CHAPTER 3

HYDRAULIC DESIGN OF SEWERS

3-1. Quantity of wastewater.

For any segment of proposed sewer, the design wastewater flow must be determined. Sanitary or domestic wastes based on the population served by a given segment, extraneous infiltration/inflow, and contributing industrial flows must be added to produce the design flow. Where existing flow records or data showing required flow capacity are not available, the methods and criteria discussed below will be used to develop design flows.

a. Tributary area. This is the area contributing wastewater to a particular sewer segment. The quantity of wastewater which is collected by a particular segment is dependent upon the types of personnel and industrial activities which are regularly found in the area. Where no information is available on existing areas to be sewered, a survey will be required to determine the number and classification of personnel and the types of industries.

b. Sanitary or domestic wastes.

(1) *Contributing population.* Domestic wastewater quantities normally are to be computed on a contributing population basis, except as noted in subparagraphs d and e below. The population to be used in design depends upon the type of area which the sewer serves. If the area is strictly residential, the design population is based on full occupancy of all housing and quarters served. If the area served is entirely industrial, the design population is the greatest number, military and civilian, employed in the area at any time, even though some of these persons may also be included in the design of sewers in the residential area. For sewers serving both residential and industrial areas, the design population includes residents and nonresidents, but in the design of these sewers obviously no person should be counted more than once. Allowances will be made for future population changes based on facility personnel requirements and master planning projections.

(2) *Average daily flow.* Average daily per capita wastewater quantities for different types of installations and buildings are given in table 3-1. The average daily flow will be computed by multiplying the resident and nonresident contributing populations by the appropriate per capita allowances and adding the two flows. The average daily flow represents the total waste volume generated over a 24-hour period. However, it is not a realistic indicator of the rate of flow when wastes are generated over shorter periods of 8, 10, 12 hours, etc. Thus, the average daily flow will be used only for designing sewers to serve the entire installation, or large sections of the installation, and where a major portion of the wastewater is generated by residents over a 24-hour period.

Table 3-1. Domestic Wastewater Allowances [1]

	Gallons/Capita/Day	
	Permanent	Field
Type of Installation [2]	Construction	Training
Army Posts, Forts, Camps, Airfields, Plants and Depots	100	35
Air Force Bases, Stations and Other Facilities	100	—
POW and Internment Camps	—	35
Type of Building [3]		
Single Family Housing (per unit) [4]	300	—
Multi Family Housing (per unit) [4]	250	—
BOQ and BEQ	70	20
EM Barracks	50	15
Hospitals (per bed) [5]	300-600	100
Other buildings and establishments normally found on military installations, such as bowling alleys, theaters, clubs, cafeterias, laundromats, schools, shops, gasoline service stations, etc., will be assigned typical waste loading values obtained from standard textbooks.		

Notes on the use of table 3-1.

1. Allowances do not include industrial and process wastes as defined in Chapter 3 of TM 5-814-8.
2. These values represent domestic waste quantities for resident personnel averaged over the entire installation for a 24-hour period. Nonresident personnel and civilian employees working 8-hour shifts will be allowed 30 gallons/capita/day. Normally, these quantities are to be used in design of wastewater treatment facilities as indicated in Chapter 4 of TM 5-814-3/AFM 88-11, Volume 3. However, they will also be used for sizing interceptors, trunk sewers and pumping stations serving large portions of the installation.
3. For design of sewers serving smaller areas where several buildings or a group of buildings must be considered, the appropriate wastewater allowances shown in the table or obtained from standard textbooks will be used.
4. In family housing areas, each housing unit will be assigned 3.6 residents for the purpose of calculating populations.
5. No separate allowance will be made for nonpatients and employees working shifts.

(3) *Average hourly flowrate.* When designing sewers to serve small areas of the installation where several buildings or a group of buildings are under consideration, and where the majority of wastewater is generated by nonresidents or other short term occupants, the average hourly flowrate will be used. The average hourly flowrate will be computed based on the actual period of waste generation. For example, 1000 nonresidents at 30 gpcd would generate 30,000 gallons in 8 hours for an average hourly flowrate of 3750 gph (90,000 gpd). Note that the average daily flow would still be 30,000 gpd, or 30,000 gallons in 24 hours, but the sewer must be designed hydraulically to carry the

30,000 gallons in 8 hours, not 24 hours.

(4) *Peak diurnal flowrate.* The normal daily range of the rate of flow, or the diurnal pattern, is from approximately 40 percent to 250 percent of the average daily flow. The peak daily or diurnal flowrate is an important factor in sewer design, especially when minimum velocities are to be provided on a daily basis. The peak diurnal flowrate will be taken as one half of the extreme peak flowrate.

(5) *Extreme peak flowrate.* Extreme peak rates of flow occur occasionally and must be considered. Sewers will be designed with adequate capacity to handle these extreme peaks flowrates. Ratios of extreme peak flowrates at average flows will be calculated with the use of the following formula:

$$R = \frac{C}{Q^{0.167}}$$

where:

R = ratio of extreme peak flowrate to average flow

Q = average daily flow or average hourly flowrate in million gallons per day, gallons per day, or gallons per hour, and

C = constant, 3.8 for mgd, 38.2 for gpd or 22.5 for gph

When designing sewers to serve the entire installation, or large areas of the installation, and where a major portion of the wastewater is generated by residents over a 24-hour period, the average daily flow will be used in the formula, and the extreme peak flowrate will be computed by multiplying the average daily flow by the ratio R. However, for sewers serving small areas of the installation where several buildings or a group of buildings are being considered, and where the majority of wastewater is generated by nonresidents or other short term occupants, the average hourly flowrate will be used in the formula, and the extreme peak flowrate will be computed by multiplying the average hourly flowrate by the ratio R. Examples illustrating the use of the above formula are provided in Appendix B.

c. *Infiltration and inflow.* Extraneous flows from groundwater infiltration enter the sewer system through defective pipe, joints, fittings and manhole walls. Sources of inflow include connections from roof leaders, yard drains, storm sewers, cooling water discharges and foundation drains, in addition to submerged manhole covers.

(1) In computing wastewater flows for new sewers, design allowances for groundwater infiltration will be 500 to 1000 gallons/day per inch diameter per mile of pipe, and will be added to the peak rate of flow. For design of Air Force facilities, use 500 gpd/in/mi. Acceptance tests required for newly constructed sewers normally limit leakage to 500 gpd/in/mi.

(2) Where infiltation/inflow must be calculated from an existing collection system, attempts must be made to obtain flow records from treatment facilities or pumping stations which will provide information on the magnitude of I/I quantities. In the absence of such flow data, and depending on the scope of the project, it may be necessary to measure flows in the existing system. Where this is not possible or feasible, allowances of 10,000 to 100,000 gpd/mile of pipe may be used depending on the size and age of the sewers, materials of construction, and the soil and ground-water conditions. Installation personnel will usually have some knowledge of these matters and should be aware of major problems. Where I/I is known to be excessive, it should be determined prior to design if corrective measures are planned for the existing system, or if U.S. Environmental Protection Agency (EPA) evaluation and rehabilitation programs will be implemented.

d. *Industrial waste flows.* Industrial waste quantities from ordnance plants, technical laboratories, laundries, vehicle maintenance shops, airplane wash racks, plating shops, and such industries cannot be computed totally on a population or fixture unit basis. Flows from such plants depend upon the type and extent of the activities. Industrial waste sewers and sanitary sewers will be designed for the peak industrial flow as determined for the particular industrial process or activity involved.

e. *Fixture unit flow.* The size of building connections, including those from theaters, cafeterias, clubs, quarters, and other such buildings, will in all cases be large enough to discharge the flow computed on a fixture unit basis as set forth in the manual on plumbing, TM 5-810-5/AFM 88-8, Chapter 4. This requirement applies to building connections only, and not to the lateral or other sewers to which they connect.

3-2. Gravity sewer design.

Sewers will be designed to discharge the wastewater flows as required by paragraph 3-1. Generally, it is not desirable to design sewers for full flow, even at peak rates. Flows above 90 to 95 percent of full depth are considered unstable, and may result in a sudden loss of carrying capacity with surcharging at manholes. In addition, large trunk and interceptor sewers laid on flat slopes are less subject to wide fluctuations in flow, and if designed to flow full may lack sufficient air space above the liquid to assure proper ventilation. Adequate sewer ventilation is a desirable method of preventing the accumulation of explosive, corrosive or odorous gases, and of reducing the generation of hydrogen sulfide. Therefore, trunk and interceptor sewers will be designed to flow at depths not exceeding 90 percent of full depth; laterals and main sewers, 80 percent; and building connections, 70 percent. However, regardless of flow and depth the minimum sizes to be used are 6-inch for building connections and 8-inch for all other sewers. The following formula, charts, procedures and criteria will be used for design.

a. Design formula and charts. The Manning formula will be used for design of gravity flow sewers as follows:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

where:
V = velocity in feet per second
n = coefficient of pipe roughness
R = hydraulic radius in feet, and
S = slope of energy line in feet per foot

(1) *Roughness coefficient.* Values of n to be used in the formula range from 0.013 to 0.015. The lowest n values apply to new or relatively new pipe (in sections greater than 5 feet) with smooth interior surfaces, smooth bore, even joints, in excellent to good condition and well constructed. Higher n values are required for older pipe with rough interior surfaces, open or protruding joints, in fair to bad condition and poorly constructed. Values up to 0.017 are often justified for very old pipe (such as brick or block sewers) in extreme deterioration, or pipe very poorly constructed with improper alignment, sags and bellies, cracked or offset joints, broken wall sections or internal corrosion. Some manufacturers of plastic and asbestos cement pipe report n values of 0.009 to 0.011. However, due to uncertainties in design and construction, plus a desire to provide a margin of safety, n values smaller than 0.013 will not normally be permitted. Variation of n with depth of flow has been shown experimentally, and may be considered in designing sewers to flow partially full. A solution to the Manning formula for full pipe flow is shown in figure 3-1, which will be used in conjunction with figure 3-2 for sewers flowing partially full.

(2) *Velocity.* Sewers will be designed to provide a minimum velocity of 2.0 feet per second at the average daily flow, or average hourly flowrate, and a minimum velocity of 2.5 to 3.5 fps at the peak diurnal flowrate, as determined in paragraph 3-1. When velocities drop below 1.0 fps during periods of low flow, organic solids suspended in the wastewater can be expected to settle out in the sewer. Sufficient velocity (2.5 to 3.5 fps) must be developed regularly, once or twice daily as a minimum, to resuspend and flush out solids which may have been deposited during low flows. A velocity of 2.5 fps minimum is required to keep grit and sand suspended. However, new sewers which are properly designed and constructed should contain only minor quantities of grit or sand. Maximum velocity is set at 10.0 fps in the event that grit becomes a problem.

(3) *Slope.* Assuming uniform flow, the value of S in the Manning formula is equivalent to the sewer invert slope. Pipe slopes must be sufficient to provide the required minimum velocities and depths of cover on the pipe. Although it is desirable to install large trunk and interceptor sewers on flat slopes to reduce excavation and construction costs, the resulting low velocities may deposit objectionable solids in the pipe creating a buildup of hydrogen sulfide, and thus will be avoided.

(*a*) Adequate cover must be provided for frost protection. Generally, a minimum 2 feet of earth will be required to protect the sewer against freezing. Where frost penetrates to a considerably greater depth and lasts for an appreciable length of time, the wastes may not contain sufficient heat to prevent the gradual cooling of surrounding earth and buildup of an ice film inside the pipe. Under these conditions, greater cover will be required.

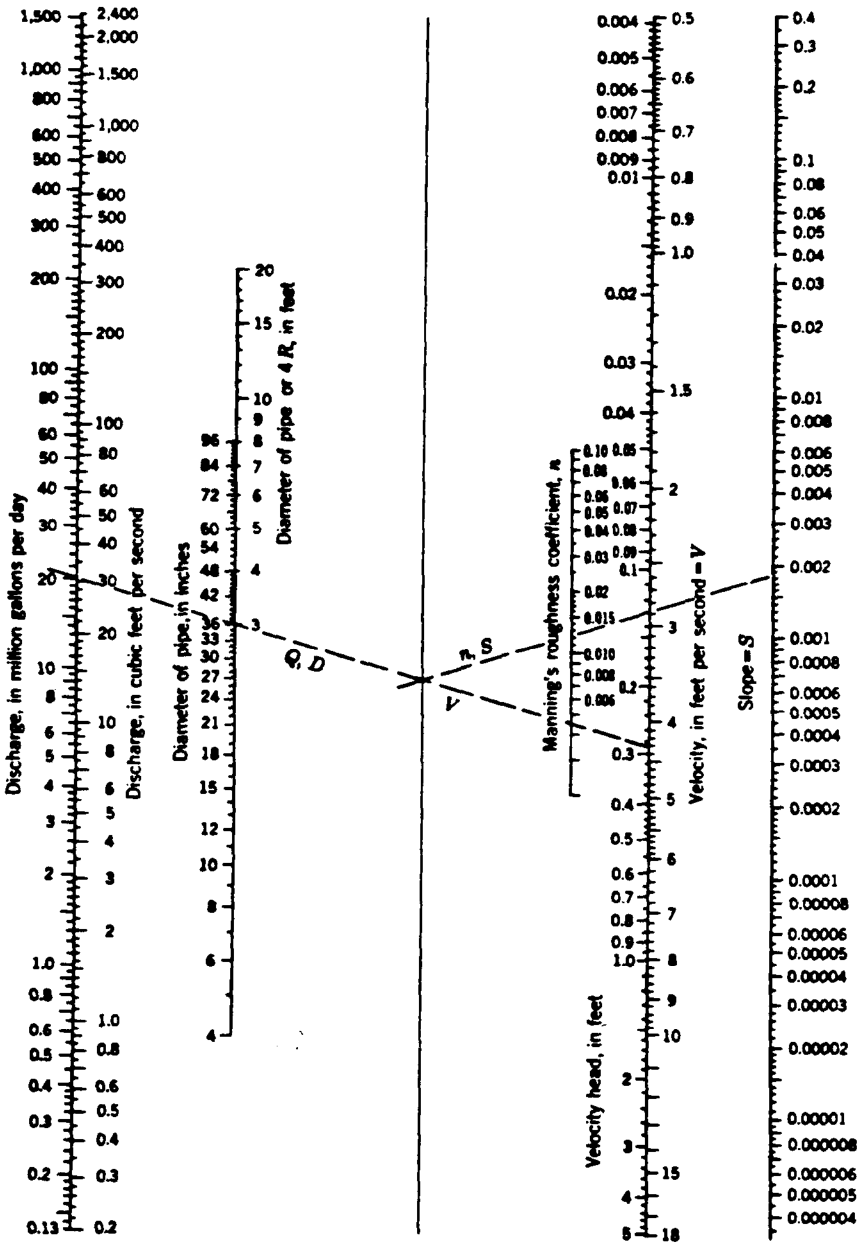
(*b*) Sufficient cover must also be provided to protect the pipe against structural damage due to superimposed surface loadings. Concentrated and uniformly distributed loads are discussed in Chapter 5.

b. Design procedure. After a preliminary layout has been made, a tabulation will be prepared in convenient form setting forth the following information for each sewer section:

—Designation of manholes by numerals or letters.
—Contributing populations—resident and nonresident.
—Design flows—average, daily peak, and extreme peak.
—Length of sewer.
—Invert elevations.
—Invert slope or gradient.
—Pipe diameter and roughness coefficient.
—Flow depths at design flows.
—Velocities at design flows.
—Depths of cover on the pipe—maximum and minimum.

c. Hydraulic profile. In most situations where small to medium sized gravity sewers are installed in long runs, it will be safe to assume uniform flow throughout the entire length of conduit. However, in cases where larger sewers, 24-inch diameter and above, are constructed in runs of less than 100 feet, and with a number of control sections where nonuniform flow may occur, a plot of the hydraulic profile is recommended. For process and plant piping at wastewater treatment facilities, a hydraulic profile is always required. Methods used to calculate and plot hydaulic profiles including backwater curves, drawdown curves and hydraulic jumps, will conform to those presented in standard hydraulics textbooks.

d. Critical flow. Gravity sewers will ordinarily be designed to maintain subcritical flow conditions in the pipe throughout the normal range of design flows. However, there are exceptions in which supercritical flow may be required, and will be justified. Minimum sized sewers (6- and 8-inch) designed to discharge very low flows, must occasionally be placed on slopes steeper than critical in order to provide minimum velocities. In addition, small to medium sized sewers when required to discharge unusually large flows, may necessitate supercritical slopes. Finally, steep slopes may be unavoidable due to natural topography and ground conditions. Where supercritical flow will occur, care must be taken in the design to insure that downstream pipe conditions do not induce a hydraulic jump or other flow disturbance. Depths of flow within 10 to 15 percent of critical are likely to be unstable, and will be avoided where pipes will flow from 50 to



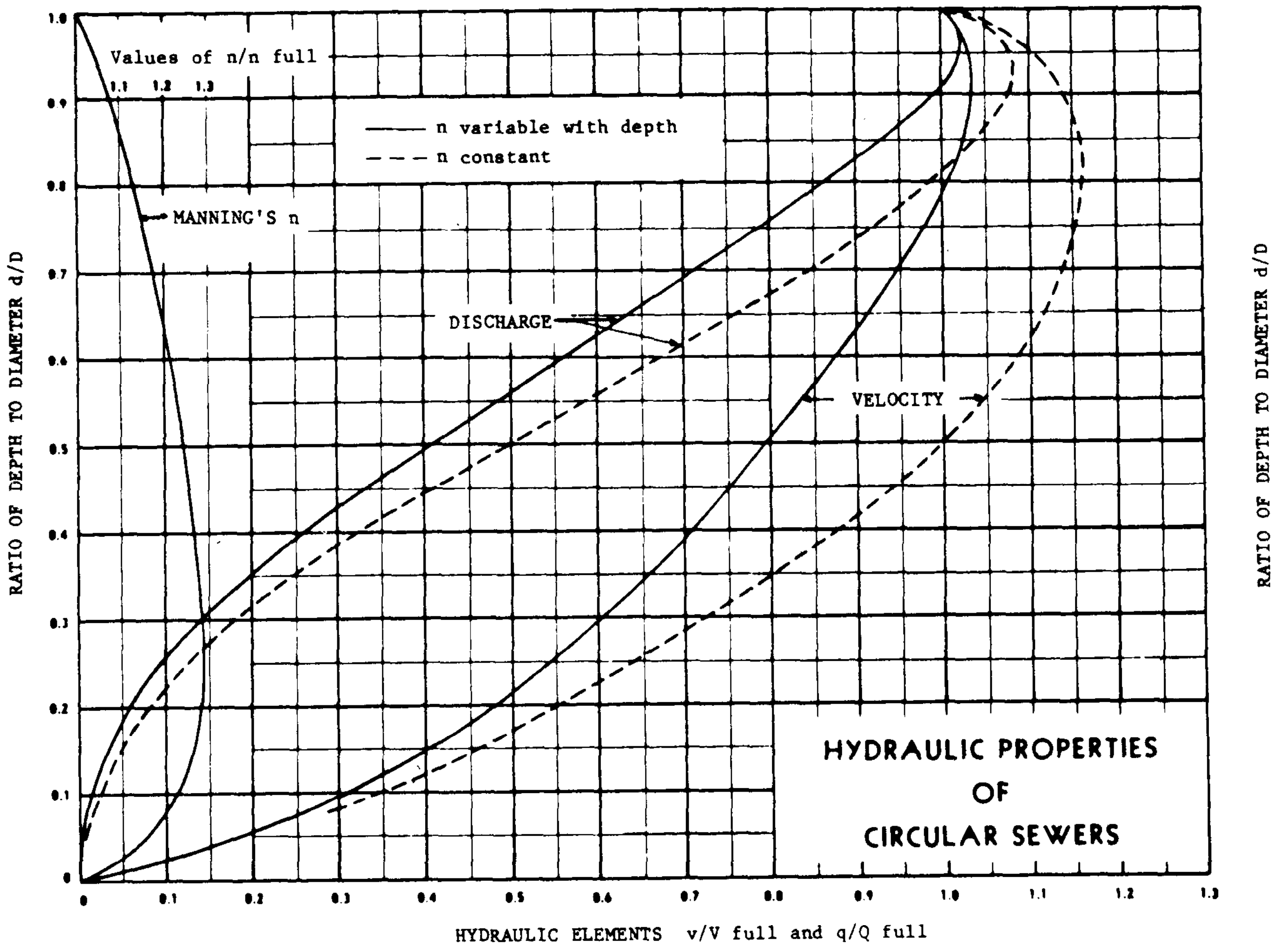
Source: Design and Construction of Sanitary and Storm Sewers - WPCF Manual of Practice No. 9 by Water Pollution Control Federation, 1970, p. 81.

Figure 3-1. Chart for Manning formula.

90 percent full. Critical depths for various flows and pipe diameters can be obtained from standard hydraulics textbooks.

3-3. Depressed sewers.

a. Velocity and flow analysis. Since a depressed sewer, or inverted siphon, is installed below the hydraulic grade line, the pipe will always be full of wastewater under pressure, even though there may be little or no flow. Thus, the design requires special care to secure velocities that will prevent clogging due to sedimentation of solids. The velocity should be as high as practicable, with a minimum requirement set at 3.0 feet per second. Hydraulic calculations may be based on the Manning formula or Hazen-Williams analysis. A minimum Manning roughness coefficient of 0.015 is recommended due to possible accumulations of grease and other materials on pipe walls. Procedures using Hazen-Williams design for pressure pipe flow are given in TM 5-814-2/AFM 88-11, Chapter 2. The pipe will be as small as the available head permits except that pipe smaller than 6-inch is not permitted. Inasmuch as the sewer must be of sufficient size to discharge the extreme peak flows, better velocities for the normal range of flows can often be obtained by using several small pipes instead of one large pipe. This requires an entrance box equipped with a diversion gate for the periodic alternation of pipes in service and with an overflow weir so arranged that, when the flow exceeds the capacity of one pipe, the excess can over-



Source: Clay Pipe Engineering Manual by National Clay Pipe Institute, July 1982, p. 25.

Figure 3-2. Hydraulic properties of circular sewers.

flow to the other pipes. However, conditions might be such that two or three pipes in lieu of one would not be advantageous or necessary. Each case will be analyzed individually.

b. Cleaning and inspection. Depressed sewers should be flushed frequently and inspected to make sure that obstructions are removed. Therefore, manhole structures or cleanout chambers will be required at each end of the sewer to allow access for rodding and pumping.

c. Pipe materials. Since a depressed sewer must withstand internal pressures greater than atmospheric, pipe materials required for use will be as indicated in TM 5-814-2/AFM 88-11, Chapter 2 for force mains.

3-4. Hydrogen sulfide in sewers.

Two of the most important problems occurring in wastewater collection systems are (1) the corrosion of sewers and appurtenances, and (2) the propagation and emission of odorous and toxic gases. Both of these problems can be attributed in large part to the generation of hydrogen sulfide (H_{2S}) in sewers. Reference is made to U.S. Environmental Protection Agency (EPA) publication, Process Design Manual for Sulfide Control in Sanitary Sewerage Systems, for a complete discussion of this topic. Sewers will be designed hydraulically in accordance with EPA guidelines established therein to prevent excessive generation of H_{2S}. In general, small diameter sewers designed to maintain velocities greater than 2.0 feet per second, and sufficient air-to-wastewater contact, normally experience no significant buildup of H_{2S}. Larger sized sewers may be susceptible to H_{2S} formation, but rates of generation can be reduced through proper design, with concentrations limited to less than 1.0 milligram per liter.

a. Corrosion control. Where it is determined that the potential exists for damaging H_{2S} concentrations, such as new sewer connections to older systems with a history of H_{2S} problems and deteriorating sewers, pipe materials must be selected to resist attack from sulfuric acid. Chapter 6 describes various pipe materials and applications suitable for sewer use. As indicated, the pure plastics (PVC and ABS), fiberglass, and vitrified clay are best suited for corrosive environments, whereas concrete (including ABS composite), asbestos-cement, ductile iron, and cast iron soil pipe should be avoided unless special protective linings, coatings, or treatments are provided.

b. Sewer gases. In designing the sewer system, consideration will be given to the possibility of objectionable odors being emitted from manholes and sewers. As noted in paragraph a. above, new sewer connections to older systems with a history of H_{2S} problems will very likely experience similar difficulties. In these cases, sewers and manholes will be located such that emissions of odorous sewer gases, and in particular H_{2S}, do not create a nuisance or hazard for nearby building occupants.