERN SANITARY METHODS IN THE DESIGN OF SEWERS AND SEWERAGE SYSTEMS, IN THEIR LAYING-OUT, COST, AND CONSTRUCTION AND IN THE DISPOSAL OF SEWAGE

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# INTRODUCTION

IN these days of complex living, the health of the public is an all-important factor which must be considered in all its phases. In olden days more serious infections and prolonged epidemics were brought about by careless sanitation than by almost any other cause. The germ theory of disease was not then understood and hence the inhabitants, blissfully ignorant of their crime, were constantly doing all sorts of fearful things and daily breaking all of the now well-established laws of sanitation and public health. Thanks to the efforts of scientists we now know just what must be done with our water, our sewage, and our garbage in order to avoid typhoid and other serious epidemics.

¶ The authors of this article have, by long service in the academic and practical fields, qualified themselves to speak with authority on this subject. They have given a great deal of practical information in the design of sewers, systems of sewerage, sewage disposal, layouts, typical specifications, sewer materials, tables and diagrams for calculating sizes, capacities, and costs of construction. Altogether the treatise will be found very interesting to the layman and extremely valuable for the practical man engaged in sewer work.

**CONSTRUCTING THE LARGEST SEWER IN THE UNITED STATES**

View of men at work in tunneling shield; wooden forms also shown. Sewer lined with brick laid in "Utica" hydraulic cement. View of 39th Street intercepting sewer, Chicago, Ill.

# CONTENTS

## DESIGN AND CONSTRUCTION OF SEWERS

CONTENTS



## DRAINS



## HOUSE SEWERAGE



## SPECIFICATIONS FOR SEWERAGE SYSTEMS

## CONTENTS

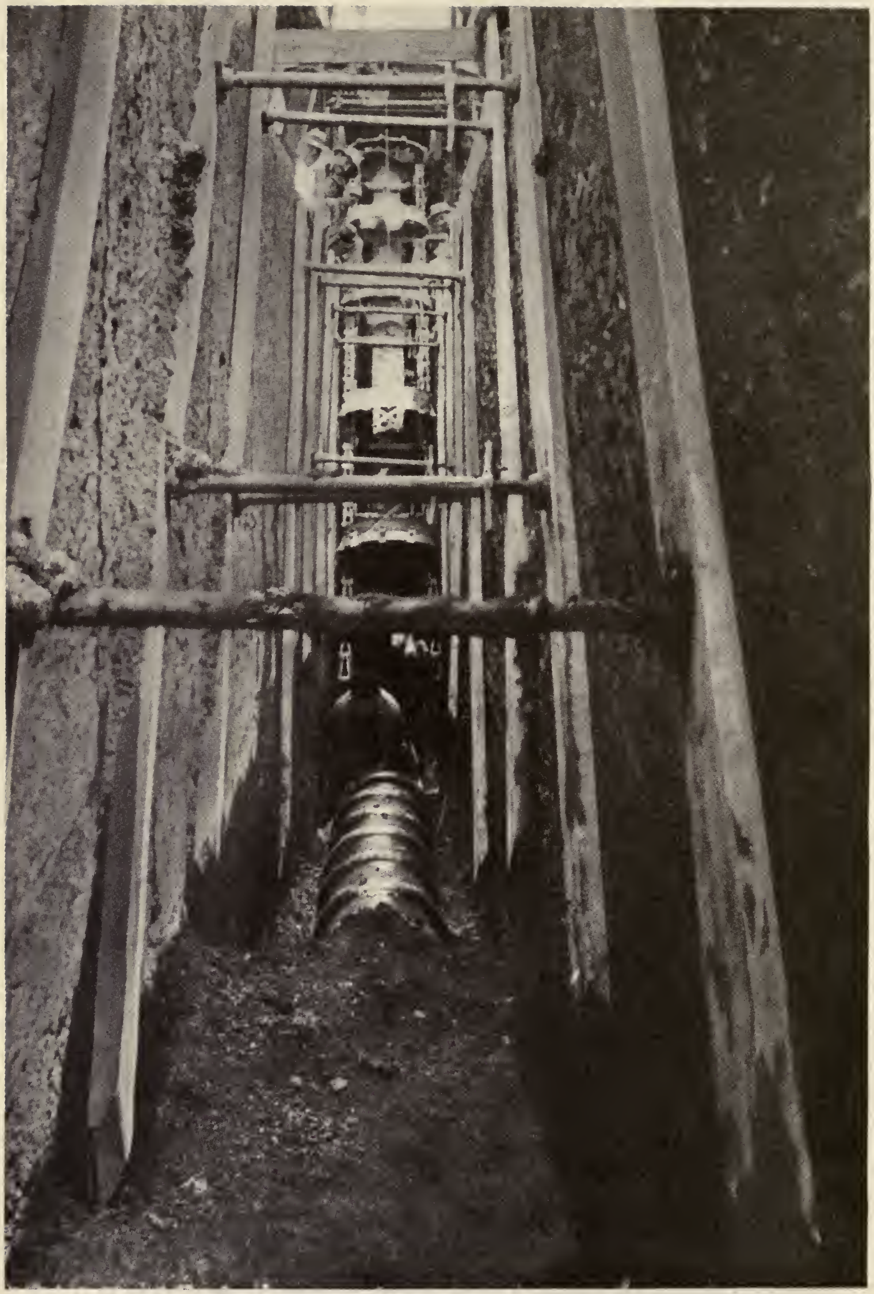
### CONSTRUCTION AND MAINTENANCE OF SEWERS



### SEWAGE DISPOSAL



### GARBAGE DISPOSAL



**AUSTIN TRENCHING MACHINE DIGGING TRENCH 18 FEET DEEP AND 40 INCHES WIDE**

*Courtesy of Municipal Engineering and Contracting Company, Chicago*

# SEWERS AND DRAINS

## PART I

**1. Introductory Definitions and Discussions.** *Sanitary Engineering* is that branch of engineering which has to do with constructions affecting health. It thus might be claimed to include the manufacture and transportation of foods, the architecture of buildings, and many other things which affect the health of communities; but in ordinary use, a more restricted definition of the term is adopted.

In common practice, the term *Sanitary Engineering* is taken to include only *water supply engineering* and *sewerage engineering,* the former branch dealing with securing a satisfactory supply of water, and the latter with the satisfactory removal of surplus and waste liquids. Sewerage is the subject of this instruction paper, water supply being treated by itself.

Sometimes *sanitary engineering* is given a still more restricted meaning, and is taken to include sewerage only.

A *drain* is a canal, pipe, or other channel for the gradual removal of liquids. In sanitary engineering, the two principal kinds of drains are, first, those for the removal of comparatively pure ground waters and surface waters, as in land drainage; and, second, those for the removal of polluted liquids, as in sewerage systems.

A *sewer* is a drain for the removal of foul, waste liquids. Usually sewers are closed, underground conduits. An *open sewer* is an open channel which conveys foul, waste liquids.

*Sewerage* is a general term referring to the entire system of sewers, together with any accessories, such as pumping plants, purification works, etc. Thus we may speak of the "sewerage" of a city, or of the "system of sewerage," or of the "sewerage system."

*Sewage* is any foul, waste liquid.

*Sanitary sewage* is the foul wastes of human or animal origin from residences, stables, stores, public buildings, and other places of human or animal abode. By far the greater part (usually 99.8 per cent or more) of sanitary sewage, commonly, is ordinary water, which is added to the wastes themselves in this large volume simply to facilitate removal.

*Manufacturing sewage* is the foul wastes from factories. In different factories, it is of extremely different nature. It is often exceedingly strong, and very offensive and difficult to dispose of, as compared with sanitary sewage.

*Storm sewage* is the storm water flowing from city surfaces during and after rainstorms. Though polluted, especially at the beginning of a storm, from the droppings of animals and the other surface filth of cities, it is not so foul, nor so liable to swarm with disease germs, as is sanitary sewage.

The terms *sewage* and *sewerage* are often misused by persons not engineers, to mean the same thing. Thus such persons often speak of the "sewage system" instead of the "sewerage system;" of the "disposal of the sewerage" instead of the "disposal of the sewage," of a city. So common is the misuse that some sanction can be found in the dictionaries; but engineers should be careful to restrict the meaning of the word "sewage" to the liquid which flows in the sewers, while the word "sewerage" should never be so applied.

*Sewer air,* often miscalled *sewer gas,* is the air in the sewers above the liquid contents. It has no definite chemical composition, but contains varying proportions of pure air and of carbonic acid gas, marsh gas, sulphuretted hydrogen, and the various products of decaying organic matter. Sewer air is constantly changing in composition even in the same sewer. While considered injurious to health when breathed, it has not been proved to be in itself the direct means of communicating infectious diseases.

**2. Historical Review.** Sewers and drains are of very early origin. Among the ruins of all ancient civilizations, are found the remains of masonry and tile conduits constructed for drainage purposes.

In Fig. 1, for example, (from Fergusson's *History of Architecture*), are shown the remains of a large masonry sewer or drain built by the ancient Assyrians in the eighth or ninth century B. C., for one of their palaces at Nimrud. This is one of the earliest examples found of the use of the arch in masonry.

In Fig. 2 is shown the mouth of the *Cloaca Maxima,* or great sewer, of ancient Rome, built in the seventh century B. C., and still in use after the lapse of 2,500 years. Without this sewer, a large tract of ancient Rome could not have been inhabited; and in speaking

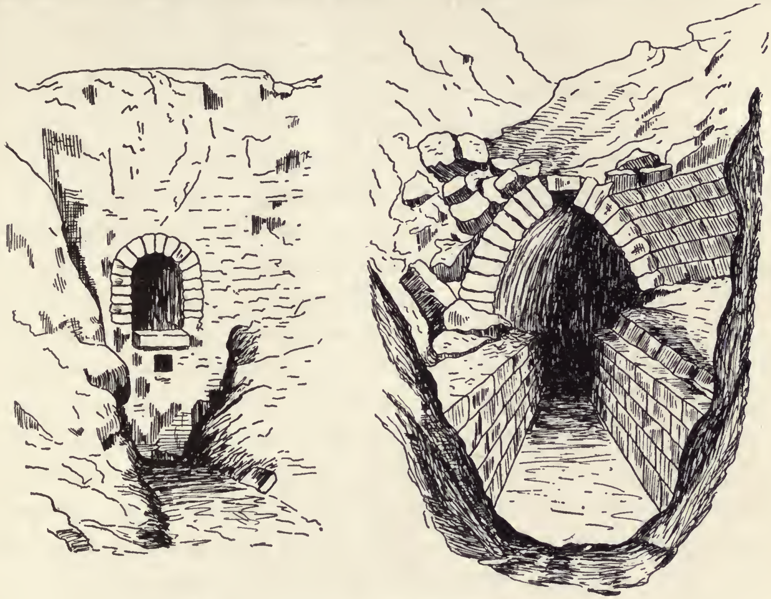


Fig. 1. Ancient Assyrian Sewers at Nimrud.

of it, one authority says: "To this gigantic work, admired even in the time of the magnificent Roman Empire, is undoubtedly owing the

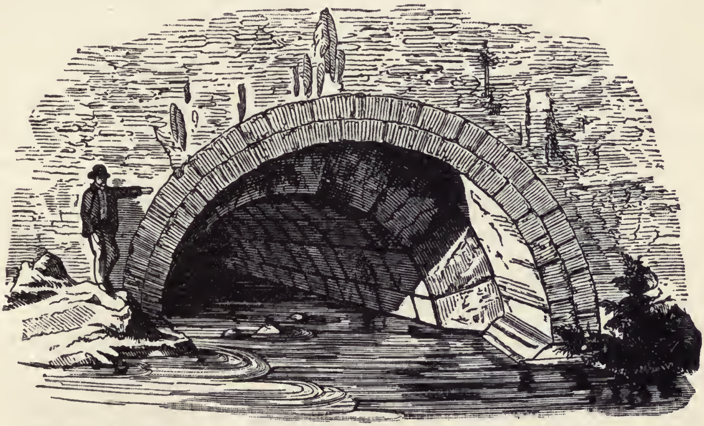


Fig. 2. Mouth of the *Cloaca Maxima*, or Great Sewer, of Ancient Rome.

preservation of the Eternal City, which it has secured from the swamping that has befallen its neighboring plains."

In many other ancient cities and structures, the remains of intelligently planned drainage systems have been discovered; and it is evident that the ancients paid great attention to this matter so vitally affecting health. The art reached its highest ancient development in the time of the Roman Empire. The Romans, in fact, were the greatest engineers of antiquity, and especially excelled in sanitary engineering (both water supply and drainage). They were proficient in land drainage, as well as in sewerage.

With the fall of the Roman Empire, sanitary engineering suffered the same retrogression which befell learning and science; and for a thousand years—throughout the Middle or Dark Ages—it was almost entirely neglected. The impure water supplies and the accumulated filth of mediæval cities produced fearful consequences in the terrible pestilences which desolated Europe.

With the revival of learning and science in the 14th and 15th centuries, attention again came to be paid to sanitary engineering; but for three or four hundred years more, little was done toward putting drainage and water supply on a scientific basis. Drains, rather than sewers, were built in the various towns as absolute necessity made imperative; but they were constructed piecemeal, and not so as to form comprehensive systems. They were not made watertight or self-cleaning; but it was usually considered necessary to make them large enough for men to enter to remove the filth, whose accumulation and festering in them were believed unavoidable.

In England, modern sanitary engineering may almost be said to have had its origin; yet so late as 1815, laws were enforced forbidding the emptying of fæcal matter into the sewers. "Such matter was generally allowed to accumulate in cesspools, either under the habitations of the people or in close proximity thereto." * In fact, though no longer enforced, these laws were not repealed until 1847, when Parliament passed an exactly contrary act, making it compulsory to pass fæcal and other similar foul matter into the sewers.

Modern sanitary engineering, especially as regards sewerage and drainage, has had almost its entire development since 1850. It was not until 1873 that there was published a comprehensive treatise on sewerage, that of Baldwin Latham, already quoted. At about this time, also, much attention began to be paid in England to sewage

*Baldwin Latham.

purification. It was reserved, however, for America to put sewage purification on the road to a satisfactory scientific solution, by the thorough investigations of the Massachusetts State Board of Health, begun in 1887 and still under way.

In America, much was done in the third quarter of the 19th century to advance sewerage engineering, through the studies of able engineers in connection with the design of systems for Chicago, Brooklyn, and other large American cities, the results being published in papers and reports, or in book form.

About 1880 the *separate* system of sewerage came strongly into prominence in America, as advocated by the late Col. Geo. E. Waring; and the construction of the Memphis (Tenn.) sewers on this system at that time, together with their great success in putting a stop to the fearful epidemics which had so often desolated that city, did much to make sewerage possible for small cities. At present, sewers have become so common and so necessary in modern life, that villages of 2,000 population, or sometimes of even less, are very generally taking up their construction.

With the present wide adoption of sewers, even by small communities, sewage disposal has come to be of very great importance, and is now undergoing great development. Many discoveries remain to be made in this line, in which the guiding principles have not yet been so thoroughly worked out as in the construction and maintenance of sewers themselves.

**3. Importance and Value of Sewerage and Drainage.** The importance and value of the constructions of sanitary engineering can hardly be exaggerated. Upon them absolutely depends the health of every city. One needs but to read descriptions of the great modern epidemics of yellow fever at Memphis and New Orleans, or of cholera at Hamburg, or to have been engaged to visit as sanitary engineer an American town during one of the numerous recent outbreaks of typhoid, to understand the truth of the scripture, "All that a man hath will he give for his life." Yet not only could sanitary engineering absolutely prevent every such epidemic; but, in addition, it could annually save thousands upon thousands of other lives which now succumb to bad sanitation.

Already very much has been accomplished in this direction by improved sanitation, though ideal conditions are yet seldom attained.

A prominent sanitary engineer estimated from actual statistics, that as early as 1885 there was a saving from this cause of 100,000 lives and 2,000,000 cases of sickness, annually, in Great Britain, in a total population of only 30,000,000. Figuring on the basis of the money value alone of the lives saved, and of the sickness and loss of time avoided, the money value of the above result would be almost incalculable.

In many individual cities, statistics have shown in death rates an immediate lowering, due to the construction of sanitary improvements, more than sufficient in money value to the community to pay for the entire cost. Funeral and sickness expenses saved, alone, often make enormous sums.

In this connection, it should be said that pure water supply and good sewerage are both essential, and that it is impossible to separate the value of one from that of the other. A polluted water supply may spread disease, no matter how perfect the sewerage, and an abundant water supply is essential to the proper working of sewers. On the other hand, without sewers and drains, an abundant water supply serves as a vehicle to enable unmentionable filth to saturate more deeply and more completely the soil under a city. Cesspools are even more dangerous than privy vaults.

In addition to direct prevention of communication of disease by unsanitary conditions, modern sewerage facilities are so great a *convenience* that this advantage alone is usually more than worth the cost. This is shown by the increased selling and rental value of premises supplied with sewerage facilities. No sooner is a partial or complete sewer system constructed in a town, than prospective buyers or renters begin to discriminate severely against property not supplied with modern sanitary conveniences; and persons looking for new locations for business ventures or residence purposes, discriminate in like manner in favor of towns having good sewerage.

So great has become the demand for sanitary conveniences, that they are now being installed in farmhouses as well as in the city. It is now possible for any farmer, at an expense of only a few hundred dollars, to have hot and cold water piped under pressure in his house, a bathroom and other plumbing fixtures, and his own sewage-disposal plant. This has already been accomplished in many cases. Such improvements, if made in accordance with correct principles, greatly better the sanitary conditions of the home; and they also prevent much disease by doing away with the exposure to inclement weather, which is so dangerous an accompaniment of the old-fashioned, barbarous, outdoor privy.

The great importance of sewerage may be realized by giving some consideration to the enormous sums of money which have already been spent for sewer systems in this country alone. Villages of 3,000 population in rural communities, often spend $50,000 or more upon a system. The city of Chicago has in recent years spent $50,000,000 in securing merely a satisfactory outlet for its sewers, without counting a dollar of the vast sums expended on the sewers themselves. In the United States, hundreds upon hundreds of millions of dollars have been invested in sewers.

## SYSTEMS OF SEWERAGE

4. A *privy vault* is a receptacle, usually a mere excavation in the ground, for the reception of fæcal matter and urine. To prevent dangerous pollution of the surrounding soil and ground water, privy vaults should be lined with water-tight masonry; but this is seldom attempted, and even if attempted, is still more seldom accomplished, for it is difficult in such work to secure absolute freedom from leakage. The privy vault, frequently, is simply abandoned and covered over with earth when full, it being cheaper to change the location than to clean out the old pit.

The privy vault, with its inevitable befouling, in the immediate vicinity of the home, of earth, air, and water, the three great requisites of health, and with its danger from pneumonia and other diseases which may be contracted from exposure, should be adopted only in case of absolute impossibility to secure something better, and even then only as a temporary resort. It is not so objectionable in the country as in the city, if located far away from the well; but here the trouble is that it is usually placed too close to the well which furnishes the drinking water. In the country the leachings from hog pens, cattle yards, and manure piles frequently add to the contamination of the drinking water. It is impossible to set any safe distance at which a well may be placed from a privy, owing to the variable nature of the soil. The contamination may be carried very far in gravel strata or rock crevices. Impervious clay confines filtration within narrower limits.

**5.** A *cesspool* is a receptacle for receiving and storing liquid sewage. It consists usually of an excavation dug in the ground, lined with masonry, and covered, into which the sewer from the house discharges. To prevent contamination of the surrounding soil and ground water, the cesspool should be made absolutely water-tight, and its contents should be removed whenever it becomes full.

A *leaching cesspool* is one not made water-tight. The liquid contents partly leach away into the surrounding soil, and often into sand or gravel strata, or crevices in the rock, which may carry the contamination to great distances. Owing to the offensive nature of the work of cleaning out cesspools, and to the expense thereof, cesspools as a usual thing are deliberately made not water-tight. The owner congratulates himself if he strikes a crevice in the rock or a gravel stratum which prevents his cesspool from filling up, though even a little thought will often show that he is thus directly contaminating the water vein which supplies his own or his neighbor's well. Even then he does not usually escape permanently the expense and annoyance of being forced to clean out the cesspool, for in time almost any crevice or porous stratum will clog so as to permit only partial escape of sewage.

Leaching cesspools should be absolutely prohibited by law. They are even more dangerous than the privy, for the liquid sewage in them can penetrate further into the surrounding soil than the fæcal matter of the privy vault.

The frequent effect of cesspools and privies is illustrated in Fig. 3, which does not at all exaggerate conditions very frequently found in cities and villages. Often the tearing down of old buildings, prior to the erection of new, exposes to view the rear of lots, and shows sometimes a half-dozen privies grouped within a few rods of several wells. The nose and the eye give convincing evidence of foulness in such cases; and chemical or bacterial analyses are not necessary to demonstrate the danger in using the wells; but the same dangerous conditions pass unnoticed in many other places in the same city, because not exposed to casual view. In time, the whole ground water under such a village or city becomes contaminated, and poisons wells and damp cellars and the exhalations from the ground.

6. A *dry closet* is a privy having a tight, removable receptacle in place of the vault, and provided with means for covering the contents with dry dust, ashes, or lime each time the closet is used. Usually a small shovel and a box are used to hold the dust or other absorbent material. Enough of the dry material should be used to absorb all liquids. The contents should be removed and hauled away in the tight box when it is full, to be emptied in a safe place or used for fertilizer. The dry earth closet is an improvement over the privy vault, but is not a safe or otherwise satisfactory arrangement.

7. The *pail system* is one in which the fæcal matter and urine are received in tight pails, which are removed daily, or at least every few days, by regular city employees. The pails are carried to some safe place, there emptied, and returned after disinfection. Although the pail system has been tried in America under exceptional conditions, it is entirely unsuited for use here, and is almost never employed, even in Europe, where the people will submit to the police interference necessary for satisfactory operation.

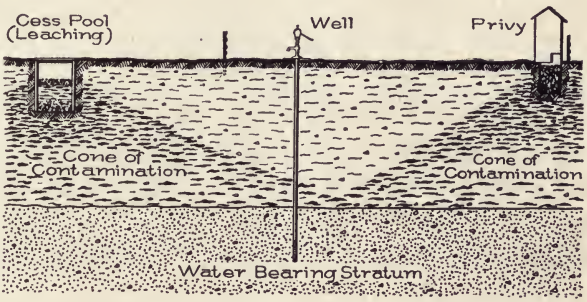



Fig. 3. Showing How Contamination of Well Water may Occur through Proximity of Cesspools and Other Sources of Filth.

8. *Pneumatic systems* of sewerage are those in which the sewage is forced through the street pipes by air, either by a partial vacuum, as in the *Liernur system* (tried in Holland), or by compressed air, as in the *Berlier system* (tried in France). Neither system is used at all in America, or to any important extent in Europe. The expense of construction and operation, and the liability of all such mechanical appliances frequently to get out of order, make them unworthy of consideration.

9. *Crematory systems* are devices for disposing of fæcal matter, urine, and garbage on the premises by drying and then burning. There are several patented methods. The matter to be disposed of is received in a furnace-like structure on the premises, built usually

of masonry, which is open to a chimney, as well as to the various closets in the building. The chimney is supposed to maintain a current of air out of the rooms in which the closets are located; this dries the material, which is then burned at intervals.

Where sewers have not been available, crematory systems have been installed in many schools and other public buildings in the United States; but, while sometimes fairly satisfactory for a while, they are usually soon found to be troublesome, expensive, and dangerous. The air-currents sometimes reverse into instead of out of the rooms containing the closets; danger ensues unless the burning is regularly attended to; and, without constant care in the attendance, the whole apparatus is likely to get out of order. Moreover, it is entirely unadapted to the disposal of liquid wastes such as those from sinks, washbowls, laundry basins, and bathtubs, which are as necessary to be taken care of as fæcal matter and urine.

In the foregoing paragraphs (Arts. 4 to 9), various makeshifts for caring for sewage have been described which are not worthy the name of "systems," although the privy vault and the cesspool are in very wide use. We next come to the only methods for removing sewage which are at present worthy of serious consideration when planning a sewerage system.

**10. Water-Carriage Systems.** Water-carriage systems of sewerage are those in which water is added to the fæcal matter and other foul wastes in such quantities as to permit of their rapid removal by gravity in sewers. As already stated, the water so added usually constitutes 99.8 per cent or more of the resulting sewage.

Water-carriage systems are now so universally used for sewerage purposes, that usually the two terms may be considered synonymous. That is, in the present day, a sewerage system is practically always a water-carriage system.

There are two kinds of water-carriage systems—namely, the *Combined System* and the *Separate System.*

**11. Combined System.** The combined system of sewerage is that in which the storm sewage flows in the same sewers with the sanitary and the manufacturing sewage. The combined system came into use prior to the separate.

**12. Separate System.** The separate system of sewerage is that in which separate sewers are provided for the storm sewage and for the sanitary and manufacturing sewage.

**13. Comparative Merits of Combined and Separate Systems.** The separate system came into prominence about 1880. At that time and for many years following, there was an active discussion over the relative merits of the two systems, some prominent engineers advocating one, and some the other. At the present time, the discussion has died down, and sanitary engineers use both, adopting whichever is best suited to local conditions, and often using a combination of the two.

*In favor of the separate system,* the following points have been cited:

1. The sanitary sewage which constitutes the dry-weather flow of combined sewers is so very small in comparison with the storm sewage, that in circular sewers, which are the most economical to build, it forms merely a trickling stream, with little velocity, over the bottom of the large sewers required; while in the separate system the sewers are proportioned for this small volume, and the sewage consequently has good depth and velocity. Moreover, sanitary sewers are free from the sand and other street detritus which are inevitably washed into combined sewers during storms, and which are especially troublesome in forming deposits. Hence, in the separate system, it is easier to make sewers self-cleansing from deposits.

2. Above the low-water line in combined sewers, the extensive interior surfaces of the large sewers required become smeared with filth in times of flood, which remains to decay and produce foul gases after the flood subsides.

3. On account of the comparatively small size of the sanitary sewers of the separate system, it is easier to flush them so as to keep them clean. Automatic flush-tanks can be used at small expense to do this very satisfactorily.

4. On account of the comparatively small size of the sanitary sewers of the separate system, the air in them is much more frequently and completely changed by the daily fluctuations in the depth of sewage and by the currents of air through ordinary ventilation openings. Hence, in the separate system, ventilation is easier and more perfect.

5. In case the sewage has to be purified, the separate system is more economical, because only the sanitary sewage need be treated, the storm sewage being discharged into nearby natural watercourses.

6. In small cities, and in large portions of large cities, the storm water can usually be carried some distance in the gutters, and then removed by comparatively short lengths of storm sewers, laid at shallow depths and discharging into the nearest suitable natural watercourses. In such cases, a separate system of sewers will usually cost only a fraction, frequently only one-third, as much as a combined system. For small towns, the great cost of a combined system would often prohibit the construction of sewers entirely, or postpone it almost indefinitely, were it not that a separate system can be built so cheaply. On this account alone, the introduction of the separate system of sewers has been of incalculable benefit in America.

7. On account of their relatively small size, sewers of the separate system can be made almost entirely of vitrified sewer-pipe, which has the important advantages over brick sewers, of greater smoothness, of being impervious, of having few joints, and of ease in making the joints practically water-tight. It is impossible to make even a pipe sewer absolutely water-tight, and with brick sewers the difficulty is very much greater.

*In favor of the combined system*, the following allegations, corresponding to the above points, have been made:

1. By making combined sewers egg-shaped with the small end down, or by making a small, semicircular channel in the bottom (see Figs. 19, 24, and 25), the depth and velocity of the dry-weather flow can be made sufficient to cause the sewer to be self-cleansing.

2. The coating on the interior surface of large sewers above the low-water line is not dangerous, and in fact is of very little importance.

3. While it is true that the smaller, separate sewers can be flushed more perfectly for the same expense, the larger, combined sewers are more convenient for removing obstructions, and are flushed out very completely (though at too long intervals in dry weather) by the floods of storm sewage during rains.

4. In regard to ventilation, the larger volume of air over the sewage in the larger, combined sewers dilutes to a much greater degree the gases from the sewage.

5. In case the sewage must be purified, it must be remembered that the early flow of storm sewage from the streets is foul, to some extent, from the droppings of animals and other surface filth; and it may in some cases be questionable whether this may not require purification in addition to the sanitary sewage.

6. Wherever, as in the case of the business districts of large cities, it is necessary to provide as great a length of storm sewers as of sanitary sewers, it will be cheaper to build one set of sewers, as in the combined system, rather than two, as would be required in such districts with the separate system.

The *general conclusions of sanitary engineers* at present regarding the relative merits of the separate and combined systems, are as follows:

*a.* Either system can be made satisfactory from a sanitary point of view.

*b.* The cost of a properly designed system, including means for safe disposal of sewage, should ordinarily decide which of the two systems should be built.

*c.* On the basis of cost, the separate system is usually the better for small cities, for suburban and sometimes residence districts of large cities, and for all cases, even those of large cities, where the sanitary sewage requires treatment while the storm sewage can be safely discharged into nearby watercourses. The separate system has just been recommended for the city of Baltimore on this last account.

*d.* Similarly, on the basis of cost, the combined system is usually the best for the business and other very thickly built-up districts of large cities, and, in general, where storm sewers must be coextensive with sanitary sewers; also for cases where both storm sewage and sanitary sewage require purification.

*e.* Often a combination of the two systems can be made to advantage, storm water being admitted to the sewers only in certain portions of the system, such as the business districts.

## GENERAL FEATURES OF SEWERS

**14. Kinds of Sewers.** *Sanitary sewers* are those constructed to carry foul waste liquids of human or animal origin—that is, sanitary sewage. Since sewage of human or animal origin is most apt to contain the germs of human diseases, sanitary sewers require special precautions in design, construction, and maintenance, to render them safe. Manufacturing sewage is often, however, even stronger and more offensive than sanitary sewage, and hence requires equal precautions. In the separate system, the manufacturing sewage should go into the sanitary sewers or into special sewers of similar character.

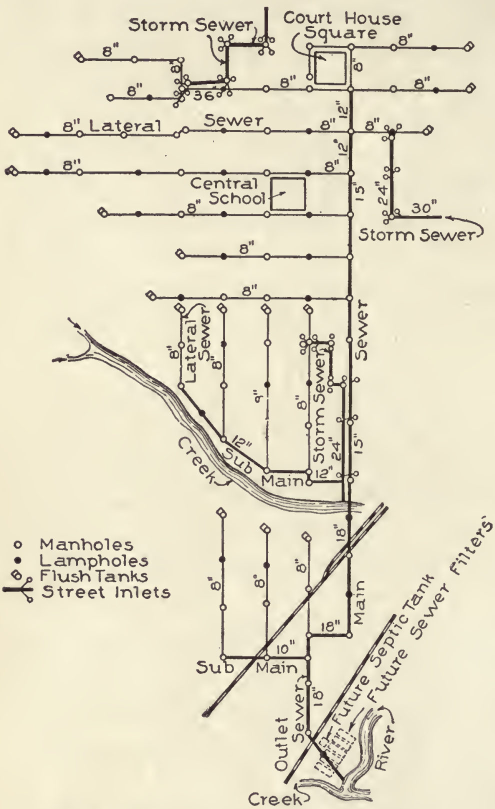



Fig. 4. Kinds of Sewers and Arrangement of Accessories.

*Combined sewers* are those constructed to carry both sanitary sewage and storm sewage. With the combined system, the manufacturing sewage also usually goes into the combined sewers.

*Storm sewers* are those constructed to carry storm sewage only.

An *outlet sewer* is one connecting a sewer system, or a part thereof, with the point of final discharge of the sewage.

A *main sewer*, or *sewer main*, is the principal sewer of a city, or of a large district thereof, into which branch sewers discharge.

A *sub-main sewer* is a branch of a main sewer, receiving in its turn the discharge of smaller branches.

A *lateral sewer* is one not receiving the discharge of other sewers, hence serving only property closely adjacent.

In Fig. 4, the various kinds of sewers above described are shown, from a portion of the actual sewerage map of a small city, sewered on the separate system.

**15.** *Intercepting sewers* are those built across lines of other sewers, to intercept the sewage flowing in them and carry it away to different outlets.

In Fig. 5 are shown the intercepting sewers of the city of Chicago, built along the lake front to intercept the sewage in the sewers which formerly discharged into and polluted Lake Michigan, from which the water supply of the city is taken. From the intercepting sewers, the sewage is pumped into the Chicago River, which now discharges through the great Drainage Canal into the Desplaines river, the Illinois River, the Mississippi River, and the Gulf of Mexico.

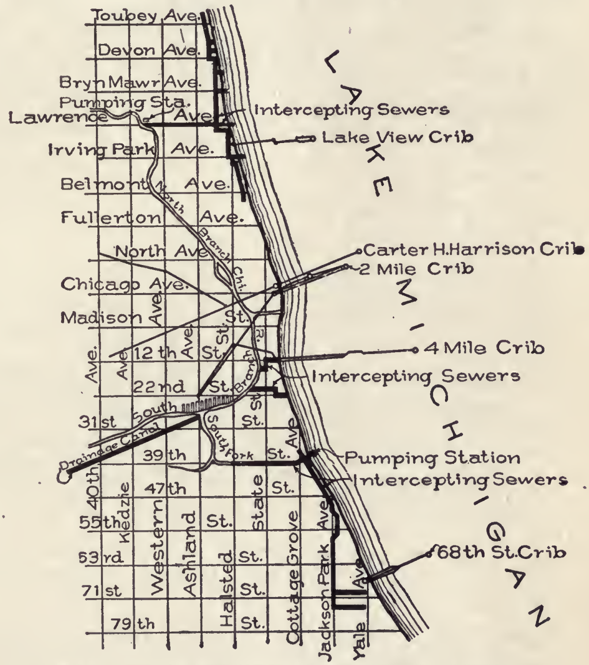



Fig. 5. Intercepting Sewers of the City of Chicago, Ill.

**16. General Description of Sewers.** Sewers, as usually built, are smooth pipe or masonry conduits, as nearly water-tight as practicable, buried in the ground as deeply as necessary to serve the adjacent houses and drain other territory tributary upstream. They are very carefully constructed to an exact grade line, determined by the engineer who made the sewer plans.

Unless special circumstances require other forms, sewers are usually made circular, this shape giving the greatest strength and area for a given amount of material. For other shapes, and the circumstances to which they are adapted, see Figs. 19 to 25.

The *invert* of a sewer is the lowest point on the interior surface (being so called because the interior curve is there inverted). When the grade of a sewer is mentioned, or the elevation of the sewer at a given place is spoken of, the invert is always meant. The invert is also sometimes called the *flow line.*

Almost all sewers up to 24 inches' diameter, and many from 24 to 36 inches' diameter, are made of vitrified or cement pipe. Above these sizes, concrete or brick masonry is ordinarily used. Stone masonry and iron pipe are also used, but only seldom. A comparison of these materials is given elsewhere in this paper.

At intervals along sewers, *manholes* (Art. 21) and *lampholes* (Art. 22) are placed to permit examination and repairs, and often *flush-tanks* (Art. 23) are provided to keep the sewers clean. In the case of storm sewers and combined sewers, either *street inlets* or *catch-*

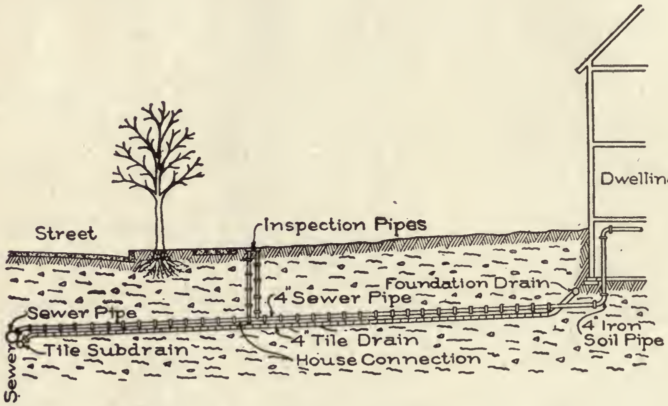



Fig. 6. Street Sewer, Subdrain, and House Connection.

*basins* (Art. 27) must be provided, for admitting the storm water to the sewers. These are usually placed at or near the curb corners at the street intersections.

A general idea of the relation of a sewer to a building served by it, may be gained from Fig. 6. The sewer there shown is a pipe sewer. Usually all lateral sewers are made of pipe; and in the separate system, the submains and mains also, unless the city is quite large.

**17. Location of Sewers.** Sanitary sewers are usually placed on the center lines of the streets, so as to give equal fall from the houses on both sides. On this account, water, gas, and heating mains, storm sewers, and other conduits should be constructed far enough from the center lines not to interfere with the sanitary sewers. Not infrequently the center of the street is found already occupied by other conduits which were located without proper foresight; and it is then necessary to place the sewer nearer to one side than the other.

In cases of streets on side hills, it is sometimes necessary to place the sewer close to the downhill side of the street, in order to serve houses on that side which are lower than the street grades.

In a few cases of excessively wide avenues, especially if paved, it is cheaper to build two lines of sanitary sewers, one on each side, than to construct the longer house connections required.

In any town having a fairly extensive system of alleys, careful consideration should be given by the sewerage engineer to the feasibility and desirability of locating part or all of the sanitary sewers in them instead of in the street. In Memphis, this plan was followed as far as practicable. It is not usually feasible to locate combined or storm sewers in alleys, because such sewers must receive storm water from the streets running in both directions, and hence must usually have the street inlets placed at the street corners.

**Streets vs. Alleys for Sanitary Sewers.** Location of the sanitary sewers in the alleys has a great advantage in avoiding the tearing up of the streets and pavements for sewer repairs and for new house connections, which not infrequently causes them serious injury. Pavements are often ruined by the trenches dug for water, sewer, gas, and other connections. Also, if the sewers are in the alleys, the trenches for house connections do not cross the lawns in front of the houses.

On the other hand, the system of alleys in the ordinary town is a public nuisance. They are usually filled mainly with manure piles, garbage, and debris of all descriptions; and they open through the middle of the blocks vistas which suggest most forcibly a neglected city dumping ground. Owing to their vile sanitary condition, the alleys are usually the first danger spots demanding attention when a town is threatened with an epidemic. Except in the business districts where they can be paved and policed, there is no necessity for alleys unless the lots are very narrow, for in almost every town there are sections which do without and never miss them. Teams can without inconvenience drive in from the front, along a cinder or gravel drive. Such sections are better off without the alleys, from both the sanitary and the æsthetic points of view.

For the above reasons, it is often unwise to perpetuate, or perhaps even extend, the alley system by locating sewers in them.

Again, the system of alleys, more often than not, is far from being as complete as the street system; and in such cases it will usually add considerably to the total length of sewers required to serve a given territory, if part of them are placed in the alleys. The alleys, also, are usually too narrow to permit the construction of sewers of considerable depth, without trouble as regards the excavated material, the handling of pipe, etc. Moreover, houses and the fixtures in them are usually so located that the house connection would be longer to the alley than to the street, requiring a deeper sewer for equal service. This, however, is not always the case.

The sanitary engineer should study each town by itself, and decide this question after giving due weight to all these various considerations.

**18. Depth of Sewers:** The depth of sanitary and combined sewers should be great enough to afford good drainage to the basements of all buildings. This will usually call for the tops of the sewers to be about $3\frac{1}{2}$ feet below the basement floors, as follows:

**MINIMUM DEPTHS FOR SANITARY AND COMBINED SEWERS**

| | |
|---|---|
| Fall from sewer to house | 2 ft. 0 in. |
| Fall from basement floor to house connection | 1 ft. 6 in. |
| Total from *top* of sewer to basement floor | 3 ft. 6 in. |
| For *sewer laterals,* add to the above for fall at sewer | 1 ft. 0 in. |
| Total from *invert of lateral sewer* to basement floor | 4 ft. 6 in. |
| For *residence districts,* add for ordinary-depth basements below street level | 4 ft. 0 in. |
| Total minimum depth to invert of *lateral sewers in residence districts* | 8 ft. 6 in. |
| For business districts, add for ordinary-depth basements | 8 ft. 0 in. |
| Total minimum depth to invert of *lateral sewers in business districts* | 12 ft. 6 in. |

Hence, under average conditions, the depth of sanitary and combined pipe sewers of 12-inch diameter and less, should be not less than $8\frac{1}{2}$ feet in residence districts, and $12\frac{1}{2}$ feet in business districts. If, however, there is only a short stretch of low-lying ground on a residence street, it may be advisable to reduce the above depth, say to 6 feet as a minimun, when by so doing a very long stretch of sewer can be lessened that much in depth throughout, and a large saving in cost made thereby.

In the case of sanitary and combined sewers more than 12 inches in height, the above depths should be increased by the excess over 12 inches, for the house connections should enter near the top of the sewer.

In the case of storm sewers and of outlet and intercepting sewers, the depth will no longer be determined by the depth of basements alongside. In these sewers three other considerations determine the depth: (1) the depth at the upper end necessary to afford a good outlet for the sewage; (2) the grade necessary to give good velocity; (3) the depth necessary to prevent injurious heaving of the sewer foundations by frost.

In regard to the third point, no danger need be apprehended of the sewer itself freezing up, even if it be laid practically at the surface, for a stream of warm, flowing sewage will not freeze. There will be little or no danger of trouble from heaving, if the sewer foundation be four feet under ground; and many stretches of pipe sewers only two or three feet deep operate with entire satisfaction even in the northern United States.

**19. Subdrains.** It has already been stated that sewers should be made as nearly water-tight as possible. Otherwise there would be danger of the sewage leaking out so as to contaminate the adjacent soil. Hence, while it is not possible at any reasonable expense to make sewers *absolutely* tight, they should be built with the utmost care in this particular.

Yet, when due care is used in this respect, the sewer is made unfit for performing another important duty—that of draining away subsoil water so as to dry out unwholesome dampness from the soil, and especially from wet cellars and from under and around houses built on low ground.

In order to secure such drainage, and also, in case of wet ditches, to help remove water from the trenches during construction, it often becomes necessary or advisable to add to the sewer a *subdrain.*

A *subdrain* is a line of drain tile or sewer pipe laid with open joints, in the same trench with the sewer.

To allow connections with cellar drains to be made from both sides of the streets, the subdrain should be placed with its top a few inches below the bottom of the sewer; and to leave a firm foundation for the sewer itself, the subdrain should be placed a little to one side of the sewer.

With the above arrangement, special care should be taken to make the sewer joints tight, and there is some danger of slight leakage of sewage into the subdrain. Such leaks tend to stop themselves as time passes.

It is not safe to connect cellar drains directly with a sewer, even though they are trapped to prevent the sewer air from penetrating into and filling the pores of the soil under houses. In dry times, there may be no water running in the cellar drains; and at such times the water in a trap may evaporate so as to unseal it. Cellar and foundation drains should be connected to the subdrain instead of to the sewer itself.

The general relation of the subdrain to the sewer in the street, and the method of connecting it with the foundation drains, may be seen in Fig. 6.

In construction, the joints of the subdrain should usually be wrapped with muslin to prevent the entrance of mud and sand. The cloth, of course, does not last long; but by the time it rots, the soil around the tile will usually have become recompacted so that there is no longer danger of its getting into the drain. In quicksand, it may sometimes be necessary to fill in fine pebbles or broken stone around the subdrain.

**20. House Connections.** In Fig. 6 is also shown the method of connecting the sewer itself with the iron soil-pipe which drains the different plumbing fixtures, and which should extend at least 6 feet outside the basement wall. The house connection should be a line of 4-inch vitrified sewer-pipe, laid at right angles to the sewer, with tightly cemented joints, and if possible to at least a 2 per cent grade (that is, with a fall of 2 feet in 100 feet length). Some prefer 6-inch house connections; but these should not be allowed with 8-inch sewers, as the house connection may then allow obstructions to be carried to the street sewer large enough to catch therein and cause stoppages. At the sewer, the house connection should turn down, by a 4-inch 45-degree elbow, into a 4-inch Y-junction laid so as to slant upward 45 degrees—all as shown in Fig. 7. This slant upward

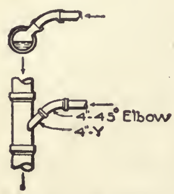


Fig. 7. Junction of House Connection with Sewer.

keeps the Y from affecting the smooth ordinary flow in the sewer.

In case the sewer is more than 12 feet deep below the street surface, the expense of digging down to it in making house connections would be so great that it is usually better, while the trench is open during sewer construction, to put in a *deep-cut house connection*, as shown in Fig. 8. In this case, sewer pipe must be used from the subdrain also, if such a drain is used; and care should be taken to turn the bells of the subdrain connection down so that the plumbers need make no mistake in the connections afterwards.

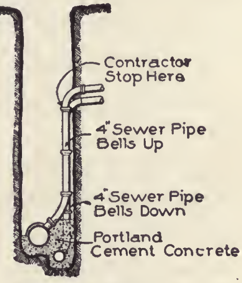


Fig. 8. Deep-Cut House Connection.

In sewer construction, a Y-junction for a house connection (or a deep-cut house connection, if the sewer is over 12 feet deep), should be conveniently located opposite each lot on each side of the sewer; and the ends should be stopped with vitrified stoppers, covered over with sand and then cemented in. Full and accurate records must be kept of the exact locations of these connections, so that they can be found without trouble at any time.

No person should be allowed to cut or break into a pipe sewer for making house connections or any other kind of junction. If there is no Y or T-branch already set for the connection, a full length of pipe should be broken out and the proper Y or T-branch inserted. A skilful workman can readily do this by breaking off one-half the bell of the new pipe, and of that of the old piece into which it must be inserted, and turning the new piece half around after insertion. The joints must then be re-cemented with great care.

**21. Manholes.** It has already been stated (Art. 16) that manholes must be placed at intervals along sewers, to permit of examination and repairs. These manholes are usually circular brick wells, with Portland cement concrete bottoms and heavy cast-iron covers, as shown in detail in Fig. 9. They must be large enough at the bottom, and for a couple of feet above the top of a pipe sewer, to permit a man to work comfortably. Four feet in diameter is a satisfactory size. Sometimes the manholes are made elliptical at the bottom, with the long axis lengthwise of the sewer; but this form is more difficult to build. Above the point mentioned, the sewer may be drawn in gradually to a diameter of about 2 feet 9 inches, at a point

2 feet 9 inches below the street surface, and thence narrowed more rapidly to about 20 inches diameter at the bottom of the cover casting.

The cover casting may be of any manufacturer's design satisfactory to the engineer, weighing at least 375 lbs. The lid should usually be perforated with 1-inch holes, to permit ventilation of the sewer; and immediately below it, there should be hung a heavy cast-iron *dustpan*, to catch any dirt entering through the perforations.

There should be a ladder of iron rungs built into the walls, as shown in Fig. 9.

The channels in the concrete bottom should be very carefully formed to give smooth, true, circular channels. They are sometimes lined with split sewer pipe. The benches at the sides of the channels should slope down towards the channels, as shown in the figure.

The concrete for the bottom may be made of 1 part Portland cement, 3 parts sand, and 5 parts of broken stone. All the brick-work should be laid with tight *shove joints*, in 1-to-3 Portland cement mortar; and the manhole walls should be plastered both inside and outside with 1-to-2 Portland cement mortar.

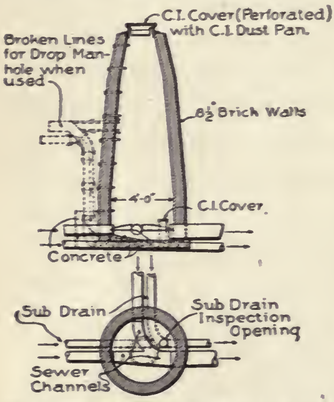



Fig. 9. Sectional Elevation and Plan of Sewer Manhole.

Should sudden drops in the sewer be desirable, they can be made at *drop manholes*, in the manner shown by the broken lines of Fig. 9.

In the case of large masonry sewers, which often are many feet in diameter the manholes may be joined directly to the masonry of the upper part of the sewer.

Opinions of sanitary engineers differ somewhat as to the distance apart at which manholes should be placed. In general, a manhole should be placed at all junctions of sewers, and at every change of grade or alignment in all sewers but those large enough to be entered readily for cleaning. This means that sewers should ordinarily be perfectly straight between manholes, to facilitate inspection and repairs, all changes in both grade and alignment being made at the manholes themselves.

Also, in any part of the system—such as in the business district—where it is especially objectionable to have the street dug up for repairs, manholes should be placed at least as often as every city block—that is, 300 to 400 feet apart. In the other parts of the system, some engineers leave out every other manhole where the grade and alignment are straight, putting manholes at least every two blocks. The intermediate manholes left out are replaced by *lampholes* (Art. 22) to save cost. In Figs. 4 and 38, the above arrangement of manholes is shown in two actual sewer systems.

**22. Lampholes.** The lampholes which, to save cost, are sometimes adopted in place of part of the manholes, consist each of a vertical line of sewer pipe, with cemented joints, reaching to the street surface, as in Fig. 10. Usually 8 inches is the minimum diameter for this pipe, which is cemented at the bottom into a regular sewer-pipe T-junction. Some concrete should be placed under and around this tee for a foundation. At the street surface, there should be an iron casting similar to a manhole casting, but smaller, as shown in Fig. 10.

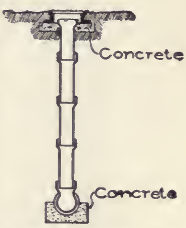


Fig. 10. Lamphole.

The earth, in refilling, needs to be very thoroughly tamped around the lamphole; and the lamphole casting should not be set until the material is thoroughly settled.

The object of the lamphole is to permit of inspection of the sewer, in determining whether it is clean and in locating stoppages. While its name suggests the lowering into it of a lamp, a beam of sunlight reflected into it from a mirror is more convenient.

A lamphole usually costs about $30 to $35 less than a manhole.

In Figs. 4 and 38 the above arrangement of lampholes in two actual sewer systems may be seen.

**23. Flush-Tanks.** Near the upper ends of sewers the flow of sewage is very small, sufficient only to make a shallow, trickling stream, liable not to be able to carry along the solid matter in the sewage so as to prevent deposits. An 8-inch lateral sewer in a residence district in a small town, even if laid at the minimum grade, would usually have an average depth of flow in the upper two and one-half blocks of less than one inch. Hence it is desirable, though not always absolutely necessary, to provide some special means for regularly flushing the upper portions of sewer laterals, to make them self-cleansing.

Again, in low-lying, level districts, it may be necessary, on account of the lack of fall, to lay the sewers at such slight grades that the velocity is insufficient to prevent deposits. Here, too, some special means should be provided for regularly flushing the sewers.

In the case of pipe sewers, such as are ordinarily used for the laterals in all systems, and for most of the mains in separate systems,

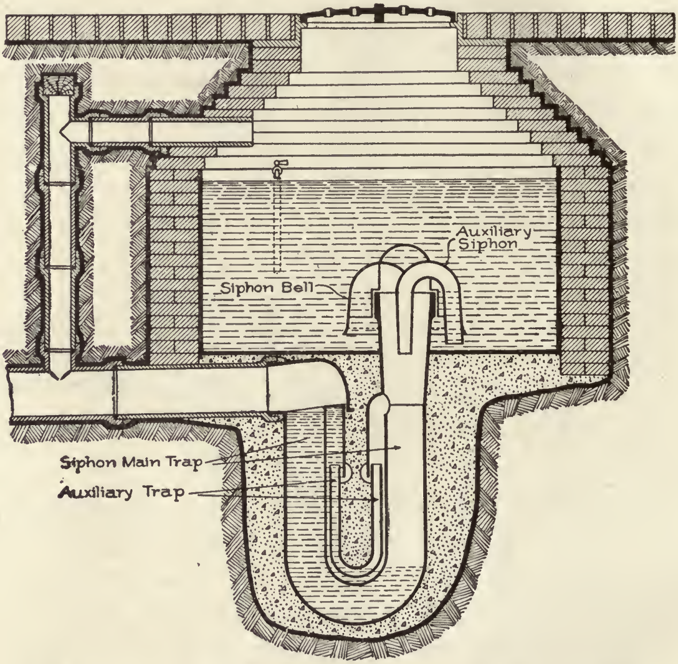



**Fig. 11. Sewer Flush-Tank with "De La Hunt" Adjustable Siphon.**

the most efficient and reliable means for securing regular flushing is the use of automatic flush-tanks.

A *flush-tank* is a masonry cistern built in the street, above the grade of the sewer, filled by a constantly running stream of water brought by a small pipe from the water-supply mains, and suddenly emptied by automatic devices into the sewer whenever the high-water line is reached.

Flush-tanks usually have a capacity of 150 to 500 gallons, and should approach the larger size named, to secure an efficient flush for two or three blocks. When made separate from manholes, flush-tanks are usually circular and of the general design of the masonry tank shown in Fig. 11. It is usually better, however, to combine the flush-tank with a manhole, as is shown by the masonry tank and manhole in Fig. 12. This permits inspection of the flush-tank and sewer, and is cheaper than to build manhole and flush-tank separate.

The bottoms of flush-tanks are usually of Portland cement concrete, and the walls of brick laid in Portland cement mortar. The

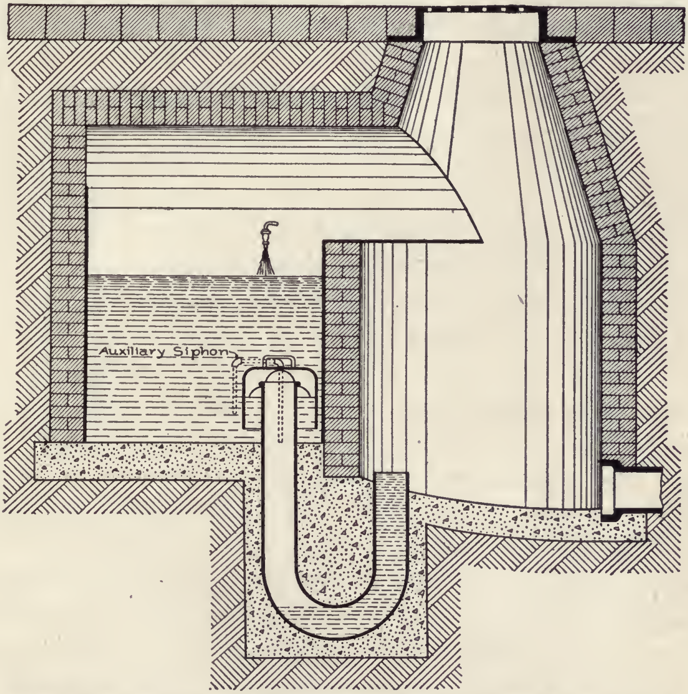



Fig. 12. Combined Flush-Tank and Manhole with Special "Miller" Siphon.

tanks should be plastered inside and outside as described for manholes (see Art. 21). Special care should be used to make flush-tanks absolutely water-tight.

The water is usually brought to the flush-tank by a $\frac{3}{4}$-inch galvanized pipe from the nearest water main. This pipe must be laid below the frost line ($5\frac{1}{2}$ to 7 feet deep, in the northern part of the United States), but should be turned up after it enters the flush-tank so as to discharge above the high-water line, as shown in Fig. 11.

The flush-tank may be prevented from freezing by being connected with the sewer above the high-water line, as shown in Figs. 11 and 12, so as to admit the warm air from the sewer.

It is a quite common practice to place flush-tanks at the heads of all laterals, as illustrated in Figs. 4 and 38. While some engineers dispute the necessity for this, it must be admitted that such an arrangement will be of great benefit, and its adoption is here advised for most cases.

In Fig. 38 the use of flush-tanks is shown at certain half-way points on the long laterals. The necessity for this arose from the fact that the sewers were not to be completed to the north ends of the laterals for some years after the southern portions were built.

The writer of this paper has used flush-tanks with success and great benefit, at intervals of about two or three blocks on sewers laid at grades below those considered necessary to make the sewers self-cleansing, though part of the flush from the intermediate tanks flows some distance upstream at each discharge.

The flush-tanks of a sewer system should be frequently inspected after the sewers are put into operation, and should be carefully kept in working order. The things needing most faithful watching are: first, the automatic discharging apparatus; and, second, the supply of water. The faucet admitting water may readily become choked up, putting the flush-tank out of service, or, on the other hand, may get wide open, wasting thousands of gallons of water every day.

**24. Automatic Flushing Siphons.** The reliability of flush-tanks in actual use will depend upon the frequency and care with which they are inspected and kept in working order, and especially on the reliability of the automatic discharging apparatus. No discharging apparatus having moving parts should be used in flush-tanks. Such apparatus is too likely to get out of order.

In Figs. 11 and 12, *sewer siphons* are shown for automatically discharging the flush-tanks suddenly whenever they fill to the high-water line. Such siphons have no moving parts whatever to get out of order, and should always be employed with flush-tanks.

In Fig. 11 the four ordinary parts of a flushing siphon are indicated. All four are usually iron castings, and must be air-tight. The *siphon bell* rests upon the *main trap*, which latter, together with the *auxiliary trap*, must be filled with water to the heights of the short legs, before the bell is placed in position. The main trap must be set plumb. The *auxiliary siphon* serves to ensure, at the end of the discharge, the *venting* of the siphon—that is, the free admission of air to the inside of the bell. With clear water, the auxiliary siphon is not always used; but it should be used whenever the siphon is to be used with raw sewage.

In the working of the siphon, the water in the flush-tank confines the air inside the bell and above the water in the main and auxiliary traps, and puts it under increasing pressure as the water rises. When the high-water line in the flush-tank is reached, this pressure becomes so great that the water in the auxiliary trap is forced down to the very bottom of the trap, and the confined air then blows out of the short leg of the auxiliary trap, thus releasing the air-pressure inside the bell, which up to this time has held back the water in the flush-tank. The water in the flush-tank then rushes out into the sewer through the main trap, and by siphonic action will continue to flow out until drawn down to the level of the bottom of the bell. Air then enters the bell through a small *sniff-hole* provided near the bottom of the bell for this purpose, *breaking* the siphonic action—that is, *venting* the siphon.

In case a siphon is used for raw sewage, there is often difficulty in securing satisfactory venting of the siphon at the close of the discharge; but this trouble can be remedied by using an *auxiliary siphon,* as shown in Fig. 11, and as illustrated by broken lines for the "Miller" siphon in Fig. 12.

In the *Miller siphon,* shown in Fig. 12, there is no auxiliary trap; but at high-water line the air-pressure in the main trap becomes so great that a bubble escapes, taking with it enough water from the short leg to start a sudden rush of water from the tank into the main trap, which suffices to establish siphonic action. This greatly simplifies the siphon; and the principle can be relied upon for siphons not larger than about eight inches internal diameter of the main trap. Larger siphons should have auxiliary traps.

In some siphons—as, for example, the *Rhoads-Miller*—the auxiliary trap is cast as a part of the main trap, out of which it opens below the floor of the tank, being entirely buried out of sight and reach in concrete. An objection to auxiliary traps such as shown in Fig. 11, is that they are inaccessible and may in time become stopped up. However, they make the action of large siphons more certain.

**25. Hand-Flushing of Sewers.** For large sewers, flush-tanks and siphons would have to be extremely large to be effective. Even in small sewers the effect of the flush will not be great for many blocks below the tank. Some engineers doubt the necessity for very extensive use of flush-tanks. When flush-tanks are not properly inspected and regulated (as to the feed faucet), they sometimes waste great quantities of city water. For these reasons, and sometimes to save cost, hand methods are sometimes relied upon for flushing sewers.

The most convenient, economical, and effective hand-flushing device is a connection with a water main by a water pipe of size large enough to flush the sewer very thoroughly. The only labor then required is that necessary for opening and closing the valves on this pipe. Such a flush, continuing much longer than the discharge of a flush-tank, can be made effective through a long stretch of sewer. The objections are the trouble and the danger of neglect inherent in hand work, and the usual greater length of time between flushings. To flush the sewers daily would be very expensive, both as to labor and as to the large amount of water needed.

Occasionally, very favorable local circumstances may permit of the admission at will of large volumes of water for flushing purposes from a stream or lake higher than the sewer.

In some cases, hand-flushing is done by temporarily damming up the sewage itself, and then suddenly releasing it when sufficient head has been secured.

A fire hose run to a manhole from a nearby hydrant may be the resort in other cases. In extreme cases, water has even been hauled to the sewer in tanks, for flushing.

**26. Sewer Ventilation.** More fear used to be felt of the danger of *sewer gas* (more properly termed *sewer air*, see Art. 1) in communicating disease, than medical knowledge warrants at the present time. Nevertheless, it is very important, not only from the sanitary but from many other points of view, that sewer air should be as pure as possible; and this requires good ventilation of the sewers. Fresh-air currents in the sewers should be maintained in some reliable way.

One method of securing this is to use perforated manhole covers (see Fig. 9). Objection is sometimes made to these as letting objectionable odors out into the street; but with well-designed and well-constructed sewers, well flushed and well ventilated, there will be no cause for complaint. If there are seriously objectionable odors from the manholes, such odors should be considered valuable as notices that the sewers are in dangerous condition, demanding immediate work to make them safe. Sewer air escaping into streets through manhole-cover perforations, is at once so diluted by fresh air as not to be dangerous to the health of passers by.

Another effective means for securing good ventilation is to extend the cast-iron soil-pipes (which form the main drainage pipes in the plumbing systems of houses) untrapped and full size through the roof. Figs. 4 and 35 show the omission of traps on the soil pipe. In Fig. 35, however, the use of a *disconnecting trap,* to disconnect the sewer air from that in the house plumbing pipes, is shown by broken lines. In case this is used, a ventilating pipe for the sewer should be extended up the sides of the house from the sewer side of the trap, and a fresh-air inlet provided on the house side, both as shown by the broken lines in Fig. 35.

The use of perforated manhole covers and untrapped soil pipes extending through the roofs, is all that is required to secure good ventilation of the sewers, the house connections, and the soil pipes themselves. Their use provides a large number of openings at different levels; and the temperature of the air in the sewers is practically always different from that above the ground. Hence air-currents are maintained for the same reason that chimneys cause draughts for fires, and a good circulation of air is maintained.

In the past, experiments in sewer ventilation have been made with tall chimneys, fan blowers, etc.; but such devices are entirely unnecessary, are very costly, and are usually unsuccessful on account of the very large number of openings into the sewer, which limit the air-currents produced by such devices to short distances.

**27. Street Inlets and Catch-Basins.** In the case of storm sewers and combined sewers, means must be provided for admitting the storm water to the sewers from the streets. For this purpose, either *street inlets,* as shown in Fig. 13, or *catch-basins,* as shown in Fig. 14, may be used. If the water can be allowed to flow one block safely in the surface gutters, the inlets for storm water would need to be only at each street intersection. In a few cases they need to be closer; but in many more cases the storm water can be carried in the gutters for two or even a greater number of blocks without injury, thus greatly reducing the number and cost of storm sewers and of inlets for storm water.

The simplest and least expensive arrangement for admitting storm water is the *street inlet*, which, as shown in Fig. 13, is a mere branch sewer, with a grated opening from the street. Besides costing less, the street inlet is often preferred for sanitary reasons, as it does not retain foul, unsanitary deposits, as does the catch-basin.

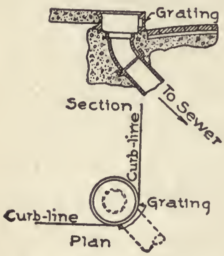



Fig. 13. Street Inlet.

The *catch-basin*, shown in Fig. 14, is designed to catch the sand, dirt, and other heavy street detritus, and prevent their entering the sewer. Unless catch-basins are frequently cleaned, however (which is very seldom the case), they fail almost entirely in this; and as they are usually well filled with more or less foul deposits, they are condemned by many engineers.

When street inlets and catch-basins are left untrapped, as shown in Figs. 13 and 14, they assist in the ventilation of the sewers. This is sometimes objected to on account of the opportunity for the escape of foul odors, and traps are introduced in both, as shown by the dotted lines in Fig. 14, to prevent ventilation of the sewers through the storm inlets. If the sewers are kept in as good condition as they should be, there will be no good ground for such objections.

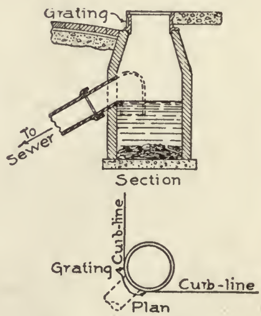



Fig. 14. Catch-Basin.

**28. Inverted Siphons.** It sometimes becomes necessary or desirable to carry a sewer down below the regular grade line, to pass under some obstacle or depression, and to raise it again to the regular grade line beyond. Such a stretch of sewer will necessarily flow full and be under some pressure. It is called an *inverted siphon*. The necessity for the use of the inverted siphon may be occasioned by some stream, by railway tracks, by another sewer, by a large water main, or sometimes merely by a low stretch of ground which happens to lie at such a level that the sewer cannot be carried across it at the regular grade.

Inverted siphons have often been constructed and operated successfully. It is wise, however, to take certain precautions in their design and construction, as otherwise serious trouble may be experienced with them.

*First,* as to material, it may be said that ordinary sewer pipe is not well suited to carry sewage under pressure, on account of the great difficulty in making absolutely tight joints, and on account of the brittle and unreliable nature of the pipe as to resistance to bursting pressures. If used under pressure, pipe sewers should be subjected to only a few feet of head, and all joints should be thoroughly encased in impervious Portland cement mortar and concrete, reinforced with imbedded steel bands. Brick masonry is still less suited to with-

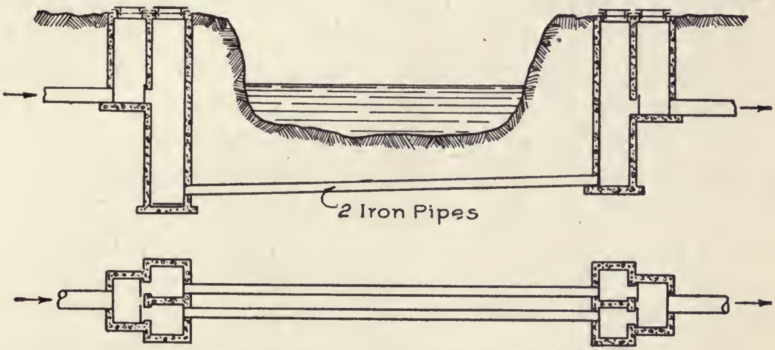



Fig. 15. Sectional Elevation and Plan of Inverted Siphon.

stand bursting pressures. Ordinarily iron pipe should be used for inverted siphons.

*Second,* it is especially important to insure a current in the inverted siphon sufficiently rapid to prevent deposits. If the flow is light at first, to increase afterwards, as is often the case, it is well to divide the siphon into two or more pipes with valves on each, so that the entire flow can be turned into one at first. If it is easy to add the second pipe in the future, it may often be left out at first. Thus in Fig. 38, the inverted siphon from the 18-inch outlet sewer to the septic tank is at present only an 8-inch cast-iron pipe, with provision for adding a 12-inch cast-iron pipe later.

*Third,* the design should be such as to permit ready access for inspection and removal of obstructions. The inverted siphon should, if possible, be so planned that the flow of sewage can be diverted for a short time, either into one pipe, or entirely away from the siphon; and the siphon should drain to a low point from which the contents can be removed by gravity through a blow-off or by being pumped out. Where feasible, and especially where it will be very difficult (as under a stream) to dig down to the siphon in emergencies, the siphon should be made absolutely straight in grade and alignment, and a manhole placed at each end.

In Fig. 15 is shown an outline of an inverted siphon designed according to the above principles.

Where the siphon can readily be opened for repairs, as is the case with the one in Fig. 38, such expensive construction need not be resorted to. The one in Fig. 38, which carries sewage across low ground to a sewage tank about seven feet above the surface, is laid at an average depth of about six feet, and neither the grade nor the alignment is straight. It drains, however, to a low point, where a blow-off into a sewer is placed.

**29. Outlets for Sewer Systems.** We have heretofore discussed the house connection, and the laterals, submains, and main sewers, with their manholes, flush-tanks, and other accessories. We come next to the *outlet*, which, though not considered first here, would be one of the first things a sewerage engineer would have to consider in designing a sewer system.

Where possible, all of the sanitary sewage or combined sewage of the city should be led to one outlet, as the cost of disposing of it properly may be lightened thereby, and as the danger of injunction suits and other legal difficulties arising from damages from impurified or only partially purified sewage may be multiplied with the number of outlets. Often this will be possible by constructing comparatively short lengths of deep sewers where at first sight the topography would seem to make it impossible to secure one outlet. The size of the city, as well as the topography, will affect the number of outlets.

Storm sewage in the separate system can usually be discharged through a number of outlets into nearby natural watercourses.

Great effort should be made to secure an outlet or outlets for the sewer system low enough to drain all parts of the city by gravity. Pumping of the sewage or a material part of it, will mean a continuous expense involving an amount which would be sufficient to pay the interest on a large initial expense to secure a gravity outlet. Besides, there is the danger of such apparatus failing at critical times.

Usually effort is made to secure, if possible, an outlet into a considerable stream or body of water, even if the sewage is to be purified.

**30. Sewage Disposal.** Heretofore, sewage has been disposed of, in the great majority of cases, by simply emptying it into the largest available stream or body of water near at hand. Such serious contamination of natural waters has resulted from this practice, that at the present time much more attention than formerly is being paid to sewage purification; and usually the outlet plans should be made with the expectation that some method of purification will have to be adopted in the future, if not at present.

Sewage disposal is discussed further on, at much greater length (see Arts. 110 to 124). It will only be said here that the methods at present in favor almost all involve passing the sewage through large tanks, and then through some form of filter.

## SEWER MATERIALS AND CROSS-SECTIONS

**31. Sewer Materials.** Sewers 24 inches in diameter and under, are usually built of *vitrified sewer-pipe.* A 24-inch pipe sewer, laid to a fall of 0.2 feet in 100 feet, will carry the sanitary sewage, under average conditions, of 29,000 people; and hence it is evident that in separate systems, all the sanitary sewers will be made of pipe, except a few main and outlet sewers in large cities. Considerable percentages of storm sewer and combined sewer systems will be pipe sewers also.

Occasionally *cement sewer-pipe* is used instead of the vitrified pipe.

Sewers 30 inches and larger in diameter, are most frequently built of *brick.* Pipe is sometimes used, however, for 30-inch to 36-inch sewers.

*Concrete* has of late years been growing in favor, to take the place of brick in sewer construction.

*Stone* was formerly used to a considerable extent for sewers; but on account of its roughness, and the great cost of cut-stone masonry, stone is suited only for backing brick linings in larger sewers. Even here, concrete would now ordinarily be employed, as both cheaper and better.

Occasionally, as in the case of submerged-outlet sewers into bodies of water, or sewers across marshes on soft foundations, *wooden stave pipe* is used for sewers. These pipes are made of pieces of timber, usually about two inches by four inches in size, put together breaking joints in the field, and hooped at regular intervals with iron bands which can be screwed tight. Wood should be used only where it will be wet all the time, to prevent rotting.

*Cast-iron pipe,* such as is used for water mains, is often adopted for short stretches of sewer under railways or streams where great strength is essential; for inverted siphons; and in cases where absolutely water-tight joints are essential, such as submerged lines in lakes, harbors, and stream crossings, or where there is much ground water.

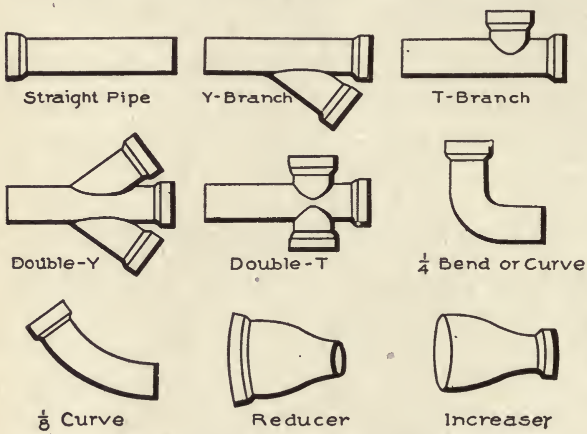



Fig. 16. Vitrified Sewer-Pipe and Specials.

**32. Vitrified Sewer-Pipe.** Vitrified sewer-pipe has many excellent qualities for sewer use. It is hard, impervious, smooth, strong, does not decay or disintegrate, and is not affected by chemicals. It has few joints as compared with brickwork, and these joints are of convenient shape to make practically water-tight. Vitrified sewer-pipe is readily handled and laid in sewer construction. The materials of which it is made are widely distributed, and hence the cost of the pipe is reasonable.

In Fig. 16 are shown the general forms of the straight pipe and also of the special fittings (*sewer-pipe specials*) most commonly used in sewer construction.

In Table I (page 35) are given standard dimensions for straight sewer-pipe.

Vitrified sewer-pipe is made from shale clays, in very much the same way as brick and other clay products. The temperature at which it is burned in the kilns must be very high, as in the case of paving brick, so as to produce an "incipient vitrification," a softening and running together of the particles of clay, which gives, on cooling, a very hard, impervious, and strong structure. Smoothness of interior and exterior surfaces is secured by the use of salt during the process of burning, so as to produce a "salt-glazed," glassy skin.

**TABLE I**

**Standard Dimensions for Sewer Pipe**

| STANDARD | | | | DOUBLE STRENGTH OR EXTRA THICK | | | |
|---|---|---|---|---|---|---|---|
| INSIDE DIAM. INCHES | THICKNESS OF SHELL. INCHES | DEPTH OF SOCKET. INCHES | WEIGHT PER FT. LBS. | INSIDE DIAM. INCHES | THICKNESS OF SHELL. INCHES | DEPTH OF SOCKET. INCHES | WEIGHT PER FT. LBS. |
| 8 | 3/4 | 2 1/2 | 22 | 8 | 7/8 | 2 1/2 | 25 |
| 9 | 3/4 | 2 1/2 | 27 | 9 | 7/8 | 2 1/2 | 30 |
| 10 | 7/8 | 2 1/2 | 30 | 10 | 1 | 2 1/2 | 34 |
| 12 | 1 | 2 1/2 | 41 | 12 | 1 1/8 | 3 | 50 |
| 15 | 1 1/8 | 3 | 60 | 15 | 1 1/4 | 3 | 70 |
| 18 | 1 1/4 | 3 | 80 | 18 | 1 1/2 | 3 | 100 |
| 20 | 1 3/8 | 3 | 95 | 20 | 1 2/3 | 3 | 120 |
| 21 | 1 3/8 | 4 | 105 | 21 | 1 3/4 | 4 | 140 |
| 24 | 1 5/8 | 4 | 135 | 24 | 2 | 4 | 180 |
| 27 | 2 | 4 | 215 | 27 | 2 1/4 | 4 | 240 |
| 30 | 2 1/4 | 4 | 270 | 30 | 2 1/2 | 4 | 300 |
| 33 | 2 3/8 | 4 1/2 | 320 | 33 | 2 5/8 | 4 1/2 | 340 |
| 36 | 2 1/2 | 5 | 365 | 36 | 2 3/4 | 5 | 390 |

The bells are made large enough to allow an annular space for cement, ranging from 3/8 inch thick for 8-inch pipe to 3/4 inch for 36-inch pipe.

Smaller sizes of pipe, down to 3 inches in diameter, are made.

Double-strength pipe is used only in cases requiring unusual strength.

Vitrified sewer-pipe must be carefully inspected, piece by piece, just before being used in the sewer, all poor material being rejected. Some of the points to be noted in making the inspection are as follows:

(1) The pipe should be straight, and true in shape.

(2) The pipe must have a hard-burned, strong internal structure showing incipient vitrification. Small pieces may be chipped out of occasional lengths to test this; and the color will also be a guide after the inspector has become thoroughly familiar with the make of pipe being used.

(3) The hub and socket ends of adjacent pipes should fit together well, leaving at least the spaces for cement given under Table I.

(4) There must not be on the lower half of the interior of the sewer any lumps, blisters, or excrescences. A few may be allowed

if not too large, if the pipe can be turned so as to bring them to the upper half.

(5) There must be no cracks extending into the body of the pipe, or of such nature as to weaken it materially. On tapping the pipe with a light hammer, if it does not give a clear ring, the presence of invisible cracks may be suspected.

(6) There must be no broken pieces of material size, from either the hub or the socket ends, nor any at all which cannot be turned to the upper half.

Nothing of human construction can be perfect, and sewer pipes are no exception to the rule. Hence the pipe inspector must have good judgment and considerable experience to draw the line properly between important and unimportant defects. In clause 25, Art. 93, of the sewer specifications given hereinafter, some definite rules are laid down to govern inspectors in this particular.

Vitrified pipe can be secured in 2, 2½, and 3-foot lengths. The longer the lengths, the fewer the joints, which is a material advantage.

**33. Joints in Pipe Sewers.** The joints are the weakest points in pipe sewers, and should be made with the utmost pains to secure as nearly as practicable an absolutely water-tight job. In Fig. 17, the upper joint shown illustrates the form commonly employed.

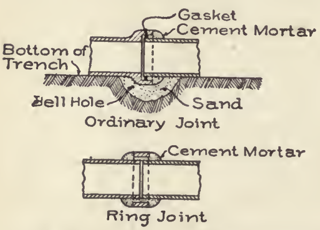



Fig. 17. Joints in Pipe Sewers.

In the bottom of the trench, which should be rounded to fit the under part of the sewer pipe, *bell-holes* are dug for all bells, to permit the joint on the under side of the pipe to be made properly, and to give the pipe a bearing on its full length instead of merely on the bells. Before the spigot end of the pipe to be laid is *entered* into the bell of the last pipe laid, it should be wrapped with a *gasket* of hemp, oakum, or jute, as shown in Fig. 17, so that the inverts of the two pipes will match in a smooth line when the pipe is entered, and so as to prevent the soft cement mortar from being forced up through the joint to project into the pipe. The gasket also assists in making the joint water-tight, especially if there is water in the trench. Disastrous results have often followed the omission of the gasket, which should always be used.

After the pipe is entered and brought exactly to grade, Portland cement mortar, mixed about 1 to 1 or 1 to 2 with sand, should be *calked* into the joint, *to fill it absolutely full,* and should be beveled off on the outside, as shown in the figure. Special care should be taken on the under side of the pipe. *Immediately* after placing the cement, the bell-hole should be packed *full* of sand, so as to support the cement on the under side of the pipe till it has set. It is best to keep the cementing back two or three lengths of pipe from the pipe laying, to avoid danger of the cement being broken in placing the next pipe.

Without the most careful watching of every joint during construction, the workmen are sure to slight the joints. An inspector should be kept constantly on the work.

In the lower part of Fig. 17 is shown the *ring joint,* formerly preferred by some engineers, but now very seldom used. It is more costly than the ordinary form.

Various joints have been invented and used to a limited extent, which include simple beveling of the ends of the pipe without using bells, the use of grooves at one end with corresponding projections at the other end, etc. Sometimes the exterior of the spigot end and the interior of the bells are grooved and made rough in the ordinary form of joint. This is an advantage in holding the cement, and in securing a water-tight job.

**34. Cement Sewer-Pipe.** Ever since the early use of pipe sewers in the latter half of the nineteenth century, cement pipe has been used to some extent for sewers; and recently there seems to be a revival and extension of its use. Experience has shown that cement is a very suitable material for making sewer pipe, and that cement pipes, when well made, of first-class materials, give excellent satisfaction for sewers, and are durable and not disintegrated by the sewage.

The manufacture of good cement sewer-pipe, however, cannot be successfully carried on by men who do not have the necessary skill, which is to be gained only by experience in this particular work; and even skilled manufacturers will not be successful unless both the cement and the sand used are of first-class quality, nor unless plenty of cement is used. Much poor cement pipe has been made, because these almost self-evident facts have not been understood; and in this way cement sewer-pipe has gained a bad reputation in many localities.

In general it may be said that the sand should be clean, sharp, and coarse, and that it should contain a considerable proportion of fine pebbles, smaller than a cherry-pit. Only the best Portland cement should be used, and the mortar should not be weaker than 1 to 3. The mixing must be very thorough, as also the tamping into the moulds.

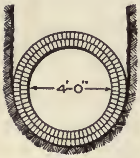


Fig. 18. Circular Brick Sewer, Ingersoll Run, Des Moines, Iowa.

Two general kinds of cement sewer-pipe are made. In one, just coming into use, the pipes are made continuously in the ditch. A form of moulds is used to give the correct shape and size, which can be forced ahead as the work progresses; and there are no joints. It is too soon yet to tell how successful this plan may be.

In the more common form of cement sewer-pipe, the pipes are made in a factory, in pieces of the same length as vitrified pipe. Usually, comparatively little water is used in mixing, in order to permit immediate removal of the pipe from the moulds. While such pipe are *curing* (setting), the omitted water must be supplied by frequently wetting them, or the process of setting and hardening cannot go on properly. Many cement sewer-pipes of this kind are spoiled in the curing.

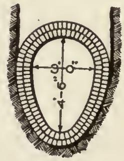


Fig. 19. Egg-Shaped Brick Combined Sewer.

Cement pipe are now made with bells for the joints, the same as vitrified pipe. The manufacture of specials, such as the Y-junctions required in such numbers for house connections, is still in unsatisfactory condition.

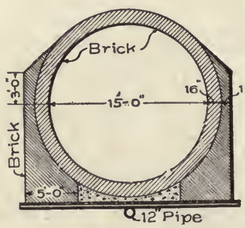


Fig. 20. Circular Brick Sewer with Sub-drain, 64th Street, Brooklyn, N. Y.

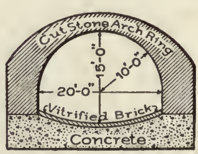


Fig. 21. Section of a Large Sewer in St. Louis, Mo.

The body of a cement sewer-pipe is of much weaker material than that of which vitrified pipe are made; and the thickness of cement pipe should be much greater than the thickness given in Table I for vitrified pipe.

**35. Typical Cross-Sections of Large Sewers.** In Figs. 18 to 25, inclusive, are shown some typical designs for sewers too large to be constructed of sewer pipe.

In Fig. 18, the common circular form is shown. This form is more economical to construct than any other when good foundations

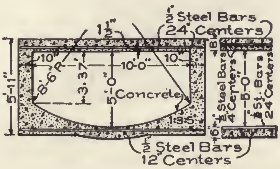



Fig. 22. Ingersoll Run Sewer with Low Headroom, Des Moines, Iowa.

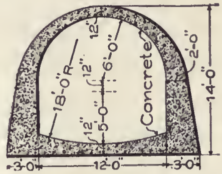



Fig. 23 Dry-Run Sewer, Waterloo, Iowa.

can be had, for the circle gives a larger area and velocity of flow when full than any other shape having the same circumference.

In the case of combined sewers, however, the dry-weather flow of sewage is so very small, in comparison with the size of the sewer, that it makes only a shallow, trickling stream of little velocity, and the sewer will not be self-cleansing. For such sewers, this difficulty can be overcome by the use of the egg-shape of sewer, shown in Fig. 19. This shape has a circular inv rt having a radius only half that of the top; and the depth and velocity of the dry-weather flow will be the same as in a circular sewer of this smaller radius, while at the same time the capacity in time of flood is equivalent to a much larger circle.

In Fig. 20, a favorite type of design for very large circular sewers

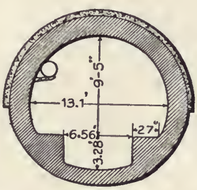



Fig. 24. Old Type of Main Sewers, Paris, France.

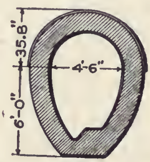



Fig. 25. New Type of Sewers, Paris, France.

is shown. For such large sewers, the upper half constitutes an arch, which exerts heavy pressures or thrusts horizontally outward against the sides of the sewer at the height of the center. To withstand these thrusts, the masses of masonry backing shown in the figure are added. This backing may be of brick, rubble-stone, or concrete masonry.

In the large sewers, too, it usually is not practicable to round the bottom of the trench to fit the circular shape, as is done for smaller sewers; and hence the flat foundation, also shown in the figure, is adopted. In soft materials, it often becomes necessary to drive piles to carry the weight of sewers.

In Fig. 21 is shown the favorite design for large sewers. For reasons given in discussing Fig. 20, the foundation is necessarily made flat; and with this shape of foundation, Fig. 21 will give a larger area and capacity for the same amount of material than Fig. 20, other conditions being the same. Also, Fig. 21 requires less headroom than Fig. 20 for the same capacity—which is often of great importance in the case of these large sewers. The invert of Fig. 21 is not so well suited to prevent deposits as that of Fig. 20; but in the case of these large sewers, there is usually a large flow even in dry weather, so that this point may be of little importance.

In Fig. 23 we have an example of the use of concrete for a large sewer of the general type shown in Fig. 21, and just discussed.

In Fig. 22 we have an extreme case of low headroom, secured by making the top an absolutely flat slab of concrete, reinforced with steel. In this case the bottom of the sewer was necessarily located at a very shallow depth below the street, while the required size of sewer was large.

Finally, in Figs. 24 and 25, are shown two typical cross-sections of the famous sewers of Paris. The large main shown in Fig. 24 acts not only as a sewer, but also as a subway for the water mains and for other purposes. The entire ordinary flow of sewage is confined within the *cunette*, or comparatively small channel shown in the bottom. The ledge on each side serves for the passage of workmen and of cleaning carts, flushing devices, etc. The section shown in Fig. 25 is a later type, and is more nearly self-cleansing. The dirt in the streets is washed into these sewers by the use of hose, and special conveniences for cleaning it out of the sewers are needed.

**36. Junction-Chambers for Large Sewers.** Where two or more large sewers join, special difficulties present themselves, in providing supports for the partial arches whose supports are cut away in making the junction. It is usually necessary, when the sewers are large, to build a masonry chamber enclosing the entire junction, and with a self-supporting roof spanning all the sewers.

Various designs for such junction-chambers are used, but the most common type is illustrated in Fig. 26. Here a *bell-mouth arch* is used to span the opening, the case being the junction of three of the Chicago intercepting sewers (see Fig. 5). Sometimes *flat roofs* are used, supported by steel beams or made of reinforced concrete.

The bottoms of such junctions are the *mathematical intersections,* executed in masonry, of the lower halves of the sewer channels; and for sewers not too large, the upper halves may sometimes be built in a similar way, or with *vault ribs,* as in the roofs of old cathedrals.

**37. Brick Sewers.** It has already been stated that brick is the favorite material for sewers too large to be made of pipe, the dividing line usually being drawn at 30 inches to 36 inches diameter. Brick present many advantages for sewer work, including their moderate cost, their durability, and their small size and regular shape, which enable them to be readily handled and used in building sewers of any desired cross-section, with comparatively smooth and true interior surfaces.

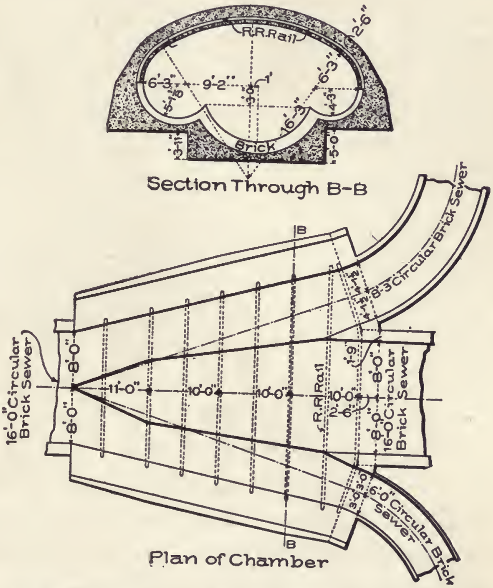



Fig. 26. Junction of Brick Sewers, Lawrence and Sheridan Avenues, Chicago, Ill.

*Sewer brick,* as those suitable for sewer construction are commonly called, should be harder burned than ordinary building brick, to enable them to stand the wear from the flow of sewage, and to insure against disintegration. They need not, however, be as hard burned as No. 1 paving brick, and hence constitute an intermediate grade between building brick and pavers. Sewer brick should be uniform in size, and of regular, true shape, so as to permit of being laid with thin joints, to form smooth, true surfaces. They should be carefully inspected on the work just before being used, and all defective brick thrown out. The common size for sewer brick approximates $8\frac{1}{2}$ by 4 by $2\frac{1}{4}$ inches.

In the sewer, the brick are laid in rings, as shown in Figs. 18 and 19, with the 4-inch dimension radial and the $8\frac{1}{2}$-inch dimension lengthwise of the sewer. Care should be taken to *break joints* in each ring. The brick should be laid in Portland cement mortar, made of at least 1 part of cement to 3 parts of clean, sharp sand of medium-sized grains. Pebbles should be screened out of the sand so as to permit thin joints. All joints should be filled *full* of mortar, the brick being laid with *shove joints,* to make a practically water-tight job. The outside ring of the invert should be laid against a layer of 1 to 2 Portland cement mortar; and the outside of the arch (or upper half of the sewer) should be plastered with the same mortar, to keep out ground water. Similarly, to prevent leakage of sewage, the entire interior surface of the sewer should be plastered with the same mortar, or else thoroughly washed with at least two coats of liquid cement, after the joints have been carefully pointed and smoothed. Even with the utmost care. it will be found impossible to secure absolute water-tightness; and the difficulties will be especially great when ground water and soft materials are encountered in the trench.

Up to 6 or 7 feet diameter, two rings of brick are usually sufficient. In fact, for the smaller sizes of brick sewers, one ring would be amply strong with firm foundations; but it is difficult to make the sewer sufficiently tight when only one ring is used, because all joints extend entirely through. Sometimes an exterior layer of concrete may be used to meet this objection, at least for the lower half of the sewer; or an outside ring of brick may be used for the invert only. Sewers larger than 6 or 7 feet in diameter usually require three rings of brick; and more are needed for very large sewers, for which the number required must be calculated for each particular case to suit the special conditions.

**38. Concrete Sewers.** Of late years, concrete has frequently been employed in preference to other kinds of masonry for many purposes, of which sewer construction is one. Its advantages for sewers are many. The following may be mentioned:

*First,* and foremost, the cost is usually less than the cost of brick masonry.

*Second,* the concrete exactly fits the irregularities of the excavation, giving better foundations.

*Third,* sewers built of concrete constitute a solid structure without joints, and hence are less liable to uneven settlement.

*Fourth,* there are no joints, as in brickwork, to be made watertight, though, on the other hand, it is not easy to make the body of the concrete entirely impervious to seepage.

*Fifth,* the concrete can be readily moulded to any desired shape of sewer.

*Sixth,* the concrete can be made by comparatively unskilled workmen, if skilled foremen are employed.

Concrete may be used for foundations, as shown in Figs. 20 and 21; for the backing of brick sewer rings; and in various other combinations with brick; or it may be used for the entire sewer, as in Figs. 22 and 23.

*Reinforced concrete,* or concrete reinforced with steel rods, to prevent cracks from tension stresses, has opened up of late years entirely new possibilities in sewer construction, of which Fig. 22 is an example.

It has been reported that the concrete invert of the large St. Louis sewer shown in Fig. 21 has shown surface pitting and disintegration from the effects of the sewage. This is a trouble which does not appear to have been experienced elsewhere, and hence is presumably uncommon, and would seem due most probably to poor materials or poor workmanship. Danger from this source could be prevented by lining the concrete sewer with one ring of vitrified paving brick.

## FORMULÆ AND DIAGRAMS FOR COMPUTING FLOW IN SEWERS

**39. Formulæ for Computing Flow in Sewers.** It has already been stated that more than 99.8 per cent of even sanitary sewage is simply ordinary water which has been added to the foul wastes to assist in removing them. Hence the mathematical formulæ for the flow of sewage are the same as those for the flow of water. They may be studied in detail in the instruction paper on Hydraulics.

Two general hydraulic formulæ have commonly been employed in sewer computations, as follows:

(1) *Weisbach's Formula.* The older computations were generally based on Weisbach's formula, which is as follows:

$$v = \frac{\sqrt{2gh}}{\sqrt{1 + e + c\frac{l}{d}}}.$$

In the above formula,

$v$ = Average velocity of flow, in feet per second.
$g$ = Acceleration due to gravity = 32.2 ft. per second.
$h$ = Fall of sewer, in feet.
$e$ = Coefficient of entrance = 0.505.
$c$ = Coefficient of friction in pipe $= 0.0144 + \frac{0.0169}{\sqrt{v}}$.
$l$ = Length of pipe, in feet.
$d$ = Diameter of pipe, in feet.

Weisbach's formula has been much used for sewer computations, for the reason that Mr. Baldwin Latham, in the first treatise on Sanitary Engineering worthy the name (1873), published extensive tables of flow, calculated from this formula, which made sewer computations very simple. Hence it was easier for later engineers simply to make use of these tables than to compute new ones of their own.

(2) *Kutter's Formula.* In later hydraulic computations, it has generally been considered that Kutter's formula gives the most reliable results. It is as follows:

$$v = c\sqrt{RS} = \left\{ \frac{41.66 + \frac{1.811}{n} + \frac{.00281}{s}}{1 + \left(41.66 + \frac{.00281}{s}\right)\frac{n}{\sqrt{R}}} \right\} \sqrt{RS}.$$

In this formula,

$v$ = Average velocity of flow, in feet per second.

$R$ = Mean hydraulic radius in feet = Area of cross-section of stream in square feet, *divided by* wetted perimeter, in feet, of length of portion of circumference of channel wet by the stream. (NOTE.—For circular pipe sewers, $R = \frac{1}{4}$ of the diameter when the pipe is flowing either full or half-full.)

$S$ = Slope of the sewer $= \frac{\text{Fall}}{\text{Length}}$.

$n$ = Coefficient of roughness, varying with the roughness of the channel.

For pipe sewers it is common to assume that $n = 0.013$; and for brick sewers, that $n = 0.015$. For cement pipe sewers, the roughness might be considered intermediate between these values of $n$; but $n = 0.013$ is generally used for them as well as for clay pipe. New and perfectly clean channels would not be so rough as indicated by these numbers; but the growths and deposits which may accumulate in sewers render it wise to adopt the above values for $n$.

Both the above sewer formulæ give merely the average velocities ($v$) of flow. *To obtain the discharge in cubic feet per second, we must multiply "$v$" by the area in square feet of the cross-section of the stream of sewage.*

Kutter's formula gives less capacities for pipe sewers than Weisbach's for the small sizes, up to about 18 inches' diameter. It will be on the safe side to adopt Kutter's formula; and this is now very generally done, though actual gaugings of small pipe sewers either new or in very good condition, may often show greater velocities and capacities than the formula would indicate, when the values of $n$ above given are adopted.

*In this paper, Kutter's formula will be adopted as the basis of all calculations of the flow of sewers.*

**40. Diagram of Discharges and Velocities of Circular Pipe Sewers Flowing Full.** Direct numerical computations of flow in sewers from the formulæ given above, would be very laborious and tedious. The work may be very greatly simplified by the use of tables or diagrams. Diagrams are more convenient than tables, and are adopted for this paper. With their aid, computations of flow in sewers are very easy and short.

Fig. 27 is such a diagram, giving the capacities and velocities of circular *vitrified* pipe sewers flowing full. *Cement* pipe sewers would probably have discharges and velocities somewhat less than those shown in this figure.

### TO USE THE DIAGRAM

(*A*) *When the diameter of the pipe and the grade are given, to find the discharge and the velocity.*

(1) Look along the bottom horizontal line till the grade is found, interpolating by the eye, if necessary, between the grades marked on the diagram. (2) Find the point where the vertical line through the given grade intersects the inclined line marked with the given diameter of sewer. (3) Trace horizontally through this point, interpolating by the eye, if necessary, between the horizontal lines on the diagram; and read the discharge of the pipe running full, on the left side of the diagram in cubic feet per second, or on the right side of the diagram in gallons per 24 hours. (4) If the velocity is desired, it can be determined by noting where the point (found in 2, above) of intersection of the given grade and diameter lines falls with reference to the inclined lines marked with the different velocities, estimating by the eye the decimals of a foot per second.

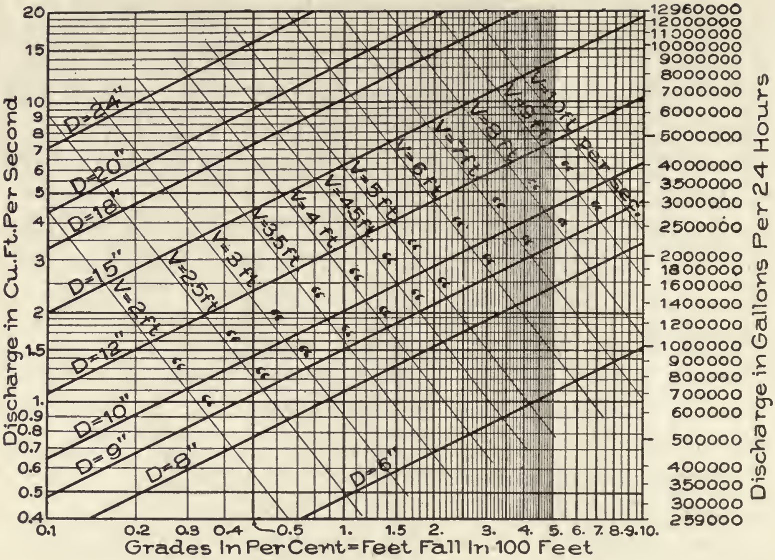



**Fig. 27.** Discharges and Velocities of Circular Vitrified Pipe Sewers Flowing Full. By Kutter's Formula ($n=0.013$).

(*B*) *When the grade and the required discharge are given, to find the necessary diameter of pipe, and the velocity.*

(1) Look along the bottom horizontal line till the given grade is found, interpolating by the eye, if necessary, between the grades marked on the diagram. (2) Find the intersection of the vertical line through this grade with the horizontal line through the given discharge, finding the discharge on the left of the diagram if it is given in cubic feet per second, or on the right if it is given in gallons per 24 hours. (3) Note between which two diameter lines this point of intersection falls, and take the diameter line nearest as that required. (4) Also note the position of the point of intersection with reference to the velocity lines, and so estimate the velocity, interpolating by the eye between the inclined velocity lines.

(*C*) *When the velocity and diameter are given, to find the grade and discharge.*

(1) Find the intersection of the given diameter line with the given velocity line, interpolating by the eye, if necessary. (2) Then vertically downward to the bottom of the diagram from this point of intersection, read the required grade; and horizontally to the left side or to the right side of the diagram, read the discharge, interpolating by the eye in each case, if necessary.

All other cases may be solved by similar obvious methods.

## EXAMPLES

*Example* 1. What will be the discharge and velocity of a 15-inch pipe sewer laid to a 0.2 per cent grade?

*Solution.* See *A*, above. From the intersection of the vertical 0.2 per cent grade line with the inclined 15-inch diameter line, we read horizontally to the left the discharge of 2.8 cu. ft. per second, or to the right, of 1,850,000 gallons per 24 hours. We further note that the point of intersection of the 0.2 per cent grade line with the 15-inch diameter line falls between the 2.0 and the 2.5 ft. per second velocity lines, and by the eye we estimate the velocity to be 2.3 ft. per second.

*Example* 2. See *B*, above. What size of pipe sewer laid at a grade of 0.5 per cent will be required to carry an average flow of 200,000 gallons of sewage per day, the maximum rate of discharge being three times the average? (NOTE.—Hence use 600,000 gallons discharge in solving the example.) Also, what will be the velocity?

*Answer.* Required diameter of sewer, 9 inches; velocity of flow, about 2.3 ft. per second.

*Example* 3. See *C*, above. If the minimum allowable velocity of flow is 2 ft. per second when a sewer flows full, what minimum grade will be required to produce this velocity in a 12-inch sewer?

*Answer.* 0.23 per cent minimum grade.

*Example* 4. If an outlet sewer serves 20,000 people, each person contributes 100 gallons per day, and the maximum rate of flow is 3 times the average, what size of sewer will be required, if its grade is 0.25 per cent?

*Answer.* 24 inches diameter.

*Example* 5. If an 8-inch pipe sewer is laid at a 0.45 per cent grade, what will be the discharge and the velocity when it flows full?

*Answer.* 480,000 gallons per day; 2.1 ft. per second.

*Example* 6. A storm pipe sewer drains 10 acres, and should be able to carry 1.5 cu. ft. per second per acre. Its grade is 0.5 per cent. What diameter will be required?

*Answer.* 24 inches diameter.

**41. Diagram of Discharges and Velocities of Circular Brick and Concrete Sewers Flowing Full.** Fig. 28 is the diagram for circular brick and concrete sewers, corresponding to Fig. 27 for pipe sewers, and is used in the same way.

### TO USE THE DIAGRAM

(*A*) *When the diameter of the pipe and the grade are given, to find the discharge and the velocity.*

(1) Look along the bottom horizontal line till the grade is found, interpolating by the eye, if necessary, between the grades marked on the diagram. (2) Find the point where the vertical line through the given grade intersects the inclined line marked with the given diameter of sewer. (3) Trace hori-

zontally through this point, interpolating by the eye, if necessary, between the horizontal lines on the diagram; and read the discharge of the pipe runn ng full, on the left side of the diagram in cubic feet per second, or on the right side of the diagram in gallons per 24 hours. (4) If the velocity is desired,

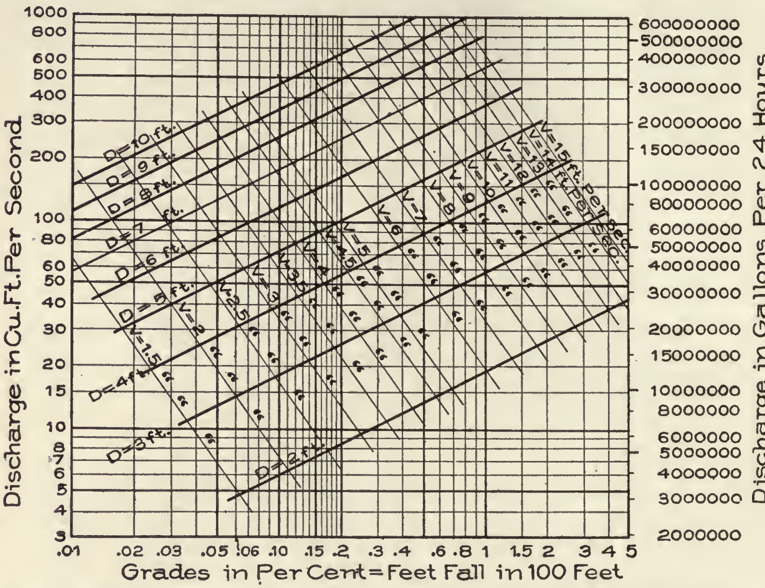



Fig. 28. Discharges and Velocities of Circular Brick and Concrete Sewers Flowing Full By Kutter's Formula ($n$=0.015).

it can be determined by noting where the point (found in 2, above) of intersection of the given grade and diameter lines falls with reference to the inclined lines marked with the different velocities, estimating by the eye the decimals of a foot per second.

(*B*) *When the grade and the required discharge are given, to find the necessary diameter of pipe, and the velocity.*

(1) Look along the bottom horizontal line till the given grade is found, interpolating by the eye, if necessary, between the grades marked on the diagram. (2) Find the intersection of the vertical line through this grade with the horizontal line through the given discharge, finding the discharge on the left of the diagram if it is given in cubic feet per second, or on the right if it is given in gallons per 24 hours. (3) Note between which two diameter lines this point of intersection falls, and take the diameter line nearest as that required. (4) Also note the position of the point of intersection with reference to the velocity lines, and so estimate the velocity, interpolating by the eye between the inclined velocity lines.

(*C*) *When the velocity and diameter are given, to find the grade and discharge.*

(1) Find the intersection of the given diameter line with the given velocity line, interpolating by the eye, if necessary. (2) Then vertically

downward to the bottom of the diagram from this point of intersection, read the required grade; and horizontally to the left side or to the right side of the diagram, read the discharge, interpolating by the eye in each case, if necessary.

All other cases may be solved by similar obvious methods.

## EXAMPLES

*Example* 7. What size of circular brick or concrete sewer laid to a 0.2 per cent grade will be required to carry a storm sewage flow of $\frac{3}{4}$ cu. ft. per second per acre from one square mile of drainage area, and what will be the velocity?

*Solution.* See *B*, above. 1 square mile = 640 acres. The capacity required is $640 \times \frac{3}{4} = 480$ cu. ft. per second, which we find on the left of Fig. 28 just below the 500 cu. ft. per second horizontal line, interpolating by eye. We next find the 0.2 per cent grade line at the bottom of the diagram, and locate the point of intersection of this vertical 0.2 per cent grade line with the horizontal 480 cu. ft. per second line already found above. This point of intersection comes nearly on the 9 feet inclined diameter line, and between the seven and eight feet per second inclined velocity lines.

*Answer.* Diameter of sewer required, 9 feet. Velocity = 7.6 ft. per second.

*Example* 8. What will be the minimum grade for a 60-inch brick or concrete sewer, if the minimum velocity allowed when flowing full is 3 ft. per second?

*Answer.* See *C*, above. 0.067 per cent grade.

*Example* 9. How large a population, contributing 75 gallons per capita per day of sanitary sewage, on the average (the maximum flow being 3 times the average), can be served by a 48-inch circular brick sewer, laid to a 0.06 per cent grade; and what will be the velocity of flow? (NOTE: Find the capacity as in *A*, above; and then divide by 3 times the average per capita amount per day.)

*Answer.* 89,000 population. 2.4 ft. per second.

*Example* 10. What will be the grade required to force a flow of 500 cu. ft. per second through a 96-inch circular brick sewer?

*Answer.* 0.38 per cent grade.

**42. Diagram of Discharges and Velocities of Egg-Shaped Brick and Concrete Sewers Flowing Full.** Fig. 29 is the diagram for egg-shaped brick sewers, corresponding to Fig. 27 for circular pipe sewers, and to Fig. 28 for circular brick and concrete sewers.

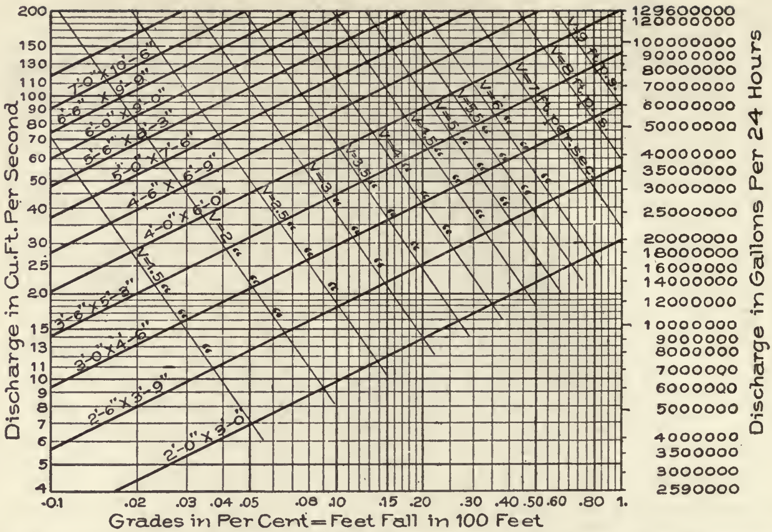



Fig. 29. Discharges and Velocities of Egg-Shaped Brick and Concrete Sewers Flowing Full. By Kutter's Formula ($n=0.015$).

## TO USE THE DIAGRAM

(*A*) *When the diameter of the pipe and the grade are given, to find the discharge and the velocity.*

(1) Look along the bottom horizontal line till the grade is found, interpolating by the eye, if necessary, between the grades marked on the diagram. (2) Find the point where the vertical line through the given grade intersects the inclined line marked with the given diameter of sewer. (3) Trace horizontally through this point, interpolating by the eye, if necessary, between the horizontal lines on the diagram; and read the discharge of the pipe running full, on the left side of the diagram in cubic feet per second, or on the right side of the diagram in gallons per 24 hours. (4) If the velocity is desired, it can be determined by noting where the point (found in 2, above) of intersection of the given grade and diameter lines falls with reference to the inclined lines marked with the different velocities, estimating by the eye the decimals of a foot per second.

(*B*) *When the grade and the required discharge are given, to find the necessary diameter of pipe, and the velocity.*

(1) Look along the bottom horizontal line till the given grade is found, interpolating by the eye, if necessary, between the grades marked on the diagram. (2) Find the intersection of the vertical line through this grade with the horizontal line through the given discharge, finding the discharge on the left of the diagram if it is given in cubic feet per second, or on the right if it is given in gallons per 24 hours. (3) Note between which two diameter lines this point of intersection falls, and take the diameter line nearest as that required. (4) Also note the position of the point of intersection with reference to the velocity lines, and so estimate the velocity, interpolating by the eye between the inclined velocity lines.

(*C*) *When the velocity and diameter are given, to find the grade and discharge.*

(1) Find the intersection of the given diameter line with the given velocity line, interpolating by the eye, if necessary. (2) Then vertically downward to the bottom of the diagram from this point of intersection, read the required grade; and horizontally to the left side or to the right side of the diagram, read the discharge, interpolating by the eye in each case, if necessary.

All other cases may be solved by similar obvious methods.

## EXAMPLES

*Example* 11. What will be the discharge and velocity of flow of a 4 by 6-feet egg-shaped brick or concrete sewer flowing full and laid to a 0.4 per cent grade?

*Solution. See A,* above. Find the 0.4 per cent grade line at the bottom of Fig. 29, and locate the point of intersection of the vertical line through this point with the inclined 4 by 6 dimension line. Then tracing horizontally to the left, we estimate by the eye 128 cu. ft. per second for the discharge. We also note that the point of intersection of the vertical 0.4 per cent grade line with the inclined 4 by 6 dimension line found above, is practically on the inclined 7 ft. per second velocity line.

*Answer.* Discharge, 128 cu. ft. per second. Velocity, 7 ft. per second.

*Example* 12. What will be the size of egg-shaped brick or concrete sewer required to carry a storm flow of ½ cu. ft. per second per acre from a drainage area of ½ square mile (= 320 acres), the grade being 0.3 per cent?

*Answer.* See *B,* above. 4 ft. 6 in. by 6 ft. 9 in.

*Example* 13. A 6-foot circular sewer and a 5 by 7 ft. 6-in. egg-shaped sewer have nearly the same area of cross-section. If both are laid to a 0.2 per cent grade, find the discharge and velocity of each when flowing full. (Note: Solve by Figs. 28 and 29. See *A,* above.)

*Answer.* Discharge, 165 cu. ft. per second; and velocity, 5.8 ft. per second, for the circular sewer; and discharge 163 cu. ft. per second; and velocity, 5.7 ft. per second, for the egg-shaped sewer.

Note: Although the egg-shaped sewer has a slightly smaller velocity when both are flowing full, it has a materially greater velocity than the circular sewer for small depths of flow.

*Example* 14. If the minimum allowable velocity of flow in storm sewers is 3 ft. per second, find the minimum allowable grades for 2 ft. by 3 ft., 4 ft. by 6 ft., and 6 ft. by 9 ft. egg-shaped sewers, respectively.

*Answer.* See *C,* above. 0.20, 0.08, and 0.05 per cent, respectively.

**43. Diagram of Discharges and Velocities in Circular Sewers at Different Depths of Flow.** The diagrams so far given show the discharges and velocities in sewers *flowing full.* It often, however, is necessary to be able to calculate the discharge and the velocity when the sewer flows only *partially* full.

For *circular sewers,* the discharges and velocities, when flowing only *partially full,* can readily be determined by the use of the diagram, Fig. 30, in connection with Figs. 27 and 28.

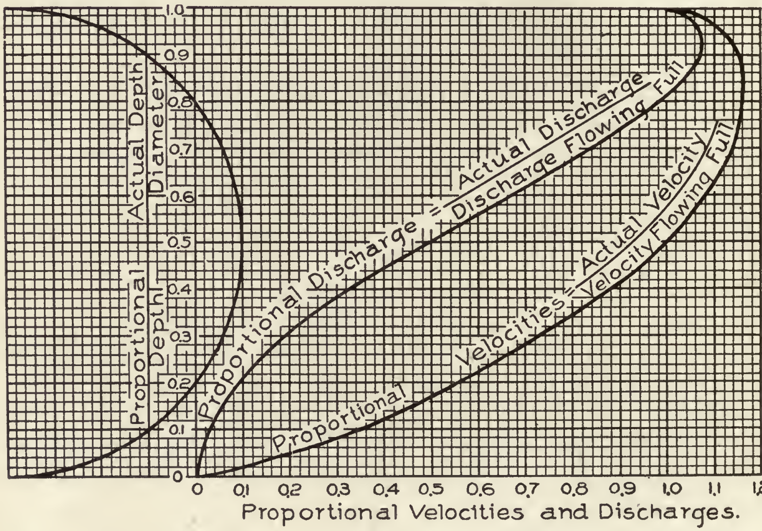



Fig. 30. Diagram Showing Changes in Velocity and Discharge in Circular Sewers for Different Depths of Flow.

### TO USE THE DIAGRAM

(*A*) *When the depth of flow is given, together with the diameter and grade of the sewer, to determine the discharge and the velocity.*

(1) By Fig. 27 if a pipe sewer, or by Fig. 28 if a brick or concrete sewer, determine the *discharge* and *velocity* of the sewer *flowing full.* (2) Divide the given depth of flow by the given diameter, to determine the *proportional depth* of flow; and find this proportional depth on the vertical scale towards the left of Fig. 30, interpolating by the eye, if necessary. (3) Find the intersection of the horizontal line through the proportional depth (found in 2, above), first, with the *proportional discharge line,* and, second, with the *proportional velocity line,* in Fig. 30; and read off at the bottom of the diagram vertically below these intersection points, the *proportional discharge* and the *proportional velocity.* (4) Multiply the *discharge and velocity flowing full* (found in 1, above), by the *proportional discharge* and *proportional velocity*

found in 3, above), and the products will be the required *actual discharge and actual velocity, for the given depth of flow.*

(*B*) *When the actual discharge is given, together with the diameter and grade of the sewer, to find the depth and velocity of flow.*

(1) By Fig. 27 if a pipe sewer, or by Fig. 28 if a brick or concrete sewer, determine the *discharge of the sewer flowing full.* (2) Divide the given discharge by the discharge flowing full, to determine the *proportional discharge*; and find this along the bottom of the diagram in Fig. 30, interpolating by the eye, if necessary. (3) Find the intersection of the vertical line through the proportional discharge (found in 2, above) with the *proportional discharge curve* in Fig. 30; and horizontally to the left, read off on the vertical scale near the left of the diagram the *proportional depth* of flow. (4) Multiply the diameter of the sewer by the proportional depth, and the product will be the *actual depth of flow for the given discharge.* (5) The actual velocity can now be found as described above for case *A*.

All other cases than *A* and *B* can be readily solved by similar obvious methods.

## EXAMPLES

*Example* 15. What will be the actual discharge and velocity of flow in a 48-inch circular brick sewer laid to a 0.15 per cent. grade, and flowing 6 inches deep?

*Solution.* See *A*, above. (1) By Fig. 28, with the sewer flowing full, the discharge would be 30,000,000 gallons per day, and the velocity 3.8 ft. per second. (2) $\frac{6 \text{ inches}}{48 \text{ inches}} = 0.12+ =$ proportional depth of flow, which we find on the vertical scale near the left of Fig. 30. (3) Horizontally opposite the point found in 2, we locate points on the proportional discharge curve and the proportional velocity curve in Fig. 30; and vertically beneath these points we read at the bottom of the diagram, 0.04 = proportional discharge, and 0.40 = proportional velocity. (4) $0.04 \times 30,000,000$ gallons = 1,200,000 gallons per day = actual discharge for 6 inches depth of flow; and $0.40 \times 3.8 = 1.5$ ft. per second = actual velocity for 6 inches depth of flow.

*Example* 16. An 8-inch pipe sewer, laid to a 0.40 per cent grade, is to carry the sewage of 500 people contributing 100 gallons each per day. What will be the average depth and velocity of flow?

*Solution.* See *B*, above. (1) By Fig. 27, the discharge and velocity flowing full would be respectively 450,000 gals. per day, and 1.9 ft. per second. (2) The actual discharge is $500 \times 100 = 50,000$ gals. per day, and hence the *proportional discharge* is $\frac{50,000}{450,000} = 0.11$. We find this proportional discharge along the bottom line of Fig. 30, interpolating by eye. (3) Vertically above the 0.11 proportional velocity, we find a point on the proportional discharge curve; and tracing horizontally to the left, we there read off the proportional depth = 0.225. (4) 0.225 × 8 = 1.8 inches = the actual depth of flow for the given discharge. (5) Horizontally to the right from the 0.225 proportional depth, we find a point on the proportional velocity line; and vertically beneath this point we read off at the bottom of the diagram, proportional velocity = 0.60. Then 0.60 × 1.9 (see 1, above) = 1.1 ft. per second = actual velocity for the given depth.

*Example* 17. What will be the discharge and velocity of a 12-inch pipe sewer laid to a 0.25 per cent grade when flowing 4 inches deep?

See *A*, above.

*Answer.* Discharge, 250,000 gals. per day; velocity, 1.7 ft. per second.

*Example* 18. What will be the depth and velocity of flow in a

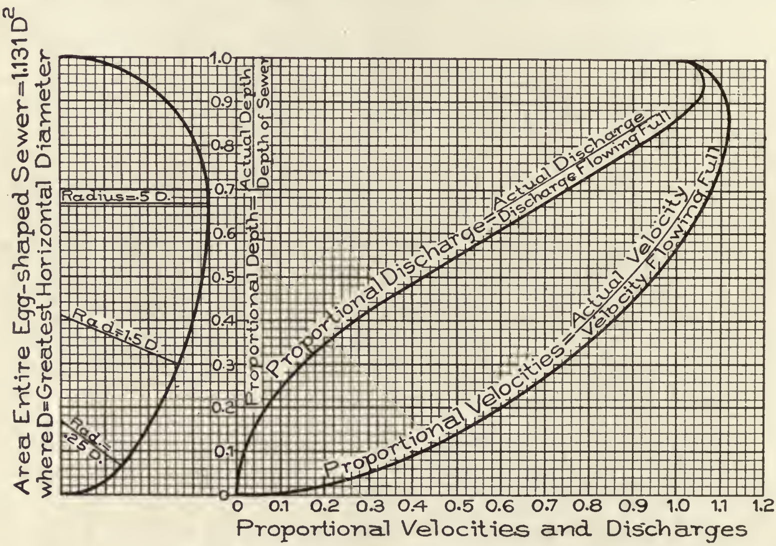



**Fig. 31. Diagram Showing Changes in Velocity and Discharge in Egg-Shaped Sewers for Different Depths of Flow.**

15-inch pipe sewer, laid at a 0.2 per cent grade, carrying 1,000,000 gallons of sewage per day?

See *B*, above.

*Answer.* Depth, 8 inches; velocity, 2.3 ft. per second.

**44. Diagram of Discharges and Velocities in Egg-Shaped Sewers at Different Depths of Flow.** For egg-shaped sewers, the discharges and velocities, when flowing *partially full*, can readily be determined by the diagram, Fig. 31, used in connection with Fig. 29.

## TO USE THE DIAGRAM

(*A*) *When the depth of flow is given, together with the diameter and grade of the sewer, to determine the discharge and the velocity.*

(1) By Fig. 29, determine the *discharge and velocity* of the sewer *flowing full.* (2) Divide the given depth of flow by the given height to determine the *proportional depth* of flow, and find this proportional depth on the vertical scale towards the left of Fig. 31, interpolating by the eye, if necessary. (3) Find the intersection of the horizontal line through the proportional depth (found in 2, above), first, with the *proportional discharge line,* and, second, with the *proportional velocity* line, in Fig. 31; and read off at the bottom of the diagram, vertically below these intersection points, the *proportional discharge,* and the *proportional velocity.* (4) Multiply the *discharge and velocity flowing full* (found in 1, above), by the *proportional discharge and proportional velocity* (found in 3, above), and the products will be the required *actual discharge and actual velocity for the given depth of flow.*

(*B*) *When the actual discharge is given, together with the diameter and grade of the sewer, to find the depth and velocity of flow.*

(1) By Fig. 29, determine the *discharge of the sewer flowing full.* (2) Divide the given discharge by the discharge flowing full, to determine the *proportional discharge,* and find this along the bottom of the diagram in Fig. 31, interpolating by the eye, if necessary. (3) Find the intersection of the vertical line through the proportional discharge (found in 2, above), with the *proportional discharge curve* in Fig. 31, and horizontally to the left, read off on the vertical scale near the left of the diagram the *proportional depth* of flow. (4) Multiply the height of the sewer by the proportional depth, and the product will be the *actual depth of flow for the given discharge.* (5) The actual velocity can now be found as described above for case *A*.

All other cases than *A* and *B* can be readily solved by similar obvious methods.

## EXAMPLES

*Example* 19. What will be the discharge and velocity in an egg-shaped brick or concrete sewer 3 ft. by 4 ft. 6 in., laid to a 0.15 per cent grade, and flowing 12 inches deep?

See *A*, above.

*Solution.* (1) By Fig. 29, discharge and velocity flowing full = 36 cu. ft. per second, and 3.45 ft. per second, respectively. (2) The proportional depth $= \frac{12}{54} = 0.22$, which we find at left of Fig. 31. (3) We locate the intersections of the horizontal line through the 0.22 proportional depth with the proportional discharge and proportional velocity curves, respectively; and vertically below these points we read off, at the bottom of the diagram, proportional discharge = 0.08, and proportional velocity = 0.63. (4) $36 \times 0.08 = 2.9$ cu. ft. per second = actual discharge; $3.45 \times 0.63 = 2.2$ ft. per second = actual velocity.

*Answer.* Discharge = 2.9 cu. ft. per second; velocity = 2.2 ft. per second.

*Example* 20. What will be the depth and velocity of flow in an egg-shaped brick or concrete sewer 5 ft. by 7 ft. 6 in. dimensions, laid to a 0.10 per cent grade, and carrying 30 cu. ft. per second flow of sewage?

See *B*, above.

*Solution.* (1) By Fig. 29, the discharge and velocity flowing full = 117 cu. ft. per second and 4.05 ft. per second, respectively. (2) Proportional discharge = $\frac{30}{117}$ = 0.26–, which find at bottom of Fig. 31. (3) Vertically above the 0.26 proportional discharge, we locate a point on the proportional discharge curve in Fig. 31, and horizontally to the left from this point read off the proportional depth = 0.39. (4) $90 \times 0.39 = 35$ inches = actual depth of flow. (5) Horizontally to the right along the 0.39 proportional depth line, we locate a point on the proportional velocity line; and vertically beneath this, we read off, at the bottom of the diagram, proportional velocity = 0.845. Then $4.05 \times 0.845 = 3.4$ ft. per second = actual velocity.

*Answer.* Depth of flow = 35 inches; velocity = 3.4 ft. per second.

*Example* 21. What will be the discharge and velocity in an egg-shaped brick or concrete sewer 2 ft. by 3 ft. dimensions, laid to a 0.50 per cent grade, flowing 18 inches deep?

See *A*, above.

*Answer.* Discharge = 5,900,000 gals. per day; velocity = 4.5 ft. per second.

*Example* 22. What will be the depth and velocity of flow in an egg-shaped brick or concrete sewer 3 ft. 6 in. by 5 ft. 3 in. dimensions, laid to a 0.08 per cent grade, carrying 25 cu. ft. per second of sewage?

See *B*, above.

*Answer.* Depth of flow = 39 inches; velocity of flow = 2.9 ft. per second.

## GENERAL EXAMPLES FOR PRACTICE WITH FIGS. 27-31

**45.** The solution of the following general examples will further familiarize the student with the principles thus far explained.

*Example* 23. A 24-inch sewer is to be laid to a 0.25 per cent grade, and may be made of vitrified sewer pipe or of brick. Compare the discharges and velocities obtained with the two materials. (NOTE: Use Figs. 27 and 28.)

*Answer.* With sewer pipe, discharge = 7,200,000 gals. per day; velocity = 3.6 ft. per second.

With brick, discharge = 6,000,000 gals. per day; velocity = 3 ft. per second.

*Example* 24. A combined sewer, laid to a 0.15 per cent grade, drains an area requiring either a 3-foot circular or a 2 ft. 6 in. by 3 ft. 9 in. egg-shaped brick sewer. (These sizes have the same cross-sectional area, and nearly the same discharges and velocities, when flowing full.) The dry-weather flow of sewage will be only 1,000,000 gallons per day. Calculate the dry-weather depth and velocity of flow with each design. (NOTE: Use Figs. 28 and 30, and Figs. 29 and 31.)

*Answer.* With circular sewer, depth = 6.1 inches; velocity = 1.6 ft. per second.
With egg-shaped sewer, depth = 9.2 inches; velocity = 1.9 ft. per second.

*Example* 25. In a 10-inch pipe sewer, laid to a one per cent grade, the maximum depth of flow observed was 7 inches; and the minimum, 2 inches. What were the corresponding discharges? (NOTE: Use Figs. 27 and 30.)

*Answer.* Maximum discharge = 1,100,000 gals. per day;
Minimum " = 120,000 " " "

*Example* 26. What size of circular sewer laid to a 0.08 per cent grade will be required to carry the sanitary sewage of a city of 100,000 population, with an average flow of sewage of 150 gallons per capita per day, the maximum rate of flow being three times the average?

*Answer.* 5 ft. 3 in. diameter.

*Example* 27. What size of egg-shaped combined sewer, laid to a 0.07 per cent grade will be required to carry a storm sewage flow of 0.5 cu. ft. per second per acre from a drainage area of 320 acres?

*Answer.* 6 ft. by 9 ft.

**46. Summary of Laws of Flow in Sewers.** The principles discussed in Articles 38 to 44, inclusive, may be briefly summarized as follows:

(1) The laws of flow for sewage are the same as for water.

(2) Kutter's formula is generally considered most reliable for calculating the flow in sewers, though complicated to use directly.

(3) In Kutter's formula, the values of the coefficient of roughness generally used for sewer computations, are $n = 0.013$ for pipe sewers, and $n = 0.015$ for brick and concrete sewers.

(4) Sewer diagrams greatly simplify sewer computations, and are presented in Figs. 27 to 31, inclusive, for circular and egg-shaped sewers, with full instructions for use.

(5) In Fig. 30, the laws of flow for different depths of flow in

circular sewers are shown. An examination of the diagram brings out this important law:

*In circular sewers flowing half-full, the velocity is the same as when the sewer flows full; and hence the discharge flowing half-full is just half the discharge flowing full.*

(6) Figs. 30 and 31 also show the following important law of flow:

*In a sewer of any shape, not flowing under pressure, the maximum discharge and velocity will occur, not with the sewer flowing full, but with it flowing a little less than full.*

This is due to the increased friction against the top of the sewer when it flows full. Owing to this law, no sewer can flow full without being under pressure.

(7) In the case of combined sewers having a dry-weather flow very small as compared with the storm flow, egg-shaped sewers give materially greater depths and velocities of dry-weather flow than circular sewers.

## CALCULATIONS OF SIZES AND MINIMUM GRADES OF SEPARATE SANITARY SEWERS

**47. Minimum Sizes of Sanitary Sewers.** In the early construction of sewers, previous to the last half of the 19th century, the laterals and sub-mains were usually made very much larger than the amount of sewage would require, with the idea, apparently, that the bigger the sewer the better. Such badly proportioned sewers were in great danger of stoppages from the inability of the shallow, trickling stream to carry along the solid matter. In fact, the sewers were expected to form deposits, and were purposely made large to hold a large amount of deposit and to enable men to enter for the purpose of cleaning them. Disastrous sanitary experience with such foul sewers made it apparent that there was just as much danger from making the sewers too large as from making them too small, especially in the case of sanitary sewers. Such sewers should be made small enough to give a good depth and velocity of flow.

Sanitary sewers should not be made small enough, however, to cause frequent stoppages by catching articles which have been admitted into them through the house connections. House owners are often reprehensibly negligent in putting into their plumbing fixtures, articles which should be carefully excluded. On this account, the size of house connections should be restricted to 4 inches.

An 8-inch sewer pipe will practically always carry freely, even crosswise, any article which can come lengthwise around the traps and bends in 4-inch soil-pipes and house connections Hence *eight inches should usually be adopted as the minimum size for sanitary sewers.*

Usually the great bulk of the sanitary sewers in a separate system will be of this minimum size, only a limited length of the larger sizes being required for sub-mains and mains. See the sewerage map of Ames, Iowa, Fig. 38.

In the early use of the separate system, many 6-inch laterals were constructed, and, except for occasional stoppages from articles improperly put into the sewers, they have worked well. Some engineers still use six inches as the minimum size.

**48. Minimum Grades and Velocities for Separate Sanitary Sewers.** In the design and construction of sewers it has been found that certain minimum grades should be adopted to prevent deposits, no sewers being built to lighter grades than the minimum unless special means for flushing, or special facilities for cleaning, are provided. This is to insure sufficient velocity to prevent the settling-out of the solid matter in the sewage to form deposits in the sewers.

These minimum grades for separate sanitary sewers are as follows:

**TABLE II**
**Minimum Grades for Separate Sanitary Pipe Sewers**

| Diameter | Minimum Grade | Diameter | Minimum Grade |
|---|---|---|---|
| 4 inches | 1.20 per cent | 18 inches | 0.12 per cent |
| 6 " | 0.67 " " | 20 " | 0.10 " " |
| 8 " | 0.43 " " | 24 " | 0.08 " " |
| 9 " | 0.36 " " | 27 " | 0.07 " " |
| 10 " | 0.30 " " | 30 " | 0.06 " " |
| 12 " | 0.23 " " | 33 " | 0.05 " " |
| 15 " | 0.16 " " | 36 " | 0.045 " " |

Caution.—*For the above minimum grades to be satisfactory and safe, there must be enough sewage to give a good depth of flow.*

The flow and velocity in a sewer fluctuate greatly, as illustrated in Article 52, below, the velocity at low flow being much less than when flowing full or half-full.

Experiments have shown that an actual velocity of $1\frac{1}{4}$ to $1\frac{1}{2}$ feet per second is sufficient to prevent deposits of the solid matters usually found in sanitary sewers; but to secure this velocity at low flow requires about 2 feet per second when the sewer flows full or half-full (see Figs. 30 and 31 for the fluctuation of velocity with depth of flow). Hence *the minimum grades for sanitary sewers should usually be those giving a velocity of* 2 *feet per second when flowing full or half-full, as shown by the diagrams, Figs.* 27, 28, *and* 29.

It is usually considered that, within a reasonable period in the future, the increased high-water flow each day should be sufficient to fill the sewer half-full or nearly so. However, in numerous cases, sanitary sewers have been observed to work well at the above grades with less depths of flow than this.

Much will depend on the nature of the sewage. Some thick, manufacturing sewages, heavily loaded with solid matter, would require considerably heavier grades to insure self-cleansing.

Where it is absolutely impossible to secure the above minimum grades, special means for flushing, such as automatic flush-tanks placed about three blocks apart, should be used.

**49. General Explanation of the Calculation of Amount of Sanitary Sewage.** The first thing necessary in computing the size required for any particular sanitary sewer, is to ascertain the amount of sewage it must carry. While this cannot be foretold with exactness, yet, by well-established methods, an approximation sufficiently close for all practical purposes can readily be made.

The *first step* in computing the amount of sewage will be to estimate the future tributary population which may use the sewer. For this, see Art. 50, below.

The *second step* will be to estimate the average amount of sewage contributed by each person per day—that is, the average flow of sewage per capita per day. This, multiplied by the tributary population, will give the total average amount of sewage per day which the sewer must carry.

Two methods are in use for estimating the average flow of sewage per capita per day:

(1) It is often assumed to equal the average consumption of water per capita per day. For this method, see Art. 51, below.

(2) The best method is to compare the local conditions with

actual sewer gaugings of flow in sewers under similar conditions elsewhere. For this method, see Art. 52, below.

**50. Methods of Estimating the Population Tributary to Sanitary Sewers.** The most important difficulty encountered in estimating the population tributary to sanitary sewers, is the fact that it is the *future* population which must be determined. To know the present tributary population is not sufficient. Two methods will be described:

(1) *The best method of estimating the future population tributary to sanitary sewers is as follows:*

(*a*) On the sewer map, lay out sewers to serve all districts to be served in the future as well as at present.

(*b*) After careful examination of the ground, and study of the conditions, estimate the number of persons tributary to the sewers per 100 feet of sewers in each district when it is built up as fully as can reasonably be expected.

In doing this, five or six persons per family should usually be allowed, and the number of families on both sides of the street for one block in the future estimated. The number of persons per block so obtained should then be divided by the number of hundred feet of sewer per block from center to center of streets.

Thus, if there are 6 lots 50 feet wide per block (=300 feet) on each side of the sewer, and the streets are 60 feet wide (=360 feet center to center of streets), and if it is thought that every lot will eventually contain one residence,

$$\text{Tributary population} = \frac{12 \times 6 \text{ persons}}{3.60} = 20 \text{ persons per 100 feet of sewer.}$$

The tributary population per 100 feet of sewer will usually range from 20 persons in the residence districts of small cities, to 100 persons in thickly built-up business districts. In the congested districts of the largest cities, the population is still denser.

(*c*) *To determine the total population tributary above any point on a sanitary sewer, scale from the sewer map the total number of hundred feet of tributary sewer above that point, including all branches; and multiply the total so obtained by the tributary population per* 100 *feet of sewer.*

Thus, if there are 8,500 ft. of tributary sewers, and the tributary population is 20 per 100 ft., the total tributary population will $= 156 \times 20 = 3{,}120$ persons. In some cases part of the length of tributary sewers may have to be multiplied by one density of tributary population, and part by another.

(2) In case the future population of an entire city is to be estimated, a different method must be used.

Usually, the past population of the city at different dates is obtained from census reports; and by study of this past growth, and of the present and probable future local conditions as affecting growth, and by comparison with the past growth of larger cities whose conditions were similar, estimates are made of the probable future populations at different dates, for 20 to 50 years in the future.

Usually, also, the past records of the city that is being studied, and of others, are platted as curves on cross-section paper, the ordinates representing population, and the abscissæ dates; and the future estimates are made by prolonging the curve of growth into the future.

**51. Use of Statistics of Water Consumption in Determining the Per Capita Flow of Sanitary Sewage.** Since about 99.8 per cent of sanitary sewage is merely ordinary water, nearly always taken from the public supply, the total flow per capita of sanitary sewage is usually approximately equal to the consumption of water per capita (that is,

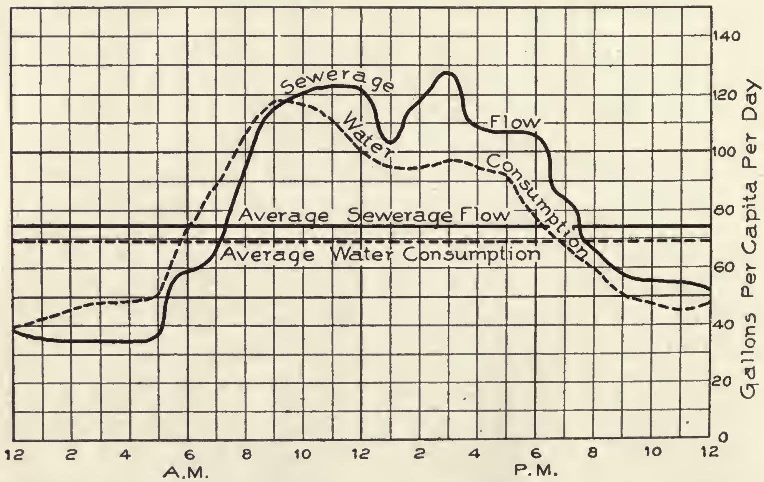



Fig. 32. Typical Gauging of Flow of Sanitary Sewage, Des Moines, Iowa, Friday, July 5, 1895.

per person). In Fig. 32 may be seen how closely sewage flow and water consumption ordinarily correspond.

In many towns, however, there will not be such close correspondence. Sometimes considerable amounts of water may be used for manufacturing or other purposes which divert it from the sewers, making the sewage flow less than the water consumption. More often there will be considerable influxes of ground water through leaking sewer joints, sometimes making the sewage flow several times as great as the water consumption.

However, very extensive statistics of water consumption in a large number of places have been collected, while actual gaugings of flow of sewage are comparatively few. Hence statistics of the water consumption of the town for which sewers are being designed, or of similar towns elsewhere, are often used as the basis for estimating the per capita flow of sanitary sewage. In studying each town preliminary to designing sewers for it, all possible information should be secured relative to its water consumption.

**TABLE III**

**Consumption of Water in American Cities, 1895**

| City | Population | Daily Consumption per Person, 1895. Gallons |
|---|---|---|
| New York | 3,437,202 | 100 |
| Chicago | 1,698,575 | 139 |
| Philadelphia | 1,293,697 | 162 |
| St. Louis | 575,238 | 98 |
| Boston | 560,892 | 100 |
| San Francisco | 342,782 | 63 |
| Buffalo | 352,387 | 271 |
| New Orleans | 287,104 | 35 |
| Minneapolis | 202,718 | 88 |
| Columbus | 125,560 | 127 |
| Atlanta | 89,872 | 42 |
| Nashville | 80,865 | 139 |

On pages 4 to 10 of the instruction paper on Water Supply, Part I, will be found a detailed discussion of water consumption. From a larger table given there, Table III herewith is condensed, to show how the average per capita water consumption varies in different American cities.

It will be noted that there is a very wide range in water consumption. The excessively low rates usually mean an incomplete water supply, which is likely to be extended later, while the excessively high rates usually mean great waste of water. This can often be greatly reduced by introducing water meters.

Under fairly average conditions the consumption will usually fall between the limits of 40 and 125 gallons per capita per day, as shown in detail in Table IV.

**TABLE IV**

**Water Consumption under Ordinary Conditions**

| Use | Gallons per Capita per Day | | |
|---|---|---|---|
| | Minimum | Average | Maximum |
| Domestic | 15 | 25 | 40 |
| Commercial | 7 | 20 | 35 |
| Public | 3 | 5 | 10 |
| Waste and Loss | 15 | 25 | 40 |
| Total | 40 | 75 | 125 |

**52. Use of Sewer Gaugings in Determining the Per Capita Flow of Sanitary Sewage.** It has already been stated that the flow of sanitary sewage is not always equal to the water consumption. In one case of sewer gaugings, the writer found the flow of sewage to be only 50 to 60 per cent of the water consumption, the remainder of the water being consumed for purposes which diverted it from the sewers. In another case of sewer gaugings, the writer found the flow of sewage to be over 500 per cent of the water consumption, the increase being due to infiltration of ground water through sewage joints. Hence, water consumption data alone are not sufficient in making estimates of sewage flow, and data from actual sewer gaugings are needed. Of late years there is an increasing accumulation of data of sewage flow obtained from actual gaugings. Some of these data are given in Table V.

At the Iowa State College, the sewage flow, as given in Table V, below, was 50 to 60 per cent of the water consumption, owing to uses of water which diverted it from the sewers. At Grinnell, on the other hand, infiltration of ground water into the sewers increased the sewage flow to about six times the total water consumption on the same day.

A study of Table V will show, however, that *in general the average flow of sanitary sewage is between the limits of* 50 *and* 125 *gallons per capita per day.*

**53. Capacities of Sanitary Sewers Required to Provide for Fluctuations in the Rate of Flow.** So far our discussion of flow of

**TABLE V**

**Gaugings of Flow of Sanitary Sewage**

| Sewer | Date | Duration, Days | Tributary Population | Sewage Flow, Gals. per Capita per Day | | |
|---|---|---|---|---|---|---|
| | | | | Min. | Av. | Max. |
| Compton Ave., St. Louis | 1880 | 6 | 8, 200 | 65 | 102 | 149 |
| College St., Burlington, Vt. | 1880 | 5–8 | 325 | 65 | 115 | 140 |
| Huron St., Milwaukee, Wis. | 1880 | – | 3, 174 | — | — | 120 |
| Memphis, Tenn. | 1881 | – | 20, 000 | 61 | — | 140 |
| 13 Sewers, Providence, R. I. | 1884 | 1–6 | 33, 825 | — | 78 | — |
| Asylum, Binghamton, N. Y. | 1888 | – | 1, 300 | — | — | 608 |
| 16 Sewers, Toronto, Ont. | 1891 | 3 | 168, 081 | — | 87 | — |
| Insane Asylum, Weston, W. Va. | 1891 | 2 | 1, 000 | 40 | 91 | 151 |
| Schenectady, N. Y. | 1892 | 1 | *10, 000 | 72 | 86 | 103 |
| Canton, Ohio | 1893 | – | 40, 000 | 54 | 129 | 180 |
| Chautauqua, N. Y. | 1894 | – | 7, 000 | 6 | 20 | 30 |
| Iowa State College, Ames, Ia. | 1894 | 7 | 289 | 0 | 32 | 77 |
| Des Moines, Ia., E. Side | 1895 | 15 | 8, 100 | 22.5 | 74 | 142 |
| Des Moines, Ia., W. Side | 1895 | 13 | 19, 400 | 23.2 | 66 | 175.3 |
| Iowa State College, Ames, Ia. | 1900 | 2 | 800 | 54 | 95 | 175 |
| Iowa State College, Ames, Ia. | 1900 | 28 | 800 | 30 | 57 | 130 |
| Marshalltown, Ia. | 1900 | 1 | 4, 200 | 67 | 85 | 111 |
| Grinnell, Ia. | 1901 | 1 | 2, 000 | 169 | 186 | 200 |
| Insane Asylum, Mt. Pleasant, Ia. | 1901 | 1 | 1,200 | 32 | 62 | 115 |
| Waverly, N. Y. | 1905 | 4 | 1, 796 | 79 | 155 | 194 |

* Estimated.

sanitary sewage (Arts. 51 and 52) has referred particularly to the *average* flow per capita per day. The flow, however, is not uniform, but fluctuates greatly. First, there is a *seasonal fluctuation.* The flow is apt to be especially high in severe cold weather, when faucets are left running to keep pipes from freezing; in hot weather, when water consumption is high; and in wet weather, when some ground water finds its way into the sewers.

Second, there is a *daily fluctuation.* For example, gaugings show that the flow usually is light on Sundays and holidays, when business is suspended. The flow on Monday is apt to be especially high, on account of wash day.

Third, there is an *hourly fluctuation,* at different times of the day and night. In Fig. 32, an example is shown of the fluctuation of sewage flow throughout one day, as determined by a continuous sewer gauging in the case of a city of 56,000 population. As shown in this figure, the flow of sanitary sewage is usually low through the night, reaching a minimum at about 2 to 3 A. M. It increases rapidly early in the morning, reaching a high point at about 10 to 11 A. M. Although there is usually a temporary drop at the noon hour, the flow continues high until early evening, and then decreases rapidly to its low night value.

A study of the sewer gaugings summarized in Table IV, together with others, shows that the flow of sanitary sewage ordinarily fluctuates from a minimum rate of 30 per cent to a maximum rate of 265 per cent of the average rate. If the gaugings had been extended over longer periods of time, still greater fluctuations of flow would certainly have been found.

It is apparent that the fluctuations in rate of flow will be greater in lateral sewers than in main sewers. To make them large enough to provide for the greatest rates of flow to be reasonably expected, *sanitary sewers should be given the following capacities*:

**PROPER CAPACITIES OF SANITARY SEWERS**

For lateral sewers, 350 per cent of the average flow.
For sub-main sewers, 325 per cent of the average flow.
For main sewers, 300 per cent of the average flow.

Table VI (page 68) is proportioned on the above basis.

**54. Ground Water in Sanitary Sewers.** In addition to the sanitary sewage itself, provision must often be made in separate sanitary sewers for leakage of ground water into the sewers. The amount of ground water to be allowed for, will depend on the character of the soil, on the height of the ground water with reference to the sewer, and on the care with which the sewer joints are made. *If the joints are made very carefully, the amount of ground water to be expected may range, with the soil, and height of ground water, from* 0 *to* 30,000 *gallons per mile.* This will constitute, say, 0 to 30 per cent of the sewage, but is a steady flow, not requiring the 300 to 350 per cent allowance for fluctuations required for sewage (see Art. 53). Hence, *if the joints are carefully made, the capacity of the sewers need not be increased more than* 10 *per cent for ground water.*

*If sub-drains with outlets separate from the sewers are provided for all wet stretches of trench, no allowance whatever for ground water need be made in the size of the sewers.*

The infiltration of ground water is apt to be much greater during and immediately after the construction of sewers than later, for the effect of sewers is to lower permanently the level of the ground water.

**55. Summary of Methods of Computing Sizes of Separate Sanitary Sewers.** The methods for computing the sizes of sanitary sewers may be summarized as follows:

(1) Lay out on the sewer map all the sewers required to serve all districts which can reasonably be expected to be included in the system, either at present or within say 30 to 50 years in the future.

(2) By a careful study of the topography, business conditions, manufacturing possibilities, and other future prospects, together with the sizes of blocks and lots, and the widths of streets, determine the probable future tributary population in each district per 100 feet of sewer, allowing usually five or six persons per family.

(3) By a careful study of the statistics of water consumption (Art. 51), and by comparison with actual sewer gaugings (Art. 52), taking into account all local conditions, estimate the average flow of sewage in gallons per capita per day.

(4) Beginning at the upper ends of the sewers, scale from the map and tabulate the total lengths of tributary sewer above successive points in the system, to the outlet. Multiply the number of hundreds of feet in these lengths by the tributary population per 100 feet, and by the average per capita flow of sewage per day, to get the total flow of sanitary sewage at the successive points.

(5) To allow for fluctuations (Art. 53), multiply the above average rates of flow of sanitary sewage by

$3\frac{1}{2}$ for lateral sewers;
$3\frac{1}{4}$ " sub-main "
3 " main "

to get the maximum rates of flow of sanitary sewage.

(6) To the maximum rates of flow so found, add 0 to 30,000 gallons per mile of tributary sewers, to allow for ground water (Art. 54).

(7) Occasionally it may be necessary also, in the case of certain sewers, to make special allowances for manufacturing sewage from large factories, each factory being studied by itself to determine its probable sewage flow. This flow will usually be subject to as much fluctuation as sanitary sewage, and hence must be multiplied by the factors given in 5, above.

(8) On the sewer profiles (see Art. 92), the grades of the sewers at the successive points will be determined and shown. Using these grades, and the total maximum rates of flow of sewage determined

## TABLE VI
### Sizes Required for Separate Sanitary Pipe Sewers

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| Diam. of Sewer, Ins. | Grade of Sewer, % | Maximum Permissible Av. Flow. Gals. per Day | Maximum Permissible Tributary Population | | | Maximum Permissible Linear Feet of Tributary Sewer for 20 Persons per 100 Feet | | |
| | | | Gals. per Capita per Day | | | Gals. per Capita per Day | | |
| | | | 75 | 100 | 125 | 75 | 100 | 125 |
| 8 | 0.43 | 130,000 | 1,700 | 1,300 | 1,000 | 8,700 | 6,500 | 5,200 |
| | 0.60 | 160,000 | 2,100 | 1,600 | 1,300 | 11,000 | 8,000 | 6,400 |
| | 0.80 | 180,000 | 2,400 | 1,800 | 1,400 | 12,000 | 9,000 | 7,200 |
| | 1.00 | 200,000 | 2,700 | 2,000 | 1,600 | 13,000 | 10,000 | 8,000 |
| | 1.40 | 240,000 | 3,200 | 2,400 | 1,900 | 16,000 | 12,000 | 9,600 |
| 10 | 0.30 | 220,000 | 2,900 | 2,200 | 1,800 | 15,000 | 11,000 | 8,800 |
| | 0.40 | 260,000 | 3,400 | 2,600 | 2,100 | 17.000 | 13,000 | 10,000 |
| | 0.60 | 310,000 | 4,100 | 3,100 | 2,500 | 21,000 | 15,000 | 12,000 |
| | 0.80 | 360,000 | 4.800 | 3,600 | 2,900 | 24,000 | 18,000 | 14,000 |
| | 1.00 | 400,000 | 5,300 | 4,000 | 3,200 | 27,000 | 20,000 | 16,000 |
| 12 | 0.23 | 350,000 | 4,700 | 3,500 | 2,800 | 23,000 | 17,000 | 14,000 |
| | 0.40 | 460,000 | 6,100 | 4,600 | 3,700 | 31.000 | 23,000 | 18,000 |
| | 0.60 | 560,000 | 7,500 | 5,600 | 4,500 | 37,000 | 28,000 | 22,000 |
| | 0.80 | 650,000 | 8,700 | 6,500 | 5,200 | 43,000 | 32,000 | 26,000 |
| | 1.00 | 720,000 | 9,600 | 7,200 | 5,800 | 48,000 | 36,000 | 29,000 |
| 15 | 0.17 | 550,000 | 7,300 | 5,500 | 4,400 | 37,000 | 27,000 | 22,000 |
| | 0.30 | 750,000 | 10,000 | 7,500 | 6,000 | 50,000 | 37,000 | 30,000 |
| | 0.40 | 850,000 | 11,000 | 8,600 | 6,900 | 57,000 | 43,000 | 34,000 |
| | 0.60 | 1,000,000 | 13,000 | 10,000 | 8.000 | 67,000 | 50,000 | 40,000 |
| | 0.80 | 1,200,000 | 16,000 | 12,000 | 9,600 | 80,000 | 60,000 | 48,000 |
| 18 | 0.13 | 800,000 | 11,000 | 8,000 | 6,400 | 55,000 | 40,000 | 32,000 |
| | 0.30 | 1,200,000 | 16,000 | 12,000 | 9,600 | 80,000 | 60,000 | 48,000 |
| | 0.40 | 1,400,000 | 19,000 | 14,000 | 11,000 | 93,000 | 70,000 | 56,000 |
| | 0.60 | 1,700,000 | 23,000 | 17,000 | 14,000 | 113,000 | 85,000 | 68,000 |
| | 0.80 | 2,000,000 | 27,000 | 20,000 | 16,000 | 134,000 | 100,000 | 80,000 |
| 24 | 0.10 | 950,000 | 12,000 | 9,500 | 7,400 | 62,000 | 46,000 | 37,000 |
| | 0.20 | 1,300,000 | 17,000 | 13,000 | 10,000 | 87,000 | 65,000 | 52,000 |
| | 0.40 | 1,900,000 | 25,000 | 19,000 | 15,000 | 126,000 | 95,000 | 76,000 |
| | 0.60 | 2,300,000 | 31,000 | 23,000 | 18,000 | 153,000 | 115,000 | 92,000 |
| | 0.80 | 2,600,000 | 35,000 | 26,000 | 21,000 | 173,000 | 130,000 | 104,000 |
| 27 | 0.08 | 1,400,000 | 19,000 | 14,000 | 11,000 | 93,000 | 70,000 | 56,000 |
| | 0.20 | 2,200,000 | 29,000 | 22,000 | 18,000 | 147,000 | 110,000 | 88,000 |
| | 0.30 | 2,700,000 | 36,000 | 27,000 | 22,000 | 180,000 | 135,000 | 108,000 |
| | 0.40 | 3,100,000 | 41,000 | 31,000 | 25,000 | 207,000 | 155,000 | 124,000 |
| | 0.60 | 3,800,000 | 51,000 | 38,000 | 30,000 | 254,000 | 190,000 | 152,000 |
| 30 | 0.06 | 2,200.000 | 29,000 | 22,000 | 18.000 | 147,000 | 110,000 | 88,000 |
| | 0.10 | 2,800,000 | 37,000 | 28,000 | 22,000 | 187,000 | 140,000 | 112,000 |
| | 0.20 | 4,000.000 | 53,000 | 40,000 | 32,000 | 267.000 | 200,000 | 160,000 |
| | 0.40 | 5,700,000 | 76,000 | 57,000 | 46,000 | 380,000 | 285,000 | 238,000 |
| | 0.60 | 7,000,000 | 93,000 | 70,000 | 56,000 | 466,000 | 350,000 | 280,000 |
| 36 | 0.05 | 3,200,000 | 43,000 | 32,000 | 26,000 | 214,000 | 160,000 | 128,000 |
| | 0.10 | 4,600,000 | 61,000 | 46,000 | 37,000 | 307,000 | 230,000 | 184,000 |
| | 0.20 | 6,500,000 | 87,000 | 65,000 | 52,000 | 433,000 | 325,000 | 260,000 |
| | 0.40 | 9,300,000 | 124,000 | 93,000 | 74,000 | 620,000 | 465,000 | 372,000 |
| | 0.60 | 11,400,000 | 152,000 | 114,000 | 91,000 | 760,000 | 570,000 | 456,000 |

in 5, 6, and 7, above, refer to Fig. 27 for pipe sewers, or to Fig. 28 for brick or concrete sewers, and find the sizes of sewers required.

*Example* 28. In a town in which the blocks are 340 feet, center to center of streets, there are 14 lots per block. The total length of tributary sewers above a certain point on a sub-main sewer in the system (separate sewers), is 16,600. The conditions affecting rate of sewage flow per capita are average. No allowance need be made for ground water or manufacturing sewage. The grade of the sewer is 0.30 per cent. What size is required?

*Solution.* The tributary population will be $\frac{14 \times 6}{3.4} = 25$ persons per 100 feet of sewer. The average rate of flow may be assumed at 85 gallons per capita per day. Hence the maximum rate of flow for this sub-main sewer will be $166 \times 25 \times 85 \times 3\frac{1}{4} = 1{,}150{,}000$ gallons per day.

Hence, by Fig. 27, for a 0.30 per cent grade, a 12-inch pipe sewer will be required.

*Answer.* A 12-inch pipe sewer.

**56. Table of Sizes Required for Sanitary Sewers.** By the methods given in Art. 55, omitting allowances for ground water and manufacturing sewage, Table VI (page 68) has been computed, to reduce the labor of computation of sizes of separate sanitary pipe sewers.

### TO USE THE TABLE

Proceed to follow out steps 1, 2, 3, and 4, in Art. 55, just above (which read), thus determining the total estimated future number of linear feet of tributary sewer at successive points, the estimated future number of persons tributary per 100 feet of sewer (which let $= P$), and the estimated average flow of sewage in gallons per capita per day (which let $= F$). Also ascertain the grade to which the sewer is to be built.

(*A*) *If $P = 20$ persons per 100 feet, and if $F$ lies between 75 and 125 gallons per capita per day, and if no allowance is necessary for ground water or manufacturing sewage,* find in column 7, 8, or 9, or by interpolating between them, according to the value of $F$, a number close to the calculated number of linear feet of tributary sewer opposite to the given sewer grade, interpolating between the grades, and take the corresponding size of sewer in column 1.

*Example* 29. For 13,100 linear feet of sewer, 20 persons per 100 ft., 85 gallons per capita per day, and 0.35 per cent grade.

We find that for a 0.35 per cent grade an 8-inch sewer would be considerably too small, as shown by interpolating between the numbers in columns 7 and 8, while a 10-inch sewer would be a little larger than needed.

*Answer.* A 10-inch pipe sewer.

(*B*) If $P$ does not $= 20$ persons per 100 feet (the other conditions remaining as in $A$, above), first multiply the number of linear feet of tributary sewer by $\frac{P}{20}$, and then proceed as in $A$, just above.

*Example* 30. For 16,300 linear feet of sewer, 30 persons per 100 feet of sewer, 110 gallons per capita per day, and a sewer grade of 0.25 per cent.

We first find $16{,}300 \times \frac{30}{20} = 24{,}450$ linear feet. Then interpolating between columns 8 and 9, we find that for a 0.25 per cent grade a 12-inch would be considerably too small, while a 15-inch sewer is a little larger than needed.

*Answer.* A 15-inch pipe sewer.

(*C*) If $F$ (rate of sewage flow) is less than 75 or more than 125 gallons per capita per day, first multiply the number of linear feet of tributary sewer by $\frac{F}{100}$, and then by $\frac{P}{20}$ (where $P$ = persons per 100 feet of sewer), and then find the nearest number in column 8 opposite the given grade.

*Example* 31. For 22,500 linear feet of sewer, 35 persons per 100 feet, 150 gallons per capita per day, and 0.45 per cent grade.

We first find $22{,}500 \times \frac{150}{100} \times \frac{35}{20} = 59{,}000$ linear feet. In column 8 we find that for a 0.45 per cent grade a 15-inch sewer would be considerably too small, while an 18-inch is too large.

*Answer.* An 18-inch pipe sewer.

(*D*) *If ground water or manufacturing sewage, or both,* must be allowed for, ascertain the *total average sewage flow,* by multiplying the linear feet of tributary sewer by $\frac{P}{100}$ ($P$ = persons per 100 feet), and this result by $F$ (= gallons per capita per day, of sanitary sewage), and by then adding to this result the total allowance for manufacturing sewage, and $\frac{1}{3}$ the total allowance for ground water. Then find by interpolation in column 3 the nearest number opposite the given grade, and take the corresponding size of sewer.

*Example* 32. For 15,600 linear feet of tributary sewer, 25 persons per 100 feet, 85 gallons per capita per day, 15,000 gallons per day per mile ground water, 200,000 gallons per day manufacturing sewage, and 0.20 per cent grade.

We find the total average flow of sewage to use is $15{,}600 \times \frac{25}{100} \times 85 + 200{,}000 + \frac{15{,}000}{3} \times 3$ (miles) = 546,000 gallons per day. In column 3 we find that for a 0.20 per cent grade, a 12-inch sewer would be considerably too small, while a 15-inch is a little larger than is needed.

*Answer.* A 15-inch pipe sewer.

## GENERAL EXAMPLE FOR PRACTICE IN DESIGNING SEPARATE SANITARY SEWERS

**57.** Working out the following example will materially help the student.

*Example* 33. Calculate the size of the outlet sewer of the sewer system shown in Fig. 4, assuming that there will be in the future 20 persons tributary per 100 feet of sewer, that the average flow of sewage will be 100 gallons per capita per day, no special allowance for ground water or manufacturing sewage being needed. Also assume that there may be in the future 15,000 feet of sewer extensions not shown in the figure. The grade of the outlet sewer is 0.20 per cent. Assume scale of drawing, 1,500 feet per inch.

*Solution.* Take a long strip of paper with one edge straight; and on this, mark off with a pencil a scale of feet from the scale assumed above. With this, scale off the lengths of all the sewers shown, except the storm sewers. Add up the lengths scaled, and add 15,000 linear feet of future extensions, to get the total length of tributary sewer. Then use Table VI.

*Answer.* An 18-inch pipe sewer.

## CALCULATION OF SIZES AND MINIMUM GRADES OF STORM AND COMBINED SEWERS

**58. Storm and Combined Sewers Calculated by Same Methods.** In combined sewers the rate of flow of sanitary sewage is so small in time of storms in proportion to that of the storm sewage, that the sanitary sewage can be neglected altogether in calculating the size. For example, a combined sewer one mile long, with 20 persons tributary per 100 feet, and 75 gallons per capita per day, would have a maximum rate of flow of sanitary sewage at its lower end of $\frac{52.8 \times 20 \times 75 \times 3\frac{1}{2}}{7\frac{1}{2} \times 86{,}400} = 0.43$ cu. ft. per second (there being $7\frac{1}{2}$ gals. in 1 cu. ft., and 86,400 seconds in 1 day, and the maximum rate of flow being $3\frac{1}{2}$ times the average).

If the blocks are 360 feet wide, center to center of streets, this same sewer would have to take the storm sewage from $43\frac{1}{2}$ acres. The amount of this at the time of the maximum storm allowed for, calculated by the methods described below, would probably be at least 20 cu. ft. per second. The sanitary sewage would therefore be only about 2 per cent of the storm sewage. The amount of the latter cannot be foretold nearly so close as 2 per cent. Thus the sanitary sewage would have no appreciable effect upon the size of the combined sewer, and can be neglected.

**59. Minimum Sizes of Storm and Combined Sewers.** In the case of sanitary sewers, 8 inches was stated to be the minimum allowable diameter (see Art. 47); but in the case of sewers carrying storm sewage, there is much greater danger of stoppages from dirt, sticks, and other debris washed in from the surface during storms. Hence *twelve inches should be the minimum allowable diameter for storm and combined sewers.*

**60. Minimum Grades and Velocities for Storm and Combined Sewers.** It was stated in connection with sanitary sewers (Art. 48), that the minimum allowable velocities to prevent deposits should be

**TABLE VII**

**Minimum Grades for Storm and Combined Sewers**

| Shape | Material | Size | Minimum Grades to Give Velocities of 3 ft. per Sec. | Minimum Grades to Give Velocities of 4 ft. per Sec. |
|---|---|---|---|---|
| Circular | Pipe | 12-in. Diam. | 0.48 | 0.88 |
| " | " | 15 " | 0.34 | 0.62 |
| " | " | 18 " | 0.25 | 0.47 |
| " | " | 24 " | 0.17 | 0.31 |
| " | " | 30 " | 0.13 | 0.23 |
| " | Brick or Concrete | 3-ft. " | 0.14 | 0.25 |
| " | " | 4 " | 0.10 | 0.17 |
| " | " | 5 " | 0.07 | 0.12 |
| " | " | 6 " | 0.06 | 0.10 |
| " | " | 7 " | 0.05 | 0.08 |
| " | " | 8 " | 0.04 | 0.06 |
| " | " | 9 " | 0.03 | 0.05 |
| " | " | 10 " | 0.025 | 0.045 |
| Egg-Shaped | " | 2 ft. × 3 ft. | 0.20 | 0.35 |
| " | " | 2½ " × 3¾ " | 0.15 | 0.26 |
| " | " | 3 " × 4½ " | 0.12 | 0.20 |
| " | " | 4 " × 6 " | 0.08 | 0.14 |
| " | " | 5 " × 7½ " | 0.06 | 0.10 |
| " | " | 6 " × 9 " | 0.05 | 0.08 |
| " | " | 7 " × 10½ " | 0.04 | 0.07 |

1¼ feet per second at the minimum depths of flow, which will require grades sufficient to give minimum velocities of 2 feet per second when the sewer flows full or half-full. For sewers carrying storm sewage, however, greater minimum velocities are necessary to prevent deposits, on account of the dirt, pebbles, and other heavy rubbish washed into them from the surface in times of storms. *For combined and storm sewers the minimum allowable grades should be steep enough to give a minimum velocity of 3 feet per second. If practicable without too great expense, 4 feet per second should be secured.*

**61. General Explanation of the Calculation of Amount of Storm Sewage.** When rain begins to fall upon the area drained by a storm sewer, the water falling in the immediate neighborhood of the outlet at once enters the sewer and begins to be discharged. As time passes and the rain continues, water arrives at the outlet from more and more remote portions of the drainage area, and the discharge at the outlet increases quite rapidly until water is being discharged from all portions of the drainage area at the same time. After that, any further increase is slow, being due only to a per cent of run-off slowly increasing as the saturation of the soil becomes more complete.

The *time of concentration* is the longest time required for water from the remotest points of the portion of the drainage area being considered, to reach the outlet of that portion.

The *general law of the heaviest rainfalls*, the ones which determine the sizes of sewers, is that the heaviest rates for short storms are much greater than the heaviest rates for long storms. *The longer the time, the less will be the average rate of the maximum storm lasting that time.*

In Fig. 33, is given a diagram prepared by Prof. A. N. Talbot, showing rainstorms in the Central States. On this diagram the ordinates represent the rate of rainfall in inches per hour (which = cu. ft. per second per acre), while the abscissæ represent the duration of the storm. Three curves are also shown, one for very rare rainfalls, one for ordinary heavy rains, and one intermediate. On the diagram each + represents o e storm.

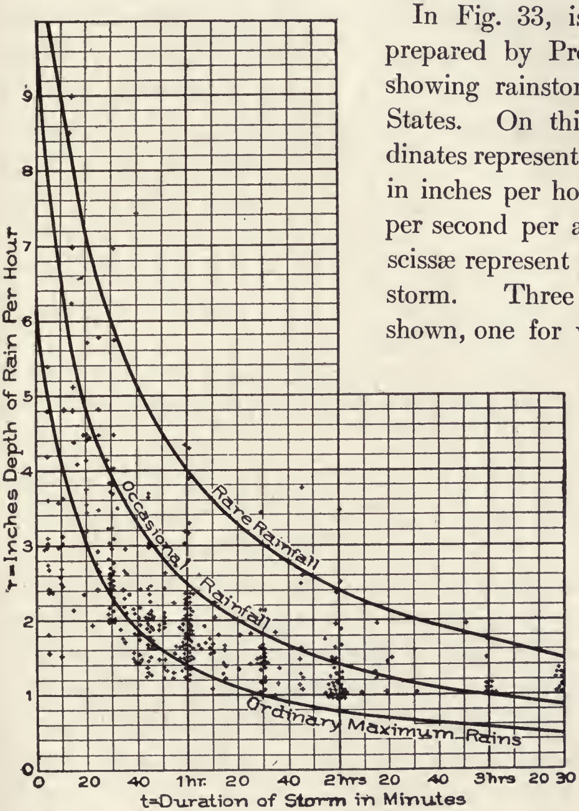



Fig. 33. Rates of Heavy Rainfall in the North Central States, Ohio, Indiana, Illinois, Missouri, Kansas, and Iowa.

*The storm causing the greatest rate of discharge in a storm sewer will usually be the maximum rain lasting a length of time equal to the time of concentration.* If a time less than this be taken, water will not be discharged at the outlet from all parts of the drainage area at once, and that from near the outlet will have a chance to run away before that from the remotest points arrives. On the other hand, if a time be taken longer than the time of concentration, the *heaviest* rate of the maximum storm lasting this long will be less than the rate of the maximum storm lasting a length of time just equal to the time of concentration; and since the storm is lighter the flow will be lighter.

Not all of the water falling on a drainage area will be carried away in the sewer. During and after the storm, some of the water is evaporated into the air, and some is absorbed into the soil. Some also accumulates on the surface, to flow off into the sewer after the rain has ended. *The engineer determines the percentage of the rain flowing off in the sewer, by estimating the percentage of maximum run-off of the drainage area.*

*The general method for calculating the amount of storm sewage for any particular drainage area,* is therefore as follows:

(*a*) Calculate the *time of concentration,* or longest time of flow to the point for which the size of sewer is being determined.

(*b*) Calculate the *rate of maximum rainfall* corresponding to the time of concentration.

(*c*) Calculate the *percentages of impervious and pervious areas* on the watershed drained by the sewer.

(*d*) Using the percentages of impervious and pervious areas obtained in *c,* calculate the *maximum percentage of run-off,* or the percentage of the rate of the maximum rainfall which will be running off in the sewer under design at the end of the time of concentration.

(*e*) *Calculate the total maximum rate of flow of storm sewage,* by *multiplying together* the *drainage area,* the *maximum rate of rainfall* corresponding to the time of concentration, and the *maximum percentage of run-off.*

**62. Calculation of the Time of Concentration.** The time of concentration, which is the longest time required for water falling on the remote portions of the watershed to flow to the point for which the size of sewer is being determined, will be the sum of, (1), the time required for the water from roofs, yards, sidewalks, and pavements to reach the sewers by way of the gutter and street inlets, and, (2), the longest time required for the water to flow through a line of sewers to the point for which the size of sewer is being calculated.

(1) *Time Required for Water from Roofs, Gutters, etc., to Reach the Sewers.* This will usually be between the limits of 5 and 15 minutes, depending on the steepness of the slopes of the surface and of the gutters, on the distance the water must flow to reach the gutters and the distance it must flow in the gutters to reach the street inlets, on the character of the surface (whether it offers obstructions to flow or not), or whether the roofs are connected to the gutters or directly to

the sewers, etc. By looking over the ground carefully, and allowing for the above conditions in a general way, the time may be estimated as closely as the data will warrant, without special calculations. The upper limit of 15 minutes may be used when the gutters have a very light grade, and are two blocks long, and where the roofs discharge into the gutters instead of into the sewer direct.

(2) *Longest Time Required for the Water to Flow through the Sewers.* This is computed by taking the grades and sizes of the different parts of usually the longest line of sewers, and determining the corresponding velocities of flow by the use of the sewer diagrams, Figs. 27, 28, and 29, already given. From these velocities, and the lengths of the several portions of the sewer, the corresponding times required for the sewage to flow through each part can be readily computed, and their sum will be the time required. The designing must be begun at the upper ends of the sewers, so that we may know the sizes of sewer needed in computing the times of flow through each portion.

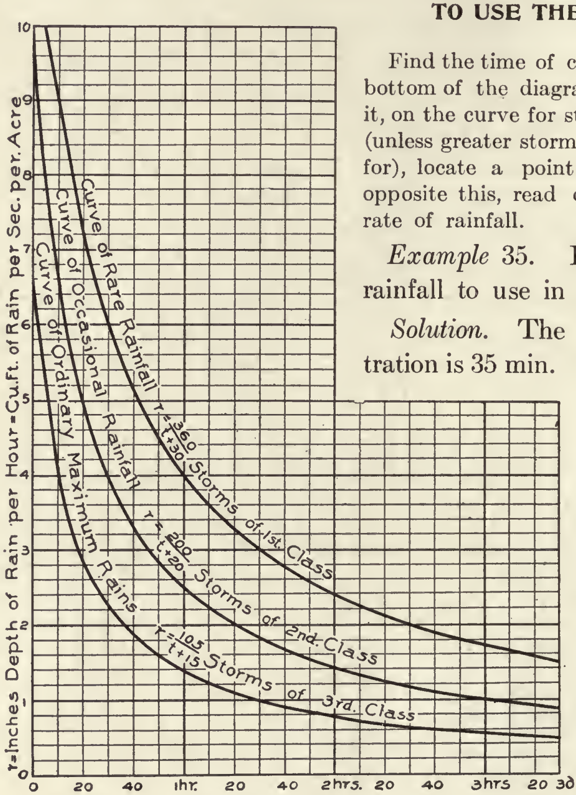
*Example* 34. Required the time of concentration in the following case: The longest sewer consists of 400 feet of 18-inch pipe sewer, grade 0.5 per cent; 800 ft. of 24-inch pipe, grade 0.3 per cent; 1,200 ft. of 36-inch brick sewer, grade 0.25 per cent; 2,400 ft. of 48-inch brick sewer, grade 0.17 per cent. The roofs discharge into the gutters, through which the sewage must flow 2 blocks at 0.5 per cent grade to reach a street inlet.

*Solution*:

| | Velocity | Time |
|---|---|---|
| Estimated for water from roofs and gutter to reach sewer | | 15.0 min. |
| In 18-inch sewer, Fig. 27 | 4.2 ft. per sec. | 1.6 " |
| " 24-inch " " 27 | 4.0 " " " | 3.3 " |
| " 36-inch " " 28 | 4.0 " " " | 5.0 " |
| " 48-inch " " 28 | 4.0 " " " | 10.0 " |
| *Answer.* Total time of concentration = | | 35 " |

**63. Calculation of the Rate of Rainfall Corresponding to the Time of Concentration.** In Fig. 34 are reproduced separately the three rainfall curves shown in Fig. 33. Storms of the 1st and 2d classes are rare, and are so very heavy that it would be excessively expensive to build sewers large enough for them. Hence sewers are usually built only large enough to provide for storms of the 3d class.

It is considered less expensive to suffer some damage from rare overcharging of the sewers than to build the greater sizes, though in case very valuable property would be damaged it may be wiser to provide for the heaviest storms.




$t$=Duration of storm in minutes=Time of concentration=Time required for water to flow from the remotest part of the area drained to the point under consideration on the sewer.

Fig. 34. Diagram Showing Rates of Maximum Rainfall to be Used in Calculating the Size of Storm Sewers.

**TO USE THE DIAGRAM**

Find the time of concentration at the bottom of the diagram. Vertically over it, on the curve for storms of the 3d class (unless greater storms are to be provided for), locate a point; and horizontally opposite this, read off on the left the rate of rainfall.

*Example* 35. Find the rate of rainfall to use in example 34.

*Solution.* The time of concentration is 35 min. Over this we read on the curve for 3d-class storms, 2.1 inches per hour.

*Answer.* 2.1 inches per hour.

**64. Calculation of the Percentages of Impervious and Pervious Areas on the Sewer Watershed.** The percentage of impervious area may be calculated in the following manner:

Take a typical unit of area, usually one average block, and divide it into different classes of surfaces, having different percentages of imperviousness, as follows:

(*a*) *Roof Area.* From the average size of buildings, and the average number of buildings per block which will be connected with the sewers or with the gutters, calculate the total roof area in the block. Take this at its full value if the roofs are connected directly with the sewers, but take only 90 per cent if the roofs are connected with the gutters.

(*b*) *First-Class Pavements.* Calculate the total area, per block, of brick, asphalt, stone block, and similar first-class pavements, with tight joints, and take 80 per cent of this area.

(*c*) *Second-Class Pavements.* Calculate the total average area per block, and take 60 per cent.

(*d*) *Third-Class Pavements.* Calculate the total average area per block of good macadam and similar pavements, and take 40 per cent.

(*e*) *Hard-Earth Roads.* Calculate the total average area per block of the traveled, hard-earth surfaces, and take 20 per cent.

(*f*) *Sidewalks.* Calculate the several total average areas per block of 1st, 2d, and 3d-class sidewalks, corresponding to the classes of pavements in *b*, *c*, and *d*, above. If these extend to the gutters, as in business districts, take the same percentages as for the corresponding classes of pavements—namely, 80, 60, and 40 per cent for 1st, 2d, and 3d-class sidewalks, respectively. But if the pavements are separated from the gutters by wide parking, as in the residence districts, take only one-half the above percentages—namely, take 40, 30, and 20 per cent, for 1st, 2d, and 3d-class sidewalks, respectively.

*Finally, add together all the reduced average areas per block* (*a*, *b*, *c*, *d*, *e*, *and f* ) *obtained as above explained, and divide the sum by the total area of the typical block. The quotient will give the percentage of impervious area.*

*The percentage of pervious area is obtained by subtracting the percentage of impervious area from* 100 *per cent.*

*Example* 36. In examples 34 and 35, assume the typical block to be 360 ft. square, center to center of streets, as follows:

Streets, 60 ft. wide; pavements, 30 ft. wide; asphalt on two streets; good macadam on the other two; cement sidewalks, 5 ft. wide, on all four streets.

One alley 20 ft. wide.

Lots, 12 in number, each 50 × 140 ft., each lot containing one house, the houses averaging 30 × 40 ft., the roofs connected with the gutter.

Calculate the percentage of impervious and pervious area.

*Solution:*

| | | | | |
|---|---|---|---|---|
| (*a*) | Roofs, | $30 \times 40 \times 12 \times .90$ | = | 12,960 sq. ft. |
| (*b*) | 1st-Class Pavements, | $2 \times 15 \times 360 \times .80$ | = | 8,640 " |
| (*d*) | 3d-Class Pavements, | $2 \times 15 \times 330 \times .40$ | = | 3,960 " |
| (*f*) | 1st-Class Sidewalks, | $5 \times 1{,}210 \times .40$ | = | 2,420 " |
| | Total impervious area per block | | = | 27,980 sq. ft. |

Total area of one block = $360 \times 360$ = 129,600 sq. ft.

*Answer.* *Percentage of impervious area* $= \frac{27{,}980}{129{,}600} = 21.58$ per ct.

*Percentage of pervious area* = 100 —21.58 = 78.42 per cent.

Mr. Emil Kuichling, M. Am. Soc. C. E., has calculated the percentages of impervious area in various cities of New York State, and his work has been repeated by Prof. H. N. Ogden,* who finds the percentage to vary with the intensity of population, as follows:

**TABLE VIII**

**Approximate Percentages of Impervious Area in Cities**

| Population per Acre | Percentage of Impervious Area | Percentage of Pervious Area |
|---|---|---|
| 5 | 4 | 96 |
| 10 | 9½ | 90½ |
| 15 | 15 | 85 |
| 20 | 20½ | 79½ |
| 25 | 26 | 74 |
| 30 | 31½ | 68½ |
| 35 | 37 | 63 |
| 40 | 42½ | 57½ |
| 45 | 47½ | 52½ |
| 50 | 52½ | 47½ |
| 55 | 58 | 42 |

Even very heavily populated sections in the largest cities will seldom have more than 80 to 85 per cent of impervious area.

Table VIII furnishes an easy method of making approximate estimates of the percentages of impervious area.

*Example* 37. In example 36, estimate the percentage of impervious area by Table VIII.

*Solution.* The typical block contains 129,600 sq. ft.; and $\frac{129{,}600 \text{ (sq. ft.)}}{43{,}560 \text{ (sq. ft.)}} = 3$ acres. The 12 houses at an average of 5½ persons per house, would give 66 persons per block = 22 per acre.

* *Sewer Design*, p. 62.

Referring to Table VIII we find by interpolating, $22\frac{3}{4}$ per cent of impervious area, as compared with 21.6 per cent obtained above by the more exact method.

**65. Calculation of the Maximum Percentage of Run-Off.** Not all of the rain falling on the impervious area of a watershed will run off during the storm. Small amounts are evaporated or absorbed at once, for no city surfaces are absolutely impervious. A larger amount goes to fill up small depressions in the surfaces. A still larger amount accumulates on the surfaces of the watershed, making its way toward the sewer, the amount so accumulated and its rate of movement increasing as the storm continues at the same rate, until finally an equilibrium of flow is established, and the rate of the run-off from the impervious area becomes practically 100 per cent of the rainfall. Thus, the shorter the storm, the less the percentage of run-off from the impervious area; and hence sewer watersheds having the smallest times of concentration are likely to have the smallest percentages of maximum run-off from the impervious areas.

The maximum downpours which determine the size of the sewer, are often preceded by lighter downpours which saturate and partially flood the watershed. Hence *it will probably never be allowable to assume less than* 75 *per cent as the percentage of maximum run-off from the impervious areas of a sewer watershed, even with very short times of concentration, and comparatively little damage from overcharged sewers.*

With long times of concentration (say 45 minutes or more), and wherever great damage would be caused by overcharged sewers, 100 per cent of maximum run-off from the impervious areas should be assumed.

In the case of long-continued storms, the pervious area becomes gradually saturated, until some run-off occurs from it also. In the case of storms lasting several hours, such as cause the great floods in rivers, this percentage of maximum run-off may be quite high; but for sewers, the times of concentration, and hence the duration of the maximum downpour, are comparatively short—rarely as long as one hour.

*For soils of average porosity and for moderate slopes, the percentage of maximum run-off from the pervious areas may be assumed to range from* 0, *for* 15 *minutes time of concentration, to, say,* 20 *for* 1 *hour's time of concentration. For porous, sandy soils and flat slopes, assume* 0 *to* 50 *per cent, and for very impervious soils and very steep slopes,* 125 *to* 150 *per cent of the above percentages of maximum run-offs from pervious areas.*

*Example* 38. In examples 36 and 37, assume that the territory is a residence district, with moderate slopes and clay subsoil. Estimate the percentage of maximum run-off.

*Solution.* Since the time of concentration is only 35 minutes, while the damage from overcharged sewers would not be so great as in a business district, we shall assume 90 per cent maximum rate of run-off from the impervious area. For the pervious area, we interpolate roughly between 0 per cent for 15 minutes, and 17 per cent for 1 hour, and assume 8 per cent maximum rate of run-off.

$.90 \times 21.6$ per cent = 19.4 per cent from impervious area.
$.08 \times 78.4$ " " = 6.3 " " " pervious "

*Answer.* Total = 26 per cent maximum rate of run-off.

**66. Summary of Methods of Computing Sizes of Storm Sewers.** We may now summarize the methods of computing the sizes of storm sewers, described above in Articles 61 to 65, inclusive, as follows:

(*a*) Calculate the *time of concentration* (Art. 62), or longest time of flow from the remote portions of the sewer watershed to the point for which the size of sewer is being calculated.

(*b*) Calculate the *maximum rate of rainfall* (Art. 63) corresponding to the time of concentration.

(*c*) Calculate the *percentages of impervious and pervious areas* on the sewer watershed (Art. 64).

(*d*) From the percentages of impervious and pervious areas, and knowledge of the characteristics of the sewer watershed, calculate the *percentage of maximum run-off* (Art. 65).

(*e*) Calculate the *maximum rate of flow of storm sewage*, by *multiplying together* the *area of the sewer watershed in acres*, the *maximum rate of rainfall in inches per hour* (*b*), and the *percentage of maximum run-off* (*d*). The product will be the *cubic feet per second of maximum storm sewage flow.*

(*f*) Knowing the grade of the sewer, refer to Fig. 27, or Fig. 28, or Fig. 29, according to the shape and material of the sewer, and determine the size of sewer required to carry the maximum flow of storm sewage (*e*) when flowing full.

*Example* 39. In examples 34 to 38, assume that the sewer watershed is 5,280 feet long by 800 feet wide, and that the grade of the circular brick outlet sewer is to be 0.15 per cent. Calculate the required diameter.

(*a*) The time of concentration = 35 min. (see Ex. 34).
(*b*) The rate of maximum rainfall = 2.1 in. per hr. (see Ex. 35).
(*d*) The percentage of maximum run-off = 26 (see Ex. 38).
(*e*) The drainage area $= \frac{5,280 \times 800}{43,560} = 97$ acres.

$$97 \times 2.1 \times .26 = 53 \text{ cu. ft. per sec.}$$
$$= \text{maximum flow of storm sewage.}$$

(*f*) Referring to Fig. 28, we find, by interpolating between the 4-foot and 5-foot diameters, that for a grade of 0.15 per cent a diameter of 4 ft. 3 in. will be required for a circular brick sewer which can carry 53 cu. ft. per sec.

*Answer.* A 4 ft. 3 in. circular brick sewer.

## GENERAL EXAMPLE FOR PRACTICE

**67.** Before proceeding further, the student should work out the following example in computation of the proper size of sewer:

*Example* 40. A thickly built-up sewer district, having a population of 35 persons per acre, contains 160 acres. The slopes are very flat, and the soil is sandy and porous. The longest line of sewers is 6,000 feet; and the velocity of flow in the sewers averages four feet per second. The roofs are connected with the gutters, in which the longest flow is two blocks. Calculate the diameter of the circular, brick outlet sewer, laid to a 0.08 per cent grade (NOTE: Use Table VIII.)

*Answer.* A 6-foot circular brick sewer.


**PARSONS TRENCH EXCAVATOR CUTTING A 15-FOOT DITCH IN A 14½-FOOT ALLEY**

*Courtesy of G. N. Parsons Company, Newton, Iowa*

# SEWERS AND DRAINS

## PART II

### LAND DRAINS AND SUBDRAINS

**68. General Discussion of Land Drains.** Definitions of sewers and drains were given in Art. 1. Land drains have for their object the reclaiming of wet lands, to render them suitable for cultivation. The reclamation of wet lands also greatly improves the sanitary condition of the vicinity.

There are two principal kinds of land drains—namely, *tile drains,* or lines of agricultural drain tiles laid a few feet beneath the surface of the ground, to remove ground water; and *drainage ditches,* or open channels, made to serve as outlets for the tile drains and to drain ponds and remove surface water.

**69. Planning and Construction of Land-Drainage Systems.** When a tile drainage system is projected, a competent drainage engineer should at once be engaged to do the necessary surveying, plan the system, and pass on the construction.

The surveying will include the obtaining of data for a complete map of the system; and each drain should be staked out, stakes being set 50 feet apart, and an elevation taken with a good level at each stake. All the work should be checked.

The engineer should then prepare for the landowner a complete map of the system, to a scale of 200 to 400 feet per inch; also a sheet of profiles, including a profile of each drain, showing the depth and grade at all points. Without such map and profiles, knowledge of the system may be lost, and, on some future occasion, when very badly needed, may be unavailable.

The engineer should plan as simple and regular a tile system as possible, adopting long, parallel, straight lines of tile when practicable, with as few junctions as possible.

The grades may be very light in case of necessity, and short tile drains have worked well even at level grades; but the lighter the grade, the greater should be the care used in construction.

The minimum depths should usually be 3½ to 4 feet. Shallower depths do not drain out the soil so thoroughly; and tile, if laid 3½ to 4 feet deep, can be placed farther enough apart to more than make up for the cost of the greater depth.

The lines of tile should usually be placed from five to ten rods apart, depending on the soil—farthest apart in the most porous soil. The outlet should be built with special care; and a masonry wall should be constructed to hold the last length of tile.

For drainage ditches, careful surveys of the entire watershed must be made by a very competent engineer; and fully detailed plans and specifications must be prepared.

**70. Contracts and Specifications for Tile Drains.** The employer and the tile ditcher should sign a printed contract with detailed specifications, such as given herewith:

## CONTRACT

It is hereby agreed between ....................................., employer, and ..............................................., contractor, that the contractor shall, except for the furnishing of the tile along the ditch and the refilling of the ditch, entirely construct for the employer the following described drains:

..............................................................................

..............................................................................

..............................................................................

..............................................................................

..............................................................................

..............................................................................

It is further agreed that for the above work the employer shall pay the following prices:

..............................................................................

..............................................................................

..............................................................................

It is further agreed that the employer ..................................... ...............................furnish board free to the contractor and his helpers during active prosecution of the work.

It is further agreed that the contractor shall begin the work by........ ..........................and complete the same by..................

It is further agreed that all the above work and the payments therefor shall be in strict accordance with the specifications given below and with the engineer's maps, profiles, and plans, all of which are hereby made a part of this contract.

Witness the hands of the respective parties, this................day of ........................A. D.....

........................Employer

........................Contractor

## SPECIFICATIONS

1. *Staking Out the Work.* The work will be staked out by the engineer, and his stakes must be carefully preserved and followed.

2. *Digging the Ditches.* The digging of each ditch must begin at its outlet, or at its junction with another tile drain, and proceed toward its upper end. The ditch must be dug along one side of the line of survey stakes, and about ten inches distant from it, in a straight and neat manner, and the top soil thrown on one side of the ditch and the clay on the other. When a change in the direction of ditch is made, it must be kept near enough to the stakes so that they can be used in grading the bottom. In taking out the last draft, the blade of the spade must not go deeper than the proposed grade line or bed upon which the tiles rest.

3. *Grading the Bottom.* The ditch must be dug accurately and truly to grade at the depths indicated by the figures given by the engineer, measured from the grade stakes. At each grade stake, a firm support shall be erected; and on these supports a fine, stout cord shall be tightly stretched over the center line of the ditch and made parallel with the grade by careful measurements at each stake, using a carpenter's level. Supports shall be kept erected at at least three grade stakes, and the work checked each time by sighting over them. Intermediate supports shall be set and lined in by careful sighting wherever necessary, to support the cord every 50 feet. A suitable measuring stick shall be passed along the entire ditch, and the bottom in all parts made true to grade by measuring from the cord. The bottom must be dressed with the tile hoe, or, in the case of large tiles, with the shovel, so that a groove will be made to receive the tile, in which the tile will remain securely in place when laid.

4. *Laying the Tile.* The laying of the tile must begin at the lower end and proceed upstream. The tile must be laid as closely as practicable, and in lines free from irregular crooks, the pieces being turned about until the upper edge closes, unless there is sand or fine silt which is likely to run into the tile, in which case the lower edge must be laid close, and the upper side covered with clay or other suitable material. When in making turns, or by reason of irregular-shaped tile, a crack of one-fourth inch or more is necessarily left, it must be securely covered with broken pieces of tile. Junctions with branch lines must be carefully and securely made.

5. *Blinding the Tile.* After the tile have been laid and inspected by the employer or his representative, they must be covered with clay to a depth of six inches, unless, in the judgment of the employer or his representative, the tile are sufficiently firm so that complete filling of the ditch may be made directly upon the tile. In no case must the tile be covered with sand without other material being first used.

6. *Risk During Construction.* The ditch contractor must assume all risks from storms and caving-in of ditches; and when each drain is completed, it must be free from sand and mud before it will be received and paid for in full. In case it is found impracticable, by reason of bad weather or unlooked-for trouble in digging the ditch or properly laying the tile, to complete the work at the time specified in the contract, the time may be extended as may be mutually agreed upon by the employer and contractor. The contractor shall use all necessary precaution to secure his work from injury while he is constructing the drain.

7. *The Tile to be Used.* Tile will be delivered on the ground convenient for the use of the contractor. No tile shall be laid which are broken, or soft, or so badly out of shape that they cannot be well laid and make a good, satisfactory drain.

8. *Prosecution of the Work.* The work must be pushed as fast as will be consistent with economy and good workmanship, and must not be left by the contractor for the purpose of working upon other contracts, except by permission and consent of the employer. All survey stakes shall be preserved, and every means taken to do the work in a first-class manner.

9. *Subletting Work.* The contractor shall not sublet any part of the work in such a way that he will not remain personally responsible, nor shall any other party be recognized in the payment for work.

10. *Plant and Tools.* The contractor shall furnish all tools which are necessary to be used in digging the ditches, grading the bottom, and laying the tile. In case it is necessary to use curbing for the ditches, or outside material for covering the tile where sand or slush is encountered, the employer shall furnish the same upon the ground convenient for use.

11. *Payments for Work.* Every............weeks during the prosecution of the work, the contractor may claim and the employer shall pay 75% of the value of the work completed satisfactorily, the engineer being the arbiter in case of dispute as to the amount of work satisfactorily completed. The remaining 25% will be retained until the entire work is completed satisfactorily, as certified by the engineer after a final inspection, at which time the whole amount due shall be paid. Prior to any payment, the employer may require a correct statement of all claims incurred by the contractor for labor, materials, or damages on account of the work; and the employer may withhold payments until proof has been presented by the contractor of release of all liens against the employer on account of such claims.

12. *Duties of Engineer.* The engineer shall have authority to lay out and direct the work, and to inspect and supervise the same during construction and on completion, to see that it is properly done in accordance with the contract. His instructions should be fully carried out.

13. *Failure to Comply with Specifications.* In case the contractor shall fail to comply with the specifications, or refuse to correct faults in the work as soon as they are pointed out by the engineer or other person in charge, the employer may declare the contract void; and the contractor, upon receiving seventy-five per cent of the value of the completed drains at the price agreed upon, shall release the work and the employer may let it to other parties.

**71. Benefits of Tile Drains.** The advantages of tile drains may be enumerated as follows:

1. Tile drainage, by making the soil firm, enables earlier cultivation in the spring. Low ground drained can be cultivated earlier than high ground not drained.

2. Careful observations have shown that tile drainage makes the soil several degrees warmer in the spring. Scientific tests have

shown this increased warmth to be of the utmost importance in promoting the germination and growth of crops.

3. Tile drainage promotes pulverization of the soil, putting it in good condition to cultivate, and preventing baking and the formation of clods.

4. Tile drainage removes from the pores of the soil surplus and stagnant water, which would drown and destroy the roots of plants.

5. Tile drainage makes certain the proper "breathing" of the soil, or free circulation of air in its pores, which is essential to healthy plant growth.

6. Tile drainage establishes in the soil the proper conditions required for the satisfactory carrying on of the chemical processes necessary to prepare the plant food for its use by vegetation.

7. Tile drainage fits the soil for the vigorous life and action of the soil bacteria which are essential to preserve and increase its fertility and promote the growth of crops.

8. Tile drainage increases the depth of soil which can be reached by the roots of plants and drawn upon for plant food.

9. Because in them the roots of plants can penetrate deeper, where they are protected from heat and drouth and can reach the deep-seated moisture, tile-drained soils stand drouth better than undrained soils.

10. By putting the top 3-feet or 4-feet layer of soil into a porous condition, tile drainage enables soils to absorb rain water instead of discharging it over the surface, and so helps to prevent surface wash and consequent loss of fertility.

11. By causing this porous condition, tile drainage makes the upper 3 or 4 feet of soil into an enormous reservoir to catch the rain water and discharge it only slowly into the streams. Thus tile drainage prevents floods instead of causing them.

12. Tile drainage does away with irregular shaped fields, cut up by sloughs and ditches, and so cheapens cultivation.

**Benefits of Large Ditches.** Tile drainage is always preferred to open-ditch drainage if the drain is not too large. The advantages of large ditches may be enumerated as follows:

1. By furnishing channels to remove storm water, they prevent, if of ample size, the inundation of low-lying lands by floods and surface water.

2. They have a minor value for draining off the ground water from a narrow strip of land each side.

3. One of their main values is in furnishing outlets for tile drains, and in many places tile drainage is impracticable till outlet drainage ditches have been built.

**72. Method of Computing Sizes of Tile Drains.** The drained soil above the level of tile drains contains a large percentage of air-space in the pores between the soil particles; and this layer of porous soil acts like a great sponge several feet thick to absorb the rain as it falls. Hence the water reaches the tiles very slowly. It has been found that under average conditions tiles will not be called upon to carry more than $\frac{1}{4}$-inch depth of water in 24 hours. This equals 6,800 gallons per acre per day, or 4,352,000 gallons per square mile per day. The sizes of tile drains for average conditions may readily be taken from Table IX.

**TABLE IX**

**Number of Acres Drained by Tiles Removing $\frac{1}{4}$-Inch Depth of Water in 24 Hours**

| Grades | | Diameters of Tile Drains | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Per cent | Inches per rod | 3 in. | 4 in. | 6 in. | 8 in. | 10 in. | 12 in. | 15 in. | 18 in. | 20 in. | 22 in. | 24 in. |
| 0.03 | $\frac{1}{16}$ | | | | | 37 | 59 | 109 | 159 | 205 | 254 | 319 |
| 0.05 | $\frac{3}{32}$ | | 5 | 13 | 28 | 49 | 75 | 131 | 219 | 264 | 332 | 411 |
| 0.10 | $\frac{3}{16}$ | 4 | 7 | 19 | 40 | 69 | 109 | 186 | 289 | 373 | 471 | 582 |
| 0.15 | $\frac{9}{32}$ | 4 | 9 | 24 | 49 | 85 | 132 | 232 | 355 | 458 | 577 | 713 |
| 0.25 | $\frac{3}{8}$ | 5 | 10 | 28 | 56 | 97 | 153 | 264 | 410 | 529 | 667 | 823 |
| 0.30 | $\frac{9}{16}$ | 6 | 12 | 33 | 69 | 119 | 188 | 322 | 502 | 648 | 808 | 1,008 |
| 0.40 | $\frac{13}{16}$ | 7 | 14 | 39 | 79 | 138 | 216 | 371 | 580 | 748 | 942 | 1,165 |
| 0.50 | 1 | 8 | 16 | 44 | 89 | 154 | 246 | 416 | 648 | 838 | 1,050 | 1,300 |
| 0.60 | $1\frac{3}{16}$ | 9 | 17 | 48 | 97 | 169 | 266 | 457 | 710 | 911 | 1,154 | 1,422 |
| 0.70 | $1\frac{3}{8}$ | 10 | 19 | 50 | 105 | 182 | 287 | 488 | 768 | 988 | 1,242 | 1,549 |
| 0.80 | $1\frac{9}{16}$ | 10 | 20 | 55 | 114 | 195 | 307 | 526 | 822 | 1,059 | 1,332 | 1,645 |
| 0.90 | $1\frac{3}{4}$ | 10 | 21 | 59 | 119 | 207 | 326 | 558 | 872 | 1,123 | 1,414 | 1,747 |
| 1.00 | 2 | 11 | 22 | 62 | 126 | 218 | 343 | 589 | 917 | 1,176 | 1,495 | 1,838 |
| 1.50 | 3 | 13 | 28 | 75 | 153 | 267 | 419 | 722 | 1,123 | 1,450 | 1,824 | 2,256 |
| 2.00 | 4 | 15 | 31 | 88 | 178 | 309 | 485 | 832 | 1,297 | 1,676 | 2,110 | 2,594 |
| 3.00 | $5\frac{15}{16}$ | 19 | 39 | 107 | 216 | 377 | 593 | 1,020 | 1,589 | 1,957 | 2,592 | |
| 4.00 | $7\frac{15}{16}$ | 22 | 45 | 123 | 253 | 437 | 683 | 1,176 | | | | |
| 5.00 | $9\frac{7}{8}$ | 25 | 50 | 138 | 280 | 486 | 765 | | | | | |
| 7.50 | $14\frac{7}{8}$ | 30 | 61 | 169 | 344 | | | | | | | |
| 10.00 | $19\frac{13}{16}$ | 35 | 71 | 195 | | | | | | | | |

Table IX is computed from the form of Poncelet's formula recommended for use with tile drains by C. G. Elliott, drainage expert to the U. S. Agricultural Department, Washington, D. C., who recommends the above sizes to drain ground water only. If surface water is also to be removed, as in the case of ponds without other outlets, the tiles will drain safely only one-half to one-third the number of acres given in the table.

When part of the land in the watershed is rolling, not requiring tiling, count only one-fifth to one-third of such rolling land, in addition to all of the low, flat land, in getting the size of tiles to remove ground water only.

*Example* 41. What size of tile laid to a 0.1 per cent grade will carry the under-drainage of 160 acres of flat land?

*Answer.* 15 inches.

*Example* 42. What size of tile to a 0.2 per cent grade will carry the under drainage of 240 acres, two-thirds rolling?

*Answer.* 80 acres flat land, *plus* one-third of 160 acres rolling, gives 133⅓ acres, requiring a 12-inch tile.

*Example* 43. What size of tile laid to 0.3 per cent grade will be required to remove both ground and surface water from a pond whose watershed includes 40 acres?

*Answer.* 10-inch. (NOTE.—Double or triple the area for both ground and surface water.)

**73. Method of Computing Sizes of Drainage Ditches.** Since drainage ditches must carry surface water as well as ground water, their capacities must be larger than those of tile drains for the same number of acres drained. It has been found by experience that they must carry from ¾-inch depth for small drainage areas, to ¼-inch depth for large drainage areas per day. Their size can be taken from Table X.

*Example* 44. What width of ditch, having a fall of 5 feet per mile, and a depth of water of 3 feet, will be required to drain an area of 5 square miles (3,200 acres)?

*Answer.* About 12 feet.

*Example* 45. What size ditch having a fall of 3 ft. per mile, and 9 ft. depth of water, will drain an area of three townships (69,120 acres)?

*Answer.* About 22 feet.

**74. Method of Computing Sizes of Subdrains for Sewers.** Sewer subdrains act like tile land drains to remove the ground water from the soil. Being deeper, they will drain wider strips of land—say, averaging 16 rods wide, instead of 8 rods, for ordinary land drains in average soil; but also, owing to the greater depth, the water will reach the tiles more slowly, and this may offset the greater width drained. We may assume roughly that each subdrain may be called upon to remove ⅛-inch depth of water per day from a strip 16 rods wide, *which is the same thing as ¼-inch depth per day from a strip of land 8 rods wide.*

## TABLE X

### Number of Acres Drained by Open Ditches

| Grade | | *Depth of Water, 3 feet.* Average Width of Water | | | | | | *Depth of Ditch, at least 4 feet.* | | *Depth of Water, 5 feet.* Average Width of Water | | | | | *Depth of Ditch, at least 6.5 feet.* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Per cent | Feet per Mile | 4 feet | 6 feet | 8 feet | 10 feet | 15 feet | 20 feet | 30 feet | 50 feet | 6 feet | 8 feet | 10 feet | 15 feet | 20 feet | 30 feet | 50 feet |
| 0.02 | 1.0 | | | 725 | 970 | 1,570 | 2,240 | 5,300 | 18,400 | 980 | 1,470 | 1,900 | 5,000 | 7,150 | 23,800 | 43,800 |
| 0.04 | 2.1 | 400 | 690 | 1,000 | 1,360 | 2,250 | 4,700 | 7,470 | 26,100 | 1,390 | 2,090 | 2,800 | 7,200 | 20,400 | 33,500 | 62,500 |
| 0.06 | 3.2 | 492 | 850 | 1,260 | 1,690 | 2,770 | 5,770 | 18,400 | 31,900 | 1,710 | 2,560 | 5,100 | 17,600 | 24,700 | 40,800 | 75,500 |
| 0.08 | 4.2 | 572 | 980 | 1,460 | 1,950 | 4,820 | 6,670 | 21,400 | 37,400 | 1,980 | 2,980 | 6,100 | 20,400 | 30,000 | 48,800 | 88,000 |
| 0.10 | 5.3 | 636 | 1,100 | 1,630 | 2,180 | 5,360 | 7,440 | 23,700 | 41,400 | 2,220 | 5,010 | 7,600 | 23,400 | 33,400 | 54,500 | 98,000 |
| 0.15 | 7.8 | 791 | 1,330 | 2,010 | 2,670 | 6,600 | 19,000 | 30,200 | 52,100 | 2,720 | 6,300 | 17,100 | 28,700 | 40,500 | 66,700 | 120,000 |
| 0.20 | 10.6 | 905 | 1,560 | 2,310 | 4,720 | 7,870 | 21,800 | 35,000 | 60,300 | 4,820 | 7,300 | 19,500 | 33,000 | 47,000 | 77,000 | 139,000 |
| 0.25 | 13.2 | 1,020 | 1,740 | 2,660 | 5,300 | 17,500 | 24,600 | 39,000 | 67,700 | 5,370 | 16,300 | 21,900 | 37,500 | 53,000 | 86,000 | 155,000 |
| 0.30 | 15.8 | 1,100 | 1,970 | 2,900 | 5,850 | 19,400 | 26,800 | 42,700 | 74,000 | 5,900 | 17,900 | 23,900 | 40,700 | 57,000 | 94,000 | 170,000 |
| 0.40 | 21.1 | 1,300 | 2,290 | 5,050 | 6,740 | 22,200 | 30,800 | 49,400 | 85,700 | 6,830 | 20,600 | 27,700 | 47,000 | 67,000 | | |
| 0.50 | 26.4 | 1,475 | 2,550 | 5,620 | 7,500 | 24,800 | 34,800 | 55,300 | 95,200 | 7,600 | 23,000 | 31,000 | | | | |
| 0.60 | 31.7 | 1,600 | 2,790 | 6,230 | 16,500 | 27,200 | 37,700 | 60,400 | | 16,700 | 25,200 | 33,900 | | | | |
| 0.70 | 37.0 | 1,720 | 3,010 | 6,650 | 17,800 | 29,400 | 41,200 | | | 18,100 | 27,300 | | | | | |
| 0.80 | 42.2 | 1,850 | 4,850 | 7,170 | 19,100 | | | | | 19,000 | | | | | | |
| 0.90 | 47.5 | 1,955 | 5,140 | 7,550 | 20,100 | | | | | 20,500 | | | | | | |
| 1.00 | 52.8 | | 5,400 | | | | | | | | | | | | | |

## TABLE X—(Concluded)

### Number of Acres Drained by Open Ditches

| Depth of Water, 7 feet. Depth of Ditch, at least 9 feet. | | | | | | | | Depth of Water, 9 feet. Depth of Ditch, at least 11.5 feet. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grade | | Average Width of Water | | | | | | Average Width of Water | | | | |
| Per cent | Feet per mile | 8 feet | 10 feet | 15 feet | 20 feet | 30 feet | 50 feet | 10 feet | 15 feet | 20 feet | 30 feet | 50 feet |
| 0.02 | 1.0 | 2,300 | 4,700 | 16,600 | 28,000 | 48,000 | 88,500 | 6,550 | 27,800 | 40,800 | 69,500 | 127,000 |
| 0.04 | 2.1 | 4,850 | 6,740 | 23,400 | 35,400 | 58,000 | 106,000 | 18,500 | 34,400 | 50,000 | 83,500 | 157,000 |
| 0.06 | 3.2 | 5,920 | 17,000 | 29,600 | 43,400 | 72,000 | 129,000 | 22,600 | 41,600 | 61,000 | 103,000 | 193,000 |
| 0.08 | 4.2 | 6,940 | 19,100 | 34,200 | 50,000 | 83,000 | 150,000 | 26,300 | 48,300 | 71,000 | 120,000 | 221,000 |
| 0.10 | 5.3 | 7,720 | 21,800 | 38,400 | 56,000 | 92,600 | 167,000 | 30,400 | 54,000 | 79,100 | 132,000 | 244,000 |
| 0.15 | 7.8 | 19,400 | 27,000 | 47,200 | 68,500 | 112,000 | 202,000 | 37,300 | 66,100 | 96,200 | 162,000 | 298,000 |
| 0.20 | 10.6 | 22,400 | 31,300 | 54,200 | 78,700 | 130,000 | 235,000 | 42,900 | 76,200 | 104,000 | | |
| 0.25 | 13.2 | 25,000 | 34,800 | 60,500 | 88,000 | 146,000 | | 48,000 | 85,300 | 125,000 | | |
| 0.30 | 15.8 | 27,400 | 38,200 | 66,200 | 96,500 | | | 52,500 | 93,200 | | | |
| 0.40 | 21.1 | 31,700 | 44,100 | | | | | 60,800 | | | | |
| 0.50 | 26.4 | 35,400 | | | | | | | | | | |

Table X, for open ditches, is calculated by the well-known standard Kutter's formula, using a "coefficient of roughness" equal to 0.030. This coefficient of roughness is the value recommended by Kutter for channels in moderately good condition, having stones and weeds occasionally, and agrees with actual gaugings of drainage channels made at the Iowa State College. For ditches in first-class condition, the number of acres given may be increased about 25 per cent. The table has been calculated for ditches having sides with slopes of one foot horizontal to one foot vertical but is approximately correct for other slopes.

The capacity of the ditches has been made as recommended by C. G. Elliott, U. S. Agricultural Department drainage expert, as follows, the ditches to run not more than $\frac{8}{10}$ full for the capacities mentioned:

Above the upper heavy line, $\frac{3}{4}$-inch depth of water per 24 hours
Between the two heavy lines, $\frac{1}{2}$-inch depth of water per 24 hours.
Below the lower heavy line, $\frac{1}{4}$-inch depth of water per 24 hours.

Local conditions may vary the size needed, and it is necessary to consult a drainage engineer in each case.

*Hence the sizes required for sewer sub-drains may be taken from Table IX, calculating the number of acres drained by multiplying the total lengths of tributary drain tile, in feet, by* 132 *feet* ( = 8 *rods*), *and dividing the product by* 43,560 *sq. ft.*

The above method will give a capacity approximating 110,000 gallons per day per mile of tributary subdrains. As sewers are ordinarily distributed, it will give a capacity approximating 1,500,000 gallons per day per square mile of territory served by the sewers.

*Example* 46. Calculate the size of subdrains laid to a 0.25 per cent grade, required to serve as outlet for 30,000 linear feet of tributary subdrains.

*Solution*: $\frac{30{,}000 \times 132}{43{,}560} = 91$ acres = eouivalent area drained for $\frac{1}{4}$-inch depth.

In Table IX, opposite the 0.25 per cent grade, we find that a 10-inch tile would be required.

*Answer.* 10-inch tile subdrain.

**75. Cost of Tile Land Drains and Drainage Ditches.** The cost of tile-drain construction in central Iowa in 1904, can be approximated from Table XI. Local prices should be determined before using the table for close estimates of work done elsewhere.

**TABLE XI**
**Cost of Tile Drains**

| Size of Tile | Price per 1,000 Feet | Weight per Foot | Cost of Hauling 1,000 Feet 5 Miles | Cost of Digging and Laying, per Rod | | | Refilling, per Rod |
|---|---|---|---|---|---|---|---|
| | | | | 3 feet deep or less | Add per foot for additional depth over 3 feet | | |
| | | | | | 3–6 ft. | over 6 ft. | |
| 3 in. | $ 16.00 | 5 | $ 3.12 | $ 0.35 | $ 0.15 | $ 0.30 | 2c.-5c. |
| 4 in. | 22.00 | 8 | 5.00 | 0.35 | 0.15 | 0.30 | 2c.-5c |
| 5 in. | 30.00 | 10 | 6.25 | 0.35 | 0.15 | 0.30 | 2c.-5c. |
| 6 in. | 40.00 | 12 | 7.50 | 0.35 | 0.15 | 0.30 | 2c.-5c. |
| 7 in. | 50.00 | 15 | 9.37 | 0.35 | 0.20 | 0.35 | 2c.-5c. |
| 8 in. | 60.00 | 20 | 12.50 | 0.40 | 0.20 | 0.35 | 2c.-5c. |
| 10 in. | 95.00 | 30 | 18.75 | 0.45 | 0.20 | 0.35 | 2c.-5c. |
| 12 in. | 120.00 | 40 | 25.00 | 0.50 | 0.20 | 0.35 | 2c.-5c. |
| 15 in. | 250.00 | 50 | 31.25 | | | | |
| 18 in. | 400.00 | 80 | 50.00 | | | | |
| 20 in. | 600.00 | 100 | 62.50 | | | | |
| 24 in. | 800.00 | 125 | 78.12 | | | | |

The cost of hauling given in Table XI is on the basis of $1.25 per ton, or $2.50 per day for a man and team, making two trips.

The prices for digging and laying given above include board furnished by the ditcher. If the farmer furnishes board, deduct about 20 per cent. The prices for digging and laying are for average ground, and should be increased for quicksand or very wet soils.

N. B. To all estimates it is wise to add 5 per cent to 10 per cent for contingencies and engineering.

*Example* 47. What will be the cost of 2,000 feet of 6-in. tile drain, 2½ miles from the tile yard, of which 1,000 feet is 4 feet deep, 500 feet 5 feet deep, and 500 feet 6 feet deep, in average soil?

*Answer*:

| | |
|---|---|
| 2,000 ft. of 6 in. tile @ $40.00 | $80 |
| Hauling 2,000 ft. 2½ miles, @ $3.75 | 7½ |
| Digging and laying 60.6 rods 4 ft. deep, @ 50c | 30½ |
| " " " 30.3 rods 5 ft. deep, @ 65c | 19½ |
| " " " 30.3 rods 6 ft. deep, @ 80c | 24 |
| Refilling 121.2 rods (by team), @ 2c | 2½ |
| | $164 |
| Add 10 per cent for engineering, etc. | 16 |
| Estimated cost | $180 |

**Cost of Open Drainage Ditches.** The cost of open drainage ditches is estimated by the cubic yard.

To calculate the number of cubic yards per foot of length of ditch, multiply the average width by the average depth, and divide by 27. Thus a 7-ft. by 12-ft. ditch contains $\frac{7 \times 12}{27} = 3\frac{1}{9}$ cubic yds. per foot length.

The cost per cubic yard in Iowa varies from 7c. to 18c., depending on the size of the job, the character of the soil, and other local conditions, including the certainty of the contractor getting his money promptly. The larger the work, the less is the cost per cubic yard.

## HOUSE SEWERAGE

**76. Definitions and General Description.** A *house sewer* is a small branch sewer which connects the house with the street sewer. In Fig. 6 a general view of a house sewer is given.

A *soil pipe* is the main drainage pipe of the system of house plumbing, into which the different fixtures discharge. See Fig. 35.

A *trap* is a bend or depression in a pipe or drain, which remains constantly full of liquid, thus shutting off air-connection between the portions of the pipe or drain on opposite sides of the trap. See Fig. 35.

A general idea of an entire system of house sewerage can be obtained from Figs. 6 and 35, which see.

The house sewer and outlet for the cellar and foundation drains, extend from the street sewer to the house as shown in Fig. 6.

The iron soil pipe should begin a few feet outside the house, and extend full size through the roof, the separate fixtures discharging into the soil pipe, each protected by a trap, and all traps being vented, as shown in Fig. 35. The dotted lines in Fig. 35 show alternative plans sometimes adopted for house sewerage.

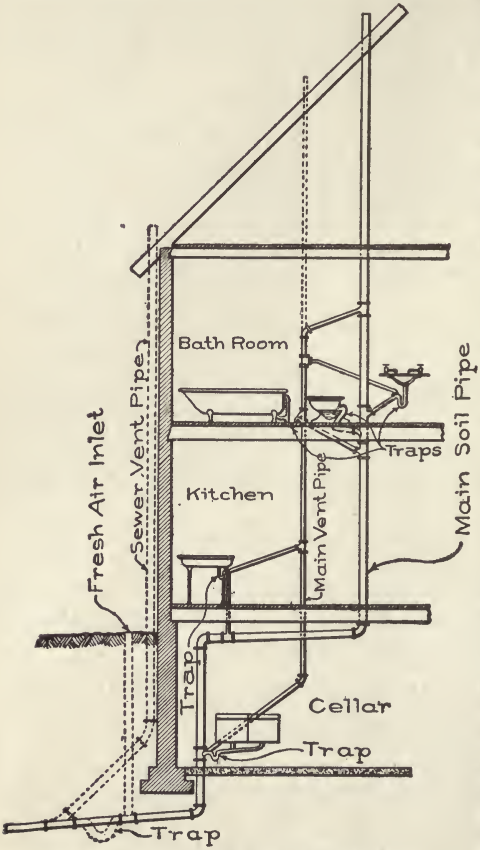


Fig. 35. Diagram of House Sewerage System.

**77. House Sewers.** House sewers (see Fig. 6) are usually made of vitrified sewer pipe the same as street sewers, and should be constructed with fully as much care. The joints should have gaskets of hemp or oakum, and be carefully cemented, the same as street sewers. (See Art. 33.)

Each piece of pipe should be laid to the exact grade by measuring from a grade string, the same as for street sewers (see Art. 98). The grade should usually be not less than 2 per cent. The house sewer should, if possible, be perfectly straight, both in alignment and in grade, from the house to the house connection at the sewer.

Inspection pipes should be placed just inside the lot line, as indicated in Fig. 6.

House sewers should usually be 4-inch circular pipe. If too large, they are more difficult to keep flushed clean, and they may carry to the street sewer things large enough to cause stoppages, improperly put into the house fixtures. Sometimes 5-inch or 6-inch house sewers are used.

**78. General Principles of House Plumbing.** The following general principles should be carefully observed in the installation of all house plumbing:

1. The iron pipe should begin a few feet outside the house, as vitrified pipe does not have tight joints and is liable to be broken, where it passes through the foundation wall, by uneven settlement.

2. No pipes carrying sewage should be allowed to be buried under the basement floor, unless placed in masonry-lined trenches with removable covers.

3. All pipes of the plumbing system should be iron or lead, with absolutely tight joints of lead, or screwed, or soldered.

4. In general, no pipes should be built into partitions or walls, where they cannot be gotten at, unless removable panels are placed over them.

5. All fixtures should be completely exposed to view, and should not be enclosed in woodwork. Sinks and washbowls, for example, should be supported on brackets or legs, with clear, open spaces under them.

6. All fixtures should be of durable, smooth, and non-absorbent material, such as porcelain or enameled iron. The least possible woodwork should be used.

7. All fixtures should be located in well-lighted and well-ventilated places.

8. Each fixture must be protected by a good trap. There must be no openings from the plumbing system into the interior of the house not thoroughly protected by traps sure to stav full of liquid.

9. Thorough ventilation of all pipes must be provided for.

10. All pipes must be laid to good grades, without sags, so as to drain completely and quickly.

11. The cellar and foundation drains should be connected with a sewer subdrain, if possible, and not with a sewer, owing to the danger of the water in the traps evaporating in dry weather when no water runs in the drains. If absolutely necessary to connect to the sewer, excessively deep traps should be used, to lessen the danger of evaporation.

**79. Soil Pipes.** The iron soil pipe begins, as already stated, a few feet outside the foundation wall. At this point a *disconnecting trap* is sometimes placed, as shown by the dotted lines in Fig. 35, in which case a *fresh-air inlet* must be placed on the house side of the trap, as also shown by dotted lines in Fig. 35, to permit complete ventilation of the soil pipe.

The soil pipe should extend full-sized and without any obstruction, a few feet above the roof. It should everywhere be readily accessible, and will naturally be placed in the location most convenient for attaching the fixtures.

The soil pipe is usually 4 inches in diameter, made of cast iron, with air-tight, leaded and calked joints.

**80. Traps.** The best traps are simply *smooth bends* in the plumbing pipes, giving depressions which stand full of liquid. If the curves are not smooth, or if there are sudden changes in size, the danger of stoppage is increased. The depth from the highest level of the water in the trap to the top of the liquid in the lowest portion, is called the *seal* of the trap. Traps are necessary evils in plumbing systems, as they tend to cause stoppages.

The seals of traps may be forced by any compression or rarefaction of air in the plumbing pipes, such as may be caused by *plugs* of sewage from other fixtures descending the pipes, unless a *vent pipe* is extended from the *crown* or highest point of each trap on the side next to the soil pipe, as shown in Fig. 35.

Traps should be located as closely as possible to the fixtures they are to protect.

**81. Ventilation.** The vent pipes from the traps mentioned in Art. 80, above, and shown in Fig. 35, serve also to secure ventilation of branch pipes. They should unite in a *main vent pipe,* 2 inches in diameter, as shown in Fig. 35, and this may turn into the soil pipe above the highest fixture, or may extend independently above the roof, as shown by the dotted lines in Fig. 35.

The extension of the main soil pipe unobstructed through the roof, with admission of air from the sewer (or through the fresh-air inlet if a disconnecting trap is used), together with the trap vent pipes and the main vent pipe, as shown in Fig. 35, insure ventilation of all parts of the plumbing system.

## COST OF SEWERS, AND METHODS OF PAYING FOR THEM

**82. Preliminary Estimates of Cost of Sewers.** One of the first things which the sewerage engineer will be asked about sewers for which he has made plans, is what will be their cost. He must be able to answer this question readily, and with close approximation to the actual cost.

Many factors affect the cost of sewers, some of which cannot be exactly foretold. Among the things which can be closely ascertained in advance, are the sizes, lengths, and depths of the sewer, and the amounts of the various kinds of materials required. Among the things which cannot be exactly foretold, are the nature of the soil, the amount of ground water to be encountered, the weather conditions, and the labor conditions.

The competent engineer will thoroughly study all conditions which may affect the cost, before preparing his estimates, and even then will allow a liberal percentage for contingencies.

The engineer should have borings made to determine the character of the soil and the level of ground water, and should learn all he can of previous experience in the town with ditches and other excavations. Even then the actual soil often proves very different from what was anticipated.

After making the preliminary study and plans, the engineer tabulates the sewers by lengths, depths, sizes, and character, together with the manholes, lampholes, flush-tanks, and other items of the system. He then assigns a unit price to each item, after careful study of all conditions, and calculates the total cost.

The data of cost which follow are for average conditions only, and only for the localities named. They will need to be modified by the engineer to meet different conditions.

**83. Cost of Pipe Sewers.** In estimates of the cost of pipe sewers, the work is usually divided into the following items:

(1) *Trenching and Refilling.* This includes excavating the trench for the sewer, refilling it, and compacting the material after the sewer pipe is laid. Trenching and refilling are usually itemized according to depth, thus:

Trenching and Refilling under 6 feet depth
" " " " 6 to 8 feet depth
" " " " 8 to 10 feet depth
Etc., etc.

The cost of trenching and refilling will vary somewhat also with the diameter of the sewer; but this is often not separately itemized.

For estimates and bids, the lengths in linear feet of each depth of sewer are taken from the profiles, and listed in the tabulation.

(2) *Furnishing Sewer Pipe and Specials.* The pipe are usually specified to be delivered on board cars at the town where they are to be used. The amounts are usually itemized according to the diameters, thus:

| | | | | | |
|---|---|---|---|---|---|
| Furnishing | sewer | pipe | 8 | inches | diameter |
| " | " | " | 10 | " | " |
| " | " | " | 12 | " | " |
| etc., etc. | | | | | |

Specials are sometimes itemized separately, and sometimes included in the prices for furnishing pipe, the average distance apart being specified.

For estimates and bids, the total lengths of each size of pipe are ascertained and listed in the tabulation.

(3) *Hauling and Laying Sewer Pipe and Specials.* This includes taking the sewer pipe from the cars, hauling them to the sewer, furnishing cement, sand, and hemp or oakum, and laying the pipe according to the specifications. Some labor in excavating bell holes and a few inches at the bottom of the ditch shaped to fit closely the under side of the pipe, is also included. Hauling and laying are usually itemized according to the diameters of the pipe, thus:

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Hauling | and | Laying | sewer | pipe | and | specials, | 8 | inches | diameter |
| " | " | " | " | " | " | " | 10 | " | " |
| " | " | " | " | " | " | " | 12 | " | " |
| Etc., etc. | | | | | | | | | |

The lengths of each size are listed for estimates and bids, the same as sewer pipe.

In Fig. 36 is given a diagram for estimating the cost of pipe sewers and subdrains in the Middle West. It may be used elsewhere by noting local conditions and their variation from the conditions assumed, as follows:

(*a*) If the sewers are to be paid for promptly as the work progresses, in cash instead of in assessment certificates, deduct about 10 per cent.

(*b*) Get actual prices on sewer pipe delivered, and add about 8 per cent for additional cost of specials in the average residence district, and 16 per cent in the average business district.

(*c*) Ascertain the character of the soil, and the likelihood of encountering ground water. If the conditions are very favorable, the cost of trenching, refilling, and pipe laying may be materially decreased, even sometimes to 50 per cent of the figures shown in the diagram; while on the other hand, for very unfavorable conditions, the cost shown for these items will have to be increased, sometimes even to 150 per cent.

*Example* 48. Estimate the cost of a pipe sewer consisting of 1,200 ft. of 18-inch pipe averaging 16 feet deep, and 2,700 feet of 15-inch pipe averaging 12 ft. deep, under average conditions, together with a 6-inch subdrain.

*Solution*:

| | | | |
|---|---|---|---|
| 1,200 × 2.35 (from diagram) | = | $3,020 | for 18-inch sewer |
| 2,700 × 1.60 ( " " ) | = | 4,320 | " 15 " " |
| 3,900 × 0.15 ( " " ) | = | 585 | " 6 " subdrain |
| *Answer.* Total estimated cost | = | $7,925 | |

**84. Cost of Brick Sewers.** The cost of a brick sewer may be estimated by determining separately the cost of the excavation and refilling and that of the brickwork. The number of cubic yards of each of these items is computed for 1 linear foot length of sewer; and the cost per linear foot is estimated by multiplying the results so obtained by estimated costs per cubic yard of excavation and brickwork respectively.

(1) *To calculate the number of cubic yards of excavation per linear foot length of sewer, multiply the average depth of sewer trench by the average width, and divide by* 27.

The *average depth* for a circular bottom will approximate the *average depth from the surface to the invert,* while the *average width* will be *at least as great as the internal diameter plus twice the thickness of the brickwork.*

Thus, for a 2-ring (9 inches of brickwork) circular sewer 6 feet in diameter, with grade line 12 ft. deep, the number of cubic yards excavation per linear foot of sewer is:

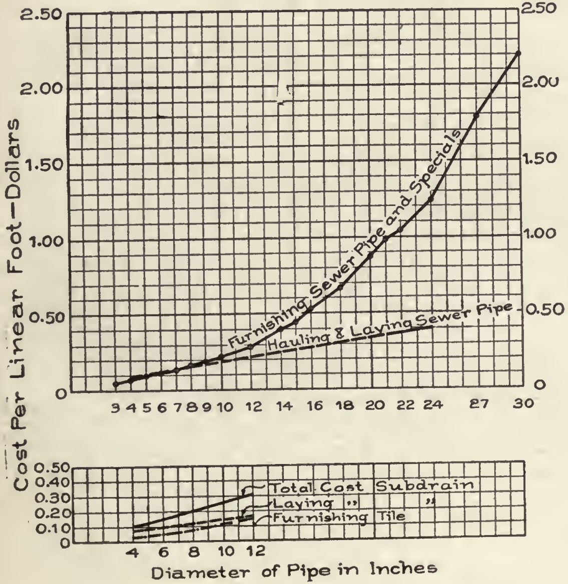
$$\frac{12 \times (6 + 1\tfrac{1}{2})}{27} = \frac{90}{27} = 3\tfrac{1}{3} \text{ cu. yds. per linear ft.}$$

*The cost of sewer excavation and refilling varies usually from* $0.20 *per cu. yd. to* $1.20 *per cu. yd., averaging perhaps* $0.50 *to* $0.75 *per cu. yd.*

**DIAGRAMS FOR ESTIMATING COST OF PIPE SEWERS**

Prepared from data collected for average conditions in the Middle West, 1906; ditches braced and partially sheathed; amount of water, moderate; common labor, $1.75 a day; payments to contractor, partly in assessment certificates.

For especially favorable or unfavorable conditions, the cost may vary 50 per cent either way, except for furnishing.



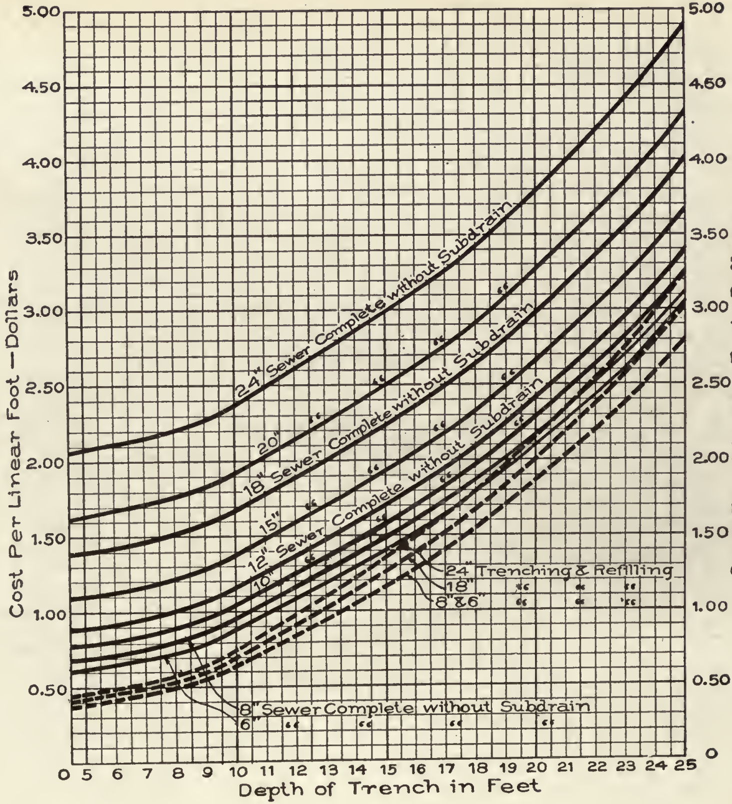




Fig. 36. Cost of Pipe Sewers.

Thus, for average conditions, fairly favorable, the cost of excavation for the 6-foot sewer, 12 feet deep, referred to above, would be $3\frac{1}{3} \times .60 = \$2.00$ per linear foot.

The favorable conditions for low cost per cubic yard, are, large sewers; neither great shallowness nor excessive depth; little water; soil firm enough not to require much bracing, yet not hard enough to require to be picked; and the use of excavating machinery. The opposites of these conditions give the unfavorable conditions.

(2) *The number of cubic yards of brickwork per linear foot* of brick sewers, may be taken from Tables XII and XIII, which are taken mainly from Gillette's *Handbook of Cost Data.*

**TABLE XII**

**Cubic Yards per Linear Foot of Brick Masonry in Circular Sewers**

| Diameter | One Ring | Two Rings | Three Rings |
|---|---|---|---|
| 2 ft. 6 in. | 0.125 | 0.283 | |
| 3 " 0 " | 0.147 | 0.327 | |
| 3 " 6 " | 0.169 | 0.371 | |
| 4 " 0" | 0.191 | 0.415 | |
| 4 " 6 " | 0.213 | 0.418 | |
| 5 " 0 " | 0.234 | 0.502 | 0.802 |
| 5 " 6 " | 0.256 | 0.544 | 0.867 |
| 6 " 0 " | 0.278 | 0.589 | 0.933 |
| 6 " 6 " | | 0.633 | 0.998 |
| 7 " 0 " | | 0.677 | 0.063 |
| 7 " 6 " | | 0.720 | 0.128 |
| 8 " 0 " | | 0.764 | 1.194 |
| 8 " 6 " | | 0.807 | 1.260 |
| 9 " 0 " | | 0.851 | 1.325 |
| 9 " 6 " | | 0.895 | 1.390 |
| 10 " 0 " | | 0.938 | 1.456 |

**TABLE XIII**

**Cubic Yards per Linear Foot of Brick Masonry in Egg-Shaped Sewers**

| Dimensions | One Ring | Two Rings | Three Rings |
|---|---|---|---|
| ft. in. ft. in. | | | |
| 2–0 by 3–6 | 0.128 | 0.286 | |
| 2–6 " 3–9 | 0.154 | 0.341 | |
| 3–0 " 4–6 | 0.182 | 0.396 | |
| 3–6 " 5–3 | | 0.451 | 0.725 |
| 4–0 " 6–0 | | 0.506 | 0.808 |
| 4–6 " 6–9 | | 0.561 | 0.891 |
| 5–0 " 7–6 | | 0.617 | 0.974 |
| 5–6 " 8–3 | | 0.673 | 1.056 |
| 6–0 " 9–0 | | 0.729 | 1.140 |
| 6–6 " 9–9 | | 0.785 | 1.223 |

*The cost of brick masonry in sewers usually varies from* \$8.00 *to* \$14.00 *per cubic yard, averaging perhaps* \$9.50 *to* \$12.00.

Thus, under average conditions, the cost, per linear foot, of the brick masonry of the two-ring, 6-foot circular brick sewer mentioned above, would be about 0.589 cu. yds. (from Table XII) × \$10.50 per cu. yd. = \$6.17 per foot. It will depend upon the grade of brick used, their cost per 1,000, the cost and proportions of cement and sand in the mortar, the wages of brick masons, the size and depth of the ditch, etc.

*Example* 49. Estimate the cost, under fairly favorable conditions, as to excavation and brickwork, of a 10-foot, 3-ring, circular brick sewer 1,875 ft. long, averaging 10 ft. deep.

*Solution*:

$$\text{Cu. yds. excavation per foot} = \text{about } \frac{10 \times 13}{27} = 5$$

(allowing 13 ft. width of trench, to provide a little extra room for bracing).

Since the conditions are fair, assume \$0.60 per cu. yd. as cost of excavation and refilling.

The brickwork = 1.456 cu. yds. per linear foot (Table XII); and since the conditions are fair, we shall assume a cost of \$9.50 per cu. yd.

Then the estimate will be as follows:

| | | |
|---|---|---|
| Excavation and Refilling, | 5 × \$0.60 = | \$ 3.00 per lin. ft. |
| Brickwork | 1.456 × 9.50 = | 13.83 " " " |
| Total | | \$16.83 " " " |

1,875 × 16.83 = \$31,556 for total cost, to which, however, it may be wise to add, say, 5 to 10 per cent for contingencies unforeseen.

*Answer*. About \$33,500.

**85. Cost of Concrete Sewers.** The cost of concrete sewers may be estimated by a method precisely similar to that described in Art. 84, above, for brick sewers—namely:

(1) *Compute the cubic yards of excavation per linear foot of sewer* $\left(= \frac{\textit{average depth} \times \textit{average width}}{27}\right)$, *and multiply by the estimated cost per cubic yard, which will be from* \$0.20 *to* \$1.20, *usually* \$0.50 *to* \$0.75.

(2) *Compute the number of cubic yards of concrete per linear foot of sewer*

$$\left(= \frac{\textit{total area of concrete in square feet in a cross-section of the sewer}}{27}\right)$$

*and multiply by the estimated cost of the concrete per cubic yard, which will be from* $6.50 *to* $12.00, *usually from* $7.50 *to* $9.50.

(3) *In the case of reinforced concrete sewers, compute the number of pounds of steel reinforcing per linear foot of sewer, and multiply by* $0.04 *to* $0.05 *per lb.*

The details of designs for concrete and reinforced concrete sewers vary so much that no tables can be given, as for brick sewers, showing the cubic yards of concrete per linear foot of sewer.

The cost of the concrete will depend upon the costs of cement, sand, and broken stone or gravel, and on their proportions; on the size and depth of the trench and its freedom from water; on the cost of labor, etc.

**86. Cost of Manholes, Combined Manholes and Flush-Tanks, Flush-Tanks, Lampholes, and Deep-Cut House Connections.** Under these headings the following data of cost will be found valuable:

*Manholes.* Under average conditions, the cost of brick manholes of the design shown in Fig. 9, will be *about* $40 *for* 8 *ft. depth of sewer.* For greater depths, *add about* $3 *per foot of additional depth.*

*Combined Manholes and Flush-Tanks.* Under average conditions, the cost of these may be estimated at $80, *plus* $4 *per foot of additional depth of sewer over* 8 *ft.* This is for about 500 gallons' capacity of the flush-tank part.

*Flush-tanks* of 500 gallons' capacity, under average conditions, may be estimated to cost *about* $60 *each.*

*Lampholes,* such as shown in Fig. 10, may be estimated at *about* $10, *plus* $0.35 *per foot of additional depth over* 8 *feet.*

*Deep-cut house connections* (see Fig. 8) may be estimated at $2.00 to $3.00 *each,* according to the depth of the sewer.

**87. Engineering and Contingencies.** In estimates of the cost of a sewer system, it is necessary to allow for unforeseen contingencies and for the cost of the engineering work. From 5 per cent to 20 per cent is usually added to the estimated cost on these accounts, depending upon the certainty or uncertainty of the knowledge of all the conditions.

## EXAMPLE FOR PRACTICE

**88.** *Example* 50. Estimate the cost of the sewer system shown below, the conditions being assumed to be average. (NOTE: See Articles 84 to 87, inclusive.)

PRELIMINARY ESTIMATE OF COST OF SEWER SYSTEM FOR ____________

| Item | Approx. Quantity | Cost | |
|---|---|---|---|
| | | Unit | Total |
| 4-ft. brick sewer, 2 rings, 8 ft. average depth | 850 ft. | | |
| 3-ft. " " 2 " 10 " " " | 625 " | | |
| 24-in. pipe sewer, 9 ft. average depth | 3,780 " | | |
| 18 " " " 11 " " " | 1,740 " | | |
| 12 " " " 14 " " " | 2,640 " | | |
| 8 " " " 10½ " " " | 46,800 " | | |
| Manholes 12 " " " | 68 | | |
| Comb. M.H.& F.T. 10 " " " | 18 | | |
| Lampholes 11 " " " | 38 | | |
| Total of above | | | |
| Engineering and Contingencies, 10 per cent of above, | | | |
| Total estimate of cost | | | * |

* Answer. About $82,500.

**89. Methods of Paying for Sewers.** This is another question which comes up early in determining whether a city can or will build or extend a sewer system.

Three methods are in common use in paying for sewers, as follows:

(1) *The City as a whole may pay the entire cost.* When this plan is followed, all or part of the money may be raised by selling bonds, or all or any part may be raised at once by taxation.

In some States, cities are given a right to levy a *sewer tax* of a certain rate for a certain number of years in advance, and to anticipate the proceeds of this tax by issuing *sewer warrants.*

Often, when it comes to the construction of sewers, the City will be found to have already issued bonds to the highest legal amount, to build waterworks, an electric light plant, etc., so that no money for sewers can be raised from bonds.

(2) *The entire cost of the sewers may be assessed against the property abutting upon or adjacent to the sewer.* Here the legal principle is that the assessment must be in proportion to the benefit received. Property abutting directly upon the sewer receives the greatest benefit, and must be assessed for most of the cost. Sometimes the benefit will be in proportion to the number of feet frontage of the lots abutting on the sewer; and sometimes the benefit per unit lot is considered to be the same in all parts of the city, a large unit size of lot being adopted in the residence part of the city, and a much smaller size in the business section, with often an intermediate size between these two.

The "assessment" is levied upon the completion of the sewer, when the entire cost can be ascertained. Due notice to all property owners assessed must be given, so that they can present objections if they desire. Usually all property owners who desire are allowed to spread the payment of their assessments in equal installments over a considerable period of years, in which case *assessment certificates* are issued to cover the payments. The contractor is often required to take these certificates in payment for the sewer.

(3) *The cost of the sewers may be divided between the City and the property directly abutting upon or adjacent to the sewer.* This seems the fairest way; since, in the first place, the entire city receives benefit from improved sanitation, attractiveness to investors, etc., from a sewer constructed anywhere within its limits; and since, in the second place, any system of sewers for a city should be planned to give outlets of proper size to all parts of the district, which enlarges and deepens the sewers on many streets. On the other hand, the property along the sewer is benefited much more than the rest of the city, and should accordingly pay a much larger proportion of the cost.

The City Council usually has the right to decide what percentage of the cost is to be paid by the City and what by the property along the sewers.

## PREPARATION OF PLANS AND SPECIFICATIONS FOR SEWERAGE SYSTEMS

**90. Sewer Reconnaissance.** When a sanitary engineer is called upon to prepare plans and specifications for a sewerage system, the first thing which he should do is to make a *reconnaissance* or general study of the entire city and its surroundings, with special reference to its sewerage conditions.

He visits the city and obtains copies of the best *maps* procurable. If these maps do not show the contours or elevations of the surface at different points, he obtains the best procurable information as to such elevations, and enters it upon the maps. Often the elevations of *street grades* will prove sufficient, if better and more detailed information is lacking. If *street profiles* are available, they will of course be of great value.

With maps thus prepared for the purpose, *he rides or walks over all parts of the city,* making himself thoroughly familiar with its *topography* and other features. Some of the information thus obtained may be entered upon the maps. He will note the *present density of population in different sections, and the prospects for future growth.* The presence or absence of *manufacturing industries,* and the future prospects in this line, are of importance. Statistics of the *past growth* of the city will be obtained. Full information regarding the character of the *water supply* and the amount and fluctuations of the *water consumption,* and the distribution of the *water mains* throughout the city, will be of great value. The local *labor conditions,* and the probable *local cost of cement, sand, brick, sewer pipe,* and other needed materials, must be ascertained. All possible information should be secured regarding the *ground water* and the *character of the soil* in different sections of the city. Information about old excavations and about wells can usually be secured, and will give much light on these points.

From his general study of the conditions, including especially the topography, the engineer must decide whether the system of sewerage shall be a *separate* system, or a *combined* system (see Articles 10 to 13, inclusive).

The question of the *outlet* will be one of the most important controlling points to be decided, and the engineer must carefully examine all possibilities in this line. The *number of outlets should be as small as feasible, one outlet being secured if possible.* The outlet must be low enough to drain thoroughly all portions of the district it serves, and should be chosen with a view to safe and satisfactory disposal of the sewage.

*Sewage disposal* is one of the very important points to be considered. In the past, most cities have simply discharged their sewage into the nearest available body or stream of water which it was considered could be used without causing damage or injunction suits on account of the pollution. At the present time, cities are being compelled more and more to provide means for purifying the sewage (see Articles 110 to 124); and the engineer, in choosing the outlet and planning the sewers, should always consider it probable that in the not distant future the city will be compelled to use some method of purification, and his plans should be so made as readily to permit this in the future, even if the city builds no sewage purification works at first.

During the reconnaissance, the engineer must constantly be recording the significant information he secures, in a neat and systematic manner in *a standard notebook,* which he keeps for the purpose. *Loose-leaf notebooks* of pocket size have many advantages for this purpose. In the same notebook, he should make all his preliminary computations.

On completing the reconnaissance, the engineer usually makes a *preliminary report* to the city officers, stating the conditions he has found, and his conclusions as to the general features of the system he has decided to recommend as best. He also usually presents at this time some rough estimates of cost.

The city then decides whether or not to adopt the general recommendations of the engineer, and whether to go on with the preparation of plans and specifications.

**91. Surveys for Sewer Plans.** After the reconnaissance, if it is decided to go ahead with the plans, the next step will be to make the necessary *surveys.* These may usually be divided into three principal parts as follows:

(1) *Surveys of Sewage Disposal Site.* In case a sewage disposal plant is to be built, a survey of the site must be made to secure the data needed for the design. Usually this will include data for a *contour map* of the entire tract, and borings or pits to determine the character of the soil.

(2) *Surveys for the Outlet Sewer.* Transit and level lines must be run, and profiles prepared, to determine the best route for the outlet sewer. Data must be secured for an accurate map and profile of the final location of this sewer.

(3) *Surveys for the Street Sewers.* Usually, existing plats can be found sufficiently accurate to give the dimensions necessary for constructing the *general sewerage map,* without special surveys. Small errors on these plats will not affect the general design, and will not be of much importance in view of the accurate surveys which must be made later during construction. Sometimes a few measurements with tape-line and transit must be taken in special localities. Usually the main part of the surveys for the street sewers consists in running *lines of levels* along all the streets on which there is possibility of planning sewers, in order to secure the data necessary to make the *sewer profiles* of all the sewers.

These levels should be referred to the *city datum*—that is, the reference level above which all city elevations are given. If such a datum has not already been adopted, one should be established, and marked by a *permanent bench-mark.* A six-inch iron pipe set six feet in the ground, filled and surrounded with concrete, makes a good, permanent bench-mark. The top, not quite filled with concrete, projects a little above the ground, and a copper bolt is set in the concrete at the top, the top of the bolt constituting the bench-mark. The pipe should have a hinged iron cap to protect the bolt.

In running the level, no effort should be made to trace out the main lines of sewers and their branches, but *each street should be surveyed by itself.* A zero point should be taken at some definite point (such as the center line, or one of the side lines, of a cross-street) at one end of the street, and *station points* 100 feet apart determined by continuous measurements with a steel tape. These stations should be numbered continuously from the zero point, intermediate points being located, in the usual way, by *plus* distances from the preceding station. Thus station 9 + 72 is 972 feet from the zero point.

The exact plus of each side line of each cross-street, and of points opposite other important things, should be determined and recorded in the notebook, to give measurements to be used in preparing the profiles, and in checking the map.

*All lines of levels must be checked.* At the end of each street, the leveling can be extended across to an adjacent street, and checked with the line of levels on that street.

*Numerous bench-marks* should be established around the city, located on permanent points, such as the tops of the foundation walls of buildings.

**92. Sewerage Plans.** From the data obtained by the surveys, the sewerage plans must be prepared. These will usually consist of a large number of separate sheets, the following being a list of the sheets of one particular set of plans, for a separate system of pipe sewers.

1. Index Sheet. (Giving the contents of all other sheets.)
2. General Sewerage Map.
3. General Map of Sewage-Disposal Plant.
4. Detailed Plans of Septic Tank. (For the Sewage-Disposal Plant.)
5. Detailed Plans of Filter Beds. (For the Sewage-Disposal Plant.)
6. Plans of Standard and Drop Manholes, and Lampholes.
7. Plans of Combined Manholes and Flush-Tanks.

8 to 33. Profile Sheets. (Showing profiles of all the sewers.)

In other cases, separate sheets may be needed for many other things, as, for example,

Details of Brick Sewers, of different sizes.
" " Concrete Sewers, " "
Plans of Flush-Tanks.
" " Catch-Basins.
" " Street Inlets.
" " Sewage Pumping Station.
Etc., etc.

For the sake of convenience and of neatness and system, *all the sheets of a set of sewerage plans should be made of a standard size* (*one or two can be made larger and folded to the standard size*), *and they should be bound together in regular book covers,* 18 inches by 24 inches being a convenient standard size of sheet for most cases.

Fig. 37 is a photographic view of such a cover containing a set of sewerage plans. The cover protects the sheets from injury, and is so arranged that any sheet can readily be removed and replaced A cover like that shown costs about $1.50.

The original drawings were all made on tracing cloth, except the profiles, which were made on transparent profile paper. Thus all the sheets can readily be reproduced by the process of blue-printing, and only the blue-print sheets are used on the work or by the City, the engineer retaining the original tracings in his office, where they can be kept safe.

In such a set of plans, the sheets should be numbered in order (see Figs. 38 and 39); and a *standard title* (see title of Fig. 38) should be adopted for all sheets which will require few changes of the different sheets.

*Sewerage Map.* In Fig. 38 is shown a reduced copy of an actual *sewerage map* of a separate system of sewers for a small town. The original size of the map shown was 36 inches by 24 inches, so that folding it once reduced it to the 18-inch by 24-inch size.

Fig. 37. Standard Cover for Sewerage Plans.

The original scale of the map shown was 200 feet per inch; but for larger places, 300 feet or even 400 feet per inch may be sufficient, since large-scale maps of all the individual sewers appear on the profile sheets.

*The lines of sewers in a system such as shown in Fig. 38, ought to be restricted as far as possible to the streets on which the lots front.* Sewers on cross-streets add to the mileage of sewers without serving additional lots, and are useless except for connecting other sewers.

*The manholes, lampholes, flush-tanks, etc., should be numbered systematically,* something as shown in Fig. 38, no two structures of the same kind having the same number. This avoids danger of duplication where the same structure is shown on two or more sheets, as is often the case.

*Sewer Profiles.* In Fig. 39 is shown a sample profile sheet from an actual set of plans.

The original profile was made on "Plate B" transparent profile paper, so that the profiles can be reproduced easily by blue-printing, the same as the other drawings. The sheets were cut to the standard size, 18 inches by 24 inches, to bind with the other drawings.

*The profiles should be made in systematic order of the streets, each* *street completed before beginning the next,* instead of trying to follow up the main lines of the sewers and their branches.

The profile sheets show large-scale maps of the individual

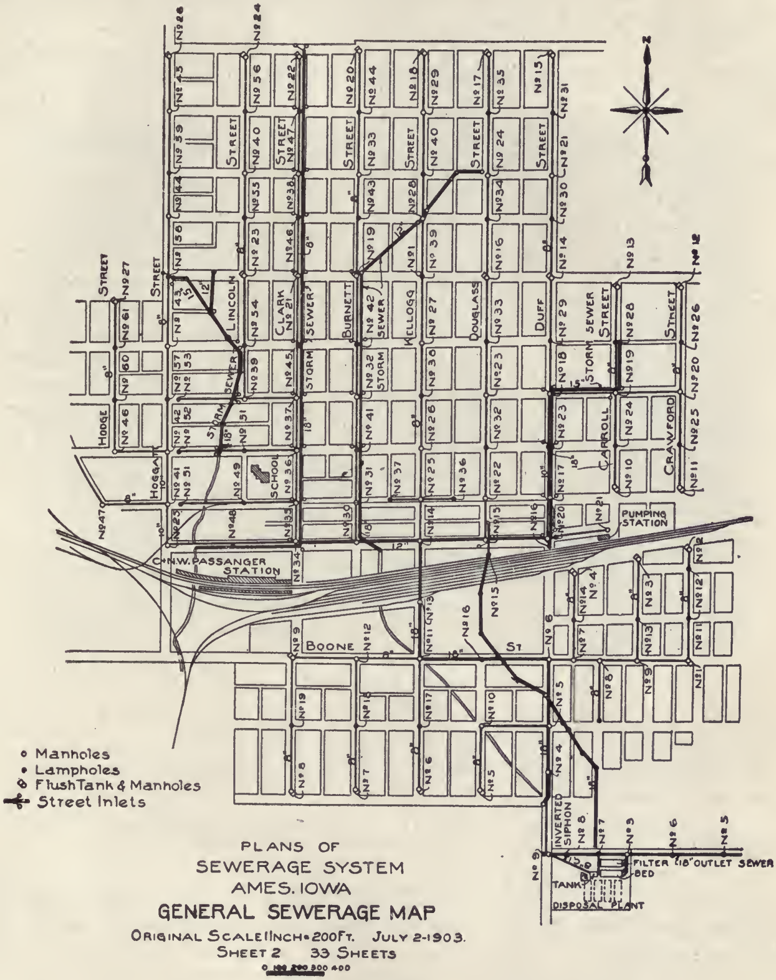



Fig. 38.

sewers immediately below their profiles, to permit the exact location of manholes, etc., and of the sewer itself in the street.

**93. Specifications for Sewers.** Besides the plans, it will be necessary for the sewerage engineer to prepare precise instructions regarding all matters of importance not fully shown by the plans, likely to come up during the construction of any part of the sewerage system. Such instructions are called *Specifications*.

An ordinary set of sewer specifications will consist of three parts:

(1) A *Notice to Contractors*, or form of advertisement for the city officers, to use in advertising for bids.

(2) A *Form for Proposal*, with suitable blanks, on copies of which, furnished by the city, all contractors are required to make their bids.

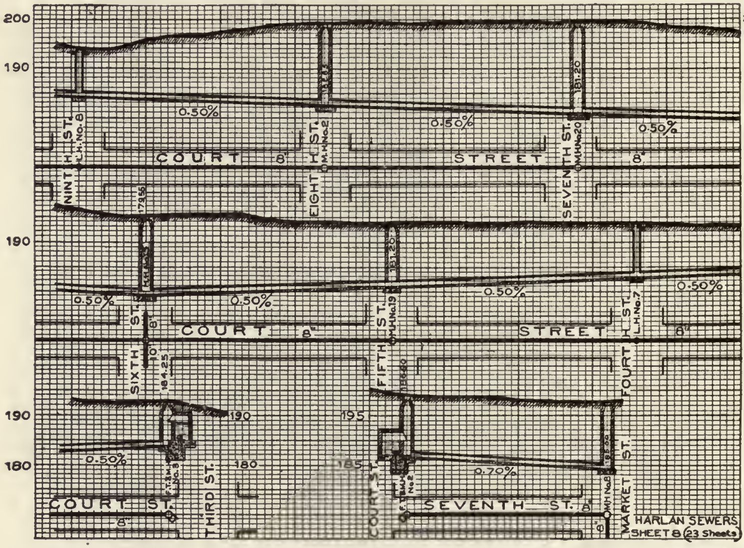



Fig. 39. Typical Sewer Profile Sheet.

(3) *The Specifications Proper*. These again will consist of two main divisions:

(*a*) General clauses, relating to payments, guarantees, etc., and to general features of the work.

(*b*) Specific clauses, specifying the exact details of different parts of the work.

A copy of an actual set of specifications for the construction of a separate system of pipe sewers, with a sewage-disposal plant, is given herewith:

CITY OF____________________, _______

SPECIFICATIONS

FOR

SEWERS AND SEWAGE-DISPOSAL PLANT

NOTICE TO CONTRACTORS

The Incorporated City of——————————,————., will receive sealed bids until———, ———, at ——————————; (1) for the construction of a sewage-disposal plant, consisting of a sewage tank of about ———gals. capacity, and —— sand filter beds, each of about——sq. ft. area; and (2) for the construction of sewers as follows: about —— ft. of 18-inch, —— ft. of 15-inch, —— ft. of 12-inch, —— ft. of 10-inch, and —— ft. of 8-inch, with suitable appurtenances, all in accordance with plans and specifications prepared by ——————, Engineer, ——————, and now on file in his office and with the City Clerk. All bids must be accompanied with certified checks, approximately in the amount of 5 per cent of the bid, made payable without recourse to the City of——————,———. The City reserves the right to reject any or all bids, to waive defects, and to accept any bid. All bids must be in sealed envelopes, marked on the outside "Sewerage Bids," and addressed to———————, City Clerk.

INSTRUCTIONS TO BIDDERS, AND GENERAL SPECIFICATIONS

(1) *Items.* The items of work intended to be covered by these specifications are those required for the entire completion of the System of Sanitary Sewers for the City of——————————, ——————, according to the plans prepared by——————, Engineer, and include the following:

(*a*) The construction of a Sewage-Disposal Plant, including a sewage tank of about ——— gallons capacity, and —— sand filter beds, each of about —— sq. ft. area, and including all valves, sewer pipes, outlets, etc.

(*b*) The construction of Sewers as follows:

| | |
|---|---|
| 18-inch.......................... | Ft. |
| 15-inch.......................... | " |
| 12-inch.......................... | " |
| 10-inch.......................... | " |
| 8-inch.......................... | " |
| Manholes ...................... | " |
| Lampholes...................... | " |
| Combined Manholes and Flush-Tanks, | " |

together with subdrains as directed by the City.

(2) *Application.* These general specifications and instructions to bidders shall apply to all items of workmanship or materials enumerated above or hereinafter mentioned.

(3) *Definitions of Terms.* Wherever the word "City" is used in these specifications, it shall be understood to mean the Incorporated City of————, ————., acting through the Mayor and Council, or their duly authorized representatives. Wherever the word "Contractor" is used in these specifications, it shall be understood to mean the person or firm employed to do all or any part of the work or furnish all or any part of the material for the Sanitary Sewerage System. Wherever the word "Engineer" is used in these specifications, it shall be understood to mean the Engineer employed by the City to design or supervise the construction of all or any part of the Sanitary Sewerage System.

(4) *Bids.* All bids must be on blanks furnished by the City for the purpose. The blanks can be obtained from ——————————, City Clerk ——————, ————., or from ——————, Engineer, ——————. ————.

All bids must be enclosed in sealed envelopes addressed to————, City Clerk,————, ———., and plainly marked on the outside with the words "Sewerage Bids."

Each bid must be accompanied with a certified check approximately in the sum of 5 per cent of the bid, and made payable without recourse to the City Treasurer, ————————,—————.

The City reserves the right to reject any or all bids, to waive defects, and to accept any bid.

(5) *Certified Checks.* The certified check mentioned above will be forfeited as damages to the Incorporated City of ————————, ————., unless the Contractor enters into contract and furnishes bonds satisfactory to the Mayor and Council within 12 days after the contract has been awarded to him. Certified checks not so forfeited shall be returned to the bidders as soon as the contract is signed and satisfactory bonds are furnished.

(6) *Bond.* A bond satisfactory to the Mayor and Council shall be furnished by the Contractor, approximately in the amount of 50 per cent of the contract price.

(7) *Time.* The Contractor shall begin work within 3 weeks after the contract is awarded to him, and shall entirely complete the work on or before ————————————, ——————.

(8) *Sub-contracts.* No sub-contracts shall be awarded to parties unacceptable to the City.

(9) *Progress of the Work.* The work shall be prosecuted at a rate to enable its completion within the time specified; and should the Contractor fail to do this, the City may, after giving ten days' written notice, take over the work and complete it at the Contractor's expense.

(10) *Penalties.* Should the Contractor fail to complete the work at the time specified, he shall forfeit to the City a sum equal to all damages to it resulting from the failure to complete the work at the time specified.

(11) *Delays.* No claims for damages shall be made against the City on account of delays in delivery of materials or performance of work; but should there be unduly prolonged delays in the delivery of any materials or the performance of work on the part of the City, the Contractor shall be entitled to corresponding extension of time.

(12) *Obstructions.* The Contractor shall carry on the work in such a way as to obstruct the city streets as little as possible, and so as not at any time entirely to shut off passage of teams and pedestrians at any place. He shall provide temporary crossings satisfactory to the City for this purpose wherever necessary.

(13) *Precautions.* The Contractor shall take all necessary precautions to prevent injury to the public or to his workmen or to stock, such as providing crossing plank, fencing off his work, keeping lanterns burning at night, etc. He shall hold the City harmless against all claims for damages.

(14) *Plans and Specifications.* The City's plans and these specifications shall be a part of the contract, and all materials and workmanship shall be in accordance with them.

(15) *Supervision.* All materials and workmanship shall be subject to the supervision and inspection of the City and of its Engineer or other authorized representative. Instructions as to the details of the work shall be carried

out, and rejected materials and work shall be promptly removed at any time discovered.

(16) *Quality of Materials and Workmanship.* All workmanship and materials shall be of the best quality.

(17) *Quantities.* The quantities named in the notice to contractors, the form of proposal, or in these specifications, are approximate only. The City shall have the right to vary them; and, if so varied, the total contract price shall be increased or diminished at the rates named per unit in the contract.

(18) *Extra Work.* No extra work shall be done without written orders from the City or its specially authorized representatives placed in charge of the work. In case extra work becomes necessary, it shall be done by the Contractor if so ordered, and shall be paid for by the City on the basis of actual cost, *plus* 10 per cent; but no extra work will be paid for unless ordered in writing by the proper authority at the time undertaken.

(19) *Changes in Plans.* The City shall have the right to make changes in plans. In making such changes, the unit prices named in the contract shall be used, as far as possible, in calculating the changes in price on account of changes in the plans, and where these do not apply, the changes in price, unless a special agreement between the City and the Contractor as to prices is made at the time the changes are ordered, shall be calculated on the same basis as extra work.

(20) *Claims.* The Contractor shall guarantee the payment of all just claims for materials or labor in connection with his contract. Preliminary to the payment for any work, he shall, if required by the City, present evidence satisfactory to the Mayor and Council that all bills for materials and labor have been paid, and any or all payments may be reserved until such evidence has been presented. If the payment of any just claim shall be deferred more than four weeks after written notice has been given concerning it to the Contractor, the City may proceed to pay such claim out of any money due the Contractor.

(21) *Payments.* Payments shall be made as follows:

(NOTE: Fill in, in this blank, whether the payment is to be made in cash, in sewer warrants, sewer certificates, or otherwise. Also whether payments are to be made monthly as the work progresses, or reserved until completion, the former plan being usual for cash payments, and the latter for payments in certificates.)

All payments shall be on estimates prepared by the Engineer and approved by the Council, of materials delivered and work performed; and in case of all payments made prior to the completion of the contract, 15 per cent of the estimate shall be reserved until the final payment on completion of the work.

No payment shall be considered as releasing the Contractor from obligation to remove and make good defective work and materials when discovered at any time.

Two per cent of the total cost may be reserved by the City for one year after the completion of the work, and any part of this reserve may be used to make good defects developed within that time from faulty workmanship and materials, provided that notice shall first be given the Contractor, and that he may promptly make good such defects himself if he desires.

(22) *Guarantee.* The Contractor shall guarantee the workmanship and materials for one year, and keep the system in repair after completion, as provided in clause 21 above.

(23) *Risks.* All materials and work will be at the risk of the Contractor until the final acceptance of the same.

(24) *Cleaning Up.* On completion of each part of the work, all rubbish and unsightly materials must be removed and disposed of as directed by the City, and the streets and grounds left in neat condition. For the sewers, each two blocks must be cleaned up immediately on completion, and on the completion of the entire contract shall be further put in good shape if needed.

## MATERIALS

(25) *Vitrified Sewer Pipe.* All sewers shall, unless special permission be given to use cement sewer pipe, be constructed of first-quality salt-glazed, vitrified clay sewer pipe, of the hub-and-spigot pattern, of standard thicknesses and dimensions of hubs. The dimensions of hubs shall be sufficient to leave an annular space for cement of at least $\frac{3}{8}$-inch thickness for 8-inch and 10-inch pipe, and $\frac{1}{2}$-inch thickness for larger diameters.

Pipe may be furnished in lengths of 2, $2\frac{1}{2}$, or 3 feet. All pipe and specials shall be sound and well burned, with a clear ring, well glazed and smooth on the inside, and free from broken blisters, lumps, or flakes which are thicker than $\frac{1}{6}$ the nominal thickness of the pipe and whose largest diameters are greater than $\frac{1}{8}$ the inner diameter of said pipe; and the pipe and specials having broken blisters, lumps, and flakes of any size shall be rejected unless the pipe can be so laid as to bring all of these defects in the top half of the sewer. No pipe having unbroken blisters more than $\frac{1}{4}$ inch high shall be used, unless these blisters can be placed in the top half of the sewer. Pipes or specials having fire-checks or cracks of any kind extending through the thickness shall be rejected.

No pipe shall be used which, designed to be straight, varies from a straight line more than $\frac{1}{8}$ inch per foot of length; nor shall there be any variation between any two diameters of a pipe greater than $\frac{1}{24}$ the nominal diameter.

No pipe shall be used which has a piece broken from the spigot end deeper than $1\frac{1}{2}$ inches or longer at any point than $\frac{1}{4}$ the diameter of the pipe; nor which has a piece broken from the bell end if the fracture extends into the body of the pipe, or if such fracture cannot be placed at the top of the sewer. Any pipe or special which betrays in any manner a want of thorough vitrification or fusion, or the use of improper or insufficient materials or methods in its manufacture, shall be rejected.

(26) *Sewer-Pipe Specials.* All T- and Y- junction curves, etc., required shall be furnished and set without extra charge, and shall conform to the pipe specifications as to quality. Y's for house connections may be required every 25 feet on the average, and shall be closed by vitrified stoppers cemented over sand.

(27) *Drain-Tile.* All drain-tile shall be best-quality vitrified agricultural drain-tile in one-foot lengths. All junctions and inspection openings shall be made with suitable T- and Y- junctions and curves, furnished and set without extra charge.

(28) *Brick.* All brick used on the work shall be sound, partially vitrified, well-shaped brick, equal to No. 2 paving brick.

(29) *Cement.* All cement used shall be ——, ——, ——, ——, ——, ——, or —— Portland Cement, perfectly fresh, and not damaged in any particular. It shall be subject to the Standard specifications of the American Society for Testing Materials, and will be rejected if it does not meet these requirements. All cement shall also be subject to close inspection as it is used on the work, and damaged cement will be rejected and must be promptly removed.

(30) *Sand.* All sand shall be clean, sharp, and coarse. All sand for mortar for sewer joints or brick masonry must have all pebbles screened out.

(31) *Broken Stone and Pebbles.* The aggregate for concrete shall consist of either broken stone or screened pebbles passing a 2½-inch ring for ordinary concrete, and a 1½-inch ring for the septic tank. The materials must be sound and hard and durable. The sand must be screened out of pebbles used; but the fine materials need not be screened out from broken stone, a reduction being made in the amount of sand used, approximately equal to the amount of stone dust.

(32) *Cast Iron.* All cast iron shall be good, tough, gray iron, free from defects. Castings shall be smooth and free from blowholes or other flaws.

(33) *Cast-Iron Water-Pipe.* All cast-iron pipe shall be cast of the hub-and-spigot pattern, of standard weights for water-pipe for light pressures. The pipe shall be well coated.

(34) *Valves.* All valves shall be iron body, brass-mounted, hub-end, double-gate, water valves, well coated, of the ———— or of equal make acceptable to the Engineer.

(35) *Valve Boxes.* All valve boxes shall be ———— extension boxes with 5¼-inch shafts, or some equal make acceptable to the Engineer.

## MORTAR AND CONCRETE

(36) *Mortar.* All mortar for brickwork or other masonry shall be made of one part of Portland cement to three parts of sand; and all mortar for sewer joints, of one part of cement to one of sand, both ingredients being measured loose and thoroughly mixed. All mortar shall be mixed fresh as used, and any mortar which has begun to set shall be thrown away and not used at all on the work.

(37) *Concrete.* All masonry shown on the plans to be made of concrete shall be constructed with Portland cement, sand, and either broken stone or screened pebbles passing a 2½-inch ring, in the proportions 1-3-5 for ordinary work, and 1-2-3½ for the septic tank, the cement being measured packed as it comes in sacks or barrels, and the sand being measured loose as thrown into the measuring box with shovels. The proportions shall be determined by suitable measuring boxes, or by the use of wheelbarrows. In case of hand-mixing, the sand and cement shall first be thoroughly mixed dry until the color of the mixture is uniform. They shall then again be mixed with water, and then again with the freshly wet aggregate, each mixing being very thorough, and sufficient to secure perfect mixture of the materials. If a machine mixer is used, it shall be of a make acceptable to the Engineer, and shall be so used as to give very thorough mixing. Just enough water shall be

used to make the concrete slightly quake when thoroughly rammed, the water freely flushing to the surface under the ramming.

In depositing, the material shall be deposited in layers not exceeding 6 inches in height, and thoroughly rammed. Where work is left for the night, the layers shall be racked back. Where fresh concrete is deposited on work which is already set or begun to set, the surface shall first be thoroughly cleaned and wet, and washed with a coat of liquid neat cement. After the concrete is deposited, great care shall be taken not to disturb it until the work is thoroughly set. The work shall be protected from the sun, and shall be wet from time to time, until it is thoroughly set.

## TRENCHING, PIPE-LAYING, REFILLING, ETC.

(38) *Excavation.* The excavation shall be made exactly to line and grade as indicated by stakes set by the Engineer. At the bottom, the trench shall have a clear width at least one foot greater than the external diameter of the body of the pipe. The last four inches shall be excavated only a few feet in advance of the pipe-laying, by men especially skilled, measuring from an overhead line set parallel to the grade line of the sewer. The bottom of the trench shall be rounded to fit the pipe; and holes shall be dug for the bells so as to give a uniform bearing, and permit the proper construction of the sewer joints on the under side of the pipe. The earth taken from the trench shall be deposited neatly at the sides, in such manner as to obstruct the streets as little as possible; and a clear space of two feet next the trench shall be left on the side on which the Engineer places his stakes. Great care shall be taken to preserve and not to cover up the Engineer's stakes.

(39) *Sheathing.* Wherever necessary to prevent caving of the banks or injury to adjacent pipes or buildings, the Contractor shall, at his own expense, brace and sheath the trenches sufficiently to overcome the difficulty to the satisfaction of the Engineer. If such bracing and sheathing is left permanently in the trench by order of the Engineer, it shall, on refilling, be cut off one foot below the surface and shall be paid for by the City at the price named in the contract; but otherwise the Contractor will receive no extra compensation for it.

(40) *Water in Trenches.* In general, all water encountered in trenches must be drained away through the sub-drains or pumped or bailed out, and the trench must be kept dry for the pipe-laying. In no case shall the sewers be used as drains for such water, and the ends of the sewer shall be kept properly blocked during construction. All necessary precautions shall be taken by the Contractor to prevent the entrance of mud, sand, or other obstructing material into the sewers or subdrains; and on completion of the work, any such materials which may have entered must be cleaned out and the sewers and subdrains left clean and unobstructed.

(41) *Refilling.* In refilling, earth free from stones shall be carefully placed by hand under and around the pipe and to the height of two feet above the top of the sewer, and thoroughly and carefully rammed in layers of not more than six inches' depth.

The remainder of the refilling shall be carefully done. Scrapers may be used if desired. The refilling shall be thoroughly flooded by the Contractor according to the direction of the Engineer, the City furnishing the water free at the hydrant; but the refilling shall be carried on in such a way that water is taken only as directed by the Waterworks Superintendent, and so that not more than —— gallons of water shall be required in any one day.

Where the trench is not flooded, it shall be left neatly rounded off on top to a height of twice as many inches as the top width of the trench in feet; and the City may from the 2 per cent reserve make good any settlement below the street surface within one year from the date of completion, notice being first given the Contractor, who may promptly do the work himself if he desires.

All surplus material shall be removed to such point within the limits of the sewer district as may be designated by the City; and in case of deficiency of material, it shall be supplied by the Contractor. The street surface shall be left in neat, sightly condition.

(42) *Foundations.* In case the material encountered should be such as not to be suitable for foundations for the sewer, the Engineer shall direct the character of foundations to be constructed, and this shall be paid for by the City as extra work.

(43) *Protection to Buildings.* The Contractor shall take all necessary precautions to protect building and other structures adjacent to the sewer trenches from injury on account of his work, and shall be responsible for all damages to such structures.

(44) *Existing Sewer and Water Mains.* Wherever existing sewers or water mains are encountered in the work, all necessary precautions shall be taken to prevent injury to them; and in case of an injury, it shall be made good by the Contractor without additional compensation. In case any sewer, drain, or water main should be encountered whose present grade should require changing on account of the new sewers, the work necessary for this shall be performed by the Contractor according to the directions of the Engineer, and shall be paid for as extra work.

(45) *Pipe-Laying.* In pipe-laying, each piece must be set exactly to grade by measuring from the invert to a tightly stretched cord set parallel to the grade line, according to stakes or marks given by the Engineer, and supported at least every 25 feet. In making each joint, a gasket of oakum or hemp freshly dipped in cement grout must first be used and packed into place, so as to make the inverts match exactly, giving a smooth, true flow-line. The joints shall afterwards be tightly packed full and beveled off with 1 to 1 Portland cement mortar; but the cementing must be done at least two pipe lengths behind the pipe-laying. The bell-holes must then be immediately packed with sand to hold the cement in place. Great care must be taken to leave no projecting cement or strings of gaskets on the inside of the sewer, and to make all joints as nearly water-tight as possible. Especial care must be taken in forming the joint on the under side of the pipe.

(46) *House Connections.* At points indicated by the Engineer opposite each lot, and at such other points as may be indicated by the Engineer, 4-inch Y's shall be laid, with the branch tilted up at an angle of about 45°. These shall be furnished and laid without extra charge, up to an average of one in each 25 feet.

At points indicated by the Engineer, deep-cut house connections shall be put in according to the plans. The City shall pay for these the regular contract price.

In both ordinary and deep-cut house connections, the connection shall be closed by a vitrified stopper filled over with sand and lightly cemented.

(47) *Subdrains.* Wherever directed by the City, drain-tile subdrains of diameters directed by the Engineer shall be constructed. Each drain shall be laid just at one side of the sewer, at a depth below the sewer invert equal to the external diameter of the subdrain, *plus* three inches. Each joint shall be wrapped twice with a 4-inch strip of muslin at the time laid. The subdrains shall be laid carefully to line and grade; and wherever the Engineer may direct,4-inch Y's stopped with brick shall be placed. In general, these Y's will be placed at the same points as the house connections on the sewer.

(48) *Subdrain Outlets.* Wherever directed by the Engineer, subdrain outlets shall be constructed, also as directed by the Engineer, and shall be paid for by the City on the basis of cost as determined by the Engineer, *plus* 10 per cent.

(49) *Measurements.* All measurements of sewers, subdrains, etc., shall be in horizontal lines from center to center of manholes and junctions.

## MANHOLES AND OTHER APPURTENANCES

(50) *Manholes.* Manholes shall be constructed as shown on the plans and provided in these specifications, the exact location being indicated by the Engineer. All joints in the brickwork shall be shove joints, being filled full. Especial care shall be taken in forming the channels in the concrete bottoms, and wooden templates or half-sewer-pipe shall be used for this work, as directed by the Engineer. Drop manholes shall be constructed as shown on the plans without additional charge over the price bid, which shall be considered an average price.

(51) *Combined Manholes and Flush-Tanks.* Combined manholes and flush-tanks shall be constructed as shown on the plans and as specified for manholes in clause 50. The siphons shall be carefully set, and the cost of furnishing and setting shall be included in the price bid. The Contractor shall provide and set the water connection and bibbs from a point one foot outside the outside wall, on such side as the Engineer may direct.

(52) *Siphons.* Siphons shall be used as shown on the plans, guaranteed by the manufacturers, and tested after being set before acceptance. For the 8- and 10-inch sewers, 6-inch siphons shall be used, and 8-inch for all sewers larger than 10 inches.

(53) *Lampholes.* Lampholes shall be constructed as shown on the plans and provided in these specifications, the exact locations being indicated by the Engineer. The refilling shall be carefully placed and thoroughly rammed by hand in layers not exceeding 6 inches, around and to a distance of three feet each side of each lamphole. Special pains shall be taken to keep the lampholes truly vertical.

## SPECIFICATIONS FOR SEWAGE-DISPOSAL PLANT

(54) *Grading.* All grading shall be done as shown by the plans. The bottom of the filter beds and bottom and sides of the septic tank shall be shaped to true surfaces by hand. All slopes shall be neatly dressed.

Should there be a deficiency of earth for the embankments, the Contractor may borrow from neatly-shaped borrow pits located on adjacent city land, where directed by the Engineer, leaving a smooth, uniform surface. Should there be surplus material, it shall be deposited along the edge of the lake, as directed by the Engineer.

(55) *Concrete Moulds.* The Contractor shall provide moulds of plank not less than two inches in thickness, thoroughly braced at intervals sufficiently close together to avoid distortion of the moulds. These planks shall be dressed on their edges and on the faces next to the wall. The moulds shall not be removed until the walls have become thoroughly set.

(56) *Facing of Concrete Walls.* In the construction of concrete walls, care shall be taken to keep all pebbles or stones away from the faces of the walls, so that the face shall be smooth and free from cavities or exposed stones or pebbles. The upper surface of the roof shall be floated with 1-2 thin mortar applied when the roof is made, and all cavities in other concrete surfaces filled and smoothed with 1-2 mortar.

(57) *Cement Wash.* On completion of concrete walls and floors, and after removal of the moulds and pointing up defects, all interior surfaces of floors and walls and roof, and the upper surface of the roof, shall be given two good coats of thin, neat Portland cement grout applied with a whitewash brush, time being left between applications for the first coat to set hard.

(58) *Alternating Siphons.* The alternating siphons shall be provided of the make shown on the plans, and set by the Contractor, strictly according to the directions of the manufacturer as given through the Engineer. Any imperfections affecting the working of the siphons when they are tested shall be corrected by the Contractor, who must guarantee their satisfactory working.

(59) *Filters.* The pebbles for the bottoms of the filters shall be screened clean of sand and properly graded, the 2-inch layer of fine pebbles being small enough to hold up the sand placed over it. All sand shall be clean and coarse, but the pebbles need not be screened out. In placing pebbles and sand, care shall be taken not to injure or disturb the drain tile, and the top surface of the sand shall very carefully be made level. Drain tile shall be laid carefully to line and grade.

(60) *Pipe-Laying.* All sewer pipe and cast-iron pipe shall be carefully laid to line and grade, with gaskets and tight joints, all as provided in the regular sewer specifications.

(61) *Sodding.* All earthwork slopes of the tank and filters shall be neatly sodded.

(62) *Bulkheads.* All bulkheads shown on the plans shall be constructed of Portland cement concrete, with moulds, and with care as to facing the same as provided for the concrete work of the septic tank.

(63) *Reinforcing.* The reinforcing shown on the plans is .......... corrugated bars of not less than 50,000 lbs. per sq. in. elastic limit; but other forms of bars having equal elastic limit, equal net area, and a mechanical bond acceptable to the Engineer, may be used. The net area of any bars used must be increased to make good any deficiency in the elastic limit.

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For brick sewers, the following specifications are suggested by Folwell in his book on *Sewerage:*

"For brick masonry in straight walls or sewers, none but whole, sound brick shall be used. For manholes, flush-tanks, and similar work, a limited number of half-brick may be used, not to exceed ⅓ of the whole in any case. Unless the Engineer direct otherwise, each brick shall be thoroughly wetted immediately before being laid. It shall be laid with a full, close joint of cement mortar on its bed, ends, and side at one operation. In no case is mortar to be slushed in afterward. Special care shall be taken to make the face of the brickwork smooth; and all joints on the interior of a sewer shall be carefully struck with the point of a trowel or pointed to the satisfaction of the Engineer. Where pipe-connections enter a sewer or manhole, "bull's-eyes" shall be constructed by laying rowlock courses of brick around them, the cost of such construction being included in the regular price bid for the sewer or appurtenances. Around pipe more than 15 inches in diameter, 2 rowlock courses shall be laid.

"Brickwork in sewers shall be laid by line, each course perfectly straight and parallel to the axis of the sewer. Joints appearing in the sewer shall in no case exceed ¼ inch in width. Sewers shall conform accurately in section and dimensions to the plans of the same. All inverts and bottom curves shall be worked from templates accurately set; the arches are to be formed upon strong centers accurately and solidly set, and the crowns keyed in full joints of mortar. No centers shall be drawn until the arch masonry has set to the satisfaction of the Engineer, and refilling has progressed up to the crown. They shall be drawn with care, so as not to crack or injure the work. The extrados is to be neatly plastered with cement mortar ½ inch thick, the arches being cleaned and wetted just before plastering. The end of each section of brick sewer shall be toothed or racked back; and before beginning the succeeding section, all loose brick at the end shall be removed and the toothing cleaned of mortar. All brickwork shall be thoroughly bonded, adjacent courses breaking joints at least ⅓ the exposed length of the brick.

"If there should be any distortion of the sewer before acceptance, this shall be corrected by tearing down and rebuilding. No local patching will be allowed, but when repairs are necessary a section shall be removed at least 3 feet long and including the entire arch, or the entire sewer if the defect is in the invert. Leakage of ground water into the sewer shall be similarly corrected, unless it can be prevented by calking the joints with oakum saturated in cement, with wooden plugs, or other material acceptable to the Engineer."

## FORM OF PROPOSAL

——————————, ————.

To the Mayor and Council of the Incorporated City of——————, ————.

*Gentlemen*:

—— have carefully examined the plans and read the specifications prepared for your proposed sewage-disposal plant and sanitary sewers by————, Engineer, and —— agree to furnish all the materials and perform all the labor required for the completion of the proposed work for the following prices:

| Item | Approximate Quantity | Unit Price | Total Price |
|---|---|---|---|
| *Sewage Disposal Plant,* complete ...... | | | |
| *Sewers,* complete, including Y's, except subdrains, manholes, lampholes, and flush-tanks. | | | |
| 18-inch ........................ | | | |
| 15-inch ........................ | | | |
| 12-inch ........................ | | | |
| 10-inch ........................ | | | |
| 8-inch ........................ | | | |
| *Subdrains,* complete | | | |
| 10-inch ........................ | | | |
| 8-inch ........................ | | | |
| 6-inch ........................ | | | |
| *Deep-Cut House Connections,* complete . | | | |
| *Manholes,* complete ................ | | | |
| *Combined Manholes and Flush-Tanks,* complete .................... | | | |
| *Lumber Left in Trenches* (per M., B. M.) | | | |

All the above shall be strictly in accordance with the plans and specifications.

In case —— bid is accepted, —— agree to begin work within three weeks after the acceptance of —— bid, and to entirely complete the work on or before——————————————, ——————.

——— further agree to enter into contract and furnish bond satisfactory to the City Council within 12 days after acceptance of —— bid.

*Respectfully submitted,*

————————————

————————————

**94. Form for Sewerage Contract.** Besides plans and specifications, the sewerage Engineer is sometimes called upon to furnish a *Form of Contract* to be signed by the Contractor and the city representatives, though this, more properly, should be the work of the City Attorney. The following simple form of contract has been used successfully with specifications such as those given above:

**This Article of Agreement,** made this ——— day of ——————— A.D., ——, by and between ——————, of ——————, ———, party of the first part, and the Incorporated City of ———, ———, acting through its Mayor and Council, party of the second part,

Witnesseth:

The party of the first part agrees to furnish all material and perform all labor required for the entire completion of sanitary sewers, subdrains, and other appurtenances, on streets in the said City of ————, ———, as follows:

(Note: In this space place a list of the sewers included in the contracts by streets, giving the sizes on each street of both sewer and subdrain, and the points at which each size begins and ends.)

All the above sewers are to have manholes and other appurtenances as shown by the plans and specifications.

The party of the first part further agrees that all the above labor and materials shall be strictly in accordance with the sewer plans and specifications prepared for the party of the second part by ——————, Engineer, said plans and specifications identified by the signatures of the parties hereto, being hereby made a part of this contract.

The party of the second part agrees to pay to the party of the first part for the above labor and materials, the following prices:

| | | |
|---|---|---|
| Sewers, complete, except subdrains, manholes, lampholes, and flush-tanks, | | |
| 24-inch | $ | per lin. ft. |
| 20 " | | " " |
| 18 " | | " " |
| 15 " | | " " |
| 12 " | | " " |
| 10 " | | " " |
| 8 " | | " " |
| Subdrains, complete, | | |
| 24-inch | | " " |
| 18 " | | " " |
| 15 " | | " " |
| 12 " | | " " |
| 10 " | | " " |
| 8 " | | " " |
| Manholes, complete | $ | each |
| Lampholes, complete | | " |
| Combined Manholes and Flush-Tanks, complete | | " |
| Flush-Tanks, complete | | " |
| Lumber ordered left in trenches | $ per | M., B. M. |

The payments shall be made in——————————————

——————————and paid to the party of the first part in accordance with the provisions of the specifications, 2 per cent being reserved for one year to guarantee the work.

In Witness Whereof we have hereunto set our hands and seals the date and place first above mentioned.

SEAL

——————————

*Party of the First Part*

The Incorporated City of ————, by

SEAL

——————————Mayor,

——————————

*Party of the Second Part*

**95. Form of Bond for Sewerage Contract.** The Contractor for a piece of sewerage work is usually required to furnish to the City a bond, which is frequently for a sum equal to about one-half the amount of the contract. The simpler the form of the bond, the better. The following form has been used successfully:

BOND

Know all men by these presents, that we, ——————————, of ——————————, ———, Principal, and

——————————————————————————————

——————————————————————————————

——————————————————————————————

*Sureties*

are held and firmly bound to the Incorporated City of ——————, ————, in the penal sum of —————————————— Dollars (——————), lawful money of the United States of America.

Now, the condition of this obligation is that whereas the above-mentioned ——————————, of ——————————, ———, has entered into contract with the Incorporated City of ————, ———, dated ————., A. D. ———, to furnish all labor and materials required for the entire completion of about ———— feet of sanitary sewers, subdrains, and other appurtenances for the said City of ——————, ————, now, if the said ——————————, shall well and truly perform all the obligations of his said contract, strictly according to the terms thereof, then shall this bond be null and void, but otherwise it shall be and remain in full force and effect.

——————————————

*Principal*

——————————————

——————————————

*Sureties*

## CONSTRUCTION OF SEWERS

**96. Letting the Sewer Contract.** After the plans and specifications have been completed and accepted by the City, the next step will be to let the contract for the work.

*First.* The work should be advertised, if possible, three or four weeks in advance, in at least two good engineering or trade journals. It must often, by law, be advertised also in at least one local journal. For a form for the advertisement see pages 112 and 113.

*Second.* On the day and at the hour specified in the advertisements, the City Council meets to open the sealed bids which have been submitted on the blank "forms for proposals" furnished by the City for the purpose.

*Third.* If the bids are satisfactory, the contract is awarded to the *lowest responsible bidder.*

*Fourth.* A contract for executing the work in accordance with the plans and specifications, is signed by the Contractor and by the City.

*Fifth.* The Contractor furnishes a bond satisfactory to the City.

In all these steps, there is need of great care on the part of the city authorities to make sure that all provisions of the law are complied with, and they should be fully advised at all times by a competent attorney.

**97. Organization of Engineering Force during Construction of Sewers.** It is not common for the Consulting Engineer who prepares the sewerage plans and specifications, to be constantly on the ground or even in the city during construction. He makes only occasional visits for inspection and consultation.

The actual work of sewer construction is usually directly supervised either by the City Engineer, or by a *Resident Engineer* employed especially for this purpose.

It will be necessary for the resident engineer in charge of the construction of a sewerage system of some magnitude, to have an office and an adequate equipment of drafting apparatus, surveying instruments, etc. He will have employed under him:

Draftsmen and clerks, in the office.
Instrument men and rodmen, to do the surveying.
Inspectors, constantly on all work, to insure its being properly executed.

The resident engineer himself will supervise these employees, visit all parts of the work frequently, and constantly exercise general supervision over all its features.

**98. Laying Out the Sewer Work.** After checking up the benchmarks on the original survey, it will be necessary for the engineering force to stake out the sewers, keeping somewhat in advance of the actual construction.

The stakes are usually placed a uniform distance to one side of the true line, so as not to be disturbed by the digging of the trench. This distance, and the side on which the stakes are placed, should be the same for all parts of the work, to avoid confusion and mistakes.

The stakes should usually be set about 25 feet apart.

The manholes should usually be located first, in accordance with the profile sheets; and the sewers should be run as straight lines, center to center of adjacent manholes. All discrepancies from the original measurements should each be adjusted, if possible, between the two manholes between which each was found; and such discrepancies should not be carried on to affect all the rest of the work.

There are two methods of giving grades for sewers.

(1) The best method is to set the grade stakes nearly flush with the surface, at a uniform offset to one side of the trench, ascertaining

the distance of the top of each stake above grade by carefully checked levels. By measuring from these stakes, a grade cord, supported on cross-frames every 25 feet, is stretched parallel to the grade line of the sewer, over its center line. For this method of giving grades, see Fig. 40.

(2) Another method is to set grade stakes at the bottom of the trench. This method is adapted only to very large sewers.

**99. Trenching and Refilling.** Sewer trenching and refilling may be done either by machines or by hand. *Excavating Machines* for sewers are of two types:

(1) *Machines which themselves do the excavating.* These are just coming into use, and are becoming more and more successful.

(2) *Machines which simply carry away the excavated material,* usually dumping it over the completed sewer further back. This type has the advantage of not piling up the dirt in the busy street. It carries, on overhead cableways or trestles, buckets which can be lowered into the trench, and in which the excavated material is placed by hand.

Machines of both types are suited best to comparatively extensive work; and under favorable conditions they lessen the cost materially.

Most sewer trenching, however, is done by *hand.* For such work the men are organized in gangs, the number of men in each gang varying from 20 to 80. Each gang has a foreman, and a water boy, and sometimes a sub-foreman. A pair of pipe-layers may work with each gang, or, if the trench be deep, one pair of pipe-layers may work part of the time with one gang and part with another.

The details of sewer trenching and refilling as ordinarily carried out, are specified quite fully in clauses 38, 40, and 41 of the sample sewer specifications given in Art. 93 (which clauses now read carefully). All details there specified should be enforced by the Inspector and the Engineer.

In clause 41, Art. 93, referred to above, the method specified for compacting the refilling is by flooding with water. While this is the cheapest method, where the water is available, and while it gives good results if properly done, it may be found necessary sometimes, in the case of paved streets, to adopt the more expensive method of *tamping.* For thorough tamping, there should be from 1 to 2 men tamping, to 1 shoveler, and the rammers used should weigh 4 to 6 pounds each. The soil refilled should be moistened if dry, and should be tamped in about 4-inch layers. It is possible by very thorough tamping to compact the soil more thoroughly than by flooding.

**100. Sheathing.** Except for shallow ditches in very solid earth, it is usually necessary to brace the sides of sewer trenches to prevent their caving in. Such bracing is called *sheathing*. The most common methods of sheathing are illustrated in Fig. 40.

The horizontal members of the sheathing are called *rangers*, and the rangers are held the right distances apart by *sewer braces* of wood or iron. The iron braces are shown in Fig. 40. The rangers are usually about 12 feet long. Behind the rangers are placed the vertical planks of the sheathing, either a few feet apart in firm material, forming *skeleton sheathing*, or in contact with each other in caving material, forming *close sheathing*. The sheathing plank are 2 inches thick and are usually about 10 feet or 12 feet long. The rangers may be 2-inch planks in favorable soil, or 4 by 4 or even 4 by 6 inches in poor soil.

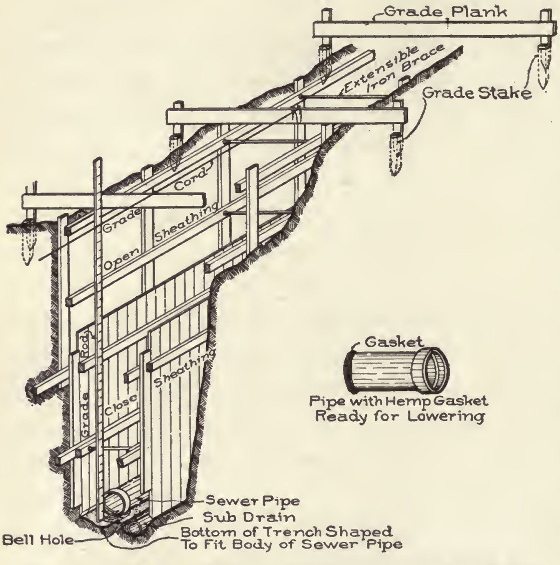



Fig. 40. Diagram Showing Construction of Pipe Sewer.

The sheathing plank are usually driven by hand, with wooden mauls.

Sometimes, for large sewers, heavy *sheet piling* may be driven by pile-drivers, to take the place of ordinary sheathing.

Ordinary sheathing is removed from the trench as the refilling proceeds. In case of special danger to near-by water mains, conduits, or foundations, on account of possibility of the banks caving before the refilling is finally settled, the Engineer may order the sheathing to be left permanently in the trench. In such case, the Inspector makes record of the exact amount of lumber left in the trench, and the City pays for it.

**101. Pipe-Laying.** The pipe-laying is usually done by two men, though, with large pipes, another may be needed. These men excavate the last few inches of the trench, as well as lay the pipes.

*The laying of every pipe, and the making of every joint, should be carefully watched by an Inspector, who should faithfully enforce the specifications.*

For specifications for pipe-laying, see clause 45, Art. 93 (which clause now read carefully).

All the sewer pipe should be carefully inspected before being used, and those pieces rejected which do not meet the specifications. See clause 25, Art. 93. The Inspector should see that no rejected or poor pipe is used.

The Inspector should see that every pipe is laid exactly to grade by measurement from the grade cord (see Fig. 40).

The Inspector should also see that house-connection Y's are placed opposite each lot on each side of the street, at the proper points; and he must exactly locate each such connection by measurements fully recorded in his notebook.

**102. Construction of Brick Sewers.** For specifications for the construction of brick sewers, see reference to Folwell in Art. 93, p. 122. (Read carefully.)

The construction of a brick sewer is shown in Fig. 41.

It will be the duty of the Inspector to inspect all brick before they are used, rejecting the poor ones, and to fully enforce the specifications for construction. He must also see that the templates are set truly to line and grade, that the house connections are set at the proper places and heights, and accurately located in his records.

In the case of large brick sewers, more trouble is to be expected with foundations than in the case of pipe sewers. Sometimes soft soil or quicksand may make it almost impossible to shape the material in the bottom to fit the outside of circular sewers. In such cases, special foundations, such as shown in Fig. 20, may have to be put in through the treacherous material. Other forms of special foundations are often used.

The Engineer should make full record of all such features of the work.

**103. Records of Sewer Construction.** *Daily Reports.* The resident Engineer in charge of the construction of a sewerage system, should require, from all members of his engineering force, daily reports, on suitable blank forms, showing the exact work on which each was engaged. Another set of exact reports should show the work accomplished by the Contractor each day, and the materials and labor used on each part of the work.

*Data of Sewer Construction.* The information from these daily reports should be entered in a permanent book, showing all features

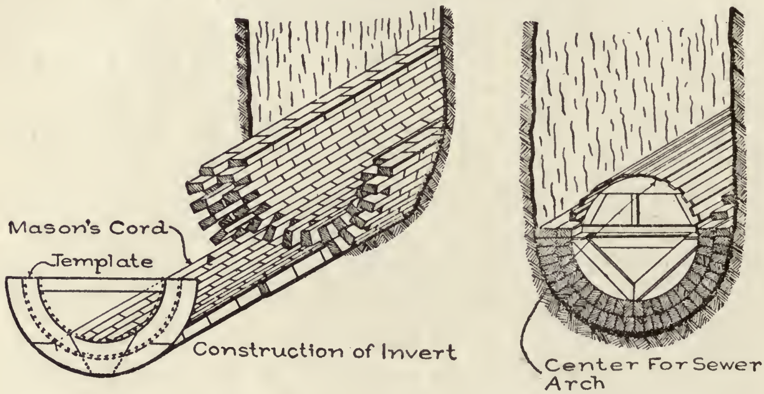



Fig. 41. Diagrams Showing Construction of Brick Sewer.

of the progress of the work, and giving data for itemized estimates of the cost.

*Sewer Record Book.* In another permanent book, a complete, final record of all the sewers should be entered.

On the left-hand page may be given in order the numbers of the stations of the sewer survey, running from the bottom to the top of the page, together with the surface elevations, the grade elevations, and the rate of grade.

The exact character of the soil should also be shown, with exact levels for computing any rock excavation. Notes should be made of the level and amount of any ground water encountered.

On the right-hand page should be made a large-scale sketch of the sewer, showing its exact location with reference to the street lines and the lot lines, and the exact location of manholes and other accessories. This sketch should also show the location of all house connections, with exact measurements (such as the station and *plus* of each connection) by which to locate all such connections.

On the right-hand page may also be entered the exact limits of sheathing left in trenches, and the amounts of lumber in such sheathing, as well as the exact limits and character of all special sewer

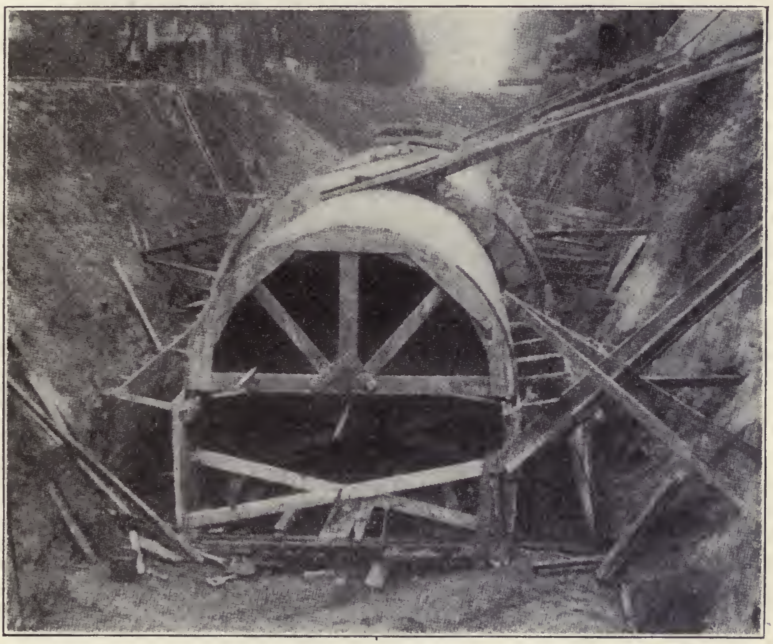


Fig. 42. Construction of Dry-Run Concrete Sewer, Waterloo, Iowa.

foundations, of changes of grade where other conduits are crossed, and of all other extra work.

*Final Sewerage Map and Profiles.* On completion of the system, the resident Engineer should make a complete final sewerage map, and complete final profiles of all sewers, both corrected by any changes from the original plans adopted during construction.

*Plat of Sewer Connections.* For small towns, at least, large-scale plats of the different streets should be prepared, showing the exact location of all house connections.

## MAINTENANCE OF SEWERS

**104. Sewerage Systems should be Carefully Maintained in Good Condition.** Too often it appears to be considered that when a sewerage system is completed all further care of it can be neglected with impunity. This is a great mistake. The sewerage system may become a source of danger to the public health, instead of a means of safety, unless it is given proper care and attention.

**105. Sewer Ordinances, Permits, and Records.** Every city having sewers should pass a carefully prepared *Sewer Ordinance,* prescribing in detail the conditions under which citizens are permitted to use the sewers.

One provision of the Sewer Ordinance should be, that all property owners desiring to make sewer connections shall first secure a *Sewer Permit.* For this and for the application for it, blank forms are provided, which are to be filled in by the applicant, giving full description of the connection. The permit will require the work to be done according to the city regulations.

Every house sewer should be connected with the sewer at a regular house connection. No cutting into the sewer whatever should be permitted, as there is great danger of such cutting ruining the sewer.

Full *Sewer Records* should be kept by the proper city officers, showing full details of all connections with the sewers. This is too often neglected, to the great detriment of the City, which finds itself without means of ascertaining what people or how many are using the sewers, and perhaps putting injurious substances into them.

**106. Plumbing Regulations, Tests, and Licenses.** The city should also prescribe by ordinance strict *Plumbing Regulations,* setting forth in full detail the requirements for good plumbing (see Articles 76 to 81 inclusive). All property owners should be required to do all plumbing in strict accordance with these regulations.

The work should be carefully *inspected and tested* by a City Inspector, to see that it fully complies with the ordinance. The *water test* is applied by stopping up the outlets of the soil-pipe and of the various fixtures, and filling the pipes with water, when defects will be shown by leaks. In the *smoke test,* the pipes are blown full of smoke; and in the *peppermint test,* oil of peppermint is poured into them. In neither case must it be possible to detect any of the odor in the interior of the house.

Plumbing regulations usually require that plumbing shall be done only by plumbers holding *plumbers' licenses* granted by the City. The proper city officers have blank forms for making applications for such licenses, as well as for the licenses themselves. The plumber making application for a license should be required to show proof of proficiency, and should be placed under bond to comply fully with the sewer ordinance and the plumbing regulations, and to protect the City from damages on account of his work. The plumber may also be made subject to fines for violating the sewer ordinance and regulations, and to revocation of his license.

**107. Regular Sewer Inspection.** In sewer maintenance, besides the work of granting sewer permits, and inspecting house plumbing and the making of connections with the sewers, the entire sewerage system should be gone over regularly and carefully by a Sewer Inspector, once every two weeks if possible.

The Inspector, in this work, should open all manholes and lampholes, and carefully examine the sewer to make sure that it is keeping clean, well-ventilated, and reasonably free from offensive odors. He should also examine carefully the working of all flush-tanks, to make sure that they are operating satisfactorily. He should also examine all catch-basins, to make sure that they are cleaned frequently enough.

Small defects found on these periodical inspections should be remedied at once, and full notes made of more extensive work found to be necessary.

**108. Flushing and Cleaning of Sewers.** In many sewerage systems, it is found impossible to prevent absolutely the formation of deposits in the sewers, which must then be removed by hand-flushing, or by direct cleaning of the sewers.

Flushing is ordinarily preferred to hand-cleaning methods where the water for the purpose is available, and where it is readily possible to remove the deposits in this way. For the most common methods of hand-flushing, see Art. 25.

In hand-cleaning, large sewers may be entered by the workmen themselves to remove the deposits. In small sewers, lines are often floated down from one manhole to the next below; and by means of these lines, various cleaning devices are dragged through the sewer, or back and forth in it, to remove the deposits. Sometimes, for small sewers, a ball, a little smaller than the sewer, with a line attached to haul it back in case of stoppage, is allowed to float down the sewer, from manhole to manhole. The sewage is dammed back by it, and spurts out on all sides under pressure, thus scouring and cleaning the sewer.

For large sewers, discs or gates, traveling on carriages, or boats, may be used, working on the same principle. Many forms of such apparatus have been devised. A notable example of the use on a large scale of traveling sewage-scouring gates is in connection with the Paris sewers, Fig. 24.

**109. Cleaning of Catch-Basins.** In Art. 27, catch-basins were described; and it was stated that unless they are frequently cleaned they become filled with filth and soil and debris from the street, and fail utterly in their purpose, which is to keep such materials out of the sewers. Moreover—which is still worse than this—uncleaned catch-basins are unsanitary, and are sources of foul odors. Hence catch-basins, when used, should be regularly cleaned, and the City should have a regular arrangement for this work, and should provide labor-saving apparatus for the work, such as hoisting apparatus or special pumps for lifting the material from the catch-basins to the wagons.

## SEWAGE DISPOSAL*

**110. Basic Principle.** The subject of sewage disposal seems prosaic at first glance, but when one considers that its processes involve the whole cycle of life, the study of it becomes most interesting. The organic matters with which we have to deal must be changed from the unstable form in which they exist to stable chemical compounds. This result is obtained by the action of millions of micro-organisms called *bacteria*. "Without them", as Woodhead says, "the surface of the earth would be covered with dead organic matter, the remains of plant and animal bodies, which, retaining the elements necessary for the building up of new plant life and animal bodies, would soon cut off the food supply of new plants and animals; life would be impossible because the work of death would be incomplete," or, as Pasteur puts it, "because the return to the atmosphere and to the mineral kingdom of all that which has ceased to live would be totally suspended."

*The following sections on Sewage and Garbage Disposal have been supplied by Thos. Fleming, Jr., of Chester and Fleming, Hydraulic and Sanitary Engineers, Pittsburgh, Pa.

**111. Historical.** It was not until the middle of the nineteenth century that sewage disposal was studied or put into effect in a systematic way. Previous to that time, it had been the habit of individuals and communities to dispose of their sewage in a manner the least expensive and yet consistent with preventing a local nuisance, and in most cases where sewer systems had been installed, this resulted in discharging the sewage into the nearest water course. In communities not fortunate enough to have sewer systems, cesspools were abundant, and in many instances were arranged with overflows to the nearest surface drain. In 1858, conditions became so acute in England, with its small streams and large tributary population, that a law was passed prohibiting the pollution of rivers, and during the next few years several able commissions were appointed by the Government to study the problem. The commissions invariably declared that the proper method for purifying sewage was to distribute it on land, although during this period private companies were exploiting chemical processes and endeavoring to have chemical precipitation adopted as the proper form for sewage disposal. The disposal of sewage by broad irrigation was carried out on an extensive scale in England during the latter part of the nineteenth century, and several extensive chemical precipitation plants were also installed. Germany soon followed England in prohibiting the discharge of unpurified sewage into the streams and in adopting broad irrigation and chemical precipitation for treating it. America followed shortly, especially in New England, as there the small streams and dense population made the conditions quite similar to those in England.

In 1886, the State of Massachusetts passed an act preventing river pollution and placing the control of the streams in the hands of the State Board of Health. This Board constructed an experiment station at Lawrence, where extensive tests were made in the use of artificial filters, leading to the construction of the modern biological filters. Numerous experimental stations followed in England and Gemany, which resulted in many permanent installations on a large scale of artificial biological works.

In 1896, the so-called septic tanks were developed quite extensively in England, and, in the last few years, the settling tanks with separate digestion compartments have come into

TABLE XIV

**Composition of Sewage**

| Analyses of Raw Sewage | Parts per Million | | | | | | | | | | Alkalinity | Chlorine |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Suspended Solids | | | Nitrogen as | | | | Oxygen Consumed | | | | |
| | Total | Fixed | Volatile | Organic N | Free Ammonia | Nitrite | Nitrate | Total | Suspended | Dissolved | | |
| Atlanta, Ga. | 285 | 138 | 126 | 12.8 | 18.8 | 0.1 | 2.2 | 90.6 | ... | ... | ... | ... |
| Columbus, O. | 209 | 130 | 79 | 9.0 | 11.0 | 0.09 | 0.20 | 51.0 | 25.0 | 26.0 | ... | 65 |
| Waterbury, Conn. | 165 | 50 | 115 | 14.8 | 7.8 | 0.14 | 1.52 | 46.0 | 20.0 | 26.0 | 41 | 48 |
| Philadelphia, Pa. | 189 | 59 | 130 | 6.3 | 4.0 | 0.23 | 1.00 | 76.0 | 35.6 | 40.4 | 128 | 39 |

prominence together with methods for the disinfection of sewage and the removal of suspended matter by fine screens.

## SEWAGE

**112. Character of Sewage.** The average sewage consists mainly of water used for washing and flushing purposes. In America, the daily water consumption ranges from thirty gallons to four hundred gallons per capita with an average of one hundred gallons per capita. This water, in passing through the sewer system, contains a variable amount of solids and liquids representing the waste products of the community which altogether does not exceed two per cent of the water. If analyzed bacteriologically, it will, however, be found to contain at least one million bacteria per cubic centimeter; and if these bacteria be further differentiated, it will be found that most of them are of a harmless type. The character of sewage is naturally extremely variable, depending on the amount of water consumption per capita, the admission of storm water into the system, the character of effluent from the various industries, and the constituents of the mineral compounds in the water supply itself. It will also vary at different hours of the day.

**113. Analyses of Sewage.** Table XIV of analyses gives an idea of the composition of sewage. It will be noted that the quantities are expressed in parts per million by weight and that a com-

**TABLE XV**

**Typical Analysis of City Sewage**

ANALYSIS OF ALLIANCE, O. SEWAGE JULY 1914
Chester & Fleming Consulting Engineers Pittsburgh, Pa.

| | Sewage Flow in Million Gallons | PARTS PER MILLION | | | | | | | | | | | | Ratio of Available Oxygen to Oxygen Required for Equilibrium Expressed in Per Cent. STABILITY at 37°C. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SUSPENDED SOLID | | | DISSOLVED OXYGEN | | | | CONSUMED OXYGEN | | | | | | | | |
| | | Screened Sewage | Effluent of Septic Tank #1 | " " #3 | Screened Sewage | Effluent of Septic Tank #1 | " " #3 | " Contact Beds | Screened Sewage | Effluent of Septic Tank #1 | " " #3 | " Contact Beds | Effluent of Septic Tank #1 | " " #3 | " Sand Bed #2 | " " #3 | " " #4 |
| July 2 | 2.51 | 125 | 65 | 90 | 0 | 0 | 0 | 0 | 45 | 24.5 | 29.2 | 13.6 | | | | | |
| " 3 | 2.52 | 190 | 80 | 96 | 0 | 0 | 0 | 0 | 50 | 31.6 | 36.4 | 16.0 | | | | | |
| " 4 | 2.37 | 193 | 105 | 115 | 0 | 0 | 0 | 0 | 79 | 11.6 | 27.6 | 13.6 | 2 | 0 | 33 | 99 | |
| " 5 | 2.38 | 185 | 96 | 174 | 0.6 | 0 | 0 | 0 | 30 | 20.0 | 28.0 | 10.8 | | | | 99 | 99 |
| " 6 | 2.57 | 166 | 116 | 136 | 0 | 0 | 0 | 1.7 | 46 | 25.0 | 40.0 | 11.2 | | | | | |
| " 7 | 2.51 | 195 | 35 | 103 | 0 | 0 | 0 | 1.5 | 84 | 36.0 | 47.0 | 26.8 | | | | | |
| " 8 | 2.45 | 150 | 75 | 135 | 0 | 0 | 0 | 1.5 | 49 | 40.0 | 42.0 | 12.8 | | | | | |

plete detailed analysis of the constituent parts of the sewage is not made, but totals of the solids, organic compounds, and other indicative tests are given. The form in which the organic matter exists in sewage is quite complex and would be difficult to analyze, whereas, indicative tests, which can be used for comparison, furnish the information desired.

Table XV shows an analysis of sewage and effluents from the various units of sewage disposal works at Alliance, Ohio. The significance of these tests is as follows:

*Suspended Solids.* Dr. Imhoff divides solids found in sewage into four classes: (1) settling solids (removed by 2 hours' quiescent sedimentation); (2) finely divided solids (finer than above but removable by filtration through paper); (3) colloidal matter (finer than either of the above but removable by a dialyzing membrane); and (4) solids in true solution.

Of these, the first three are classified as suspended solids and are subdivided into fixed and volatile solids. Most of the fixed solids represent the inorganic matter in the sewage, consisting mainly of the material in the water supply. The volatile solids serve as an index of the amount of organic matter and are the solids with which we have to deal in purification.

*Nitrogen.* The organic nitrogen indicates the amount of undecayed organic matter containing nitrogen in the sewage, and the free ammonia indicates the amount of decomposing organic matter containing nitrogen. The nitrites indicate a partial breaking down of the organic matter into inorganic compounds, and the nitrates indicate the amount of organic matter that has been completely broken down and changed into stable inorganic compounds.

*Oxygen Consumed.* A very important test as indicating the condition of the sewage with respect to stability shows the relative amount of carbonaceous organic matter in the various effluents. It is the amount of oxygen absorbed by the sewage and is used to compare with the effluent as to purification effected.

*Alkalinity.* The alkaline test furnishes a comparison of the sewage with the water supply, and any serious modification would indicate pollution with trade wastes of an acid character. It also serves as an index of the degree of purification by comparing sewage with effluent.

*Chlorine.* Chlorine is harmless in the form of common salt, in which it occurs in sewage, and is only indicative of the strength of the sewage.

*Bacteria.* Bacteria are microscopic organisms belonging to the vegetable kingdom. They have been divided into two classes, namely, saprophytes, which live on inanimate matter, and parasites which live on substances of animal bodies. They are further classified by their ability to thrive in the absence or presence of oxygen. Those which thrive in the presence of oxygen are called *aërobic* bacteria, and those which thrive in the absence of oxygen are called *anaërobic* bacteria. Each of the classes has so-called facultative bacteria also which exist with or without oxygen, but thrive under the conditions suited to their class. Among the subdivisions of these general classes are the pathogenic bacteria which are the means of transmitting water-borne diseases. These bacteria are of course parasites and do not increase after leaving the human body. They may exist, however, for months under most unfavorable conditions.

The reduction of organic matter to inorganic matter is accomplished by the action of enormous numbers of those bacteria upon the organic material. It has been found from experiments and from the results of the operations of numerous biological disposal plants, that *aërobic* bacteria in the presence of free oxygen bring

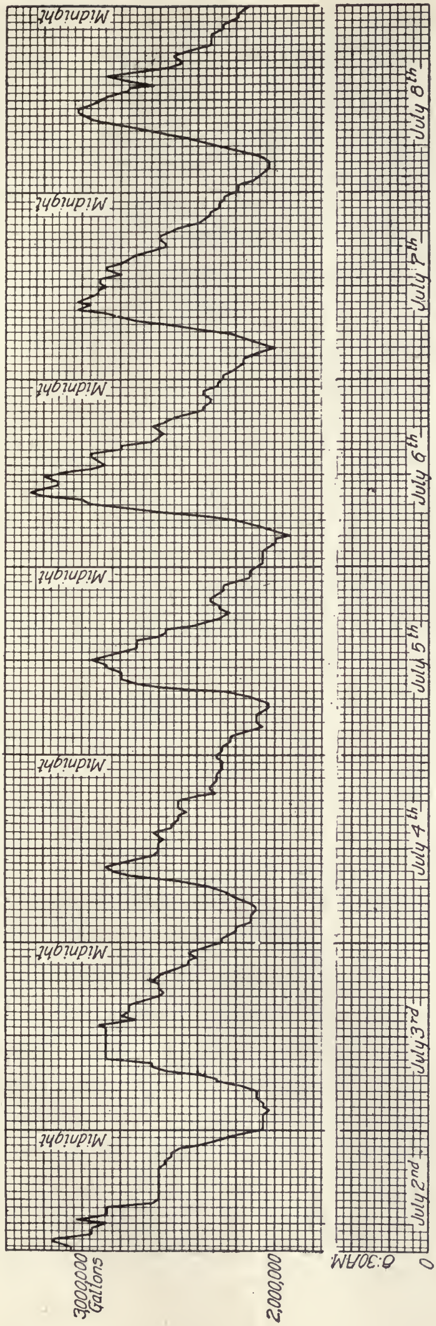



Fig. 43. Chart of Sewage Flow at Alliance, Ohio

about an oxidizing decomposition of the organic matter in sewage with but few or no objectionable odors; that *anaërobic* bacterial action, on the other hand, in the absence of free oxygen is usually accomplished with offensive odors mainly resulting from sulphurated hydrogen compounds which are formed thereby. The total number of bacteria in the sewage per cubic centimeter is indicative of the pollution, and serves as a comparison with the treated sewage as to degree of purification. Where disinfection of the sewage is desired, a count of the number of *b. coli communis* is made. This form of bacteria exists in the intestines of all animal life and is indicative of animal pollution. While it is in itself harmless, yet it is more easy to differentiate than the pathogenic bacteria, of typhoid, cholera, enteritis, and other water-borne intestinal bacteria which may or may not be present, and as these bacteria are less hardy, the removal of *b. coli* is an indication of the removal of harmful bacteria.

## DISPOSAL SYSTEMS

**114. Requirements of Sewage Disposal.** The requirements as to sewage disposal are varied for there are few cases where the conditions are the same. A study must be made of the conditions in each particular case, taking into consideration the location of water supplies; other industries which might be affected; the capacity and nature of the stream into which the sewage is to be discharged; the condition of the sewage itself; the possibilities of elimination of storm flows; and of the suitable location of treatment works. The variation of the hourly flow of the sewage must also be studied where treatment works are to be installed and data obtained on the amount of storm water admitted during rains.

Fig. 43 shows the weekly flow of the sewage at Alliance, Ohio. During the wet season this flow is tripled for brief periods.

There are many towns on large bodies of water where disposal by dilution is entirely feasible. On smaller streams, a partial purification in the nature of the elimination of solids or disinfection, or both, may be satisfactory, and in other cases, on small streams or in locations immediately above important water supplies, the highest degree of purification must be effected, including the removal of all organic matter and the disinfection of the bacterial content.

**115. Classification of Methods.** The methods employed in disposal of sewage are dilution and purification. The methods of purification now in use consist of broad irrigation, chemical precipitation, screens, settling tanks, septic tanks, contact beds, sprinkling filters, sand filters, disinfection, and electrolytic treatment. Each of these methods may be subdivided into various types, but in this book it is the intention in describing them, to outline only the most widely used and successful type under each. In considering the different methods, it is to be understood that one or more may be necessary to solve the problem, as will be outlined hereafter.

### DILUTION

**116. Controlling Factors.** Nearly all of the larger cities of America dispose of their sewage by dilution. This is due to their location on the seaboard or large rivers.

For the proper dilution of sewage, there must be a volume of water sufficient to permit of *aërobic* bacterial action which will effect a complete breaking down of the organic matter and at the same time not destroy fish life; or in other words, the oxygen content of the stream must not be materially reduced. The minimum is set by authorities at from 30 per cent to 70 per cent of the saturation volume. The amount of water required to attain this result depends on the amount of dissolved oxygen in the stream and conditions for replacing it. Leading authorities estimate this at from 4 cubic feet to 10 cubic feet per second per 1000 tributary population. There must also be current sufficient to prevent silting-up of the stream or bay, and it is also important that there be no inshore currents which will deposit floating material on the shore lines. Large quantities of trade wastes from industries may kill fish life and must therefore be considered. The distance required to complete the purification by this method varies also with the character of the stream. A mountain stream with many waterfalls will manifestly purify itself much more quickly than a sluggish lowland river. There are no signs of pollution of the Mississippi at New Orleans and yet it receives above this point, the sewage of over 10,000,000 people. However, for the last 600 miles it travels through delta country where the drainage is away from the river.

**117. Dilution of Chicago Sewage.** The Chicago Drainage Canal is a notable example of disposal by dilution. This canal was constructed at a cost of $64,000,000 to divert the flow from the lake harbor through the Chicago River to the Illinois River, a tributary of the Mississippi. The sewage is diluted on a basis of 3.3 cubic feet per second per 1000 population, although the engineers in charge recommended a minimum of 4 cubic feet per second.

The Illinois River enters the Mississippi 357 miles from Chicago, a few miles above the St. Louis Water Works Intake. In a suit brought by the city of St. Louis to prohibit this arrangement, extensive tests showed that there was no substantial pollution from this source. Recent reports show, however, that for a distance of one hundred miles from Chicago along the Desplaines and Illinois rivers there is a very unwholesome condition and that along the Chicago River there are serious nuisances. Recommendations have been made to remove the solids before dilution.

**118. Other Examples of Dilution.** The sewage of New York is discharged through many outlets into New York Harbor. This has resulted in considerable deposits of silt at many points and studies are now being made of a partial purification of sewage from this metropolitan district.

The sewage from the main district of Boston is carried by an outfall sewer to an island in the outer harbor where it is stored in basins and discharged only during the early hours of the outflowing tide.

Many of the lake cities have long outlet sewers into the lake to prevent silting-up and deposit of solids on harbor front, and also to insure proper dilution.

## BROAD IRRIGATION

**119. General Principles.** Broad irrigation is the oldest type of scientific purification of sewage. It has been practiced on a large scale in England and Germany, and several installations have been made in America. It consists in applying the sewage by a system of ditches to farm areas with the idea of irrigating them and also obtaining the fertilizing value of the sewage. The principle is that of *aërobic* bacterial action by natural filtration, and depends for success on a light and preferably sandy soil and on being able to operate uniformly at all times and seasons without overloading the treated area. An acre of area is the average requirement for each one hundred of tributary population. When this method first came into use, it was predicted that considerable profit would be derived. It has, however, been found that in the wet seasons it is very difficult to take care of the sewage and prevent water-logging the crops without by-passing the sewage; and that as a result the crops that can be raised are limited, and the fertilizing value of the sewage does not justify the expense required to apply it properly.

**120. Efficiency of Broad Irrigation.** The results obtained from well-operated irrigation farms are excellent. The effluent is stable with a marked reduction in bacterial count and in many instances showing absence of *b. coli.* Dr. Dunbar states that he is convinced that it would be cheaper for many towns to abandon irrigation and replace it with artificial biological processes and that the day is not far off when Berlin will sell its irrigation farms for building purposes and construct artificial biological filters.

This is the attitude of all sanitary engineers at the present time. The only condition where it can now be favorably considered is in a district with low rainfall where irrigation is necessary for crop raising, and when the soil is adapted to irrigation.

## CHEMICAL PRECIPITATION

**121. Controlling Factors.** The method of sewage disposal by chemical precipitation was introduced by various private companies under patents at about the same time that broad irrigation came into use, and there have been some large installations in England, Germany, and America.

The sewage is introduced into settling tanks where it is treated with chemicals such as sulphate of iron and lime. These chemicals form a heavy flocculent precipitate which settles in the tanks and carries with it a part of the suspended matter in the sewage. The precipitated material, or sludge, is then drawn off and usually compressed by sludge presses so as to remove the water and facilitate handling.

**122. Efficiency of Chemical Precipitation.** It has been found that 90 per cent of the total suspended matter and bacteria can be removed from sewage by this process. The effluent is putrescible as there has been no change in the remaining organic matter.

When this process was first installed, fabulous claims were made of the value of the sludge as fertilizers from plants of this type. This has been much overrated and it is difficult to get farmers to come to the plants and haul it free. Many such plants have to deposit the sludge in fills and as the amount will average 5 cubic yards per million gallons of sewage treated, there is a considerable quantity for a town of any size. The high cost of chemicals and labor required in the operation has also been against this method which is no longer being installed for municipal disposal works.

**123. Conditions Favoring Chemical Precipitation.** There are some circumstances in dealing with trade wastes or some special conditions, such as at London, under which the chemical process can be used to advantage.

It has been necessary at London to remove the suspended matter to prevent the silting up of the Thames. This has been accomplished by treating the sewage by chemical precipitation amounting to 200,000,000 gallons daily in nineteen settling tanks having a combined capacity of 44,000,000 gallons. About 8,000 cubic yards of sludge is deposited daily. This is pumped into tank steamers and carried out to sea.

## SCREENS

**124. Purpose.** Coarse screens are in general use at sewage pumping stations and disposal works to remove the coarse suspended matters. During the last few years, mechanically operated fine screens have been developed in Germany which can remove as high as 80 per cent of the suspended matter from the sewage. These fine screens are now being introduced into America.

**125. Coarse Screens.** The most common type of coarse screen is the bar screen consisting of vertical steel bars spaced from ½ inch to 1½ inches apart depending on conditions, and arranged in a masonry pit at the outlet end of the sewer across the line of flow of the sewage. The fibrous materials in the sewage make the problem of cleaning a difficult one and screens must, therefore, be installed in duplicate so that one can readily be removed. For small plants, the screens are usually cleaned by the attendant pulling a garden rake up over the vertical bars several times daily. In large plants, one screen is removed from the pit by hoists or hydraulic lift and cleaned with a hose on the operating floor above, or some form of mechanical cleaning device is used.

The material obtained from coarse screens consists of rags, paper, sticks, lemon peels, and other coarse organic matter. This is usually placed in large cans and hauled to a dumping ground where it is buried. If the city owns an incinerating plant, it can be mixed with the garbage and burned.

**126. Fine Screens.** There have been many types of fine screens developed, with varying success. The best known type at the present time is the Reinsch-Wurl screen as shown in Fig. 44. These screens consist of a large circular plate which is placed at an inclined angle in the outfall sewer and is revolved about its center. This plate is perforated over its entire surface with fine slots. The size of slot and diameter of plate vary with the amount of sewage to be treated and the degree of purification to be effected.

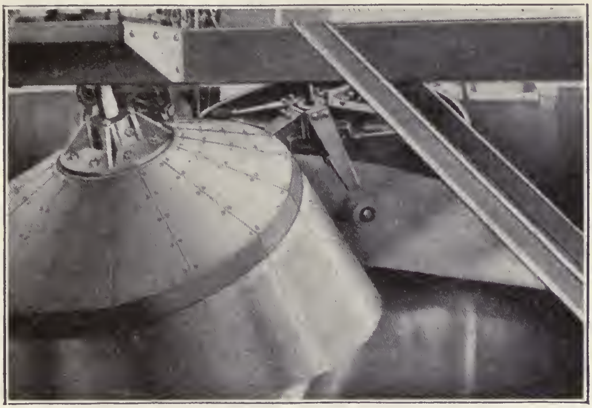


Fig. 44. Reinsch-Wurl Screen in Experimental Plant, Dresden, Germany

As the plate revolves, the deposited solids are brought above the surface of the sewage, Fig. 45, and are then brushed off the plate

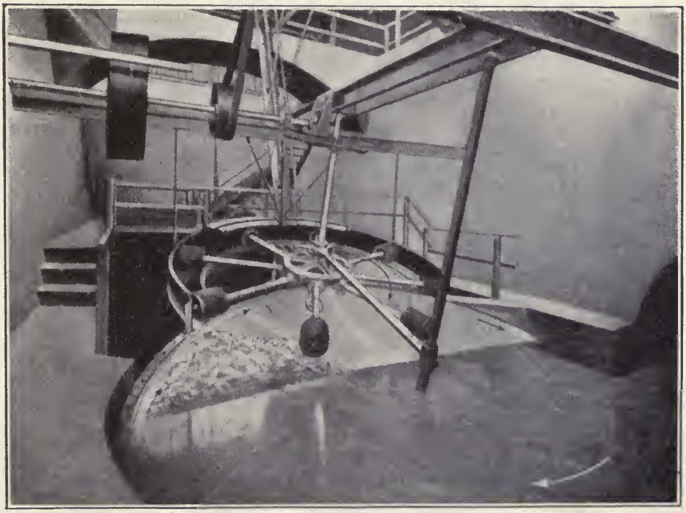


Fig. 45. Reinsch-Wurl Screen in Operation at Bremen, Showing Brushes

by metallic brushes which sweep the screenings into a trough where it is transported to the sludge presses or carted away.

Fig. 46. Installation of Reinsch-Wurl Screens at Dresden, Germany

The amount of power required to drive this apparatus is small and the installation is much less expensive than settling tanks. There are the difficulties, however, of a higher operating cost and the problem of the distribution of the screenings. The screenings can be disposed of as outlined under the paragraphs on coarse screens, but on account of their amount, it is preferable to make some arrangement regarding their use as fertilizers with the farmers, who will take them free unless there is local prejudice. While these screenings have some value, yet they must be removed daily and disposed of immediately before putrefaction sets in, and farmers will not agree to an annual contract on better conditions than free material, on account of the difficulty of distributing it in winter weather.

The plant at Dresden, as shown in Fig. 46, is the largest plant of this type in the world. It was installed in 1911, and treats a maximum flow of 4500 gallons per second. For three months in 1911, the Elbe, into which the effluent is discharged, had a flow of less than one-half that of the incoming sewage and yet no nuisance was caused thereby.

These fine screen installations are specially adapted to use where clarification alone is required for conditions under which it is necessary to install the purification works adjacent to a built-up district. The fresh screenings have not had time to putrefy and can be hauled away easily without offense. They are also used for clarification and the recovering of by-products of industrial waste, and under special conditions for screening sewage to be treated by filters.

## SEDIMENTATION TANKS

**127. Efficiency.** The method generally used for clarifying sewage is by natural sedimentation. This will remove from 50 per cent to 75 per cent of the total suspended matter from the sewage and 35 per cent of the organic matter, leaving the effluent with the balance of the organic matter in solution and in suspension as colloids. Sedimentation is used as a method of clarifying sewage before it discharges into a stream where dilution is feasible, or as the first step in complete purification.

**128. Classes.** There are three general classes of sedimentation tanks: (1) grit chambers; (2) settling tanks; and (3) septic tanks. These classes have various modifications and designs.

**129. Velocity.** Practically all designs are based on a continuous flow through the tanks at a velocity sufficiently low to deposit the suspended matter. Extensive experiments have been made to determine the carrying velocity of sewage-laden water, and as a result of these experiments authorities place the maximum velocity for settling tanks at one-half inch per second, and the average velocity of grit chambers at 1 foot per second.

### Grit Chambers

**130. Use.** Grit chambers are used on combined sewer systems or sanitary systems which admit some street drainage, in order to remove the coarse organic suspended matter before it has reached the pumps or disposal works. Where the sewer system carries only house drainage, they are unnecessary.

**131. Design.** They must be designed so that no organic matter will be deposited and so that the period of retention is not long enough to start septic action. A velocity of 1 foot per second will deposit the grit without the organic matter and the period of retention may vary from a few seconds to 5 or 10 minutes, depending on the coarseness of the material. Where the amount of sewage varies at different times, several compartments must be installed with automatic overflow weirs so that the velocity and period of retention may be uniform. The usual design is rectangular in plan with length sufficient to give the required period of retention and velocity, and with a cross-section suited to securing a uniform velocity over the entire area without complicated baffling. The bottom should be sloped on a 10 per cent grade to an outlet drain controlled by a valve. The details of design are very similar to those for the more complicated settling tanks, which will be hereafter described. The depth used, however, is comparatively shallow, as grit chambers must be cleaned frequently, and too much surplus storage capacity would affect the uniform velocity desired.

### Settling Tanks

**132. Settling vs. Septic Tanks.** Settling tanks can be distinguished from septic tanks by the fact that putrefactive action in the latter results from the action of *anaërobic* bacteria on the organic matter retained therein. An arbitrary definition of septic tanks has been that they must have an uninterrupted flow without removal of sludge for at least six weeks. However, newly cleaned settling tanks have shown signs of septic action in a few days after being placed in commission. Settling tanks retaining their solids are, however, usually distinguished from septic tanks by the frequent cleaning periods in the former case, and the six weeks' period is usually taken as the dividing line.

**133. Basic Conditions.** Settling tanks may be divided into two classes, single-story tanks and two-story tanks. The governing criteria for both classes are a maximum velocity of one-half inch per second, a minimum retention period of one hour, and a minimum distance of horizontal travel of 35 feet.

**134. Single-Story Settling Tanks.** *Design.* The usual type of the single-story settling tank is rectangular in plan and has a continuous horizontal flow lengthwise through the tank. Several compartments are constructed to permit one or more tanks to be used in proportion to the flow of sewage and to permit tanks to be cleaned without interfering with the continuous operation of the plant. The depth of tanks should preferably be 12 feet to 16 feet to give ample room for storage of sludge without its being disturbed by the flow of sewage. Their capacity should be a retention period of from 1 hour to 4 hours with additional time sufficient for sludge storage. Their length and width are governed by the number of units, the capacity and limitation of velocity and horizontal travel given above. The length does not usually exceed 100 feet and the width is usually $\frac{1}{8}$ to $\frac{1}{10}$ the length. Covers over tanks are not necessary, although they are usually installed on well-designed tanks for the sake of appearance. If covers are used, vents must be installed for gases. It is important to obtain a uniform distribution of the sewage across the entire cross-section and to maintain a uniform velocity. This is accomplished by distribution across inlet and outlet ends and by one or more baffles across the tanks. It is very necessary to design the tanks so that they can be cleaned easily. The bottoms must be sloped on a minimum slope of five per cent to a central sump where the sludge can be drained by gravity to a sludge bed or can be pumped. A fire hose with water under good pressure is indispensable in economic cleaning. The sludge bed must be constructed of gravel or other porous material and be well underdrained. The minimum depth must be at least 12 inches, and the surface must be covered with a minimum depth of 2 inches of sand to retain the sludge. The sludge bed must be of area sufficient to permit the sludge to be deposited with a maximum depth of six inches so that it can dry. With this depth it will dry under favorable conditions in from one to two weeks. With well-digested sludge, an area of 0.3 square feet per inhabitant is sufficient.

**135. Sludge.** The sludge problem is the most serious one to be considered with settling tanks. If they are frequently cleaned, this highly putrescible organic matter must be discharged onto the sludge beds every few weeks, causing very disagreeable odors; and when the sludge is scraped off after drying, it must be disposed of. Where the number of tanks is sufficient to permit, one should be placed out of commission so that the sludge can digest in the tank before being discharged, as a period of several months is required to obtain thorough digestion. This is accomplished by the action of *anaërobic* bacteria, which usually produce offensive gases and cause a highly septic liquid in the tank above the sludge. It is therefore dangerous to install plants of this type within half a mile of residences.

### Septic Tanks

**136. Basic Conditions.** These tanks are the same as the single-story settling tanks previously described, except that septic action or the action of *anaërobic* bacteria is desired. The tanks are designed with a capacity of from four hours' to twenty-four hours' settling period so as to insure capacity enough for sludge storage. In America the maximum is twelve hours. The flow through the tanks is continuous and at a slow velocity, exactly as described for settling tanks.

As the sewage flows slowly through the tank, the coarser suspended matter settles to the bottom where it is attacked by millions of *anaërobes* which have developed on the sludge previously retained. Lighter particles rise to the surface forming a thick heavy scum over the entire surface. Small atoms breaking off from this sink to the bottom, while light ones rise from below, impelled by gases. All these are teeming with *anaërobes* which are liquefying and gasi-

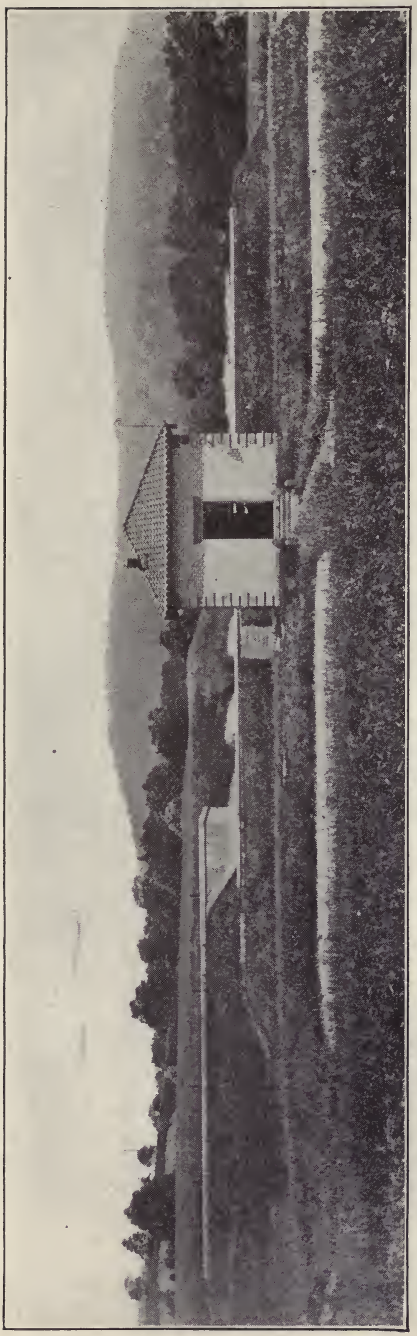


Fig. 47. General View of Sewage Disposal Plant at Polk, Pennsylvania

fying the organic matter. In septic tanks sludge is only removed when there has been an accumulation such that it overtaxes the sludge capacity. Where *anaërobic* action works perfectly, the greater proportion of the suspended matter is liquefied, and it has been found that after retention for three or four months the remaining sludge is inodorous, while in many cases it is removed once a year with little or no nuisance. The difficulties experienced with septic tanks are from the offensive gases usually present in the tank effluent. These gases are liberated when the effluent is discharged onto the biological filters, with resulting nuisance to adjacent property. The oxygen content of the sewage is also removed, which places it in bad shape for *aërobic* treatment either by dilution or filtration.

Where septic tanks work perfectly with no attendant odors in the effluent, they furnish one of the best methods for removing the suspended matters. Most of the single-story settling tanks in America are operated as modified septic tanks. The storage capacity of the sludge is in many cases limited, requiring frequent removal of same, but there is a considerable liquefaction and the sludge fairly stable. It is difficult, however, to prevent fresh sludge that has just been deposited from being drawn off with the more thoroughly digested material under these conditions.

**137. Polk Tanks.** Figs. 47 and 48 show an installation of settling tanks of this type which are used to remove the suspended matter before the sewage is applied to sprinkling filters. Figs. 49 and 50 show the details of these tanks.

This plant was designed to purify the sewage from one of the largest state institutions in Pennsylvania, and to discharge it into

Fig. 48. Covered Settling Tanks of Polk Disposal Plant

a small stream of practically pure water where it was impossible to obtain a flow in the dry season sufficient to render the effluent from the sewers inoffensive or properly diluted. The plant was designed to treat daily five hundred and sixty-four thousand gallons. It consists of screen chambers, settling tanks, sprinkling filters, and disinfection apparatus, for the disinfection of the effluent with chloride of lime.

There are four settling tanks, Fig. 48, each 80 feet long by 16 feet wide by 10 feet deep, and each with a capacity of 96,000 gallons, which permits of a settling period of 12 hours with three tanks in operation.

As will be noted in Figs. 49 and 50, the sewage is admitted into a reinforced-concrete distributing trough extending across the inlet ends of the entire group of tanks, from which sewage can be admitted into one or more compartments through two or three

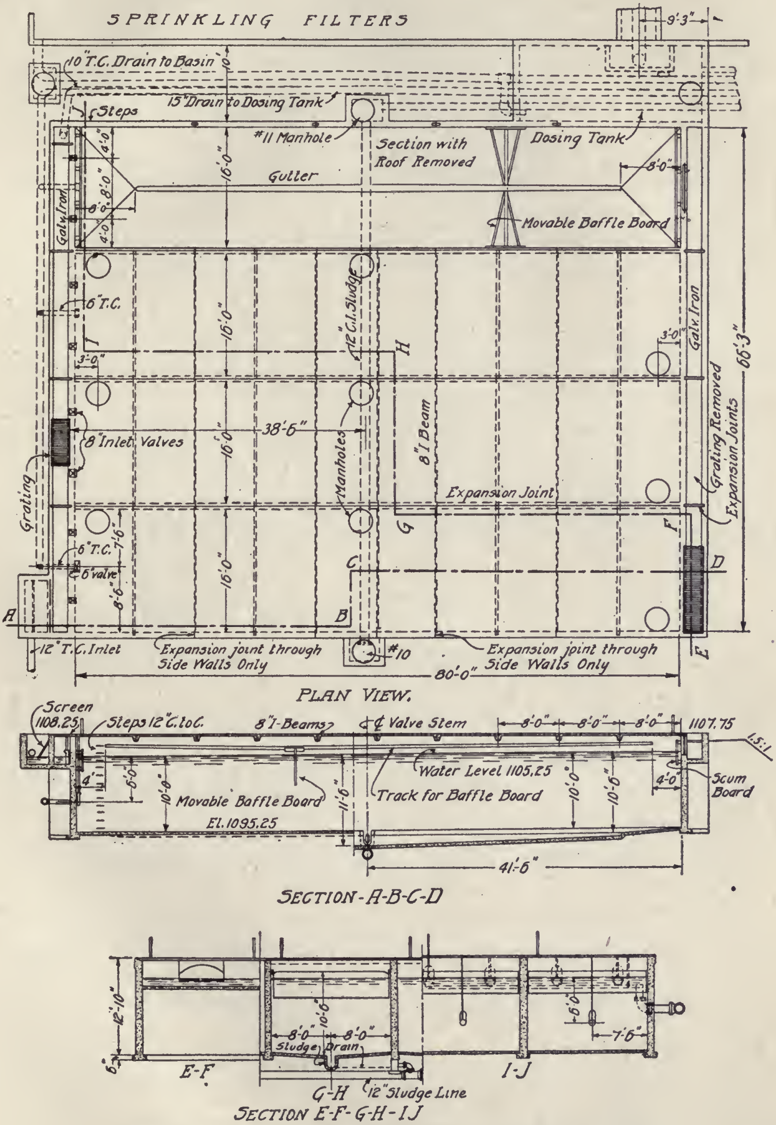



Fig. 49. Detailed Plan and Sections of Covered Settling Tanks

gate valves located immediately below the flow line. A distributing baffle of wood is constructed across the inlet end of each tank opposite these gate valves at a distance of 10 inches from the wall and extending to a depth of 2 feet below the flow line. This baffle distributes the sewage uniformly across the inlet end of the tank. At the outlet end of each tank the sewage is removed over a steel weir 6 feet long located at the flow line of each compartment and at the center of the wall. This weir is also protected by a wooden

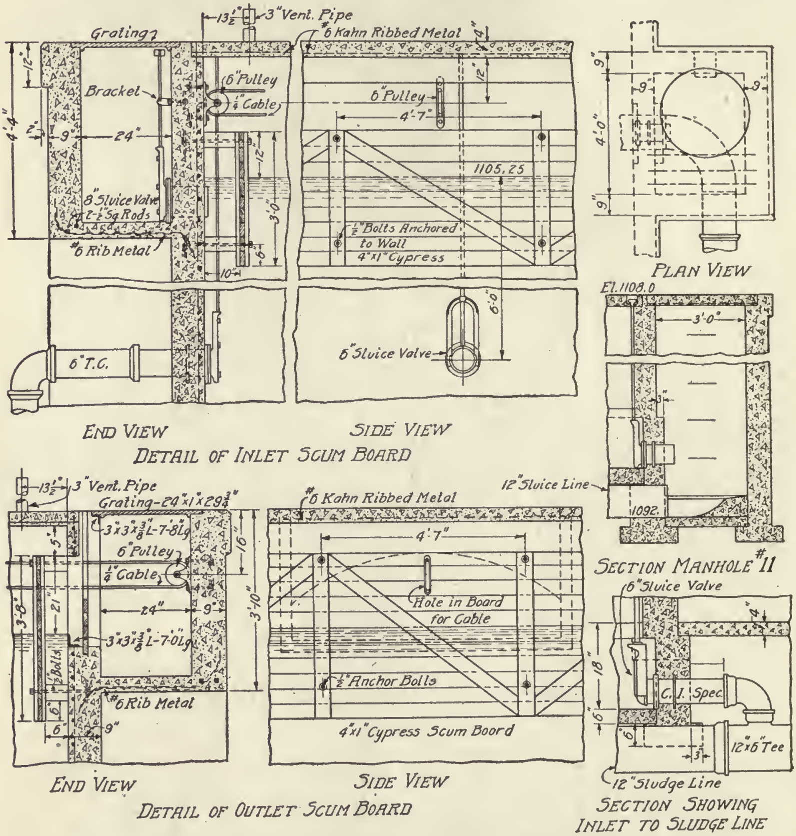



Fig. 50. Diagram Showing Special Details of Polk Covered Settling Tanks

baffle to assist in taking off the sewage uniformly from the entire width of the tank and to protect the outlet from floating material or from solid matter that may be working up from the bottom of the tank because of septic action.

A movable wooden baffle extending 4 feet 6 inches below the flow line is suspended on a trolley running the length of the tank and can be located at any point between the inlet and outlet ends as may be desired. This baffle is also used to prevent cross-currents and to assist in a uniform flow through the tank. It will be noted by further reference to the illustrations that stop planks are arranged on the outlets of the various compartments and on the inlet and outlet troughs opposite the partition walls between the tanks. By adjusting these stop planks the tanks can be operated in series instead of in parallel.

It will be noted that, for the purpose of cleaning, the concrete bottom of each compartment slopes on a 5 per cent grade to a gutter extending lengthwise through the center of each tank, as shown in section *GH* in Fig. 49. The bottom of this gutter is also placed on a 5 per cent slope and at the center of the tank there is a 6-inch valve connection for draining off the sludge to a 12-inch sludge line, extending under the tanks and carrying the sludge by gravity to sludge beds. It will also be noted that the tanks are covered with concrete roofing and that the inlet and outlet troughs are covered with cast-iron gratings which serve to improve the general appearance.

This plant has been in operation for over five years, and the results obtained from these settling tanks have been highly satisfactory. They have maintained uniformly over fifty per cent removal of the suspended matter and there has been a very small accumulation of sludge, most of it being liquefied in the tanks. A small amount is removed at frequent intervals and discharged on the sludge bed and when dried is scraped off and plowed into adjacent ground. There have been no complaints of offensive odors and practically no trouble from gases liberated by *anaërobic* action. The plant is, however, well isolated, being three thousand feet from the institution. It is typical of the higher grade settling tanks in America and if it were not for the frequent removal of sludge, thereby preventing complete septic action, it would be typical of the septic tanks.

**138. Two-Story Tanks.** *Basic Conditions.* The problem of eliminating the nuisance arising from the use of settling or septic tanks where offensive odors are in many cases given off by the effluents due to the *anaërobic* action in the compartments, and the difficulties experienced in handling the sludge and obtaining thorough digestion of it before it is removed from the tanks, has resulted in the development of a type of tank where the sewage flowing through the tank is kept entirely separate from the deposited suspended matters. It has been found also that septic action does not benefit the liquids for the secondary treatment on the biological filters, but that in fact it is preferable to get the liquids to the biological filters in a condition as fresh as possible, in order to retain some oxygen which would be favorable in the secondary treatment. The typical tank of this type is the Imhoff tank developed by Dr. Karl Imhoff, the German expert.

*Design.* In this type of tank the sewage flows through an upper compartment under the conditions previously specified

Fig. 51. Installation of Imhoff Tanks at Atlanta, Georgia

for travel and velocity, but with a retention period of from one to four hours. The compartment is equipped with a sloping bottom placed on a slope of not less than 1.2 vertical to 1 horizontal, and terminating in a sealed slot, with a lap horizontally of at least 8 inches. This slot discharges into a lower compartment that has no connection with the upper compartment other than the sealed slot. This lower compartment is designed to retain a capacity of at least six months' sludge, based on a capacity of 1000 cubic feet per thousand inhabitants. The lower compartment is usually built cone shape, terminating in a sump at the bottom from which there is a discharge line for the sludge bed. There must also be an opening from the compartment to the surface as a discharge for gases and as an admission for cleaning. As the sludge is drawn from the bottom of the compartment, and as there is six months' capacity for *anaërobic* action, if the sludge is drawn off in small

Fig. 52. Interior View of Imhoff Tanks at Batavia, New York

Fig. 53. Installation of Imhoff Tanks at Essen, North Germany

quantities at intervals of six weeks, only thoroughly worked over sludge will be placed on the sludge beds and the result is that there can be no nuisance.

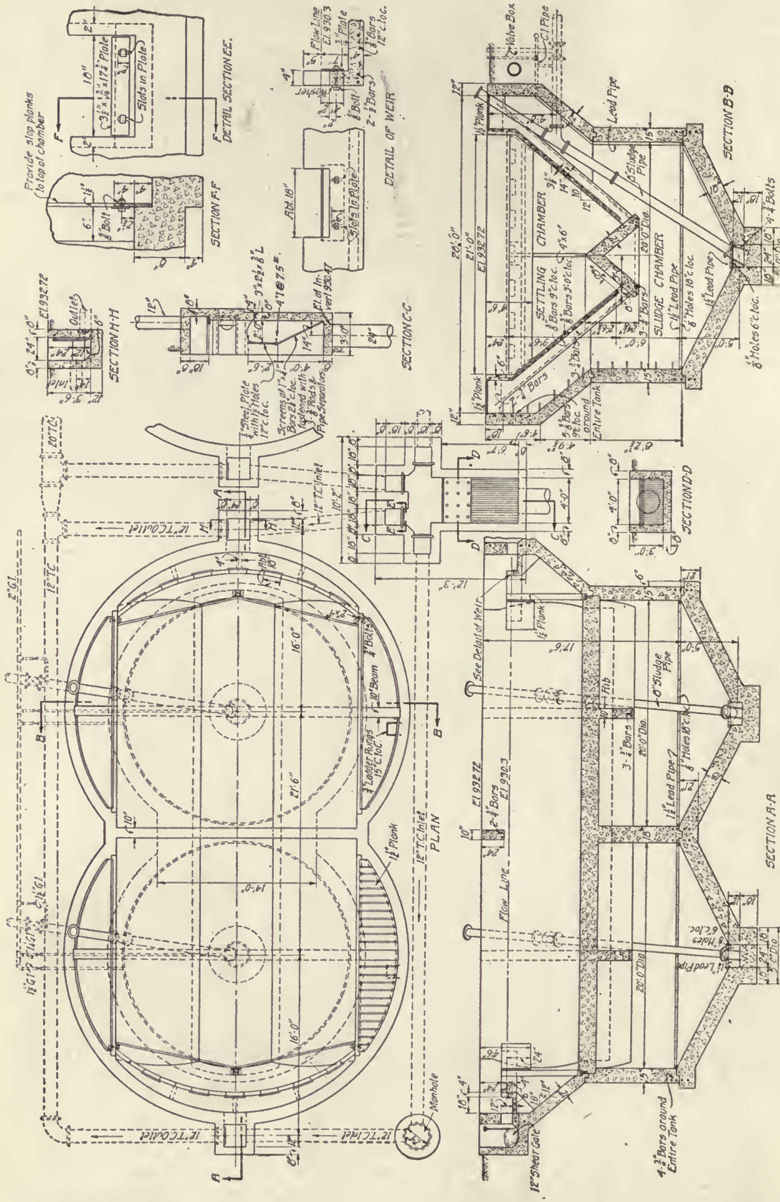



Fig. 54. Plan and Sections of Imhoff Tanks at Greenville, Pennsylvania

*Operating Results.* Figs. 51 to 53 show installations of this type of tank at Atlanta, Georgia, Fig. 51; at Batavia, New York, Fig. 52; and at Essen, North Germany, Fig. 53. The Atlanta plant was placed in service in 1912, and the result of the operations for the years 1913 and 1914, which was recently published, showed an average removal of total suspended matter by the Imhoff tanks of 80 per cent. The average period of retention in the flow of sewage was two hours. The plant at Batavia, New York, which was installed in 1912, is also giving excellent results. No nuisance has been noticed at either plant and the sludge removed from the tanks has been well-digested and inodorous.

**139. Greenville Tanks.** There are various forms of design for the Imhoff tanks. Fig. 54 shows the plans for the Imhoff tanks to be installed for Greenville, Pennsylvania. These tanks are of the circular type, constructed in pairs and arranged for a longitudinal flow through each pair. Piping facilities provide for reversing this flow, a necessary operation every few weeks in order that the deposited material may be uniformly distributed in both tanks. The entire capacity of this plant is one million gallons per 24 hours based on a settling period of $1\frac{1}{2}$ hours, and on a sludge storage of 6 months for seven thousand people. Imhoff tanks are constructed of reinforced concrete and the arrangement for admitting sewage to the tanks and reversing its flow is by means of cast-iron pipe lines controlled by concrete manholes with stop planks as shown. Sewage is distributed across the inlet end of the tank by concrete weirs spaced uniformly along the outer edge of a trough of the same material built across the entire width of the tank at the inlet end and protected by a wooden baffle extending to a depth of 24 inches below the flow line. This baffle serves to distribute sewage uniformly across the entire tank. Sewage is taken off at the opposite end of the pair of tanks by a concrete trough similar to the one described, also protected by a skimming baffle. The upper compartment is separated from the lower compartment by a reinforced-concrete slab, terminating in two slots on each side of a wedge frame built at the bottom of the compartment as shown. (See section *BB* of Fig. 54.) It will be noted in the design, that the upper or settling compartment is common to the two tanks, but that the lower or sludge compartments are entirely independent of each other. The sludge is removed from a sump at the center of the sludge compartment of each tank by means of an 8-inch sludge pipe extending to within a few feet of the flow line of the tank, where it is connected by a valve to a gravity drain extending

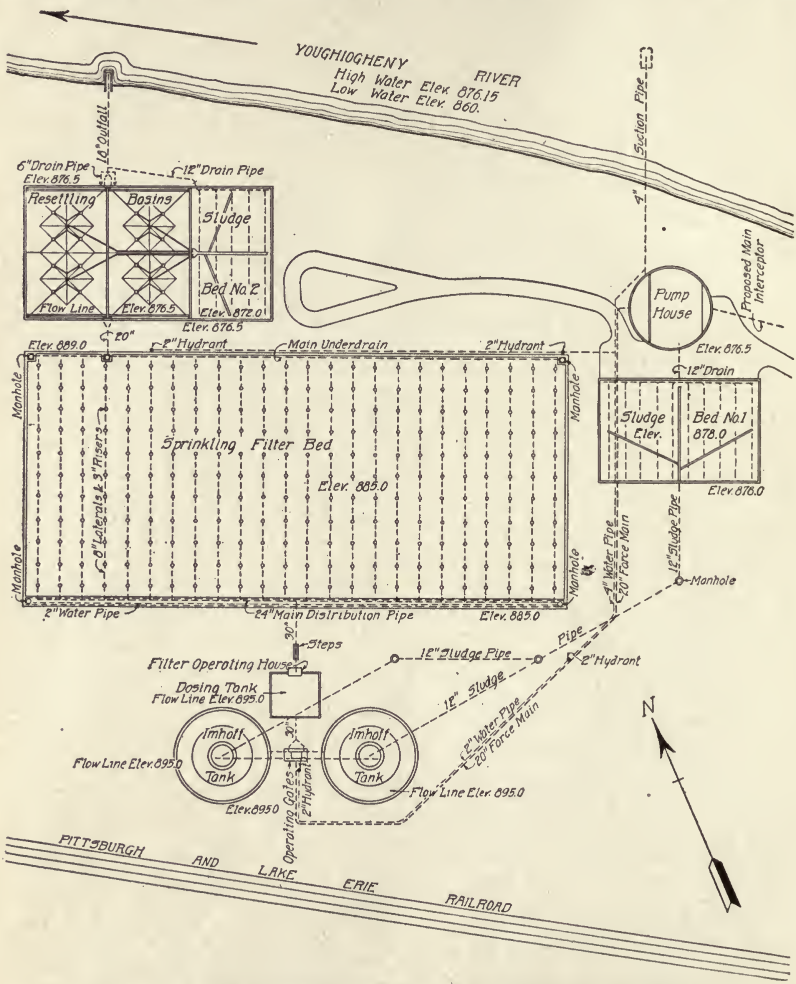



Fig. 55. Plan of Sewage Disposal Plant at Connellsville, Pennsylvania

to the sludge bed. Without interfering with the operation of the tank, sludge is removed by hydraulic pressure in the tank upon opening this valve. It will be further noted by reference to the illustration that ample area is left along the sides of the settling

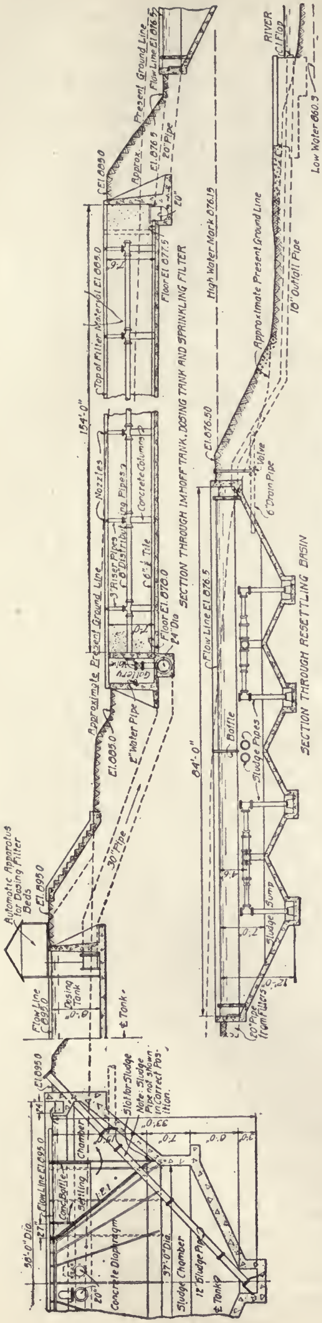



Fig. 56. Section of Sewage Disposal Plant at Connellsville, Pennsylvania

compartment at the top of the Imhoff tanks for ventilating the lower compartment. These compartments are covered with removable wooden gratings as shown.

**140. Radial-Flow Tanks.** Figs. 55 and 56 show a typical design of what is known as the radial-flow Imhoff tanks. These tanks were designed for a sewage disposal plant for Connellsville, Pennsylvania, a town having a population of sixteen thousand and a flow of sewage of three million gallons per 24 hours. Two radial-flow Imhoff tanks are planned for this installation. They are designed for two hours' capacity in the settling compartment and for a six months' storage of sludge, and are to be constructed of reinforced concrete. Sewage will be admitted through a manhole between the tanks, Fig. 55, from which it will be diverted to one or both of the tanks by means of stop planks controlling 20-inch cast-iron pipes extending to the circular trough near the center of each tank. This circular trough will be 14 feet in diameter and 27 inches wide, and will have slots in the bottom of it spaced uniformly around the circumference at a depth of 3 feet below the flow line. The diameter of each tank will be 58 feet. The settling chamber will be separated from the sludge chamber by a cone diaphragm of concrete as shown, with a slot located at the bottom of the diaphragm, between it and the outside sloping wall of the tank. Halfway across the settling chamber between the circular inlet and outlet troughs, there will be a concrete baffle extending to a depth of half the tank at this point from the top. The outlet trough will be arranged with outlet weirs spaced along the top of the trough at uniform distances and at the same level. The sludge compartment will be drained by a sludge pipe extending from a sump at the center of the compartment to a gate valve located outside of the tank and 5 feet below the flow line. By opening this valve the sludge will be drained by hydraulic pressure without interfering with the operation of the tank.

*Flushing.* One of the most important adjuncts to equipping Imhoff tanks is a good fire hose with plenty of water pressure, and with facilities for applying it to any portion of the tanks. This is valuable in breaking up or removing any scum formation in the settling compartment, in keeping the sludge pipe clean, and in washing off any compartment which may be drained.

## CONTACT BEDS

**141. Use.** Contact beds are a type of the biological filters generally used for treating sewage from which most of the suspended matter has been removed by sedimentation or by fine screens. They are employed to further remove additional organic and suspended matter and to render the effluent non-putrescible.

**142. Basic Conditions.** Contact filters are constructed of broken stone, hard slag, or well-burned cinders, preferably of material ranging in size from $\frac{1}{4}$ inch to 2 inches. The filters are usually of an effective depth of from 1 foot to 5 feet, depending on the amount of head available. The best depth is 4 feet to 5 feet and with this depth a maximum flow of 700,000 gallons of clarified sewage can be treated per acre. As a general rule 150,000 gallons per acre is the maximum amount that can be treated for each foot of filter depth. The beds must be operated so that they will be frequently filled with air, as the action is entirely that of *aërobic* bacteria. These bacteria exist in enormous numbers over the surface of the filtering material throughout its entire depth. When the sewage is placed in contact with this filtering material, the remaining suspended matter in the sewage consisting mainly of colloids and non-settling solids, is to a great extent retained in contact with the filtering material by attrition; and the enormous bacterial growths of *aërobic* bacteria attack this organic matter, quickly reducing it to inorganic forms.

**143. Design.** Most of the contact filters installed in America are operated on the fill-and-draw method, being controlled by automatic apparatus which admits the sewage to one unit of a group of filters and when this is full opens up the outlet from it, and at the same time starts the sewage flowing into the next filter. These filters must be constructed as water-tight compartments and are usually built of concrete. The number of groups to be used and the size of units in each group depend upon the amount of sewage to be handled and the depth of filter desired. It is usually not desirable to have the units larger than a quarter of an acre each, and, on the other hand, it is advisable to have at least four units in order to secure long resting periods between the dosing. It has been found that the period of retention has very little to do with the efficiency, so that in most installations, the apparatus is arranged in such a way that the tank starts to empty a few minutes after it has filled.

**144. Alliance Filters.** Figs. 57, 58, and 59 show a plan of the plant and the contact filters of Alliance, Ohio, and the automatic control apparatus for one group.

As will be noted upon reference to the plans, the Alliance filters are designed to treat sewage clarified by settling tanks. They have a capacity for two million gallons of sewage per day. They consist of three groups, each with a total area of one acre and subdivided into four filters. Each filter has an effective depth of 5 feet and consists of a concrete compartment filled with well-burned cinders and underlaid by tile drains upon the floor, which drain to the central control chamber. The sewage flows from the settling tanks to the central control chamber of each group of contact beds, where it is distributed by automatic air-lock apparatus on to each bed at the surface. This apparatus consists of Miller-Adams siphons, each of which is controlled by an air bell which can break the siphon seals. These air bells are located in concrete compartments and connected by small pipes to the siphons. As the water

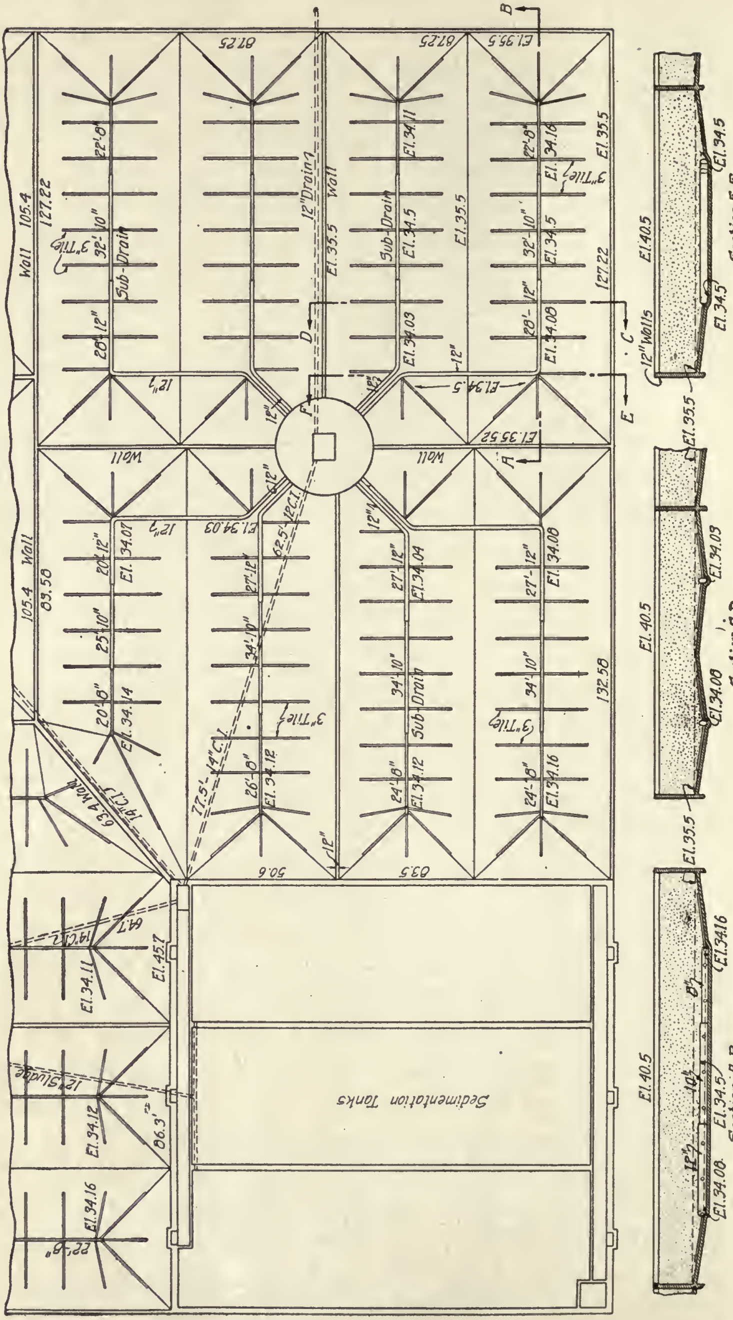



Fig. 57. Plan and Sections of the Contact Beds at Alliance, Ohio

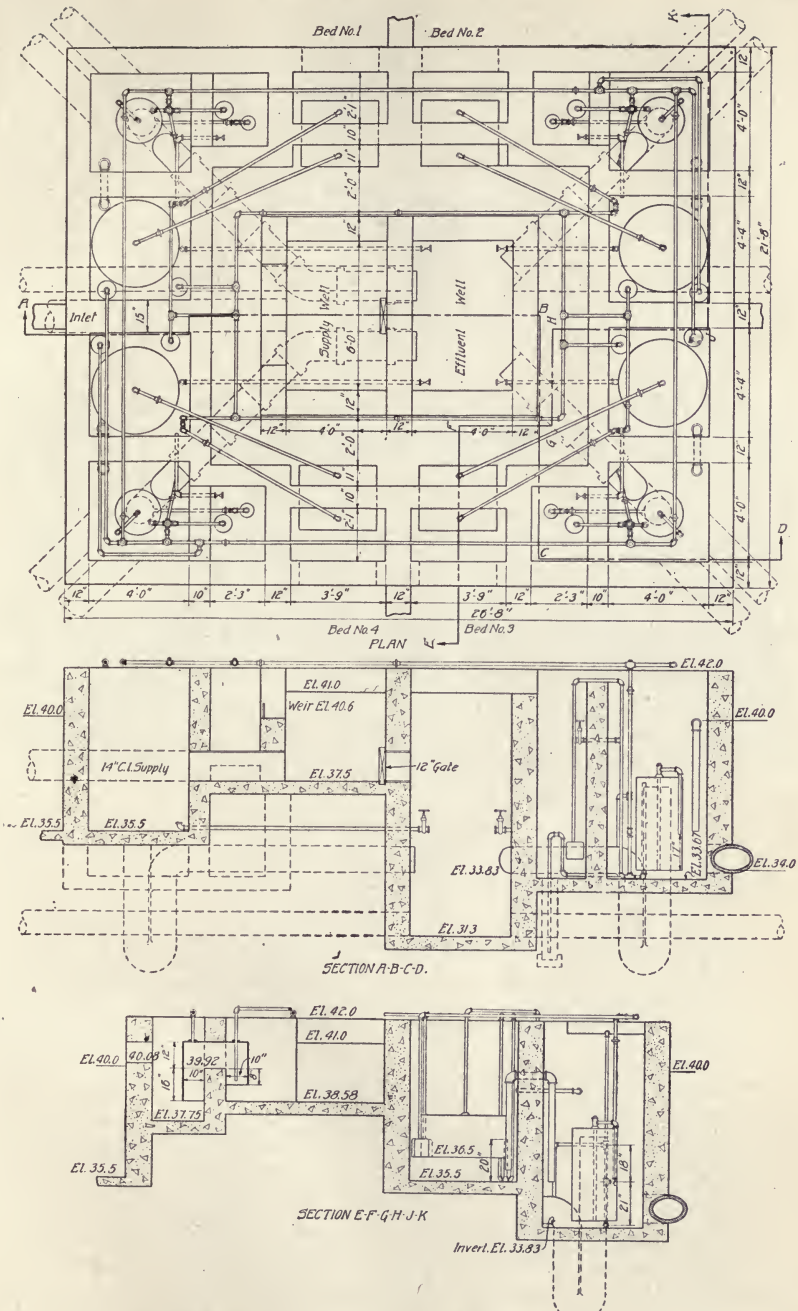



Fig. 58. Plan and Sections of Automatic Control Chamber for Contact Beds at Alliance, Ohio

rises in these compartments which are connected up to the filters, it displaces the air in the bells, gradually compressing it until it is of pressure sufficient to displace the sewage in the connected siphon, so that when one filter is full, it closes itself, opens up the inlet valve to another filter, and then opens up the outlet valve of the filter just filled.

**145. Head Required.** Contact filters are well adapted to gravity filtration plants where the loss of head due to the operation of the plant is limited to 6 feet or 8 feet. They are much more expensive in construction than sprinkling filters, which are less

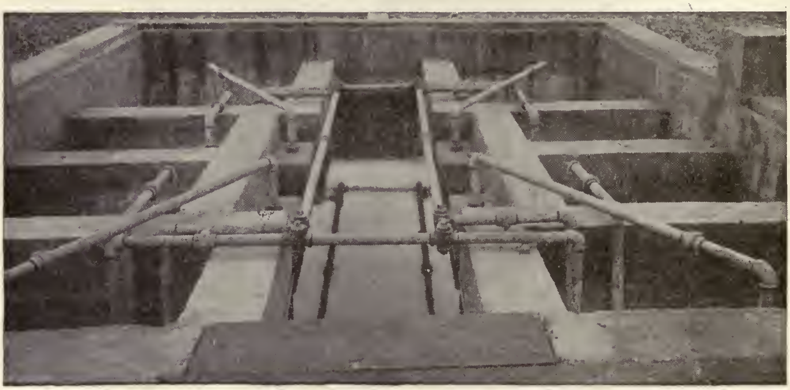


Fig. 59. Automatic Control Chamber for Contact Beds at Alliance, Ohio

likely to clog up and which give equally good results. Sprinkling filters, however, require at least eleven feet of head.

### SPRINKLING FILTERS

**146. Use.** Sprinkling filters operate on the same principle as contact filters and are used for the same purpose, although the method of application of the clarified sewage is entirely different. They are essentially biological filters depending upon the action of *aërobic* bacteria, and the same method of removing the remaining suspended and organic matter from the sewage is carried out in the sprinkling filters.

**147. Design.** Sprinkling filters do not require water-tight concrete compartments and do not have to be subdivided. They can, therefore, be constructed much more cheaply than contact beds. They are built with an effective depth of from 5 feet to 8

Fig. 60. View of Sprinkling Filters in Operation at Polk, Pennsylvania, Disposal Plant

feet and are constructed of broken stone or other material with a dense clear fractured surface of a size ranging from 1 inch to 3 inches. The sewage is applied to the surface every fifteen or twenty minutes by means of troughs, nozzles, or traveling distributors so as to spread uniformly in a fine spray over the entire surface, Fig. 60. It then trickles down through the broken stone, only a few minutes being required for it to pass through the filters. The period of application is usually five minutes. The bottom of the filter is entirely underlaid with tile to assist in aëration, and provision is usually made for ready access to the underdrains and distributors, for frequent inspection and for cleaning if necessary.

Sprinkling filters are operated in America under ordinary conditions with clarified sewage at a rate of two and one-half million

Fig. 61. Danville, Pennsylvania, Sprinkling Filters in Operation at 14 Degrees below Zero

gallons per acre per day. Here the usual method of distributing the sewage on to sprinkling filters is by fixed nozzles connected by piping system to an automatic siphon, or to a motor-driven rotating valve. This siphon or valve is supplied by a dosing tank of capacity sufficient to furnish a five-minute dose to the filter and permit the desired resting period. These tanks are usually built in the form of an inverted cone and are known as tapered tanks, this arrangement being necessary to distribute uniformly the sewage over the area supplied by each fixed nozzle. The flow line in this tank is from 5 feet to 10 feet above the surface of the filter in order to give the pressure necessary for distribution. It is, therefore, essential to have a total head of at least 11 feet for proper operation of sprinkling filters with fixed nozzles.

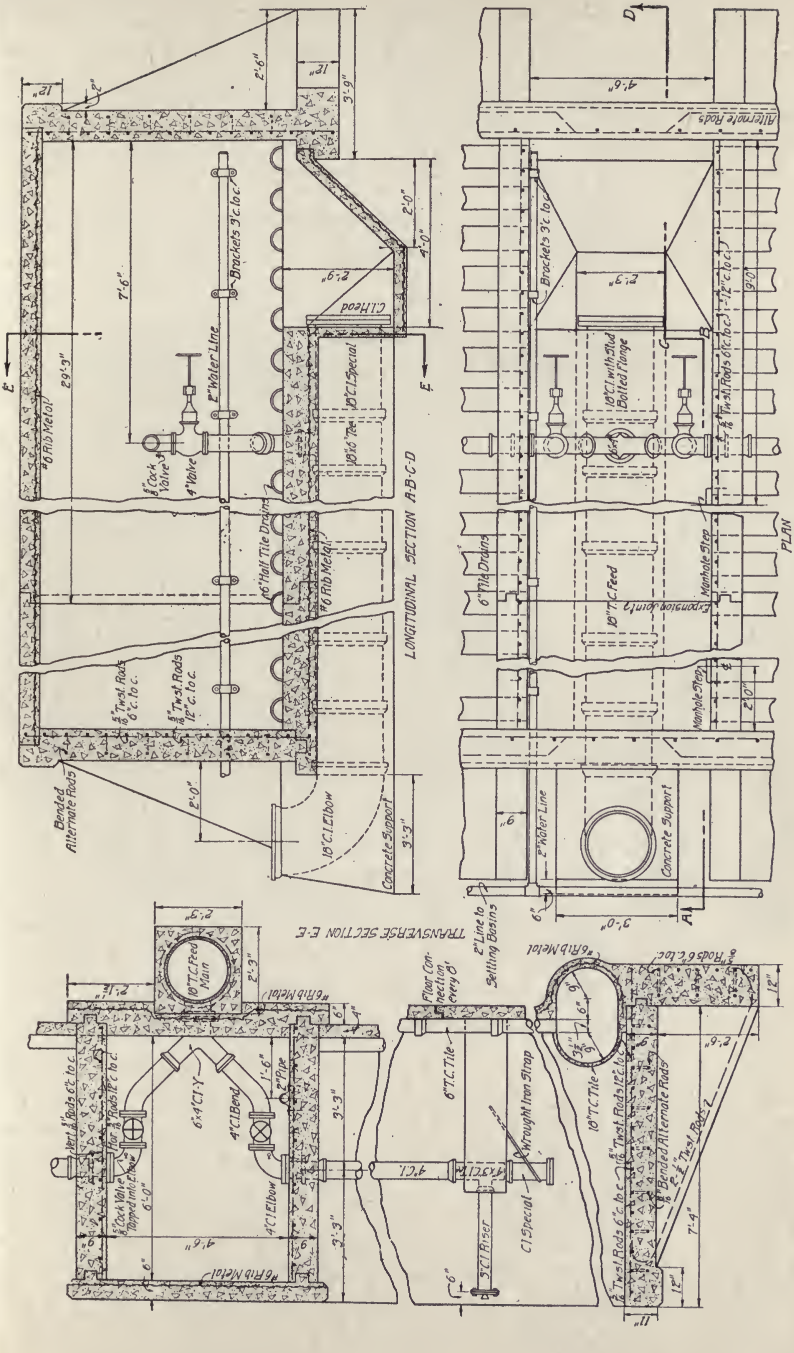



Fig. 62. Typical Details of Sprinkling Filters

**148. Results.** The effluent from filters of this type is more putrescible and usually shows a marked reduction in bacterial count over the raw sewage. These filters are self-cleansing, freeing themselves of the accumulated material after it has been mineralized. The effluents are, therefore, not clear, but this suspended material may be removed by settling.

**149. Examples.** Figs. 60 and 61 show sprinkling filters in operation for the Polk Plant and the Danville Plant. The Danville filters were being operated at a temperature of fourteen degrees

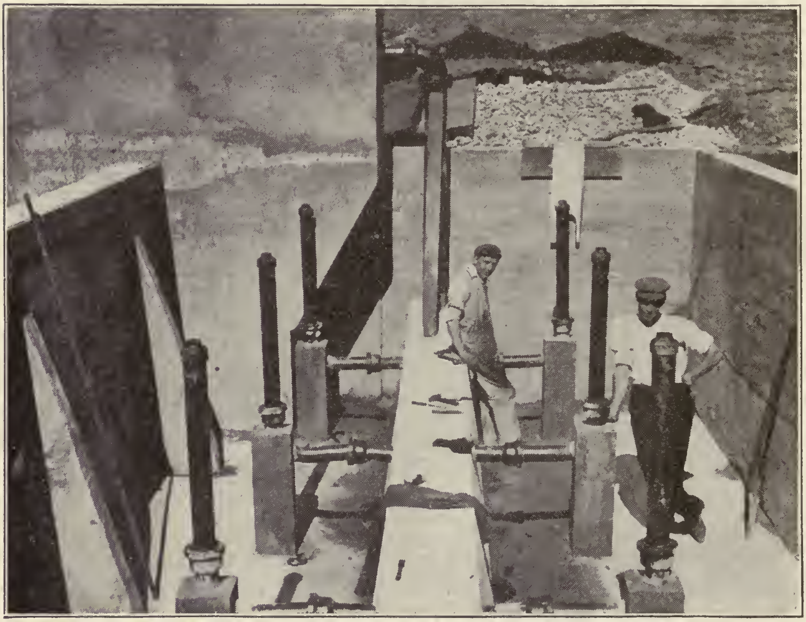


Fig. 63. Interior of Small Sprinkling Filters, Showing Distribution System

below zero at the time this picture was taken. No trouble has been experienced in America in operating sprinkling filters during cold weather.

**150. Polk Filters.** Figs. 62, 63, and 64 show details of the construction of sprinkling filters. It will be noted that all of the filters are operated by automatic siphons supplied by concrete tanks at the outlet ends of the settling tank. These siphon chambers are designed for a capacity sufficient to give an interval of fifteen to twenty-five minutes between doses as may be desired.

To refer in detail to the Polk sprinkling filters, which are typical of American installations, these filters are designed in two units, separated by a concrete gallery in which are located the valving and connections for the distributing line. This gallery is 4 feet wide and 6 feet deep. Under the floor of this gallery there is an 18-inch conduit connected to the siphon chamber at one end of the gallery and adjacent to settling tanks. From this conduit

Fig. 64. Interior of Sprinkling Filter, Showing Underdrains Partly Laid

at intervals of 12 feet there are 6-inch risers which supply the 4-inch distributing lines in the two filters. Each distributing line is controlled by a 4-inch valve. The distributing lines, as will be noted, are constructed of cast iron and are supported every twelve feet by concrete columns. Along these distributing lines are located the riser pipes to the nozzles, which are so spaced as to place the nozzles 14 feet center to center. The distributing lines can be cleaned readily by removing the flanged elbows in the operating gallery. The nozzles consist of a brass throat $\frac{9}{16}$ inch in diameter, above which is set a brass cone, as shown in Fig. 65. The sewage when discharged through the throat of the nozzle, strikes this cone and is sprayed over the surface of the filter as indicated in the illustration. The underdrains for these filters consist of 6-inch split tile laid on a concrete slab and sloping from the control gallery to a cross-drain located at the opposite side of each filter. These underdrains are spaced 12 inches center to center and extend through the gallery wall to the interior so that they can be flushed out with a hose from the gallery and can also be ventilated through same. The filtering material consists of a hard sandstone ranging in size from 4 inches to 1 inch with an effective depth of 6 feet. These filters are constructed with concrete walls around each unit. In many installations, however, a dry rubble wall is used for the outside walls and in some cases where the filters are located above ground, the filtering material itself is carefully laid up to serve as a wall for the filter.

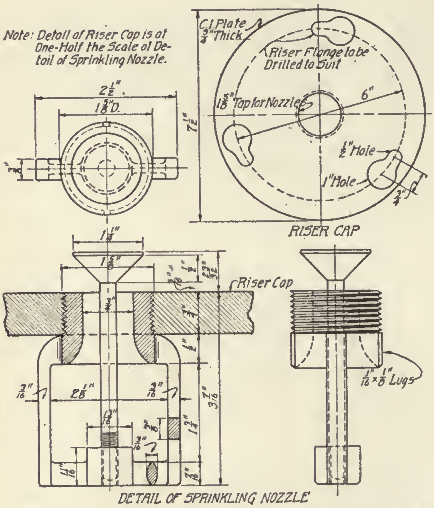



Fig. 65. Details of Sprinkling Filter Nozzle

## SAND FILTERS

**151. Use.** Sand filters represent an artificial type of broad irrigation in two respects: (1) they consist of specially prepared filters of coarse sand, well underdrained and provided with distributing troughs for applying the sewage uniformly to the surface; and (2) the results obtained are from the action of *aërobic* bacteria on the organic and suspended matter that is retained in the sand. They may be used to treat raw sewage or clarified sewage or as a final treatment after biological filters. Sand filters will give a much higher degree of efficiency than the two types of biological filters previously described, and the effluent from sand filters should not only show a high degree of efficiency in the removal of organic matter, but also a marked reduction in the bacteria.

**152. Design.** Sand filters require an area of $1\frac{1}{2}$ acres per 1000 people for raw sewage; $\frac{1}{2}$ to 1 acre per 1000 people for clarified sewage; and $\frac{1}{8}$ to $\frac{1}{4}$ acre per 1000 people as a final for biological filters. They must be operated intermittently to permit a thorough aëration of the sand between the treatment periods. These filters are usually constructed of a depth of from 2 feet to 4 feet and are underlaid with underdrains in a manner similar to the contact filters. The sewage is usually applied to a depth of 2 inches over the entire surface of the filter at intervals of not less than 8 hours apart and at longer intervals if possible. The sewage is usually distributed by a series of wooden troughs extending over the surface of the filter from the automatic control apparatus and provided at frequent intervals with gates or notches for spreading the sewage over the surface. In cold climates a ridge and furrow method of distribution must be used to prevent freezing.

Sand filters are usually installed in groups, arranged and controlled in a manner similar to that described for contact beds, with the exception that the sewage is applied to the trough system on the surface, there being no control to the outlet drains.

**153. Alliance Filters.** Fig. 66 shows the arrangement of sand filters which are used to filter the effluent from the contact beds at Alliance, Ohio. Sewage is allowed to run onto one bed at a time from a common collector connected with the contact beds. After several hours, the flow is shut off by hand and turned onto the next bed. These beds, with a uniform depth of three feet, have a total area of four acres and are therefore designed to treat the contact bed effluent at a rate of 500,000 gallons per acre per day. Having been distributed over the surface by wooden troughs, the sewage is collected by a system of terra cotta tile drains as shown. A central control tank is also frequently installed of a capacity sufficient to dose out enough sewage to cover the surface of the filter to a depth of 2 inches and to store enough to give the proper periods of intermission, as above outlined.

Sand filters in most locations in America call for an installation expensive in comparison with that of contact beds or sprinkling filters supplemented by disinfection, and they are therefore few

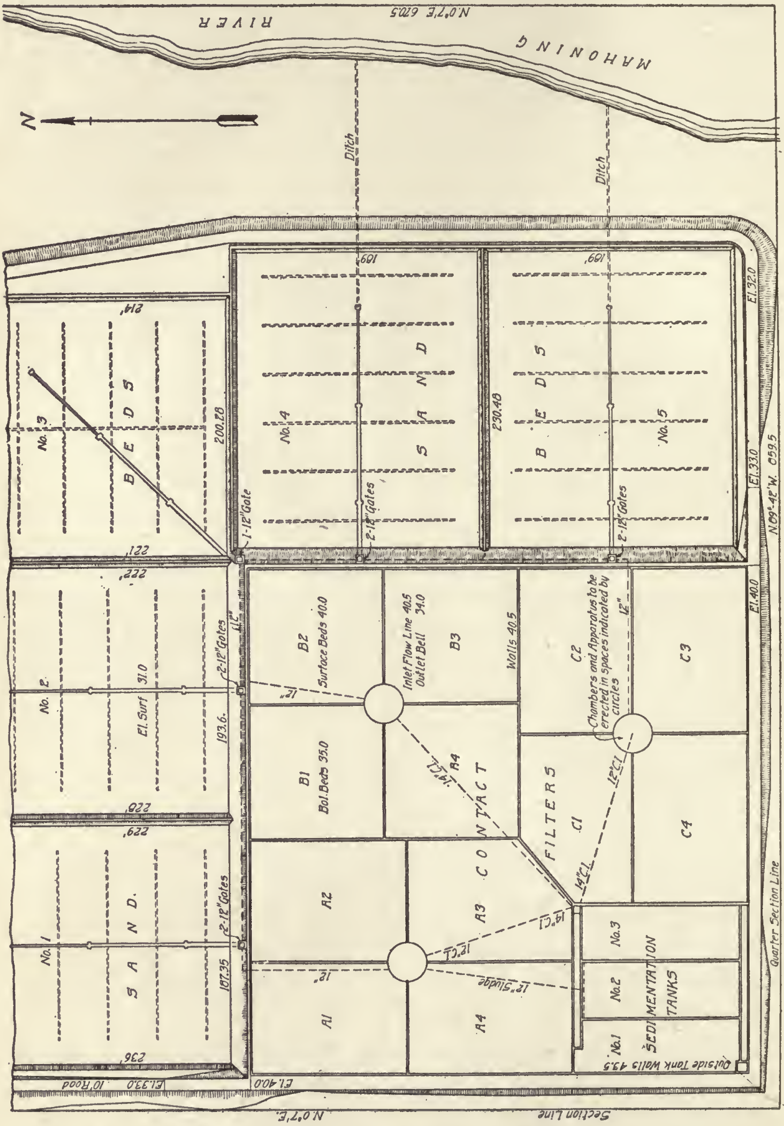



Fig. 66. Plan of Sand Filters at Alliance, Ohio

in number on any scale, outside of the New England district where sandy areas are abundant.

## DISINFECTION

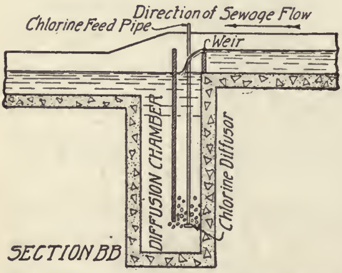
**154. Purpose.** Where sewage or the effluent from a disposal plant is discharged into a stream above a water supply, it is necessary to remove the danger of transmitting water-borne diseases. This is accomplished by disinfection or the removal of pathogenic bacteria as indicated by the absence of *b. coli.* Sterilization consists in the removal of all bacteria. As the pathogenic bacteria are weaker than the rest of the sewage bacteria, they are removed more easily and at less expense. It is found also that in sterilizing sewage, the organic matter is unaffected and upon its being discharged into a stream, new growths of bacteria will quickly develop from those already in the stream. Sterilization is, therefore, usually not attempted.

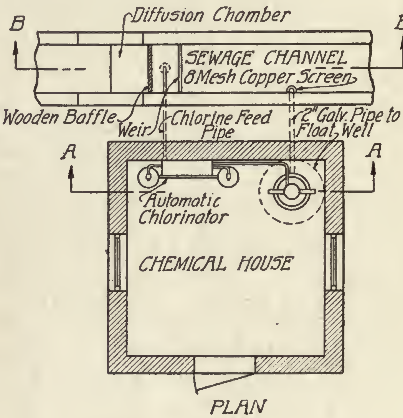
**155. Method.** Disinfection may be accomplished by the application of a definite amount of hypochloride of lime in solution, or chlorine gas, or electrolytic action. Chloride of lime may be purchased commercially at from $1\frac{1}{4}$ cents to 3 cents per pound depending on the size of containers, with a rated strength of 33 per cent available chlorine. It is then dissolved in a weak solution of water, and this solution is applied to the sewage at a rate of 3 to 4 parts available chlorine per million parts of sewage by weight, or 75 to 100 pounds per million gallons. At this rate, a complete removal of *b. coli* can be obtained and a great reduction in total bacteria. Most of the bacteria are destroyed instantly, but it is necessary to have fifteen or twenty minutes' contact to obtain thorough disinfection. After treatment, the sewage is therefore allowed to flow through a compartment of fifteen or twenty minutes' maximum flow capacity.

The chlorine gas treatment costs about the same as the chloride of lime and is more efficient in that it is more easily controlled. It consists of containers of chlorine gas compressed to a liquid. This liquid is fed by automatic apparatus at the desired rate into the sewage.

The electrolytic treatment is more expensive in operation under ordinary conditions. It consists in passing a current through the sewage between poles which form an electrolyte and give a nascent oxygen treatment to the sewage. In addition to the disinfection, there is a precipitation of a part of the suspended matter.

Fig. 67. General View of Liquid Chlorine Disinfection Plant



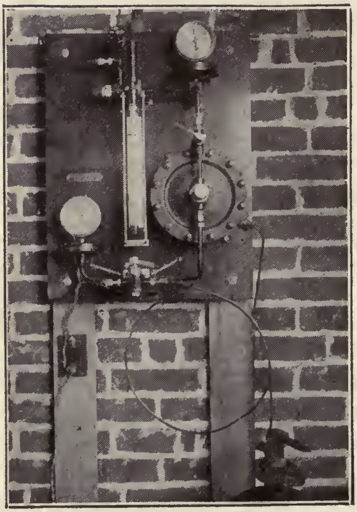



Fig. 68. Automatic Chlorinator

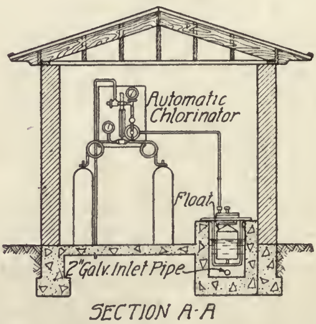



Fig. 69. Plant and Sections of Disinfection Plant

**156. Automatic Appliances.** Automatic devices are required for efficient disinfection since it is necessary to apply the solutions at a rate in proportion to the flow of sewage, and as the flow varies hourly. With the use of chloride of lime, this can be accomplished by a float chamber connecting to the sewer and arranged so that the float operates a lever which varies the head on the orifice from the solution box in proportion to the flow of sewage. A diaphragm control from a Venturi meter on the sewer is another method. Liquid chlorine must be fed by automatic apparatus that not only keeps the treatment of the sewage uniform, but also controls the liquid chlorine pressure tank.

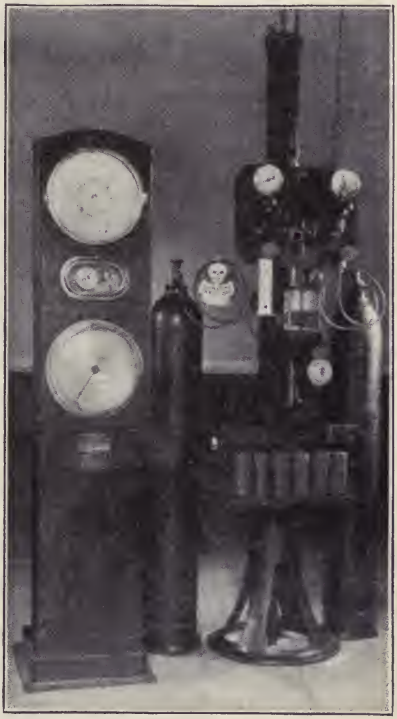


Fig. 70. Automatic Control Apparatus for Liquid Chlorine

**157. Chlorine Gas Installation.** Figs. 67 to 69 show a typical installation of a liquid-chlorine plant for treating the effluent from a sewage disposal plant. This plant consists of a small brick building, Fig. 67, in which the automatic apparatus is located and a re-settling basin of reinforced concrete which permits the sewage to come in contact with the liquid chlorine for a minimum period of fifteen minutes before being discharged into the stream. The automatic apparatus, Fig. 68, is controlled by a float chamber, Fig. 69, located in one corner of the pump room and directly connected to the sewer outside the building at a point on the upstream side of a fixed weir. This float transmits the difference in elevation, due to the varying flow of sewage over the weir, by diaphragms directly to the central control diaphragm. Here the drop in pressure across the chlorine gas constriction in the connecting valve from the chlorine-pressure tanks is kept proportional to the head on the weir. This gives a proportional flow of chlorine for the varying heads over the weir. The liquid chlorine is then fed to the outfall sewer below the weir and is liberated in a baffled concrete compartment called a "diffusion chamber", section *BB*, so that the chlorine will be thoroughly mixed with the sewage to be treated.

Fig. 70 shows another type of liquid-chlorine apparatus where a different type of control is used. This consists of pressure regulating devices to produce the initial cylinder pressure of the liquid chlorine and to control this pressure through a range sufficient to give the required discharge of gas. On the outlet line, there is attached a low-pressure chlorine gauge calibrated to indicate the rate of flow of chlorine gas. This apparatus can also be used in connection with Venturi meters to supply the chlorine automatically in proportion to the flow of sewage.

**158. Results.** Where the chlorine-gas apparatus is used on raw sewage, the results are unreliable if there are large pieces of organic matter in suspension, as the treatment will not destroy the bacteria inside these masses. For treatment of clarified sewage or effluents from disposal works, a uniformly high degree of efficiency can be obtained.

## PUMPING

**159. Requirements.** Where it is at all possible to eliminate pumping, it should be avoided, as it not only adds a high operating cost, but also is difficult in maintenance. Pumping is, however, a necessity at many disposal works where the outfall sewer is too low to permit of gravity operation or where the plant would otherwise be subjected to flood conditions. It is necessary, too, for many of the modern buildings in our large cities where the deep basements and sub-basements are entirely too low to drain to the sewers.

**160. Method.** Sewage pumps must be reliable, free from obstructions, and in many cases automatic. Centrifugal pumps with open type impellers, steam or motor driven, are naturally adapted to sewage pumping on account of simplicity, possibility of automatic operation, and their large capacity for low heads. Automatic ejectors operated by compressed air are usually used on small installations.

**161. Design.** For stations that are to be automatic, motor-driven centrifugals are well adapted. The pump must be submerged and preferably placed in a compartment separate from the sewage so as to be accessible at all times. Particular attention must be paid to protecting the pumps from injury or clogging from suspended matter in the raw sewage, and for this purpose, screen chambers must be designed and installed as previously outlined under that heading. The motor should be placed on the operating floor above the pump well to prevent trouble from dampness.

The pump well must be of capacity sufficient to permit the sewage to reach the pumps without swirling and also to give some margin for a temporary closing down or changing over of pumps, and, in the case of automatic stations, to permit of proper periods between stopping and starting. A minimum of thirty minutes' storage of the maximum flow should be used. In determining the size of the pump, study must be made of the varying flow of sewage at different hours of the day, and under maximum and minimum conditions; while its capacity must be such that it can take care of the flow of sewage under all conditions and at the same time permit of at least one pumping unit being out of operation. Where there is a possibility of the supply of electric current being interfered with, auxiliary power should be provided.

In the design of larger stations or of stations where the cost of current is not comparable with other fuel, steam-driven or gas-engine-driven installations can be made, but stations of this type must be supplied with operators.

**162. Connellsville Pumping Station.** Fig. 71 shows a plan and section of an automatic electric-driven pumping station designed for Connellsville, Pennsylvania. This station consists of a circular pit 50 feet in diameter by 30 feet deep, with the top of the pit carried up to the natural ground level, which is above extreme high-water mark, and with the bottom of the pit 7 feet below the invert of the connecting sewer. The pumping equipment consists of two 7-inch centrifugal pumps run by electric motors and each having a capacity of one and one-half million gallons per twenty-four hours; and one 10-inch auxiliary pump run by a gas engine and having a capacity of three million gallons per twenty-four hours. There is a concrete diaphragm wall separating the pump pit from

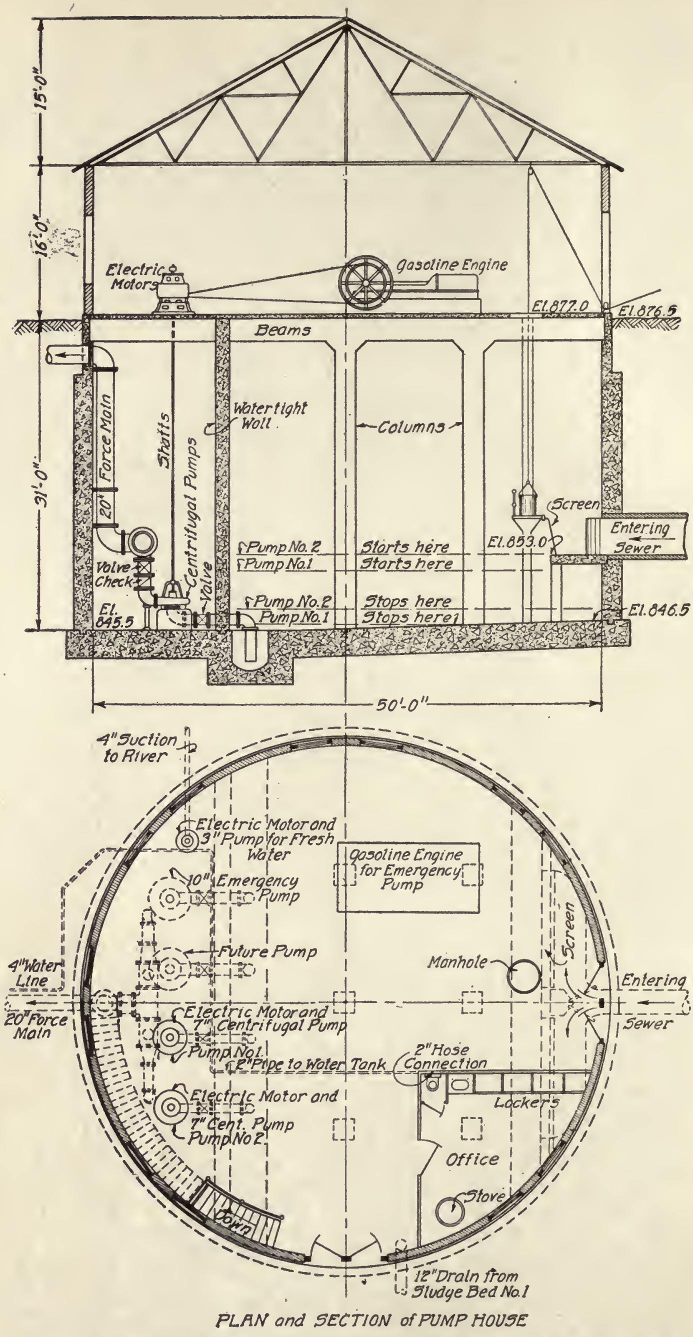



Fig. 71. Plan and Section of Connellsville Proposed Sewage Pumping Station

the suction pit so that the pump pit will be dry at all times and pumps can be conveniently reached for inspection or repairs. The main suction pit will have an effective capacity of 75,000 gallons or a minimum storage of 30 minutes under maximum conditions. The motors operating the pumps will be located on the reinforced-concrete operating floor above the pit and directly connected to the pumps by vertical steel shafts. Each motor will be automatically controlled by a float located in the pit and connected to the switchboard so that when the sewage rises in the pit to a depth of four feet, one pump starts up. If the flow is greater than the capacity of this pump, the sewage will continue to rise for another foot when the second pump will start up. When the sewage drops in the pit to within two feet of the bottom, the last pump in operation is cut off by the float and when it reaches the bottom, the second pump is placed out of commission. The auxiliary pump is provided to take care of any breakdown in the other machinery and also to provide against a failure of the current supply. A small 3-inch pump similar to the other electric-driven pumps is provided for taking raw water from the river and supplying it for flushing purposes through a force main to the disposal works.

**163. Ejectors.** Figs. 72 and 73 show an installation of Shone ejectors and also a sectional detail of one of these ejectors. Ejectors like pumping installations, should be set up in duplicate as indicated in the illustration, so that there will be a spare unit for use in emergency. Ejectors are simple in operation as they have no working parts which can become clogged with suspended matter, and when operated with compressed air, can be located at a considerable distance from the air compressor or air tank.

As will be noted in Fig. 73, these ejectors consist of a closed cast-iron vessel furnished with inlet and outlet connections which are controlled by check valves. Gate valves are also provided, but are only used to disconnect one unit for repairs. On top of the ejector is placed an automatic valve to which is connected the air pipe from the air compressor. This valve controls the admission of the compressed air into the ejector and also the exhaust of displaced air from the ejector. It is operated by the two cast-iron bells hung in reversed positions and linked to each other by a rod through the center of the main compartment as shown. When

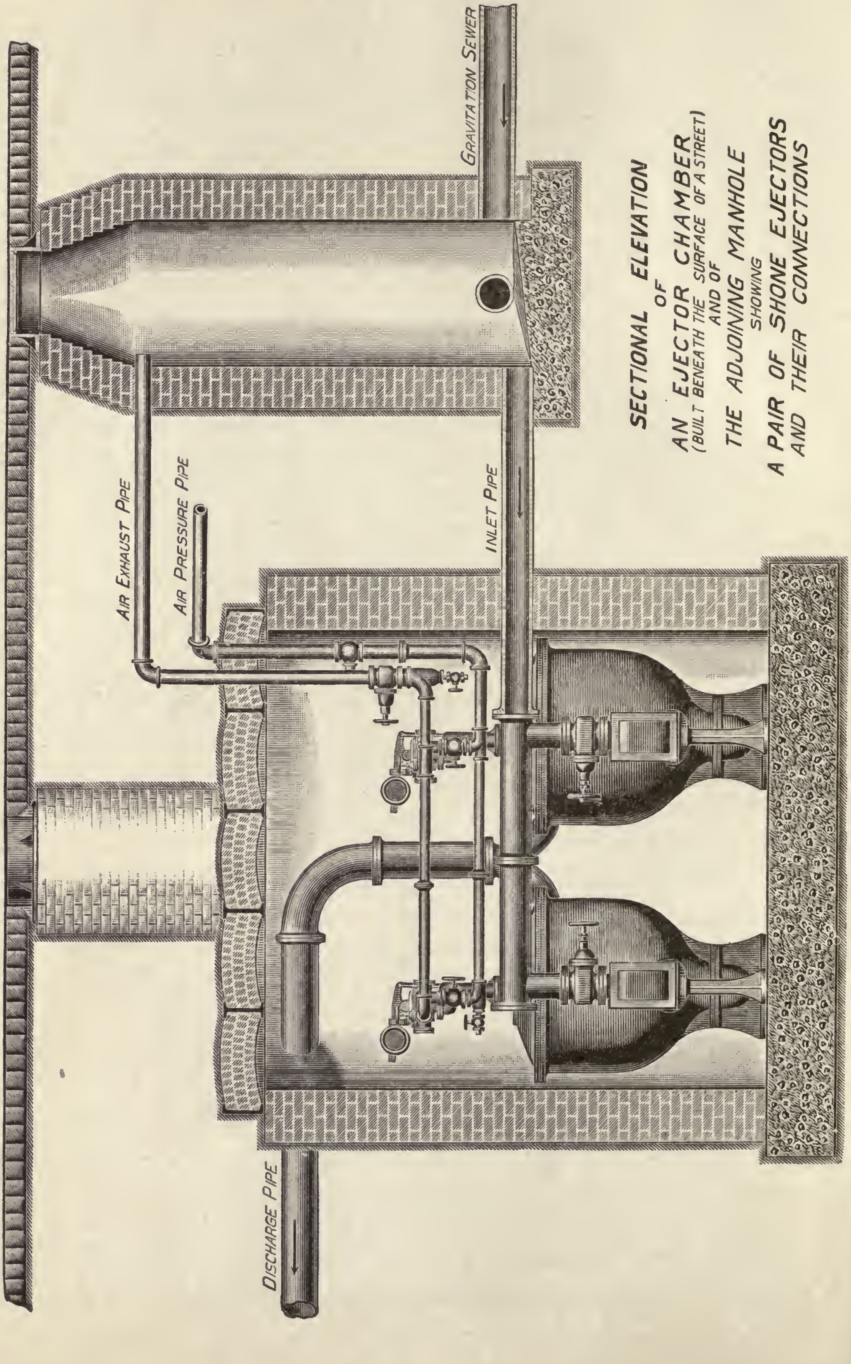



Fig. 72. Typical Installation of Shone Ejectors.

the sewage rises in the ejector, the exhaust valve is opened and the air valve is closed, the bells being in the lower position. When it reaches the top of the ejector, it traps air in the upper bell forcing it to rise by buoyancy. The lever connected with the rod from the bells quickly closes the exhaust and opens the compressed-air

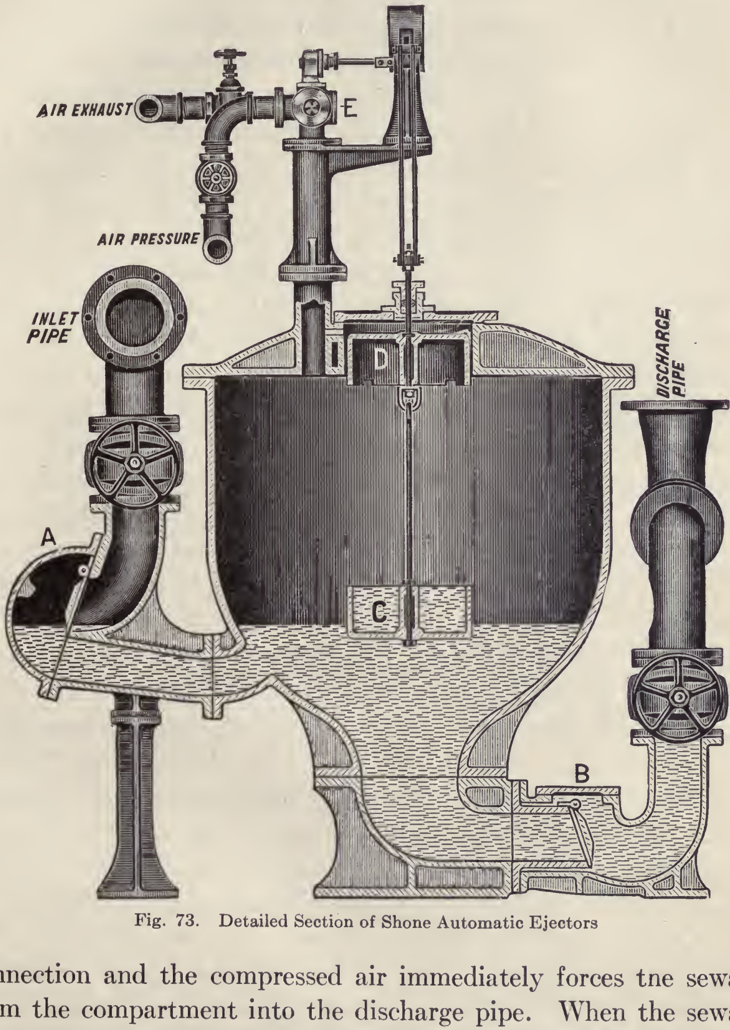



Fig. 73. Detailed Section of Shone Automatic Ejectors

connection and the compressed air immediately forces tne sewage from the compartment into the discharge pipe. When the sewage reaches the lower bell, its weight pulls down the control rod, thereby reversing the position of the pressure and exhaust valves and allowing the ejector to start again the process of filling. It requires very little more air pressure to operate this type of ejector than the head of water against which it must lift.

## SUMMARY

**164. Sewage-Disposal Method—Question of Conditions.** It will be seen from the outline given of the various methods of sewage disposal and the results that can be obtained, that each case must be studied and worked out as an individual problem. Dilution is feasible under certain conditions, but usually with some treatment such as screening or disinfection, or a partial removal of the suspended matters. Broad irrigation and chemical precipitation, which were once popular, are now installed only under exceptional conditions on account of the high cost of these methods of treatment. A non-putrescible effluent with a high percentage of removal of the organic matter and bacteria can be obtained by broad irrigation, but only a partial removal of it can be obtained by chemical precipitation.

**165. Care of Suspended Matter and Effluent.** For the removal of suspended matters, mechanical screens, Imhoff tanks, and septic tanks are generally used. Where there is danger of trouble from odors, screens or Imhoff tanks are preferable. Where it is necessary to produce a non-putrescible effluent, a secondary treatment must be given the effluent from which the suspended matter has been removed, and this is accomplished by biological filters of which the sprinkling filters and contact beds are the types generally used. Sprinkling filters are preferable to contact beds on account of lower cost, but require more head so that in many cases they cannot be considered.

**166. Disinfection of Effluent.** The effluent from biological filters is not free from bacteria and where a removal of pathogenic bacteria is required, the effluent must be disinfected. This is generally accomplished by chloride of lime or liquid chlorine. Sand filters will give a much higher degree of efficiency than the coarse-grain biological filters, but on account of high cost are not generally used.

Electrolytic treatment will efficiently disinfect sewage, but on account of cost of treatment, it has not been able to compete with the other methods of disinfection. Experiments are now being conducted on activated sludge, formed by blowing compressed air through freshly deposited suspended matters. This process appears to liquefy and nitrify the sludge in a very short period of time by accelerating the growth of enormous numbers of small worms in the sludge deposits. These experiments indicate a development of a new method of handling the sludge problem, although on account of the high cost of operating it is doubtful whether it will be as economical as the double-story tank method with separate digestion compartment now so generally and successfully used.

Pumping should be avoided if possible. If it must be used, the apparatus must be arranged to avoid clogging and in most small installations to be automatic. Where compressed air is available, an ejector is the simplest type of pump to use.

**167. Future Conditions.** As the population of this country increases and new towns spring up, the necessity for purification of sewage increases and the time is not far off when even our seacoast cities must adopt partial purification. It is, therefore, of vital importance to make the present type of partial treatment now installed, whatever it may be, subject to further development of a higher degree of purification.

Finally, too much emphasis cannot be placed on the importance of a thorough study of conditions, and of development of a comprehensive scheme to embrace not only present circumstances, but future contingencies.

## GARBAGE DISPOSAL

**168. Introduction.** The disposal of garbage, like that of sewage, has been placed on a scientific basis in recent years only. Formerly, it was common practice to dump it into rivers; to bury it in waste tracts of land; or to spread it on these tracts, leaving it to rot with the resultant stench and nuisance. In recent years, many types of incinerators and reduction plants have been developed and placed on a successful operating basis.

**169. Composition of Garbage.** The term garbage is generally applied to the rejected food wastes of a community, but in addition includes ashes and household rubbish, as well as street sweepings, and the offal from slaughter houses and carcasses. The average garbage contains 70 per cent water, 3 per cent grease, 20 per cent organic matter, while the balance is miscellaneous material. The household wastes consist mainly of paper, rags, metal, glass, bottles, and crockery. Paper and rags predominate in the rubbish. It has been estimated by Craven that in the New York City rubbish, 75 per cent is paper and 15.5 per cent rags.

**170. Quantity.** The amount of garbage and other waste materials to be disposed of obviously differs greatly in different communities, depending to a great extent on local conditions. From data collected in several cities in America, it is found that garbage will vary from 100 to 200 pounds, ashes 300 to 1000 pounds, and rubbish from 50 to 100 pounds, per capita per annum.

**171. Disposal.** Household garbage has a food value for swine, but it is impossible to handle it in a sanitary way on any great scale so that only in the case of large public institutions, or very small communities, can this method of disposal be used. The grease and organic matter also have a commercial value for soap and fertilizer; the rubbish can be sorted and sold, but as in the case of the garbage, there is no economy in their sale, unless it be carried to a considerable extent. The ashes are valuable for filling in low tracts of land.

For towns under 50,000 population, the best method for disposing of garbage and rubbish is by incineration. For larger cities, a reduction in the operating cost can usually be effected by a reduction and sorting plant, or by selling it to a reduction company.

**172. Collection.** Whatever the method adopted, dealing with garbage, it is preferable to collect it separately from the rubbish and ashes. This makes the handling much easier, and even where all materials are to be disposed of by incineration, permits of more efficient charging and operation of the incinerator. The garbage must be collected in water-tight carts with air-tight lids and arranged for automatic dumping at the point of delivery. The other material may be collected in ordinary dump wagons.

## INCINERATORS

**173. Requirements.** The essential requirements of a garbage incinerator are: (1) economy in operation with freedom from odors; and (2) capacity sufficient to take care of the entire garbage supply. It is necessary first, therefore, to know the character and amount of material to be taken care of. It is obvious that to burn garbage only will require a design of furnace radically different from that used to burn it with rubbish or ashes, or both. Where garbage alone is burned, a greater amount of fuel is necessary, while drying grates and evaporating pans must be provided to prevent the liquids from reaching the main grate bars. After determining the amount and character of the garbage to be burned, the operating periods must be determined. A continuous operation is economical from the fuel standpoint, but for small plants, it would make the labor cost too high, as one man on one shift can easily handle eight tons of material.

**174. Design.** The design of garbage crematories has been developed by a great number of companies, and the patents covering the various features are legion. To prevent odors, it has been found that a temperature of 1200° F. must be reached in the gases in the outlet flues of the plant, and this requirement, together with economy of fuel consumption and permanence of grate bars and fire linings, is the controlling feature. A good furnace builder could design an incinerator that would avoid the various patents, but it is doubtful whether this design would also incorporate all of the desired features for economy and permanence.

It is, therefore, better for the engineer, who is planning to install an incinerator, to prepare a general plan and specification for the work and to permit the various companies to submit bids on their own designs, conforming to the requirements of the general plans and specifications. Having received these bids, the engineer should carefully study the various features of each design and investigate the results that have been obtained in operation with particular attention to efficiency and replacement charges. A high first cost is in many cases justified by the saving effected in maintenance.

## REDUCTION PLANTS

**175. General Conditions.** In disposing of the garbage for cities of 50,000 population or over, a considerable saving in the operating cost can be effected by so reducing the garbage as to obtain the fats and fertilizing materials. If the rubbish is collected separately, it will also pay to install a sorting department.

As before stated, the sorting of rubbish, like the reduction of garbage, is not economical unless large quantities are handled. The waste must be subdivided into a great many parts which requires a large operating force, as one individual can handle only two or three parts. The sorting is usually done in a large room; through the center of this there is a belt conveyor, along which are distributed the operating force who pick off from the conveyor the various articles to be sorted as they pass.

The reduction plants are in most cases installed and operated by a private company which makes a contract with the city for disposing of the garbage. There are, however, several municipal reduction plants which have been installed by the cities and operated by them successfully.

**176. Columbus Reduction Plant.** The garbage reduction plant of Columbus, Ohio, is a typical one. It was installed by the city in 1910, for the reduction of all of its garbage. The plant consists of the boiler plant and machine shop, and also digesters, presses, grease-separating tanks, percolators, refining and storage tanks, drying equipment, screens and evaporators. The garbage is reduced to obtain grease, fertilizer, and hides, the last of course, being stripped before the carcasses are placed in the reduction plant proper.

The method of operation consists in first draining off the liquids from the garbage to tanks; here the grease is separated by gravity whence it is pumped to treating tanks. After the grease has been removed, the water is pumped to an evaporator and concentrated to a syrup to recover the solids in solution. The drained garbage discharged into large digesters filled with steam is thoroughly cooked. The odors or gases from the digesters are passed through condensers and the insoluble gases through deodorizing furnaces. The cooked garbage is next subjected to presses which remove the solids from the liquids. The liquids are drawn off to the grease-separating room, the solids being carried to a series of driers. The solids are then treated in sealed containers with gasoline, which acts as a solvent and separates what grease has been retained in them. The gasoline is removed by means of dry steam; the water, grease, and gasoline are separated and returned to their respective storage tanks. The solids having been mixed with the tankage left over from the evaporators so as to absorb all solids contained therein, are now dried and sold for fertilizer.

The operating report for this plant in 1912, showed that an average of 60 tons of garbage was treated per day, the total cost of operation of the plant $38,500, and the total receipts from the products $61,700. As the plant cost $210,000, it is necessary to add to the cost of operation $15,500 for interest and sinking fund. This leaves a balance of $7,700 profit. The above outlined cost of operation does not, however, include the collection of the garbage in the city nor its delivery to the disposal works.

# INDEX.

# INDEX

PAGE

PAGE