Site Utility Systems

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Note: In determining your answers to the CE questions, use only the material presented in the corresponding continuing education article. Using information from other materials may result in a wrong answer.

This chapter discusses the components and design of building and site utility services for all plumbing systems and their installation from 5 feet outside the building wall to their connection to a source. Such connections could be a public water supply or main or, with regard to drainage, any ultimate point of disposal, which could include a public sewer, retention basin, or other method as appropriate. The natural gas supply would connect to a franchised public utility main. The systems discussed include the potable water supply, fire protection water supply, sanitary sewer, site stormwater system, and natural gas service. Other methods of supply, such as wells and surface water, are outside the scope of this chapter.

PRELIMINARY INFORMATION FOR ALL SYSTEMS

The following general information must be obtained for all systems on each project. Information for specific items is discussed under the individual systems.

- Obtain an architectural site plan showing the location of the building or buildings on the site. Part of the site plan should be a location plan of the surrounding area. Also included should be the block and lot number, building address, building classification, and building height. Keep in mind that the actual height and the legal height are different, but both dimensions are necessary to determine fire protection requirements. Other pertinent information includes the location of existing buildings and any natural interference, such as boulders and trees not being removed.
- Obtain an existing utility site plan from the various purveyors or suppliers if the utilities are not shown on the architectural site plan. Ensure the availability of all services that are required.
- Create a contact sheet showing all of the building and plumbing code officials, fire marshal, fire code officials, and every other person or department necessary for the development, design, and approval of the plumbing systems. One of the most important items for the record is the utility information, such as water pressure, gas information, sanitary sewer disposal information, and stormwater sewer and disposal information.
- Make certain that north is clearly and consistently indicated on all drawings.
- If the project is an alteration, obtain all available existing plans, including the legal height of existing structures.
- Conduct a thorough code search to find all codes applicable to the project, including requirements for grease traps and stormwater management systems.
- Obtain from the plumbing and other code officials all submittal and approval requirements for plans and other contract documents prepared for the project.
- Obtain the requirements for fire protection systems from the fire department, fire marshal, and insurance carrier, including the need for a meter and backflow preventer.
- Include existing and finished grades on a topographical plan, as well as temporary or intermediate grades used for any purpose.
- Obtain soil boring information, including the groundwater level.
- Determine if a lawn or turf irrigation system is required.
- Determine the need for a private sewage disposal system.
- Determine if a sewage lift system is required.

DOMESTIC WATER SERVICE

The domestic water system provides water suitable for human consumption to all fixtures and equipment throughout a facility. The domestic water building service conveys water from a public utility or other source into a facility for further distribution.

Codes and Standards

Various codes, particularly the plumbing code, are applicable to domestic water services. Check with the local or state authorities to determine which codes apply in the area. The water purveyor also may have regulations with which the project must comply.

Getting Started

The most important piece of information concerning the water service connecting to a public water supply is the residual water pressure available at the entrance into the building. The necessity for a pressure-boosting system is based on this figure. Figure 11-1 provides a step-by-step calculation procedure.

The water pressure at the public water main is called the static pressure and usually depends on the time of day this static measurement is taken. Request this reading to be taken between 10 a.m. and noon. (For more information on flow tests, refer to *Plumbing Engineering Design Handbook, Volume 2,* Chapter 5.) From this actual pressure, the pressure losses through the installed components are deducted. In addition, the difference in height between the water main and the building entrance (or point of connection to the interior distribution system) is either added or deducted. After all service losses due to fittings, length of run through a preliminary sized water service, backflow preventer, and other connected equipment and devices have been subtracted, the result is the available, or residual, pressure. From the residual pressure, it is recommended to subtract an additional pressure loss of 5 pounds per square inch (psi) (34.5 kPa) to allow for future nearby construction that might lower the pressure.

General System Requirements

The first step in determining the general system requirements is to find the water purveyor or utility company providing water to the site. Next, calculate the preliminary (or final, if possible) maximum instantaneous water service requirements, in gallons per minute (gpm) (L/min). This is done from a preliminary (or final, if available) fixture count. An additional 10 percent is added as an allowance for cooling tower fill, boiler fill, and other miscellaneous uses of water in addition to the domestic use. For specialized facilities, add the flow rate obtained from the owner for additional processes and equipment that may use potable water. To calculate the maximum probable gpm, proceed as follows:

1. Count all fixtures to be installed in the facility by fixture type.
2. Based on each type of fixture, find the water supply fixture unit (WSFU) value for each fixture. Refer to Table 11-1 for the values for each type of fixture. Refer to the plumbing code that applies to the project's location for the exact fixture unit values to be used.
3. Add all facility water supply fixture units to calculate the total water load.
4. Convert the water supply fixture units to the maximum probable gallons per minute using a conversion chart (see Figure 11-2 for an example) or table. Several codes, such as the Uniform Plumbing Code (UPC), International Plumbing Code (IPC), state codes, and even city codes, can be used as well. The IPC currently uses the Hunter's curve fixture unit conversion to gpm developed in 1924. If this code is in effect in the project's location, the information must be used. However, tests and studies conducted by many authorities have determined that use of Hunter's curves leads to oversized piping, mainly due to the reduced water flow of modern fixtures. If this code is not the approved code for the local area, converting water supply fixture units to gpm is recommended (see Table 11-2).

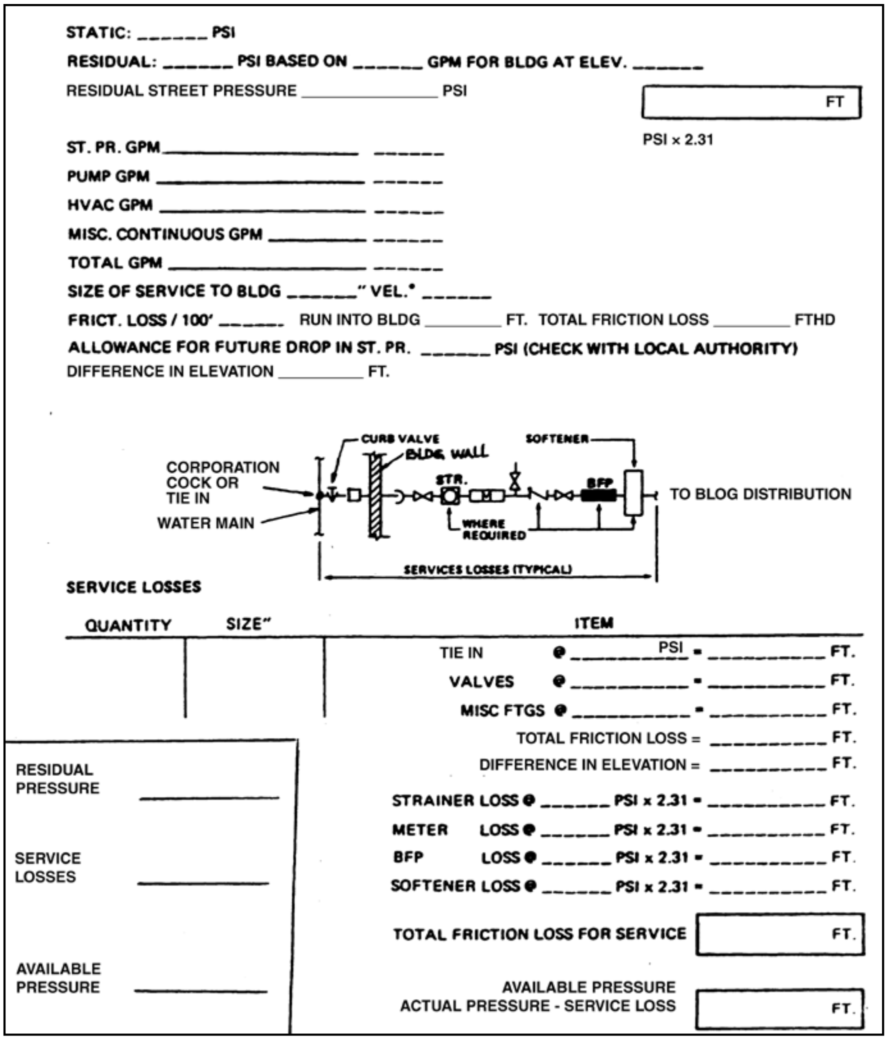


Figure 11-1 Domestic Water Service Calculations

Once this is accomplished, it is important to write a formal letter to the utility to obtain the following information: a site plan from the utility company showing all water mains adjacent to the site and other information appearing in a typical water utility letter. Once the utility company has answered the utility letter and provided most of the information requested and a site plan showing the location and size of the main and the location of the building on the site has been provided, the information obtained can be used to determine the following major design items:

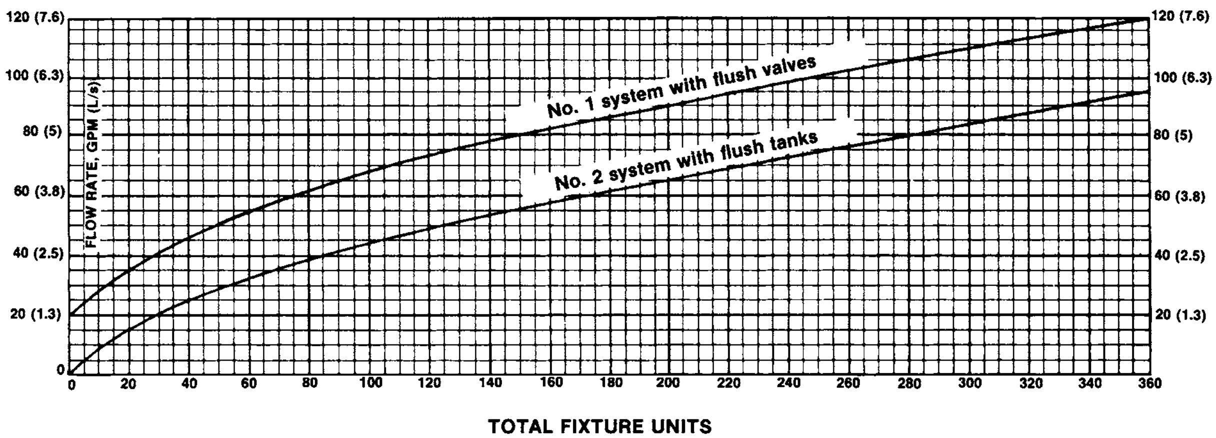


Figure 11-2 Conversion of Fixture Units to Gallons per Minute

Table 11-1 Water Supply Fixture Unit Values Assigned to Fixtures							
Fixture	**Occupancy**	**Type of Supply Control**	**WSFU**	**Fixture**	**Occupancy**	**Type of Supply Control**	**WSFU**
Bathroom group	Private	Flush tank	3.6	Shower head	Public	Mixing valve	4.0
Bathroom group	Private	Flush valve	8.0	Shower head	Private	Mixing valve	1.4
Bathtub	Private	Faucet	1.4	Urinal	Public	1-in. flush valve	10.0
Bathtub	Public	Faucet	4.0	Urinal	Public	¾-in. flush valve	5.0
Bidet	Private	Faucet	2.0	Urinal	Public	Flush tank	3.0
Combination fixture	Private	Faucet	3.0	Washing machine (8 lb)	Private	Automatic	1.4
Dishwashing machine	Private	Automatic	1.4	Washing machine (8 lb)	Public	Automatic	3.0
Drinking fountain	Offices, etc.	3/8-in. valve	0.25	Washing machine (15 lb)	Public	Automatic	4.0
Kitchen sink	Private	Faucet	1.4	Water closet	Private	Flush valve	6.0
Kitchen sink	Hotel, restaurant	Faucet	4.0	Water closet	Private	Flush tank	2.2
Laundry trays (1–3)	Private	Faucet	1.4	Water closet	Public	Flush valve	10.0
Lavatory	Private	Faucet	1.0	Water closet	Public	Flush valve	5.0
Lavatory	Public	Faucet	2.0	Water closet	Public or private	Flushometer tank	2.0
Service sink	Offices, etc.	Faucet	3.0	Notes: For fixtures not listed, loads should be assumed by comparing to listed fixtures that use water in similar quantities and at similar rates. For SI conversion, 1 in. = 25.4 mm			

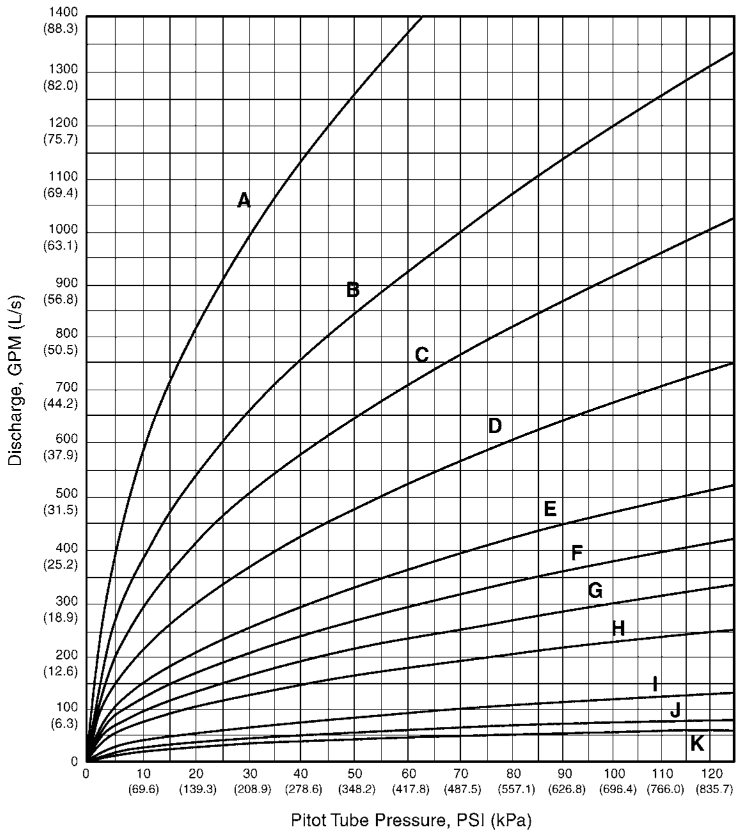
Table 11-2 Conversion of Water Fixture Units to Gallons per Minute (L/s)								
Water Supply Fixture Units	**Tank-Type Water Closets**	**Flushometer-Type Water Closets**	**Water Supply Fixture Units**	**Tank-Type Water Closets**	**Flushometer-Type Water Closets**	**Water Supply Fixture Units**	**Tank-Type Water Closets**	**Flushometer-Type Water Closets**
1	1	—	60	18.4 (1.4)	62.3 (4.6)	240	40.5 (3.0)	90 (6.8)
2	3	—	65	19.0 (1.5)	63.8 (4.7)	260	43.0 (3.2)	92 (7.0)
3	5	—	70	19.7 (1.5)	65.2 (4.9)	280	45.4 (3.4)	94 (7.2)
4	6	—	75	20.3 (1.5)	66.4 (5.0)	300	47.7 (3.6)	96 (7.2)
5	7 (0.53)	27.2 (2.2)	80	20.9 (1.6)	67.7 (5.1)	400	59.6 (4.5)	102 (7.4)
6	8 (0.60)	29.1 (2.2)	85	21.5 (1.6)	68.8 (5.2)	500	71.2 (5.3)	108 (8.2)
7	9 (0.68)	30.8 (2.4)	90	22.2 (1.7)	69.9 (5.3)	600	82.6 (6.3)	113 (8.6)
8	10 (0.70)	32.3 (2.5)	95	22.8 (1.7)	71.0 (5.3)	700	93.7 (7.1)	117 (8.9)
9	11 (0.83)	33.7 (2.5)	100	23.4 (1.8)	72.0 (5.4)	800	105 (8.0)	120 (9.1)
10	12.2 (0.92)	35 (2.6)	105	24.0 (1.8)	73.0 (5.5)	900	115 (8.7)	123 (9.3)
12	12.4 (0.94)	37.3 (2.6)	110	24.6 (1.9)	73.9 (5.6)	1,000	126 (9.5)	126 (9.5)
14	12.7 (0.96)	39.3 (2.8)	115	25.3 (1.9)	74.8 (5.7)	1,500	175 (13.3)	175 (13.3)
16	12.9 (0.98)	41.2 (3.1)	120	25.9 (2.0)	76 (5.7)	2,000	220 (16.7)	220 (16.7)
18	13.2 (1)	42.8 (3.2)	125	26.5 (2.0)	76 (5.7)	2,500	259 (19.7)	259 (19.7)
20	13.4 (1.01)	44.3 (3.3)	130	27.1 (2.1)	77 (5.8)	3,000	294 (22.3)	294 (22.3)
22	13.7 (1.02)	45.8 (3.5)	135	27.7 (2.1)	78 (5.8)	3,500	325 (24.7)	325 (24.7)
24	13.9 (1.03)	47.1 (3.6)	140	28.3 (2.1)	78.5 (5.8)	4,000	352 (26.7)	352 (26.7)
26	14.2 (1.07)	48.3 (3.7)	145	29.0 (2.2)	79 (5.9)	4,500	375 (28.5)	375 (28.5)
28	14.4 (1.09)	49.4 (3.8)	150	29.6 (2.2)	80 (6.0)	5,000	395 (30)	395 (30)
30	14.7 (1.1)	50.5 (3.9)	160	30.8 (2.3)	81 (6.1)	6,000	425 (32.3)	425 (32.3)
35	15.3 (1.1)	53.0 (4.0)	170	32.0 (2.4)	83 (6.2)	7,000	445 (34)	445 (34)
40	15.9 (1.2)	55.2 (4.1)	180	33.3 (2.5)	84 (6.3)	8,000	456 (34.6)	456 (34.6)
45	16.6 (1.3)	57.2 (4.2)	190	34.5 (2.5)	85 (6.4)	9,000	461 (35)	461 (35)
50	17.2 (1.3)	59.1 (4.3)	200	35.7 (2.6)	86 (6.5)	10,000	462 (35)	462 (35)
55	17.8 (1.4)	60.8 (4.5)	220	38.1 (2.8)	88 (6.7)			

- Based on a preliminary assessment of the available pressure inside the building wall, a decision regarding the method to use to increase water pressure in the facility, if required, can be made. The general space requirements for the necessary pumps and tanks inside the building or water tanks outside on the site shall be determined.
- Using a complete fixture count, the final maximum water supply flow rate can be calculated.
- The run into the building should be determined, and the meter assembly should be selected and located.

Typical Domestic Water Building Service Components and Design Considerations

Preliminary Flow Rate Determination

The best way to find the flow, in gpm, for a new building is to use a fixture count, convert it to gpm, and add 10 percent. Use the expected time of occupancy for the flow rate. For a preliminary flow rate for office buildings, it is best to use the number of occupants for this purpose. Use 100 square feet (9.3 m^2) per occupant for a competitive building, 150 square feet (13.9 m^2) per occupant for a normal building, and 200 square feet (18.6 m^2) per occupant for a single-company building. Using 10 gallons (37.9 L) per employee for a 10-hour day, calculate the gpm (L/min). Another figure commonly used for other kinds of buildings is 0.125 gallons per square foot (0.5 L/m^2) of building area for a 10-hour day. To this figure, add 10 percent additional for HVAC evaporation and demand, boiler feed water, and any other miscellaneous uses.



A – 2½" open hydrant butt
B – 2" smooth nozzle
C – 1¾" smooth nozzle
D – 1½" smooth nozzle
E – 1¼" smooth nozzle
F – 2½" hose with 1⅛" smooth nozzle
G – 1" smooth nozzle
H – ⅞" smooth nozzle
I – ¾" smooth nozzle
J – ½" smooth nozzle
K – ½" sprinkler head

Figure 11-3 Relative Discharge Curves
Source: *Chemical Engineers' Handbook*, McGraw-Hill

Static and Residual Water Pressure

A hydrant flow test is the method most often used to determine static and residual water pressure. This test consists of choosing the two adjacent fire hydrants closest to the site and taking three separate pressure readings, two with water flowing through a hydrant. The first pressure reading is obtained from a pressure gauge connected to one hydrant with no water flowing out of either hydrant. This is called the static pressure because no water is flowing through the test hydrant. The second reading involves both hydrants. The hydrant with the pressure gauge attached remains unchanged. The second hydrant is now opened, and a velocity pressure reading is taken using a pitot tube held directly in the water stream. At the same time, another reading is taken from the first hydrant while the second hydrant is flowing water. The actual flow rate must be known for this test to be meaningful. This is calculated by converting the velocity pressure reading from the pitot gauge into gpm by referring to a typical relative discharge curve, such as that illustrated in Figure 11-3. For fire hydrants, use the curve labeled A for an open hydrant butt.

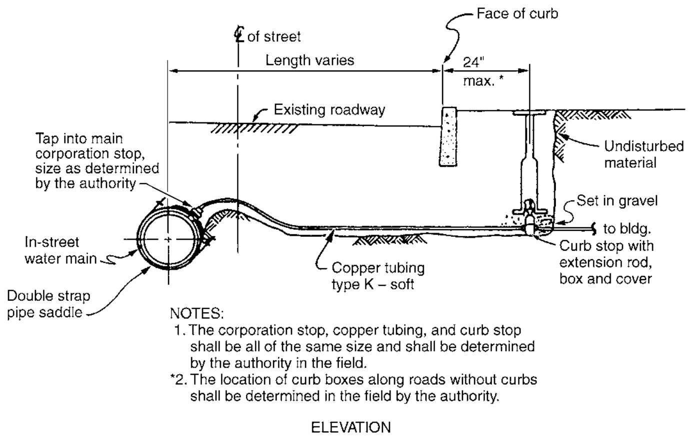


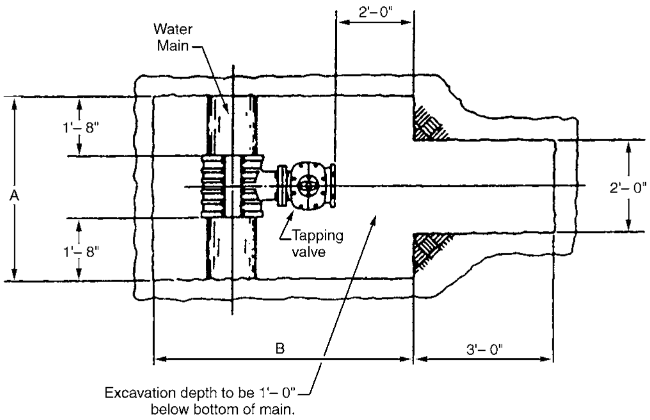
Figure 11-4 Service Connection Schematic

The time of year the test is taken will affect the flow test data. During seasonal variations, such as occurs in the summer, the flow is generally regarded as being greater than it is at other times of the year in generally residential areas. The time of day also often accounts for large differences in flow, leading to lower residual pressures. Consult with the water utility company to decide if these items are important in determining the actual pressure available to the project.

The static and residual pressure and the flow rate represent only three pieces of information. With these known, it is now possible to determine the pressure available at any flow rate. This is important since the flow rate for the project under design will almost certainly be less than the flow rate at which the hydrant flow test was conducted. The method used is to plot these two points on hydraulic graph paper. The vertical axis is the pressure, in psi, and the horizontal axis is the flow rate. By connecting the known two flow rates on different points on the graph and using care to use the proper gpm scale, any other point on the line will give the residual pressure if the flow rate desired is plotted on the line drawn.

Pressure Loss and Installation of Taps

A tap is the connection to any water main. The connection for a private residence or other building that does not require a major service is illustrated in Figure 11-4. This type of service should be limited to approximately 2 inches (50.8 mm) and smaller. Typical large main wet tap (a



MINIMUM EXCAVATION DIMENSIONS

Header Size	A	B
3" thru 8"	5'– 0"	5'– 6"
10" thru 12"	5'– 6"	6'– 0"
14" thru 24"	6'– 0"	7'– 0"

Figure 11-5 Large Wet Tap Excavation Dimensions

connection under pressure) excavation dimensions are given in Figure 11-5. Other methods of wet-tapping into a main are available, and the dimensions are approximately the same.

The exact pressure lost through taps or street ells shall be obtained from the specific manufacturer or the public water supply authority.

Pressure Loss Through Valves and Fittings

The pressure loss through valves and fittings is available from standard engineering texts. Because the size of the service could be large, it is recommended to individually count and calculate all valves and fittings, rather than add a set amount common for the distribution network inside building. The final calculation will result in an equivalent run of pipe. An equivalent straight length of pipe for fittings is given in Figure 11-6.

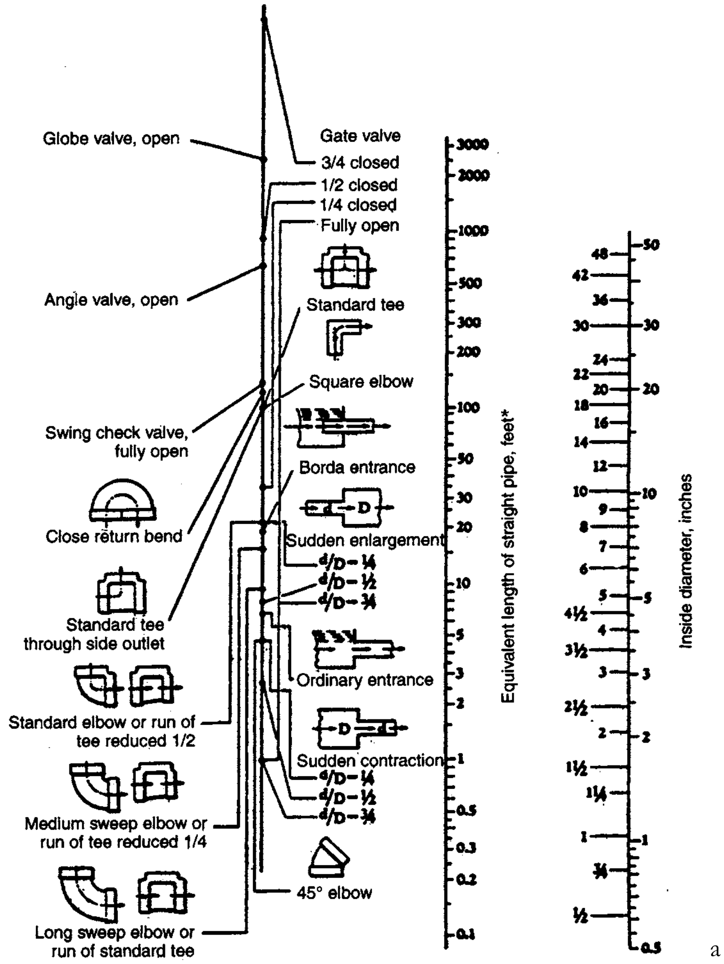


Figure 11-6 Equivalent Lengths of Pipe for Valves and Fittings

Note: For sudden enlargements or sudden contractions, use the smaller diameter on the nominal pipe size scale.

Total Pressure Loss in the Piping Run

The measured distance is from the main to the point of connection with the water distribution network inside the building. To the measured distance, add the equivalent run of pipe from pressure lost through all valves, fittings, and devices installed in the building service. Using the maximum probable gpm flow and equivalent number of feet of pipe run, the velocity and friction loss for the entire service can be obtained from standard engineering texts such as the *Plumbing Engineering and Design Handbook of Tables* and *Cameron Hydraulic Data*.

Backflow Preventers

The water utility is responsible for protecting the public water supply from any possibility of contamination due to backflow. The most common reason for the utility company to require a backflow preventer is the potential backflow from a facility that uses or produces any pollutant or contaminant. These facilities are separated into three general categories: low, moderate, and severe hazard. The facility category designated by the local authority will mandate the type of backflow preventer that shall be used. Another consideration is the presence of a close supply of impure water (such as a stream or lake) that could be used by the fire department to supply water that will be pumped into a building to fight a fire. This creates a potential source of contaminated water that could find its way back into a public main due to the pressure of the fire apparatus pumper.

The facility rating or classification should be made only after consulting with the proper authorities. Following are descriptions of the categories based on the use, toxicity, nature, and availability of contaminants:

- Low (minor) hazard: Private homes and commercial establishments without complex plumbing or fire protection systems
- Moderate (medium) hazard: Commercial buildings and establishments, fire protection storage tanks and mains with no additives, and facilities that discharge water at higher-than-normal temperatures
- Severe (high) hazard: Any facility that uses chemicals considered toxic or that has the potential to discharge toxic waste, such as hospitals, laboratories, water and sewage treatment plants, dry pipe fire protection systems, antifreeze loop sprinkler systems, and facilities involving chemical, pharmaceutical, food, and industrial manufacturing and processing

For hazardous locations, a reduced pressure zone (RPZ) backflow preventer will be required near the property line at the connection to the public main or immediately inside a building. Figure 11-7 illustrates an RPZ installed in an exterior aboveground enclosure. It should drain to an area where icing will not cause slip and fall hazards. Figure 11-8 illustrates an RPZ backflow preventer installed in an exterior belowground enclosure. (Note: Belowground installations of RPZ devices are not often allowed due to the probability of the discharge port becoming submerged in the event of a catastrophic failure of the device.)

For lesser hazards, a double check valve (DCV) is often acceptable. A double check valve in a belowground pit is illustrated in Figure 11-9. It is important to allow for adequate drainage from the RPZ discharge. The flow rate of discharge from an RPZ is given in Figure 11-10 at various pressures. There is no discharge from a DCV.

The size of drain or pump required is of critical importance to remove any possible discharge from an RPZ as quickly as possible, especially if it is located indoors or underground. Table 11-3 gives the size of drains based on the discharge and slope of discharge pipe. RPZ devices generally drip all the time so drainage to areas that will not cause icing in a walkway is important. RPZ devices should be located above grade so their discharge does not flood below-grade structures unless a gravity drain or sump pump with a drain can handle their flow and a backup power supply is provided.

A typical pressure loss through an RPZ device is 10 psi (68.9 kPa), and a typical pressure loss through a DCV is 5 psi (34.5 kPa). Since many types of backflow preventers are available, check with the manufacturer regarding the exact amount of discharge and pressure loss. They vary with size. Tests at the independent Foundation for Cross-Connection Control and Hydraulic Research at the University of Southern California have established that various manufacturers do not represent the pressure losses of their backflow preventers correctly. It would be appropriate to request the flow curves produced at the Foundation for the most accurate method of comparing various devices.

Table 11-3 Maximum Backflow Preventer Flow Rate Through Drains Flowing Full, gpm (L/m)

Drain Size, in. (Dn)	Slope	
	1⁄8 in./ft (0.5 cm/m)	1⁄4 in./ft (1.0 cm/m)
2 (50)	13 (100)	18 (135)
3 (75)	36 (275)	51 (390)
4 (100)	77 (585)	110 (835)
6 (150)	220 (1,670)	314 (2,385)
8 (200)	494 (3,755)	696 (5,290)
10 (250)	934 (7,100)	1,300 (9,900)

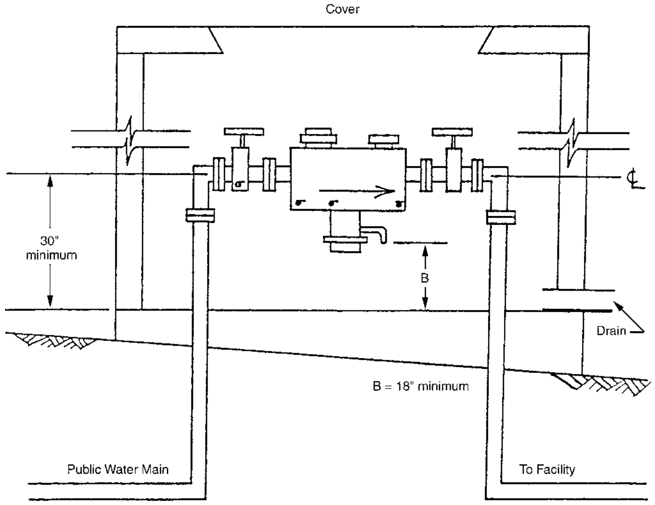


Figure 11-7 Aboveground Reduced Pressure Zone Backflow Preventer

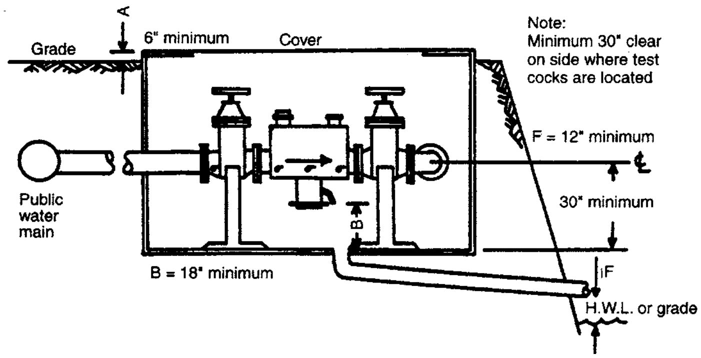


Figure 11-8 Belowground Reduced Pressure Zone Backflow Preventer

Strainer Losses

Strainers are commonly used for water with known particulate problems. Losses through different strainer types should be obtained from the manufacturer for the greatest accuracy.

Meter Losses

Water meters are usually selected by the water utility company, which very often will also provide the installation. Many different types of water meters are on the market. Compound meters and turbine meters require special installation details, and some even require strainers. The utility company should be consulted prior to designing the water meter details and calculating meter losses. Pressure losses through typical meters conforming to American Water Works Association (AWWA) standards are given in *Plumbing Engineering Design Handbook, Volume 2,* Chapter 5. Consult the manufacturer for the exact loss.

Difference in Elevation

The difference in elevation from the centerline of the public water main to the centerline of the service inside the building where it connects to the distribution network is an important item to consider. This distance shall be added or subtracted from the actual pressure (depending on whether it is higher or lower than the point of connection) along with all of the above items.

A sheet showing all of the data used to calculate the final water service pressure should be prepared to provide a permanent record (refer back to Figure 11-1).

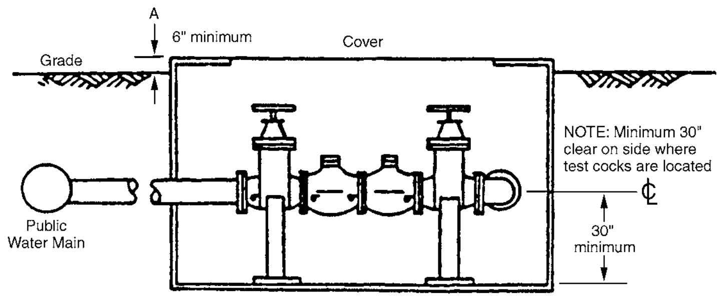


Figure 11-9 Double Check Valve Installed in a Pit

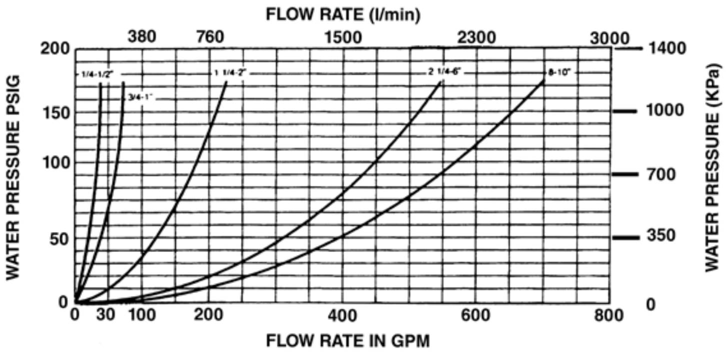


Figure 11-10 RPZ Discharge Flow Rate

FIRE PROTECTION WATER SUPPLY

The fire protection building service provides the water necessary for fire suppression purposes inside a building, such as sprinkler and standpipe systems. This service could be combined with the domestic water supply.

The fire protection building service continues from a connection to a source of water to a point inside a building where a connection to the fire suppression piping network is located. The source is usually a public water main, but other sources also could be used. The building service includes water storage tanks, backflow preventers, meters, valves, hydrants, and other devices that may be required based on the nature of the water service, insurance carrier requirements, and local regulations. (This section is not intended to cover a complete private fire service main, which is outside the scope of this chapter.)

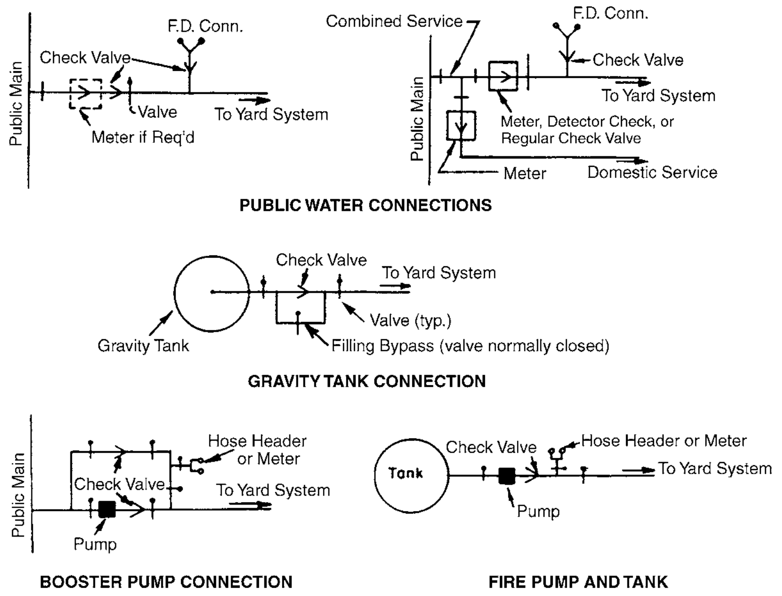


Figure 11-11 Connections to a Public Water Main

Codes and Standards

The standard most often used for the design of private fire protection water mains is NFPA 24: *Standard for the Installation of Private Service Mains and their Appurtenances*. If FM Global is the fire insurance carrier, the system must conform with FM Global Property Loss Prevention Data Sheet 3-10: *Installation/Maintenance of Fire Service Mains.*

Building Water Supply

If the water supply to a building is a combined service—that is, both domestic and fire service are fed through a single pipe—the main shall be considered a fire service until the domestic water connection is made in the combined service. Typical connections to a public water main are illustrated in Figure 11-11. If the source is a well, an aquifer performance analysis and an investigation of the history of adjacent wells should be made.

For many facilities where loss of water would be an extreme hardship, such as hospitals, multiple water supplies from two separate public mains are a very desirable feature. This allows water to be supplied to the facility from either of two directions. If multiple connections are made to a single main, a sectionalizing valve installed in the source main somewhere between the two connections shall be required.

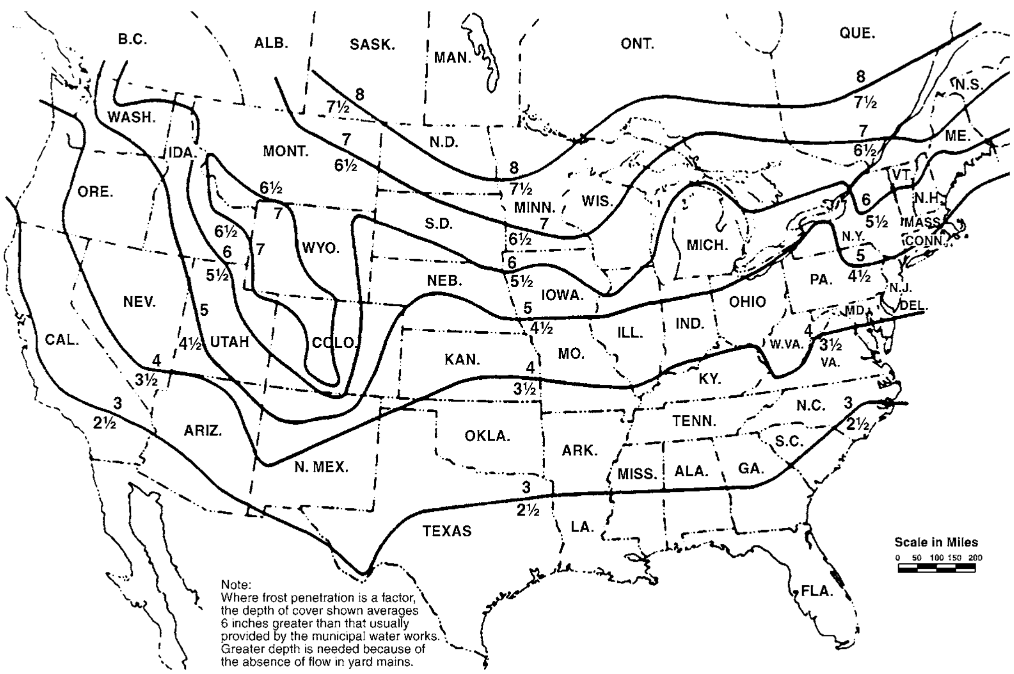


Figure 11-12 Recommended Depth of Cover Above Underground Mains, ft

The mains shall be buried below the frost line. A generalized map of the United States is given in Figure 11-12 to aid in determining that depth. Local authorities shall be contacted for conditions at the project site.

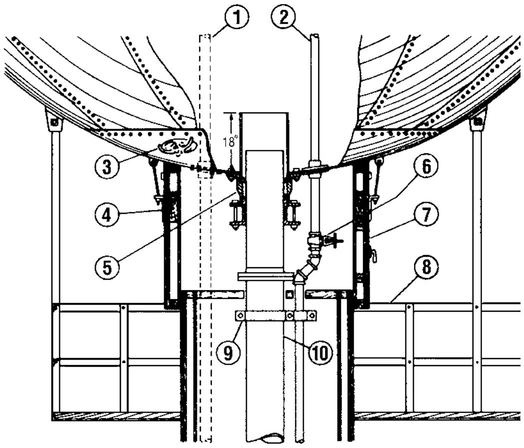
Contamination of the public water supply is a prime concern of the water company that supplies water to the project. The health department, water purveyor, or plumbing code official will determine the acceptable device for preventing contamination by the fire protection water supply. The two most often used are the double check valve assembly and the reduced pressure zone backflow preventer. These devices were discussed in the domestic water supply section.

In many cases, it is not possible to supply the required flow rate or volume of water for firefighting purposes from the public supply. These situations call for the use of a water storage tank. Such tanks can be either elevated or installed on the ground. The design of these tanks is outside the scope of this chapter. Connections from the water supply to a storage tank shall terminate 1 foot (0.3 m) over the overflow level. The overflow shall be two pipe sizes larger than the water supply pipe size. Various connections to storage tanks are shown in Figure 11-13.

Ancillary Devices

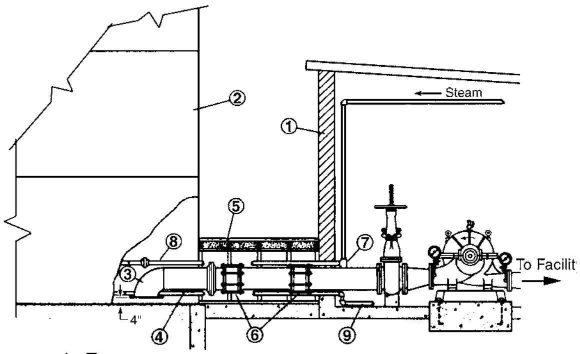
Fire Hydrants

Fire hydrants (see Figure 11-14) are directly connected to the site main or the building service. They shall be installed adjacent to roadways to allow easy connection of fire department apparatus. If reasonable, they shall be located on all sides of the building being protected. A desired separation from the building wall is 50 feet (15.2 m) to provide some protection from building wall collapses. The recommended separation between hydrants is 300 feet (91.4 m) at a building location. (Hydrant locations are mandated by the local applicable code.) Hydrants located near a road shall be protected by guard posts. It is good practice to provide a shutoff valve on the branch line to a hydrant to allow easy repair without having to shut down the main or the service.



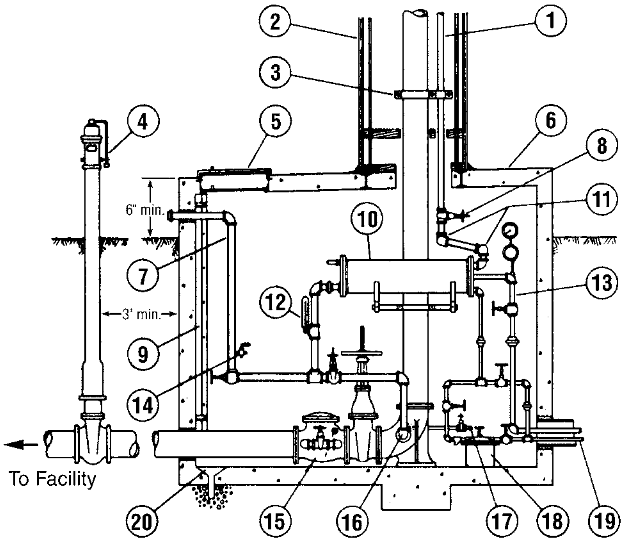
1. Inside brass overflow pipe, if used
2. Hot water circulating pipe
3. Handhole for removing sludge
4. Frostproof casing when required
5. Expansion joint
6. Approved OS&Y gate valve
7. Door in frostproof casing
8. Walkway
9. Brace for hot water circulating pipe
10. Pipe riser

Details of pipe connections to bottom of steel gravity tank with pipe riser.



1. Pump room
2. Approved aboveground suction tank
3. Entrance elbow with vortex plate or flange 4 in. (102 mm) above bottom of tank
4. Suction pipe
5. Frostproof casing, about 4 ft (1.2 m) high and 4 ft (1.2 m) wide
6. Flexible couplings
7. Steam trap on steam supply
8. Heating coil inside tank
9. Condensate return line to steam trap

Discharge pipe connected to side of suction tank.



1. Hot water circulating pipe
2. Frostproof casing
3. Pipe clamps. Locate at about 25 ft (7.6 m) intervals. Loose fit around hot water circulating pipe.
4. Indicator-post valve. May be replaced with indicating-type valve in pit on yard side of check valve if space is not available for indicator post.
5. Hatch cover
6. Valve pit
7. Drain pipe
8. OS&Y gate valve
9. Ladder
10. Tank heater with relief valve set at 120 psi (825 kPa)
11. Four-elbow swing joint
12. Thermometer
13. Steam supply pipe
14. Drain cock, 1/2 in. (13 mm)
15. Approved check valve with bypass
16. Cold water circulating pipe
17. Pipe to mercury gauge
18. Steam trap
19. Condensate return
20. Valve-pit drain

Valve pit and pipe connections at base of tank on independent tower. Tank has a pipe riser and steam-heated gravity circulating heating system.

Figure 11-13 Water Storage Tank Connections

Guard Posts

Guard posts (sometimes referred to as bollards) may be necessary to protect any device that is installed above grade near roads. A typical guard post is illustrated in Figure 11-15.

Post Indicator Valve

A post indicator valve (PIV) is used only to shut off the supply of water, never to control the flow. It is used as a section valve on water mains and also on building services. Since it is critical for emergency personnel to be certain that any control valve is open or closed, an indicator is positioned above grade with a window or some other method of allowing easy observation of the valve position. A typical post indicator valve is illustrated in Figure 11-16. Post indicator valves can be provided with a supervisory tamper switch and/or can be locked open.

Joint Restrainers

When run in a straight line, properly specified joints will provide a leakproof installation. Where changes in pipe direction occur, pressure is exerted by the flowing water on the fitting, and the joints may not provide sufficient resistance to the force exerted by the pressure of the water against the fitting. To prevent joint failure due to the pressure exerted, most pipe joints must be restrained in some manner.

Mechanical and push-on joints are sealed by a rubber-type gasket compressed in a space between the spigot end of the pipe and the bell. These joints will not resist the pressure of the water on the joint. The method of restraint used is external clamps and rods. Friction clamps are bolted around the pipe on both sides of the joint. These clamps engage steel tension rods, sometimes called tie rods, across the joint, preventing it from separating. This will combine the resistance of these joints to prevent separation. Calculations are necessary to determine the actual number of joints to be restrained.

Another method of restraint used is integrally cast glands for mechanical joint pipe with internally locked, grooved, and keyed push-on joints. This type of restraint is usually recommended only for the repair of existing systems or if soil conditions prohibit thrust blocks from being installed against virgin soil.

The most common method of restraint is to use a block of concrete that is poured against undisturbed soil and contacts the fitting. The size of the block varies with the water pressure (higher pressure = larger block), the pipe size (larger pipe = larger block), and the bearing pressure of the soil (lower soil bearing pressure = larger block). Typical thrust block dimensions are given in Figure 11-17. Table 11-4 provides soil-bearing load values, and Table 11-5 gives the pressure, in pounds, at various joints. One problem with this method is that many project sites do not have undisturbed soil against which the thrust block can be based, and another is that the size of the concrete block prevents piping from being placed adjacent to the run of pipe being protected.

Table 11-4 Soil Bearing Loads

Soil	Bearing Load, lb/ft^2
Muck	0
Soft clay	1,000
Silt	1,500
Sandy silt	3,000
Sand	4,000
Sandy clay	6,000

Sizing the Fire Protection Water Service

When all of the information required for the design of the domestic water system has been obtained, the fire marshal, fire protection code official, and insurance company shall be contacted for their installation requirements.

What constitutes an adequate water supply has generated much discussion over time. Many factors, when all are considered, result in an adequate water supply. The water supply should be capable of supplying the largest demand, which is usually the sprinkler or standpipe system, and the expected hose flow under reasonably adverse conditions. If other factors such as building occupancy, yard storage, external structures that must be protected, exposure protection, and catastrophic hose demand are considered, they will all add to the flow rate.

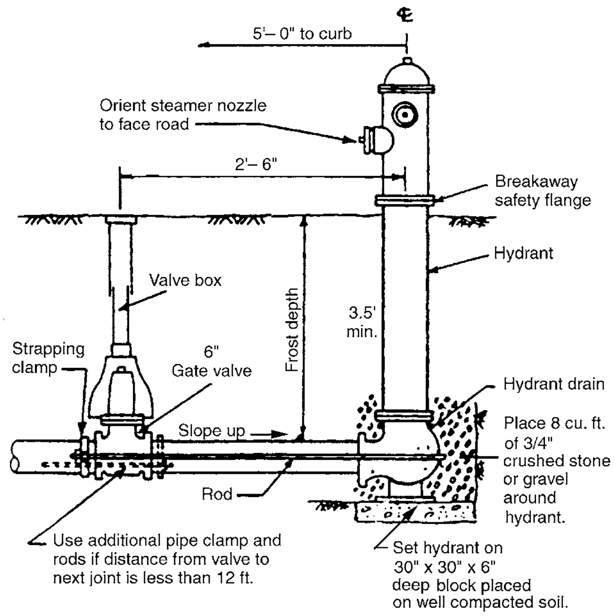


Figure 11-14 Fire Hydrant

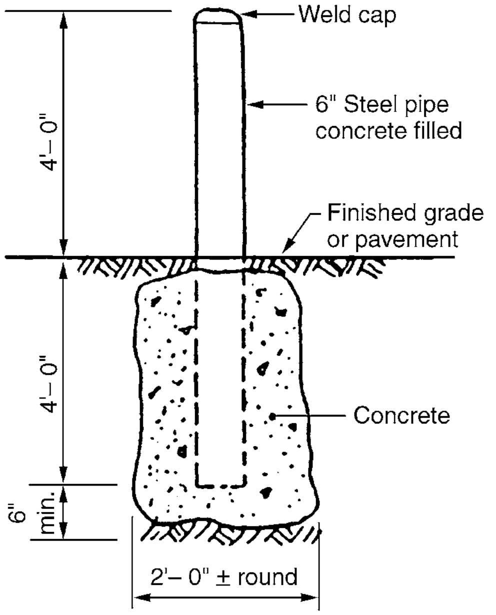


Figure 11-15 Guard Post

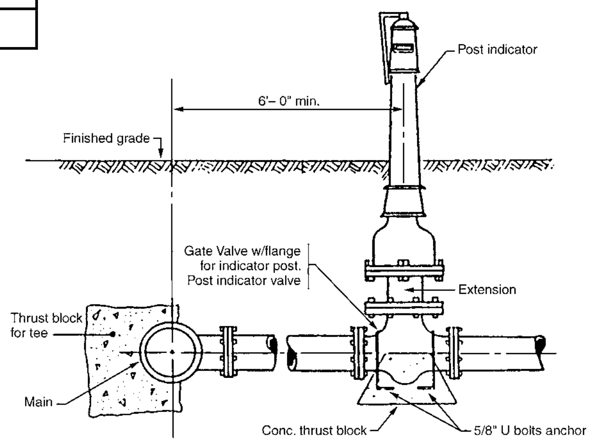


Figure 11-16 Post Indictor Valve

Thrust Block Dimensions											
		¼ Bend		1/8 Bend		1/16 Bend		Tee		Plug	
Type	Size, in.	A, in.	B, in.	A, in.	B, in.	A, in.	B, in.	A, in.	B, in.	C, in.	D, in.
Type I 4000 PSF Soil	6	8	10	6	8	3	8	8	8	10	15
	8	12	12	8	10	5	9	9	12	12	20
	10	16	14	10	12	6	10	11	14	14	25
	12	19	16	12	14	8	11	14	16	16	30
	14	23	18	14	16	10	12	16	18	18	34
	16	26	20	16	18	11	13	18	20	20	38
Type II 2000 PSF Soil	6	16	10	9	10	6	8	10	12	10	21
	8	22	13	12	13	8	10	13	16	12	29
	10	26	17	14	17	10	13	16	20	14	36
	12	29	21	16	21	11	16	18	24	16	41
	14	35	24	19	24	12	20	22	27	18	48
	16	38	27	21	27	12	24	24	30	20	54

Note: Based on 100-psi static pressure plus AWWA water hammer. All bearing surfaces to be carried to undisturbed ground.

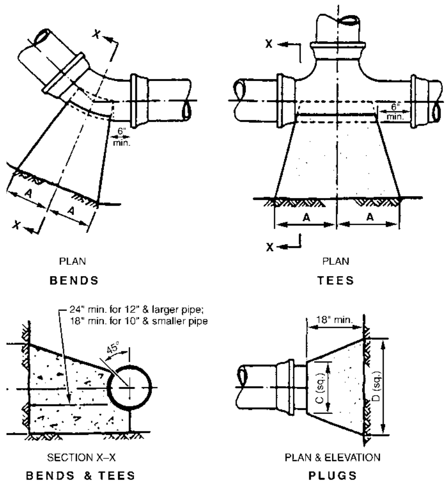


Figure 11-17 Thrust Block Installation

Demand Flow Rate

The demand flow rate used to size the building service usually is based on several factors. The first is the gpm based on the calculated flow rate for the sprinkler system, which is based on hydraulic calculations. The second is the flow of water for additional hose streams used by the fire department to fight a fire.

The following figures are presented for preliminary discussion purposes only. They are not to be used for actual design calculations, which should be made only on a specific project basis after consulting with the fire marshal, insurance carrier representative, and fire code official.

Fire department hose streams depend on the occupancy hazard, which can be as follows.

- Light and ordinary hazard: 500 gpm (1,900 L/min)
- Extra hazard, group 1: 750 gpm (2,900 L/min)
- Extra hazard, group 2: 1,000 gpm (3,800 L/min)
- High-piled storage: As required by the insurance company

The hose demand shall be increased by 25 percent for the following conditions:

- Combustible construction
- Possible delay in response by the fire department
- Minimum protection less than that recommended by insurance company requirements
- Limited access to remote interior sections

For the design of a large site consisting of multiple buildings, the typical fire protection flow rate requirements are given in Table 11-6.

Table 11-5 Total Pounds Resultant Thrust at Fittings at 100-psi Water Pressure

Nominal Pipe Diameter, in.	Dead End	90° Bend	45° Bend	22½° Bend	11¼° Bend
4	1,810	2,559	1,385	706	355
6	3,739	5,288	2,862	1,459	733
8	6,433	9,097	4,923	2,510	1,261
10	9,677	13,685	7,406	3,776	1,897
12	13,685	19,353	10,474	5,340	2,683
14	18,385	26,001	14,072	7,174	3,604
16	23,779	33,628	18,199	9,278	4,661
18	29,865	42,235	22,858	11,653	5,855
20	36,644	51,822	28,046	14,298	7,183
24	52,279	73,934	40,013	20,398	10,249
30	80,425	113,738	61,554	31,380	15,766
36	115,209	162,931	88,177	44,952	22,585
42	155,528	219,950	119,036	60,684	30,489
48	202,683	286,637	155,127	79,083	39,733
54	256,072	362,140	195,989	99,914	50,199

Note: To determine thrust at pressures other than 100 psi, multiply the thrust obtained in the table by the ratio of the pressure to 100. For example, the thrust on a 12-inch pipe with a 90° bend at 125 psi is $19,353 \times 125/100 = 24,191$ lb.

Tank Capacity

If a gravity tank is the sole source of water, the tank should be capable of being filled in eight hours. In evaluating the total capacity, consider the following storage capacities, based on the categories appearing in NFPA 13: *Standard for the Installation of Sprinkler Systems:*

- Light and ordinary hazard occupancies, group 1: Two hours
- Ordinary hazard occupancies, groups 2 and 3: Three hours
- Extra hazard occupancies: Four hours

Table 11-6 Typical Fire Protection Flow Rate Requirements

Land Use	Flow Rate Range, gpm	Average Flow Rate, gpm
Single-family residential	500–2,000	750
Multifamily residential	1,500–3,000	2,000
Commercial	2,500–5,000	3,000
Industrial	3,500–10,000	—
Central building district	2,500–15,000	3,000

SANITARY SEWER

The purpose of the sanitary house sewer is to convey all sanitary waste from a facility to an approved point of disposal, which is usually a public sewer.

The first step is to find the department or jurisdiction responsible for the approval, design, and installation of sanitary sewers. Also, find the authority having jurisdiction (AHJ) responsible for the disposal of other kinds of waste, notably kitchen waste that contains fats, oil, and grease (FOG). Once this is established, a formal letter should be written to obtain the following information:

- What are the size, location, and inverts of all available sewers fronting the property?
- Are the sewers sanitary, storm, or combined?
- What is the material of these sewers?
- If no sewers are available, who is the AHJ for a private disposal system (septic tank and field)? What codes and standards regulate the design and installation of the septic system?
- Are street sewer connections preferred at spurs between manholes, or shall a manhole be used for the connection? Are standard details available? Will these manholes be constructed by the plumbing contractor or the AHJ?

When the utility company has provided most of the information requested, the following work can be accomplished:

- The run from the building to the sewer can be selected. If the invert elevations are not suitable, determine if a force main will be necessary.
- The house sewer can be sized based on the fixture count and the slope of the sewer.

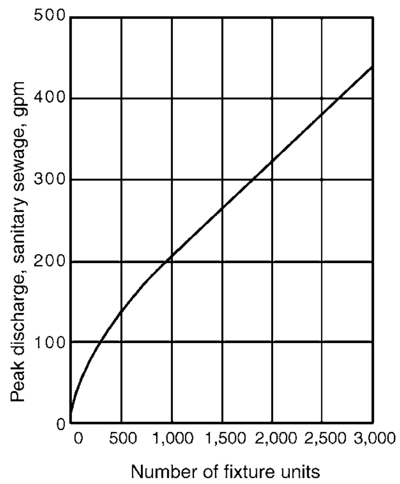


Figure 11-18 Fixture Unit Conversion to gpm

Sizing the Sanitary Sewer

The size of the sewer from the building to the property line is based on the applicable plumbing code requirements. If the house sewer extends beyond the property line to connect to a pubic sewer, the plumbing code may not apply. However, other codes may be applicable in the area. A self-scouring velocity must be maintained to prevent solids from settling out and stopping the pipe. Table 11-7 is provided to allow sizing at a minimum slope to maintain a velocity of 2 to 2.5 feet per second (fps) (0.61 to 0.76 m/s). Figure 11-18 can be used to convert the sanitary drainage fixture units to gpm. Since sanitary effluent has a viscosity similar to water, Figure 11-19 can then be used to size the sewer based on flow and pitch. Good engineering practice is to use a pipe size based on it flowing half-full.

Sewer Components and Design Criteria

Public Sewer Availability

The question of availability is a concern. It is up to the AHJ to determine whether the project shall connect to any particular sewer. This is a potential problem in rural areas, where considerable distances are necessary to connect to a sewer. A run by gravity is the preferred method, but this is costly for a long run and a large size. A force main, which is discussed later, may be desirable.

Trenching and Bedding

Bedding is the point of contact between the pipe and the earth. The type of bedding has an important influence on the load the pipe can support.

The bedding for metallic pipe is different than that for plastic pipe because trench walls are needed to help support plastic pipe. A typical trench for plastic pipe is shown in Figure 11-20, and one for metallic pipe is shown in Figure 11-21. The methods shown are for class B bedding, as is suitable for the majority of piping buried underground. If the weight placed on the buried pipe is a concern, other bedding methods that increase the resistance of the pipe can be used (see Figure 11-22).

Grease Interceptors

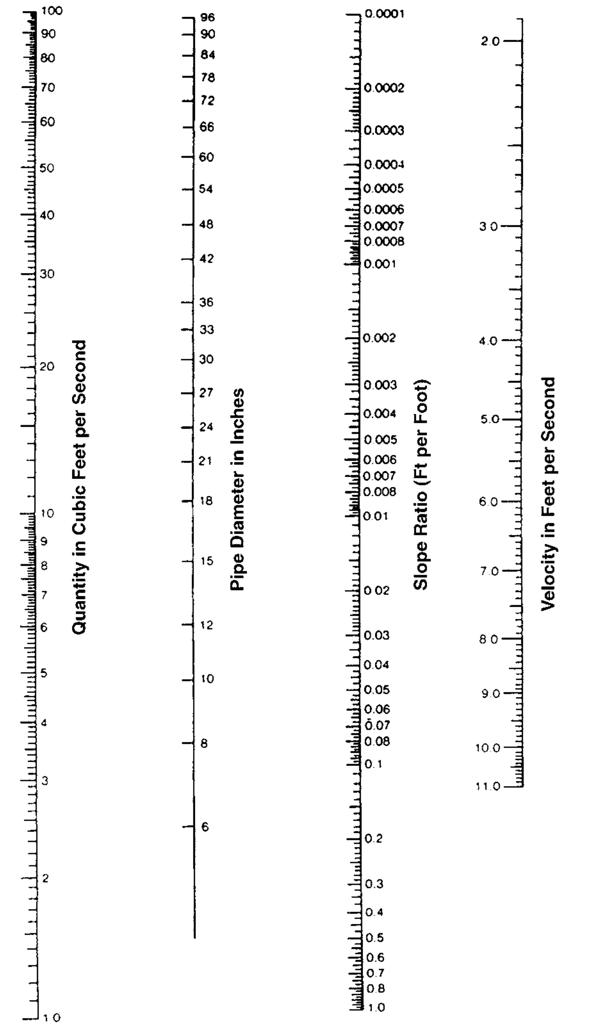
When a project has a kitchen or cafeteria, fats, oil, and grease are bound to be discharged. Grease is typically removed from the waste stream with a grease interceptor. If not removed from the waste stream, FOG must be intercepted before entering the public sewer by means of a FOG interceptor.

Typical Sewer House Connection

A typical small house or building will connect to the sewer in a manner similar to that illustrated in Figure 11-23 where a spur is provided. A spur is a pre-installed fitting located at fixed distances along the length of a sewer line.

Drainage Structures

A drainage structure is any appurtenance built into a sewer run, including manholes, stormwater inlets, and catch basins.



Value of n	0.008	0.010	0.011	0.012	0.013	0.015	0.019	0.021	0.024
Conversion factor for discharge and velocity	1.62	1.30	1.18	1.08	1.00	0.87	0.68	0.62	0.54

Figure 11-19 Diagram to Solve the Manning Formula for Circular Pipes Flowing Full where n = 0.013

Table 11-7 Sewer Size Based on Velocity and Slope*

Pipe Size, in.	Velocity, fps	1/4 Full		1/2 Full		3/4 Full		Full	
		Slope, ft/ft	Flow, gpm	Slope, ft/ft	Flow, gpm	Slope, ft/ft	Flow , gpm	Slope, ft/ft	Flow, gpm
2	2	0.0313	4.67	0.0186	9.34	0.0148	14.09	0.0186	18.76
	2.5	0.0489	5.84	0.0291	11.67	0.0231	17.62	0.0291	23.45
3	2	0.0178	10.77	0.0107	21.46	0.0085	32.23	0.0107	42.91
	2.5	0.0278	13.47	0.0167	26.82	0.0133	40.29	0.0167	53.64
4	2	0.0122	19.03	0.0073	38.06	0.0058	57.01	0.0073	76.04
	2.5	0.0191	23.79	0.0114	47.58	0.0091	71.26	0.0114	95.05
5	2	0.0090	29.89	0.0054	59.79	0.0043	89.59	0.0054	119.49
	2.5	0.0141	37.37	0.0085	74.74	0.0067	111.99	0.0085	149.36
6	2	0.0071	43.18	0.0042	86.36	0.0034	129.54	0.0042	172.72
	2.5	0.0111	53.98	0.0066	107.95	0.0053	161.93	0.0066	215.90
8	2	0.0048	77.20	0.0029	154.32	0.0023	231.52	0.0029	308.64
	2.5	0.0075	96.50	0.0045	192.90	0.0036	289.40	0.0045	385.79
10	2	0.0036	120.92	0.0021	241.85	0.0017	362.77	0.0021	483.69
	2.5	0.0056	151.15	0.0033	302.31	0.0026	453.46	0.0033	604.61
12	2	0.0028	174.52	0.0017	349.03	0.0013	523.55	0.0017	698.07
	2.5	0.0044	218.15	0.0026	436.29	0.0021	654.44	0.0026	872.58
15	2	0.0021	275.42	0.0012	550.84	0.0010	826.26	0.0012	1,101.68
	2.5	0.0032	344.28	0.0019	688.55	0.0015	1,032.83	0.0019	1,377.10

* Slopes of cast iron soil pipe sanitary sewers required to obtain self-cleansing velocities of 0.6096 and 0.762 m/s (based on Manning's Formula with n = 0.012)

Table 11-7(M) Sewer Size Based on Velocity and Slope*

Pipe Size, mm	Velocity, m/s	1/4 Full		1/2 Full		3/4 Full		Full	
		Slope, m/m	Flow, L/s	Slope, m/m	Flow, L/s	Slope, m/m	Flow, L/s	Slope, m/m	Flow, L/s
50	0.6096	0.0313	0.295	0.0186	0.59	0.0148	0.89	0.0186	1.18
	0.762	0.0489	0.369	0.0291	0.74	0.0231	1.11	0.0291	1.48
75	0.6096	0.0178	0.68	0.0107	1.35	0.0085	2.03	0.0107	2.71
	0.762	0.0278	0.85	0.0167	1.69	0.0133	2.54	0.0167	3.38
100	0.6096	0.0122	1.2	0.0073	2.4	0.0058	3.6	0.0073	4.8
	0.762	0.0191	1.5	0.0114	3.0	0.0091	4.5	0.0114	6.0
125	0.6096	0.0090	1.89	0.0054	3.77	0.0043	5.65	0.0054	7.54
	0.762	0.0141	2.36	0.0085	4.72	0.0067	7.07	0.0085	9.42
150	0.6096	0.0071	2.72	0.0042	5.45	0.0034	8.17	0.0042	10.9
	0.762	0.0111	3.41	0.0066	6.81	0.0053	10.22	0.0066	13.62
200	0.6096	0.0048	4.87	0.0029	9.74	0.0023	14.61	0.0029	19.48
	0.762	0.0075	6.09	0.0045	12.17	0.0036	18.26	0.0045	24.34
250	0.6096	0.0036	7.63	0.0021	15.26	0.0017	22.89	0.0021	30.52
	0.762	0.0056	9.54	0.0033	19.08	0.0026	28.61	0.0033	38.15
300	0.6096	0.0026	11.01	0.0017	22.02	0.0013	33.04	0.0017	44.05
	0.762	0.0044	13.77	0.0026	27.53	0.0021	41.3	0.0026	55.06
380	0.6096	0.0021	17.38	0.0012	34.76	0.0010	52.14	0.0012	69.52
	0.762	0.0032	21.72	0.0019	43.45	0.0015	65.17	0.0019	86.9

* Slopes of cast iron soil pipe sanitary sewers required to obtain self-cleansing velocities of 0.6096 and 0.762 m/s (based on Manning's Formula with n = 0.012)

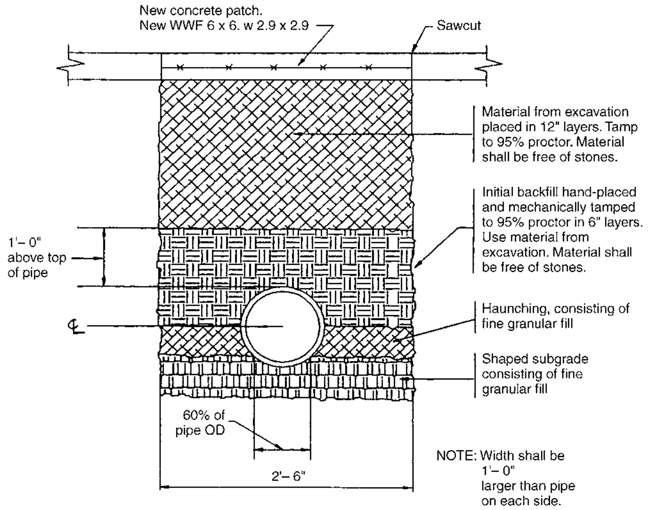


Figure 11-20 Bedding for Plastic Pipe

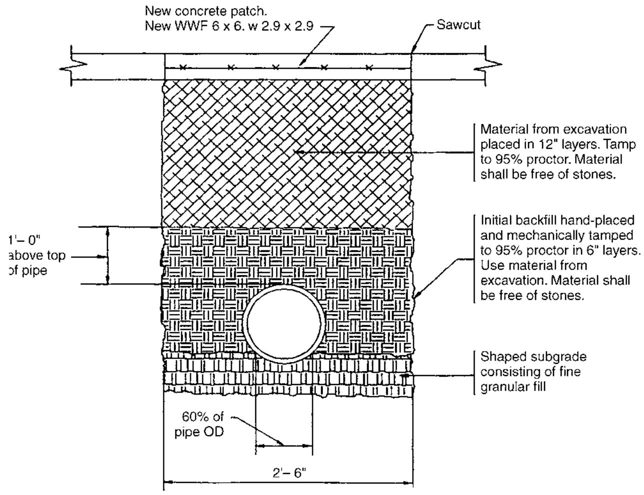


Figure 11-21 Bedding for Metallic Pipe

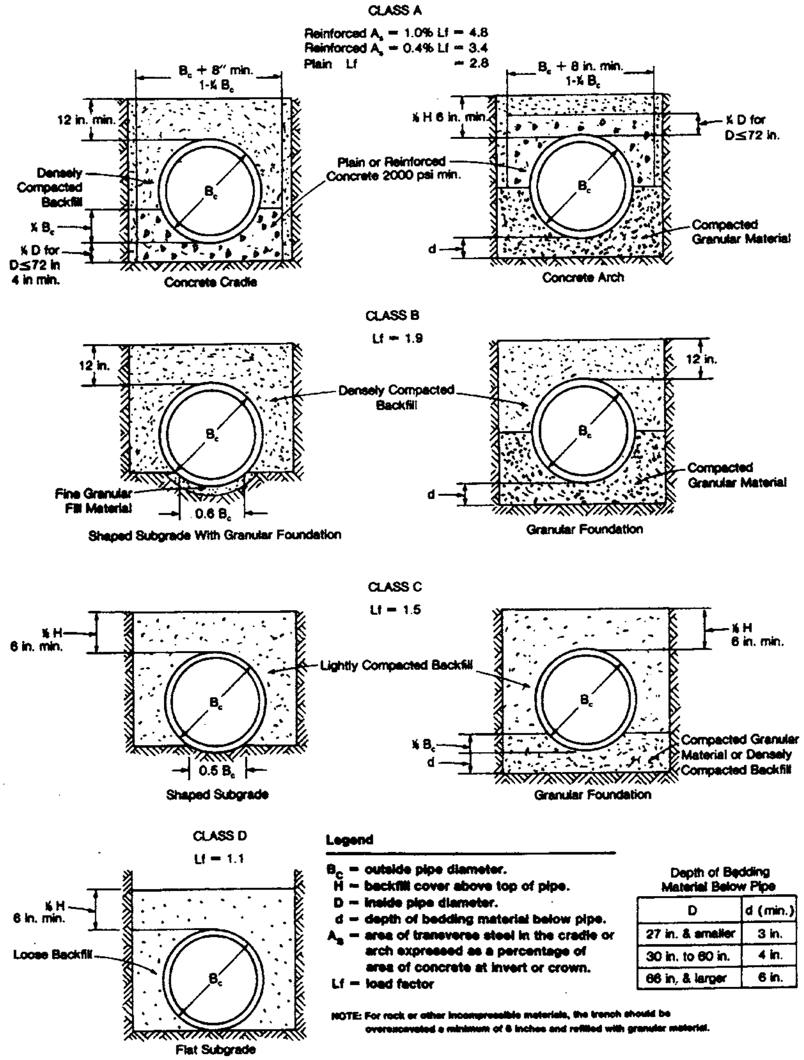


Figure 11-22 Rigid Pipe Bedding Methods

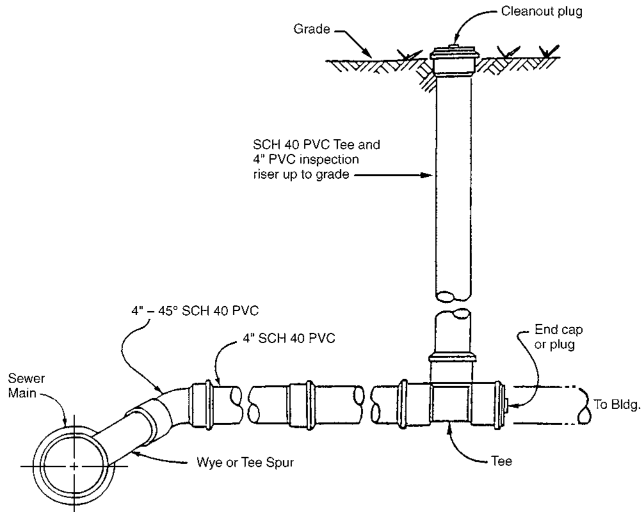


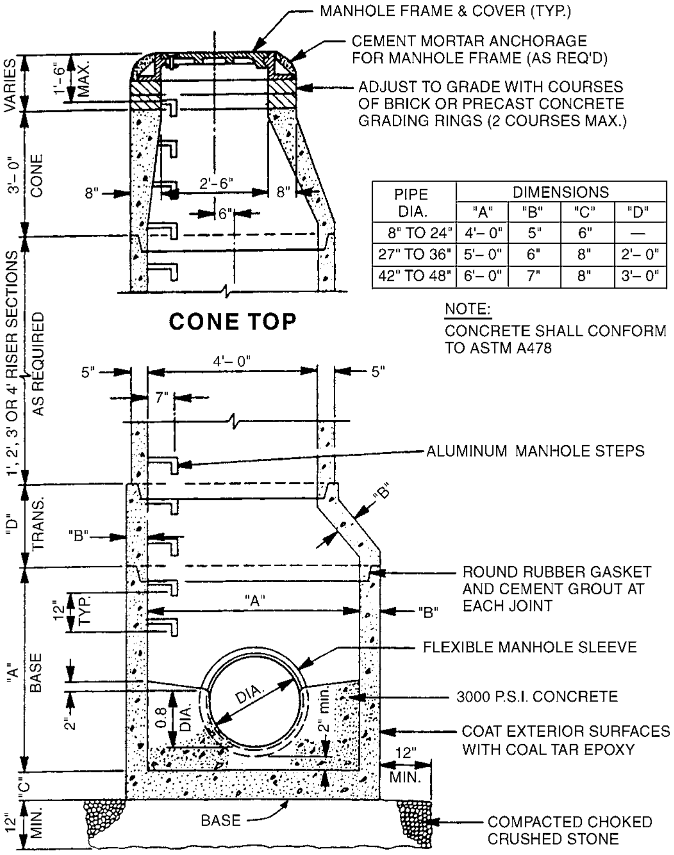
Figure 11-23 House Sewer Connection

Manholes can be made of poured concrete, bricks, blocks, or precast sections. Precast manholes (see Figure 11-24) are the most widely used type. Manholes are installed for the following reasons: at changes of direction in the sewer, for inspection and cleaning, at substantial changes of grade, at changes of pipe size, and to make a connection to a public sewer for large sewers.

The primary purpose of a manhole is to provide a smooth invert to allow pipes that join the main sewer to have an unimpeded entry to that sewer and to provide a smooth invert when pipes change size and pitch. To accomplish this, the bottom of the manhole is channeled smooth from the invert of all the pipes entering the manhole. It is accepted practice for the tops of the joining sewer pipes to be even. Manhole construction requirements should be verified with the authority having jurisdiction. If the building has an acid drainage component, such as a laboratory, an acid neutralizing system should be installed. A separate line should be provided from the building to the point of disposal. A detail of an acid manhole is given in Figure 11-25.

If the depth from finished grade to the invert of the sewer is 3 feet (0.9 m) or less, a shallow manhole (see Figure 11-26) should be used.

When a difference in the inverts of the pipes is more than approximately 2 inches to 2 feet (50.8 mm to 0.61 m), the falling water will cause the lower pipe to erode. When this is the case, a chute shall be created at the manhole bottom. If the difference in the inverts of the pipes is greater than 2 feet, a drop manhole should be installed, as shown in Figure 11-27.



PIPE DIA.	DIMENSIONS			
	"A"	"B"	"C"	"D"
8" TO 24"	4'– 0"	5"	6"	—
27" TO 36"	5'– 0"	6"	8"	2'– 0"
42" TO 48"	6'– 0"	7"	8"	3'– 0"

NOTE:
CONCRETE SHALL CONFORM TO ASTM A478

Figure 11-24 Precast Manhole

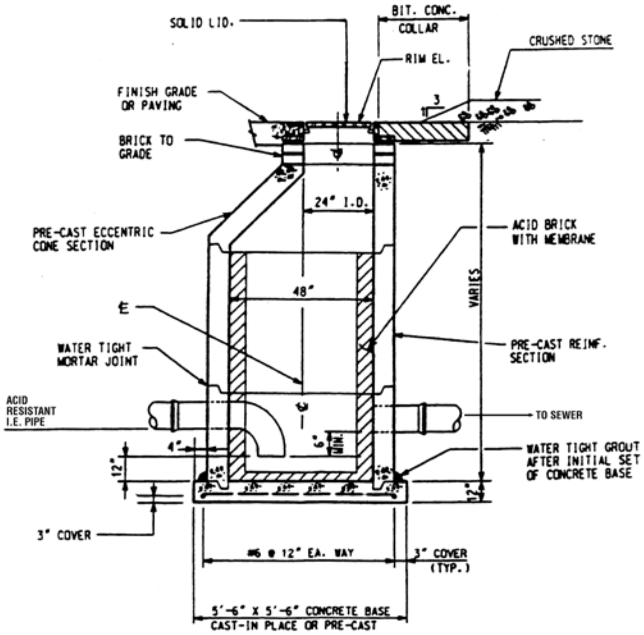
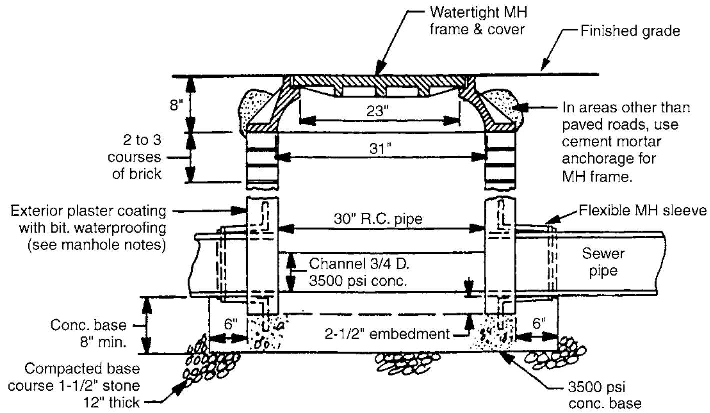


Figure 11-25 Acid Manhole



NOTES:
1. Shallow MH (circular) to be used at locations where distance from finished grade to pipe invert is 3'– 0" or less.
2. For depths of 3'– 0" and less, measured from the top of the pipe, contractor shall install ductile iron pipe, Class 52, under traffic areas.

Figure 11-26 Shallow Manhole

Other manhole accessories are manhole steps and standard manhole and watertight frames and covers. In some cases where the watertight manhole cover is required, an outlet for the air that accumulates in the manhole may not exist. Where this is a concern, a vent should be installed, as illustrated in Figure 11-28.

For short runs of sewers into the main, cleanouts shall be provided on the site every 75 feet (22.9 m) or as dictated by code to allow the line to be rodded out in the event of a stoppage.

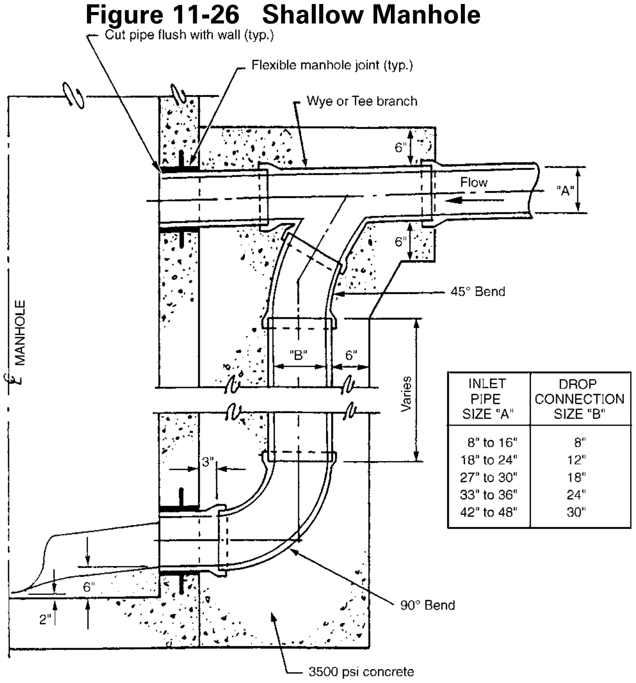
General manhole spacing and locations are given in Table 11-8.

Sewage Lift Station

When the discharge of the sanitary sewer from a facility is lower than the public sewer intended for disposal due to topography or low elevation, pumping will be required to reach that higher elevation. A sewage lift station or sewage pumping station is the system used to accomplish this. (Note: The following discusses only the methods used to pump sewage discharged from an industrial/commercial type of facility.)

The difference in terminology between a sewage ejector and a lift station is one of scope. In general, the ejector system is used to pump discharge from a portion of the building up to the main house sewer for disposal, while the lift station is used to pump discharge from an entire building or site for disposal. The components of a sewage ejector system and sewage lift station are very similar to the ejector system discussed in *Plumbing Engineering Design Handbook, Volume 2,* Chapter 1: Sanitary Drainage Systems.

The components of a sewage lift station are the sewage pumps, basin, discharge pipe (routed to the public sewer or point of disposal), controls, and alarms. The sewage pump discharge line often is called a force main. The design of the complete sewage lift station as a whole is an iterative one, where the selection of each component somewhat depends on the other components for size and capacity.



INLET PIPE SIZE "A"	DROP CONNECTION SIZE "B"
8" to 16"	8"
18" to 24"	12"
27" to 30"	18"
33" to 36"	24"
42" to 48"	30"

NOTE: Drop pipe to be used in all cases where difference between inlet invert and lowest outlet invert is 2 feet or greater.

Figure 11-27 Drop Manhole

Sewage Pumps

The types of pumps used in sewage lift stations are similar to the ejector systems discussed in Volume 2.

The pump most often selected is the submersible type (see Figure 11-29) because of its low initial cost, wide range of capacities, and tolerance of many starts. Another advantage is that a smaller basin can be used because additional height below grade is not required to house the motor of a conventional vertical, submerged ejector pump.

For a facility sewage pump, it is accepted practice for the pump capacity to equal the highest instantaneous flow rate expected from the facility. The reasoning is that in the event the basin is incapable of being used, a single pump must be capable of discharging all possible effluent from all sources. It is also critical that at least a duplex set of pumps be included, each one with the same capacity, to ensure that the facility will be kept in operation if one pump is out of service. If a wide range of instantaneous flow rates is possible, a three-pump system, with each pump sized at 75 percent of the maximum calculated flow, should be considered. One pump typically would always be on standby.

The maximum discharge is calculated for two conditions. The first is for the maximum possible inflow. This is done by adding the plumbing fixture load, in gpm, obtained from Hunter's curve, and other possible sources of discharge to arrive at a maximum probable instantaneous flow rate. If the facility is discharging mostly effluent from plumbing fixtures, add 10 percent to that figure as a safety factor. The second condition is based on a reasonable number of starts per hour.

Table 11-8 Manhole Spacing and Location of Pipe Sewers

Maximum Spacing of Manhole on Pipe Sewers

Pipe Size, in. (mm)	Recommended Maximum Spacing, ft (m)	Absolute Maximum Spacing, ft (m)
10 Dia. to 24 Dia. (254 to 610) Circular	150 (45.7)	200 (61)
14 H×23 W (356×584) Horiz. Elliptical Pipe		
23 H×14 W (584×356) Vert. Elliptical Pipe		
27 Dia. to 48 Dia. (686 to 1,219) Circular	300 (91.4)	400 (121.9)
19 H×30 W to 48 H×76 W (483×762 to 1,219×1,930) Horiz. Elliptical Pipe		
30 H×19 W to 49 H×32 W (962×483 to 1,245×813) Vert. Elliptical Pipe		
54 Dia. to 66 Dia. (1,372 to 1,676) Circular	400 (121.9)	500 (152.4)
53 H×83 W to 68 H×106 W (1,346×2,108 to 1,727×2,692) Horiz. Elliptical Pipe		
53 H×34 W to 68 H×43 W (1346×864 to 1,727×1,092) Vert. Elliptical Pipe		
72 Dia. (1,829) and Larger Circular	500 (152.4)	600 (182.8)
72 H×113 W (1,829×2,870) and larger Horiz. Elliptical Pipe		
76 H×48 W (1,930×1,219) and larger Vert. Elliptical Pipe		

Manhole Location on Pipe Sewers

1. Change in grade or elevation: At all changes in grade or elevation for all sizes of sewers
2. Change in alignment:
   (a) At all changes in alignment for circular sewers up to and including 42 in. (1,067 mm) diameter
   (b) At all changes in alignment for elliptical pipe sewers up to and including 43 in. H × 68 in. W (1,092 mm × 1,727 mm) and 42 in. H × 27 in. W (1,067 mm × 686 mm) sizes

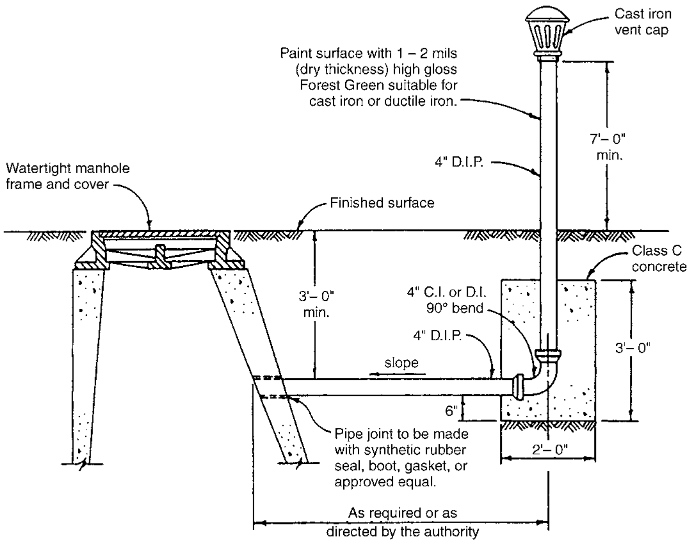


Figure 11-28 Detail of Waterproof Manhole

Required Head

The required system head is calculated by adding the static height (in feet) from the bottom of the basin to the point of discharge (or the highest point of the force main run) to the friction loss of the liquid running through the pipe based on the equivalent length of run. The friction loss is obtained from standard engineering charts for the material selected using water as the liquid. For more viscous liquids, appropriate charts shall be used.

Storage Basin

Basins, often referred to as sumps or wet wells, are typically manufactured from cast iron, fiberglass, poured-in-place concrete, and steel. Large basin capacities require the design of the basin to include principles important to proper pump functioning. These principals are as follows.

- The flow of effluent from the liquid entrance should be directed to the pump inlet in a manner that will reduce swirl and hydraulic loss.
- The water depth shall be the minimum established by the manufacturer to prevent surface vortices.

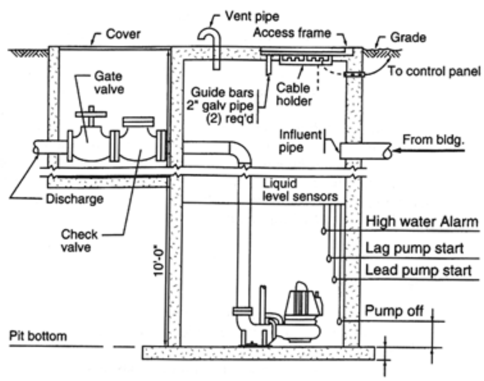


Figure 11-29 Submersible Pump Assembly

- Excessive turbulence should be avoided. A small amount of turbulence shall be limited to that required to prevent stagnation of stored water.
- To prevent sedimentation and the accumulation of solids, the floor of the basin should be sloped to the pumps. The floor joints should be welded with fillets at walls.
- Where the inflow into the sump is at a high elevation, the falling water entrains air as it spills onto the surface of the water in the sump. This entrained air should be allowed to rise to the surface before reaching the pump by providing a baffle wall in the sump and/or a dissipation arrangement at the inflow. If the basin is large, a significant distance from the point of liquid entry to the pumps should be provided to allow air to dissipate.
- Pumps should be installed as close to the outside walls as practical to avoid stagnant areas that allow solids to accumulate.
- A small sump pump in a pit should be installed in the basin to allow total drainage of the basin for maintenance.

Many systems consist of relatively small units. For this type of installation, a standard basin should be obtained from the pump manufacturer. In this way, the basin size corresponds to the number and size of the pumps selected, the inlet and discharge piping will be pre-installed in the basin, and the depth is predetermined to contain the desired quantity of liquid. The basin could then be installed as a single, integrated unit.

Basins receiving sanitary effluent shall be provided with a gasketed cover that has an atmospheric vent pipe to the outside. The location shall be such that an odor emanating from the basin would be easily dissipated before causing any discomfort to people. The cover shall be easy to remove so the pumps can be raised to the surface for servicing. Guide rails are attached to the inside of the basin for this purpose. A hose bibb or lawn hydrant should be provided to wash off the pump.

The capacity of the basin is based on the primary pump discharge flow rate and the desired number of starts per hour. Recommended practice is an average of six to seven starts per hour, with a maximum of 12 starts. Another consideration is to have a minimum capacity to allow a minimum running time of one minute. With these parameters and after consulting with the pump manufacturer, the storage capacity can be selected. Since the exact inflow into the basin during any period will never be known, a minimum running time shall be selected based on the number of gallons stored, and if any additional flow occurs, the running time of the pump is extended, which is an added benefit.

The actual size may be limited by space conditions at the location where the basin is located. Additional depth may be used to obtain the desired volume if the length or width (or diameter) cannot be adjusted. To size the basin, use Table 11-9, which shows the capacities of various size basins.

The basin should not be located at a point of the site that is subject to flooding unless that is the only possible location. Borings of the area should be made to determine if the area has a high groundwater condition or other underground obstacles that would interfere with the installation of the basin. The top shall be installed above ground to prevent the entrance of stormwater.

Any structure extending into the groundwater table or into any soil that may become saturated must be protected

Table 11-9 Capacity of Sump and Ejector Basins

Circular		Square	
Diameter, ft	Gallons	Side, ft	Gallons
2	23.50	2	30
2½	36.72	2½	45
3	52.88	3	67.50
3½	71.91	3½	90
4	94	4	120
4½	110.32	4½	149.60
5	146.89	5	187
6	158.64	6	270
7	170	7	365.50
8	181		
9	193		
10	204		

Note: 1 ft = 0.3 m
1 gal = 3.8 L

Table 11-10 Approximate Buoyant Force of Empty Circular Tanks

Tank Capacity, gal	Tank Diameter	Tank Depth, ft	Tank Weight, lbs	Wall Thickness	Net Buoyancy Totally Submerged in Water, lbs*
560	4′	6	480	12 gauge	4,190
560	4′	6	828	7 gauge	3,842
1,000	5′4″	6	875	10 gauge	7,475
1,000	4′	11	968	10 gauge	7,382
1,000	5′4″	6	1,180	7 gauge	7,459
1,500	5′4″	9	1,575	7 gauge	11,200
2,000	5′4″	12	1,980	7 gauge	14,720
2,500	5′4″	15	2,375	7 gauge	18,479
3,000	5′4″	18	2,765	7 gauge	22,235
3,000	6′	14	2,565	7 gauge	22,150
4,000	5′4″	24	3,560	7 gauge	29,790
4,000	6′	19	3,310	7 gauge	30,040
4,000	7′	14	3,150	7 gauge	30,200
5,000	6′	24	5,400	¼ inch	36,300
5,000	8′	13.5	4,775	¼ inch	36,925
6,000	6′	29	6,380	¼ inch	43,720
6,000	8′	16	5,370	¼ inch	44,630
7,500	8′	20	6,500	¼ inch	56,238
8,000	8′	21.5	7,000	¼ inch	59,750
8,000	10′6″	12.5	6,470	¼ inch	60,980
10,000	8′	27	8,360	¼ inch	74,356
10,000	10′6″	15.5	7,600	¼ inch	75,019
12,000	10′6″	18.5	8,400	¼ inch	91,440
15,000	10′6″	23.3	12,600	5/16 inch	112,833
20,000	10′6″	13	15,900	5/16 inch	151,345
25,000	12′	30	20,875	3/8 inch	190,509
30,000	10′6″	46.3	27,000	3/8 inch	222,518
30,000	12′	36	24,294	3/8 inch	229,329

* lbs x 2.2 = kg

against flotation by checking that the buoyant force will not cause the basin to float. This is done by comparing the downward force and the upward force. If the upward force is greater, the basin will float.

The downward force is the sum of basin and equipment weights plus the dry weight of any soil over the basin. Dry weight is calculated by subtracting the weight of any water from the weight of the soil. If it is determined that the basin will float, a concrete base slab of sufficient weight is added to the bottom of the basin. It is common practice to multiply the slab weight by a factor of four to calculate the weight of the bottom slab. The buoyant force of empty circular tanks is given in Table 11-10.

Controls

The basic operating controls of a lift station are similar to that of a typical ejector system. Experience has shown that a minimum of 6 inches (152.4 mm) between levels should be used.

Force Main

The discharge pipe, or force main, is the pipe from the pump discharge to the point of disposal. The force main includes valves, cleanouts, vacuum release, and thrust restraints.

Pipe Material

The selection of the pipe material is based on the effluent's flow rate, friction loss and velocity and the material's chemical resistance to the effluent, pressure rating, and strength. For sanitary effluent, pressure-rated polyvinyl chloride (PVC) or polyethylene (PE) is often selected, but the possibility of soil contamination may prevent plastic from being used. When the force main is routed in public streets, the AHJ may have specific requirements.

Where the strength of the material is a factor, ductile iron may be preferable. With ductile iron, it is common practice to protect the exterior with a PE wrap. Several installation methods are outlined in AWWA C105: *Polyethylene Encasement for Ductile-Iron Pipe Systems.*

Flow Rate

The flow rate used to size the force main is based on two conditions. In the first (normal), one pump of the multiple-pump installation is running. In the second (emergency), all of the pumps are running in parallel at the same time.

Velocity

The velocity in the pipe shall be between a minimum 2 fps (0.61 m/s) and a generally accepted maximum 10 fps (3.05 m/s). It is necessary to know the difference in flow rate between one and two pumps running to determine the velocity for both conditions (normal and emergency), with the higher velocity and friction loss of the increased flow both taken into consideration. One recommendation is to use a slow-acting check valve to limit the generation of excessive pressure every time the pump is stopped.

Pipe Sizing

The discharge pipe is sized to convey the effluent economically from the pump to its ultimate point of discharge, based on friction loss due to flow and velocity. Selecting the size is an iterative process. A comparison of the pump system head curve should be done between different pipe sizes. The total friction loss between sizes is used to compare the higher head required. The total friction loss based on flow and size can be obtained from standard engineering texts such as the *Plumbing Engineering and Design Handbook of Tables.*

Design Considerations

The most commonly used method of connecting a force main to a gravity public sewer is illustrated in Figure 11-30. This method allows accumulated air to be discharged through the top of the connection. Cleanouts are generally required along the pipe run. A cleanout in a manhole is illustrated in Figure 11-31. Air and vacuum relief valves shall be installed at all high points. A typical detail of valves in a manhole is given in 11-32.

Vacuum and Pressure Venting

It is good practice to provide an air pressure vent at the high point of the piping run. If the high point of the system occurs prior to the point of discharge, it is desirable to place a combination pressure/vacuum device in the pipe to allow the accumulated air at the high point to be eliminated. Since the remainder of the run might be downhill, the flowing liquid might produce a vacuum that must be broken to allow the free flow of liquid. The air relief device might discharge some water, so the device is usually put in a large valve box or a manhole with a gravel bottom to absorb the liquid. Ease of maintenance is the most important consideration.

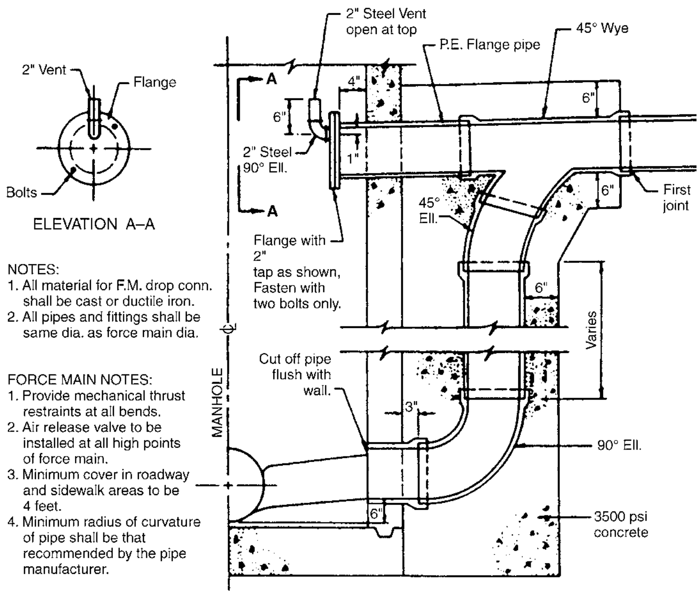


Figure 11-30 Detail of Force Main Connection to Public Sewer

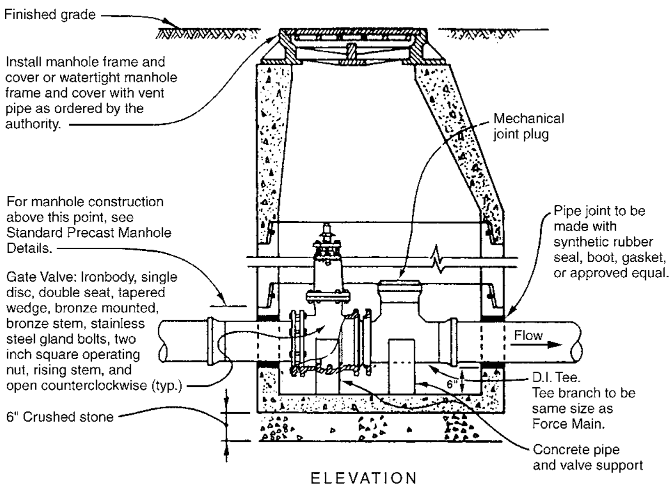


Figure 11-31 Force Main Cleanout in Manhole

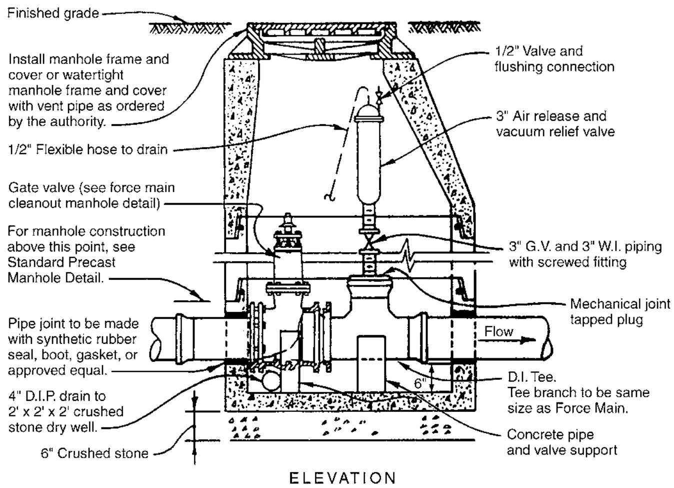


Figure 11-32 Force Main Air Release and Vacuum Relief Valves

Alternative Methods of Disposal

Problems are compounded when a public sewer is not available at the project site. Alternative methods of disposal include a private sewage disposal system, generally consisting of a septic tank and disposal field, and a sewage treatment plant discharging into seepage trenches. The designs of those systems are outside the scope of this chapter but are discussed in *Plumbing Engineering Design Handbook, Volume 2*.

SITE STORMWATER DRAINAGE SYSTEM

The site stormwater drainage system removes rainwater from roofs and other areas exposed to the weather from a point 5 feet (1.52 m) outside the building wall to the point of ultimate disposal. Ponding may be allowable in areas such as a paved schoolyard or parking lot, where it would cause few problems because of the normal inactivity during a rainy period or over a weekend. The stormwater drainage system is not allowed to receive any other waste, including clear waste, without the permission and approval of the code official.

If any pollutants, including oils, might be discharged into the environment, stormwater management laws require a stormwater management device to be provided to separate all pollutants of interest prior to discharge to the environment or to a public storm system. Based on the Clean Water Act and the requirements of the local jurisdiction, oil/water separators and pollutant removal devices are now mandatory in large projects. In addition, stormwater mitigation during construction is more stringent than after site buildout. The AHJ must approve all drainage plans, including detention and outfall structures, and must issue permits.

Preliminary Investigation for the Entire Site

The following procedures must be performed prior to designing the proposed stormwater system:

1. Determine the ultimate discharge location or method of disposal. This could be a public sewer, local waterway or body of water, or developed drainage pattern on the site (an existing flow path the stormwater follows on the undeveloped site). Every effort should be made to follow this pattern. Drywells can be used if the soil structure allows this method. A retention basin can be used if a method of disposal for the rainwater is available, but it cannot accept the full flow rate during a design storm. A detention basin can be used where the water on the site is routed to be evaporated and absorbed into the ground.
2. If streams or rivers are to be used as a final outfall, contact state and federal agencies regarding the allowed flow, outfall structures, and required permits. Such agencies may be the U.S. Army Corps of Engineers, Environmental Protection Agency (EPA), or the local sewer department. Obtain EPA permits if the waterway is considered navigable.
3. If a public sewer is to be the final outfall, contact the AHJ regarding allowed flows, connection details, plan submittal, and required approvals.
4. Determine the high and low water levels of all streams and rivers, including the past history of floods. If the waterway is considered navigable, special approval may be required.
5. Ensure that the discharge of site stormwater directly into smaller streams won't create a possible flood condition downstream.
6. Include provisions for any future development of surrounding site areas or building additions.
7. Finally, the preliminary investigations shall include the location size, topography, and elevation, soil conditions and type, water table, location and pipe material of the public storm sewer, location of existing manholes, location of other utilities under and on the site, etc.

Codes and Standards

The first step is to find the department or jurisdiction responsible for the design and installation of sewers. It may be the same plumbing code official responsible for sanitary sewers. In jurisdictions with a stormwater management requirement, a separate department may be responsible for stormwater sewers. If the discharge is into public streams or navigable waterways, additional approval from state and national jurisdictions will be necessary. The information needed should be part of the utility letter.

It must be determined whether a stormwater management program is in place. Such a program is established where the AHJ requires the stormwater discharge from the developed site to be the same flow rate that existed before the site was developed.

Materials

Underground piping should be of cast iron (service or extra-heavy weight, depending on the loads exerted on the pipe), ductile iron, hard-temper copper, acrylonitrile butadiene styrene (ABS), polyvinyl chloride drain, waste, and vent (PVC DWV), concrete, or extra-strength vitrified clay. If plastic piping is used, a proper class B bedding must be provided for adequate laying and support of the pipe. Plastic piping does not have the scour resistance of metal piping, especially at changes of direction. Metallic pipe in corrosive soils must be wrapped or coated. All materials must be approved by the local code body. See *Plumbing Engineering Design Handbook, Volume 1* for data on pipe schedules, joining methods, plumbing drains, etc.

Sizing a Stormwater System

When large areas with few drainage points—such as commercial and industrial sites, parking lots, highways, airports, and whole cities—require storm drainage, the methods and tables found in most plumbing codes are not applicable. The solutions obtained using those methods would result in systems that are oversized for the flows involved and pipe sizes that are far too large to be economically feasible. The reason is that in large systems, time is required for flows to peak at the inlets and accumulate in the piping system. Because of this time factor, the peak flow in the piping does not necessarily coincide with the peak rainfall. The design of large storm drainage systems usually is the responsibility of the civil engineer; however, the applicable theories and principles are often used by the plumbing engineer.

The rate of runoff from an area is influenced by many factors:

- Intensity and duration of the rainfall
- Type, imperviousness, and moisture content of the soil
- Slope of the surfaces
- Type and amount of vegetation
- Surface retention

The Rational Method of Determining Design Flow

The rational method is used to determine the theoretical water inflow into a storm sewer system. This method of storm drainage design states that the peak discharge is approximately equal to the product of the area drained, runoff coefficient, and maximum rainfall intensity. Since its introduction slightly before the turn of the century, the rational method has been widely used. It is an empirical formula suited for the design of small watersheds (less than 10 square miles). The formula is:

Equation 11-1

$$Q = CIA$$

$$[Q = CIA/100]$$

where

Q = Quantity of stormwater runoff, cubic feet per second (cfs) (1 cfs = 450 gpm = 1,700 L/min)

C = Imperviousness factor of the surface comprising the drainage area, dimensionless coefficient

I = Rate of rainfall (intensity), inches per hour (mm/hr)

A = Area to be drained, acres (43,560 square feet = 1 acre = 4,070 m^2)

The rational method reduces an inexact set of conditions to an exact formula. Variables such as rainfall rate, overland water flow, and the amount of stormwater that actually reaches the drainage system can never be exactly determined. Because of this unpredictability, it is important to realize that some judgment is required in applying the calculated and obtained information in the design of a stormwater system.

Design Storms

The stormwater drainage system generally is designed to remove the maximum expected runoff as quickly as it falls to prevent ponding and flooding. The ability to calculate the flow rate is complicated by one's inability to predict accurately many of the factors affecting the actual amount of runoff resulting from any given storm. For the purpose of calculating the estimated maximum runoff, an artificial design storm is created. This storm serves as a simulation for the purpose of predicting runoff volume accurately enough to provide a basis for the design of the piping network.

Design storms are based on actual rainfall records and have been presented in a convenient form by the National Oceanic and Atmospheric Administration's National Weather Service (NWS). Design storms are available as either intensity-duration-frequency curves or as charts and formulas. The intensity-duration-frequency charts are in a very convenient, easy-to-use form and are considered accurate for the watersheds that are the subject of this book. A typical chart is illustrated in Figure 11-33. Charts for various cities throughout the United States are available in U.S. Weather Bureau Technical Paper No. 40: *Rainfall Frequency Atlas of the United States.* However, it has been superseded by NOAA Technical Memorandum NWS HYDRO-35: *Five- to 60-Minute Precipitation Frequency for the Eastern and Central United States* because of the longer period of data collection for the memorandum, which must be considered the latest information available. However, the intensity-duration-frequency charts obtained from Technical Paper No. 40 are more often used because of their simplicity. Use of this information is discussed later in the chapter.

Imperviousness Factor

The imperviousness factor (I), expressed as a decimal, is that portion of rain that falls on an area and flows off as free water and is not lost to infiltration into the soil, ponding in surface depressions, water remaining on vegetation, or evaporation. This allows for the loss of rainwater as it flows over the ground from a remote point of the tributary area until it enters a drainage inlet. The average imperviousness figures of various surfaces are found in Table 11-11.

The infiltration rate is much greater for loose, sandy soils than for hard, clay-type soils. Once saturated, the soil will not absorb any more water, which causes greater runoff. The rate of infiltration and the amount of water held in depressions decrease as the precipitation duration and the slope of the ground increase. Inspection, if possible, is the best way to determine the nature of an existing surface. In places where the exact nature of future development is uncertain, the figure selected should represent the least amount of loss that might be expected to allow the largest quantity of stormwater to reach a drainage inlet. Where any tributary area consists of different types of surfaces and/or soil combinations, a weighted overall value should be assigned for ease of calculations and for use in intensity-duration-frequency charts. Use Equation 11-2 to determine the weighted average.

Equation 11-2

$$F = \frac{A_1 \times C_1 + A_2 \times C_2 + A_n \times C_n}{A}$$

where

A = Total area for the tributary area under design, acres

A_1 (etc.) = Separate individual contributing area for area under design, acres

C_1 (etc.) = Imperviousness factor for the separate surface types under design

F = Weighed factor for the combined tributary area

n = Number of different types of surfaces within the tributary area

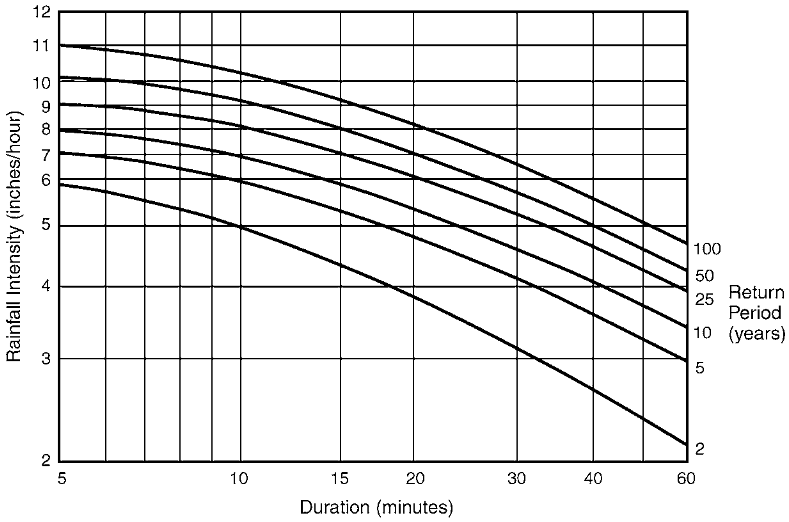


Figure 11-33 Intensity-Duration-Frequency Chart for Houston

Table 11-11 Imperviousness Factors

Surface	Flat Slope, < 2%	Average Slope, 2.0–7.0%	Steep slope, >7.0%
Roofs and pavement (all types)[a]	0.95	0.95	0.95
Clay, sparse vegetation	0.40	0.55	0.70
Clay, lawn	0.15	0.20	0.30
Clay, dense vegetation	0.10	0.15	0.20
Clay, dense woods	0.07	0.12	0.17
Sand, sparse vegetation	0.20	0.30	0.40
Sand, lawn	0.07	0.12	0.17
Sand, dense vegetation	0.05	0.10	0.15
Sand, dense woods	0.03	0.08	0.13

[a] For ease of calculation, the factor for roofs and pavement could become 1.0 if excessive runoff will not result in a significant overdesign.

Source: Baltimore County Design Standards

Example 11-1

As an example, three separate individual areas comprising 1.2 acres of a tributary area have previously been determined to be 0.5 acre of grass, 0.5 acre of pavement, and 0.2 acre of roof. What is the weighed factor for this total tributary area?

$$F = ([0.50 \times 0.15] + [0.50 \times 0.95] + [0.2 \times 1.00])/1.2 = 0.625$$

Rate of Rainfall

The rate of rainfall, or rainfall intensity, is the amount of average precipitation per hour that falls in a short period. This figure uses the duration of rainfall, in minutes, along with a set of curves for the frequency of occurrence to find the rainfall intensity, or rate of rainfall, in minutes of duration. To enter an intensity-duration-frequency chart, the return frequency of a design storm must have been selected, and the rainfall duration, which is the sum of the overland flow time and the time in pipe, if applicable, will have been calculated. To use the chart, find the calculated duration at the bottom. Draw a vertical line up until it intersects the curve for the selected return frequency. From this intersection, draw a horizontal line to the left to read the rainfall intensity in inches per hour.

The determination of several interdependent criterion is necessary to calculate the peak rate of runoff. The rate of runoff is hard to accurately evaluate and is impacted by the precipitation rate, surface composition and slope, duration of the precipitation, and degree of saturation of the soil.

Return Period

The design storm return period, or frequency, is the statistical period of years that must elapse to produce the most severe design storm once in that period. The theory is that the worst storm that would be expected to occur once in 100 years is much more severe than the worst storm that would be expected to occur once in two years.

The curve for a given frequency is actually a plot of different storms of varying lengths, each with a different duration, not a single storm plotted against time. Therefore, a storm of 10 minutes is one that lasts for exactly 10 minutes and then stops. It is not an extension of any other plot. Any storm with a longer duration would have a lower instantaneous peak flow.

Flooding will result if the design storm is exceeded and the stormwater is not removed by the design stormwater piping. Special consideration should be given to the degree of protection provided for the building and its contents by the rapid removal of rainfall by the stormwater drainage system. This depends on the importance of the facility, how flooding may affect access, the importance of uninterrupted service, and the value of the equipment or material installed or stored. Since a severe thunderstorm or hurricane could produce rainfall rates greater than those anticipated, the property value may necessitate the selection of a frequency longer than the minimum determined.

Choices on the reoccurrence of a storm are usually based on code requirements (if applicable), economic considerations, and risk trade-off. The following criteria may be helpful as a guide:

- For average sites, a design storm frequency of 10 years is generally used.
- Certain clients design their projects for 40 years of useful life, which may require a 50-year design storm if flooding might cause a problem.
- Many municipal authorities use a two- or five-year design storm for city sewers. Some use a 10-year storm.
- The U.S. Army Corps of Engineers typically uses a 10-year storm, but for military installations a 25-year storm is used.

The exceedance probability, which is the probability of any storm exceeding the rainfall rate to be used in the design of the stormwater system for any one year, shall be calculated using the following formula:

Equation 11-3

$$P = 1/T$$

where

P = Exceedance probability for a one-year period

T = Frequency (return period) of occurrence used in the design, years

Example 11-2

Using a 25-year storm as an example, what is the possibility that this storm will be exceeded?

$$P = 1/25 = 0.04, \text{ or } 4 \text{ percent}$$

In this example, the probability that a rainfall will occur in a one-year period that exceeds a 25-year storm is 4 percent. It is entirely possible for a specific rainfall rate to be exceeded at any time. With the selection of a higher average frequency of occurrence, such as 100 years, the probability of a similar storm occurring is considerably lower.

Rainstorm Duration

The duration, or time of concentration, is measured in minutes. It is found by calculating the overland flow time and the time in pipe of a theoretical drop of water as it moves from the most remote point on the site to any design point on a branch or main drainage line. The duration of the rainfall is needed to establish the rate.

This is important because the rate of rainfall is more intense in shorter amounts of time. This heavy rainfall, multiplied out to one hour, would be much greater than the rainfall expected for a one-hour period. As an example, for New York City, the heaviest total amount of rain on record for a five-minute period is 0.75 inch. Multiplying the five-minute reading out to determine the one-hour rate gives an hourly figure of 9 inches of rain, yet the largest amount of rainfall ever recorded over a one-hour period is 5.01 inches. Thus, it can be seen that the rate of rainfall measured during a short period is much more intense than the rate measured over a longer period.

The underlying theory is that the rainfall will stop at the exact moment the entire design area is contributing to the flow in a particular section of the sewer. Therefore, calculations must establish the shortest amount of time a drop of water takes to run from the farthest point of the site to any design point of the sewer. This is necessary so the shortest time of concentration is obtained and the largest hourly rainfall rate is used for design purposes.

The overland flow time, often called the inlet time, is the number of minutes it takes a drop of water to travel on the surface of the ground from the farthest point of the area contributing flow to a drainage inlet until it spills into the inlet. The impedance to overland flow of water by a grass surface is greater than that by an asphalt surface. For equal distances and slopes, it takes longer for a drop of water to enter a drainage inlet from the farthest point of a lawn than it does from a paved parking lot. The slope of the land is also a factor, since for any given surface, water flows faster down steeper slopes.

Figure 11-34 offers a way to determine overland flow time when the slope of grade and type of surface are known. During a rainstorm, the flow of water from surfaces covered with pavement is in the form of a very shallow sheet of water covering the surface of the ground. This phenomenon is known as sheet flow.

The time in pipe is the number of minutes the theoretical drop of water takes to flow from the drainage inlet to the design point. Determining this requires the pipe to be sized and the velocity, in feet per second, of the stormwater to be known. Multiplying that figure by the actual pipe length, in feet, gives the time in pipe, in seconds. Convert this to minutes.

Final Calculations

When the inflow into the piping network (total flow rate) from all sources has been calculated for each design point using the intensity-frequency-duration curve, the run of stormwater piping on the site shall be made to determine the slope of the pipe.

Stormwater System Design Procedure

To design the stormwater system, the drainage structures should be located, and final coordination should be completed with the site planner.

1. Select the return period and the type of drainage structures, either drainage inlets or catch basins.

2. A site plan showing the location of the drainage structures and contour lines should be used to determine the exact surface area and type of surface contributing to the flow into each drainage structure. A chart or tabulation in any convenient form should be prepared indicating the type of surface and the area of each type of surface draining into each drainage structure. Figure 11-34 is a direct reading chart that gives the overland flow time for runoff traveling over the surface to the drainage inlet. It is calculated by first measuring the distance of the furthest point of the tributary area, then determining the average slope of the ground, and finally determining the type or combination of surfaces. If the area consists of more than one surface, calculate the weighed coefficient. Find the distance on the left side of the diagram, and using the appropriate distance point, draw a line horizontally until it intersects the average slope. From there, draw a vertical line until it intersects the curve of the selected imperviousness coefficient. From this intersection, draw a line to the right to find the number of minutes that would be the overland flow time. The minimum overland flow time should be 10 minutes. Rarely will a lesser time be economically justifiable.

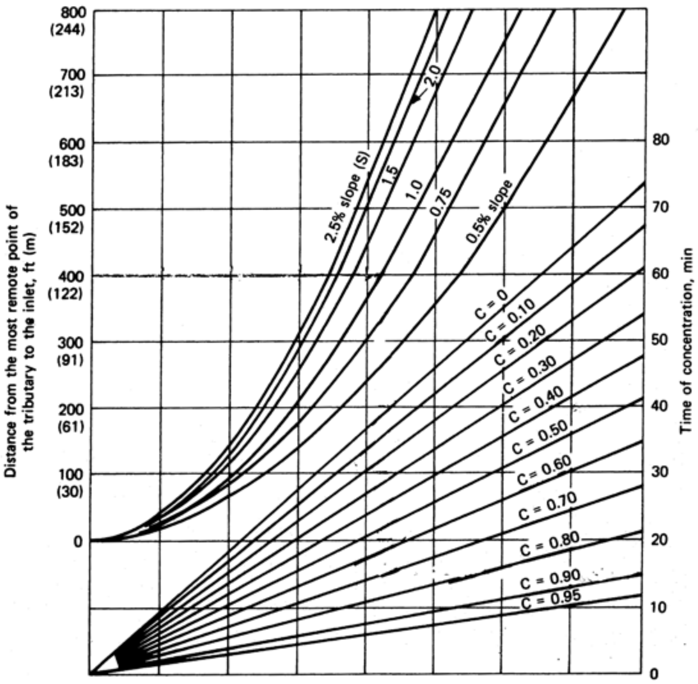


Figure 11-34 Overland Flow Time

3. Utilizing the rainfall intensity-duration-frequency curves for the city closest to the project's location, select the rainfall intensity using the return period selected and the time of concentration previously calculated. The time of concentration will be the overland flow time plus the time in pipe, if applicable. This will provide the final piece of information necessary to use Equation 11-1.
4. Using the data just collected and the rational method (Equation 11-1), calculate the total inflow into each drainage structure. The individual pipe from each drainage structure will be sized from this information.
5. With the total inflow in cubic feet per second to each drainage structure now known, select the grate type and size. Consult the manufacturer's literature for the correct size, and adjust the drainage structure locations for the flow requirements, if necessary. Most manufacturers have developed inlet flow charts for specific grates. Obtain from their catalog the size of grate that can accept the calculated flow.
6. Lay out the piping system from the drainage structure to the point of disposal. Locate manholes, and then select the pipe material and determine the n value, or roughness coefficient, for the pipe selected from Table 11-12.
7. Building roof drain runouts should be connected to the stormwater drainage lines, and their drainage areas should be noted.
8. Select the critical inlet, which is the one that produces the maximum combination of inlet time (overland flow time) plus the flow time in the sewer to the very first connection with any other branch. The inlet at the farthest end of the drainage system should be selected as the starting point. This point will be the longest in time, not necessarily in distance. This may require some trial calculations of several drainage inlets at various far ends to determine which drainage inlet actually is critical. Distance will not be the only criterion. An area comprised of asphalt, which has a fast inlet time, might be a much greater distance from an inlet than an area consisting of grass, which produces a longer inlet time. The slope and length of the sewer pipe also must be considered.

Table 11-12 Roughness Coefficients (n Values) for Pipes

Pipe Material	Range of n Values	Generally Accepted Value
Asbestos-cement	0.011–0.015	0.013
Corrugated metal pipe	0.022–0.026	0.024
Cast iron	0.011–0.015	0.013
Concrete pipe	0.011–0.015	0.013
Ductile iron (cement lined)	0.011–0.015	0.013
Plastic pipe, all kinds	0.009–0.015	0.010
Steel pipe	0.012–0.020	0.015
Vitrified clay	0.011–0.015	0.013

9. With the selection of the critical inlet, the individual sewer pipe now can be sized from the critical inlet up to the first point of intersection with any other contributing source of stormwater. Using Figure 11-34 and the flow in cubic feet per second, draw a straight line from the flow rate to the slope of the piping. This establishes the pipe size and water velocity. Adjust the line to intersect a standard size. If necessary, make the adjustment as indicated by the conversion factor if a different n value from that of the chart is used. Multiply the desired figure by the conversion factor found under the actual n value. Generally accepted practice assigns a value of 0.013 to the most commonly used pipe materials.
10. When the first junction with another contributing source has been reached, add the entire area of all contributing sources up to this first junction. Calculate the new time of concentration from the most remote inlet and the time in pipe to the design point of the storm sewer. Using the appropriate intensity-duration-frequency chart to find the rainfall rate will provide all of the necessary information required to use the rational method to find the total cubic feet per second. The resultant flow into the pipe is used to size that particular segment downstream from the design point. This is continued in succession to the end of the system, requiring a longer time of concentration each time a new design point is reached.

11. As progress is made along the route of the sewer, all branches to the main sewer line should be sized individually as their connection is reached. The branch is sized using the time of concentration required only for that branch. To size the main, add all of the areas contributing to the flow at any particular junction and use the longer time of concentration determined from the initial overland flow time from the critical inlet added to the flow time of the water in the pipe.

Stormwater Disposal Methods

Disposal into a Public Sewer

A public sewer is the simplest method, requiring only a house sewer that is properly sized using the applicable code from the building wall to the public sewer. The connection should be made to a manhole. Codes call for the house sewer to be sized from the building wall to the property line if only receiving runoff from the roof. A problem exists if the building roof and surrounding areas are larger than the areas appearing in the charts provided in the applicable code. If this is the case, the rational method of calculating the volume of stormwater runoff should be used.

The stormwater house sewer should be a separate line leaving the building, even if a combined public sewer is used as the point of disposal. The stormwater and sanitary house sewers can be combined on the site, if allowed. A combined sewer is one that receives both sanitary and stormwater drainage. The reason for separate lines is that if separate public sewers are constructed in the future, a new connection can easily be accomplished. The final connection to the public sewer must be into a hooded manhole or catch basin to prevent sewer gas from entering the stormwater sewer.

Disposal into a Drywell

A drywell is an underground structure with openings or porous walls that allow the stormwater entering the drywell to escape out the sides and be absorbed into the surrounding soil. This disposal method is used in very limited areas with AHJ approval and where sandy soil permits its effective use. Local codes specify the number and size of drywell sections, depth of bury, and the distance between structures.

Disposal into a Recharge Basin

A recharge basin is a depressed area on a site that is normally dry, with no outlet. These basins are sized to collect runoff from the surrounding area due to a storm of a given duration, usually a 100-year, 24-hour storm, with a 10 percent safety factor and additional height above the top to account for wave action when full. When in such a basin, the water is mostly absorbed into the surrounding soil, and some evaporates into the air. A headwall should be constructed to prevent erosion around the inflow pipe.

Disposal into a Retention Basin

A retention basin is intended to collect rainwater and to allow discharge at a rate that is slower than the rate of inflow into the basin because a stormwater management program is in effect. Water in the retention basin is not intended to be absorbed into the surrounding soil. The design engineer should first determine the discharge from the undeveloped site and then calculate the discharge from the developed site. The volume of water in the retention basin to be stored is based on the allowable discharge flow rate volume compared to the inflow flow rate over a period of time, while not exceeding the allowable discharge flow rate.

Limited-Discharge Roof Drain

Another possible storage method is a limited-discharge system. Special roof drains are available with limited-discharge characteristics that store water on the roof and discharge the rainwater at a rate that is slower than the rate at which it accumulates. Their use must be coordinated with the architect and structural engineer to ensure the provision of a watertight roof and elevated sections at entrances to roof stairways to prevent water flow from entering the building.

Discharge into an Existing Flow Path

A project might be constructed on a site where the only method of removing stormwater is by discharging it into swales or ditches on the site. These flow paths eventually find their way into a remote watercourse.

The following criteria shall be used to size a ditch:

- The discharge into the ditch shall be from a headwall. A headwall is necessary because the outflow from the pipe will eventually wear away the invert.
- The sides should be no steeper than 1 on 3 to allow mowing.
- A 4-foot-tall fence might be required for larger channels.
- The suggested cross-section is given in Table 11-13.
- The roughness coefficient, or n value, shall be as listed in Table 11-14.
- The maximum recommended velocity is listed in Table 11-15.

The ditch is sized using Manning's formula. This formula requires a value to be selected to account for the roughness of the area being sized. When sizing, it is a reasonable assumption for the ditch to flow full during design flow. Using the design

Table 11-13 Typical Cross-Sections for Ditches—Depths of 10 ft and Less

Surface	Cross-Section
Asphalt or concrete lined	1.5 horizontal to 1 vertical
Grass lined	3 horizontal to 1 vertical
Gravel lined	2 horizontal to 1 vertical
Clay	2 horizontal to 1 vertical

Table 11-14 Coefficient of Roughness Values for Ditches Used in the Manning Formula

Description	n
Paved invert corrugated metal steel pipe	0.020
Cast iron, ductile iron, concrete, and steel pipe	0.013
Unpaved corrugated metal steel pipe	0.024
Small plant ditches (no vegetation, fair condition)	0.025
Main plant ditch (grass, some weeds, fair condition)	0.030
Natural ditches (dense weeds, high as flow depth, poor condition)	0.120

flow and calculating the wetted length of the ditch sides and bottom, converted to the diameter of a pipe, use Figure 11-19 to size the ditch.

Ditches should be sized to run full at the design discharge rate with a minimum freeboard of 6 inches (152.4 mm). The preferred minimum freeboard on larger ditches is 12 inches (304.8 mm). For ditches running parallel to plant roads, the maximum design water surface elevation should not be higher than the bottom of the road base. Low-capacity ditches should have a minimum slope of 0.002 foot per foot. Larger ditches should be hydraulically designed to set the ditch slope.

Table 11-15 Design Velocity of Water in Ditches

Ditch Material	Maximum Velocity, fps
Unlined	
Fine sand	1.5
Silt loam or silt	1.5
Fine gravel	2.5
Sandy clay or clay	3.0
Sod	3.0
Still clay or coarse gravel	4.0
Shale and hardpan	6.0
Lined	
Asphalt, concrete, and granite	8.0

Storm System Design Considerations

The velocity in the piping system should not be less than 2 fps (0.61 m/s). This is to allow for the movement of sediment and any other solids in the pipe by the flow of water at this minimum velocity.

The maximum velocity should be limited to approximately 30 fps (9.14 m/s). This is to prevent erosion of the pipe interior. Large quantities of sand in the water will add to the scouring action, and the velocity should be limited to a lesser figure for this condition.

To limit velocity, a shallow slope of the piping system should be chosen rather than over-sizing the pipe. Other methods are also available. If the slope of the ground is steep, a drop manhole should be used where the difference in elevation between the inlet and outlet inverts is more than 2 feet 0.61 m).

A manhole should be located at every change in slope, pipe size, or direction. In many cases, a drainage structure can be used for this purpose if such placement is practical.

The minimum size pipe should be 12 inches (304.8 mm) to reduce the possibility of stoppage by debris. A lesser size runout from a building roof stormwater system is generally acceptable.

When a change in pipe size occurs, the pipe should be installed crown to crown to eliminate a surcharge in the upstream portion of the pipe.

An item such as snowmelt may add additional quantities of water that are unexpected. This does not add a significant amount of inflow, but it should be considered if the snow is deep. However, increasing one pipe size may lead to a problem of too little velocity. If this is the case, it is advisable to increase the slope of the sewer line. As a general rule, be a little generous with pipe sizes. The slight increase in cost will be more than made up for by the safety factor of the additional capacity provided.

Exfiltration occurs when water leaks out of a pipe into the surrounding ground through bad joints and cracks. When a pipe passes under a road or railroad, select a joint that has very little or no leakage to prevent the subgrade from being washed away.

Piping should be installed roughly parallel to the slope of the ground. Standard percentages of slopes should be used where possible to allow for easier installation of the pipe.

NATURAL GAS SERVICE

Natural gas is obtained from one of two sources. The first, restricted to very large users of gas, is a transportation gas company whereby the gas is directly purchased by the facility from the point where the gas originates, usually at the wellhead. The second is from a franchised public utility. As part of this service, the utility company usually supplies and installs the service line from the utility main in addition to providing a regulator and meter assembly in or adjacent to the building.

An installation fee might be charged if utility company regulations concerning the time of payback from expected revenues do not justify the cost of installing the service. The same might be true if the volume of gas intended for a commercial or industrial facility is considered too little. In such a case, it would be the responsibility of the owner to pay for the design and installation of the complete site service in conformity with utility company regulations.

Codes and Standards

The standard most often used for the design of natural gas systems is NFPA 54: *National Fuel Gas Code,* along with applicable provisions of the local plumbing code. Some insurance carriers, such as FM Global and Industrial Risk Insurers, have standards that might be more stringent than those listed. The local utility company also might have standards to be followed as well. When a gas-fired emergency generator is provided, valve arrangements at the meter assembly must comply with NFPA 110: *Standard for Emergency and Standby Power Systems.*

General Procedures

The first step is to find the utility company that supplies gas in the area. If the project is existing, the owner can supply the utility company's name. In general, the engineering department of the utility company will be the first contact to obtain the information necessary for design.

The next step is to calculate the total connected load in cubic feet per hour (cfh). This is done based on information about the boilers obtained from the HVAC department, water heating requirements, cooking requirements, and process requirements, if any. This total connected load shall be given to the utility company, which has its own method of calculating the actual load.

The distance from the property line to the proposed meter location shall be given. The utility company shall provide the gas pressure in the utility main.

The following various types of services that a utility company can provide each have a different cost (or rate). (Specific types of services might be unavailable or known by different names in various localities.)

- Firm or uninterruptible service: Provides a constant supply of gas under all conditions without exception. This service has the highest rate.
- Interruptible service: Allows the utility company to stop the gas supply to the facility, under predetermined conditions, and start it again when these conditions no longer exist. The rate is lower than that for firm service, and the service will require a backup source of fuel, such as fuel oil or liquid propane.
- Light or heavy process service: Provided for industrial or process use and is reserved for quantities of gas that the utility company defines for this class of service.
- Commercial and industrial service: Provided for heating and cooling system loads for these buildings.
- Transportation gas service purchased directly from a company other than the public utility, with the gas actually carried to the site by the utility company's mains: In addition to the cost of the gas, the utility company will charge a fee for this service.

The following criteria and information should be obtained in writing from the public utility company:

- British thermal unit (Btu) content of the gas provided
- Minimum pressure of the gas at the outlet of the meter
- Extent of the installation work done by the utility company and the point of connection by the contractor
- Location of the utility supply main and the proposed run of pipe on the site by the utility company
- Acceptable location of the meter and/or regulator assembly and any work required by the owner to allow the assembly to be installed (such as a meter pit or slab on grade)
- Types of service available and the cost of each

For the utility company to provide this data, it must have the following information:

- Total connected load: The utility will use its own diversity factor to calculate the size of the service line. This is not required if the design engineer is responsible for the installation, since the diversity factor calculated by the design engineer for the facility shall be used.
- Minimum pressure requirements for the most demanding device
- Site plan indicating the location of the proposed building on the site and the specific area of the building where the proposed natural gas service will enter the building
- Preferred location of the meter and regulator assembly
- Expected date of the start of construction

Btu Content of Gas

The Btu content of natural gas varies. Generally, a figure of 1,050 Btu per cubic foot of gas (reduced to 1,000 Btu for ease of calculations) has been used for design purposes. It is recommended that the design engineer ask the supplier to provide the Btu content of the gas supplying the project.

System Operating Pressures

The pressure in a site main depends on the existing pressure in the mains of the utility company, since pressure is not reduced until the point where the facility meter is installed. This pressure is generally in the range of 15 to 50 pounds per square inch gauge (psig) (103.4 to 344.7 kPa).

The maximum allowable system operating pressure of fuel gas when installed inside a building is governed by NFPA 54, unless local codes or insurance carriers have more stringent requirements. Natural gas systems are not allowed to exceed 5 psig (34.5 kPa) unless all of the following conditions are met:

- Local authorities allow a higher pressure.
- All piping is welded.
- The pipe is run inside buildings or areas used only for industrial processes, research, warehouse, or boiler and/or mechanical equipment rooms.

Placement of the Meter Assembly

The requirements of various utility companies differ regarding the placement of the meter assembly. It could be installed in an underground, exterior meter pit, at an aboveground exterior location exposed to the weather, or inside the building in a well-ventilated area or mechanical equipment room. The utility company often has installation requirements for the gas service pipe into the facility. For large installations, the meter pad could be as large as 8 feet (2.4 m) wide by 20 feet (6.1 m) long. In addition, an electrical and telephone outlet should be installed at the pad location.

Major System Components

Gas Line Filter

Filters for natural gas are installed on the site service to protect the regulator and meter from damage due to particulate clogging, which also may damage the equipment inside the building. Filters should be considered when:

- Limescale, dirt, or rust is known to be present.
- Dirty gas is obtained from a transmission company.
- Wet gas (sometimes referred to as sour gas) is known to be present, such as occurs after large utility company pressure-reducing valves.

The filter consists of a housing and a cartridge filter element. Selection of the housing is based on the highest flow rate and pressure expected and the size of the proposed building service. The housing should be capable of having interchangeable elements to allow replacement of the original filter if desired. Over-sizing a filter is considered good practice if the cost of the larger size is not excessive, since this allows for longer service life.

The filter element is usually cellulose or synthetic fiber. Generally, the cellulose type is used for sizes 3 inches (76.2 mm) and smaller, and fiber is used for 4 inches (101.6 mm) and larger. Fiber is stronger and should be considered where the pressure differential might be excessive and when recommended by the manufacturer. A filter rating of 10 microns is suggested as a starting point, with actual operating conditions being the final criterion.

The size of the filter is based on actual cubic feet per minute (acfm) and the velocity across the filter. The pressure drop across the filter when it is dirty shall be considered in the actual pressure loss allowed for the service assembly. Since the filter should be changed when the pressure difference approaches 10 percent of the operating pressure, it is good practice to provide pressure gauges on both sides of the filter. If no filter is installed on the service, a spool piece should be provided. Most filters are mounted horizontally.

Gas Meter

Gas meters are part of a service assembly that may consist of filters, valves, regulators, and relief valves. The complete assembly is usually supplied and installed by the utility company. For rare instances where this is not the case, gas meters are selected using the local utility company's standards, while the size and arrangement of the entire meter assembly is based on the flow rate and pressure. Because steady pressure is necessary for accurate metering, the regulator is installed before the meter. The utility company will provide sketches and details with space requirements for typical meter assemblies for various capacities and pressures. This allows accurate determination of the dimensional and space requirements for the area where the complete assembly will be installed. Obtain from the utility company all requirements for the specific installation being designed.

The plumbing contractor is usually responsible for providing a pit for the assembly or a concrete slab under the complete meter assembly when it is installed outside the building. This includes determining the meter slab size for outdoor meter installations and pit sizes and access openings for meters installed in pits. For facilities with high demands for boilers and other equipment, a meter assembly with dimensions of 6 feet (1.8 m) wide by 25 feet (7.6 m) long is common.

Generally, if the contractor is installing the site service, the utility company will either supply the meter or install the entire assembly. This must be confirmed in the utility letter.

Pressure Regulator

Gas pressure regulators are pressure-reducing devices used to reduce a variable high inlet pressure to a constant low outlet pressure. Two types of regulators are available: direct acting and pilot operated. The direct-acting type uses the difference in pressure between the high and regulated sides of the regulator to directly move a closure (adjusting) member inside the regulator to adjust the pressure. The pilot-operated type uses a primary regulator to sense and magnify differences in pressure between the high and low pressure sides and a second, main valve with the closure member to achieve the desired pressure.

Regulators are categorized based on their end use. One type is the line regulator, which is used to reduce high pressure, often in the range of 25 to 50 psig (172.4 to 344.7 kPa), from the gas service provided by the utility company to a lower pressure used for the building service. An intermediate regulator is used to reduce the lower pressure, often in the range of 3 to 5 psig (20.7 to 34.5 kPa), to a pressure required to supply terminal equipment such as a boiler gas train. The third type is an appliance regulator used at the individual piece of equipment to achieve the final pressure.

The line regulator can be pilot operated and provided with an internal or external relief valve. The regulator is pressure rated to withstand the highest pressure expected. The relief valve is installed downstream of the regulator and is set to trip at a pressure that is about 10 percent higher than the highest set pressure. The line regulator is placed upstream of the meter to provide the meter with a constant pressure, allowing accurate measurement. This line pressure regulator is most often selected and installed by the utility company as part of the gas meter assembly.

An intermediate regulator is used within a facility where high pressure used for distribution purposes must be reduced to a lower pressure required by the terminal appliances. This is the most often-used regulator. Two types of intermediate regulator are available, and the choice is determined by the accuracy desired and the ability to install a relief valve and associated gas vent discharge. One type of intermediate regulator has an internal relief valve set to discharge when the pressure rises above the setpoint. This has the lowest initial cost and the least degree of accuracy. Another type of intermediate regulator, called a monitor type, consists of two pilot-operated regulators. They can be installed in two configurations, both of which use regulators in series. In the first configuration, the upstream regulator reduces the inlet pressure initially to some intermediate value, and the downstream regulator further reduces the pressure to the final setpoint. This arrangement puts less stress on each of the regulators. In the second configuration, the upstream regulator is wide open, and the downstream regulator does all of the pressure reducing. If the gas pressure goes above the setpoint, the upstream regulator closes to partially lower the pressure. This installation has a high initial cost.

The appliance regulator is used to control the pressure of gas directly connected to the terminal appliance or equipment. This is most often provided by the manufacturer as part of the equipment gas train. The gas train is an assembly of piping, valves, regulators, and relief vents used to connect the gas supply directly to the terminal equipment. For large pieces of equipment, such as boilers, the gas train arrangement is dictated by insurance carrier requirements. An additional requirement of most gas trains is small relief vents from various devices. These vents must be piped outside the building to a point where they can be diluted by the outside air and pose no threat to the public or create a fire hazard. This is usually above a roof or the highest point of the structure.

Another type of appliance regulator is called an atmospheric regulator, or a zero governor. This is a very sensitive type of regulator that works with a very low gas pressure and extremely small differentials.

A differential regulator is a multiple-port regulator used to produce a single, uniform outlet pressure when supplied with multiple inlets of different pressures.

A backpressure regulator is arranged to provide accurate inlet pressure control. It is used as a relief valve where the application requires a higher degree of regulation and sensitivity than is possible with a standard poppet-type relief valve. When operating as a relief valve, it limits the inlet pressure to a setpoint. At pressures below this point, it remains closed. If the pressure rises above the setpoint, it begins to open and will bleed off enough pressure to maintain the system setpoint.

A piped gas vent must be provided from the regulator to a point several feet above the roof of any adjacent structure and must be properly sized to carry the amount of gas that will be discharged. This is necessary to protect the system from overpressure in the event of a malfunction or failure to lock up fully.

It is common practice to oversize the capacity of a regulator by about 15 percent to provide a margin for accurate regulation. However, care should be taken when sizing a gas pressure regulator to not provide a large regulator when small loads are connected. It may be advisable to provide a separate regulator to handle small loads, such as a kitchen. For large loads, regulators in parallel are often used to keep the pressure drop to a minimum.

The adjustment range of a regulator should be approximately from 50 percent more than the desired regulated pressure to 50 percent less than that pressure.

The utility company may require regulators to be of the lock-out type. The lock-out feature will stop regulator operation when the pressure falls below a predetermined setpoint when the downstream portion of the piping is normally under pressure.

Drip Pot

Drip pots are necessary to prevent water that is in the utility company mains from reaching the building. Modern technology has reduced, but not eliminated, the presence of moisture in utility company mains.

Site Distribution

The site distribution portion of the system starts at the property line of the customer and usually ends above grade (or at the concrete pad) at the valve after the meter. The connection to the utility company main and the installation of the meter assembly are generally done by the utility company. Electrical and telephone connections usually are requested at the meter assembly pad.

The most often-used piping material for underground installations is high-density polyethylene (HDPE). The rating for pipe 4 inches (101.6 mm) and smaller should be SDR 11, and that for pipe 5 inches (127 mm) and larger should be SDR 13.5. The pipe shall be buried a minimum of 3 feet (0.91 m) belowground, and a 14-AWG corrosion-resistant tracer wire should be placed in the pipe trench 6 inches (152.4 mm) over the pipe. Another detection method is to put a warning tape containing metallic material with the words "natural gas" on it. This will allow location by a metal detector and warn of the gas line immediately below the tape if digging takes place without the pipe being located beforehand.

The pipe aboveground shall be metal; therefore, a transition fitting (see Figure 11-35) is required if HDPE is used for the supply service. The transition fitting shall comply with ASTM D2513: *Standard Specification for Polyethylene (PE) Gas Pressure Pipe, Tubing, and Fittings*.

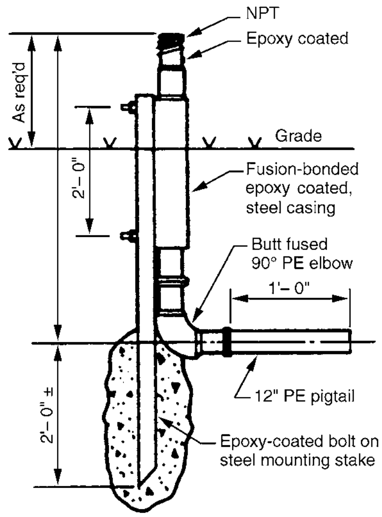


Figure 11-35 Transition Fitting from Plastic to Steel

Site Service Sizing Procedure

Existing Pressure

The pressure in the main provided by the utility company and the flow rate of the facility are the basis for sizing, which is done by the utility using proprietary charts for the specific pressure in the gas main. If these charts are not available, compressed-air friction-loss tables can be used, based on the pressure in the gas service main with adjustments made to compensate for the difference in the specific gravity of the gas, which is usually 0.6 compared to compressed air, which is 1. This will provide sizing within a range that is acceptable for this system. The pressure drop selected is at the discretion of the design professional, but is generally kept to approximately 10 percent of the available pressure. To use the pressure-loss tables, calculate the pressure drop per 100 feet of pipe.

If the design engineer is responsible for sizing the meter and regulator, the following information must be calculated or established:

- Adjusted maximum flow rate, in acfm, for all connected equipment in the facility
- Highest pressure required for the most demanding equipment inside the building
- Pressure in the building service main immediately downstream of the regulator (which will be reduced by pressure loss through the filter, if expected)
- Allowable pressure loss for the piping system inside the facility
- Pressure differential between the service main pressure and the pressure required inside the building (the sum of the highest pressure required and the allowable pressure loss subtracted from the pressure in the building service main)

The regulator and meter now can be sized using literature and catalog information from the manufacturers.

Maximum Probable Demand

For some types of buildings, such as multiple dwellings and laboratories, the total connected load is not used to size the piping system, since it is unlikely that all of the connected devices will be used at the same time. For design purposes, it is necessary to apply a diversity factor to reduce the total connected load when calculating the maximum probable demand. The demand and diversity factors are given in *Plumbing Engineering*

Design Handbook, Volume 2, Chapter 7. The total connected load shall be given to the utility company, as it has a proprietary method of establishing the actual maximum flow rate.

This calculation first requires listing every device using gas in the building and the demand, in British thermal units per hour (Btuh), for each. The manufacturer of each device should be consulted to determine the actual input gas consumption.

For industrial or process installations and for major gas-using equipment, such as boilers and water heaters, in all building types, the connected load with no diversity factor is used because it is possible for all connected equipment of these types to be used at the same time.

Natural Gas Pipe Sizing Methods

The most conservative method for sizing piping systems is by the use of tables, such as those prepared by the American Gas Association and included in Appendix C of the National Fuel Gas Code. Other methods using tables appear in *Plumbing Engineering Design Handbook, Volume 2,* Chapter 7. Proprietary gas tables and calculators are available. Calculators are considered more accurate than prepared tables.

Two high-pressure tables are provided in this chapter. Table 11-16 is for 20-psi pressure with a 2-psi pressure loss, and Table 11-17 is for 50 psi with a 5-psi pressure loss. To use the tables, follow these steps :

1. Measure the length of the pipe from the property line to the gas meter location. Add a fitting allowance of 50 percent of the measured length. This is the equivalent length of pipe.
2. Find the length that is equal to or more than the equivalent length just calculated.
3. Use that horizontal row to locate all gas demand figures for this particular system. This is the only row to use. If the exact figure is not shown, choose the figure closest to or more than the calculated demand.
4. Above the demand figure selected, find the correct size of pipe.

Table 11-16 Capacity of Horizontal Gas Piping, Initial Gas Pressure 20 psig, 2-psig Pressure Loss, cfh

Length, ft	Pipe Diameter, in.											
	0.50	0.75	1	1.25	1.5	2	2.5	3	3.5	4	5	6
10	2,040	4,329	8,240	17,121	25,820	50,285	80,771	144,079	212,400	247,753	543,611	887,323
20	1,446	3,060	5,826	12,332	18,262	35,556	57,113	101,929	150,190	210,385	384,391	629,684
25	1,293	2,738	5,211	10,828	16,334	31,803	51,084	91,168	134,334	188,174	343,810	561,192
30	1,180	2,499	4,757	9,885	14,911	29,032	46,633	83,225	122,630	171,779	311834	512,296
35	1,093	2,314	4,404	9,150	13,791	26,878	43,174	77,051	113,532	159,035	290,572	474,294
40	1,022	2,165	4,120	8,561	12,913	25,143	40,385	72,674	106,200	148,764	271,806	443,662
45	964	2,040	3,883	8,071	12,175	23,705	38,075	67,953	100,127	140,257	256,260	418,288
50	915	1,936	3,685	7,657	11,550	22,488	36,122	64,466	94,988	133,059	243,110	396,823
60	835	1,767	3,340	6,990	10,544	20,529	32,974	58,848	86,712	121,466	221,928	362,248
70	773	1,636	3,114	6,471	9,761	19,006	30,528	54,483	80,276	112,455	205,466	335,377
80	723	1,530	2,913	6,053	9,131	17,779	28,556	50,964	75,095	105,193	192,196	313,716
90	682	1,443	2,746	5,707	8,609	16,761	26,924	48,050	70,794	99,176	182,750	294,774
100	646	1,369	2,606	5,414	8,167	15,902	25,670	43,584	67,167	94,087	171,905	280,596
125	578	1,224	2,331	4,843	7,305	14,223	22,845	40,770	60,076	84,153	153,756	250,973
150	528	1,118	2,128	4,421	6,668	12,110	20,855	37,219	54,842	76,822	140,360	229,106
200	437	968	1,843	3,828	5,775	11,244	18,061	32,232	47,494	66,529	121,555	198,411
300	374	790	1,504	3,126	4,715	9,181	14,747	26,318	38,779	54,322	99,299	162,002
400	324	685	1,303	2,707	4,083	7,950	12,771	22,792	33,583	47,043	85,952	140,299
500	289	612	1,141	2,421	3,653	7,111	11,423	20,386	30,038	42,077	76,878	125,487
1,000	204	433	824	1,712	2,383	5,028	8,076	14,413	21,240	29,753	54,361	88,732
1,500	166	354	673	1,398	2,109	4,106	6,595	11,770	17,342	24,293	44,385	72,449
2,000	145	306	583	1,210	1,826	3,557	5,712	10,193	15,018	21,039	38,439	62,743

Pipe and System Materials

All of the piping materials must be listed in NFPA 54 and other applicable codes. In addition to the codes, the recommendation of the utility company, which has experience in the location of the project, should be considered. The most often-used material for underground lines is HDPE. The material for larger lines and piping for high pressures (more than 100 psig) is steel pipe protected against corrosion by a plastic coating.

Codes do not permit plastic pipe to be run aboveground. For aboveground lines, the piping and jointing methods depend on the pipe size and system pressure. For piping up to 3 psig (20.7 kPa), black steel pipe or pipe conforming to ASTM A53: *Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless* or ASTM A106: *Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service* is

Table 11-17 Capacity of Horizontal Gas Piping, NG Pipe with Initial Pressure of 50 psig and 5 psig Pressure Drop, cfh

Length, ft	Pipe Diameter, in.											
	0.5	0.75	1	1.25	1.5	2	2.5	3	3.5	4	3	6
10	5,850	12,384	23,575	48,984	73,889	143,864	231,083	412,407	607,670	851,220	1,555,251	2,538,598
20	4,137	8,757	16,670	34,637	52,248	101,727	163,400	291,616	429,688	601,903	1,099,729	1,795,060
25	3,700	7,832	14,910	30,980	46,732	90,988	146,150	260,829	384,324	538,359	983,627	1,465,660
30	3,377	7,150	13,611	28,281	42,660	83,060	133,416	238,103	350,839	491,452	897,923	1,356,938
35	3,127	6,619	12,601	26,183	39,495	76,899	123,519	220,441	324,813	454,996	831,317	1,356,938
40	2,925	6,192	11,787	24,492	36,945	71,932	115,541	206,203	303,835	425,610	777,626	1,269,299
45	2,758	5,838	11,113	23,091	34,832	67,818	108,934	194,411	286,459	401,269	733,152	1,196,706
50	2,616	5,538	10,543	21,906	33,044	64,338	103,343	184,434	271,758	380,677	695,529	1,135,295
60	2,388	5,056	9,624	19,998	30,165	58,732	94,339	168,364	248,080	347,509	634,929	1,036,378
70	2,211	4,681	8,910	18,514	27,927	54,376	87,341	155,875	229,678	321,731	587,830	959,500
80	2,068	4,378	8,335	17,319	26,124	50,864	81,700	145,808	214,844	300,952	549,864	897,330
90	1,950	4,128	7,858	16,328	24,630	47,955	77,028	137,469	202,557	283,740	518,417	846,199
100	1,850	3,916	7,456	15,490	23,366	45,494	73,075	130,415	192,162	269,179	491,814	802,775
125	1,655	3,503	6,668	13,855	20,899	40,691	65,360	116,646	171,875	240,761	439,891	718,024
150	1,510	3,197	6,087	12,648	19,078	37,146	59,663	106,483	156,900	219,784	401,564	655,463
200	1,308	2,769	5,271	10,953	16,522	32,169	31,672	92,217	135,879	190,339	347,765	567,648
300	1,068	2,261	4,304	8,943	13,490	26,266	42,190	75,295	110,945	155,411	283,949	463,482
400	925	1,958	3,727	7,745	11,683	22,747	36,537	65,207	96,081	134,590	245,907	401,388
500	827	1,751	3,334	6,927	10,450	20,345	32,680	58,323	85,938	120,381	219,946	359,012
1,000	585	1,238	2,357	41,898	7,389	14,386	23,108	41,241	60,767	113,122	155,525	253,860
1,500	478	11,011	1,925	4,000	6,033	11,746	18,868	33,673	49,616	69,502	126,986	207,276
2,000	414	876	1,667	3,464	5,225	10,173	16,340	29,162	42,969	60,190	109,973	179,506

used. Other materials, such as corrugated stainless steel, may be permitted by the AHJ, and they must be listed for gas service. Fittings are cast or malleable iron screwed fittings in sizes 3 inches (76.2 mm) and smaller and butt-welded joints in sizes 4 inches (101.6 mm) and larger. Where natural gas is considered dry gas, type L copper pipe may be used. All piping for pressures more than 3 psig (20.7 kPa) should be steel with welded joints. Welded fittings shall conform to ASME B16.9: *Factory-Made Wrought Buttwelding Fittings*. Screwed fittings shall be black malleable iron, 150-pound class, conforming to ASTM A197: *Standard Specification for Cupola Malleable Iron*. Check valves shall be cast iron, 316 SS trim, disk type, with a soft seat. In sizes 3 inches (76.2 mm) and smaller, use screwed joints. Larger sizes shall be flanged.

Joints for PE should be butt-type, heat-fused joints. Socket-type joints have been found to introduce a stiffness in the joint area that is undesirable. Joints for steel pipe shall be screwed for pipe sizes 3 inches (75 mm) and smaller. Sizes 4 inches (100 mm) and larger should be welded. Where flanged connections are necessary to connect some devices, flanges are heat welded to the HDPE pipe ends.

To make the transition from underground plastic pipe to aboveground steel pipe, an adapter fitting (Figure 11-35) is required.

Testing and Purging

After installation of the pipe is complete, the site system shall be tested, purged of air, and then filled with natural gas. The testing phase shall be done with compressed air at a gauge pressure 50 percent higher than the highest pressure expected in the main. No loss of pressure shall be allowed. The test period is based on the size of the line and the length of run (see Table 11-18).

After successful testing, the line shall be purged of air with dry nitrogen to prevent a flammable mixture of gas and air when the pipe is filled with natural gas for the first time. This is accomplished by calculating the volume of the piping and introducing an equal volume of nitrogen into the pipe. After the nitrogen purge, natural gas is introduced until the nitrogen is displaced. It is recommended that the pipe be left under normal operating pressure.

Table 11-18 Test Duration for Plastic Gas Mains, hours[a]

Main Size, in.	2	3	4	6	8	10	12	14	16	18	20	22	24
	Maximum Length of Pipe Being Tested, ft												
≤1	6,590	11,000	15,400	24,200									
2	1,700	2,830	3,960	6,220	8,490								
3	743	1,240	1,730	2,730	3,720	4,710	5,700						
4	439	732	1,030	1,610	2,200	2,780	3,370	3,960	4,540	5,130			
6	189	315	442	694	947	1,200	1,450	1,710	1,960	2,210	2,460	2,730	2,970
8	108	180	252	396	541	685	829	973	1,120	1,260	1,410	1,550	1,700
12	48	80	112	177	241	306	370	435	499	563	628	692	757
14	41	68	96	151	206	261	316	371	426	482	537	592	647
16	30	50	70	110	150	191	231	271	311	352	392	432	472
20	19	31	44	69	95	120	146	171	197	222	247	273	298
24	13	21	30	48	65	83	100	118	135	153	170	188	205

[a] Mains to operate at less than 125 psig.

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Expiration date: Continuing education credit will be given for this examination through **December 31, 2018**.

CE Questions — "Site Utility Systems" (CEU 254)
Test written by Ronald K. Bartley, PE, CPD, CPI/CPE

1. For domestic water service, in addition to domestic water use, ________ percent is added as an allowance for cooling tower fill, boiler fill, and other miscellaneous uses of water.
   a. 5
   b. 10
   c. 15
   d. 20

2. The exact pressure loss through taps or street ells shall be obtained from the ________.
   a. specific manufacturer
   b. public water supply authority
   c. either a or b
   d. neither a nor b

3. Which of the following are considered a moderate (medium) contamination hazard?
   a. private homes
   b. fire protection storage tanks
   c. hospitals
   d. dry pipe fire protection systems

4. If multiple service connections are made to a single main, what kind of valve shall be required to be installed in the source main somewhere between the two connections?
   a. balancing valve
   b. check valve
   c. supervised valve
   d. sectionalizing valve

5. The total pounds resultant thrust for a 10-inch, 90-degree bend at 100-psi water pressure is ________.
   a. 7,406
   b. 9,097
   c. 13,685
   d. 19,353

6. The fire department hose stream demand shall be increased for which of the following?
   a. noncombustible construction
   b. minimum protection less than that recommended by insurance company requirements
   c. unrestricted access to remote interior sections
   d. all of the above

7. A ________ is a pre-installed fitting located at fixed distances along the length of a sewer line.
   a. catch basin
   b. lamphole
   c. manhole
   d. spur

8. For sewage systems, if a wide range of instantaneous flow rates is possible, a three pump system, with each pump sized at ________ percent of the maximum calculated flow, should be considered.
   a. 75
   b. 67
   c. 50
   d. 33

9. If the high point of a sewage system occurs prior to the point of discharge, it is desirable to place a ________ in the pipe to allow the accumulated air at the high point to be eliminated.
   a. air admittance valve
   b. sanitary vent
   c. combination pressure/vacuum device
   d. catch basin

10. For ease of calculation, the imperviousness factor for roofs and pavement could become ________ if excessive runoff will not result in a significant overdesign.
   a. 0.90
   b. 0.95
   c. 1.0
   d. 2.0

11. Natural gas systems when installed inside a building are not allowed to exceed what pressure unless the local authorities allow a higher pressure, all piping is welded, and the pipe is run inside buildings or areas used only for industrial processes, research, warehouse, or boiler and/or mechanical equipment rooms?
   a. 2 psig
   b. 5 psig
   c. 10 psig
   d. 20 psig

12. After installation of the pipe is complete, the site natural gas system shall be tested with compressed air at a gauge pressure ________ percent higher than the highest pressure expected in the main.
   a. 5
   b. 10
   c. 25
   d. 50