CE 432
Environmental Engineering Sessional-II
(Lab Manual)

Department of Civil Engineering
Ahsanullah University of Science and Technology
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Preface

Environmental engineering is the branch of Engineering that is concerned about finding the solutions related to the problems of safe, palatable, and ample water supply, sanitation, proper disposal of wastewater, adequate drainage system for sanitation, air, water quality and pollution etc. The benefits of improved water supply, sanitation and drainage systems include prevention of disease, improved water quality, increased quantity of and access to water, reduction in time and effort required for water collection, promotion of economic activity, strengthening of community organization, improvements in housing, and ultimately, improved quality of life. Environmental Engineering Lab II mainly deals with fundamental design procedures of water supply and sewerage system, estimation of industrial, domestic and fire demands, ground water exploration, estimation of industrial, domestic, and commercial wastewater generation and wastewater network design. This manual also aids in understanding the design basis and steps of the household plumbing system.

This Lab manual was prepared with the help of "Plumbing Technology" by American Society of Plumbing Engineers, "A textbook of water supply engineering" by Dr. M. A. Aziz; 'Environmental Engineering' by Howard S Peavy, Donald R Rowe and George Tchobanoclous.

Prepared By

Raziya Sultana Chowdhury
Assistant Professor
Department of Civil Engineering, AUST

Md. Asif Hossain
Assistant Professor
Department of Civil Engineering, AUST

Modified By

Md.Yasin
Assistant Professor
Department of Civil Engineering, AUST

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Chapter 1
Organogram of the Industry

An organogram, also known as an organizational chart, is a visual representation or diagram that illustrates the structure of an organization. It provides a hierarchical view of how different positions, departments, and roles within an organization are organized and how they relate to one another. The organogram graphically shows the relation of once official to another or other, the chain of command of a company or an organization. It is also used to show the relation of one department to another, or others, enabling one to visualize a complete organization by means of the diagram it presents.

The organogram proved to be crucial for the estimation of the population of our industrial village for the design of the water supply, sanitation, and sewerage system of the industrial village. We decided on the number and types of different industrial units and the number of workers and officials required to run industry arbitrarily by reviewing organograms of different industries that found to be appropriate. From there, we calculated the population of the industrial village also selected the residential and recreational facilities for workers and officials of different ranks with the organogram.

Organograms are commonly used in business, government, non-profit organizations, and other entities. A sample organogram is attached below –

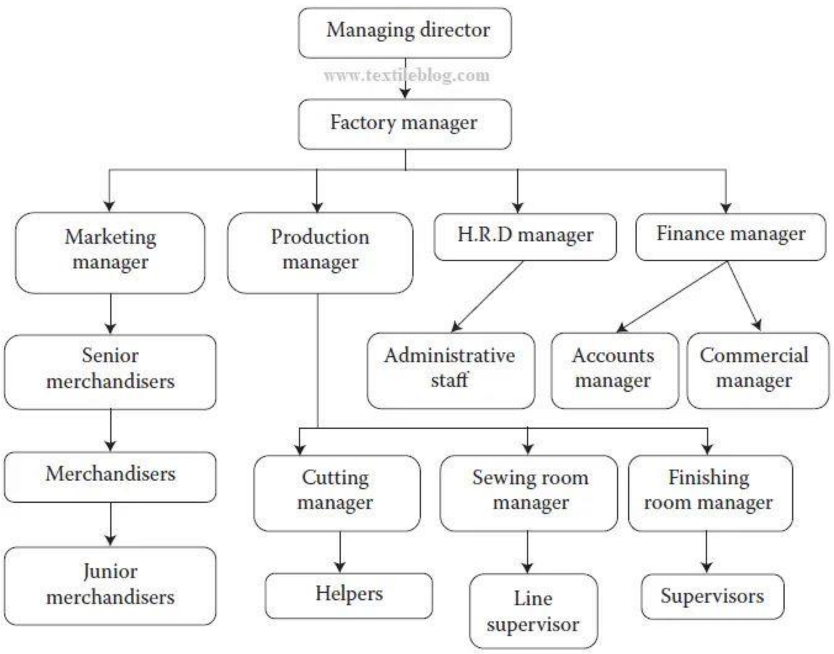


Figure 1.1: sample organogram

Chapter 2
Layout of an industrial village

2.1 Objective: Preparation of layout plan of an industrial village

A complete layout of an industrial village is to be made. The area must include the following distinct zones-

1. Industrial Zone – Includes industry, office, cafeteria, storage place, garage, port, place for loading & unloading of the materials, effluent treatment plant etc.

2. Residential Zone- Includes residence of CEO, officers, workers etc. The people working in the industry will be provided housing facilities within the industrial village. People will be divided into different types depending on their position in the industry. Such as-
    - A type: CEO, General Manager, Director, Executive Engineers, Managers etc. are A type people. They will be given best available facilities.
    - B type: Consists of assistant executive officers, officers etc.
    - C type: Junior executive officers, operators, supervisors etc.
    - D type: Workers and labors.
3. Institutional Zone- Includes school, college.
4. Commercial Zone- Includes market, bank, post office, park etc.

Notes:

- The total area will be expressed in square meter.
- The layout must have clear road network.
- The effluent treatment plant will be placed near river.
- CEOs’ residence must have all facilities.
- All four zones must be separated from each other using main roads.

Chapter 3
Population Prediction and Estimation of Water Demand

3.1 Water Demand Calculation:

The total water demand for residential, industrial, commercial and institutional zones can be evaluated based on the following factors.

- Population
- Design Period
- Rate of water consumption or design flow

3.2 Population Estimation:

Present population can be estimated from the organogram of the industry. Future population for residential area is predicted by using the following empirical formula given by Hardenbarg.

$$P_f = P_p(1+r)^n$$

Here, P_f and P_p represent future and present population respectively. r is the growth rate and n is the design period in year.

The population for commercial, industrial, and institutional area will be calculated by assuming the reasonable growth percentage. The growth percentage depends on the expansion and development of the industrial village.

3.3 Design Period:

The design period is the time *(expressed in years usually)* into the future for which the water supply system and its component structures are to be adequate. The water demand calculation is to be made for this design period. The year must not be too short or too long. The design period must be selected so that the design is economical, and the design cost is not so high for the present population. Usually, 20-30 years is selected as design period.

3.4 Rate of water supply required or design flows:

The design flows is expressed as average water consumption per capita per day. This value differs for different occupancy group. According to BNBC, all buildings or structures are classified depending on their use or considering the character of their occupancy. The occupancy classification is given below:

- Occupancy A: Residential
- Occupancy B: Educational
- Occupancy C: Institutional
- Occupancy D: Health Care
- Occupancy E: Assembly
- Occupancy F: Business and Mercantile
- Occupancy G: Industrial
- Occupancy H: Storage
- Occupancy J: Hazardous

- Occupancy K: Miscellaneous

For industrial area, the water demand will be calculated as employee basis and as well as production basis. The water requirement for industrial production will be expressed as gallons per unit of production. Then the unit of production will be estimated and by multiplying the total units of production with the water requirement per unit, the design flows will be obtained.

3.5 Water demand calculation:

- The total present and future population will be estimated.
- The water requirements will be obtained from BNBC depending on the occupancy type.
- Time consumption factor is considered. Time consumption factor is given to account the effect of supplying water required in a day in less than twenty four hours. For example- The water required in the residential area during about eighteen hours in a day. From 12.00 am to 6.00 am, water demand is almost zero. BNBC 2020 gives the flow rate per day considering twenty-four hours. If we need to supply water in less than twenty hours, then the flow rate needs to be increased. For residential area, Time consumption factor is 24/18.
- For residential demand calculation, peak factor is considered as the water demand in residential zone varies with the hours of a day and peak demand occurs at certain times of a day.
- The design flows will be obtained by multiplying the BNBC 2020 water demand with time consumption factor, peak factor (residential zone only) with the present and future population to get the present and future demand respectively.
- Population of residential area will increase according to the population growth rate while people in office, industry, school, market etc. will be increased in a certain percentage.
- Water demand for industry will be calculated for employee basis and production basis.

3.6.1 WATER DEMAND CALCULATION OF RESIDENTIAL ZONE

Type of BNBC occupancy	Description	No. of units	Member per Family	Total Population (Present)	Total Population (Future)	Water Requirement For Full Facilities (lpcd)[BNBC]	Water Requirement For restricted Facilities (lpcd)[BNBC]	Peak Factor	Time-Consumption Factor	Water Demand (lpd)	
										present	future

3.6.2. A. WATER DEMAND CALCULATION FOR INDUSTRY *(Based on the employee's consumption)*

Employee in Departments	Total worker	No of shift	No of worker per shift		Water requirement (lpcd) for Full Facility [BNBC]	Time Consumption Factor	Water Demand (lpd)	
			Present	Future			present	Future

3.6.2. B. WATER DEMAND CALCULATION FOR INDUSTRY *(Based on the production)*

Type of industry	Water requirement (Litre per 1000 product)	Unit of production per day		Time Consumption Factor	Water demand (lpd)	
		Present	Future		present	Future

3.6.3 WATER DEMAND CALCULATION OF COMMERCIAL ZONE

Occupancy Group (As per BNBC)	Facility	Population per unit	no. of unit	Total Population (present)	Total population (Future)	Water Requirement (lpcd) (Full Facilities) [BNBC]	Water Demand(lpd)	
							present	future

3.6.4 WATER DEMAND CALCULATION FOR EDUCATIONAL/INSTITUTIONAL ZONE

Occupancy Group (As per BNBC)	Facility	Occupation	No of Shift	Class Hour	Present population	Future population	Time Consumption Factor	Per capita Water consumption (lpcd)	Present Water demand (lpd)	Future Water demand (lpd)
	Primary & Secondary School	Student								
		Teacher								
		Staff								
		Total								
	College	Student								
		Teacher								
		Staff								
		Total								

3.7 Fire demand calculation

The fire demand is a function of population, with a minimum limit, because the greater the population the greater the number of buildings and the greater the risk of fire. The minimum limit of the fire demand is the amount and the rate of supply that are required to extinguish the largest possible fire in a community. The following empirical equations can be used for computing rates of fire demand.

National Board of Fire Underwriter's formula,

$$Q = 1020\sqrt{P}(1-0.01\sqrt{P})$$

Kuiching proposed, $Q = 7000\sqrt{P}$

Freeman proposed, $Q = 250\left(P/5 + 10\right)$

Where, $Q \rightarrow$ Fire demand in gpm

$P \rightarrow$ Population in thousands

Chapter 4
Design of Production Tube well

4.1 Design of Production Well

A water well is an excavation or structure created in the ground by digging, driving, boring, or drilling to access groundwater in underground aquifers.

Designing water well involves

- selection of proper dimensional factors for the well structures and
- choosing the materials to be used in its construction.

Good design should assure an optimum combination of

- performance (highest yield with minimum drawdown)
- long service life and
- reasonable short term and long-term cost

The main components of a production well design involves determination of

1. Well depth
2. Well casing/housing pipe length, diameter, and pipe material
3. Screen (strainer) length, diameter, and screen material.
4. Screen transmitting capacity/ yield capacity
5. Number of tubes well pumps required.

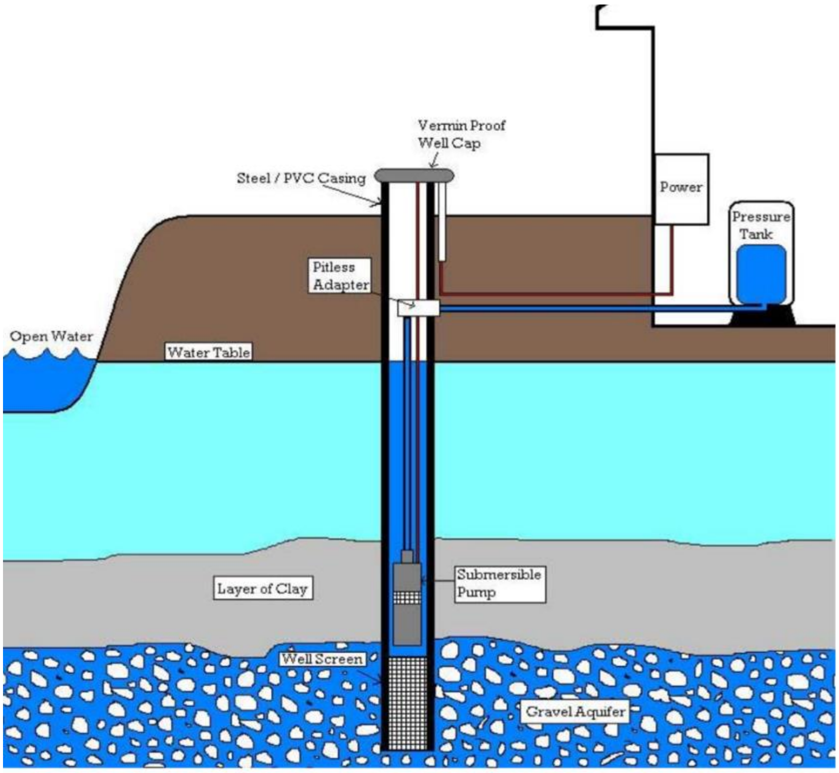


Figure 4.1: Elements of a production well

4.2 Determining the Well Location

The location of a well is mainly determined by the well's purpose. For drinking and irrigation water-production wells, groundwater quality and long-term ground water supply are the most important considerations. The hydro-geological assessment to determine whether and where to locate a well should always be done by a knowledgeable driller or professional consultant. The water quality criteria to use for drinking water wells are the applicable local or state drinking water quality standards. For irrigation wells, the primary chemical parameters of concern are salinity and boron and the sodium-adsorption ratio.

4.3 Well Depth

- The expected depth of a well is usually determined from the log of a test drilling or from logs of other nearby wells in the same aquifer or during the drilling of the production well.
- Generally a well is completed to the bottom of the aquifer.
- Before the main production well drilling, usually 37mm dia test drilling is conducted and a bore log is prepared on the basis of sieve analysis result of soil samples collected from every 10 ft interval.

4.4 Well Casing/Housing Pipe Diameter

- The well casing must be larger enough to accommodate the pump with proper clearance and should assure good hydraulic efficiency of the well.
- The diameter of the well casing should be around two sizes larger than the nominal diameter of the pump.
- For an anticipated yield of 600 to 1300 gpm, well casing outer diameter ranges from 14 to 16 inches are usually taken.

4.4.1 Well Casing/Housing Pipe Material

- Usually, seamless MS pipe is used for bigger diameter (12″ to 18″) casing pipe.
- For small diameter (4″to 6″) production well, uPVC material is also used now a days.

4.4.2 Well Casing/Housing Pipe Length

Length of casing pipe must be sufficient so that well pump remain submerged all the time sufficiently below the maximum pumping water level even after a reasonable operation period (12-15 years) of well.

$$\text{Length of casing pipe} = \sum \left\{ \begin{array}{l} \text{Static water level at present} \\ \text{Assumed drawdown of } 10'\text{-}15' \text{ while pumping} \\ \text{Average rate of decrease of water level per year} \times \text{design period} \\ \text{Total length of tubewell pump} \\ \text{Extra allowance of 5-8ft depth for safety} \end{array} \right.$$

*****Collect information on the existing PWL from nearby DTW of the same capacity and installed in the same aquifer.***

4.5 Well Screen (strainer)

A properly constructed well screen.
- allows water to enter the well freely at low velocity
- prevents sand from entering with the water and
- serves as the structural retainer to support the loose formation material.

4.5.1 Well Screen (Strainer) Length

- The bore log previously prepared using test drill data at an interval of 10ft is used for selection of strainer position.
- From the grain size analysis result the following soil characteristics are determined.

  a. **Fineness Modulus**

  $= \sum$ (Cumulative % retained on sieve #8, 16, 30, 50 and 100) / 100

  b. **Effective Size (D_{10})**

  size that presents 10% finer and 90% coarser of soil sample

  c. **Coeffecient of Uniformity**

  $= \mathbf{D_{60}/D_{10}}$

  Higher value of U (>2.0) indicates well graded sample.

  d. **D_{30}**

  e. **Size Classification** *(Coarse, Medium, Fine)*

  Coarse sand > 0.6 mm
  Medium sand = 0.6 to 0.2 mm
  Fine sand < 0.2 mm

- The optimum length of well screen is chosen in relation to the thickness of the aquifer *(indicated by comparatively coarser sand layers),* available drawdown and stratification of the aquifer.

Aquifer Thickness	Recommended Screening Length (% of water bearing depth)
< 25′	70
25′ - 50′	75
> 50′	80

- As it is very difficult to maintain vertical alignment of a long strainer, it will not be practical to go beyond 100ft screening.
- Strainer should not be extended up to the bottom of the aquifer to allow upward converging flow of water during pumping.

4.5.2 Blank Pipe

Blank pipe should be provided-

- Between two strainers of a discontinuous aquifer.
- 10′ blank pipe is placed at the bottom of the trap soil particles that may enter the pipe through upward converging flow.

4.5.3 Well Screen Diameter

- Screen openings depend upon
    - The gradation of the sand
    - The requirement of water
- Usually 4″ and 6″ diameter are common.
- Screen diameter is selected to satisfy an essential basic principle, i.e. enough total area of screen openings so that the entrance velocity is equal or less than 0.1 ft/sec.

4.5.4 Well Screen Material

- Usually Bridge-type stainless steel screen is preferable.
- Recently Continuous Slot-type stainless screen are manufactured locally.

4.5.5 Screen Slot Opening

- For an available depth of aquifer where strainer will be placed comparatively **finest sand layer** is identified form the soil characteristics on the basis of sieve analysis result.
- When d_{50} of formation materials > 0.25mm and U > 3, well screen will be designed as naturally developed well/screened well.
- When the aquifer is homogeneous and U < 3 and d_{50} < 0.25mm, well screen will be designed as gravel packed well.

4.5.5.A For naturally developed well/Screened well.

Well screen slot openings are selected as the size that will retain 40-50% of the finest sand.

Table: Separate Slot sizes having different opening area

Slot Size	Assumed Opening (Steel Screen)
40 slot	20%
30 slot	15%
20 slot	10%
For PVC screen, opening area is considered to be half of the above-mentioned areas.	

4.5.5.B Gravel Pack Material

- Grain size distribution curve of the **finest sand layer** is drawn on a semi-log graph paper. D_{30} of the finest sand is multiplied by a factor between 4 (for fine and uniform sand) and 6 (coarser and non-uniform sand). Place the result of this multiplication on the graph as D_{30} of the gravel pack materials. This is the first point on the curve that represents the grading of the artificial gravel pack materials.

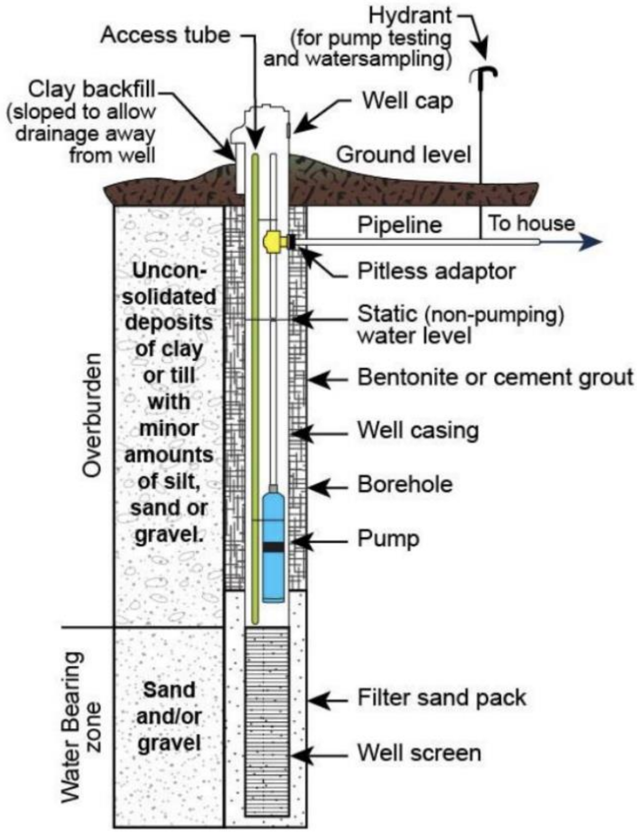


Figure 4.2: Gravel Packed Well

- Through the initial point, a smooth curve nearly parallel to the gradation curve of aquifer material is drawn by trial and error, representing the gravel pack material with a uniformity coefficient of 2.5 or less.
- Size of the well screen openings are selected to retain 90% or more of the gravel-pack material (i.e.D_{10}). Slot number is determined by dividing the slot size (expressed in mm) by 25.4 and multiplying by 1000.
- Specification of the gravel pack materials is prepared by first selecting 4 to 5 sieve sizes that cover the spread of the curve and then set down a permissible range (± 8%) for the percent retained on each of the selected sieves. Gravel pack materials should be clean and well rounded.
- To ensure that an envelope of gravel will surround the entire screen, a thickness of 3-8 in can be maintained.

4.6 Screen Transmitting Capacity/Estimated Yield

Yield of a well

= (Available opening area of screen × Entrance velocity) / Factor of safety

= (π D Ls A × v) / FS

Where, D = diameter of screen

Ls = length of screen

A = available opening area of screen per linear ft of screen

v = entrance velocity *(max^m 0.1 ft/sec)*

FS = factor of safety *(considered assuming screen blockage while operation)*

Sample Calculation

Grain size distribution for different soil layers:

- ✓ To locate the expected depth of water bearing layer, drilling is done, and sieve analyses of various layers are found out. The layer with higher FM, greater uniformity coefficient (Cu) & higher percentage of coarse & medium sand is the expected layer for water extraction.
- ✓ Grain size distribution curves are drawn for different soil layers using soil data.
- ✓ Effective grain size (D10, D30, D60) and uniformity coefficient are found for each layer.
- ✓ From the grain size distribution curves relative percentage of different particles are found using MIT classification of soil (Appendix: Table 1).

The soil data provided for grain size analysis is given in the next page –

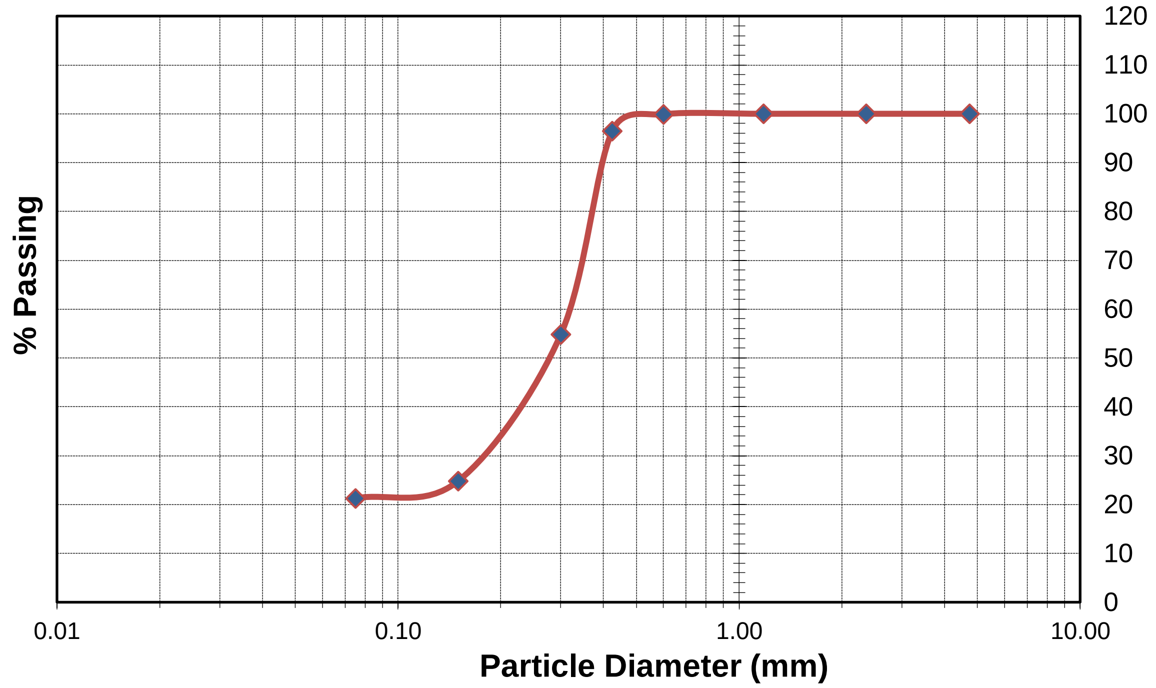
Depth (ft)	590-600	600-620	620-640	640-660	660-670	670-680	680-700
Sieve Size (mm)	Material Retained (gm)						
No. 4(4.75)	0	0	0	0	0	0	0
No. 8(2.36)	0	0	0	0	0	0	0
No. 16(1.18)	0	0	0	0	0	0	0
No. 30(0.6)	0.1	1.2	14.4	1.6	0.5	1.5	0.3
No. 40(0.425)	3.4	6.6	36.2	7.3	6.2	68.4	70.1
No. 50(0.3)	41.7	32.9	27.5	26.1	37.8	20.6	20.1
No. 100(0.15)	30.0	49.1	17.5	42.3	46.0	4.4	5.5
No. 200(0.075)	3.5	7.4	2.8	8.2	7.0	1.9	2.3
Pan	2.3	2.8	1.6	14.5	2.5	3.2	1.7
Total	81.0	100	100	100	100	100	100

*Static water level = 380ft.

The sieve analysis of soil layer for various depths are shown in the following table –

Gradation Chart of Sieve Analysis at Depth (590 – 600) ft

Sieve Number	Diameter (mm)	Soil Retained (g)	Soil Retained (%)	Cumulative % Retained	% Finer than
#4	4.75	0	0.0	0.0	100.0
#15	2.36	0	0.0	0.0	100.0
#16	1.18	0	0.0	0.0	100.0
#30	0.60	0.1	0.1	0.1	99.9
#40	0.425	3.4	3.4	3.5	96.5
#50	0.30	41.7	41.7	45.2	54.8
#100	0.15	30	30.0	75.2	24.8
#200	0.075	3.5	3.5	78.7	21.3
Pan		2.3	2.3	81.0	19.0
	Total	**81.0**	**100**		

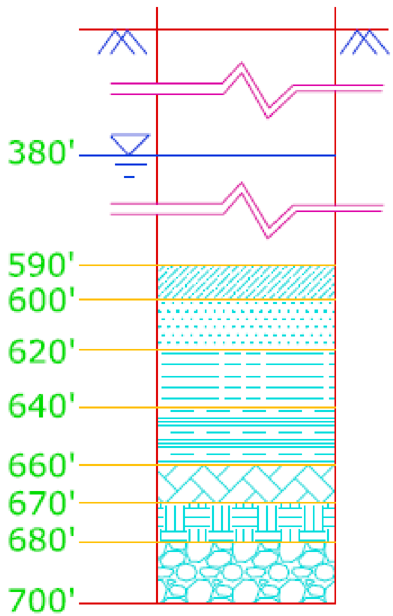


Grain Size Distribution Curve Results:				
			D_{10}:	0.17
	% Coarse Sand:	0	**D_{30}:**	0.26
	% Medium Sand:	66	**D_{60}:**	0.35
	% Fine Sand:	14	**U:**	2.06

<u>Follow the same procedure to do gradation chart of Sieve Analysis for the rest of the depth.</u>

Summary of Grain Size Distribution

Serial	Depth	FM	D60	D10	D30	U	Fine Sand (%)	Medium Sand (%)	Coarse Sand (%)
1	590-600								
2	600-620								
3	620-640								
4	640-660								
5	660-670								
6	670-680								
7	680-700								



Bore Log

Grain Size Distribution

FIne Sand (%)	Medlum Sand (%)	Coarse Sand (%)
16	84	0
17	79	2
11	75	14
26	59	2
22	75	2
7.5	91	1.5
7	93	0

Locating the aquifer and the water bearing strata:

- **Factors to be considered:**

• FM>1 indicates medium to coarse sand which has potential to good permeability and presence of water.

• Greater uniformity U (>2.0) coefficient increases permeability.

• Higher fineness modulus means bigger soil particle.

• Higher percentage of course and medium sand indicates higher water carrying capacity.

So, based on the above factors and the grain size analysis the location of the water bearing soil layer is found to be 590'-640' **(This depth will vary according to your data and calculation).**

- **Length of the casing pipe:**

Based on the position of aquifer and water bearing strata length of casing pipe was determined. Casing pipe must be sufficient so that submersible pump always remains below water.

Static water level=380’

Average rate of water level declination per year =2’

Design period= 20 year

Drawdown of 15’ while pumping each time

Safety distance= 8’

Length of casing pipe = 380+2*20+15+8=443’ ≅450’

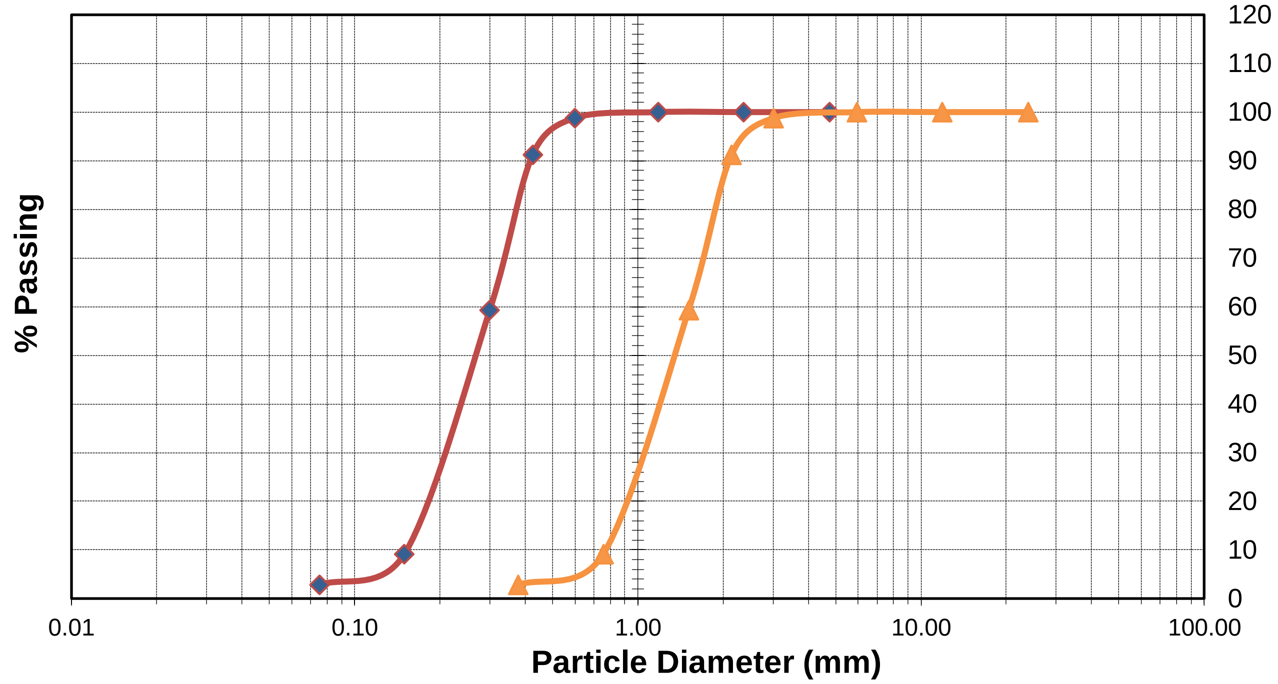
- **Design of gravel pack material:**

Gravel pack size distribution is obtained from the sieve analysis curve of comparatively finest sand stratum among the water bearing soil layer (600'-620') and shown in tabular form. As the strata is finer and uniform, 30% size or percent finer is multiplied by 5 and a reference point is obtained. Through this point, a parallel smooth curve is drawn which has uniformity coefficient 2.5 or less. In the sieve analysis of gravel pack material, range of % retained is assumed to be ±8%.

Here, multiplying factor = 5 (by interpolation)

Gravel Pack Material (600 - 620 ft)

Sieve Number	Diameter (mm)	Soil Retained (g)	Soil Retained (%)	Cumulative % Retained	% Finer than	Diameter X 5.04
#4	4.75	0	0.0	0.0	100.0	23.94
#15	2.36	0	0.0	0.0	100.0	11.8944
#16	1.18	0	0.0	0.0	100.0	5.9472
#30	0.60	1.2	1.2	1.2	98.8	3.024
#40	0.425	7.6	7.6	8.8	91.2	2.142
#50	0.30	31.9	31.9	40.7	59.3	1.512
#100	0.15	50.1	50.1	90.8	9.2	0.756
#200	0.075	6.4	6.4	97.2	2.8	0.378
Pan		2.8	2.8	100.0	0.0	0
	Total	**100.0**	**100**			



<u>Curve Results:</u>

D_{10}:	0.8
D_{30}:	1.1
D_{60}:	1.6
C_u:	2

Determination of strainer length and position:

Primary factors:

1. Length of casing pipe must be selected first
2. Casing pipe must be sufficient enough so that submersible pump always remain below water

Here, aquifer depth = (640-590) = 50’
So, 75% of the aquifer screening can be made which gives the strainer length of 50*0.75=37’

So, a strainer of 37’ is chosen.

Selection of strainer size:

Slot size of the strainer is obtained from D10 size of gravel pack material. From gravel pack size distribution curve,
At depth of 600’-620’,

D10 = 0.8

To retain 90% of gravel pack materials

Slot Number = (D10/25.4)*1000
= (0.8/25.4)*1000
= 31.49

4–6-inch dia **30 slot** strainer is selected having each area of 30/1000 inch or 6” diameter envelop of gravel pack material will surround the entire screen.

Yield of Well:

Capacity in cusec= Available opening area of screen*entrance velocity*safety factor

For 30 slot strainers,
Strainer area = 15% of strainer surface area
= 0.15*3.14*diameter*strainer length

Here, **strainer diameter = 6”**
length = 37’
Assuming,
flow velocity = 0.1fps
Screen blockage factor = 0.33

Yield of a well= 0.15*3.14*6/12*37*0.1*0.33 = 0.2984 ft^3/s

= 30,424 lph

As pumping is for **16 hours per day**,

Yield =30,424 * 16 lpd = **4,86,789 lpd**

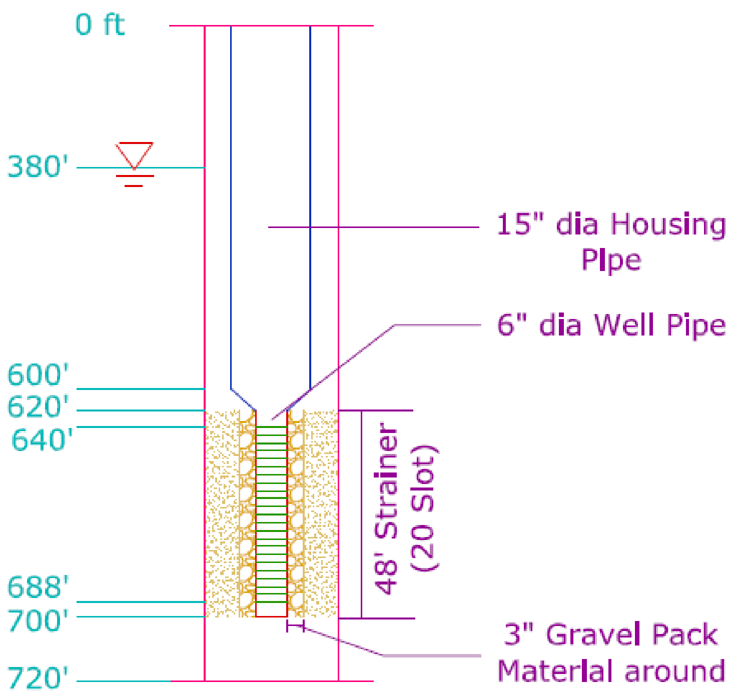
Now, water demand for that area (Present) = _____________ lpd (Obtained from your water demand calculation)

No. of tube-wells required (**Present**) = (Present water demand/486789) = _____

Now, water demand for that area (After 20 years) = ____________ lpd (Obtained from your water demand calculation)

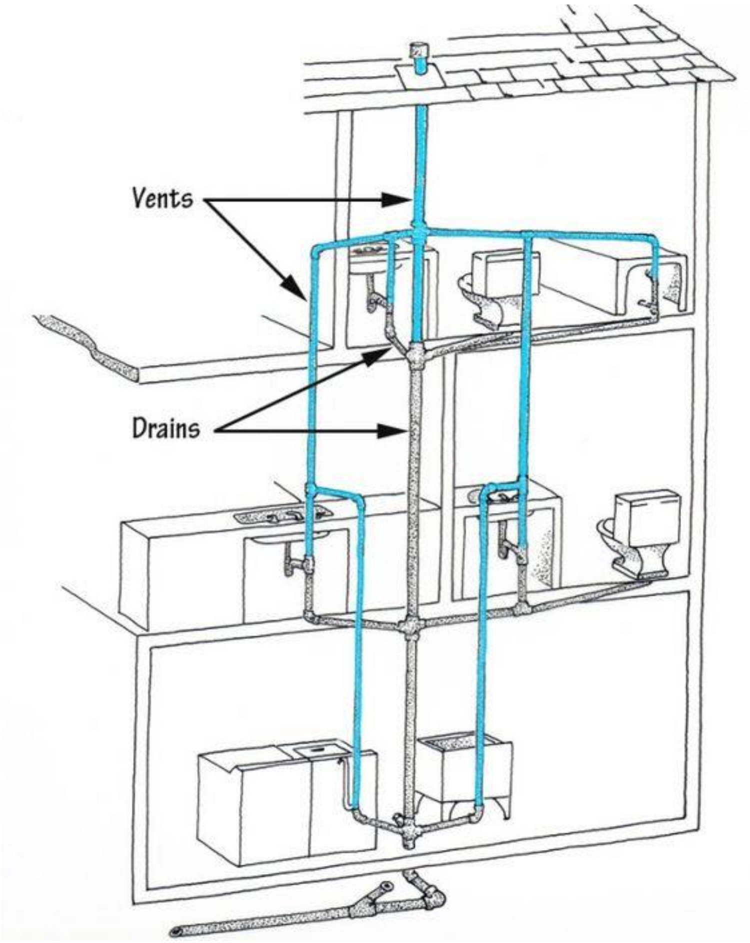
No. of tube-wells required (**After 20 years**) = (Water demand after 20 years)/486789)

= ______________



WELL LOG

Chapter 5
Design of Plumbing System



5.1. Plumbing System

It is the entire system of pipings, fixtures, appliances etc. for providing water supply and drainage to a building.

5.1.1. Objectives

a. To supply/furnish water to various parts of a building.
b. To remove the liquid waste and discharge them into sewer.

The water supply system of a building must accomplish two objectives:

- Provision of sufficient amount of water to serve each fixture.
- Provision of no opportunity of backflow of used water into the water supply pipes.

The drainage system of a building must accomplish two objectives:

- Wastewater must be removed quickly with minimum chance for stoppage of drains or leakage.
- Entrance of vermins and sewer gas or foul-smelling air form the drainage system into the house must be prevented.
-

5.1.2. Plumbing fixtures

- Plumbing fixtures are installed receptacles, devices or appliances to an existing plumbing system which are designed to receive pure water and discharge wastes.
- The fixtures most included in toilet and kitchen are:
    - Lavatory
    - Sink
    - Bathtub
    - Water Closet

- **Flush Tank/Flush Cistern** → A chamber in which water is accumulated and discharged rapidly for flushing out water closets and urinals.

- **Flush Valve** → A flush valve is a device located at the bottom of a tank for the purpose of flushing water closets and similar fixtures and is closed by direct water pressure or some other mechanical means.

- **Fixture Unit**

  A fixture unit (F.U.) is a quantity in terms of which the load producing effects on the plumbing systems of different kinds of plumbing fixtures are expressed on some arbitrary chosen scale.

  A fixture unit is <u>not a flow rate</u> unit but <u>a design factor</u>.

- **Riser**

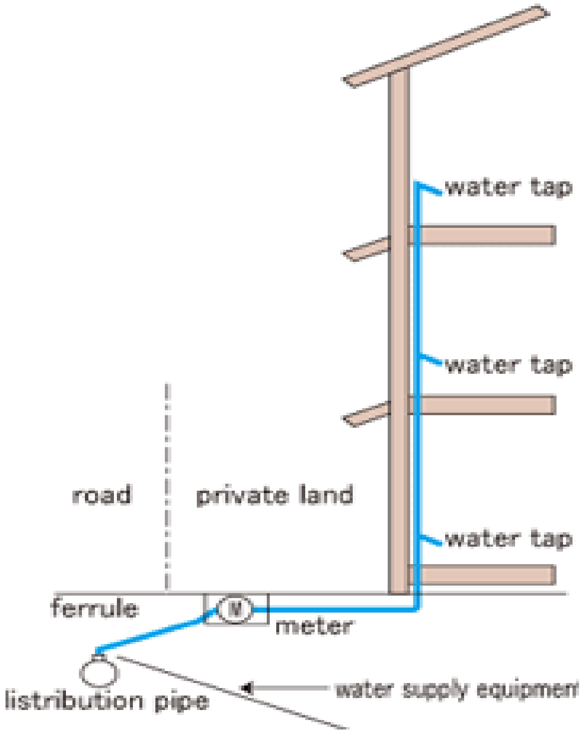
  A water supply pipe which extends vertically one full story or more to convey water to branches or fixtures or to OH tank.

5.1.3. Water Distribution System

Water distribution within a building can be achieved by several piping systems. The piping systems must be designed to provide uniform flow in all areas and floors within certain practical limitations.

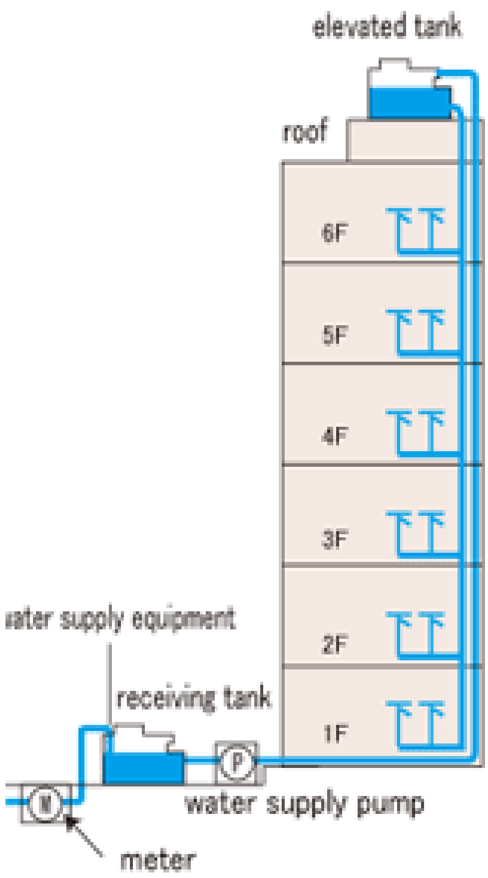
i. Direct Supply

- Water is supplied to all parts of a building directly from the city mains through a suitable connection and meter.
- This system is applicable only when the water supply is available in adequate quantity and pressure round the clock.
- The minimum pressure available limits the number of floors to which the water can be supplied.
- This system is economical, eliminates the need of storage tank which is source of contamination.



ii. Overhead Tank Supply System

- In many cities, the water pressure is sufficient to reach upto 4-5 floors or higher but only for limited hours.
- To meet the water requirement during the non-supply hours, water is stored in overhead tanks placed on the terrace which are fitted by direct connection form the mains.
- Water is supplied to all parts of a building from the overhead tank.

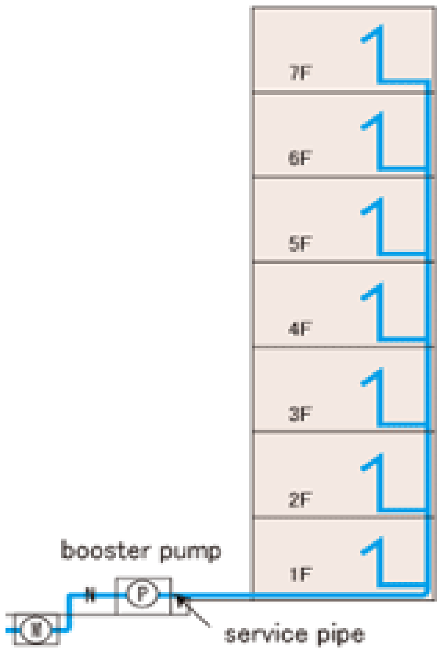


iii. Underground and Overhead Tank Supply System

- Supplied water having low pressure all the time requires storage of water at ground level for individual buildings. Water is collected in these tanks which fill up despite low pressure in the mains. It is then pumped to the overhead tanks.
- Water is supplied to all parts of a building from the overhead tank.

iv. Pumped System

- Water can be distributed by an automatic pumping system (i.e. hydropneumatic system) directly to the supply point, similar to the direct supply. The pressure in the system is boosted by pumping sets that pump water from an underground/ground level tank.
- This system eliminates the need for overhead tanks. This is also suitable in hot and cold climates.



5.1.4. Water Distribution in a Building

Water distribution in to building can be done in following ways:

a. Upfeed distribution

Simple upfeed:

- Water fed to fixtures in a building only by the incoming pressure of the supply water.
- This method is good for building up to 5 to 6 stories high.

Pumped upfeed

- Water fed to the fixtures in a building by increasing the pressure of the supply water using additional pumps.

b. Down Feed Distribution

- Uses pumps to deliver water to a rooftop storage tank of the building.
- The water in the storage tank feeds fixtures below due to the force of gravity.
- Commonly one roof top tank is used to distribute water to whole building. For tall building intermediate tank(s) are often used to supply water at different levels.
- If main does not have sufficient pressure to carry water to OH tank, underground water reservoir (UGWR) is provided to store water from main and deliver to the overhead tank.
-

Table 5.1: Rate of flow and required pressure during flow for different fixtures.[1]

Fixture	Flow Pressure (psi)	Flow Rate (gpm)
Lavatory faucet	8	3.0
Lavatory faucet, self-closing	12	2.5
Sink faucet, $^{3}/_{8}$ in	10	4.5
Sink faucet, $^{1}/_{2}$ in	5	4.5
Laundry-tub cock, $^{1}/_{2}$ in	5	5.0
Bathtub faucet, $^{1}/_{2}$ inch	5	5.0
Shower, $^{1}/_{2}$ inch	12	5.0
Water closet, Ball cock flush tank	15	3.0
Water closet, flush valve type	10 to 20	15 to 40
WC FV, 1 inch @ 25psi	25	35.0
WC FV, 1 inch @ 15psi	15	27.0
WC FV, $^{3}/_{4}$ inch @ 15psi	15	15
Urinal, Flush valve	15	15
Garden hose, 50 feet and sill cock	30	5.0

** Flow pressure is the pressure in the pipe at the entrance of the particular fixture.

Table 5.2: Demand weight of fixtures in fixture units.[a] [1]

Fixture of Group[b]	**Occupancy**	**Type of Supply Control**	**Weight in Fixture Units[c]**
Water closet	Public**	Flush valve*	10
Water closet	Public	Flush tank*	5
Pedestal urinal	Public	Flush valve	10
Stall or wall urinal, 1”	Public	Flush valve	5
Stall or wall urinal, $3/4$ ”	Public	Flush tank	3
Lavatory	Public	Faucet	2
Bathtub	Public	Faucet	4
Shower head	Public	Mixing valve	4
Service sink	Office, etc.	Faucet	4
Kitchen sink	Hotel or restaurant	Faucet	4
Water closet	Private**	Flush valve	6
Water closet	Private	Flush tank	3
Lavatory	Private	Faucet	1
Bathtub	Private	Faucet	2
Shower head	Private	Mixing valve	2
Bathroom group	Private	Flush valve for closet	8
Bathroom group	Private	Flush tank for closet	6
Separate shower	Private	Mixing valve	2
Kitchen sink	Private	Faucet	2
Laundry machine	Private	Automatic	2
Laundry machine	Commercial (8 lb)	Automatic	3
Laundry machine	Commercial (16 lb)	Automatic	4

[a]For supply outlets likely to impose continuous demands, estimate continuous supply separately and add to total demand for fixtures.

[b]For fixtures not listed, weights may be assumed by comparing the fixture to a listed one using water in similar quantities and at similar rates.

[c]The given weights are for total demand. For fixtures with both hot and cold water supplies, the weights for maximum separate demands may be taken as ¾ the listed demand for the supply.

* Flush valve fixtures impose high loads because a large rate of flow occurs over a short period of time.

** In public buildings, simultaneous fixture usage is more likely than in private building. Hence, fixture demand weights are higher for a fixture in a public building than for the same fixture in a private building.

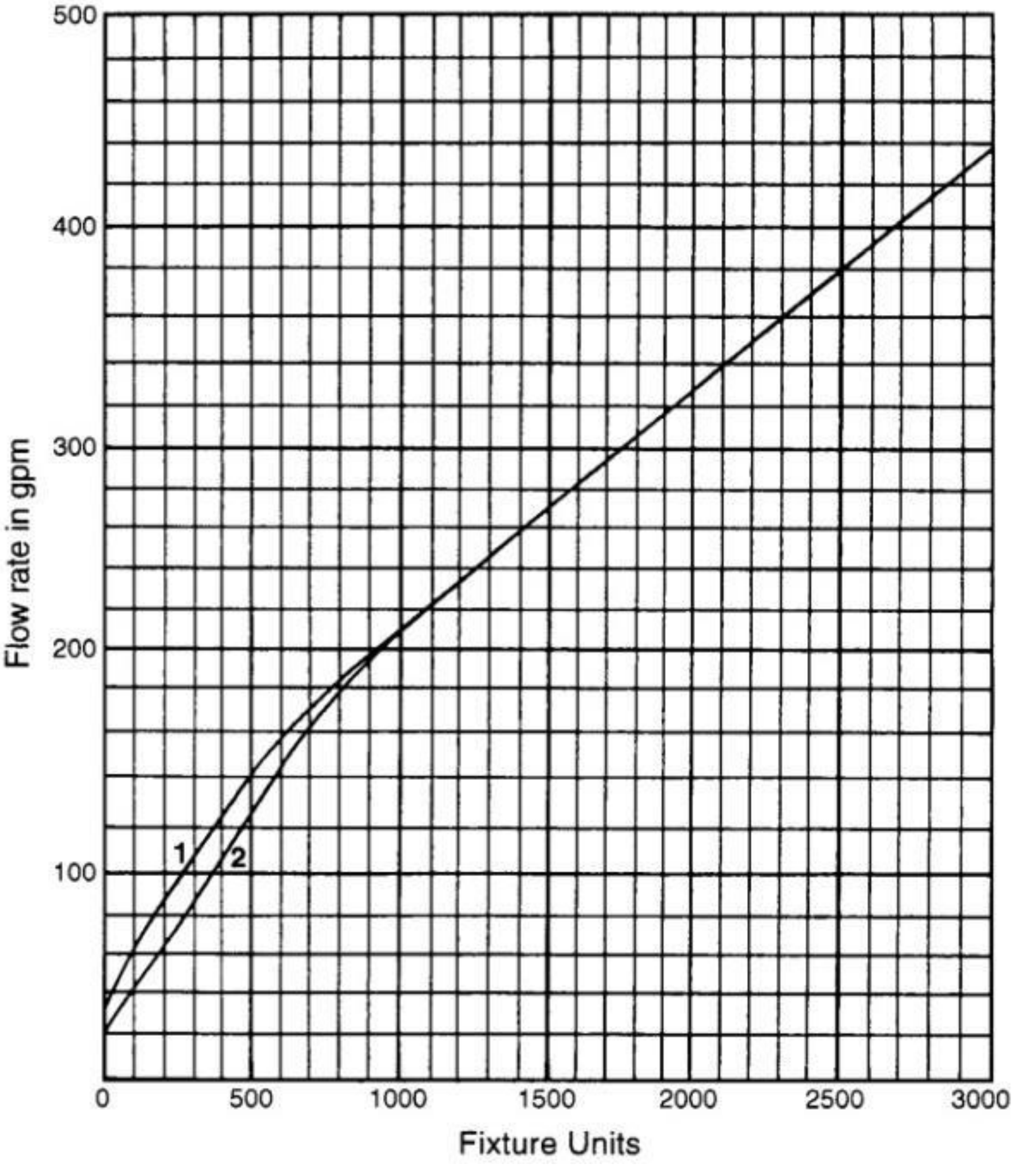


Figure 5.1: Estimate Curve for Demand Load
(Curve No. 1 – System with Flush Valves,
Curve No. 2 – System with Flush Tanks) **[1]**

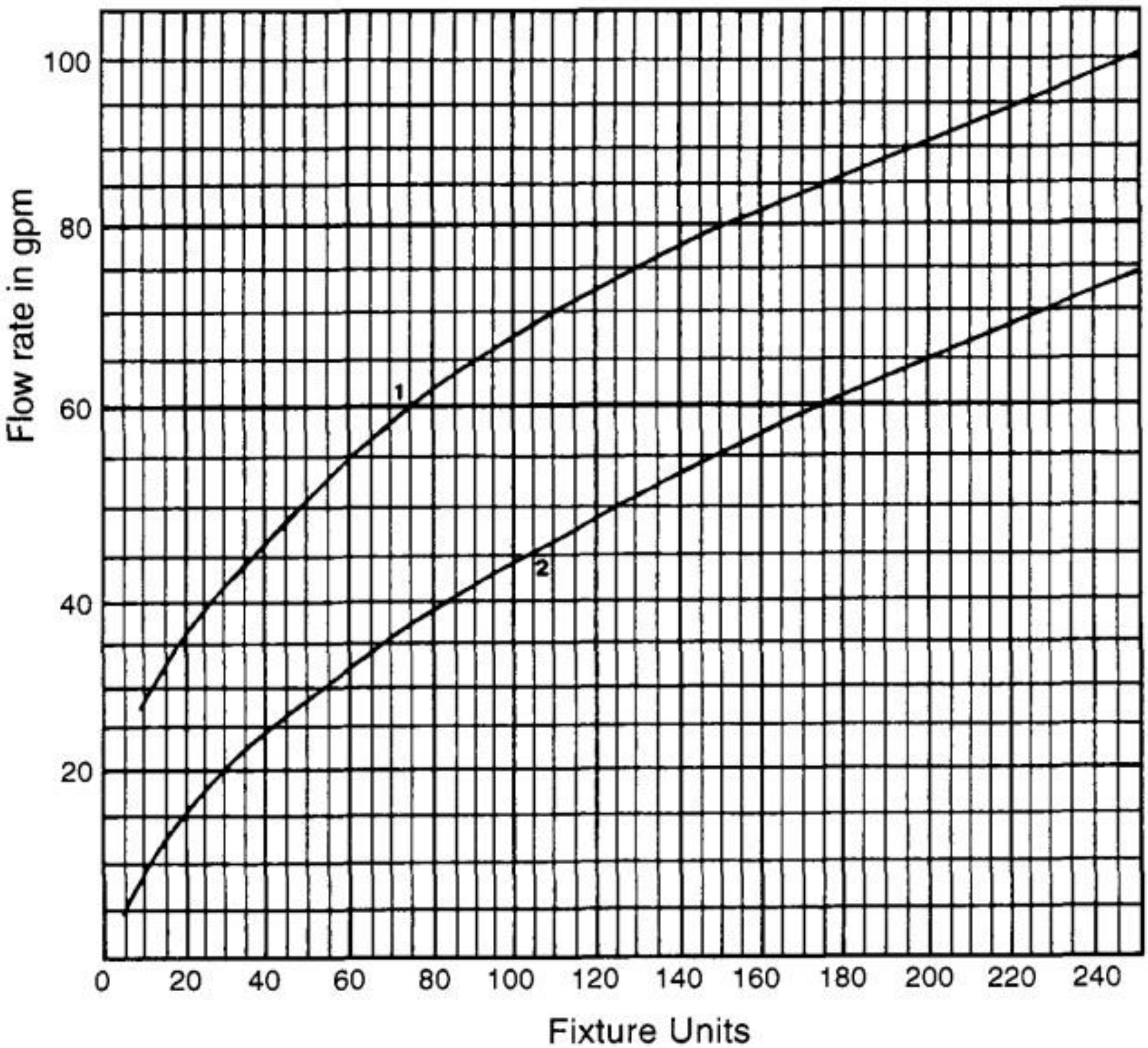


Figure 5.2: Enlarged Scale Demand Load estimation Curve
(Curve No. 1 – System with Flush Valves,
Curve No. 2 – System with Flush Tanks) **[1]**

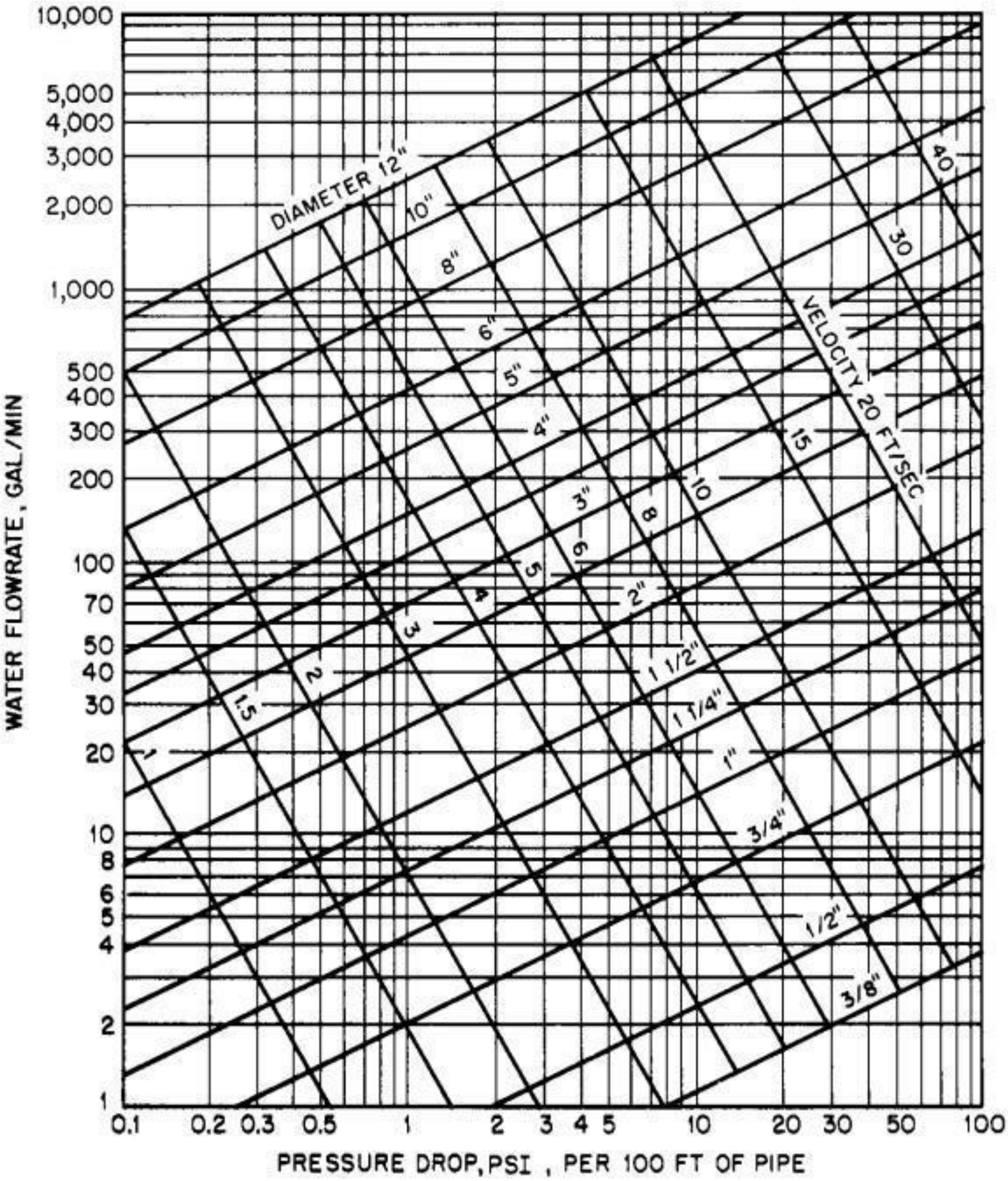


Figure 5.3: Chart for determination of flow in pipes such as galvanized steel and wrought iron that will be fairly rough after 15 to 20 years of use **[2]**

5.1.5. Design of Water Supply System of a Building

a. Design of Water Supply Main

- Estimate total fixture units of the building.
- Determine water supply demand in gpm (from demand load curve).

- Selection of the required pipe size to allow design flow and determine the allowable frictional loss in the selected pipe size. Comparatively larger pipe dia can be selected to conserve pressure for the upfeed zone. Frictional loss of the pipe will vary with the velocity, flow rate, pipe dia and as well as piping materials.
- Zoning of water distribution
  - Lower floors can be upfeed from the service main pressure.
  - Upper floor must be supplied by downfeed risers from elevated tank.

b. Destermination of Upfeed Zone (from the service main)

In an upfeed zone,

$$P = p + 0.434h + f$$

where, P = service main pressure, psi
p = pressure drop through water meter, piping and equipment, psi.
h = height from the main to the top fixture served by upfeed zone, ft.
f = fixture pressure, psi

Pressure drop though the piping will be determined based on the selection of pipe and demand flow. Comparatively larger pipe dia can be selected to conserve pressure for the upfeed zone.
Pressure drop through water meter will be obtained from manufacturer's data.

c. Determination of Downfeed Zone (from the overhead tank)

Position of overhead tank,

$$P = 0.434h$$

where, P = minimum allowable pressure for a fixture, psi (depends on type of fixture)
h = height from the overhead tank to the topmost fixture served by downfeed zone, ft.

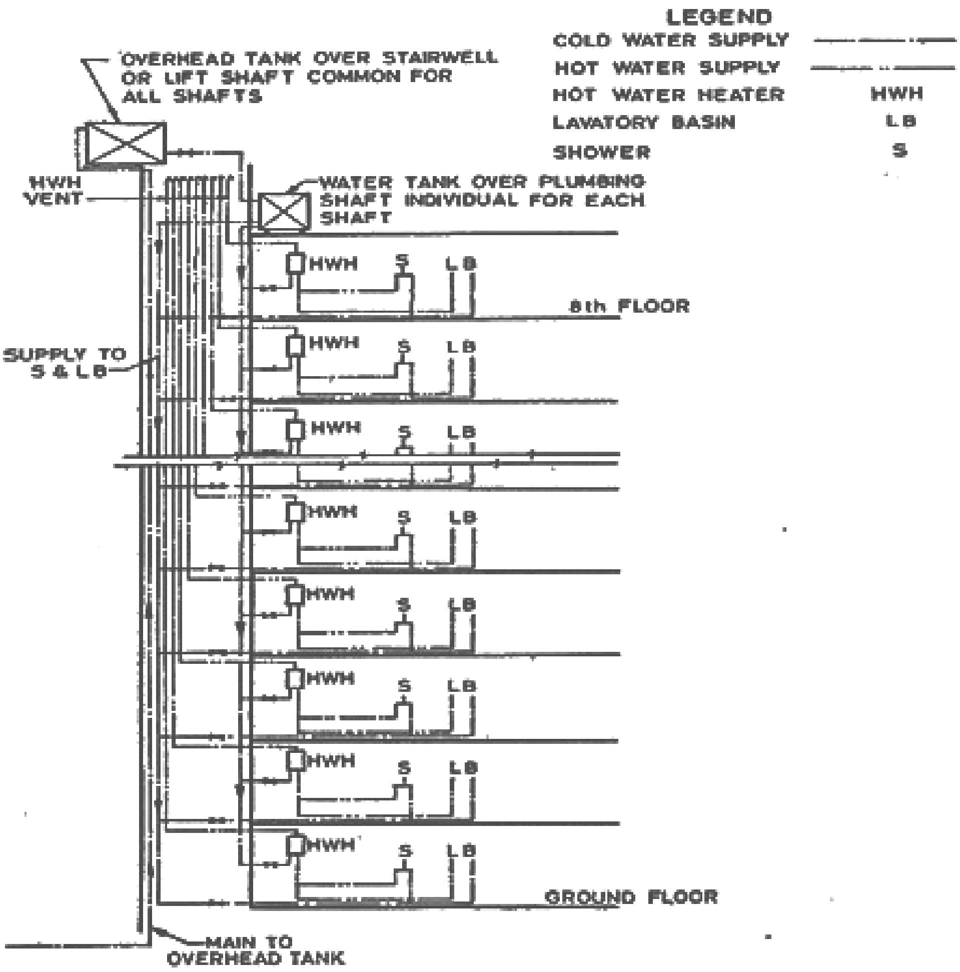


Figure 5.4: Layout plan of the water supply system of a tall building

d. Check the available pressure allowable to overcome friction loss (Upfeed zone)

$$p = P - (p' + 0.434h + f + b)$$

Where, p = pressure drop due to friction through piping, fitting and equipment, psi
P = service main pressure, psi
p′ = pressure drop through the water meter, psi.
h = height from the main to the top fixture served by upfeed zone, ft.
f = maximum fixture pressure, psi
b =fixture branch pressure, psi (usually 1 psi)

Check that the available pressure drop due to friction in pipe will be adequate to overcome the friction in pipe of total equivalent length (Actual pipe length and equivalent length)

** We evaluate the fitting friction by stating the length of straight pipe of the same size which will offer equal pressure drop at the same rate of flow.

Table 5.3: Pipe Sizing for Upfeed zone of the water supply system

Floor	Fixture unit	Accumulated fixture unit	Design flow (gpm)	Pipe dia (in)

e. Check the available pressure allowable to overcome friction loss (Downfeed zone)

$p = 0.434h - f - b$

where,

p = pressure drop due to friction through piping, fitting and equipment, psi.
h = height from the overhead tank to lowest fixture served by downfeed zone,ft.
f = maximum fixture pressure, psi
b =fixture branch pressure, psi (usually 1 psi)

Check that the available pressure drop due to friction in pipe will be adequate to overcome the friction in pipe of total equivalent length (Actual pipe length and equivalent length)

Table 5.4: Pipe Size for Downfeed zone of the water supply system

Floor	Fixture unit	Accumulated fixture unit	Design flow (gpm)	Actual pipe Length (ft)	Equivalent Pipe Length (ft)	Total Equivalent Pipe Length (ft)	Pressure drop (psi/ 100ft)	Pipe dia (in)

- Total equivalent pipe length = Actual pipe length + Equivalent pipe length
- The fitting friction is evaluated by stating the length of straight pipe of the same size which will offer equal pressure drop at the same rate of flow which is defined as equivalent pipe length. The total pipe length is increased by 50% to consider the fitting friction effect.

5.2. Building Drainage System

5.2.1. Drainage System:

A drainage system (drainage piping) includes all the piping within public or private premises, which conveys sewage, rainwater, or other liquid wastes to a legal point of disposal but does not include the mains of a public sewer system or a private sewage treatment or disposal plant.

5.2.2. Important Terminologies

Stack:

A stack is the vertical main of a system of soil, waste, or vent piping.

Stack Vent/ Soil Vent/ Waste Vent:

A stack vent is the extension of soil or waste stack above the highest horizontal drain connected to the stack.

Waste Pipe:

A waste pipe is a pipe which conveys only liquid waste free of fecal matter.

Soil Pipe:

A soil pipe is any pipe which conveys the discharge of water closets, urinals, or fixtures having similar functions, with or without the discharge from other fixtures to the building drain or building sewer.

Vent Stack:

A vent stack is a vertical vent pipe installed primarily for the purpose of providing circulation of air to and from any part of the drainage system to protect trap seals from siphonage and back pressure.

5.2.3. Drainage System of Building

Drainage system of a building can be divided into following categories:

i. Two pipe system
ii. One pipe system
iii. Single stack system

i. Two Pipe System

- Two separate pipes are installed for conveyance of sewage and waste water.
- All fixtures which carry human excreta, urine or obnoxious wastes are connected to a separate stack known as **soil stack**, which is connected directly to a sewer line through a manhole. Each fixture connected to the soil stack must be provided with a trap.
- Fixtures, which receive waste water (from basins, bathtubs, showers etc.) are connected to a separate horizontal pipe called wastewater pipe, which discharge into a separate vertical stack

known as **waste stack**. These stacks are connected to a combined sewer. Many of these fixtures do not have their own traps.

- The soil stack and as well as waste stacks are separately ventilated, by providing separate vent pipe or anti-siphonage pipe.

ii. One Pipe System

- In one pipe system, both soil and waste fittings are discharged into a common verticalstack. Each fixture is provided with a trap having a minimum seal of 50mm for waste and 75 mm for soil appliances.
- The main pipe is ventilated at the top, in addition a separate vent pipe or anti-siphonage pipe is also provided. This system has two vertical pipes.

iii. Single Stack System

- The system consists of a single pipe for soil, waste and vent without any separate ventilation pipe. It uses only one pipe, which is usually extended upto 2m above the roof level with a cowl to act as vent pipe for removal of foul gases.

5.2.4. Design Considerations:

- The waste branch from bath room, wash basin or sink should be of 32 mm to 50 mm diameter and should be trapped immediately beneath such wash basins or sink by an efficient siphon trap with adequate means of inspection and cleaning.
- The minimum recommended size of waste stack is 75 mm.
- The soil and waste stack should be continued upward undiminished in size 0.6 m above the roof surface when the roof will be used only for weather protection. Where the roof will be used for any purpose other than weather protection, the soil and vent stack shall run at least 2 m above the roof surface to ensure least possible nuisance.
- The soil and waste stack should be firmly attached to the wall with a minimum clearance of 25 mm from the wall.
- The diameter of a branch vent pipe on a waste pipe should not be less than 25mm or two-thirds of the diameter of the branch waste pipe ventilated.
- The branch vent pipe on a soil pipe should be at least 32 mm in diameter.
- A relief vent should be at least on-half the size of the drain it vents (no less than 1 ¼”, 32 mm).
- All vent stacks should extend undiminished in size above the roof or should be reconnected to a vent header or to the stack vent portion of the soil or water stack, at least 150 mm above the flood level of the highest fixture connection discharging into the soil or waste stack. Where the roof is to be used for any purpose other than weather protection, the vent extension should be in accordance with as stated earlier in this topic.
- The soil pipe conveying any solid or liquid filth to a sewer drain should be circular with a minimum diameter of 100mm.

5.2.5. Slopes:

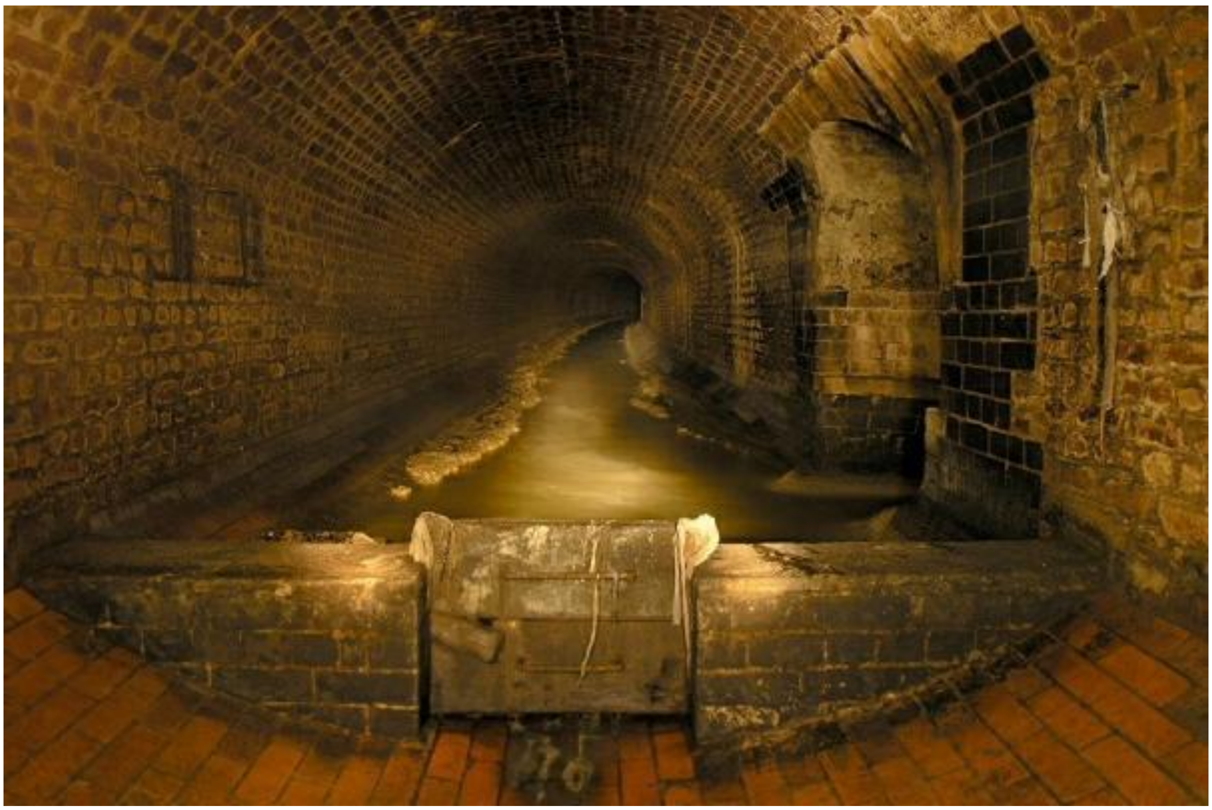
- Horizontal drainage piping of 75mm diameter and less is to be installed with a fall of not less than 20 mm per m.

- Horizontal drainage piping larger than 75 mm diameter need to be installed with a fall of not less than 10 mm per m.
- It is a good policy to design the system for the highest possible velocity. However, velocities in pipes with slopes greater than 20 mm per m may cause self-siphonage of trap seal.

5.2.6. Design Steps

1. Design “Two pipe drainage system”.
2. To estimate the total load weight (DFU) carried by a soil or waste pipe, the relative load weight for different kinds of fixtures use are provided.
3. Slope:
   Design the building drains and sewer to discharge the peak simultaneous load weight flowing half-full with a minimum self-cleansing velocity if 0.75m per second.
   However, flatter gradient may be used if required but the minimum velocity should not be less than 0.6m per second. Again, it is undesirable to employ gradients giving a velocity of flow greater than 2.5m per second.
4. The maximum number if fixture units that may be connected to a given size of building sewer, building drain, horizontal branch or vertical soil or waste stack shall be as provided. Using load factor unit as obtained in step-1, calculate size of horizontal branches or vertical soil or waste stack(s).
   In the same way determine soil/ waste stack diameter depending on total number of branches connecting to the part of the stack and number of story in the building.
5. Vents are normally sized by using the “Developed Length” (total linear footage of pipe making up the vent) method. Determine the size of vent piping from its length and the total of the fixture units connected.
6. Determine the branch vent size.

Chapter 6
Design of Wastewater Collection System
(Sanitary Sewer System)



Design of Wastewater Collection System

Conventional Sewerage System

6.1. Basic Functional Elements

(a) the house connections for collection of household or institutional wastewater,
(b) a network of sewer systems for collection and conveying the wastewater,
(c) a treatment plant for processing the wastewater, and
(d) the receiving environment (water or land) for disposal of the treated wastewater.

6.2. Types of Sewerage Collection Systems

There are three different sewage collection systems:

a. Separate Sewerage System: In this system sanitary sewage and storm waste are collected and conveyed separately through two different systems.

Suitable Conditions:

- In flat areas a separate system is economical as deep excavations are not required.
- Where rainfall is not uniform throughout the year a separate system is suitable.
- In areas near rivers or streams, only a sanitary system may be installed; storm water may be disposed of into rivers untreated, through open drains.
- Where pumping is required at short intervals.
- In rocky areas where large combined systems may be difficult to install.
- If sewers are to be laid before actual development of the area, a separate system is desirable.

b. Combined Sewerage System: In this system, both sanitary sewage and storm water are collected and carried together through a single set of sewers.

Suitable Conditions:

- Where rainfall is uniform throughout the year, a combined system is economical.
- Where pumping is required for both sanitary sewage and storm water.
- Where sufficient space is not available for two separate sets of sewer systems.

c. Partially Combined or Partially Separate System: Only one set of sewers is laid to carry sanitary sewage as well as storm water during low rainfall. During heavy rainfall excess storm water is carried separately e.g., through open drains to natural channels.

6.3. Types of Sanitary Sewers

- Building sewer: Conveys wastewater from buildings to lateral/branch sewers or any other sewer.
- Lateral/branch sewer: First element of wastewater collection system, usually in street. Collects wastewater from one/multiple building sewers and conveys it to main sewer.
- Main Sewer: Carries wastewater from lateral/branch sewers to Trunk sewers.
- Trunk sewer: Large sewers. Conveys wastewater to treatment or disposal facilities, or to large intercepting sewers.
- Intercepting sewer: collects wastewater from mains or trunk sewer and conveys to treatment or disposal facilities.

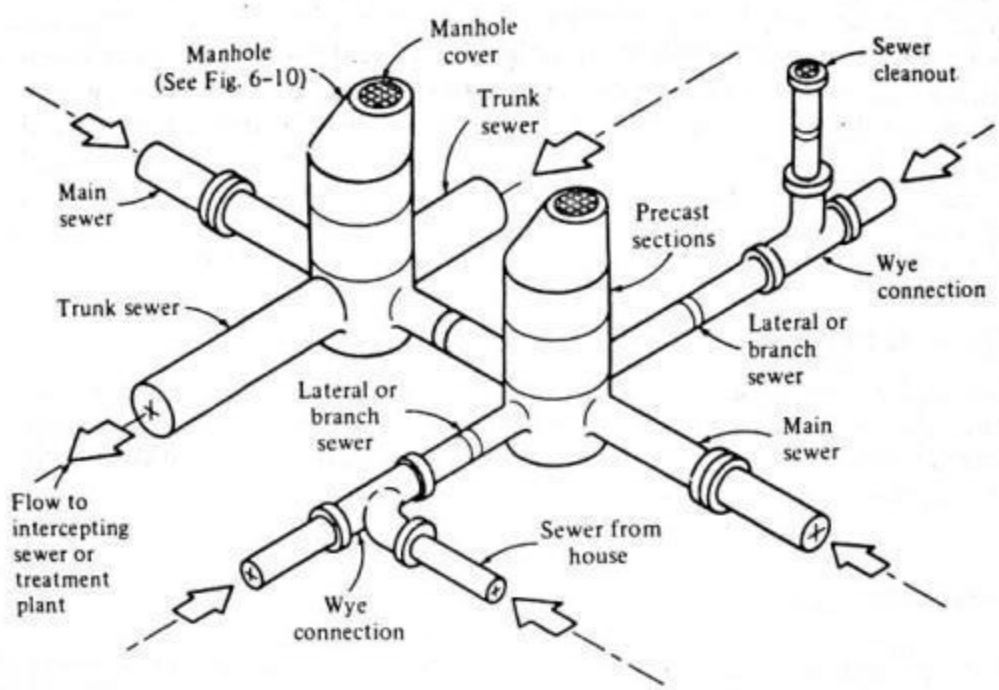


Figure 6.1: Definition sketch for types of sewers

6.4. Basic Design Consideration of Sanitary Sewer

Following factors must be considered:

i. Estimation of wastewater design flow rate.
ii. Selection of design parameters
    a. Hydraulic design equation
    b. Alternative sewer pipe materials
    c. Minimum sizes
    d. Minimum and maximum velocities.

iii. Selection of appropriate sewer appurtenances
iv. Evaluation of alternative alignments.
v. Evaluation of the use of curved sewers.

6.5. Determination of Design Flow Rates

Total wastewater flow in sanitary sewers is made up of three components:

1) Residential, commercial, and institutional wastewater,
2) Industrial wastewater,
3) Infiltration

6.6. Sanitary sewers are designed for:

- Peak flows from residential, commercial, institutional and industrial sources for the entire service area.
- Peak infiltration allowance for the entire service area.

6.7. Hydraulic design equation:

Most commonly used for design of sanitary sewers: Manning's equation –

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

Where, V = velocity, m/s

n = friction factor

R = hydraulic radius

$= \frac{Cross\ sectional\ area\ of\ the\ flow\ , m2}{Wetted\ perimeter, m}$

S = slope of energy grade line, m/m

- Recommended n value for new existing well-constructed sewers is 0.013.
- Recommended value for older sewers 0.015.

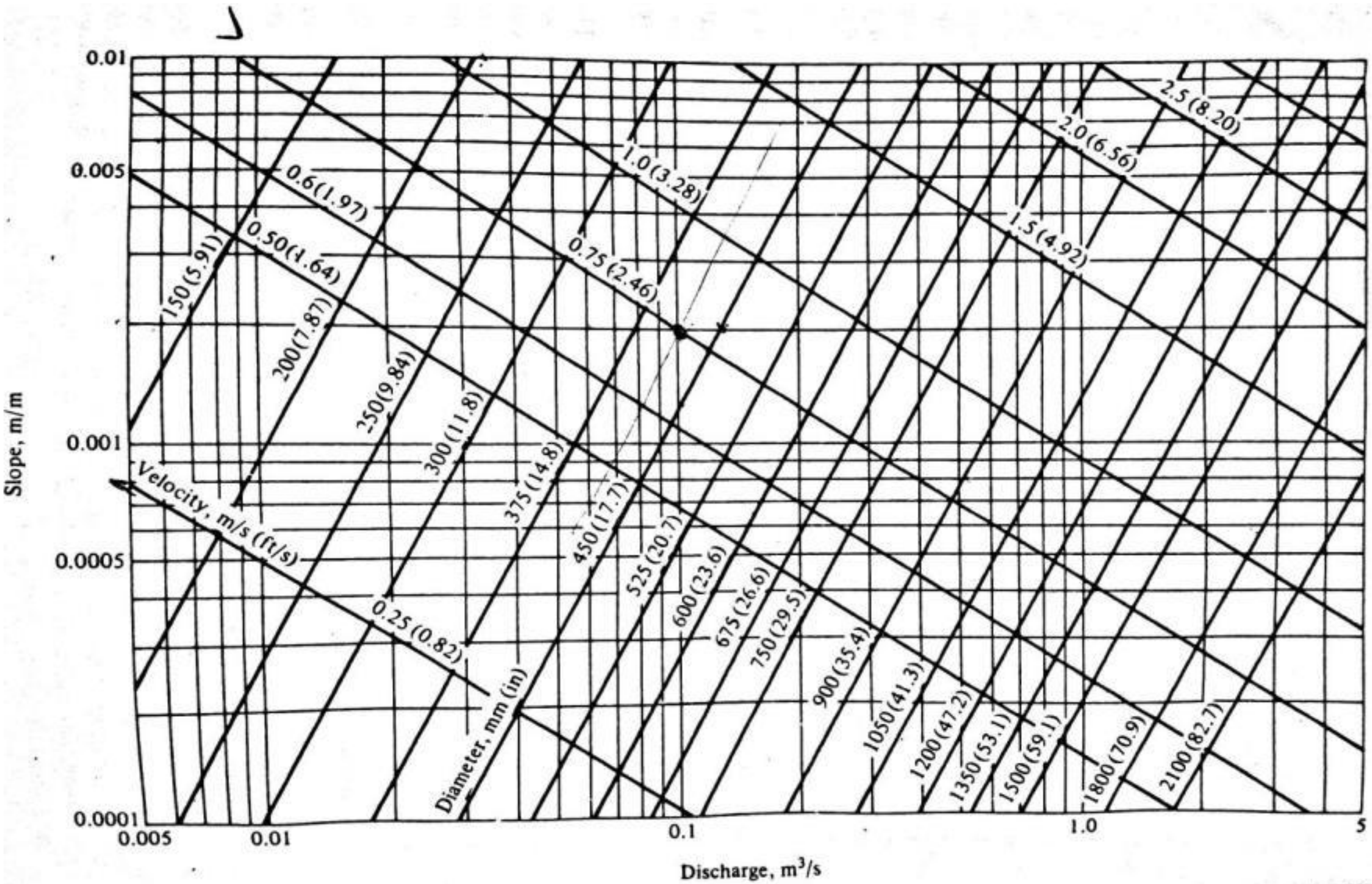


Figure 6.2: Graphical presentation of manning's equation for n = 0.013

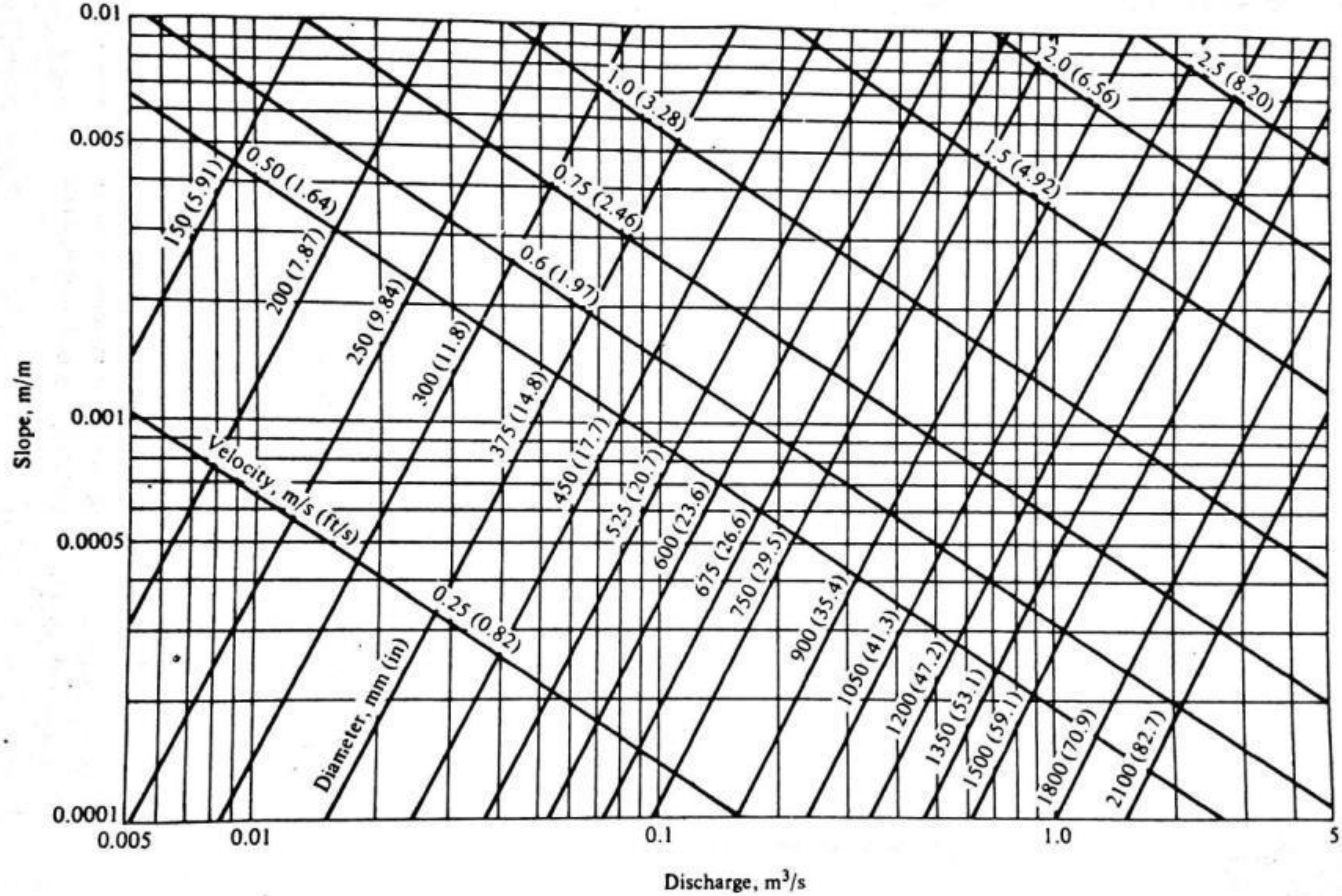


Figure 6.3: Graphical presentation of manning's equation for n = 0.015

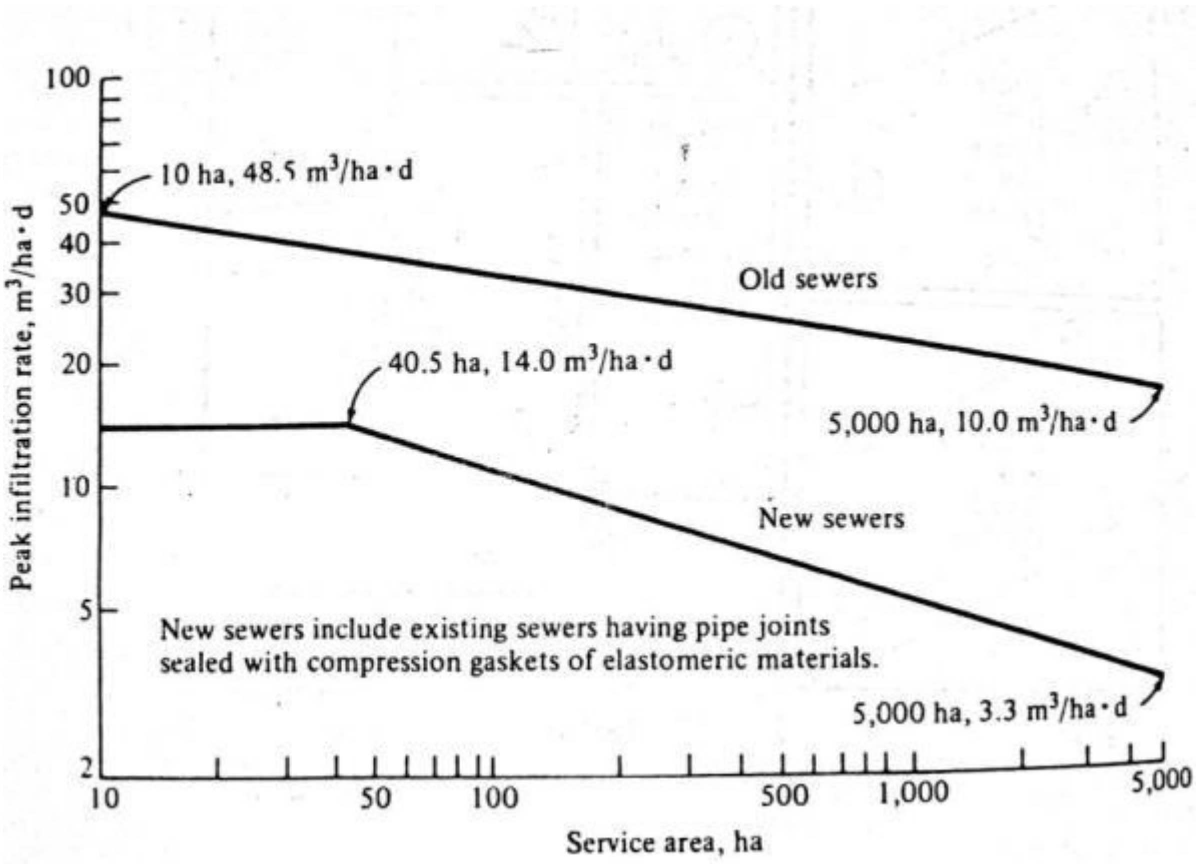


Figure 6.4: Peak infiltration rates for residential areas**.**

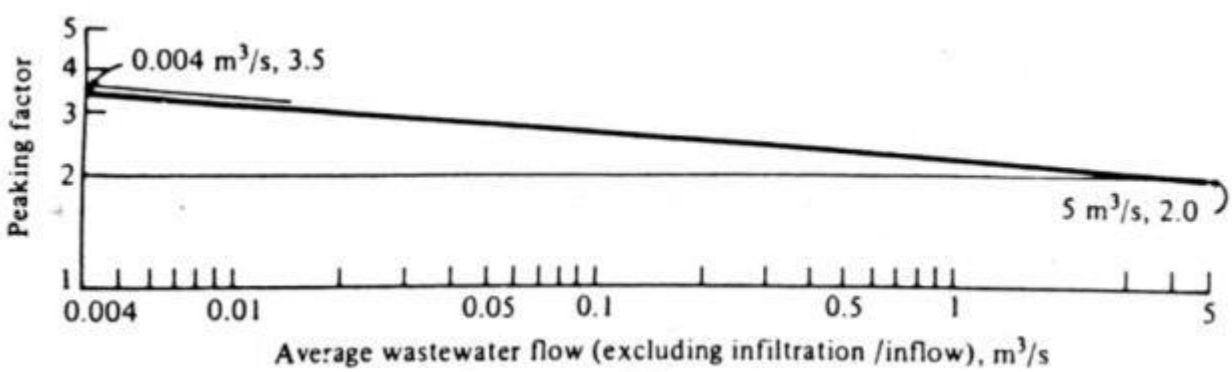


Figure 6.5: Peak factor for residential areas.

6.8. Sewer Pipe Materials and sizes

- **Asbestos Cement – (100 – 900 mm)** – Weighs less. Susceptible to acid corrosion and hydrogen sulfide attack.
- **Ductile iron – (100-1350 mm)** – Used where unusually high loads of water is passing leak-proofing is necessary. Also susceptible to acid corrosion and sulfide attacks. Should not be used in brackish waters.
- **Reinforced Concrete – (300-3600 mm)** – Most available. Susceptible to sulfide attacks.
- **Prestressed Concrete – (400-3600 mm)** – Especially suited for long transmission mains without building connections and where precautions against leakage is necessary. Susceptible to corrosion.
- **Polyvinyl chloride (PVC) – (100-375 mm)** – Plastic Pipe, Light weight but strong, highly resistant to corrosion.
- **Vitrified clay (VC) – (100-900mm)** – Widely used in the past for gravity sewers. Resistant to both acids and alkalis. Resistant to hydrogen sulfide. But brittle in nature and susceptible to breakage.

6.9. Sewer Appurtenances

Primary appurtenances for sanitary sewers:

- Manholes
- Drop inlets to manholes.
- Building connections
- Junction chambers

6.10. Manholes must be placed depending on the following criteria.

- Changes in direction
- Changes in slope
- Pipe junction
- Upper ends of sewers
- Intervals from 90m to 120m.

6.11. Limiting Conditions for Design of Sanitary Sewer

6.11.1 Minimum and Maximum velocities

- If velocity is too low, undissolved solids in the wastewater tend to settle down. Eventually accumulates into large enough quantity to block the flow.
- Based on past experience, sanitary sewers are recommended to be designed with a slope such that minimum flow velocity of 0.75 m/s (2.5ft/s) is maintained when the sewer is flowing full or half full.
- To avoid damage of sewers, velocity should be limited to 3.0m/s (10 ft/s).

6.11.2 Minimum Slopes

- Often used to avoid extensive excavation where the slope of the ground surface is flat.
- Minimum slopes based on manning's equation have proved to be adequate for small-diameter sewers.
- As pipe size increases beyond 600 mm, the minimum practical slope for construction is about 0.0008 m/m.

5.12. Design of Sanitary Sewers

Design involves –

- Fieldwork
- Preparation of maps and profiles
- Detailed design computations.

5.13. Design computations for Sanitary Sewers

- **Example: Designing a gravity-flow sanitary sewer -**Design a gravity-flow trunk sanitary sewer for the area shown in the following figure, The trunk sewer is laid along Peach Avenue starting at 4^{th} Street and ending at 11^{th} Street.

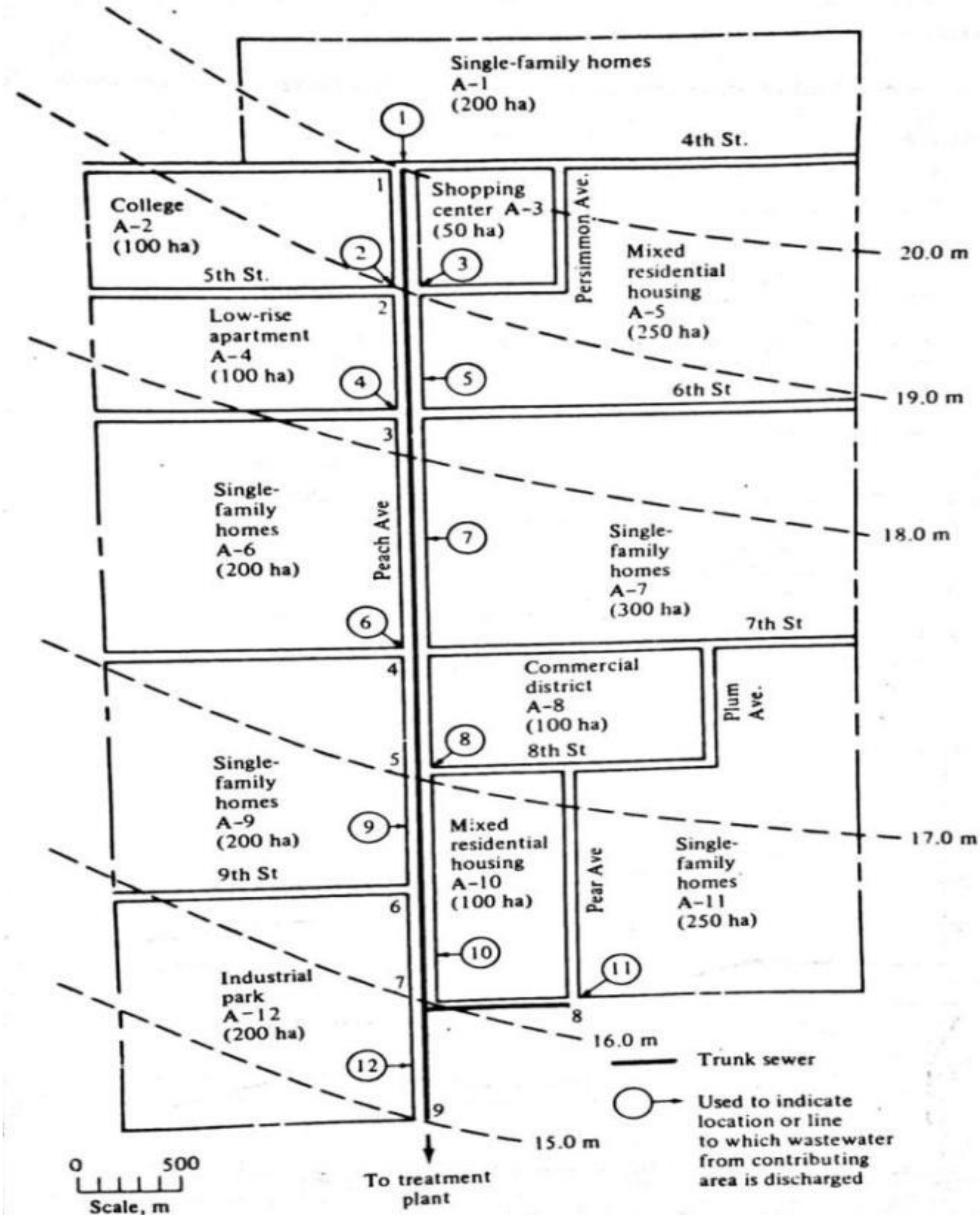


Figure 6.6: Contour Map and sewer network of trunk sewer within the contributing area Peak factor for residential areas

Solution:

6.14. Calculation

The sewers will be designed for flows from one manhole to another.

- The calculation will be done in tabulated form.
- Wastewater average flow will be determined as a specific percentage of water demand in that zone as was calculated previously as given below. For,

- Residential: 40%
- Commercial/ Institutional – 55%
- Industrial – 90%

- Wastewater flow at a particular manhole will be determined, and sewer from that manhole to the next manhole in line will be designed for cumulative flows from upper manholes + wastewater flow to that section of the sewer.
- Average wastewater flow will be a multiplied by peak factor to determine the peak flow. Peak factor for Industrial, Institutional, and commercial wastewater flow is given as a constant. Peak factor for residential must be determined from the graph provided.

6.15. Sample calculation: Between manhole 3 to 4 –

– Wastewater is flowing from two subareas: A4 & A7.
  - As calculated in table, wastewater flow from A4 is 2640 cubic meter per day, and A7 is 4560 m^3/d.
  - Cumulative wastewater flow up to manhole 3 was m^3/d.
  - So, Cumulative wastewater flow for sewer section from manhole 3 to 4 is
  = 7415+2640+4560 = 14615 m^3/d.

– Cumulative average flow is converted to m3 /s. Then peak factor is determined from the graph provided; in this case, peak factor = 2.6.

– So, Cumulative peak flow = 2.6 x 14615

- Peak infiltration is determined from the graph provided depending upon the subarea magnitude. For, residential area 100% of the area is considered as effective area, whereas for commercial, industrial and institutional areas, 50% of actual area is considered effective area.
- There are two graphs for determining infiltration. One is to be used for analyzing older sewers and the other for designing newer sewers. For this problem, we will be using the graph provided for new sewer.
  = 37,999 m^3/d

– Tabulated Calculations are done in a similar fashion for industrial, institutional and commercial flows.

– After all four sub-calculations, a cumulative subtotal is determined.

- Section between manhole 3 and 4 has to account for infiltration from subarea A4 and A7. Both are residential areas. Therefore 100% of the area will be considered as effective area. Cumulative area is determined. Peak infiltration allowance is determined for area from the graph provided. For section 3 to 4, this would consist of area under subarea A4 and A7. Cumulative subarea here is: 925ha.
- Cumulative area is multiplied by the peak infiltration allowance for that area to determine cumulative infiltration allowance.

6.16. For section from manhole 3 to 4:

= 925 x 5.5 = 508 m^3/d.

- Cumulative peak flow is determined by adding Cumulative subtotal flow with peak infiltration allowance.

  = 5088 + 41399 =46487 m^3/d.
- Now sewer is designed for this flow rate. From cumulative flow rate in m^3/d, we would determine the flow at m^3/s. Now the discharge is known, and we know minimum velocity of 0.75 m/s must be maintained. Using this, from Nomograph, n = 0.013 :
  - Peak flow = 0.538 m3/s;
  - Draw a line vertically upward from the discharge. For section from manhole 1 to 2, we would try to maintain a minimum velocity of 0.75 m/s. So, discharge line would be intersected with velocity 0.75 m/s line on the nomograph and the slope and pipe diameter for that intersection point would be determined. For later section between manhole 3 and 4, the slope will be kept constant from previous slopes if possible.
  - Therefore, from previous section: slope = 0.0009 and discharge 0.538 m3/s. From intersection in nomograph, we get velocity of approximately 0.85m/s and Pipe diameter between 900mm and 1050mm. Pipe diameter will be rounded down to 900mm.
  - The other sections will be designed likewise.
  - If the ground in NOT horizontal, as is the case in the question: then ground surface elevation at the beginning and end of every section would be determined from the given data in the map. For section from manhole 3 to 4, the elevation of upper end and lower end is 18.33m and 17.40m respectively.
  - Now the sewer pipe invert elevation must be determined, considering 2.0m cover from G.L.
  - For next section, upper end invert could have been placed at the lower end invert of previous section. But this is not possible since the pipe diameter changed in the new section.
  - In that case, pipe in the new section must be placed such that pipe crown elevation at upper end of new section must be placed at previous section lower end pipe crown elevation.

- Pipe invert elevation at upper end for section from manhole 1 to 2.
  = G.L. – 2.0m – Pipe thickness – Pipe diameter
  = 20.0 – 2.0m – 0.05m – 0.45m
  = 17.5m

6.17. Pipe invert at lower end of section:

= elevation at upper end – (slope x length of section)
= 17.5m – (0.0018 x 707) m
= 16.23m

- For section MH 2 to 3: since pipe diameter changed – Pipe crown of lower end of section MH 1 to 2 must be determined.
  = 16.23+0.45
  = 16.68
- So, Pipe crown in new section must be placed at 16.68m elevation.
- Now, determining the new pipe invert elevation
  = Pipe crown elevation - Pipe diameter
  = 16.68m - 0.75m
  = 15.93
- Then, Lower end pipe invert for that section comes at,
  = Pipe invert elevation at upper end – Pipe decline due to slope
  = 15.93m – (707m x 0.0009m/m)
  = 15.29m
- The rest of the pipe sections' upper and lower invert elevation must be determined likewise.

Table 6.1: Sewer Computation Table

Sewer computation table

Location					Residential flows							
Line	From	To	Length of sewer, m	Subarea*	Area, ha	Population density, persons/ha	Population increment, persons	Average unit flow, L/capita · d	Flow increment, m^3/d	Cumulative average flow, m^3/d	Peaking factor	Cumulative peak flow, m^3/d (11 × 12)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1	1	2	707	A-1	200	40	8,000	380	3040	3,040	2.9	8,816
2	2	3	707	A-2	—	—	—	—	—	3,040	2.9	8,816
				A-3	—	—	—	—	—	3,040	2.9	8,816
				A-5	250	70	17,500	250	4375	7,415	2.7	20,021
3	3	4	1414	A-4	100	120	12,000	220	2640	10,055	2.6	26,143
				A-7	300	40	12,000	380	4560	14,615	2.6	37,999
4	4	5	707	A-6	200	40	8,000	380	3040	17,655	2.5	44,138
5	5	6	707	A-8	—	—	—	—	—	17,655	2.5	44,138
				A-9	200	40	8,000	380	3040	20,695	2.5	51,738
6	6	7	707	A-10	100	70	7,000	250	1750	22,445	2.5	56,113
7	8	7	707	A-11	250	40	10,000	380	3800	3,800†	2.9	11,020
8	7	9	707	707	A-12					26,245	2.5	65,613

Table 6.2: Sewer Computation Table (continue)

Sewer computation table (*Continued*)

Location					Commercial flows					Industrial flows				
Line	From	To	Length of sewer, m	Subarea*	Area, ha	Average unit flow, m³/ha · d	Cumulative average flow, m³/d	Peaking factor	Cumulative peak flow, m³/d (16 × 17)	Area, ha	Average unit flow, m³/ha · d	Cumulative average flow, m³/d	Peaking factor	Cumulative peak flow, m³/d (21 × 22)
(1)	(2)	(3)	(4)	(5)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
1	1	2	707	A-1	—	—	—	—	—	—	—	—	—	—
2	2	3	707	A-2	—	—	—	—	—	—	—	—	—	—
				A-3	50	20	1000	1.8	1800	—	—	—	—	—
				A-5	—	—	1000	1.0	1800	—	—	—	—	—
3	3	4	1414	A-4	—	—	1000	1.8	1800	—	—	—	—	—
				A-7	—	—	1000	1.8	1800	—	—	—	—	—
4	4	5	707	A-6	—	—	1000	1.8	1800	—	—	—	—	—
5	5	6	707	A-8	100	20	3000	1.8	5400	—	—	—	—	—
				A-9	—	—	3000	1.8	5400	—	—	—	—	—
6	6	7	707	A-10	—	—	3000	1.8	5400	—	—	—	—	—
7	8	7	707	A-11	—	—	—	—	—	—	—	—	—	—
8	7	9	707	A-12	—	—	3000	1.8	5400	200	30	6000	2.1	12,600

Table 6.3: Sewer Computation Table (continue)

Sewer computation table (*Continued*)

Location					Institutional flows			Cumulative subtotals		Infiltration			
Line	From	To	Length of sewer, m	Subarea*	Cumulative average flow, m^3/d	Peaking factor	Cumulative peak flow, m^3/d (24 × 25)	Cumulative average flow, m^3/d (11 + 16 + 21 + 24)	Cumulative peak flow, m^3/d (13 + 18 + 23 + 26)	Area, ha	Cumulative area, ha	Peak unit infiltration allowance $m^3/ha \cdot d$	Cumulative infiltration allowance, m^3/d (30 × 31)
(1)	(2)	(3)	(4)	(5)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)
1	1	2	707	A-1	—	—	—	3,040	8,816	200‡	200	8.0	1600
2	2	3	707	A-2	400	4.0	1600	3,440	10,416	50†	250	7.5	1875
				A-3	400	4.0	1600	4,440	12,216	25‡	275	7.5	2063
				A-5	400	4.0	1600	8,815	23,421	250	525	7.0	3675
3	3	4	1414	A-4	400	4.0	1600	11,455	29,543	100	625	6.5	4063
				A-7	400	4.0	1600	16,015	41,399	300	925	5.5	5088
4	4	5	707	A-6	400	4.0	1600	19,055	47,538	200	1125	5.0	5625
5	5	6	707	A-8	400	4.0	1600	21,055	51,138	50‡	1175	5.0	5875
				A-9	400	4.0	1600	24,095	58,738	200	1375	4.9	6738
6	6	7	707	A-10	400	4.0	1600	25,845	63,113	100	1475†	4.8	7080
7	8	7	707	A-11	—	—	—	3,800	11,020	250	250†	8.0	2000
8	7	9	707	A-12	400	4.0	1600	35,645	85,213	100‡	1825	4.0	7300

Table 6.4: Sewer Computation Table (continue)

Sewer computation table (*Continued*)

Location					Institutional flows			Cumulative subtotals		Infiltration			
Line	From	To	Length of sewer, m	Subarea*	Cumulative average flow, m³/d	Peaking factor	Cumulative peak flow, m³/d (24 × 25)	Cumulative average flow, m³/d (11 + 16 + 21 + 24)	Cumulative peak flow, m³/d (13 + 18 + 23 + 26)	Area, ha	Cumulative area, ha	Peak unit infiltration allowance m³/ha · d	Cumulative infiltration allowance, m³/d (30 × 31)
(1)	(2)	(3)	(4)	(5)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)
1	1	2	707	A-1	—	—	—	3,040	8,816	200‡	200	8.0	1600
2	2	3	707	A-2	400	4.0	1600	3,440	10,416	50†	250	7.5	1875
				A-3	400	4.0	1600	4,440	12,216	25‡	275	7.5	2063
				A-5	400	4.0	1600	8,815	23,421	250	525	7.0	3675
3	3	4	1414	A-4	400	4.0	1600	11,455	29,543	100	625	6.5	4063
				A-7	400	4.0	1600	16,015	41,399	300	925	5.5	5088
4	4	5	707	A-6	400	4.0	1600	19,055	47,538	200	1125	5.0	5625
5	5	6	707	A-8	400	4.0	1600	21,055	51,138	50‡	1175	5.0	5875
				A-9	400	4.0	1600	24,095	58,738	200	1375	4.9	6738
6	6	7	707	A-10	400	4.0	1600	25,845	63,113	100	1475†	4.8	7080
7	8	7	707	A-11	—	—	—	3,800	11,020	250	250†	8.0	2000
8	7	9	707	A-12	400	4.0	1600	35,645	85,213	100‡	1825	4.0	7300

Table 6.5: Sewer Computation Table (continue)

Sewer computation table (*Continued*)

Location					Design flows		Sewer design				Sewer layout			
											Ground surface elevation		Sewer pipe invert elevation	
Line	From	To	Length of sewer, m	Subarea*	Cumulative peak flow, m^3/d (28 + 32)	Cumulative peak flow,§ m^3/s	Sewer diameter, mm	Slope, m/m	Capacity when full, m^3/s	Velocity when full, m/s	At upper manhole	At lower manhole	Upper end	Lower end
(1)	(2)	(3)	(4)	(5)	(33)	(34)	(35)	(36)	(37)	(38)	(39)	(40)	(41)	(42)
1	1	2	707	A-1	10,416	0.121	450	0.0018	0.121	0.75	20.00	19.00	17.50	16.23
2	2	3	707	A-2	12,291	0.142	—	—	—	—	—	—	—	—
				A-3	14,279	0.165	—	—	—	—	—	—	—	—
				A-5	27,096	0.314	750	0.0009	0.330	0.75	19.00	18.33	15.93	15.29
3	3	4	1414	A-4	33,606	0.389	—	—	—	—	—	—	—	—
				A-7	46,487	0.538	900	0.0009	0.540	0.85	18.33	17.40	15.14	13.86
4	4	5	707	A-6	53,163	0.615	1050	0.0008¶	0.770	0.87	17.40	17.00	13.71	13.14
5	5	6	707	A-8	57,013	0.660	—	—	—	—	—	—	—	—
				A-9	65,476	0.758	1050	0.0008¶	0.770	0.87	17.00	16.50	13.14	12.58
6	6	7	707	A-10	70,193	0.812	1050	0.0009	0.820	0.95	16.50	16.00	12.58	11.94
7	8	7	707	A-11	13,020	0.151	525	0.0014	0.165	0.75	16.20	16.00	12.46	13.46
8	7	9	707	A-12	92,513	1.071	1200	0.0008¶	1.100	0.98	16.00	15.00	11.79	11.22

* See figure (*a*).
† Line 7 receives flow from subarea A-11 only.
‡ 50 percent of area (see assumption *6b*).
§ $m^3/s = (m^3/d)/(86{,}400\ s/d)$.
¶ The minimum practical slope for construction is about 0.0008 m/m.

APPENDIX

Table 1: MIT classification of soil

MIT Classification	
Silt/Clay	< 0.06 mm
Fine Sand	0.06 – 0.20 mm
Medium Sand	0.20 – 0.60 mm
Course Sand	0.60 – 2.00 mm
Fine Gravel	> 2.00 mm

Table 2: Limitation of strainer length

Aquifer Thickness	Recommended Screening
< 25'	70% Screening
25' – 50'	75% Screening
> 50'	80% Screening

Zoning	Type of development	Saturation population density, person/ha	Wastewater flow, L/capita · d
Residential	Single-family dwellings	40	380
Residential	Duplexes	60	300
Residential	Low-rise apartments	120	220
Residential	Mixed housing	70	250

For residential wastewater flows use the data given in the table.

For commercial and industrial flows (average):

a. Commercial—20 $m^3/ha \cdot d$.

b. Industrial—30 $m^3/ha \cdot d$.

For institutional flows (average):

College—400 m^3/d (5330 students × 75 L/student · d)/(1000 L/m^3)

For infiltration allowance:

a. For residential areas, obtain the peak infiltration values from the accompanying figure (*b*).

Peaking factors:

a. Residential—use the curve given in the accompanying figure (*c*).

b. Commercial—1.8

c. Industrial—2.1

d. Institutional (school)—4.0