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

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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
SECTION OF A SAND-CATCHER
Metropolitan Sewerage System, Boston, Mass.
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 of it, one authority says: "To this gigantic work, admired even in the time of the magnificent Roman Empire, is undoubtedly owing the 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 mediaeval 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 faecal 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 faecal 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

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*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 fecal 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 fecal 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 fecal 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.

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 **Lienur 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 fecal 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 faecal 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 faecal 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 incautelable 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.

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.

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-

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 aesthetic 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 3½ feet below the basement floors, as follows:

MINIMUM DEPTHS FOR SANITARY AND COMBINED SEWERS

<table>
<thead>
<tr>
<th>Description</th>
<th>Depth</th>
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<tbody>
<tr>
<td>Fall from sewer to house</td>
<td>2 ft. 0 in.</td>
</tr>
<tr>
<td>Fall from basement floor to house connection</td>
<td>1 ft. 6 in.</td>
</tr>
<tr>
<td>Total from top of sewer to basement floor</td>
<td>3 ft. 6 in.</td>
</tr>
<tr>
<td>For sewer laterals, add to the above for fall at sewer</td>
<td>1 ft. 0 in.</td>
</tr>
<tr>
<td>Total from invert of lateral sewer to basement floor</td>
<td>4 ft. 6 in.</td>
</tr>
<tr>
<td>For residence districts, add for ordinary-depth basements below street level</td>
<td>4 ft. 0 in.</td>
</tr>
<tr>
<td>Total minimum depth to invert of lateral sewers in residence districts</td>
<td>8 ft. 6 in.</td>
</tr>
<tr>
<td>For business districts, add for ordinary-depth basements</td>
<td>8 ft. 0 in.</td>
</tr>
<tr>
<td>Total minimum depth to invert of lateral sewers in business districts</td>
<td>12 ft. 6 in.</td>
</tr>
</tbody>
</table>

Hence, under average conditions, the depth of sanitary and combined pipe sewers of 12-inch diameter and less, should be not less than 8½ feet in residence districts, and 12½ 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 minimum, 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
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.

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 skillful 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 brickwork should be laid with tight shoe 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.

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.

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,

![Diagram: 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.](image)

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 ¾-inch galvanized pipe from the nearest water main. This pipe must be laid below the frost line (5½ 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 flooor 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 objec-
tionable 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.

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.

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 in-
verted 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 withstand 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, sub mains, 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.

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
HARLEM CREEK PUBLIC SEWER, ST. LOUIS, MISSOURI

View showing forms and reinforcing bars in place. Length of sewer, 4,800 ft. Clear span at lower end, 29 ft.; at upper end, 25 ft. Height, from 19 to 18 ft. Designed for 15-ft. fill.

Courtesy of Expanded Metal & Corrugated Bar Company, St. Louis, Mo.
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*

<table>
<thead>
<tr>
<th>STANDARD</th>
<th>DOUBLE STRENGTH OR EXTRA THICK</th>
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<tr>
<td><strong>INSIDE</strong></td>
<td><strong>THICKNESS</strong></td>
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<td><strong>DIAM.</strong></td>
<td><strong>SHELL</strong></td>
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<td>24</td>
<td>5</td>
</tr>
<tr>
<td>27</td>
<td>4</td>
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<tr>
<td>30</td>
<td>4½</td>
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<tr>
<td>33</td>
<td>5½</td>
</tr>
<tr>
<td>36</td>
<td>6</td>
</tr>
</tbody>
</table>

The bells are made large enough to allow an annular space for cement, ranging from ¾ inch thick for 8-inch pipe to ¾ 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.

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 calcined 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.

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.

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

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 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 invert 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 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.

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 1/2 by 4 by 2 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 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 watertightness; 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. Formulae 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 formulae 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 formulae 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:

\[ v = \frac{\sqrt{2gh}}{\sqrt{1 + e + e \frac{l}{d}}} \]

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:

\[ v = c \sqrt{RS} = \left( \frac{41.66 + \frac{1.811}{n} + \frac{0.00281}{s}}{1 + \left(41.66 + \frac{0.00281}{s}\right)n/R} \right) \sqrt{RS}. \]

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 formulae 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 formulae 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-
izontally 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 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 \( \frac{1}{3} \) 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 \( 640 \times \frac{1}{3} = 480 \) 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.
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 \( \frac{1}{2} \) cu. ft. per second per acre from a drainage area of \( \frac{1}{2} \) 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.

![Diagram Showing Changes in Velocity and Discharge in Circular Sewers for Different Depths of Flow.](image)

**TO USE THE DIAGRAM**

1. When the depth of flow is given, together with the diameter and grade of the sewer, to determine the discharge and the velocity.

2. 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) \[ \frac{6 \text{ inches}}{48 \text{ inches}} = 0.12 + = \text{proportional depth of flow} \]

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) \[ 0.04 \times 30,000,000 \text{ gallons} = 1,200,000 \text{ gallons per day} \]

= actual discharge for 6 inches depth of flow; and \[ 0.40 \times 3.8 = 1.5 \text{ ft. per second} = \text{actual velocity for 6 inches depth of flow} \]

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 \[ 500 \times 100 = 50,000 \text{ gals. per day} \]

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) $0.225 \times 8 = 1.8$ 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 $0.60 \times 1.9$ (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 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 $= \frac{30}{117} = 0.26\text{,}$ 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>
<thead>
<tr>
<th>Diameter</th>
<th>Minimum Grade</th>
<th>Diameter</th>
<th>Minimum Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 inches</td>
<td>1.20 per cent</td>
<td>18 inches</td>
<td>0.12 per cent</td>
</tr>
<tr>
<td>6 in.</td>
<td>0.67</td>
<td>20 in.</td>
<td>0.10</td>
</tr>
<tr>
<td>8 in.</td>
<td>0.43</td>
<td>24 in.</td>
<td>0.08</td>
</tr>
<tr>
<td>9 in.</td>
<td>0.36</td>
<td>27 in.</td>
<td>0.07</td>
</tr>
<tr>
<td>10 in.</td>
<td>0.30</td>
<td>30 in.</td>
<td>0.06</td>
</tr>
<tr>
<td>12 in.</td>
<td>0.23</td>
<td>33 in.</td>
<td>0.05</td>
</tr>
<tr>
<td>15 in.</td>
<td>0.16</td>
<td>36 in.</td>
<td>0.045</td>
</tr>
</tbody>
</table>

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}{2} to 1\frac{3}{4} 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 15,600 ft. of tributary sewers, and the tributary population is 20 per 100 ft., the total tributary population will = \( 85 \times 20 = 1,700 \) 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 plotted as curves on cross-section paper, the ordinates representing population, and the abscissae 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,

![Diagram](https://via.placeholder.com/150)

Fig. 32. Typical Gauging of Flow of Sanitary Sewage, Des Moines, Iowa, Friday, July 5, 1893.

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

**TABLE III**

Consumption of Water in American Cities, 1895

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

preliminary to designing sewers for it, all possible information should be secured relative to its water consumption.

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

<table>
<thead>
<tr>
<th>Use</th>
<th>GALLONS PER CAPITA PER DAY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
</tr>
<tr>
<td>Domestic</td>
<td>15</td>
</tr>
<tr>
<td>Commercial</td>
<td>7</td>
</tr>
<tr>
<td>Public</td>
<td>3</td>
</tr>
<tr>
<td>Waste and Loss</td>
<td>15</td>
</tr>
<tr>
<td>Total</td>
<td>40</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Sewer</th>
<th>Date</th>
<th>Duration Days</th>
<th>Tributary Population</th>
<th>Sewage Flow, Gals. per Capita per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compton Ave., St. Louis</td>
<td>1880</td>
<td>6</td>
<td>8,200</td>
<td>Min. 65 102 149</td>
</tr>
<tr>
<td>College St., Burlington, Vt.</td>
<td>1880</td>
<td>5–8</td>
<td>325</td>
<td>Av. 65 115 140</td>
</tr>
<tr>
<td>Huron St., Milwaukee, Wis.</td>
<td>1880</td>
<td>–</td>
<td>3,171</td>
<td>Max. 115 140 140</td>
</tr>
<tr>
<td>Memphis, Tenn.</td>
<td>1881</td>
<td>–</td>
<td>20,000</td>
<td></td>
</tr>
<tr>
<td>13 Sewers, Providence, R. I.</td>
<td>1884</td>
<td>1–6</td>
<td>33,825</td>
<td></td>
</tr>
<tr>
<td>Asylum, Binghamton, N. Y.</td>
<td>1888</td>
<td>–</td>
<td>1,300</td>
<td></td>
</tr>
<tr>
<td>16 Sewers, Toronto, Ont.</td>
<td>1891</td>
<td>3</td>
<td>168,081</td>
<td>Min. 87 608 608</td>
</tr>
<tr>
<td>Insane Asylum, Weston, W. Va.</td>
<td>1891</td>
<td>2</td>
<td>1,000</td>
<td>Av. 87 608 608</td>
</tr>
<tr>
<td>Schenectady, N. Y.</td>
<td>1892</td>
<td>*10,000</td>
<td>72</td>
<td>Max. 87 608 608</td>
</tr>
<tr>
<td>Canton, Ohio</td>
<td>1893</td>
<td>–</td>
<td>40,000</td>
<td></td>
</tr>
<tr>
<td>Chautauqua, N. Y.</td>
<td>1894</td>
<td>–</td>
<td>7,000</td>
<td></td>
</tr>
<tr>
<td>Iowa State College, Ames, Ia.</td>
<td>1894</td>
<td>7</td>
<td>280</td>
<td></td>
</tr>
<tr>
<td>Des Moines, Ia., E. Side</td>
<td>1895</td>
<td>15</td>
<td>8,100</td>
<td>Min. 129 151 180</td>
</tr>
<tr>
<td>Des Moines, Ia., W. Side</td>
<td>1895</td>
<td>13</td>
<td>19,400</td>
<td>Av. 129 151 180</td>
</tr>
<tr>
<td>Iowa State College, Ames, Ia.</td>
<td>1900</td>
<td>2</td>
<td>800</td>
<td>Max. 129 151 180</td>
</tr>
<tr>
<td>Iowa State College, Ames, Ia.</td>
<td>1900</td>
<td>28</td>
<td>800</td>
<td></td>
</tr>
<tr>
<td>Marshalltown, Ia.</td>
<td>1900</td>
<td>1</td>
<td>4,200</td>
<td></td>
</tr>
<tr>
<td>Grinnell, Ia.</td>
<td>1901</td>
<td>1</td>
<td>2,000</td>
<td></td>
</tr>
<tr>
<td>Insane Asylum, Mt. Pleasant, Ia.</td>
<td>1901</td>
<td>1</td>
<td>1,200</td>
<td></td>
</tr>
<tr>
<td>Waverly, N. Y.</td>
<td>1905</td>
<td>4</td>
<td>1,796</td>
<td></td>
</tr>
</tbody>
</table>

*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

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

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>
<thead>
<tr>
<th>Diam. of Sewer, Ins.</th>
<th>Grade of Sewer, %</th>
<th>Maximum Permissible Av. Flow, Gals. per Day</th>
<th>Maximum Permissible Tributary Population Gals. per Capita per Day</th>
<th>Maximum Permissible Linear Feet of Tributary Sewer for 20 Persons per 100 Feet Gals. per Capita per Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>75</td>
<td>100</td>
<td>125</td>
</tr>
<tr>
<td>8</td>
<td>0.28</td>
<td>130,000</td>
<td>1,700</td>
<td>1,300</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>190,000</td>
<td>1,100</td>
<td>1,000</td>
</tr>
<tr>
<td>10</td>
<td>0.20</td>
<td>250,000</td>
<td>1,800</td>
<td>1,600</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>310,000</td>
<td>2,400</td>
<td>2,000</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>370,000</td>
<td>2,800</td>
<td>2,300</td>
</tr>
<tr>
<td>12</td>
<td>0.20</td>
<td>350,000</td>
<td>1,500</td>
<td>1,200</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>450,000</td>
<td>2,100</td>
<td>1,600</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>550,000</td>
<td>2,700</td>
<td>2,100</td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>650,000</td>
<td>3,300</td>
<td>2,500</td>
</tr>
<tr>
<td>15</td>
<td>0.20</td>
<td>750,000</td>
<td>1,000</td>
<td>800</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>850,000</td>
<td>1,400</td>
<td>1,100</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>950,000</td>
<td>1,800</td>
<td>1,400</td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>1,050,000</td>
<td>2,200</td>
<td>1,700</td>
</tr>
<tr>
<td>18</td>
<td>0.20</td>
<td>1,200,000</td>
<td>1,000</td>
<td>750</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>1,300,000</td>
<td>1,400</td>
<td>1,100</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>1,400,000</td>
<td>1,800</td>
<td>1,400</td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>1,500,000</td>
<td>2,200</td>
<td>1,700</td>
</tr>
<tr>
<td>24</td>
<td>0.20</td>
<td>1,600,000</td>
<td>900</td>
<td>700</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>1,700,000</td>
<td>1,300</td>
<td>1,000</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>1,800,000</td>
<td>1,700</td>
<td>1,400</td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>1,900,000</td>
<td>2,100</td>
<td>1,700</td>
</tr>
<tr>
<td>27</td>
<td>0.20</td>
<td>1,900,000</td>
<td>800</td>
<td>600</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>2,000,000</td>
<td>1,200</td>
<td>900</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>2,100,000</td>
<td>1,600</td>
<td>1,200</td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>2,200,000</td>
<td>2,000</td>
<td>1,400</td>
</tr>
<tr>
<td>30</td>
<td>0.20</td>
<td>2,200,000</td>
<td>700</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>2,300,000</td>
<td>1,100</td>
<td>800</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>2,400,000</td>
<td>1,500</td>
<td>1,100</td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>2,500,000</td>
<td>1,900</td>
<td>1,400</td>
</tr>
<tr>
<td>36</td>
<td>0.20</td>
<td>2,500,000</td>
<td>600</td>
<td>450</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>2,600,000</td>
<td>1,000</td>
<td>750</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>2,700,000</td>
<td>1,400</td>
<td>1,000</td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>2,800,000</td>
<td>1,800</td>
<td>1,200</td>
</tr>
</tbody>
</table>
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 \( 166 \times 25 \times 85 \times 3 \frac{1}{2} = 1,150,000 \) 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.

(1) 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.

(2) If \( P \) does not = 20 persons per 100 feet (the other conditions remaining as in 1, above), first multiply the number of linear feet of tributary sewer by \( \frac{P}{20} \), and then proceed as in 1, 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 \(16,300 \times \frac{33}{20} = 24,450\) 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 \(\frac{1}{2}\) 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

\[
\frac{52.8 \times 20 \times 75 \times 3^{\frac{1}{2}}}{7^{\frac{1}{2}} \times 86,400} = 0.43 \text{ cu. ft. per second (there being } 7^{\frac{1}{2}} \text{ gals. in 1 cu. ft., and 86,400 seconds in 1 day, and the maximum rate of flow being } 3^{\frac{1}{2}} \text{ times the average).}
\]

If the blocks are 300 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

<table>
<thead>
<tr>
<th>Shape</th>
<th>Material</th>
<th>Size</th>
<th>Minimum Grades to Give Velocities of</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 ft. per Sec</td>
</tr>
<tr>
<td>Circular</td>
<td>Pipe</td>
<td>12-in. Diam.</td>
<td>0.48</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>15 &quot;</td>
<td>0.34</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>18 &quot;</td>
<td>0.25</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>24 &quot;</td>
<td>0.17</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>30 &quot;</td>
<td>0.13</td>
</tr>
<tr>
<td>&quot;</td>
<td>Brick or Concrete</td>
<td>3-ft. &quot;</td>
<td>0.14</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>4 &quot;</td>
<td>0.10</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>5 &quot;</td>
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<td>&quot;</td>
<td>&quot;</td>
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<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>10 &quot;</td>
<td>0.025</td>
</tr>
<tr>
<td>Egg-Shaped</td>
<td>&quot;</td>
<td>2 ft. × 3 ft.</td>
<td>0.20</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>3 ½ × 3¾ &quot;</td>
<td>0.15</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>4 &quot; × 4½ &quot;</td>
<td>0.12</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>5 &quot; × 5½ &quot;</td>
<td>0.08</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>6 &quot; × 9 &quot;</td>
<td>0.06</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>7 &quot; × 10¼ &quot;</td>
<td>0.05</td>
</tr>
</tbody>
</table>

1½ 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 abscissae 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 one storm.

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:

<table>
<thead>
<tr>
<th>Estimated for water from roofs and gutter to reach sewer</th>
<th>Velocity</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>In 18-inch sewer, Fig. 27</td>
<td>4.2 ft. per sec.</td>
<td>15.0 min.</td>
</tr>
<tr>
<td>&quot; 24-inch &quot; &quot; 27</td>
<td>4.0 &quot; &quot; &quot;</td>
<td>3.3 &quot;</td>
</tr>
<tr>
<td>&quot; 36-inch &quot; &quot; 28</td>
<td>4.0 &quot; &quot; &quot;</td>
<td>5.0 &quot;</td>
</tr>
<tr>
<td>&quot; 48-inch &quot; &quot; 28</td>
<td>4.0 &quot; &quot; &quot;</td>
<td>10.0 &quot;</td>
</tr>
</tbody>
</table>

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.

**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 pervious 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

<table>
<thead>
<tr>
<th>Population per Acre</th>
<th>Percentage of Impervious Area</th>
<th>Percentage of Pervious Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>4</td>
<td>96</td>
</tr>
<tr>
<td>10</td>
<td>9(\frac{1}{2})</td>
<td>90(\frac{1}{4})</td>
</tr>
<tr>
<td>15</td>
<td>15</td>
<td>85</td>
</tr>
<tr>
<td>20</td>
<td>20(\frac{1}{2})</td>
<td>79(\frac{1}{4})</td>
</tr>
<tr>
<td>25</td>
<td>26</td>
<td>74</td>
</tr>
<tr>
<td>30</td>
<td>31(\frac{1}{4})</td>
<td>68(\frac{1}{4})</td>
</tr>
<tr>
<td>35</td>
<td>37</td>
<td>63</td>
</tr>
<tr>
<td>40</td>
<td>42(\frac{1}{2})</td>
<td>57(\frac{1}{4})</td>
</tr>
<tr>
<td>45</td>
<td>47(\frac{1}{2})</td>
<td>52(\frac{1}{4})</td>
</tr>
<tr>
<td>50</td>
<td>52(\frac{1}{2})</td>
<td>47(\frac{1}{4})</td>
</tr>
<tr>
<td>55</td>
<td>58</td>
<td>42</td>
</tr>
</tbody>
</table>

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 129,600 (sq. ft.) \(= 3\) acres. The 12 houses at an average of 5\(\frac{1}{2}\) 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.

\[
0.90 \times 21.6 \text{ per cent} = 19.4 \text{ per cent from impervious area.} \\
0.08 \times 78.4 \quad " = \quad 6.3 \quad " \quad " \quad \text{pervious} \quad "
\]

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

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.
The time of concentration = 35 min. (see Ex. 34).

The rate of maximum rainfall = 2.1 in. per hr. (see Ex. 35).

The percentage of maximum run-off = 26 (see Ex. 38).

The drainage area = \[ \frac{5,280 \times 800}{43,560} = 97 \text{ acres.} \]

\[ 97 \times 2.1 \times .26 = 53 \text{ cu. ft. per sec.} \]

= maximum flow of storm sewage.

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.
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.

(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 [City Name],

SPECIFICATIONS

FOR

SEWERS AND SEWAGE-DISPOSAL PLANT

NOTICE TO CONTRACTORS

The Incorporated City of [City Name], [Date], 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 speci-
fications 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 specifi-
cations 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:

<table>
<thead>
<tr>
<th>Size</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-inch</td>
<td>Ft.</td>
</tr>
<tr>
<td>15-inch</td>
<td>&quot;</td>
</tr>
<tr>
<td>12-inch</td>
<td>&quot;</td>
</tr>
<tr>
<td>10-inch</td>
<td>&quot;</td>
</tr>
<tr>
<td>8-inch</td>
<td>&quot;</td>
</tr>
<tr>
<td>Manholes</td>
<td>&quot;</td>
</tr>
<tr>
<td>Lampholes</td>
<td>&quot;</td>
</tr>
<tr>
<td>Combined Manholes and Flush-Tanks</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

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 repre-
sentatives. 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 specifi-
cations, 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 Sewer-
age 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
LARGEST SEWER IN THE UNITED STATES

View of 39th Street Intersecting Sewer, Chicago, Ill., showing a portion of the wooden forms and brick lining. Length of sewer, 12,000 ft.; diameter, 24 ft. 10 in. external, and 20 ft. internal; bricks laid in "Utica" hydraulic cement, of which 60,000 barrels were used. This sewer is one of a system of similar sewers paralleling the shore of Lake Michigan, to prevent egress of sewage into the lake. Its level being 20 ft. below that of the lake, the sewerage is pumped up to higher levels, and then flows westward by gravity into the new outlet afforded by the Drainage Canal.

Courtesy of Meacham & Wright, Chicago, Ill.
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 ¼-inch thickness for 8-inch and 10-inch pipe, and ¼-inch thickness for larger diameters.

Pipe may be furnished in lengths of 2, 2½, 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 ¼ the nominal thickness of the pipe and whose largest diameters are greater than ¼ 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 ¼ 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 ¼ inch per foot of length; nor shall there be any variation between any two diameters of a pipe greater than ¼ the nominal diameter.

No pipe shall be used which has a piece broken from the spigot end deeper than 1½ inches or longer at any point than ½ 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 2\(\frac{1}{2}\)-inch ring for ordinary concrete, and a 1\(\frac{1}{4}\)-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 5\(\frac{1}{4}\)-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 2\(\frac{1}{2}\)-inch ring, in the proportions 1-3-5 for ordinary work, and 1-2-3\(\frac{1}{2}\) 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 no: 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, 1-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 filling 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 ¼ 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 ½ inch in width. Sewers shall conform accurately in section and dimensions to the plans of the same. Allinvertsand 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 ¼ 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:

354
<table>
<thead>
<tr>
<th>Item</th>
<th>Approximate Quantity</th>
<th>Unit Price</th>
<th>Total Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sewage Disposal Plant, complete</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sewers, complete, including Y’s, except subdrains, manholes, lampholes, and flush-tanks,</td>
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<tr>
<td>18-inch</td>
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<td>8-inch</td>
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<tr>
<td>Subdrains, complete</td>
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<td>10-inch</td>
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<tr>
<td>6-inch</td>
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<tr>
<td>Deep-Cut House Connections, complete</td>
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<td></td>
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<tr>
<td>Manholes, complete</td>
<td></td>
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<tr>
<td>Combined Manholes and Flush-Tanks, complete</td>
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<tr>
<td>Lumber Left in Trenches (per M., B. M.)</td>
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</tbody>
</table>

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,

<table>
<thead>
<tr>
<th>Size (in.)</th>
<th>Quantity</th>
<th>Price per lin. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>20</td>
<td>$</td>
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<tr>
<td>18</td>
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<td>10</td>
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<td>$</td>
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<tr>
<td>8</td>
<td></td>
<td>$</td>
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</table>

Subdrains, complete,

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<thead>
<tr>
<th>Size (in.)</th>
<th>Quantity</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td></td>
<td>$</td>
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<tr>
<td>18</td>
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<tr>
<td>8</td>
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<td>$</td>
</tr>
</tbody>
</table>

Manholes, complete...

Lampholes, complete...

Combined Manholes and Flush-Tanks, complete...

Flush-Tanks, complete...

Lumber ordered left in trenches...

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.

Party of the First Part

[Seal]

The Incorporated City of __________, by

______________—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:

**B O N D**

**Know all men by these presents,** that we, ————, ————, 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 com-