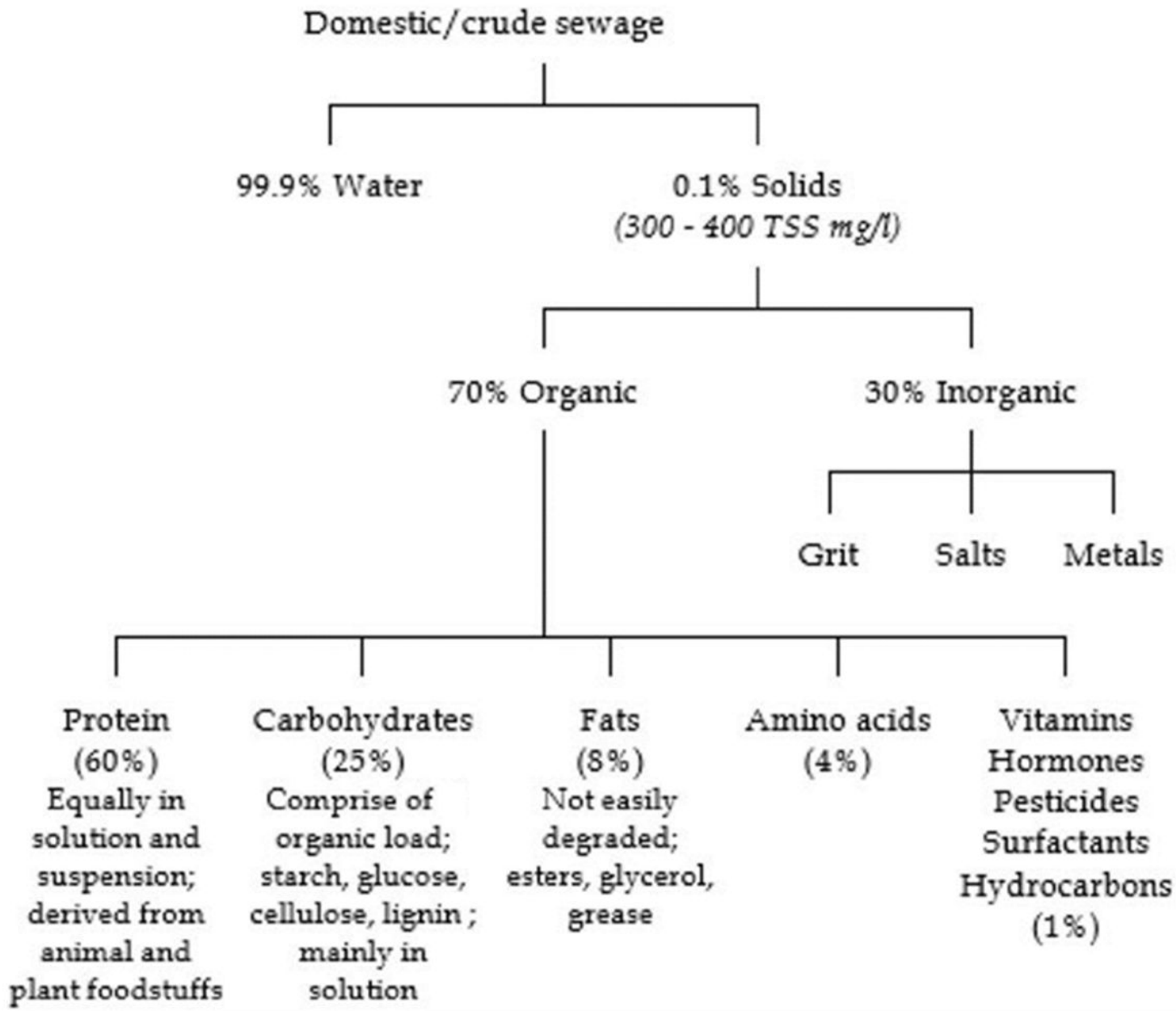
Characteristics of Wastewater

Sewage or Waste water Characteristics

- Wastewater consists of human excreta, waste from domestic processes, trade effluent from industrial processes, infiltration and washing from streets and roofs in raining times. It include every thing else that find its way from consumer's house to sewer.
- Domestic sewage having almost uniform quality, but quantity will be different. Industrial effluents having different quality as well as quantity. Domestic Wastewater characteristics are usually as.
- organic part of sewage carbohydrates (25-50 %) Proteins (40 - 60%) and oil and fats (10%) are present. Inorganic part of sewage salt, grit and metals are present in various composition.

The composition of domestic sewage



Sewage characteristics can be divided into three broad categories:

(1) Physical (Temperature, colour, smell, Solids)

(2) Chemical (BOD, COD, Nutrients and Dissolved solids)

(3) Bacteriological

Physical Characteristics of wastewater

The physical characteristics are its total solids content, odor, temperature, density, color and turbidity.

Fresh sewage is usually gray, light brown, yellowish and having no unpleasant odor.

Foul and unpleasant odor may develop as a result of septic or stale condition.

Its color changes to black or dark brown when sewage becomes stale.

Its odor changes within 2-4 hours due to exhaustion of oxygen and presence of H_2S gas in sewage.

Temperature affect chemical reaction and biological activities.

Solids like total suspended solids (TSS), volatile suspended solids (VSS) and settleable solids affect the operation and sizing of treatment units.

Physical characteristics- Odor

Odor is produced by gas production due to the decomposition of organic matter or by substances added to the wastewater.

Detection of odor: Odor is measured by special instruments such as the Portable H_2S meter which is used for measuring the concentration of hydrogen sulfide.

Compound	Chemical Formula	Odor quality
Amines	CH_3NH_2, $(CH_3)_3H$	Fishy
Ammonia	NH_3	Ammoniacal
Diamines	$NH_2(CH_2)_4NH_2$, $(CH_2)_5NH_2H_{25}$	Rotten eggs
Mercaptans (E. g, methy1 and ethy1)	CH_3SH, $CH_3(CH_2)SH$	Decayed cabbage
Skatole		Fecal matter
Organic sulfides		Rotten cabbage

Physical characteristics- Temperature

Temperature of wastewater is commonly higher than that of water supply. Depending on the geographic location the mean annual temperature varies in the range of 10 to 21°C with an average of 16 °C.

Importance of temperature:-

Affects chemical reactions during the wastewater treatment process.

Affects aquatic life (Fish, ……).

Oxygen solubility is less in worm water than cold water.

Optimum temperature for bacterial activity is in the range of 25°C to 35°C.

Aerobic digestion and nitrification stop when the temperature rises to 50°C.

When the temperature drops to about 15°C, methane producing bacteria become in active.

Nitrifying bacteria stop activity at about 5°C

Density:-

Almost the same density of water when the wastewater doesn't include significant amount of industrial waste.

Color:-

Fresh waste water ⟶ light brownish gray.
With time ⟶ dark gray
More time ⟶ black (septic).

Some times pink due to algae or due to industrial colors.

Turbidity:-

It's a measure of the light – transmitting properties of water.

Chemical Characteristics

In sanitary sewage about 75 % of suspended solids and 40% of filterable solids are organic.

Organic compounds are usually consists of C; H; O; N along with S; P and Iron.

The organic substances found in sewage are Protein (40- 60%);

Carbohydrates (25-50%) and 10% as fats and oils.

small amount of synthetic organic compounds like VOCs, Pesticides, insecticides and Organic Pollutants

Sewage also contain inorganic substances.

Chemical Characteristics

BOD (Biochemical Oxygen Demand): When biodegradable Organic Matters is released into a water body, microorganisms feed on the wastes, breaking them into simpler organic and inorganic substances. When this decomposition occurs in ***aerobic environment*** the process produces non-objectionable, stable end products like CO_2, SO_4, PO_4 and NO_3. A simplified form of Aerobic decomposition is

$$OM + O_2 + \text{Microorganisms} \rightarrow CO_2 + H_2O + C_5H_7NO_2 \text{ (New Cells)} + \text{stable Products like } NO_3; PO_4; NO_3\ldots.$$

When insufficient O_2 is available ***Anaerobic decomposition*** occurs by different microorganisms. They produce end products that can be highly objectionable, including H_2S; NH_3 and CH_4 .

The reaction is $OM + \text{Microorganisms} \rightarrow CO_2 + H_2O + C_5H_7NO_2$ (New Cells) + Unstable Products (NH_3; H_2S; CH_4….). CH_4 is a stable gas, while other products are usually unstable.

Bacteria placed in contact with organic matter will utilize it as food source.

Biochemical Oxygen Demand (BOD)

The amount of oxygen required by the bacteria to oxidize the organic matter present in sewage to stable end products is known as biochemical oxygen demand.

Significance: -

Used in design of waste water treatment plants.

DERIVATION OF BOD EQUATION

Biological oxidation of organic matter by bacteria is considered to be a first order reaction for all practical purposes. In a first order reaction, the rate of reaction is proportional to the concentration of the reactant present. So, we can say that in case of biological oxidation of organic matter by bacteria, the rate of oxidation is proportional to the organic matter REMAINING.

BOD EQUATION

Let L_t = the amount of BOD remaining or the organic matter

remaining at any time t

L_0 = the initial concentration of Organic matter or BOD remaining at

time =0 also known as ultimate BOD

Mathematically dL/dt α -L (the negative sign show that L is decreasing) or dL/dt = -kL where K is reaction rate constant. It depends on a number of factors like nature of waste, ability of microbes to decompose waste and temperature.

Or dL /L = -K′dt

Taking integration, the equation is

$\int_{L0}^{Lt} dL/L = -k \int_{-0}^{t} t$ =ln L_t – ln L_o= -Kt or ln L_t/L_o = -Kt

$L_t/L_o = e^{-Kt}$ or $L_t = L_o e^{-Kt}$

BOD EQUATION

Let 'y' be the concentration of organic matter (BOD) consumed up to time 't'

$y = L_o - L_t$

$y = L_o - L_o e^{-Kt} \Rightarrow y = L_o (1 - e^{-Kt})$

i.e BOD consumed = ultimate BOD $(1 - e^{-Kt})$ in 't' days

Typical value of K = 0.23 per day for domestic sewage at 20°C. Value of 'K' is temperature dependent. $K_T = K_{20} (\theta)^{T-20}$ where $\theta = 1.047$

$K_T = K_{20} (1.047)^{T-20}$

K_T = Value of K at temperature T in ^0C

Limitation in BOD test:

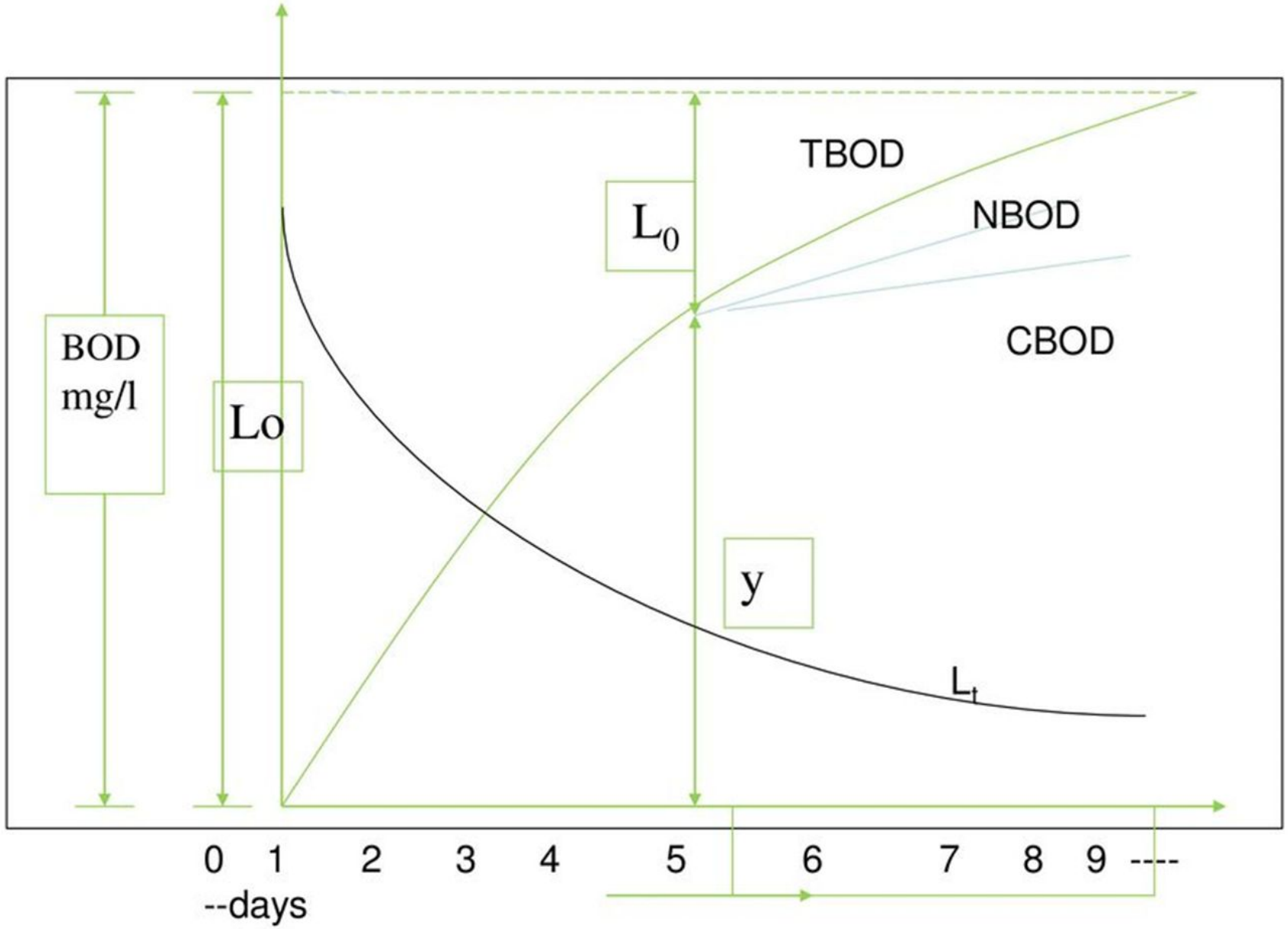
i. A high concentration of active microorganisms required

ii. Pre-treatment is required if toxic materials are present in wastewater

iii. Only biodegradable organics are measured

iv. Long time is required to calculate BOD

BOD Sketch



Example

Determine the 1-day BOD and ultimate BOD for a wastewater whose 5-day 20 °C BOD is 200 mg/L. The reaction constant K= 0.23d^{-1} what would have been the 5-day BOD if it had been conducted at 25°C?

Solution:-

- $BOD_t = UBOD - BODr = UBOD\ (1-e^{-kt}) = L_0(1-e^{-kt})$

$200 = L_0\ (1-e^{-0.23x5})$

$L_0 = 293$ mg/L (this is UBOD)

- Determine the 1-day BOD:-

$BOD_t = L_0\ (1-e^{-kt})$

$BOD_1 = 293\ (1-e^{-0.23x1}) = 60.1$ mg/L

- Determine the 5-day BOD at 25°C:-

$K_T = K_{20}\ (1.047)^{T-20} \Rightarrow K_{25} = 0.23\ (1.047)^{25-20}$

$BOD_5 = L_0\ (1-e\ -kt\ ) = 293\ (1-e^{-0.29x5}) = 224$ mg/L

BOD for Nitrogenous OM

- As Carbonaceous BOD is easily decomposed into various compounds, the Nitrogen which is a critical element for protein synthesis is bound up in complex organic molecules is released as ammonia nitrogen. Similarly the living organisms when died, nitrogen is converted into ammonia. The oxidation of ammonia required oxygen. Also it is an important nutrient for algal growth.
- Increased nitrogen control utilizes aerobic bacteria to convert ammonia(NH_3) to Nitrite (NO_2^-). This type of bacteria is known as Nitrosomonas.

  The Nitrate bacteria (Nitrobactor) convert nitrite to Nitrate ((NO_3^-).

  This process is termed as nitrification.

BOD for Nitrogenous OM

The Nitrogenous Oxygen demand consists of two steps.

$NH_3 + 3\ O_2$ Nitrosomonas $\rightarrow 2\ NO_2^- + 2H^+ + 2H_2O$

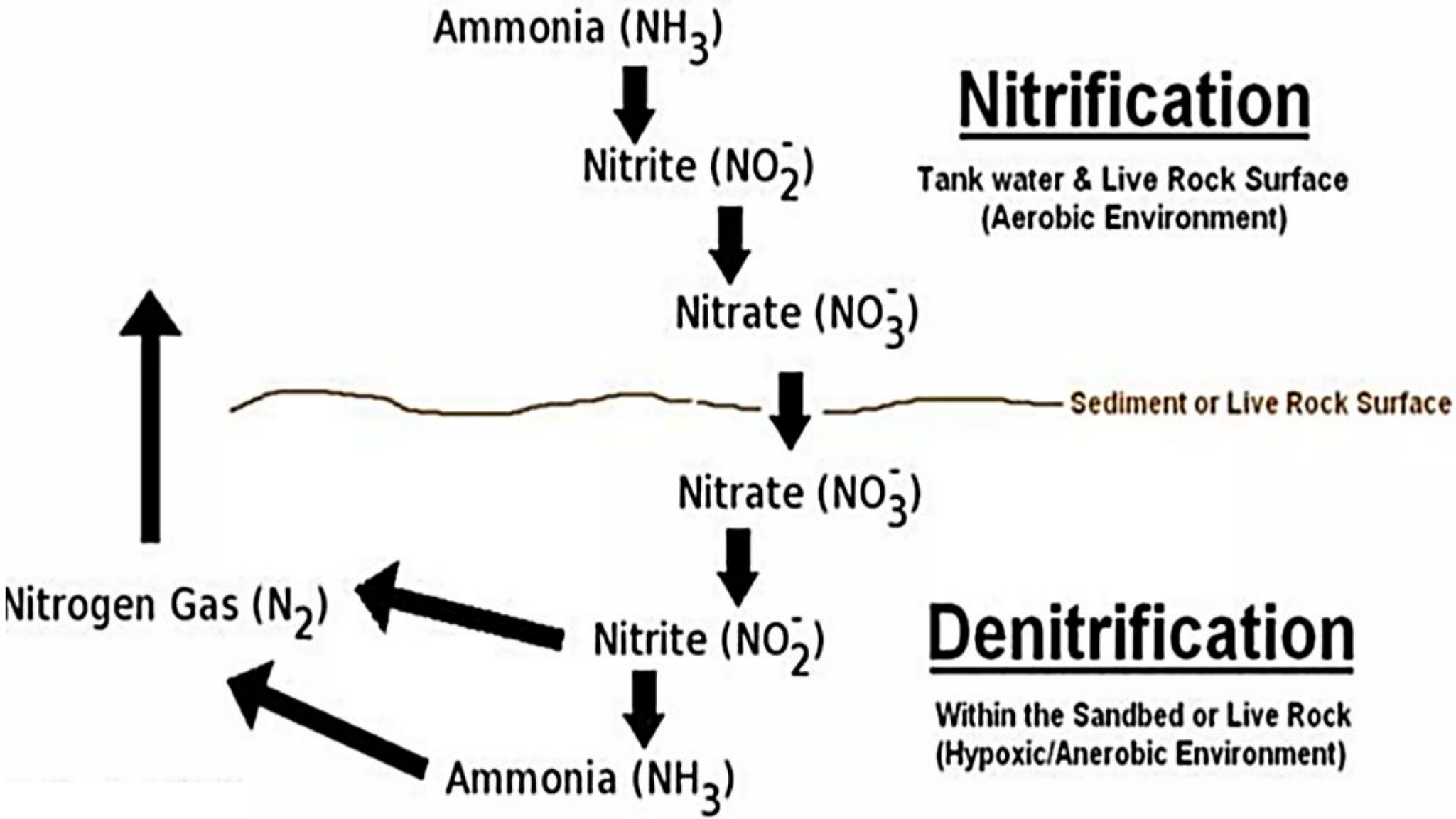
$2\ NO_2^- + O_2 \rightarrow$ Nitrobactor $2\ NO_3^-$

The overall reaction is $NH_3 + 2O_2 \rightarrow NO_3^- + H^+ + H_2O$

As Oxygen is consumed in this reaction. This type of oxygen demand is termed as Nitrogenous Oxygen Demand.

The total concentration of Organic and ammonia nitrogen in sewage is known as Kjeldahl Nitrogen (TKN).

Theoretical NBOD = grams of Oxygen used / Grams of Nitrogen Oxidized =(4*16)/ 14 = 4.57 gram of O_2/ gram of Nitrogen.


Ammonia (NH_3)
Nitrite (NO_2^-)
Nitrate (NO_3^-)
Sediment or Live Rock Surface
Nitrate (NO_3^-)
Nitrogen Gas (N_2)
Nitrite (NO_2^-)
Ammonia (NH_3)
Nitrification
Tank water & Live Rock Surface
(Aerobic Environment)
Denitrification
Within the Sandbed or Live Rock
(Hypoxic/Anerobic Environment)

Chemical Oxygen demand (COD)

Chemical Oxygen Demand (COD): The biodegradable organic matters are degraded completely by microorganisms either of CBOD or NBOD. There are some organic matters like cellulose, phenols, benzene and tannic acid which resists to biodegradation. Similarly other organic matters like pesticides, insecticides and various industrial chemicals are non biodegradable and they are toxic to microorganisms. The COD is a measured quantity that does not depend on microorganisms. To calculate the concentration of oxygen for non biodegradable materials a strong oxidizing agent known as potassium dichromate will be used. The reaction is Organic matter ($C_aH_bO_c$) +$Cr_2O_7^{-2}$+ H2O -→Cr^{+3} + CO_2 + H_2O

COD and TheoD

- The COD test is much quicker than BOD test, but it does not distinguish between the biodegradable and non biodegradable organic matter. The measured COD is usually more than BOD if there is non biodegradable impurity present. If all are the biodegradable organic matter then COD remains the same as that of BOD. Roughly the BOD/COD is 0.4 to 0.8.
- **Theoretical Oxygen Demand (TheoD)**: Organic matter of animal or vegetable origin in wastewater is generally a combination of carbon, hydrogen, oxygen, nitrogen and other elements. If the chemical composition of an organic matter is known then the amount of oxygen required to oxidize it to carbon dioxide and water can be calculated using stoichiometry. This amount of oxygen is known as Theoretical Oxygen Demand. If that oxidation is carried out by bacteria then it is BOD, if by chemical process then it is COD. If a combination of both then it is TheoD

Theoretical Oxygen demand (ThOD): Example

Calculate the Theoretical Oxygen Demand (ThOD) for sugar $C_{12}H_{22}O_{11}$ dissolved in water to a concentration of 100 mg/L. Calculate "TOC".

Solution:-

$$C_{12}H_{22}O_{11} + 12O_2 \rightarrow 12\,CO_2 + 11\,H_2O$$

$$\text{ThOD} = \frac{12 \times 32 g O_2}{342 g_{sugar}} = 1.123 g O_2 / g_{sugar}$$

$$\text{ThOD} = \frac{100 mg_{sugar}}{L} * \frac{1.123 g O_2}{g_{sugar}} * \frac{10^3 mg O_2}{1 g O_2} * \frac{1 g_{sugar}}{10^3 mg_{sugar}}$$

ThOD = 112.3 mg O_2 / L

TOC = 144 g carbon/ 342g sugar = 0.42 gc/ gs

TOC = 0.42 x 100 = 42 mg carbon/L

Chemical Oxygen demand (COD) and Total Organic carbon (TOC)

Example:

Determine BOD_5/COD, BOD_5/TOC, TOC/BOD_5 ratios for the following organic compound ($C_5 H_7 NO_2$). Assume "K" = $0.23d^{-1}$.

1. determine COD:-

$C_5 H_7 NO_2 + 5O_2 \rightarrow 5 CO_2 + NH_3 + 2H_2O$

Mw =113 mw =160

COD = 160/113 = 1.42 mg O_2 / mg $C_5 H_7 NO_2$

2. Determine the BOD_5 of $C_5 H_7 NO_2$:-

$\frac{BOD5}{UBOD} = |-e^{-0.23x5} = 0.68$

BOD5 =0.68 UBOD $\rightarrow$ but COD = UBOD

So BOD5 = 0.68XCOD = 1.42X0.68=0.97 mg BOD/mg $C_5 H_7 NO_2$

3. Determine the TOC of the compound:-

TOC = 5X12/113 = 0.53 mg TOC/mg $C_5 H_7 NO_2$

4. $\frac{BOD5}{COD} = \frac{0.97}{1.42} = 0.68$

$\frac{BOD_5}{TOC} = \frac{0.97}{0.53} = 1.82$

$\frac{TOC}{COD} = \frac{0.53}{1.42} = 0.37$

Note: COD = THOD = UBOD This is true only when the organic compound is assumed to be completely biodegradable

Inorganic Matter

The following are the main inorganic materials of concern in wastewater treatment:

1. **Chlorides:-**

- High concentrations indicate that the water body has been used for waste disposal.
- It affects the biological process in high concentrations.

2. Nitrogen:-

TKN = Total Kjeldahl nitrogen.

= Organic Nitrogen + ammonia Nitrogen (120 mg/l).

3. **Phosphorus:-**

- Municipal waste contains (4-15 mg/l).

4. Sulfur:-

* Sulfate exists in waste and necessary for synthesis of proteins.

Organic matter $+SO_4^{-2} \rightarrow S^{-2} + H_2O + CO_2$

$S^{-2} + 2H^{+} \rightarrow H_2S$

5. Toxic inorganic Compounds:-
Copper, lead, silver, chromium, arsenic, boron.

6. Heavy metals:-
Nickels, Mn, Lead, chromium, cadmium, zinc, copper, iron mercury.

Gases:-

The following are the main gases of concern in wastewater treatment:
N_2, O_2, CO_2, H_2S, NH_3, CH_4

pH:-

The hydrogen-ion concentration is an important parameter in both natural waters and wastewaters. It is a very important factor in the biological and chemical wastewater treatment. Water and wastewater can be classified as neutral, alkaline or acidic according to the following ranges:

PH = 7 neutral.
PH > 7 Alkaline.
PH < 7 Acidic.

Biological/Micro bacteriological Characteristics

Most biological waste and wastewater treatment processes employ bacteria as primary microorganisms; certain other microorganisms may also play an important role.

Bacteria usually consists of 80% water and 20% dry material, of which 90% is organic and 10% inorganics.

An approximate formula for organics fraction is $C_5 H_7 O_2 N$, when phosphorus is considered then the formula is $C_{60} H_{87} O_{23} N_{12} P$.

Main groups of Microorganisms:-

The main microorganisms of concern in wastewater treatment are Bacteria, Fungi, Algae, Protozoa, Viruses, and pathogenic microorganisms groups.

Bacteria:-

Types: Spheroid, rod curved rod, spiral, filamentous. Some important bacteria:-

Pseudomonas:- reduce NO_3 to N_2, So it is very important in biological nitrate removal in treatment works.

Zoogloea:- helps through its slime production in the formation of flocs in the aeration tanks.

Sphaerotilus natuns:Causes sludge bulking in the aeration tanks.

Bdellovibrio: destroy pathogens in biological treatment.

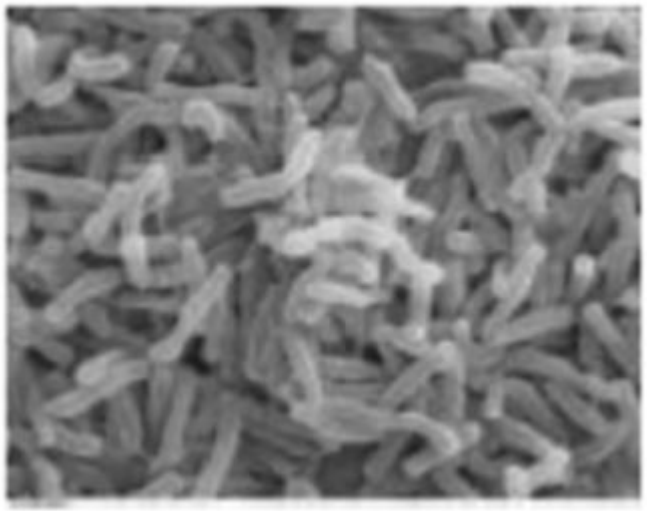
Acinetobacter: Store large amounts of phosphate under aerobic conditions and release it under an – anaerobic condition so, they are useful in phosphate removal.

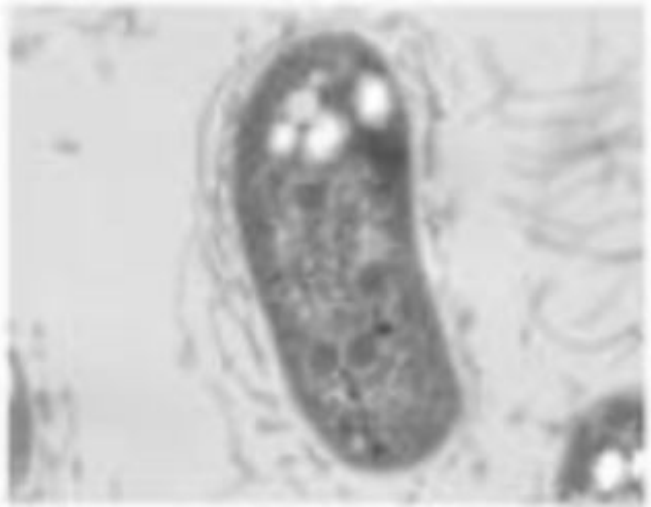
Nitrosomonas: transform NH_4 into NO_2^-

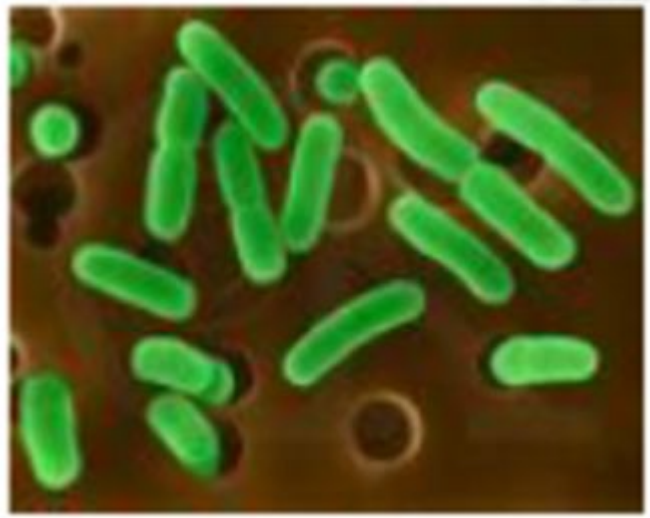
Nitrobacter: transform NO_2^- to NO_3^-

Coliform bacteria:- The most common type is E-Coli or Echerichia Coli, (indicator for the presence of pathogens).

E-Coli is measured in (No/100mL)







Fungi:

- Important in decomposing organic matter to simple forms.

Algae:

- Cause eutrophication phenomena. (negative effect)
- Useful in oxidation ponds. (positive effect)
- Cause taste and problems when decayed. (negative effect)

Protozoa:

- Feed on bacteria so they help in the purification of treated waste water.
- Some of them are pathogenic.



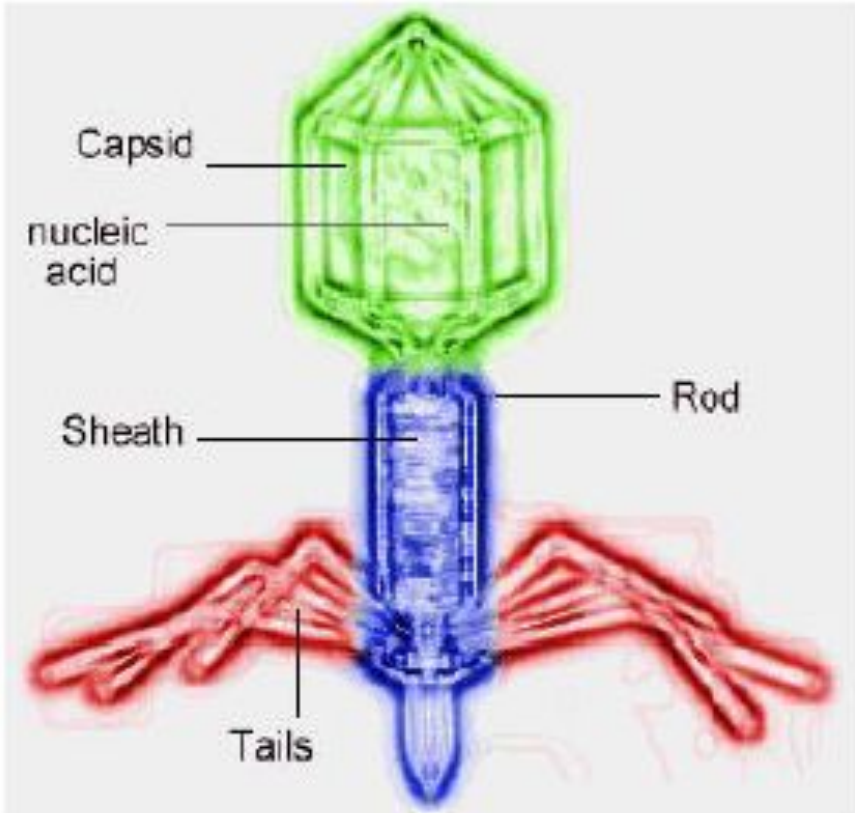


Viruses:

Viruses are a major hazard to public health. Some viruses can live as long as 41days in water and wastewater at 20 °C. They cause lots of dangerous diseases.

Pathogenic organisms:

The main categories of pathogens are:-
Bacteria, Viruses, protozoa, helminthes



Typical Wastewater Composition

Concentration				
Contaminants	**Unit**	**Weak**	**Medium**	**Strong**
Solids, total (TS)	mg/L	350	720	1200
Dissolved, total (TDS)	mg/L	250	500	850
Fixed	mg/L	145	300	525
Volatile	mg/L	105	200	325
Settle able solids (SS)	mg/L	100	220	350
Fixed	mg/L	20	55	75
Volatile	mg/L	80	165	275
Settle able Solids	mg/L	5	10	20
Biochemical oxygen demand, mg/l: (BOD 5-day, 20 °C)	mg/L	110	220	400
Total organic carbon (TOC)	mg/L	80	160	290
Chemical oxygen demand (COD)	mg/L	250	500	1000

Nitrogen (total as N)	mg/L	20	40	85
Organic	mg/L	8	15	35
Free ammonia	mg/L	12	25	50
Nitrites	mg/L	0	0	0
Nitrites	mg/L	0	0	0
Phosphorus (total as P)	mg/L	4	8	15
Organic	mg/L	1	3	5
Inorganic	mg/L	3	5	10
Chlorides[a]	mg/L	30	50	100
Sulfate[a]	mg/L	20	30	50
Alkalinity (as $CaCO_3$)	mg/L	50	100	200
Grease	mg/L	50	100	150
Total coliform[b]	no/100 ml	10^6 - 10^7	$10^7 – 10^8$	$10^7 – 10^9$
Volatile organic compounds (VOC_s)	Mg/L	<100	100 - 400	> 400

Wastewater treatment standards

The most common WWT standards are set for the secondary treatment effluent. The main effluent parameter are: BOD_5, TSS, pH and $CBOD_5$.

*CBOD: (Carbonaceous BOD, from organic compounds and oxidation of inorganic compounds such as ferrous iron)

"secondary treatment" standards in the USA.

Characteristic of discharge	unit	Average 30-day concentration	Average 7-day concentration
BOD_5	mg/L	30	45
TSS	mg/L	30	45
pH	pH units	Within the range 6-9 always	
$CBOD_5^*$	mg/L	25	40

The standards for the removal of nitrogen and phosphorus (N,P) are not included in this table because (N) and (P) need tertiary treatment.

Removal of the coliform bacteria is also regulated according to reuse purpose:-

Fecal coliforms < 500/100 ml (disposed into recreational waters)

1000/100 >ml (for irrigations)

Wastewater Collection System

Content

- Estimation of wastewater;
- Wastewater collection systems;
- Hydraulics of sewer;
- Design, construction and maintenance of (i) sanitary sewer and (ii) storm drainage system;
- Sewer appurtenances;

Important Terms

- ***Domestic (Sanitary) sewage*** is the liquid waste which originates in the sanitary conveniences, e.g., water closets (wc), urinals, baths, sinks etc. of dwellings, commercial or industrial facilities, and institutions. This is sometimes also referred to as **black water**.
- ***Industrial wastewater*** includes the liquid discharges from spent water in different industrial processes such as manufacturing and food processing.
- ***Sullage*** is the liquid discharge from kitchens, wash basins etc. and excludes discharge from WCs and urinals. Sullage, also known as **grey water**, is less foul than domestic sewage and can be discharged through open surface drains in unsewered areas.
- ***Infiltration*** is the water which enters the sewers from the ground through leaks or faulty joints.

Important Terms

- ***Storm water*** is the surface runoff obtained during and immediately after the rainfall, which enters sewers through inlets. Storm water is not as foul as sanitary or industrial sewage and hence can be carried through open drains or channels and disposed of in natural rivers or streams without any treatment.
- ***Sanitary sewer*** carries sanitary sewage and is designed to exclude storm sewage, infiltration, and surface inflow. Industrial waste may be carried in sanitary sewers, depending upon its characteristics.
- ***Storm sewer*** carries storm sewage and any other waste which may be discharged into the streets or onto the surface of the ground.

- Sewage: It is the Liquid Waste or Wastewater produced as a result of water use.
- Sewer: It is a pipe or conduit for carrying sewage. It is generally closed and flow takes place under gravity .





- Sewerage: Sewerage is the system of wastewater collection and conveying it to the point of disposal with or without treatment.

Conventional Sewerage System

Basic Functional Elements

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

Types of Collection Systems

There are three different sewage collection systems:

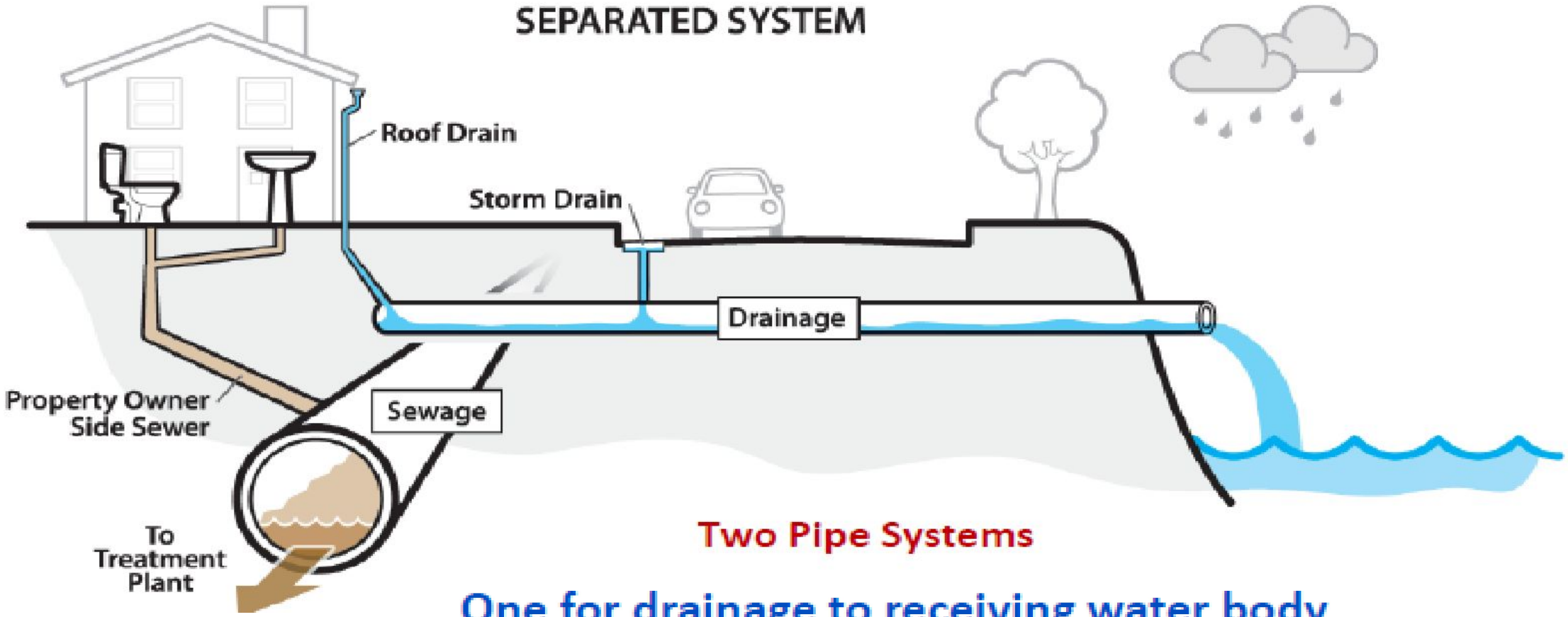
1. **Separate Sewerage System:** In this system sanitary sewage and storm waste are collected and conveyed separately through two different systems

Advantages

- Sewers are of smaller sizes;
- Only sanitary sewage is treated;
- Storm water can be discharged without treatment;
- Sewage lifting is less costly because of less volume.

Disadvantages

- Two sets of sewers may prove costly;
- Smaller sewers may be difficult to clean.



Two Pipe Systems

One for drainage to receiving water body

One for sewage to Treatment Plant

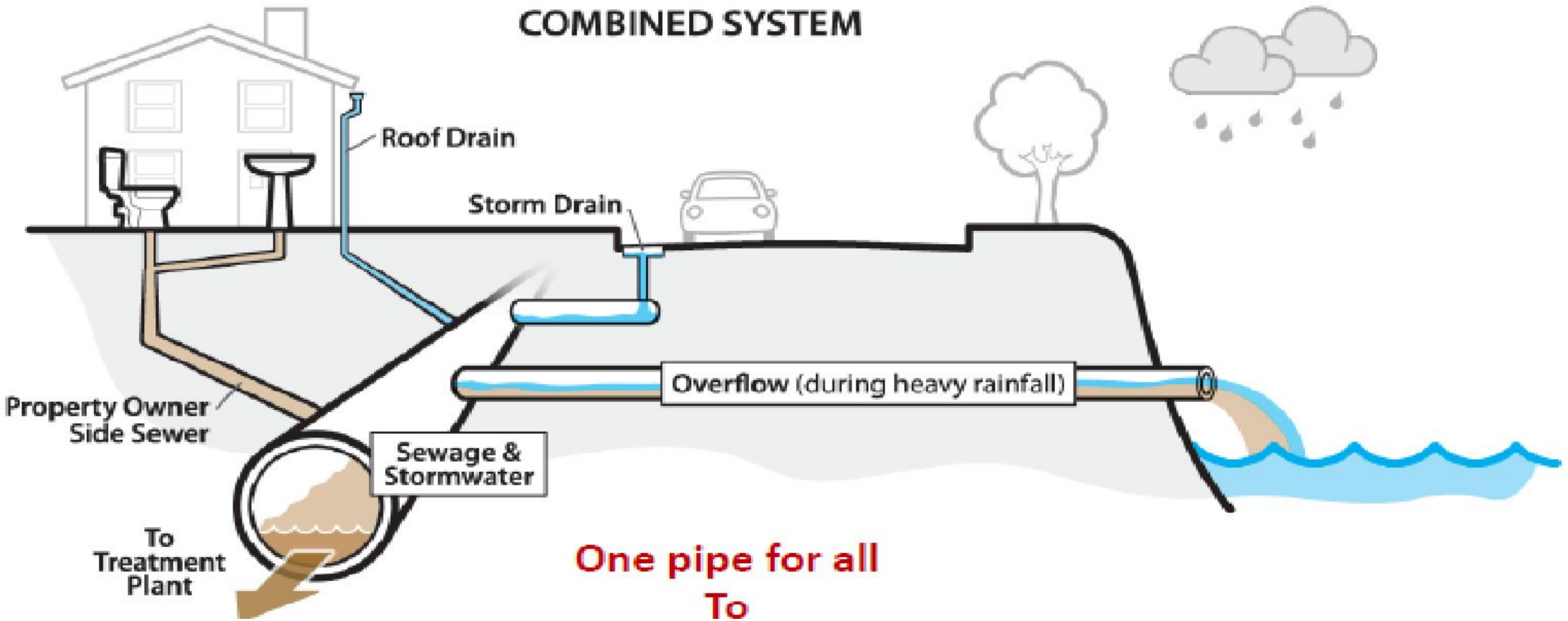
2. Combined Sewerage System: In this system both sanitary sewage and storm water are collected and carried together through a single set of sewers.

Advantages

- Only one set of sewers might prove economical;
- Larger sewers are easy to clean;
- Strength of sewage diluted with storm water.

Disadvantages

- Increased load on treatment plant;
- Larger volume requires to be lifted;
- Heavy rains may cause overflow and thus create a nuisance;
- Storm water is polluted unnecessarily;
- More difficult to properly treat the wastewater to high quality standards;
- Flow during the dry period may cause difficulties in maintaining minimum flow.



One pipe for all

To

Treatment Plant

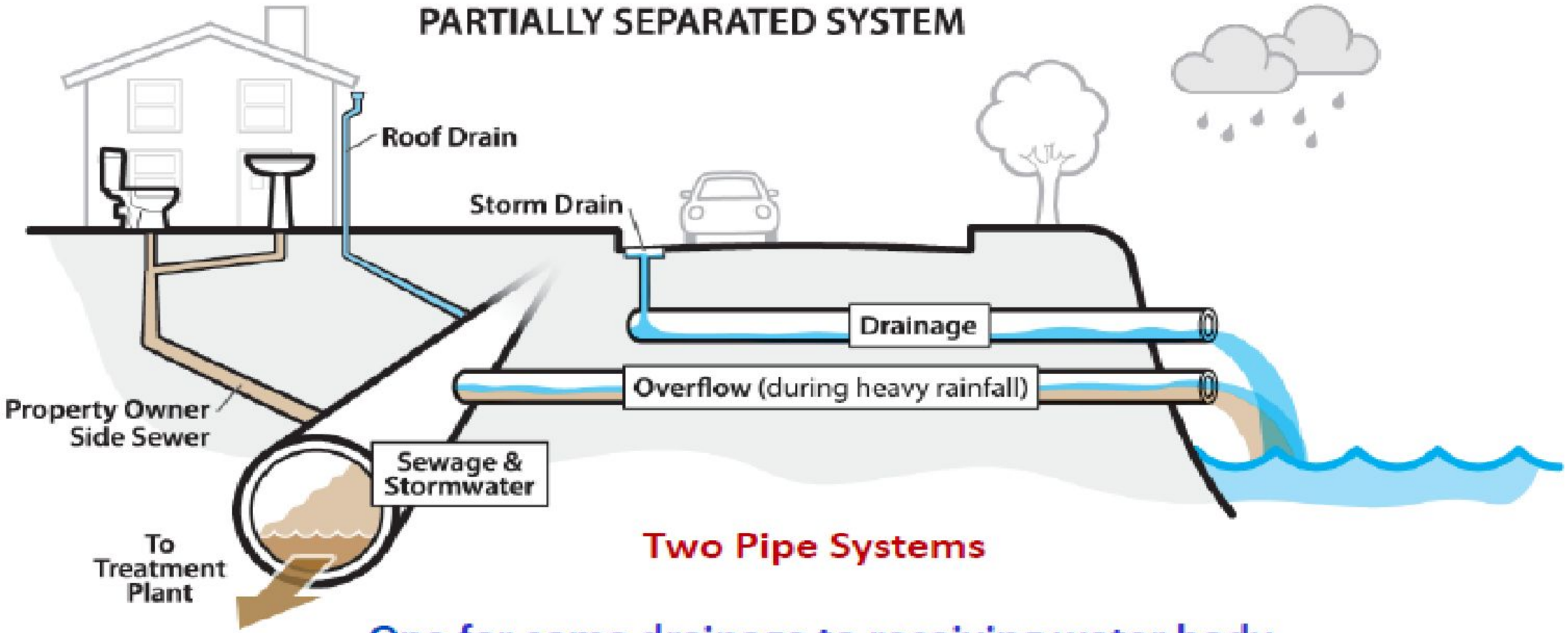
3. Partially Combined or Partially Separate System: In this system only one set of sewers is laid to carry sanitary sewage as well as storm water during low rainfall. During heavy rainfall excess storm water is carried separately e.g., through open drains to natural channels.

Advantages

- Sizes of sewers is not very large;
- Advantages of both separate and combined systems;
- Minimal solids deposition problem;
- Problems of storm water discharges from homes are simplified.
- Where pumping is required at short intervals.

Disadvantages

- Velocity of flow may be low during the dry period;
- Increased load on pumps & treatment unit.



Two Pipe Systems

One for <u>some</u> drainage to receiving water body

One for sewage/stormwater to Treatment Plant

Suitable Conditions for Separate System

- In flat areas a separate system is economical as deep excavations are not required.
- When sufficient funds are not available for two sets of sewer systems, only a sanitary sewerage system may be installed.
- 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.

Suitable Conditions for Separate System

- 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.

Suitable Conditions for Combined System

- 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.

What is the difference between Separate and Combined Sewerage system?

Which sewerage system is suitable for Dhaka City?



Separate: non-uniform rainfall

flat topography

treatment eff.

use existing drain to address storm

Types of Sewers

- Sewerage is converging network of sewers (building connections, lateral sewers, main sewers, trunk sewers and intercepting sewers)
  - Building sewers/building connections – begins beyond a building foundation conveying sewage from the building to (lateral) sewer
  - Lateral/branch sewer – first element of the sewerage system – receives sewage from buildings and conveys to main sewers
  - Main sewer – receives sewage from lateral sewers and conveys to trunk sewers or intercepting sewers
  - Trunk sewers – large sewers conveying sewage from main sewers to STP or disposal facilities or to large intercepting sewers
  - Intercepting sewers – large sewers used to intercept a number of main or trunk sewers and convey sewage to STP/disposal facilities

Outfall Sewer: There are the lengths of main or trunk or interceptor sewers which lie between connections and the final point of disposal or treatment plant.

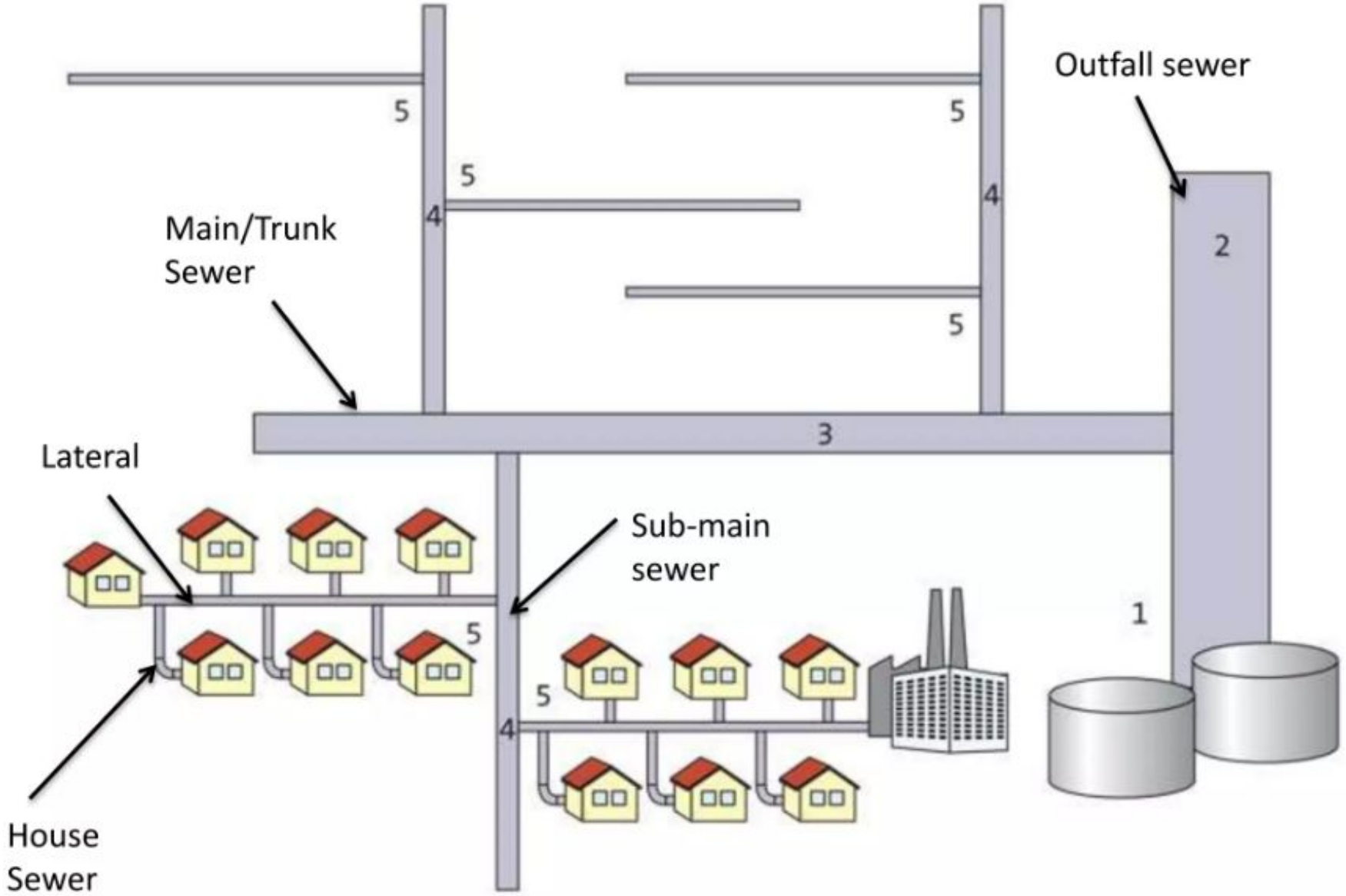
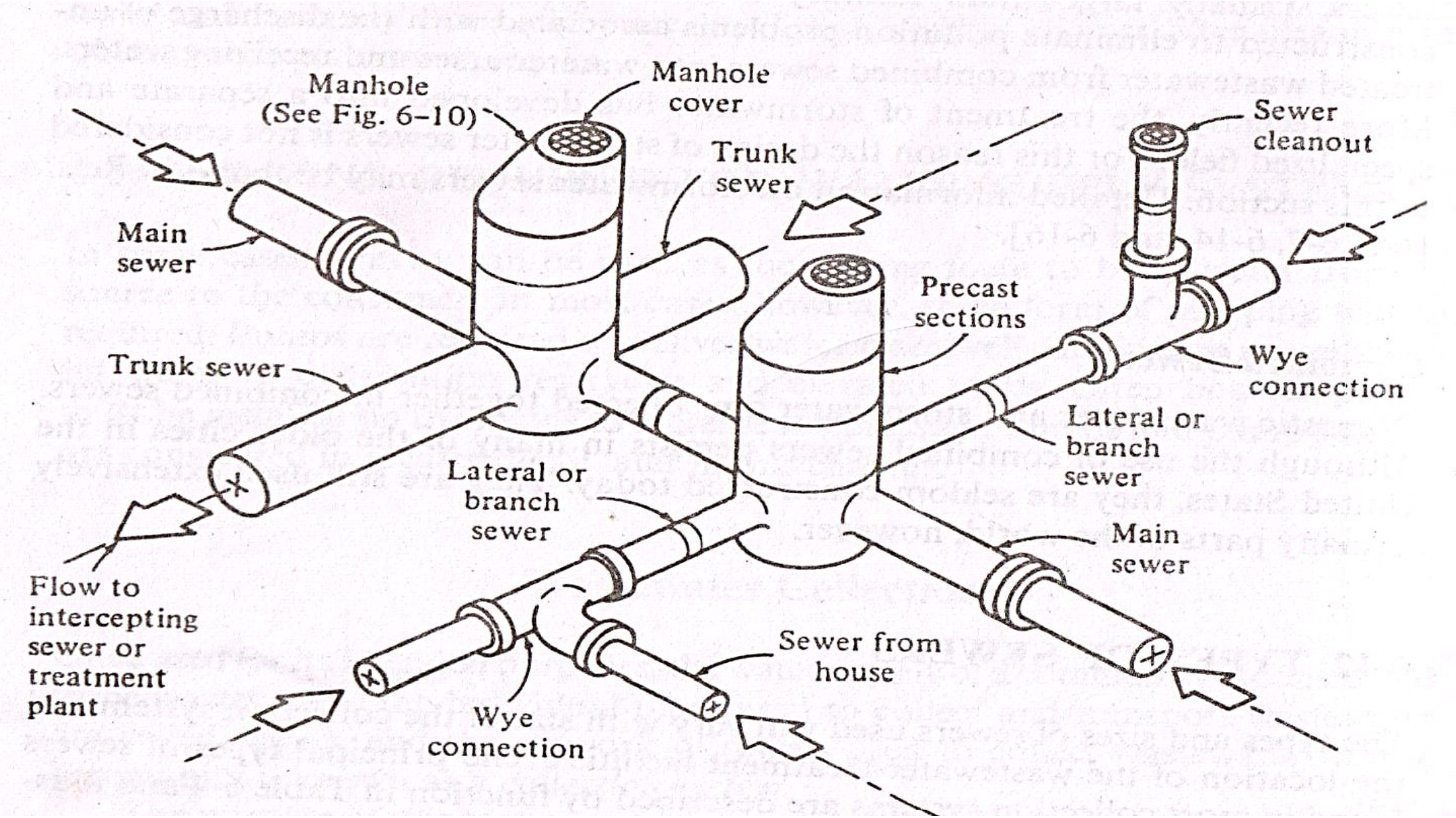


Fig: Types of Sewers



Definition sketch of different types of sewers (peavy et al. 1986)

Design of Sanitary Sewer System

The important objectives of the design of a sanitary sewer system are:

- to ensure ease of operation;
- to minimize maintenance requirements.

Two major factors

- Quantity/Estimation of wastewater flow
- Flow hydraulics

Quantity Estimation of Sewage

Very high discharge estimated will lead to larger sewer size affecting economy of the sewerage scheme

Lower discharge actually flowing in the sewer may not meet the criteria of the self cleansing velocity and hence leading to deposition in the sewers.

Since sewers are design to serve for some more future years, engineering skills have to be used to accurately estimate the sewage discharge.

Estimation/Quantity of Sanitary Sewage

The sewers are designed to carry:

- Spent water from a community
- Some groundwater as infiltration
- Fraction of the storm water
- Industrial wastewater for small establishments

- The sanitary sewers are designed to carry the wastewater from the above sources to a sewage/wastewater treatment plants
- Carrying capacity of the sewers depends on: 1. Present and 2. Future quantities of flow rate expected.
- Important to estimate the design flow rate for the sewers to be constructed.

Estimation of Sewage Flow rate

Two Parameters:

1. The contributing population, and
2. Per capita (per person) flowrate of sewage

Both of these quantities depend on the design period

- Design period: The length of the time up to which the capacity of a sewer will be adequate is called a design period.
- Normally design period for a sewerage system is considered as **30 years**
- But, mechanical rotating equipment such as pumps are designed for **15 years**

Estimation of Waste Water Flows

Population Estimates: often made using the following simple equation $P = P_0 [1 + r]^n$

Relation to water use: estimate would be

- too high for a residential community with hot, dry summers
- too low for a community containing industries, or commercial institutions with private water supplies.

Also affected by factors affecting water use:

- characteristics (economic level) of the population
- metering of water supply;
- other factors (e.g., climate, quality, pressure, and conservation programs).

Per Capita Sewage Flow rate

- Ideally the entire amount of water used by a community should appear as the total flow in a sanitary sewer
- Water is lost due to:
  - Evaporation Loss
  - Seepage into ground
  - Leakages
- The dry weather flowrate is slightly less than the per capita water consumption
- For very dry and arid regions,
  - Average sewage flowrate ≥ 40% of the consumption rate
- In well-paved and well-developed areas,
  - Average sewage flowrate ≈ 90% of the consumption rate
- Conservative estimate is 80% of water consumption rate

Design Flows

The unit quantities of wastewater for which the sewer sizes have to be designed are called the **design flows**.

Wastewater flow is not uniform throughout the day and throughout the year.

- It varies during the day due to the varying use of water for domestic, commercial and industrial purposes.
- Variations throughout the year are due to seasonal variation of rainfall and rainfall intensity.

Due to such variations in wastewater flow, some terms are used:

ADWF (Average dry weather flow)**:**

- Is the average of the daily dry weather flow to the sewer system
- Not affected by storm infiltration
- Reflects the wastewater discharges from domestic, industrial and commercial fixtures.

PDWF (Peak dry weather flow):

- During normal daily flows, two distinct peaks usually occur - the morning peak and the evening peak.
- The maximum hourly or short-term flow rate in a sewer system without rainfall, often defined as the average of the highest flows over several dry days.
- Includes sanitary sewage (domestic, commercial, industrial) and Groundwater Infiltration (GWI) but excludes storm water.

PWWF (Peak Wet weather flow):

- Is the maximum flow to be considered in designing the capacity of sewers
- highest flow rate in a sewer system during rain or snowmelt, combining regular sanitary sewage with significant amounts of storm water entering through cracks (infiltration) or illegal connections (inflow).

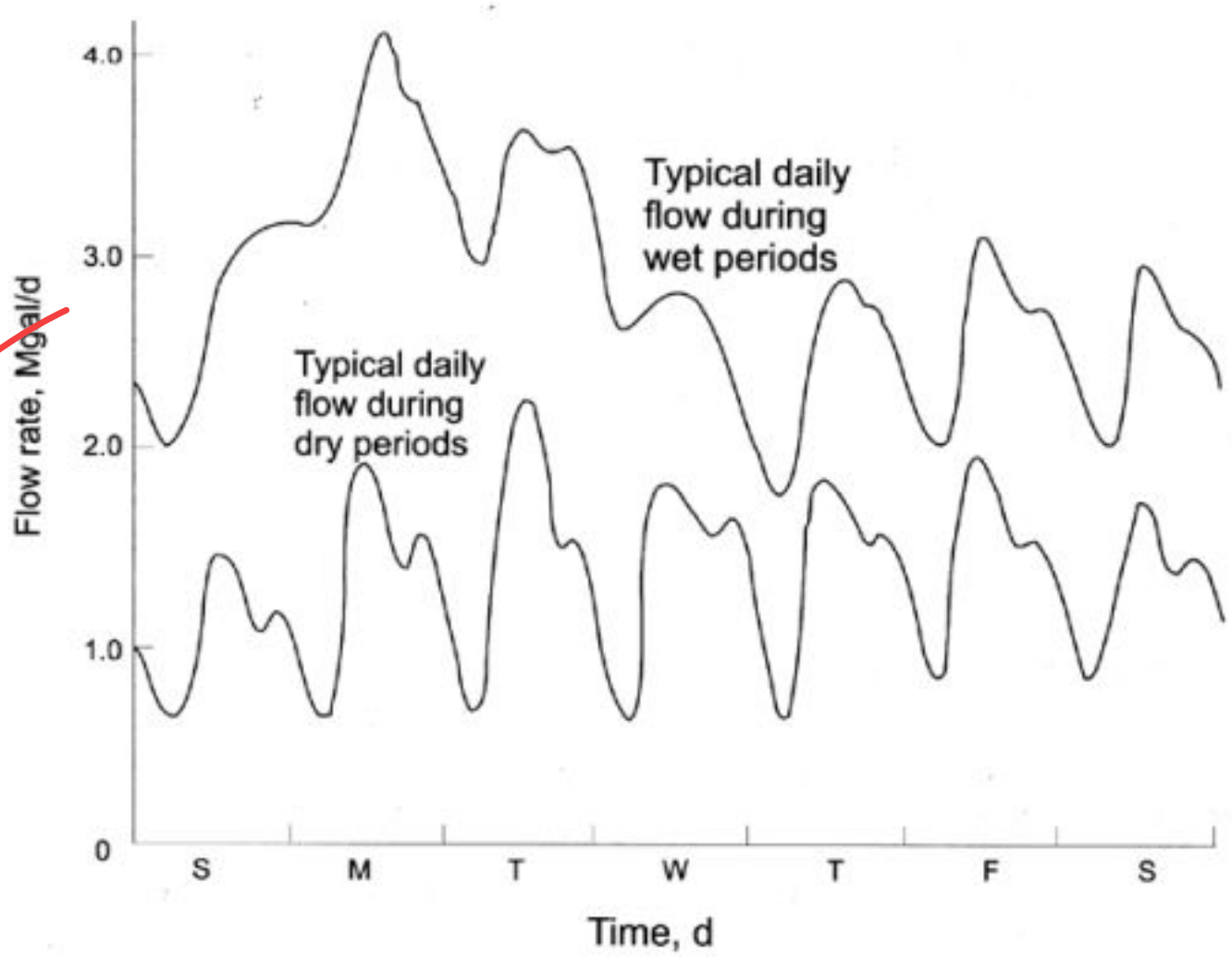
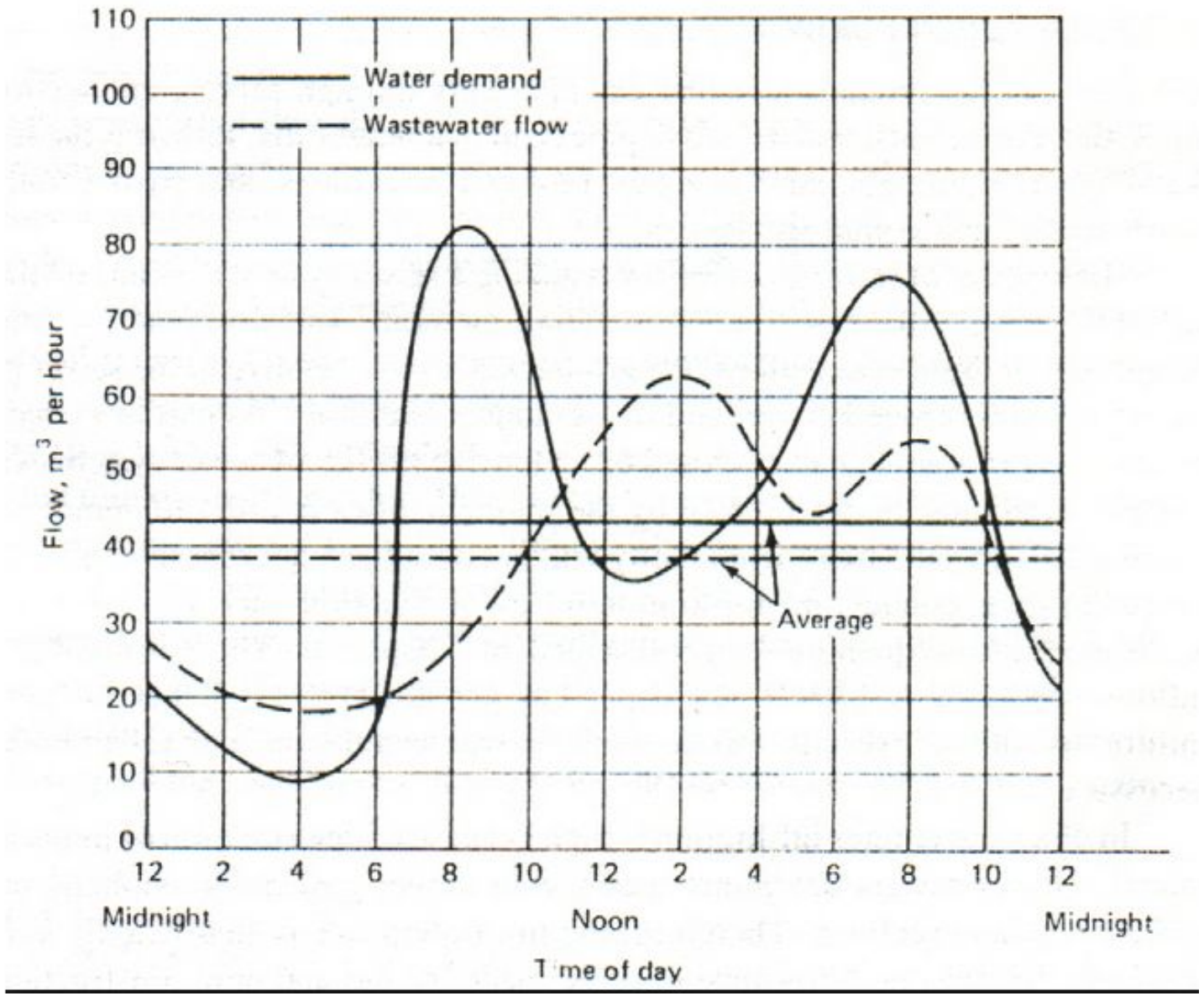


Figure 4.2: Typical dry and wet weather hydrographs

Variation in Sewage Flow



Design Flows

- For design purpose, sewers are always designed to carry maximum or peak flow rates, rather than designing it for average flowrate.

$$\text{Peak Factor (PF)} = \frac{\text{Maximum wastewater flow rate}}{\text{Average flow rate of wastewater}}$$

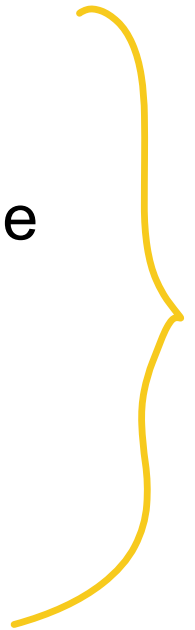
Population	Peak factor
< 20,000	3.0
20,000 – 50,000	2.5
50,000 – 7,50,000	2.25
> 7,50,000	2.0

Groundwater infiltration

The presence of a high groundwater table results in seepage into the sewers through the joints and in an increase in the quantity of wastewater.

The rate and quantity of infiltration depends on a number of factors:

- Depth at which sewer is laid
- Materials of the sewers
- Length of sewer below groundwater table
- Nature and types of soils
- Types of joints
- Workmanship



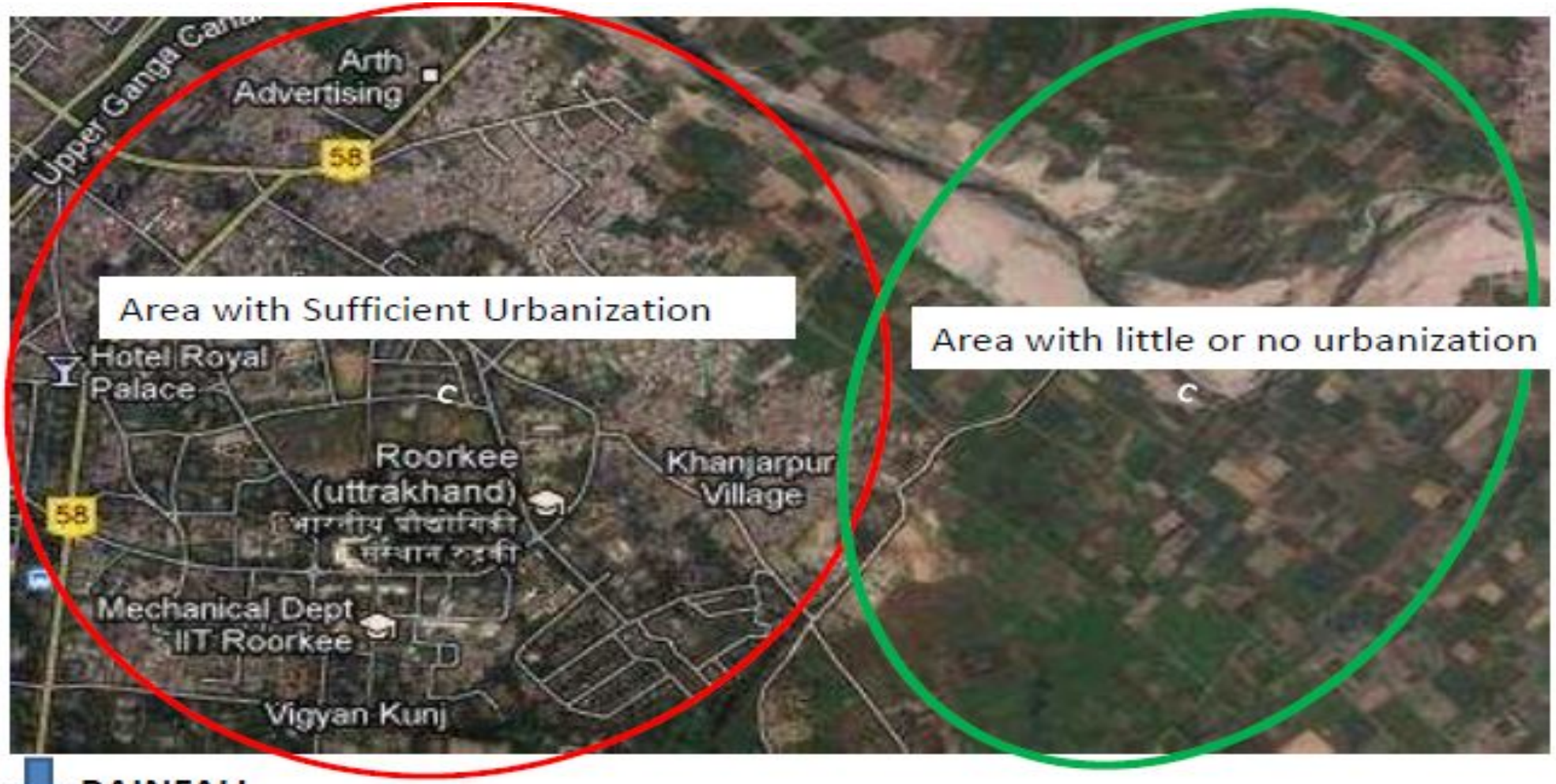
Groundwater infiltration

Usually, for a sanitary sewer below the groundwater table the following values are taken,

	Minimum	Maximum
Liters/ha.d	5000	50000
Liters per day/ manhole	250	500

PEAK FLOW RATE or MAXIMUM FLOW RATE

Maximum sanitary flow rate = Average domestic flow rate X PF + infiltration flow rate



RAINFALL

More paved surface, higher imperviousness, less absorption by soil

High volume of water on the surface, High runoff, needs quick evacuation to avoid flooding/ inundation

How to evacuate this increased runoff?

BUILD EFFICIENT STORM SEWER SYSTEM

Quantity of Storm Water

The quantity of storm water that goes to the system depends upon:

(a) **Area to be drained off (catchment area):** larger the catchment area larger the storm water

(b) **Topography and Nature of the surface:** Steep slope produce larger amount of storm water

(c) **Intensity of the rainfall**: If intensity is high, less time duration of rainfall, small evaporation, thus more storm water

(d) **Extent of rainfall**: greater rainfall greater storm water

(e) **Antecedent condition**: If soils are already wet, then more storm water

(f) **Obstructions**: Obstruction in areas and depressions decrease the quantity of storm water to be drained out.

Methods for Estimation of Quantity of Storm Water

1. Rational Method

2. Empirical formulae method

In both the above methods, the quantity of storm water is considered as function of intensity of rainfall, coefficient of runoff and area of catchment.

Time of Concentration: The period after which the entire catchment area will start contributing to the runoff is called as the time of concentration.

The rainfall with duration lesser than the time of concentration will not produce maximum discharge.

Methods for Estimation of Quantity of Storm Water

The runoff may not be maximum even when the duration of the rain is more than the time of concentration. This is because in such cases the intensity of rain reduces with the increase in its duration.

The runoff will be maximum when the duration of rainfall is equal to the time of concentration and is called as *critical rainfall duration*.

The time of concentration is equal to sum of inlet time and time of travel.

Time of concentration = Inlet time + time of travel

Methods for Estimation of Quantity of Storm Water

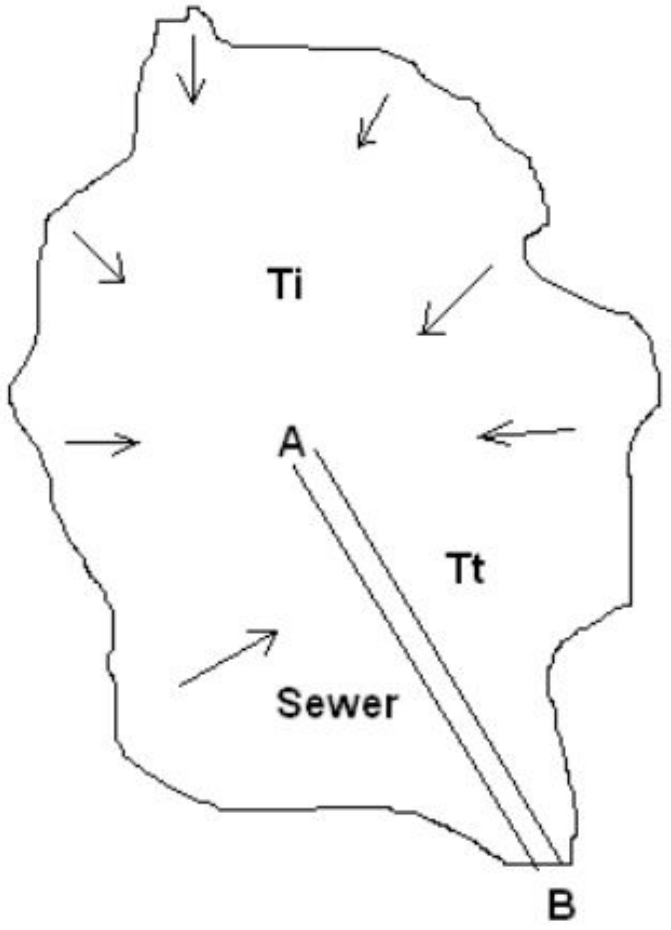


Figure 6.1 Runoff from a given catchment

Methods for Estimation of Quantity of Storm Water

Inlet Time: The time required for the rain in falling on the most remote point of the tributary area to flow across the ground surface along the natural drains or gutters up to inlet of sewer is called inlet time.

The inlet time 'Ti' can be estimated using relationships similar to following.

These coefficients will have different values for different catchments.

$$Ti = [0.885\ L^3/H]^{0.385}$$

Methods for Estimation of Quantity of Storm Water

Where, Ti = Time of inlet, minute

L = Length of overland flow in Km from critical point to mouth of drain

H = Total fall of level from the critical point to mouth of drain, m

Time of Travel: The time required by the water to flow in the drain channel from the mouth to the point under consideration or the point of concentration is called as time of travel.

Time of Travel (Tt) = Length of drain/ velocity in drain

Time of concentration Tc = Ti + Tt

Rainfall Intensity

- Amount of rainfall in a specific time expressed as mm/hour, cm/hour etc.
- The intensity of a rainfall is the rate at which it is falling
- The duration is the time for which it is falling with that given intensity
- Frequency is the number of times it occurs
- The intensity of rainfall over short periods has been observed to be greater than the average for the whole day.

- $I\ (cm/hr) = 76.2 / (t + 10)$ for $t = 5 – 20$ minutes

  $= 101.6 / (t + 20)$ for $t = 20 – 100$ minutes

Time of Concentration

The maximum time taken by water to travel from the extreme catchment boundary to the catchment outlet is known as time of concentration.

Bransby-Williams formula:

$$t_c = \frac{FL}{A^{0.1} S^{0.2}}$$

Where, t_c = time of concentration in minutes

F = Factor of proportionality
= 58.5 when A in km^2 = 92.7 when A in 'ha'

L = Mainstream length

A = Catchment area

S = Mainstream slope (m/km)

RUN-OFF ESTIMATE

Rational formula

$Q = FICA$; $Q \rightarrow l/s$, $I \rightarrow cm/hr$, $A \rightarrow ha$

Peak discharge, $Q = FCIA$

$F = \frac{10^{-3} \times 10^{4}}{3600} \times 1000$

$= 27.8$

Where, Q = peak discharge in l/s

F = Factor of proportionality = 27.8 (when A in ha and I in cm/hr)

C = run-off coefficient (is a function of area type, soil)

I = Rainfall intensity, cm/hr

A = Catchment area, ha

$I(cm/hr) = \frac{76.2}{t+10}$; $0 < t < 20$ min

$\frac{101.6}{t+20}$; $20 < t < 100$ min

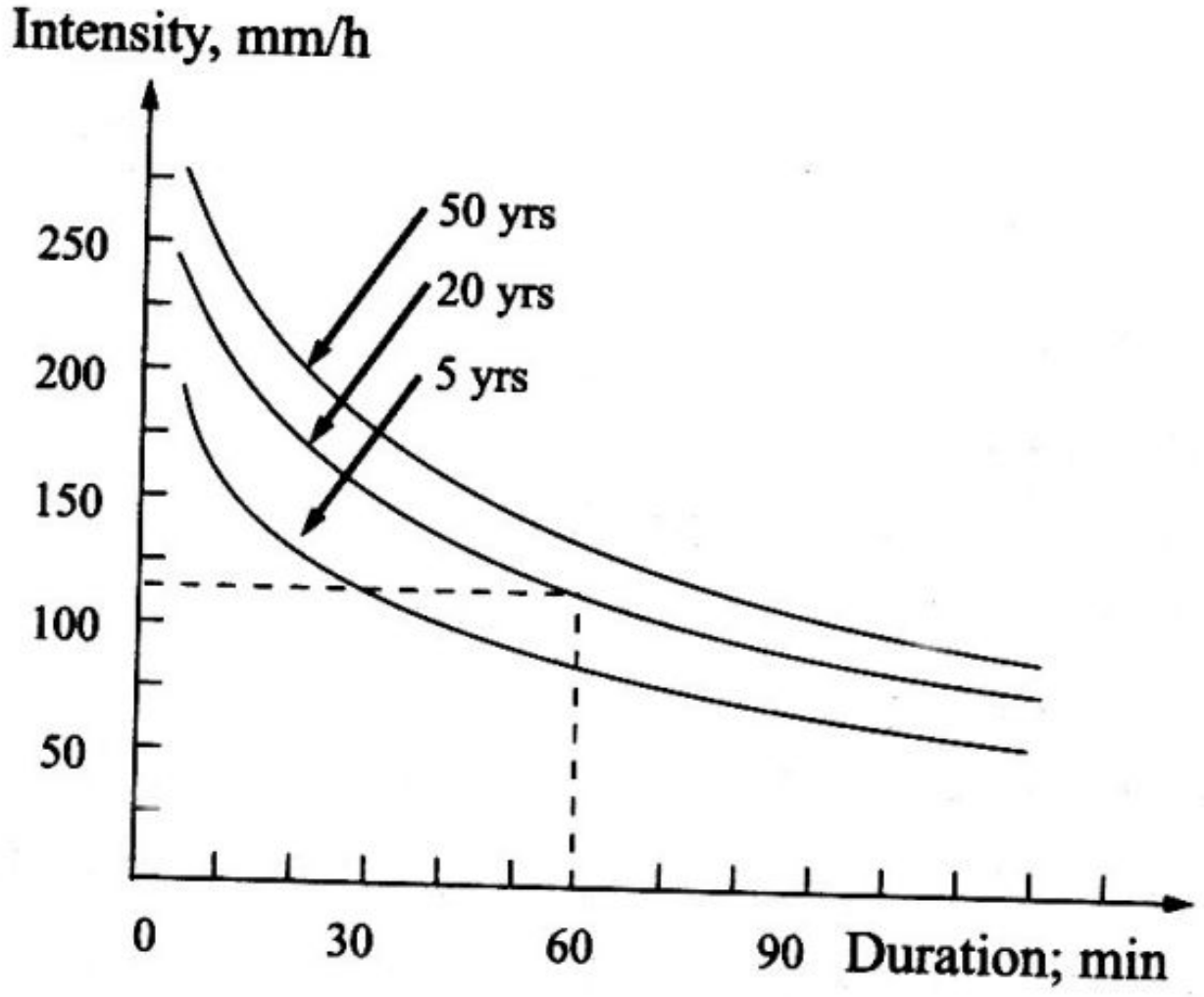
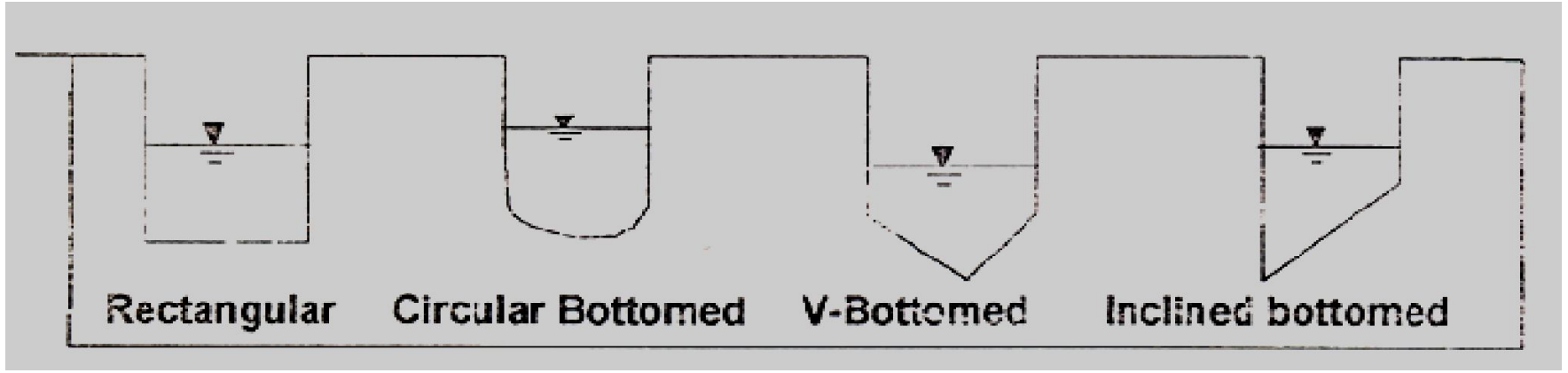


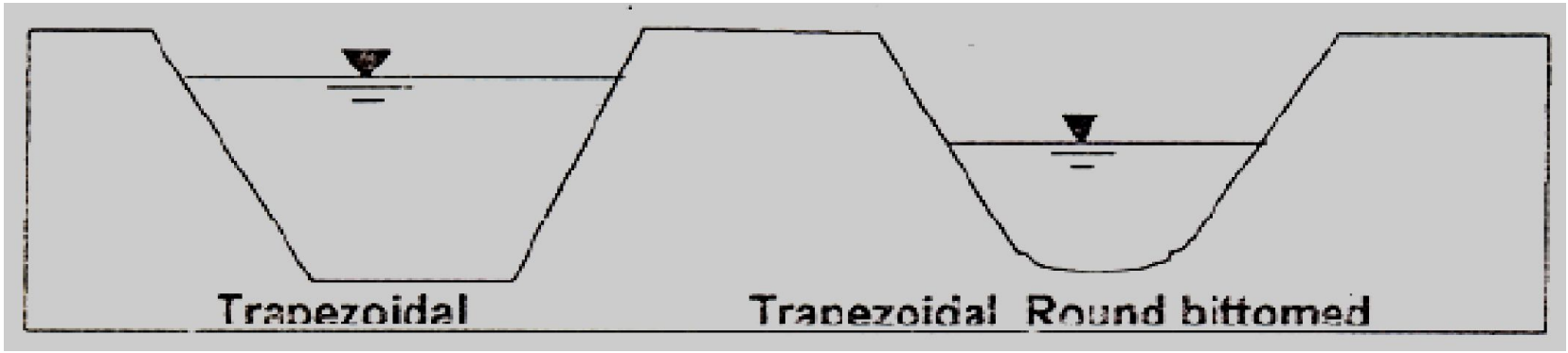
Fig: Rainfall Intensity-Duration-Frequency Curves

SURFACE DRAINS

An ideal drain section should meet the following requirement:

1. It should develop self-cleansing velocity
2. It should not develop high velocity to scour the sides
3. It should possess structural stability
4. It should be of inexpensive construction and easy and cheap to maintain
5. It should prevent weathering action and wearing action
6. It should have smooth interior surface
7. It should be capable of being cleaned easily


Rectangular
Circular Bottomed
V-Bottomed
Inclined bottomed


Trapezoidal
Trapezoidal Round bittomed


V- Shaped
Semi-Circular

Estimation of Design Flow

Based on the rational approach, the design flow consists of the sum of the PDWF plus wet weather additive and may be expressed as **$Q = \Sigma D.\ d + \Sigma I.\ i$**

ΣD = sum of all dry weather flow components; d = peak dry weather factor; ΣI = basic wet weather additive; i = appropriate infiltration factor

- **$\Sigma D = P.\ q_r + A_c.\ q_c + A_i.\ q_i$**

P = population; q_r = residential discharge rate (say, 100 – 400 lpcd); A_c = commercial area; q_c = commercial discharge rate (say, 0.25 - .5 l/sec/ha for sub-urban business areas, but may be up to 8.0 l/sec/ha in high-rise business area); A_i = industrial area; q_i = industrial discharge rate (depends on industry type, e.g., 0.25 – 0.35 l/sec/ha)

Estimation of Design Flow

- $\Sigma I = A_r . K + A_c . K/4 + A_i . K/4$

A_r = residential area; A_c = commercial area; A_i = industrial area; K = ground constant (higher values for clayey soils and lower values for sandy soils).

- d = vary from 3.0 for small areas and 0.7 for large areas

- i = varies from 1.0 for small area to 0.5 for large areas in a manner similar to decrease of rainfall intensity with increasing area

Sewers are usually designed to have a capacity ≥ Q

Self-cleansing velocity

- The velocity that would not permit the solids to settle down and even scour the deposited particles of a given size is called as self-cleansing velocity.
- Minimum velocity should at least develop once in a day so as not to allow any deposition in the sewers.
- If such deposition takes place, it will obstruct free flow causing further deposition and finally leading to the complete blocking of the sewers.
- For removing the impurities present in sewage i.e., sand up to 1 mm diameter with specific gravity 2.65 and organic particles up to 5 mm diameter with specific gravity of 1.2, it is necessary that a minimum velocity of about 0.45 m/sec and an average velocity of about 0.9 m/sec should be developed in sewers.

Self-cleansing velocity

- While finalizing the sizes and gradients of the sewers, they must be checked for the minimum velocity that would be generated at minimum discharge, i.e., about 1/3 of the average discharge.
- While designing the sewers the flow velocity at full depth is generally kept at about 0.8 m/sec or so. Since, sewers are generally designed for ½ to ¾ full, the velocity at 'designed discharge' (i.e., ½ to ¾ full) will even be more than 0.8 m/sec.

  Thus, the minimum velocity generated in sewers will help in following ways:
  - Adequate transportation of suspended solids,
  - Keeping the sewer size under control; and
  - Preventing the sewage from decomposition by moving it faster, thereby preventing evolution of foul gases.

Maximum Velocity or Non-scouring Velocity

- The interior surface of the sewer pipe gets scoured due to the continuous abrasion caused by suspended solids present in sewage. The scouring is pronounced at higher velocity than what can be tolerated by the pipe materials.
- This wear and tear of the sewer pipes will reduce the life span of the pipe and their carrying capacity.
- In order to avoid this, it is necessary to limit the maximum velocity that will be produced in sewer pipe at any time. This limiting or non- scouring velocity mainly depends upon the material of sewer.

Maximum Velocity or Non-scouring Velocity

Sewer Material	Limiting velocity (m/sec)
Vitrified Clay	5.5
Cast iron	4.5
Cement concrete	3.0
Stone ware	4.5
Brick lined	2.5

- The problem of maximum or non-scouring is severe in hilly areas where ground slope is very steep and this is overcome by constructing drop manholes at suitable places along the length of the sewer.

Sewer gradients are affected by:

- Slope of the ground: The gradient should as far as possible follow the slope of the ground along the same direction to minimize excavation.
- Gradient should not be steeper than 1 in 20.
- For house connections 1 in 40 to 1 in 80
- Minimum gradient 1 in 100
- Minimum and Maximum velocities
- Diameter of the sewer and the quantity to be discharged

Hydraulic design of sewers

- ***Chezy's formula***
- ***Manning's formula***
- ***Hazen-William formula***

Manning's Formula: $V = 1.486/n\ R^{2/3}\ S^{1/2}$

Where,

V is velocity in fps, R=hydraulic radius in ft, S=hydraulic gradient, n=Manning's roughness co-efficient.

Choice of suitable n is the most important factor in design.

1)Vitrified clay, concrete, asbestos-cement and corrugated steel pipe with smooth asphaltic lining, a co-efficient ranging from 0.012 for clear water to 0.015 for strong sewage, 0.013 being a common design value for sanitary sewers.

2) Cast iron pipes, a co-efficient ranging from 0.015 to 0.035 is generally used.

Substituting Q=AV, where $A=0.785D^2$ and hydraulic radius R=D/4=0.25D for a circular sewer flowing full the required diameter is:

$$D=(2.16Qn/\sqrt{S})^{3/8}$$

the required slope is:

$$S=(Vn/1.486R^{2/3})^2$$

Sewers flowing partly full

Let. D = full depth (sewer diameter)

V = velocity of flow during full flow

A= cross sectional area

P = perimeter

Q = average discharge while flowing full

When sewer is flowing partly.

Let. d = flow depth (sewer diameter) v = velocity of flow during partial flow

a= cross sectional area of flow p = wetted perimeter

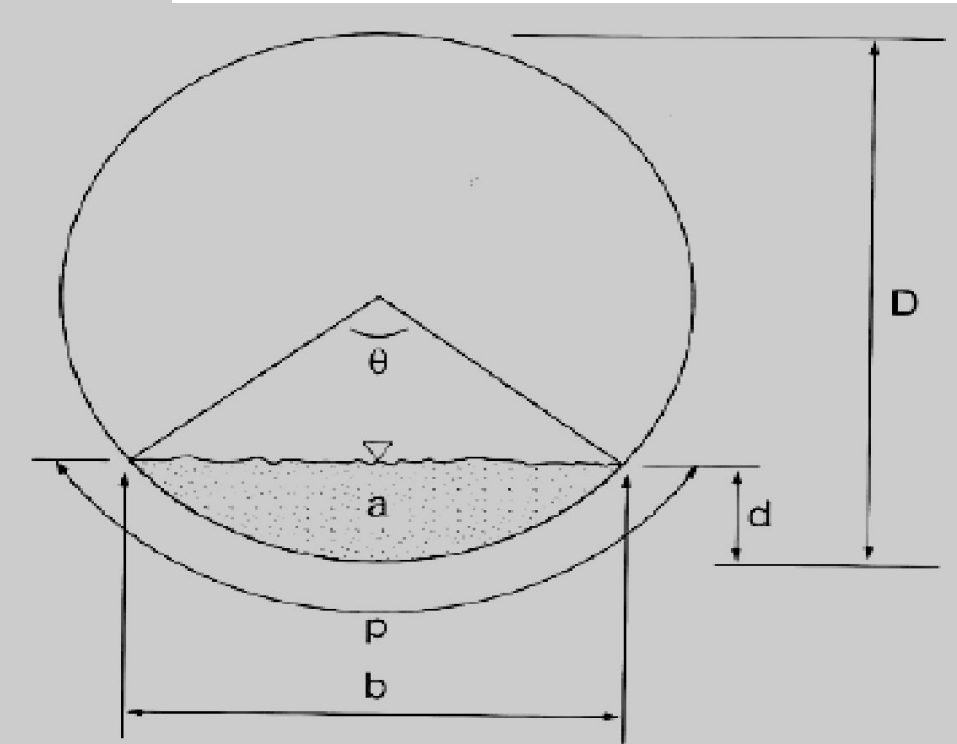
q = average discharge of partial flow

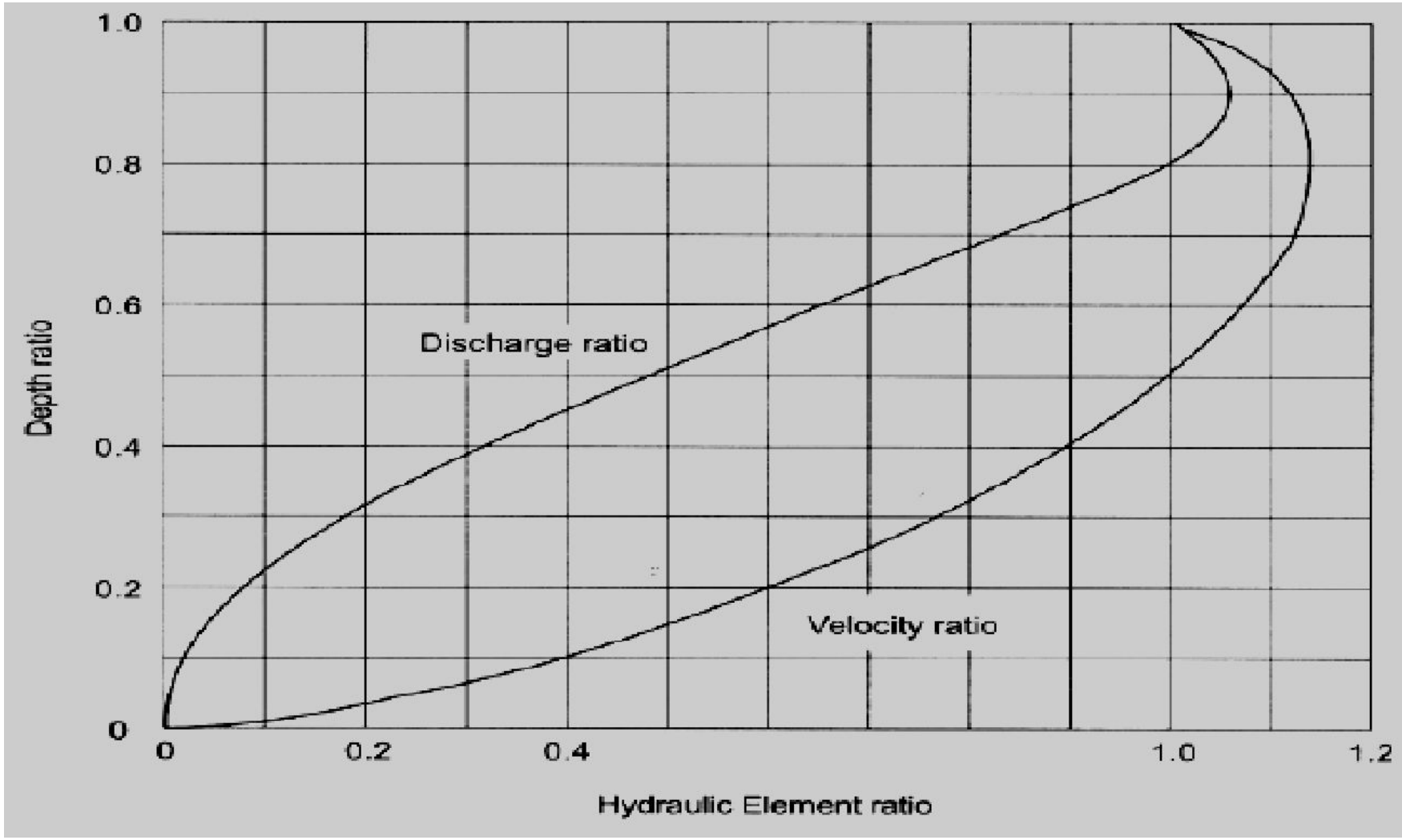
- $d/D = \frac{1}{2}(1 - \cos\frac{\theta}{2})$

$$\theta = 2\cos^{-1}\left(1 - \frac{2d}{D}\right)$$

- $a/A = (\theta/360 - \sin\theta/2\pi)$
- $p/P = \theta/360$
- $r/R = (1 - 360\sin\theta/2\pi\theta)$
- $v/V = (1 - 360\sin\theta/2\pi\theta)^{2/3}$
- $q/Q = (\theta/360 - \sin\theta/2\pi)(1 - 360\sin\theta/2\pi\theta)^{2/3}$

Only 'θ' is variable e.g. depth of flow





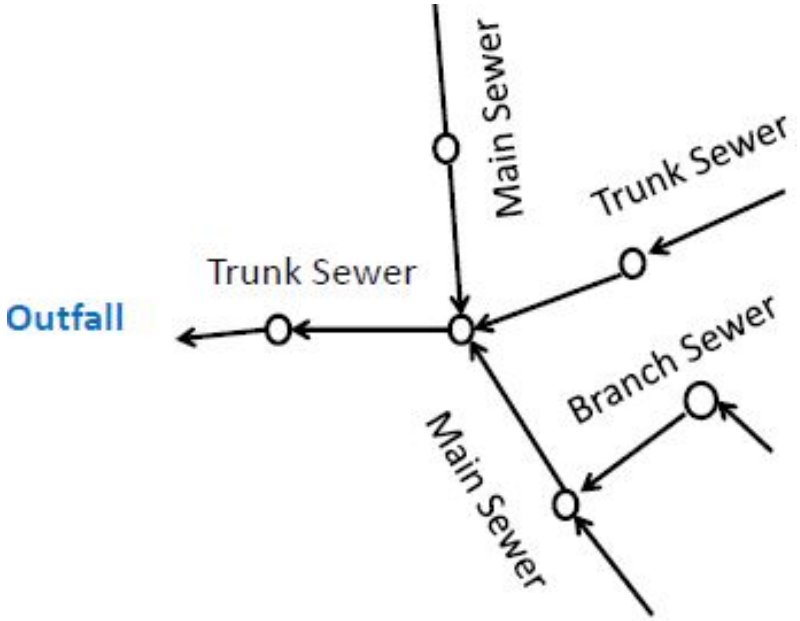
- **Velocity under full flow and half full flow conditions are equal, i.e. *v=V* at both *d/D= 0.5 and d/D= 1***
- ***Maximum velocity at d/D = 0.81 which is v/V = 1.14***
- ***Maximum flow at d/D = 0.94 which is q/Q = 1.07***

Layout of Sewer Lines

Steps followed for making the layout:

- Selection of an outlet or disposal points
- Fixing limits to the drainage area or zone boundaries
- Finalizing the location of Trunk and Main sewers
- Finalizing the location of Pumping stations wherever necessary

- Trunk sewer is with the largest diameter in the network that extends farthest from the sewage outfall
- All other sewers are considered as branches
- Whenever two sewers meet at a point, the incoming one with larger diameter is called the main sewer.



Laying of Sewer Pipes

All the sewer pipes are generally laid starting from their outfall end towards their starting. *The laying of a new sewer pipes consists of the following 9 steps:*

1. **Marking of alignment**
   - The center line of the sewer is marked along the road with a theodolite and invert tap. The position of the manhole is also marked.
2. **Setting benchmark**
3. **Establishment of grade lines**
4. **Excavation of trench**
   - The excavation may be carried out either by manual labor or by machines like power shovels, track excavators etc. The width of the trench at the bottom is generally kept 15 cm more than the dia of sewer pipe.
5. **Dewatering of trench if need**
   - If water is met with during excavation, it is removed by pumping or any other suitable method.

Laying of Sewer Pipes

6. Bedding

- For soft soil, the bed of the sewer is prepared by plain concrete (1:3:6). The thickness of concrete varies from 15 to 20 cm. The bedding layer is not required in case of rocky or hard soil.

7. Laying and joining of pipes

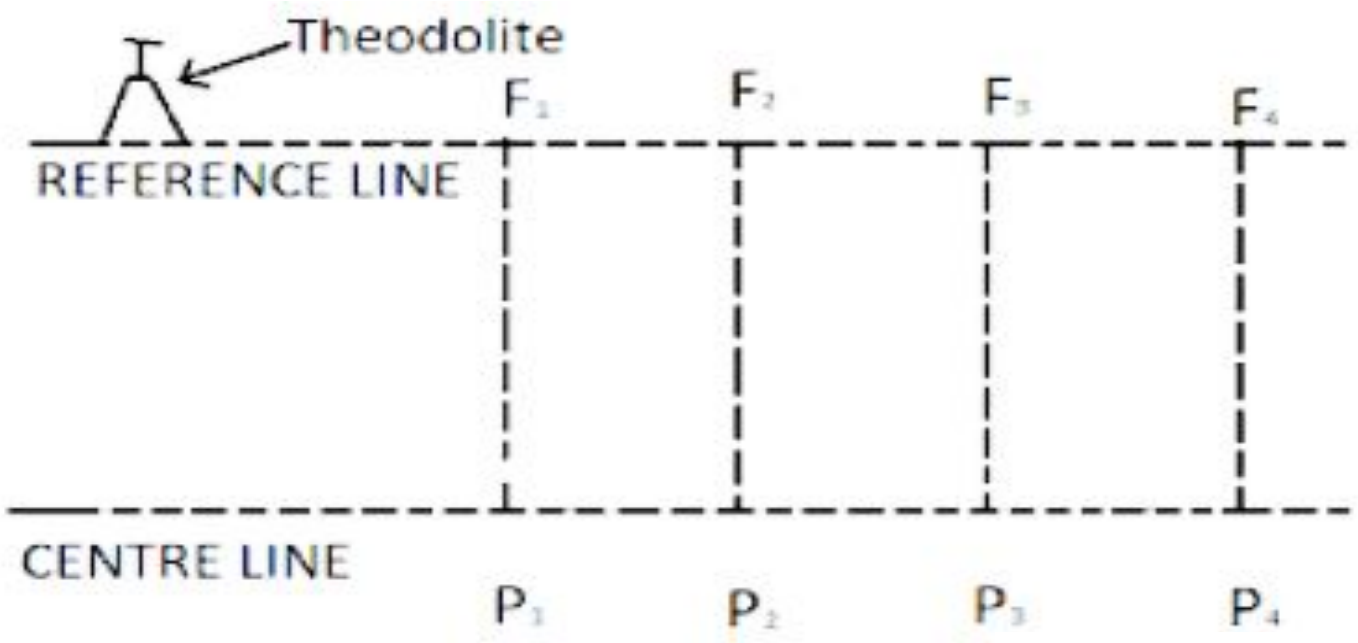
- The sewers are laid along the trench very carefully. Then the joining of the sewer is done as per requirements. After joining, both sides of the pipe are finished with concrete.

8. Inspection of leakage

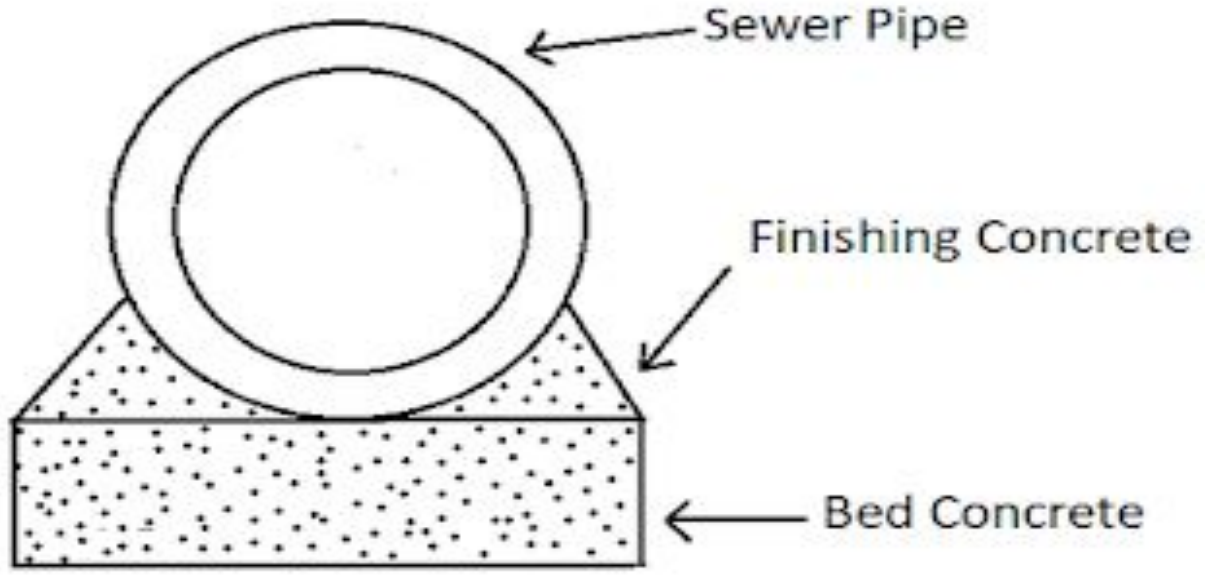
- The leakage in the pipe joints or any other points is tested by water test or air test.

9. Backfilling of trench

- Lastly, the trenches are filled up with the excavated earth in layers of about 15 cm thick. Each layer is properly watered and rammed.

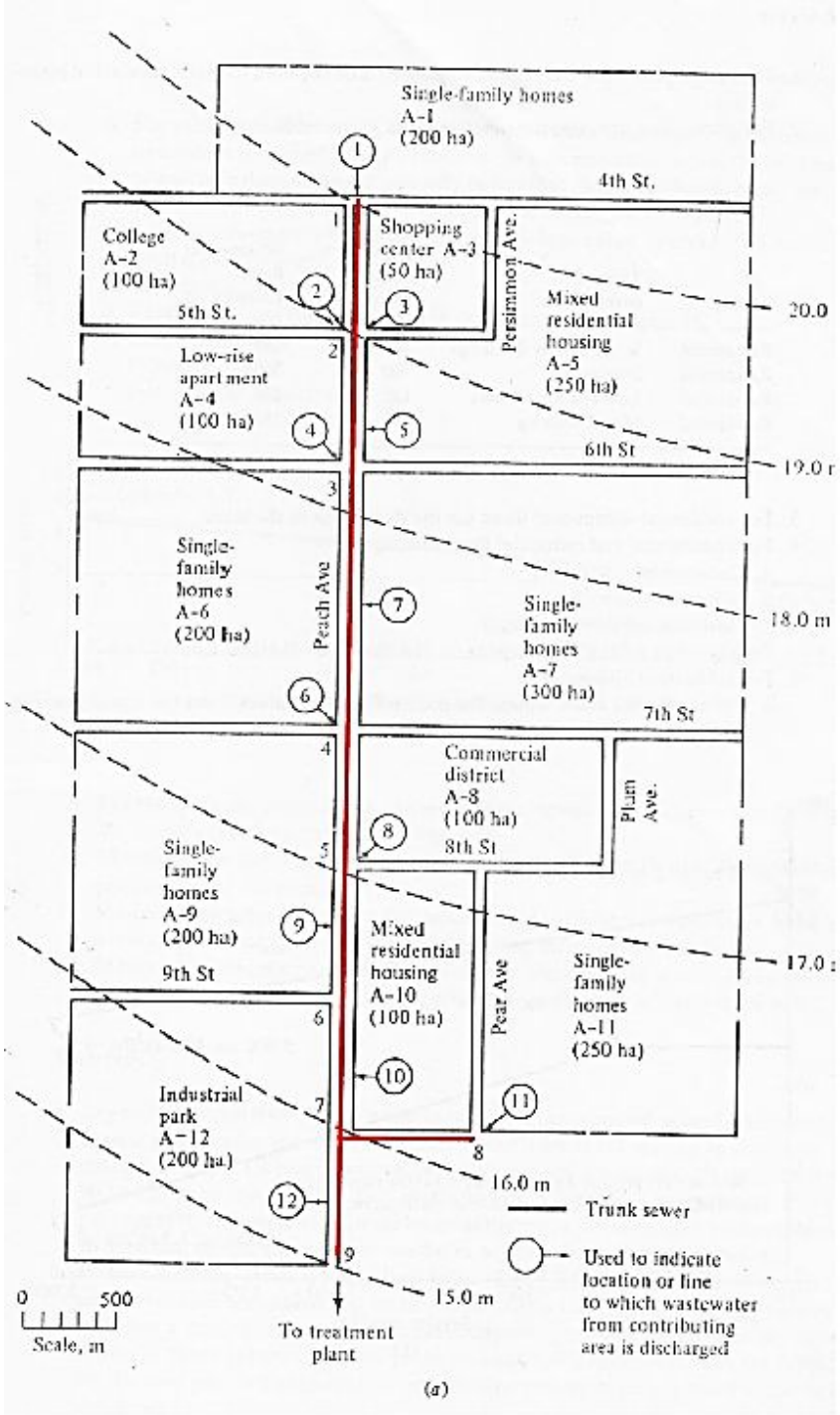


Marking of the Alignment



Laying and Joining of Pipes

SEWER DESIGN


Single-family homes
A-1
(200 ha)
4th St.
College
A-2
(100 ha)
5th St.
Shopping
center A-3
(50 ha)
Persimmon Ave.
Mixed
residential
housing
A-5
(250 ha)
20.0
Low-rise
apartment
A-4
(100 ha)
6th St
19.0 r
Single-
family
homes
A-6
(200 ha)
Peach Ave
Single-
family
homes
A-7
(300 ha)
7th St
18.0 m
Commercial
district
A-8
(100 ha)
8th St
Plum
Ave.
Single-
family
homes
A-9
(200 ha)
9th St
Mixed
residential
housing
A-10
(100 ha)
Pear Ave
Single-
family
homes
A-11
(250 ha)
17.0 r
Industrial
park
A-12
(200 ha)
16.0 m
15.0 m
Trunk sewer
Used to indicate
location or line
to which wastewater
from contributing
area is discharged
0
500
Scale, m
To treatment
plant

(a)

Design of a gravity-flow sanitary sewer

Design a gravity-flow trunk sanitary sewer for the area shown in the accompanying figure (a). The trunk sewer is to be laid along Peach Avenue starting at 4th Street and ending at 11th Street. Assume that the following design criteria have been developed based on an analysis of local conditions and codes.

1. For design period use the saturation period (time required to reach saturation population).

2. For population densities use the data given in the following table.

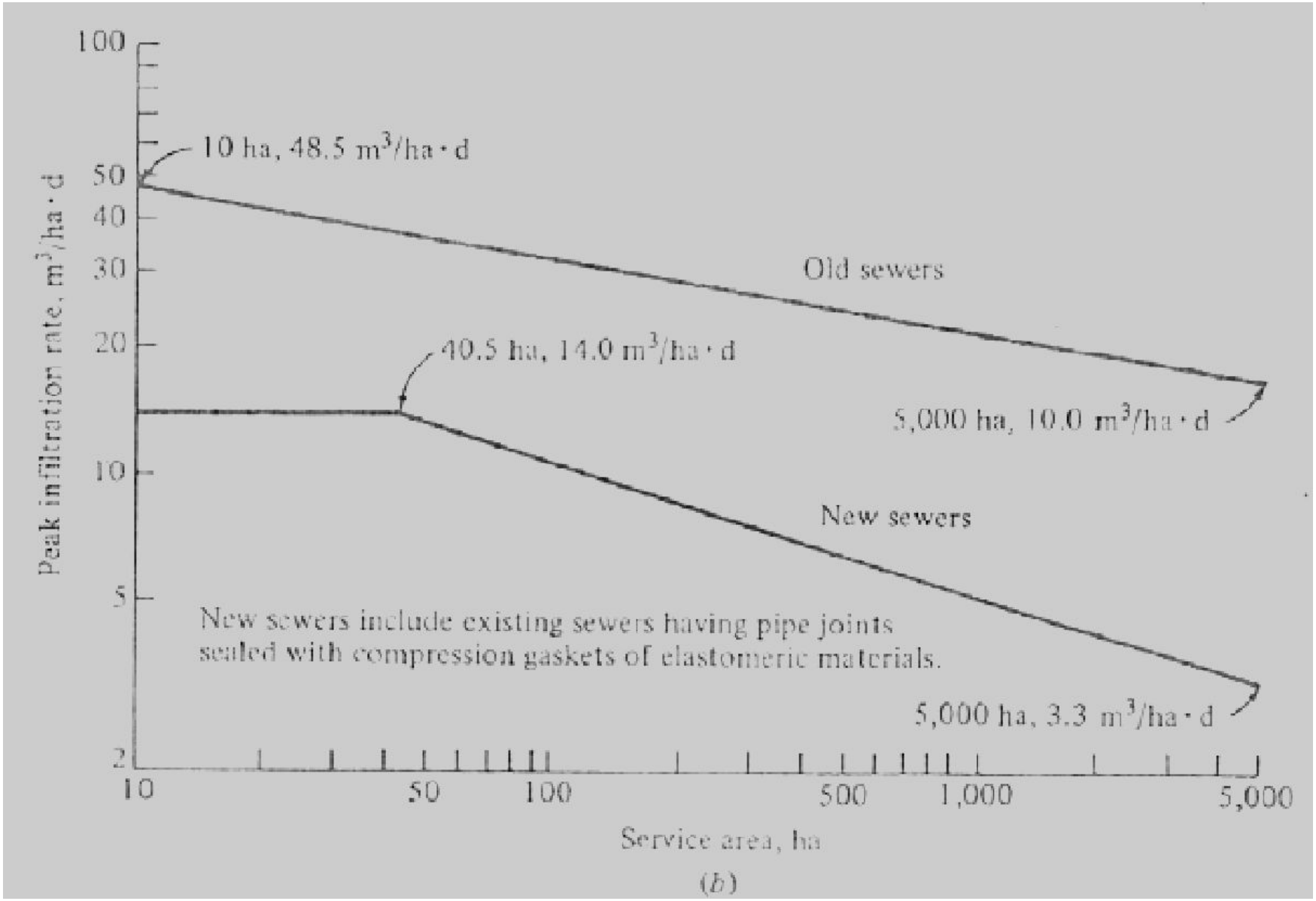
Zoning	Type of development	Saturation population density, person/ha	Wastewater flow, L/capita · d
Residential	Single-family dwellings	40	380
Residential	Duplexes	60	300
Residential	Low-rise apartments	120	220
Residential	Mixed housing	70	250

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

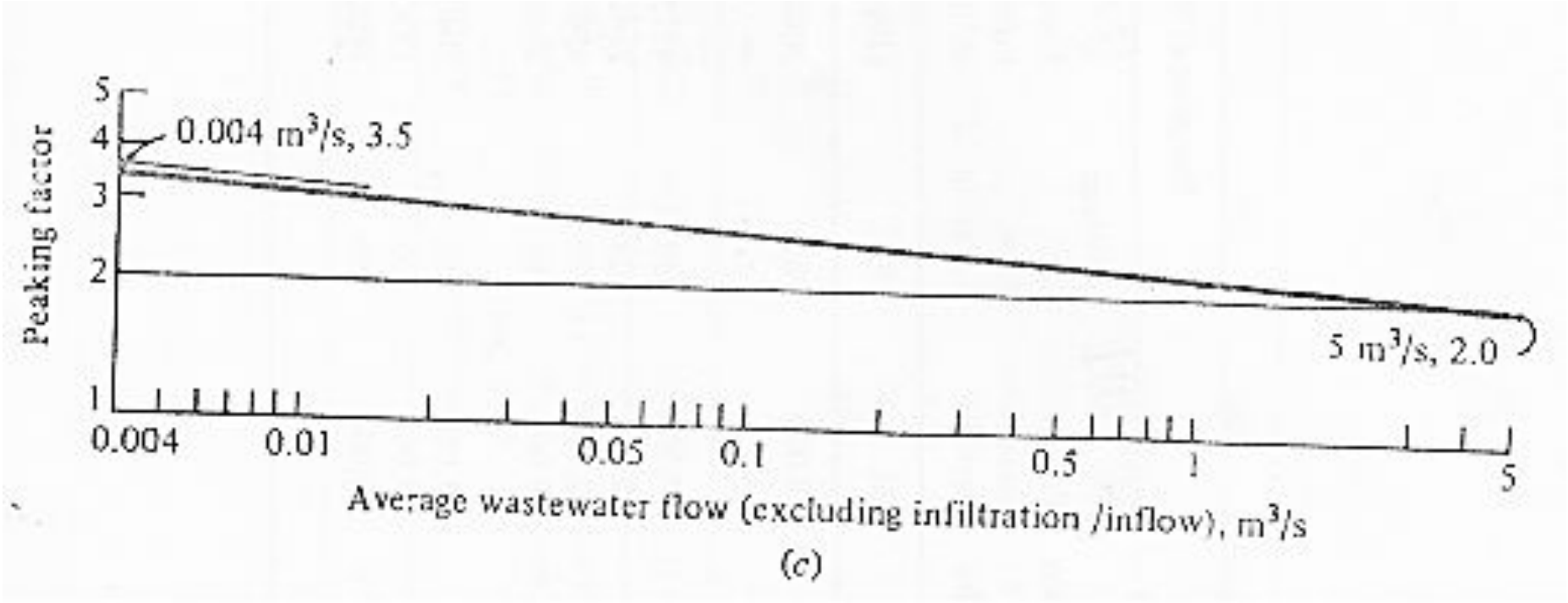
4. For commercial and industrial flows (average):
a. Commercial – 20 m^3/ha. d
b. Industrial – 30 m^3/ha . d

5. For institutional flows (average):
College – 400 m^3/d (5330 students × 75 L/student. D) /(1000 L/m^3)

6. For infiltration allowance:
a. For residential areas, obtain the peak infiltration values from the accompanying figure (b).
b. For commercial, industrial and institutional areas, also obtain the peak infiltration values from the figure (b). However, to make into account that the total length of sewers in these areas will generally be less than that in residential areas, use only 50 percent of the actual area to compute the infiltration allowance.



7. For inflow allowance assume that the steady flow inflow is accounted for in the infiltration allowance.



(c)

8. 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

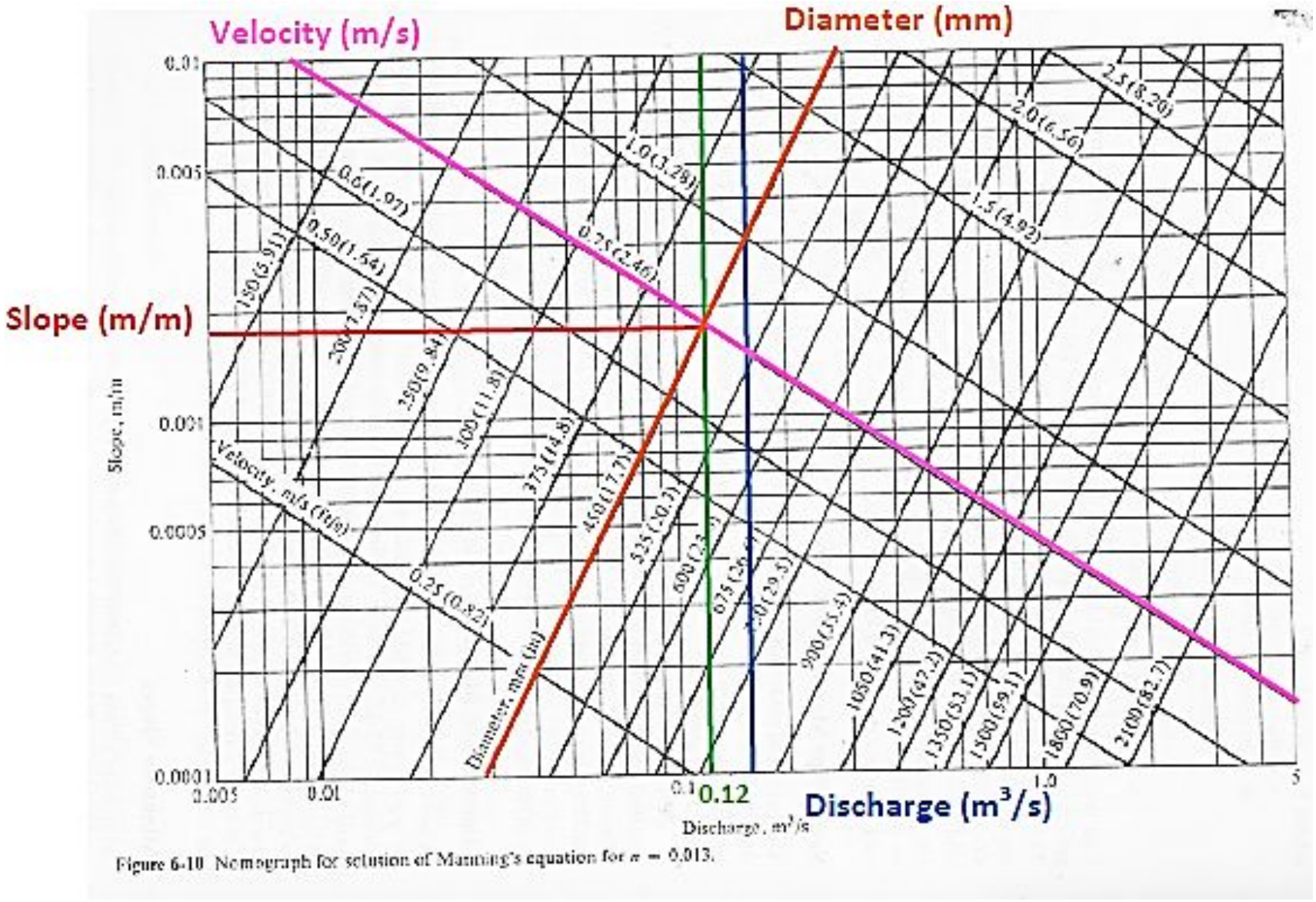


Figure 6-10 Nomograph for solution of Manning's equation for $n = 0.013$.

9. For the hydraulic design equation, use the Manning equation with an n value of 0.013. To simplify the computations, use Fig 6.10.

10. Minimum pipe size: The local building code specifies 200 mm (8 in) as the smallest pipe permissible for this situation.

11. Minimum velocity: To prevent the deposition of solids at low waste water flows, use a minimum velocity of 0.75 m/s (2.5 ft/s) during the peak flow conditions.

12. Minimum cover (minimum depth of cover over the top of the sewer): As established by the local community building code, the minimum depth of cover is 2.0 m.

Solution

1. Lay out the trunk sewer. Draw a line to represent the proposed sewer [figure (a)].

2. Locate and number the manholes. Locate manholes at (1) changes in direction, (2) changes in slope, (3) pipe junctions, (4) upper ends of sewer and (5) intervals from 90 to 120 m or less. Identify each manhole with a number. For the purpose of this problem only the manholes at the major junctions have been numbered [figure (a)]. In actual design, intermediate manholes would be located and numbered.

3. Prepare a sewer design computation table. Based on the experience of numerous engineers, it is found that the best approach for carrying out sewer computations is to use a computation table. The necessary computations for the sanitary sewer shown in figure (a) are presented in the accompanying 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	A-12	A-12					26,245	2.5	65,613

Sewer computation table (*Continued*)

	Location				Commercial flows					Industrial flows				
Line	From	To	Length of sewer, m	Subarea*	Area, ha	Average unit flow, $m^3/ha \cdot d$	Cumulative average flow, m^3/d	Peaking factor	Cumulative peak flow, m^3/d $(16 \times 17)^1$	Area, ha	Average unit flow, $m^3/ha \cdot d$	Cumulative average flow, m^3/d	Peaking factor	Cumulative peak flow, m^3/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	1.8	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

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 (21 + 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	—	—	—	3,960	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

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 6*b*).

§ $m^3/s = (m^3/d)/(86,400\ s/d)$.

¶ The minimum practical slope for construction is about 0.0008 m/m.

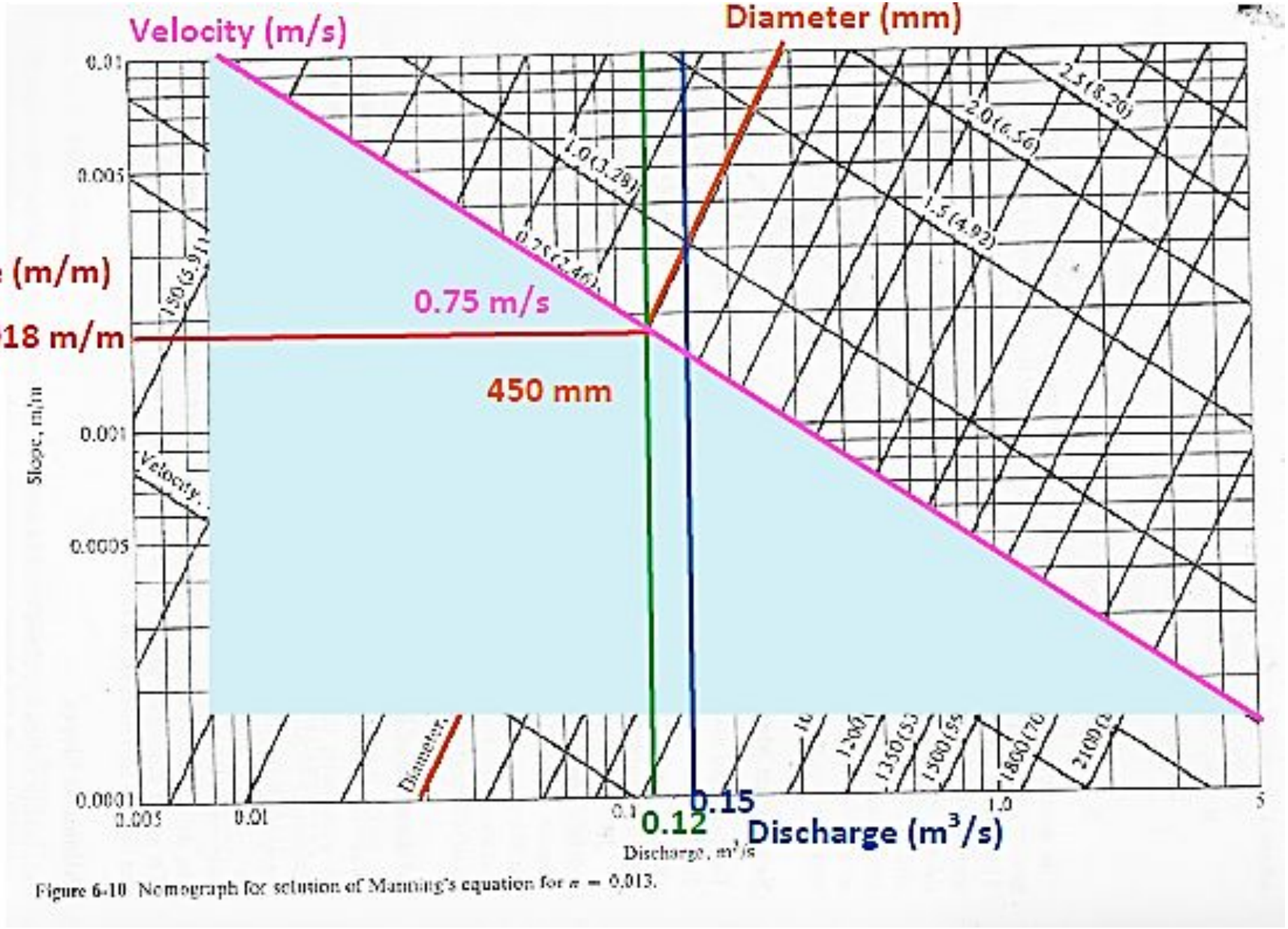


Figure 6-10 Nomograph for solution of Manning's equation for $n = 0.013$.

a. The entries in columns 1 through 5 are used to identify the sewer lines under consideration and to summarize the basic physical data from figure (*a*).

b. The entries in columns 6 through 13 are used to obtain the cumulative peak domestic flow (column 13). The area (column 6) is obtained from figure (*a*). The population density (column 7) and the unit flow data (column 9) were given. Peaking factors, obtained from figure (*c*), are entered in column 12.

c. The commercial area, the corresponding unit flow, and the cumulative average flows are entered in columns 14, 15, and 16, respectively. The given peaking factor for the commercial area is entered in column 17, and the computed cumulative peak commercial flows are entered in column 18.

d. The entries in columns 19 through 23 for the industrial flows are the same as described for the commercial flows (columns 14 through 18).

e. The institutional flows are entered in columns 24 through 26.

f. The cumulative average and peak flows are summarized in columns 27 and 28, respectively.

g. The infiltration allowance (columns 29 through 32) is determined using the curve for new sewers in figure (*b*).

h. The total cumulative peak design flow (column 33) is obtained by summing columns 28 and 32.

i. Sewer design information is summarized in columns 35 through 38. The required pipe sizes are estimated using Manning's equation with an n value of 0.013 (see Fig. 6-10). The capacity of the selected pipe and the velocity when full are tabulated in columns 37 and 38. In all cases the velocity should exceed 0.75 m/s (2.5 ft/s).

j. The necessary layout data for the sewer (columns 39 through 42) are obtained as follows: The ground surface elevations at the manhole locations entered in columns 39 and 40 are obtained by interpolation with the elevation data given in figure (*a*). The sewer invert elevations shown in columns 41 and 42 are obtained by trial and error with a sewer profile work sheet. The first step in preparing a work sheet is to plot the ground-surface elevations given in columns 39 and 40, working backwards from a convenient point. After the ground-surface profile is drawn, the next step is to begin sketching the invert and crown (inside bottom and inside top of the pipe, respectively) of each sewer section as the necessary elevation data are developed.

The method for establishing the invert elevations will be illustrated by analyzing selected sewer lines starting with line 1, which connects manholes 1 and 2. The first step is to locate the invert of the upper end of the pipe at such an elevation that the minimum cover requirement is satisfied, taking into account both the inside diameter of the pipe and its wall thickness. The upper invert elevation of the 450-mm pipe is set initially at elevation 17.5 m:

ground surface	−	depth of cover	−	pipe wall thickness	−	pipe diameter
20.00 m	−	2.00 m	−	0.05 m	−	0.45 m

The pipe thickness will vary with the type of sewer. For this example, 0.05 m will be used for all pipe sizes. The lower elevation is computed by subtracting the fall as follows:

Lower invert elevation	=	Upper invert elevation	−	Slope of sewer	×	Length of sewer

For line 1:

$$\text{Lower invert elevation} = 17.50\ \text{m} - (0.0018\ \text{m/m})(707\ \text{m}) = 16.23\ \text{m}$$

If the depth of cover (remember to allow for the pipe wall thickness above the crown) for any section has become too shallow, repeat the process with a lower initial invert elevation or a steeper slope for that section.

When a manhole is located at a sewer junction, the outlet sewer elevation is fixed by the lowest inlet sewer. If the pipe size increases, the crowns of the two pipes must be matched at the manhole. This is done to avoid the backing up of wastewater into the smaller pipe. An example of this situation is the increase in size from 450 to 750 mm at manhole 2. For this case, the calculations are as follows:

Lower invert elevation of the 450-mm sewer is 16.23 m.
Upper invert elevation for the 750-mm-sewer (line 2) is 15.93 m (16.23 m + 0.45 m − 0.75 m).
Lower invert elevation for the 750-mm sewer is 15.29 m [15.93 m − (0.0009 m/m) × (707 m)].
These procedures are repeated until the elevations for the entire sewer are established.

COMMENT A computation table, such as the one shown in this example, not only saves time but also is useful for summarizing both the data and the computed results in an orderly sequence for subsequent use. The specific columns in a given computation table depend on the factors that must be considered in arriving at the peak design flows. Most sanitary and civil engineering consulting firms have developed tabulation forms of their own for sewer design computations. Although the forms may differ in specific details and in the order of presentation from this table, the same information is usually presented. Some engineering firms have developed computer programs for sewer design.

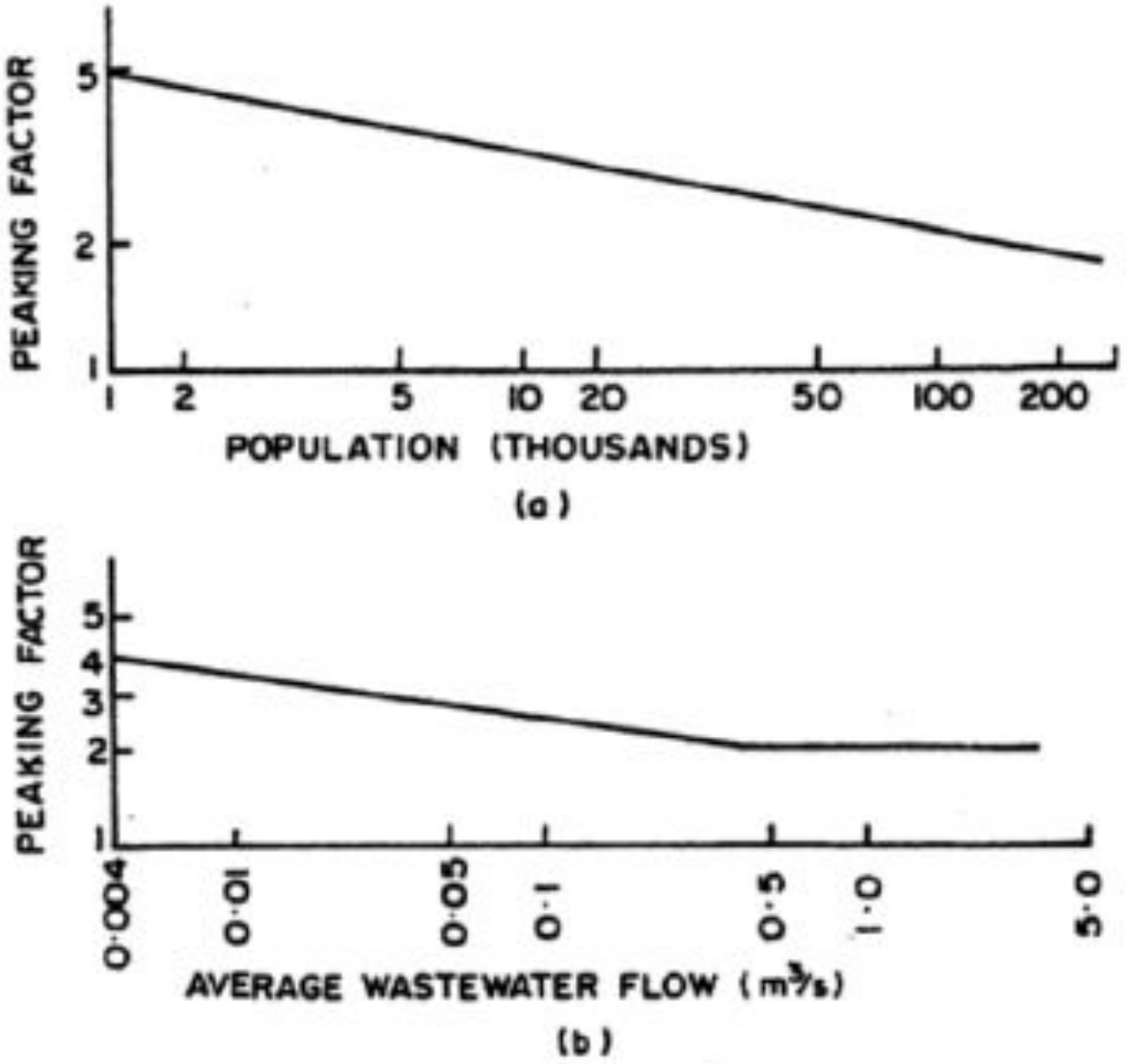


FIG. PEAKING FACTORS FOR DOMESTIC SEWAGE

Contributing Population	Peak Factor
Up to 20,000	3
20,000 to 50,000	2.5
50,000 to 7,50,000	2.25
Above 7,50,000	2

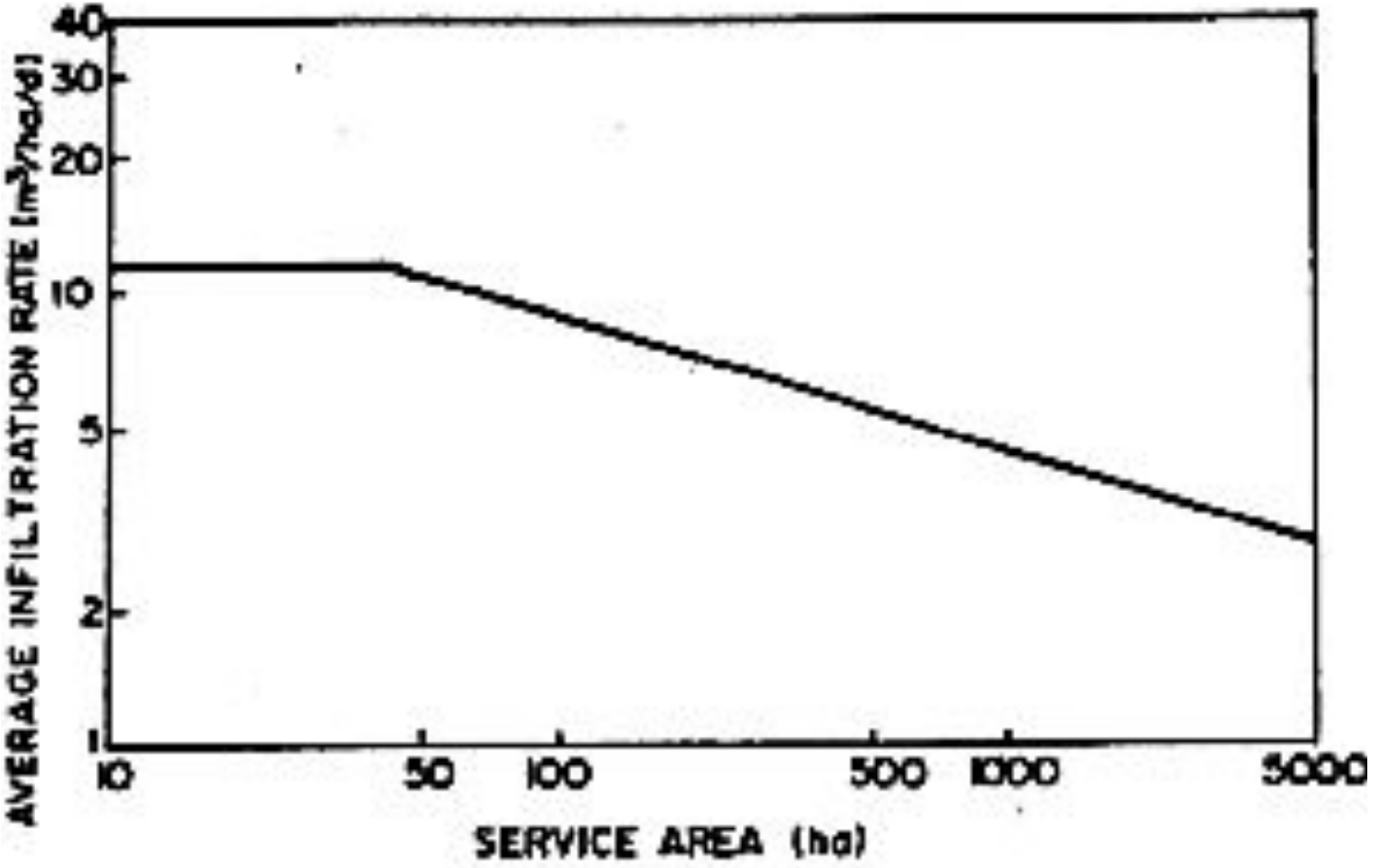
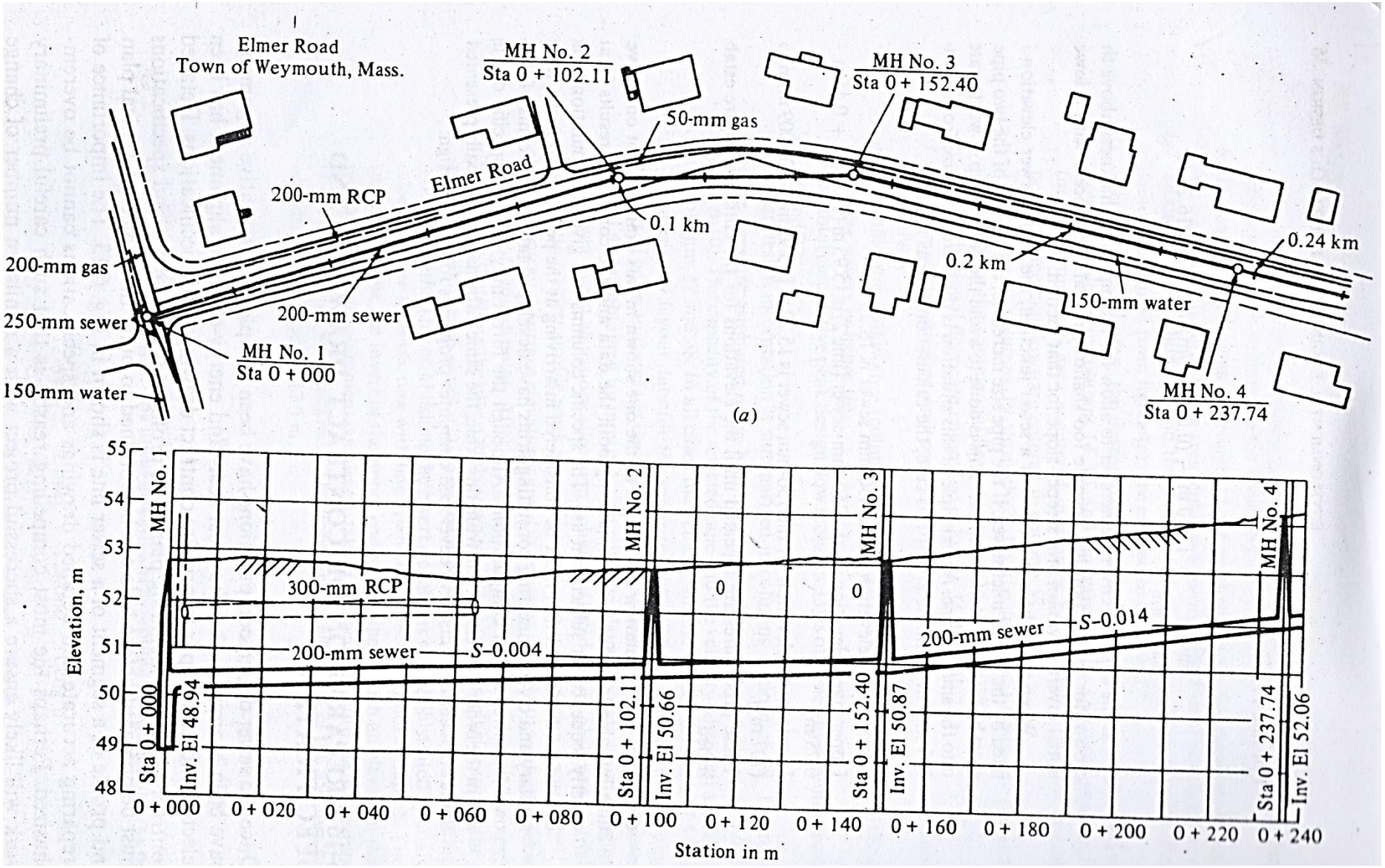


FIG. AVERAGE INFILTRATION RATE CURVE


Elmer Road
Town of Weymouth, Mass.
MH No. 2
Sta 0 + 102.11
MH No. 3
Sta 0 + 152.40
50-mm gas
Elmer Road
200-mm RCP
0.1 km
0.2 km
0.24 km
200-mm gas
250-mm sewer
200-mm sewer
150-mm water
MH No. 1
Sta 0 + 000
MH No. 4
Sta 0 + 237.74
(a)
Elevation, m
55
54
53
52
51
50
49
48
MH No. 1
MH No. 2
MH No. 3
MH No. 4
300-mm RCP
200-mm sewer — S–0.004
200-mm sewer — S–0.014
0
0
Sta 0 + 000
Inv. El 48.94
Sta 0 + 102.11
Inv. El 50.66
Sta 0 + 152.40
Inv. El 50.87
Sta 0 + 237.74
Inv. El 52.06
0 + 000
0 + 020
0 + 040
0 + 060
0 + 080
0 + 100
0 + 120
0 + 140
0 + 160
0 + 180
0 + 200
0 + 220
0 + 240
Station in m

Wastewater Collection System

(Math Prob)

Description of flow	Ratio to average
Maximum daily	2.5 to 1
Maximum hourly	3 to 1
Minimum daily	0.67 to 1
Minimum hourly	0.33 to 1

Problem 1. Estimate the maximum **hourly, average daily and minimum hourly residential sewage flows** from an area occupied by 750 people having average per capita sewage flow of 59 gpcd. Consider the length of the sewer and house connections to be 1.3 miles and infiltration to be 30,000 gpd per miles.

Solution

Design Flows:

Qav (san) = 100 % of water use (60 –80% for developed country)

Qav (design) = Qav (san) + Infiltration + Storm Inflow

Qmax (design) = 3 Qav (san) + Infiltration + Storm Inflow

Qmin (design) = 0.33 Qav (san) + Infiltration + Storm Inflow

No of people to be served = 750

Average sanitary sewage flow, Qavg (san) = 750 × 59 = 44250 g/d = 1843.75 g/h

Infiltration = 30000 × 1.3 = 39000 g/d = 1625 g/h

Qav (daily) (design) = Qav (san) + Infiltration = 44250 + 39000 = **83250 g/d**

Qmax (hourly) (design) = 3 Qav (san) + Infiltration = 3× 1843.75 + 1625 = **7156.25 g/h**

Qmin (hourly) (design) = 0.33 Qav (san) + Infiltration = 0.33× 1843.75 + 1625 = **2233.44 g/h**

Problem 2. A drainage area, having rain falls during four months of the year only, has an area of 15 ha, with 30 houses/ha. The area has the following surface characteristics:

(i) The average area of the roof is 80 m^2/house, with runoff coefficient of 0.9.

(ii) The roads occupy 25% of total area. The main roads are tarred and interior ones are of water bound macadam. Impermeability factor for these roads could be taken as 0.6.

(iii) The remaining area is open space whose coefficient of runoff may be taken as 0.12.

If the rainfall records show that the intensity of an ordinary rainstorm is 4.5 cm/h, what will be the discharge from this district? Determine the dry weather flow from the area if the population is 300 persons/ha and the rate of water supply is 250 lpcd. Also find the ratio of storm sewage to dry weather flow and indicate the suitability of separate sewerage scheme in the area in preference to combined sewerage scheme.

Solution

For the area of 1 ha,

Roof area, A1 = 30 × 80 = 2400 m^2

Equivalent roof area, A1 C1 = 2400 × 0.9 = 2160 m^2

Road area, A2 = 0.25 × 1 = 0.25 ha = 2500 m^2

Equivalent road area, A2 C2 = 2500 × 0.6 = 1500 m^2

Open space area, A3 = (10000 – (2400 + 2500) = 5100 m^2

Equivalent open space area, A3 C3 = 5100 × 0.12 = 612 m^2

$$\text{Now, } C = \frac{A_1C_1 + A_2C_2 + A_3C_3}{A_1 + A_2 + A_3}$$

$$C = \frac{2160 + 1500 + 612}{10000} = 0.43$$

Q = FCIA = 27.8 ×0.43 × 4.5 × 15 = 807 l/s

Total population to be served = 300 persons / ha = 300 × 15 = 4500 persons

Average daily sewage contribution = 80% of average water supply = 0.8 × 250 × 4500

= 900000 l/d = 10.42 l/s

Assuming that the sewer is a branch/ lateral sewer, the maximum discharge of dry weather flow,

Q max = 2.5 × 10.42 = 26.05 l/s

Now, ratio of storm sewage to max dry weather flow = 807/26.05 = 31

From this problem, it is clear that if a combined sewer is adopted for the given area, the sewer would carry only **1/ 31 th** of total discharge for about 8 months of a year. Thus, a separate sewerage scheme is most suitable for the area given in this problem. However, the modern trend for well-planned cities is to adopt combined schemes for their overall merits over separate sewerage schemes.

Storm Sewer

Determine the peak discharge for use in the design of a highway crossing a canal. The catchment has the following characteristics:

Mainstream length	L	=	3.0 km
Catch area	A	=	7.5 km^2
Mainstream slope	S	=	5.0 m/km
Catchment type:	medium soil, (C = 0.48)		

A recurrence interval of 5 years is assumed to be suitable for the crossing.

Solution: The time of concentration,

$$t_c = \frac{FL}{A^{0.1}\ S^{0.2}}$$

$$= \frac{58.5 \times 3.0}{(7.5)^{0.1} \times (5.0)^{0.2}} = \frac{58.5 \times 3.0}{1.22 \times 1.38} = 104 \text{ mins or } 1.7 \text{ hrs}$$

The design rainfall intensity for a duration of 104 minutes and recurrence interval of 5 years in an area located close to the crossing is

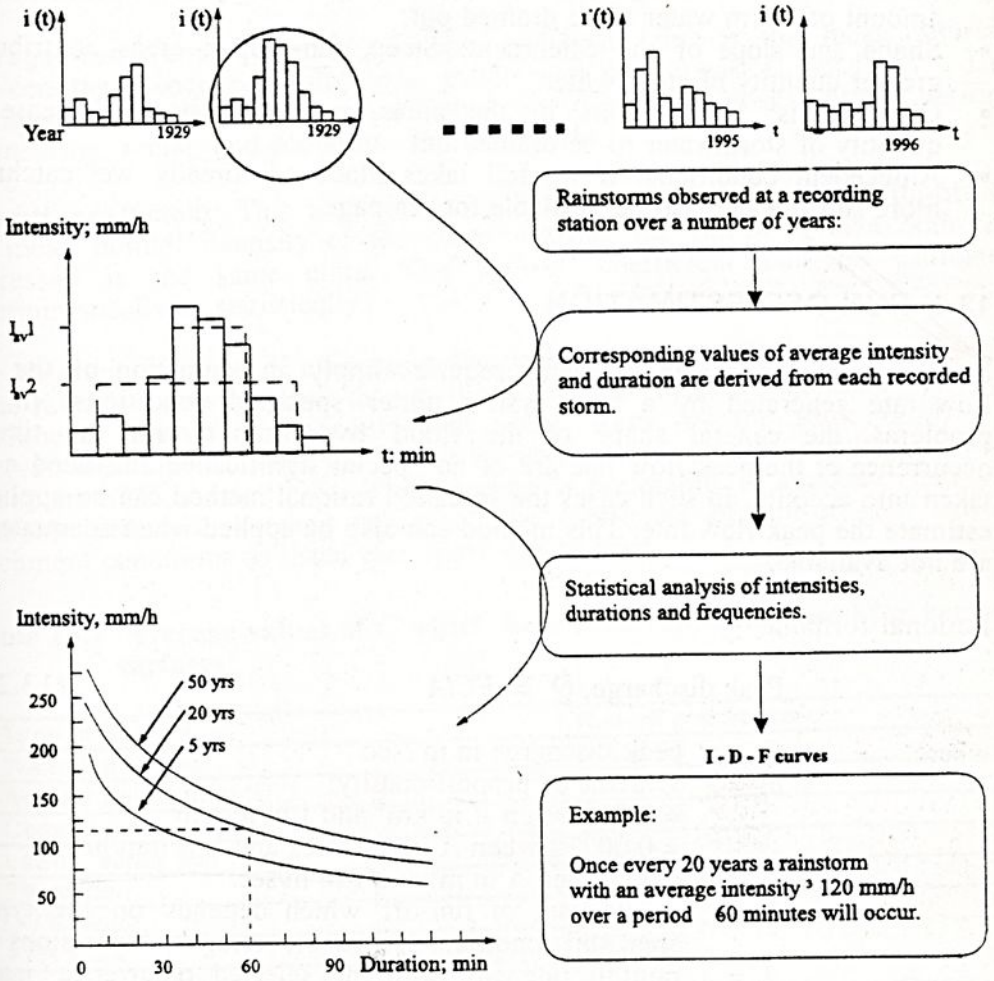
I = 70 mm/hrs [from intensity - duration - frequency curve]

The peak discharge can be found by using the rational formula,

$$Q = FCIA$$
$$= 0.278 \times 0.48 \times 70 \times 7.5$$
$$= 70.0 \text{ } m^3/sec$$

$$t_c = \frac{FL}{A^{0.1} S^{0.2}}$$

where t_c = time of concentration in minutes
F = factor of proportionality,
58.5 when A in km^2,
92.7 when A in hectares
L = mainstream length (km)
A = catchment area
S = mainstream slope (m/km)



IDF Curve

Example 2

Also determine the diameter of the storm sewer crossing the highway, for the above example, with sewer material having $n = 0.013$ and laid at a slope of 0.001. The velocity at full flow should be less than 3.0 m/sec.

Solution:

Discharge $Q = AV$

$$= \frac{\pi D^2}{4} (1/n\ R^{2/3}\ S^{1/2}) \quad \text{[using Manning's equation]}$$

$$\text{or,} \quad 70.0 = \frac{\pi D^2}{4} \times \frac{1}{0.013} (D/4)^{2/3}\ (0.001)^{1/2}$$

$$= D^2 . D^{2/3} . \pi/4 \times 1/0.013 \times (1/4)^{2/3} \times (0.001)^{1/2}$$

$$= D^{8/3} \times 0.76$$

$$\therefore \quad D^{8/3} = 70/0.76 = 92.10$$

$$\therefore \quad D = 5.5 \text{ m}$$

Use 5500 mm diameter storm sewer.

Check for velocity:

$$V = Q/A = \frac{70.0 \times 4}{\pi \times 5.5 \times 5.5}$$

$$= 2.95 \text{ m/sec. } 3.0 \text{ m/sec. Hence the velocity is o.k.}$$

Example:

A combined sewer was designed to serve an area of 60 sq. km with an average population density of 185 persons/hectare. The average rate of sewage flow is 350 L/Capita/day. The maximum flow is 50% in excess of the average sewage flow. The rainfall equivalent of 12 mm in 24 h can be considered for design, all of which is contributing to surface runoff. What will be the discharge in the sewer? Find the diameter of the sewer if running full at maximum discharge.

Solution:

Total population of the area = population density x area

$= 185 \times 60 \times 10^2$

$= 1110 \times 10^3$ persons

Average sewage flow $= 350 \times 11.1 \times 10^5$ Liters/day

$= 4.5$ m^3/sec

$= 388.5 \times 10^5$ L/day

Storm water flow $= 60 \times 10^6 \times (12/1000) \times [1/(24 \times 60 \times 60)]$

$= 8.33\ m^3/sec$

Maximum sewage flow $= 1.5 \times$ average sewage flow

$= 1.5 \times 4.5 = 6.75\ m^3/sec$

Total flow of the combined sewer = sewage flow + storm flow

$= 6.75 + 8.33 = 15.08\ m^3/sec$

Hence, the capacity of the sewer $= 15.08\ m^3/sec$

Hence, diameter of the sewer required at the velocity of 0.9 m/s can be calculated as

$\pi/4\ (D)^2 \times 0.90 = 15.08\ m^3/s$

Hence, $D = 4.62$ m

Example:

A 300 mm diameter sewer is to flow at 0.3 depth on a grade ensuring a degree of self cleansing equivalent to that obtained at full depth at a velocity of 0.9 m/sec. Find the required grade and associated velocity and rate of discharge at this depth. Assume Manning's rugosity coefficient n = 0.013. The variation of n with depth may be neglected.

Solution:

Manning's formula for partial depth

$$v = \frac{1}{n} r^{2/3} s^{1/2}$$

For full depth

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

Using V = 0.90 m/sec, N = n = 0.013 and R = D/4 = 75 mm = 0.075 m

$$0.90 = \frac{1}{0.013} 0.075^{2/3} S^{1/2}$$

S = 0.0043

This is the gradient required for full depth.

and, $Q = A.V = \pi/4\ (0.3)^2 \times 0.90 = 0.064\ m^3/s$

At depth d = 0.3D, (i.e., for d/D = 0.3) we have a/A = 0.252 and r/R = 0.684 (neglecting variation of n)

$\gamma_w \cdot r \cdot s_s = \gamma_w \cdot R \cdot S$

Hence,

$s_s = (R/r)\, S$

Or $\dfrac{s_s}{S} = \dfrac{R}{r}$

$d/D = \frac{1}{2}\left(1 - \cos\dfrac{\theta}{2}\right)$

$r / R = (1 - 360 \sin \theta / 2\pi\, \theta)$

$a/A = (\theta/360 - \sin\theta/2\pi)$

Now for the sewer to be same self cleansing at 0.3 depth as it will be at full depth, we have the gradient (s_s) required as $s_s = (R/r)S$

Therefore, $s_s = S / 0.684$

$= 0.0043 / 0.0684 = 0.0063$

Now, the velocity v_s generated at this gradient is given by

$$v_s = V\frac{N}{n}\left(\frac{r}{R}\right)^{1/6}$$

$= 1 \times (0.684)^{1/6} \times 0.9$

$= 0.846$ m/s

The discharge q_s is given by

$$q_s = Q\frac{N}{n}\frac{a}{A}\left(\frac{r}{R}\right)^{1/6}$$

$q_s = 1 \times (0.258) \times (0.939) \times (0.064)$

$= 0.015$ m^3/s

$$\frac{v_s}{V} = \frac{N}{n}\left(\frac{r}{R}\right)^{2/3}\left(\frac{s_s}{S}\right)^{1/2}$$

OR, by substituting $r/R = S/s_s$

$$\frac{v_s}{V} = \frac{N}{n}\left(\frac{r}{R}\right)^{1/6}$$

And

$$\frac{q_s}{Q} = \frac{N}{n}\frac{a}{A}\left(\frac{r}{R}\right)^{1/6}$$

Example:

Design a sewer running 0.7 times full at maximum discharge for a town provided with the separate system, serving a population 80,000 persons. The water supplied from the water works to the town is at a rate of 190 LPCD. The manning's n = 0.013 for the pipe material and permissible slope is 1 in 600. Variation of n with depth may be neglected. Check for minimum and maximum velocity assuming minimum flow 1/3 of average flow and maximum flow as 3 times the average.

Solution

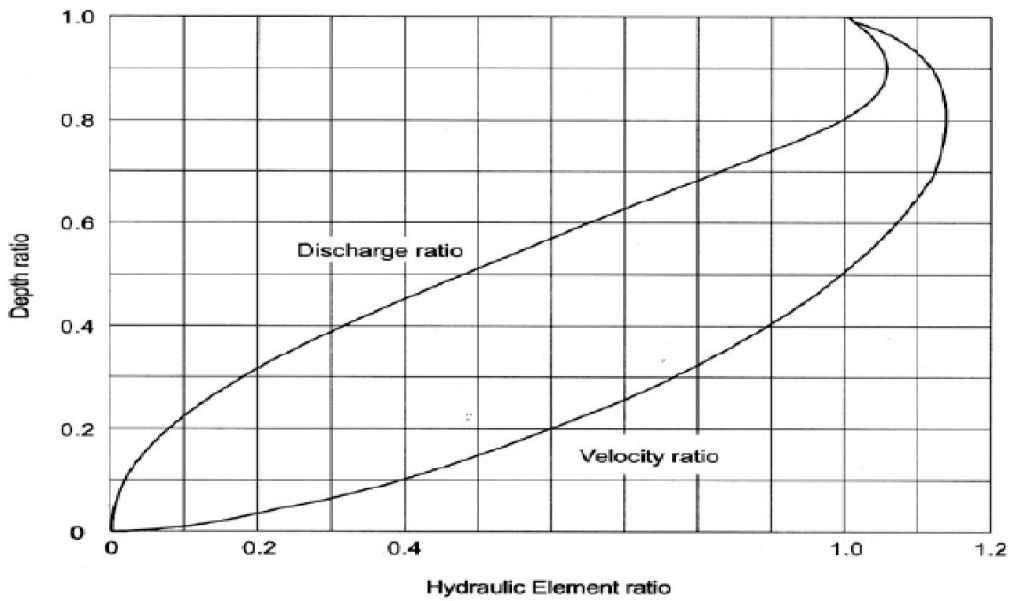
Average water supplied = 80000 x 190 x (1/24 x 60 x 60 x 1000) = 0.176 m^3/sec

Sewage production per day, (considering 80% of water supply) = 0.176 x 0.8 = 0.14 m^3/sec

Maximum sewage discharge = 3 x 0.14 = 0.42 m^3/sec

Now for d/D = 0.7, q/Q = 0.838, v/V = 1.12

Therefore, Q = 0.42/0.838 = 0.5 m^3/sec



Now

$$Q = \frac{1}{n}\frac{\pi D^2}{4}\left(\frac{D}{4}\right)^{2/3} S^{1/2}$$

$$Q = \frac{1}{0.013}\frac{\pi D^2}{4}\left(\frac{D}{4}\right)^{2/3}\left(\frac{1}{600}\right)^{1/2}$$

Therefore, D = 0.78 m

Check for maximum velocity

V = Q/A = 1.04 m/sec

Now, v/V = 1.12

Therefore v = 1.12 x 1.04 = 1.17 m/sec

This velocity is less than limiting velocity **3 m/s** hence, OK

Check for minimum velocity

Now $q_{min} = 0.14/3 = 0.047$ m^3/sec

$q_{min}/Q = 0.047/0.5 = 0.09$

From proportional chart, for q/Q = 0.09, d/D = 0.23 and v/V = 0.65

Therefore, the velocity at minimum flow = 0.65 x 1.04 = 0.68 m/sec

This velocity is greater than self cleansing velocity **0.6 m/s** hence OK

Assignment: Solve the above problem with population 100000 persons and pipe flowing 0.75 full at maximum discharge. The rate of water supply is 150 LPCD, n = 0.013, and permissible S = 1 in 600.

Problems to Solve:

1. An 18 inch sewer with n=0.013 is laid on a slope of 0.015.
   a) What is the capacity when flowing half full?
   b) What will be the velocity when the depth of flow is 4.5 inch.

Problem: Determine the rate of discharge and discharge velocity in a 30 cm circular sewer with n = 0.013, slope = 0.004 and depth of flow equal to 7.5 cm, using both of the Nomograms and Partial flow diagram, given below.

Solution

From the nomograms –

for slope =0 .004 (m/m) = 4m/ 1000 m and diameter, D = 30 cm,

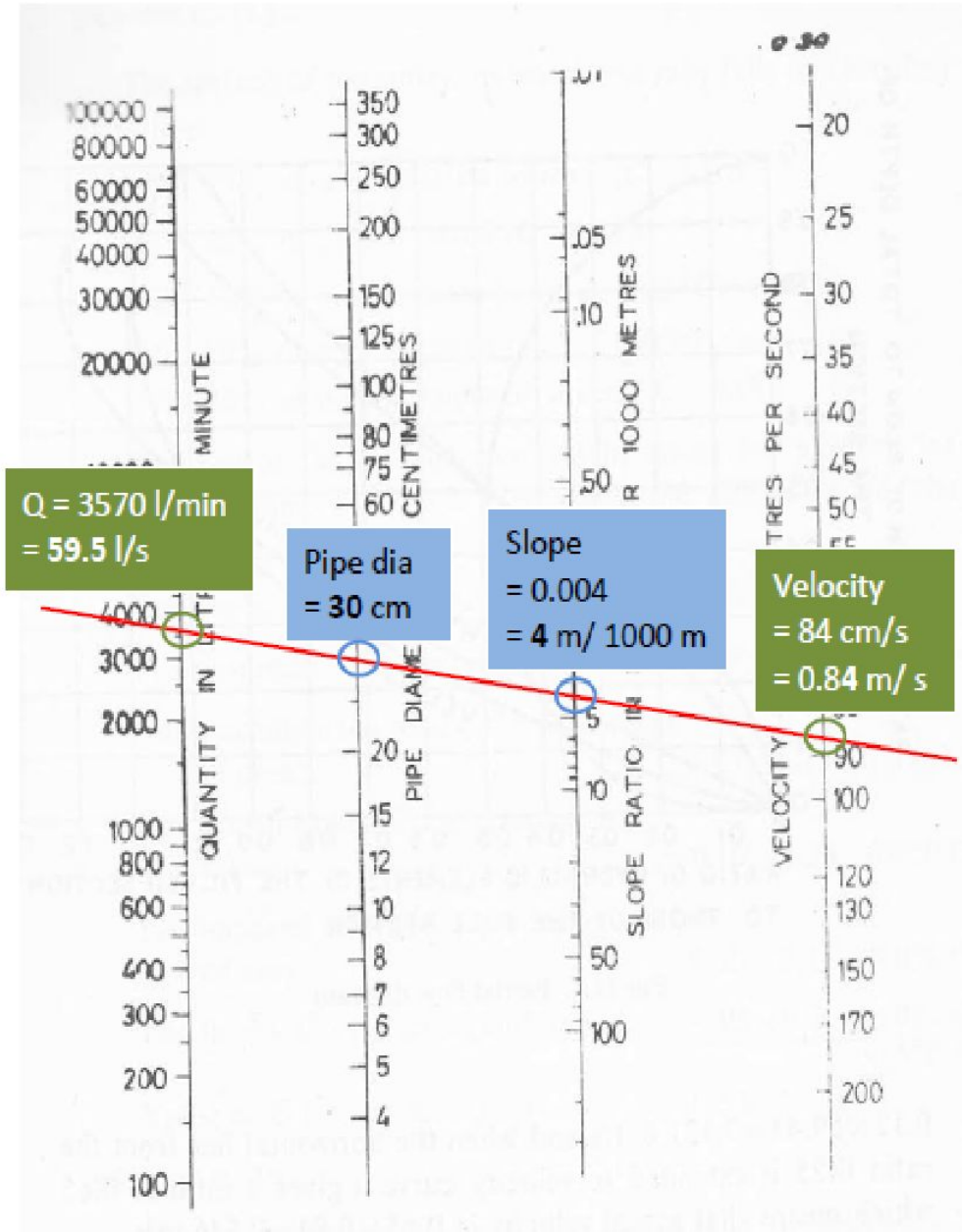
Discharge, Q = 3570 l/min = 59.5 l/s and Velocity, V = 84 cm/s = 0.84 m/s

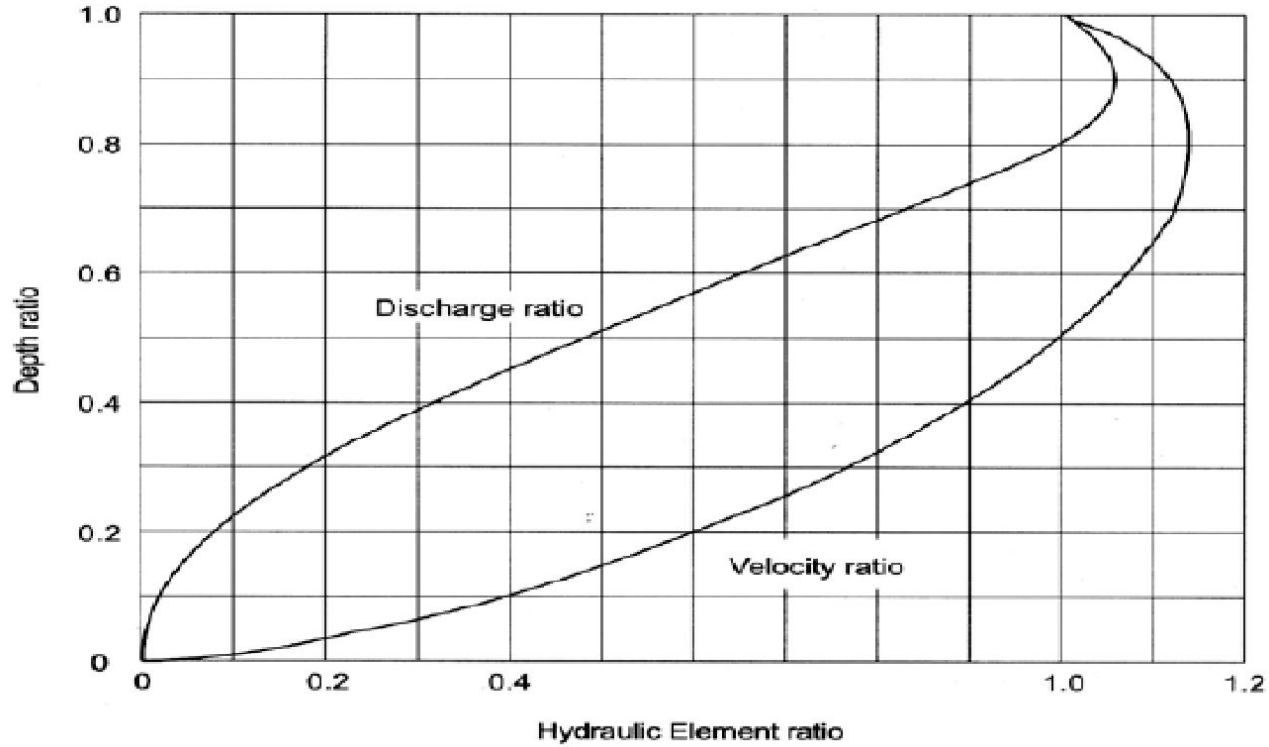
Now, depth ratio, d/D = 7.5 / 30 = 0.25

From the partial flow diagram, q/Q = 0.12

Therefore, q = 0.12 × 59.5 = **7.14 l/s**

Again, v = 0.65 × 0.84= **0.55 m/s**


Q = 3570 l/min
= 59.5 l/s
Pipe dia
= 30 cm
Slope
= 0.004
= 4 m/ 1000 m
Velocity
= 84 cm/s
= 0.84 m/ s
QUANTITY IN LITRES PER MINUTE
PIPE DIAMETRES IN CENTIMETRES
SLOPE RATIO IN 1000 METRES
VELOCITY IN METRES PER SECOND


Depth ratio
Discharge ratio
Velocity ratio
Hydraulic Element ratio
0
0.2
0.4
0.6
0.8
1.0
1.2



Infiltration



Inflow

I & I

Problem: A trunk sewer is to be sized for a 25 km^2 (2,500 ha) city with a naturally sloped towards the major river with a gradient of 1 in 1000. It will be 60% residential, 30% commercial, and 10% industrial. The residential area will have 40% large lots, 55% small single family lots, and 5% multi-story apartments. The average domestic wastewater flow rate is 800 L/d/capita (9.26×10^{-6} m^3/sec/person), the average commercial flow rate is 25,000 L/D/ha ($2.89 \times I0^{-4}$ m^3/sec/ha), and the average industrial flow rate is 40,000 L/d/ha ($4.63 \times I0^{-4}$ m^3/sec/ha). I & I is 1,000 L/d/ha for the entire area. Estimate the peak and minimum flows to be handled by the trunk sewer. Given: $Q_{peak}/Q_{avg} = 5.5/(p^{0.18})$ and $Q_{min}/Q_{avg} = 0.2(p^{0.16})$,where *'p' is the total city* population in thousands. Also design the sewer based on the estimated flow and the saturation densities for the residential areas given in the table below:

Type of area	Density (Persons/ha)
Large lots	5-7
Small lots, single-family	75
Small lots, two-family	125
Multistory apartments	2,500

Type	Area(ha)	Density (persons/ha)	Population	Flow (m^3/s)
Large lots	0.4(1500)= 600	6	3,600	0.03
Small single family lots	0.55(1500) = 825	75	61,875	0.57
Multistory apartments	0.05(1500) = 75	2500	187,500	1.74
Total			**252,975**	**2.34**

Commercial sector = 30% of 2500 ha = 750 ha
Average flow from commercial sector = 750x25,000 L/d= 0.22 m^3/s

Industrial sector = 10 % of 2500 ha = 250 ha
Average flow from industrial sector = 250x40,000 L/d = 0.12 m^3/s
Thus,
Average wastewater flow (excluding I/I) = 2.34+0.22+0.12 = 2.68 m^3/s
Assuming total population is equal to residential population, i.e.

P= 252,975

Then,

$$\frac{Q_{peak}}{Q_{ave}} = \frac{5.5}{(P/1000)^{0.18}} = \frac{5.5}{(252.975)^{0.18}} = 2.0$$

$$\frac{Q_{\min}}{Q_{ave}} = 0.2(P/1000)^{0.16} = 0.2(252.975)^{0.16} = 0.48$$

Hence,

Peak flow = Peak factor x wastewater + I/I = 2.0(2.68)+0.03= 5.39 m^3/s

Minimum flow = 0.48(2.68) + 0.03 = 1.32 m^3/s

Using Manning's Equation for a full-flowing pipe (n=0.013 for concrete) at a gradient S=0.001

$$Q = \frac{1}{n} \cdot \frac{\pi D^2}{4} \cdot (\frac{D}{4})^{2/3} \cdot S^{1/2}$$

$$D = \left(\frac{5.39 \cdot 0.013}{0.3117 \cdot \sqrt{0.001}} \right)^{3/8}$$

$$D = \left(\frac{0.07007}{0.009857} \right)^{3/8} \approx 2.278 \text{ m}$$

Velocity Check:

It is essential to ensure the flow velocity (V) is within the self-cleansing range (typically 0.6 m/s to 3.0 m/s)

$$V = \frac{Q}{A} = \frac{5.39}{\frac{\pi \cdot 2.28^2}{4}} \approx 1.32 \text{ m/s}$$

Since 1.32 m/s is greater than 0.6 m/s and less than 3.0 m/s the design is hydraulically stable.

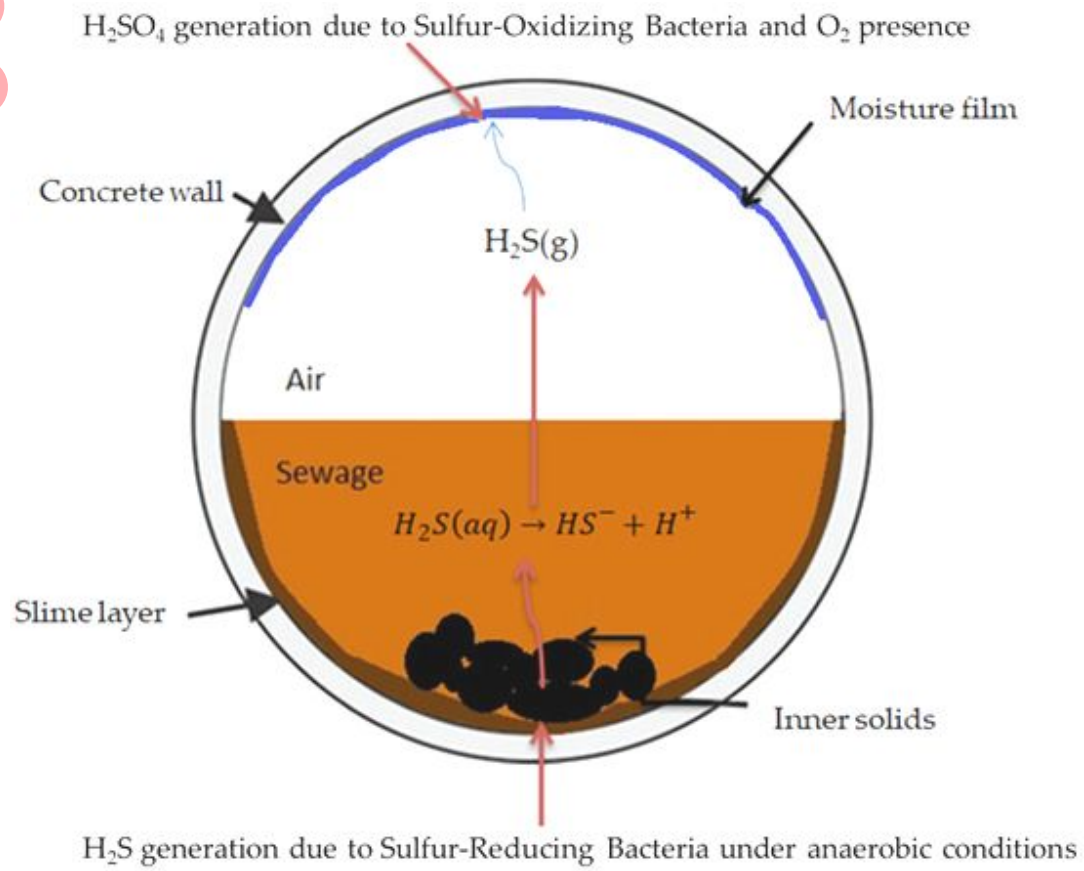
The design requires a sewer pipe with a diameter of **2.28 meters** (or the nearest standard commercial size, such as 2300 mm)

Why does H_2S form in sewers?

H_2S is formed by anaerobic processes in the thin slime layer that develops on the inside of the sewer walls as organic material in the sewage breaks down.

The formation of H_2S in wastewater mainly depends on:

- Flow (velocity) of sewage in pipes
- Slope of the pipe
- Ratio of wetted perimeter of the pipe wall to surface width of the stream
- Temperature of the sewage
- Biochemical oxygen demand (BOD)



Sulfide Generation

$$Z = 0.308 \frac{EBOD}{S_0^{0.5} Q^{0.33}} \times \frac{P}{B}$$

$$EBOD = BOD \times 1.07^{T-20}$$

$BOD =$ 5-day biochemical oxygen demand

$S_0 =$ Slope of the pipe

$Q =$ Discharge through the pipe

$P, B =$ Wetted perimeter and top width of the flow, respectively

$$P = \frac{D\theta}{2}$$

Top Width, B= D sin (θ/2)

Z values	Sulfide Condition
$Z < 5{,}000$	Sulfide rarely generated
$5{,}000 < Z < 10{,}000$	Marginal condition for sulfide generation
$Z > 10{,}000$	Sulfide generation common

Problem: A 2000 mm dia. RCC pipe is laid with a slope of 0.0015 for a design flow of 0.6 m^3/sec when flowing partially full having a width of 1.414m at the top. The sewer pipe provided is designed to carry domestic sewage having BOD_5 of 200 mg/L and a maximum temperature of 30°C. Determine the potential for Sulfide Generation (Z).

Step 1: Calculate the Effective BOD ($EBOD$)

The Effective BOD accounts for the increased biological activity at higher temperatures. It is calculated using the formula:

$$EBOD = BOD_5 \cdot 1.07^{(T-20)}$$

Given,

BOD_5=200 mg/L, T=30^0C

$$EBOD = 200 \cdot 1.07^{(30-20)} = 393.43 \text{ mg/L}$$

Step 2: Determine Geometric Parameters

For a circular pipe with diameter

D=2000 mm =2.0 m

R=1.0 m and a top width of flow B=1.414 m

Find the central angle

B=2Rsin (θ/2)

1.414=2(1.0) sin (θ/2) $\Longrightarrow$sin (θ/2)=0.707$\Longrightarrow\theta$/2=45^0

θ=90^0 (or π/2 radians).

Find the wetted perimeter

P=$R\cdot\theta$=1.0$\cdot\pi$/2≈1.571 m

Calculate the ratio

P/B =1.571/1.414≈1.111

Step 3: Calculate the Z-index

The Z-index formula is defined as:

$$Z = 0.308 \frac{EBOD}{S_0^{0.5} Q^{0.33}} \times \frac{P}{B}$$

Substitute the given values (S=0.0015, Q=0.6 m^3/sec)

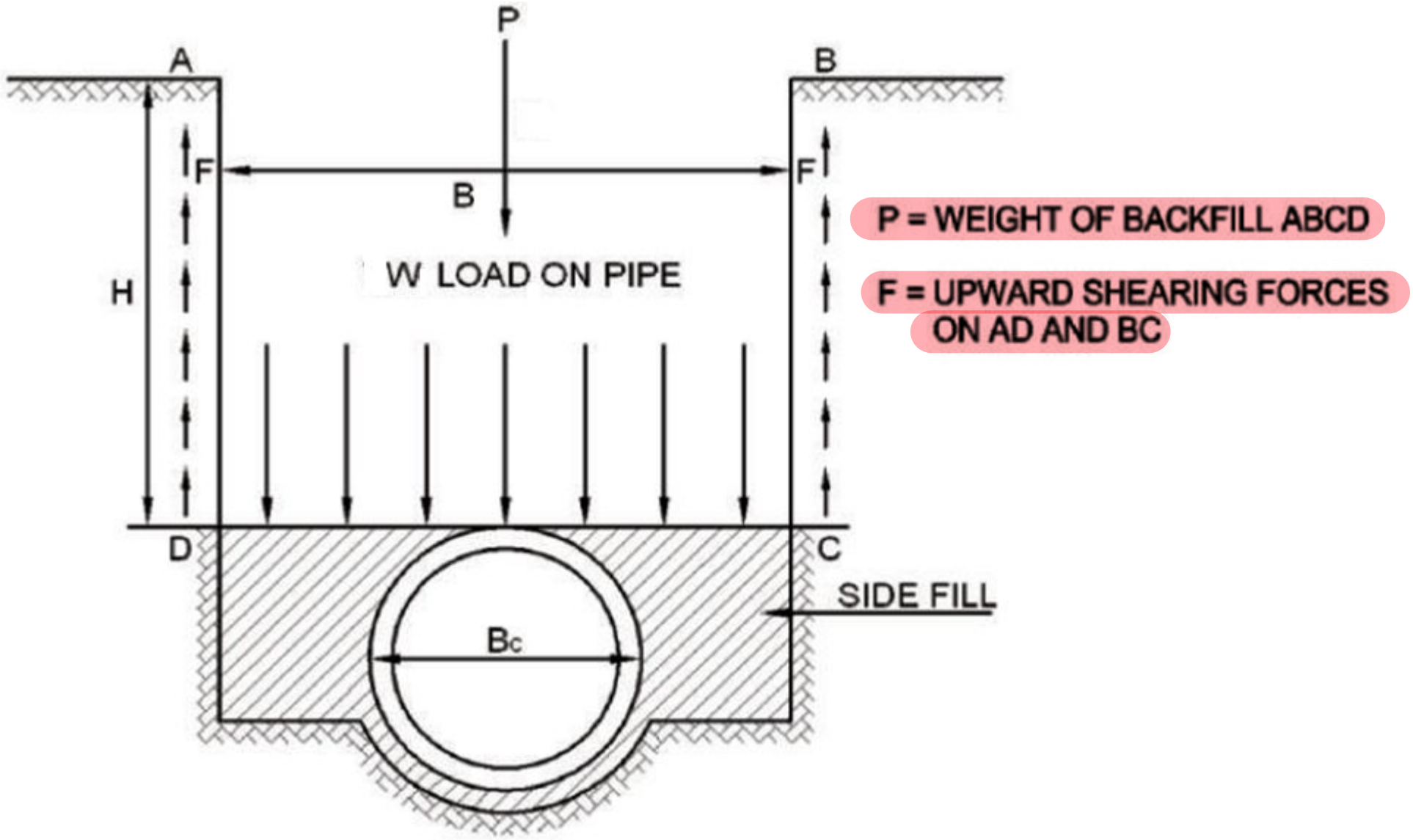
Z = 0.308 (393.43x1.111)/ $(0.0015)^{1/2}$x $(0.6)^{1/3}$

Z= 0.308 (393.43 x 1.111)/(0.03873 x 0.8434) ≈ 134.63/ 0.03266 ≈ 4,122

The potential for Sulfide Generation (Z) is 4,122. Since this value is less than 5,000, sulfide generation is **likely** not to occur.

Loads on Sewer

- In a buried sewer, stresses are induced by external loads and by internal pressure in case of a pressure main.
- The external loads are of two categories viz., load due to backfill material known as backfill load and superimposed load, which again is of two types viz. concentrated load and distributed load.
- The load on a buried conduit is equal to the weight of the prism of earth directly over the conduit, called the interior prism of earth plus or minus the frictional shearing forces transferred to the prism by the adjacent prism of earth.


P
A
B
F
F
B
W LOAD ON PIPE
H
P = WEIGHT OF BACKFILL ABCD
F = UPWARD SHEARING FORCES ON AD AND BC
D
C
SIDE FILL
Bc

Loads on Sewer

The general form of Marston's formula is

$$W = C\,w B^2$$

Where,

W : Load on the pipe in kg/m

w : Unit weight of backfill soil in kg/m^3

B : Width of trench at the top of the pipe in m and

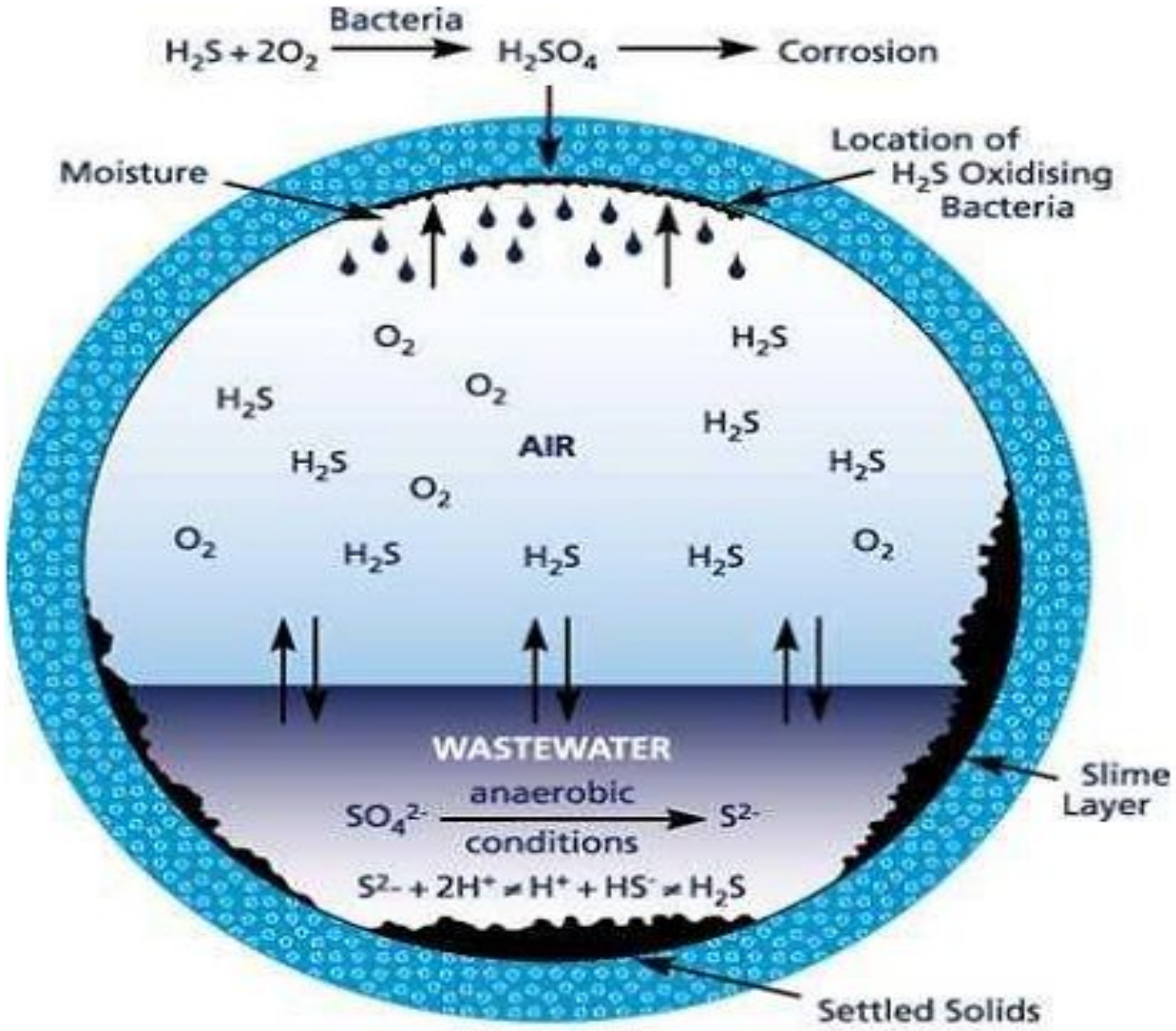
C : Load coefficient which is a function of a ratio of height of fill to width of trench (H/B) and of the friction coefficient between the backfill and the sides of the trench.

Maintenance of Sewerage System

- Maintenance of sewers consists mainly of the removal or prevention of stoppages, cleaning of sewers and other sewer appurtenances and repair works.
- Maintenance of sewers becomes costly when they are laid on flat gradients and tree roots find easy entrance in sewers through defective joints.
- The maximum expenditure in maintenance comes on the cleaning of sewers,
- Which have been clogged due to deposition of silt, grease and oily materials.

Sewer

- Most sewers are **circular** in section. Other shapes such as **egg-shaped, rectangular** etc. were formerly used, especially in combined sewers.
- **Clay, concrete, cast-iron, asbestos** and **PVC** pipes were generally used as sewer pipes. Due to health hazards use of asbestos has been banned.
- Concrete is somewhat susceptible to corrosion by H_2SO_4 from H_2S gas generated in sewers or from industrial wastes.
- In case of sewage is strong, stable and very warm hasten the bacterial activities, thus generation of hydrogen sulfide. It is advisable to use clay pipe for diameter smaller than 24 inches and concrete pipes for cast in-situ plastic linings for larger sizes.
- The smallest sizes are 3-4 inches for house connections.


Bacteria
$H_2S + 2O_2$
H_2SO_4
Corrosion
Moisture
Location of H_2S Oxidising Bacteria
O_2
H_2S
AIR
WASTEWATER
anaerobic conditions
SO_4^{2-}
S^{2-}
$S^{2-} + 2H^+ \rightleftharpoons H^+ + HS^- \rightleftharpoons H_2S$
Slime Layer
Settled Solids

Sewer lines



Brickwork sewer line



HDPE sewer pipe



RCC sewer pipes



A view inside a sewer in London

Small Bore Sewerage (SBS) System

- High cost of conventional sewerage has stimulated interest in alternative low-cost proposals to extend adequate sanitation services to medium and low-income communities.
- Small Bore Sewerage (SBS) system is a recent sanitation technology.
- This system offers all the advantages of conventional sewerage systems at a much lower cost.

Three basic elements of SBS system:

- septic tanks;
- small bore sewer network;
- treatment plant

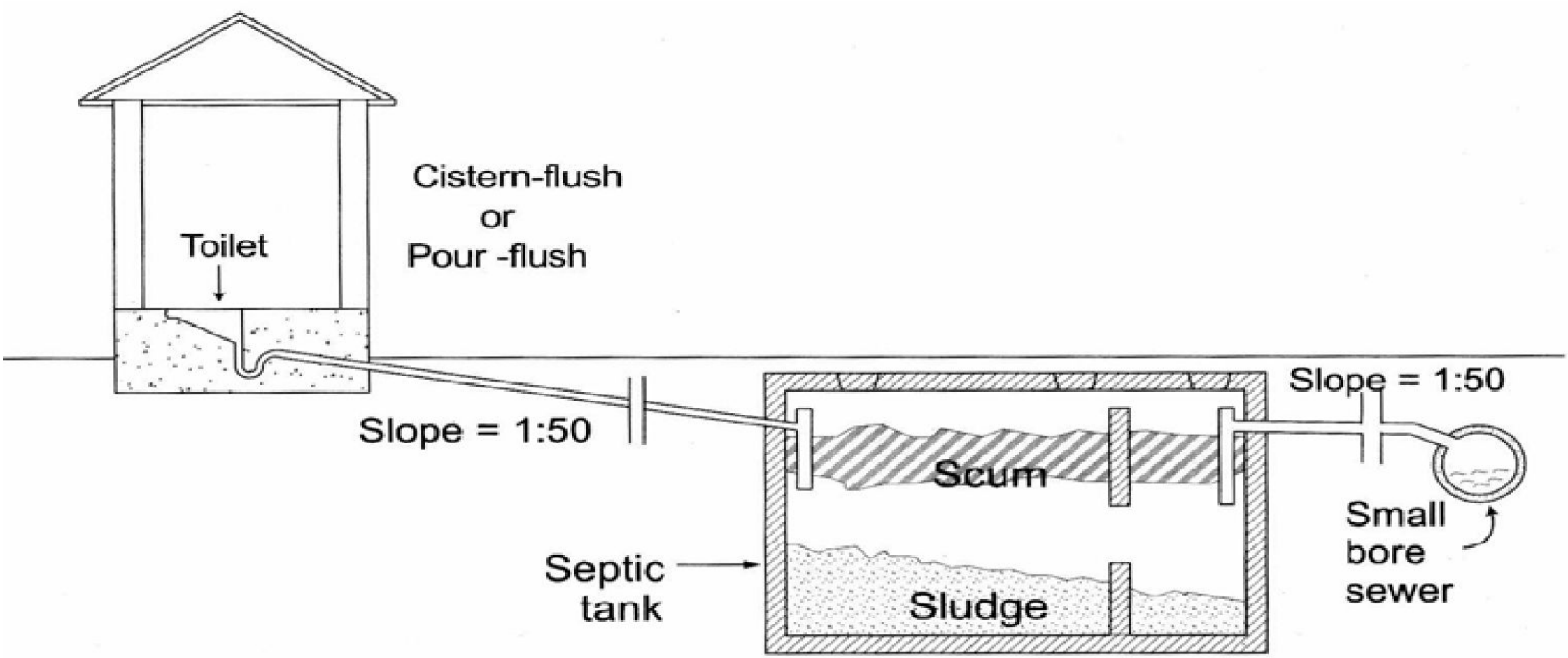


Figure: Elements of small bore sewerage system

Small Bore Sewerage (SBS) System

- They are designed to carry only the liquid part of the domestic sewage generated for off-site treatment or disposal.
- Solids are separated at a septic tank or at the aqua-privies before the sewage reaches the sewers.

Advantages:

- Sewer sizes can be reduced because each septic tank tends to act as a balancing tank, largely eliminating surge.
- Since the wastewater contains minimum solids, self-cleansing velocities are not necessary and hence sewer grades can be substantially reduced.
- Sewer blockages are minimal as septic tanks retain most of the solids content.

Small Bore Sewerage (SBS) System

Advantages:

- Volume of excavation is considerable reduced because of smaller sewers and lower sewer grades.
- Solids handling at the secondary treatment site is minimum.
- Rapid construction is possible because of lesser volume of excavation and fewer number of manholes to be constructed.

The small bore sewer system outfall can be any of the following:

a)The conventional sewer system

b) Waste stabilization ponds

c) Any other low cost treatment systems followed by fish ponds or land based disposal with precautions

Small Bore Sewerage (SBS) System

Limitations:

- Interceptor tank requires periodical cleaning and disposal of solids
- Any illegal connection without any interceptor tank shall ruin the system. So, strict vigilance is required.
- Septic tank installation is mandatory which is not required in conventional sewerage system.
- Inspection and desludging of septic tank are additional burden.
- The SBS system needs frequent flushing.

only carries solids
smaller pipe
less slope

Basic Difference with Conventional Sewerage System

- Incorporation of septic tanks within the individual premises.
- The wastewater from septic tank is transported through a network of sewers to a treatment plant comprising a series of stabilization lagoons.
- In the case of an existing septic tank system the sewer installation commences immediately downstream, and
- New developments must install septic tanks to be able to connect to the SBS system.

Design Criteria for SBS

Design Flows:

- **Wastewater flows**: 40-80 lpcd with yard tap supplies and 80-120 lpcd with multiple tap in-house supplies.
- **Design Flow** Peak Factor: peak factor of 2 should be adopted for SBS.
- **Groundwater Infiltration and Surface Inflow**: Can be eliminated in SBS system by using solvent jointed UPVC as sewer materials

Sewer Diameter:

- SBS system can employ a minimum sewer size of as low as 50 mm
- if flow is more than 60% of full capacity next higher size should be adopted
- a minimum diameter of 100 mm may be recommended in case of unavailability of cleaning equipment.

Sewer Gradients:

- it is not necessary to maintain a self-cleansing velocity in SBS
- grades can be substantially reduced in SBS by reducing the volume of excavation

Manholes:

- requires less maintenance due to minimal solids content
- a fewer number of manholes are installed.

Simplified Sewerage System

- Low-cost sanitation technology particularly suited to high-density, low-income urban areas in developing countries.
- These are modification of surface drain with covers and consist of a network of pipe laid in the areas away from the places where heavy sewage loads are expected.
- Receives all household wastewater without settlement in septic tanks.
- Pipes are laid in flat gradients following the natural slope of the ground. The minimum depth is 0.4 m.
- Laid flatter gradient than conventional sewerage- slope is determined by tractive tension (not by minimum velocity).
- Sewers are not beneath the central roads, but within the property boundaries and beneath the sidewalks.
- Capital cost is lower (50-80% lesser than conventional sewerage) and operating costs are lower.

Simplified Sewerage System

System contains:

a) House connections

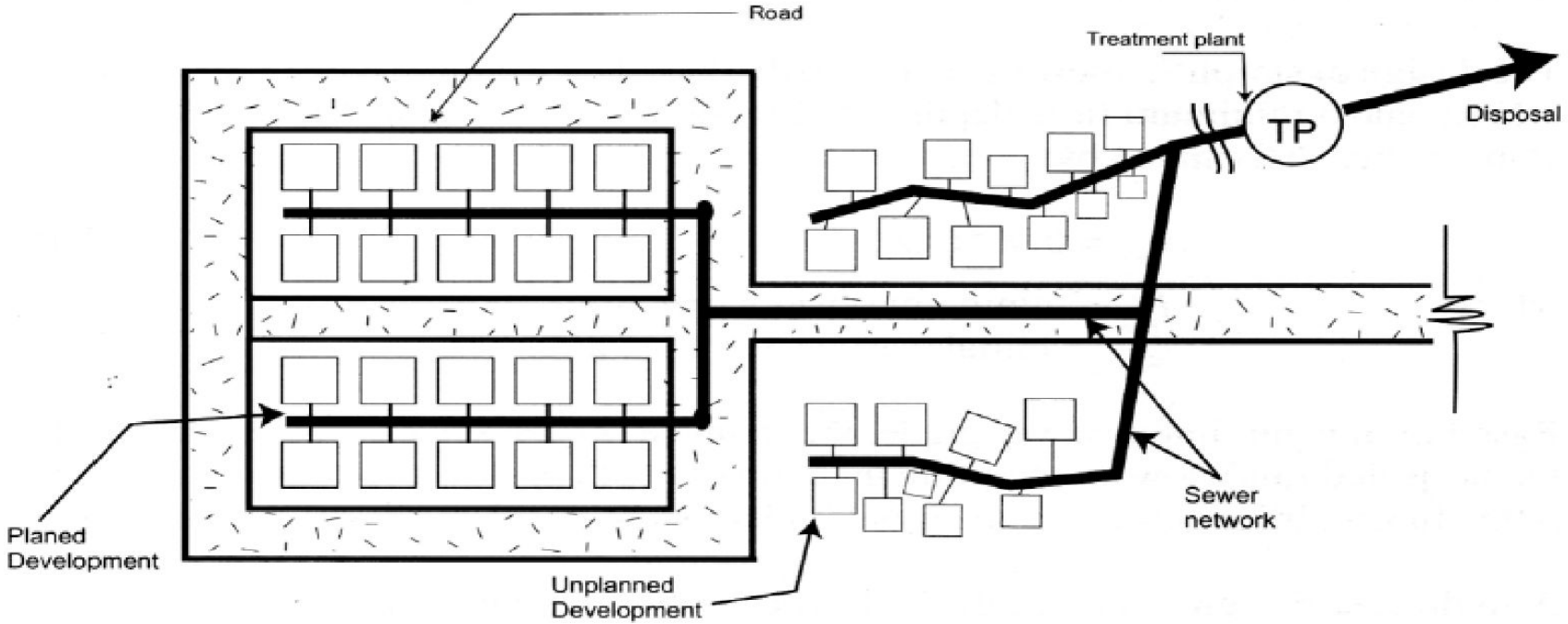
b) Inspection chambers

c) Laterals (minimum diameter of 100 mm)

d) Street-collector sewers (minimum diameter of 150 mm)

e) Pumping stations

Model layout of a small simplified sewerage scheme





Simplified Sewerage System

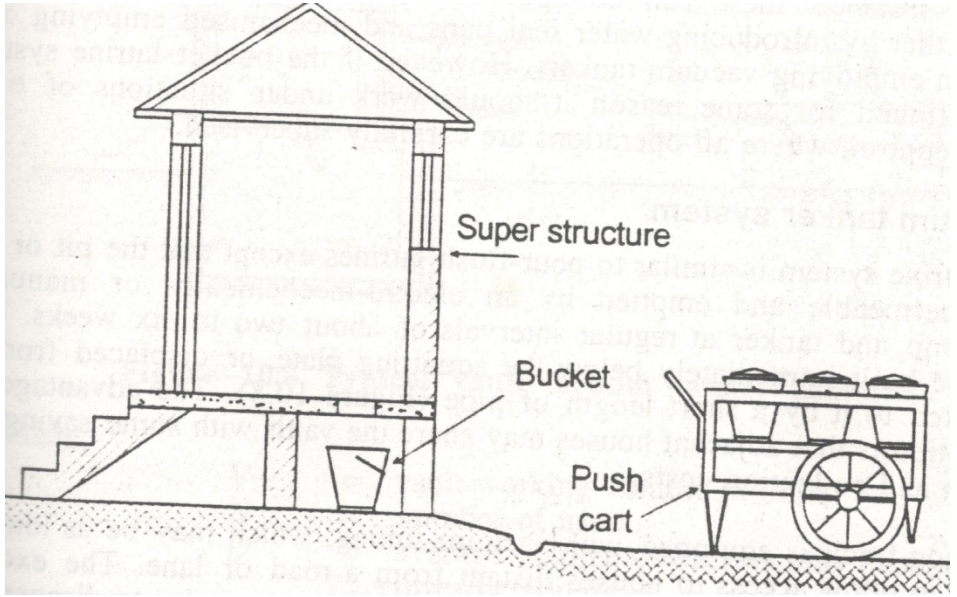
Suitability of the system:

- High density habitats such as slums or squatter settlements (with population density more than 170 per ha)
- Ground-condition is adverse and on-site disposal is not possible
- Sewage has to be disposed of and minimum water consumption is 25 lpcd.

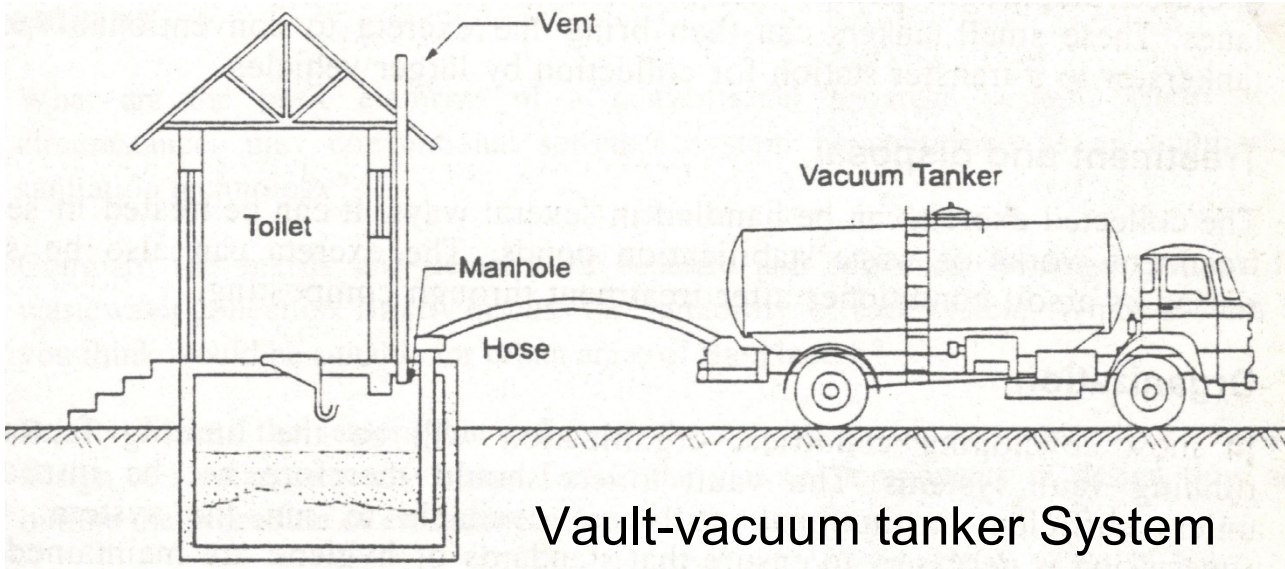
Limitations:

- It is suitable when suitable ground slope is available
- Unless flushed out at peak flow rates, there is a possibility of solids deposition if there is not enough ground slope available
- May require frequent cleaning

Non-sewered Transportation of Wastewater



Bucket Latrine System



Vault-vacuum tanker System

Sewer Appurtenances

- The structures, which are constructed at suitable intervals along the sewerage system to help its efficient operation and maintenance, are called as sewer appurtenances.
- They include manholes, lamp holes, street inlets, catch basins, inverted siphons etc.

Manholes

- Man holes are the openings of either circular or rectangular in shape constructed on the alignment of a sewer line to enable a person to enter the sewer for inspection, cleaning and flushing.
- They serve as ventilators for sewers, by the provisions of perforated man-hole covers. Also they facilitate the laying of sewer lines in convenient length.
- Man-holes are provided at all junctions of two or more sewers, whenever diameter of sewer changes, whenever direction of sewer line changes and when sewers of different elevations join together.
- For straight sewer line manholes are provided at regular interval depending upon the diameter of the sewer.

Manholes

- For sewer up to 0.3 m diameter or sewers which cannot be entered for cleaning or inspection the maximum spacing between the manholes recommended is 30 m, and 300 m spacing for pipe greater than 2.0 m diameter.
- A spacing allowance of 100 m per 1 m diameter of sewer is a general rule in case of very large sewers.
- Depending upon the depth the manholes can be classified as: (a) Shallow Manholes, (b) Normal Manholes, and (c) Deep Manholes

Manholes



Brickwork



HDPE

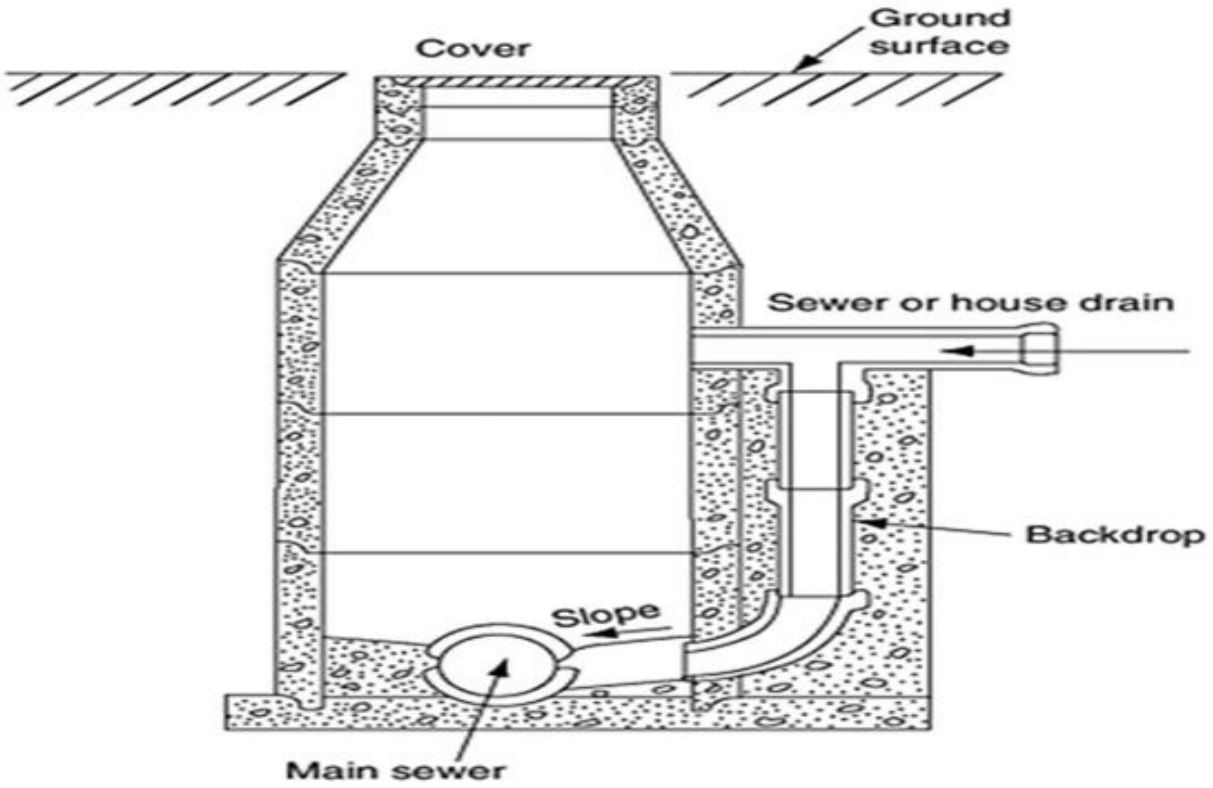


RCC precast



RCC precast

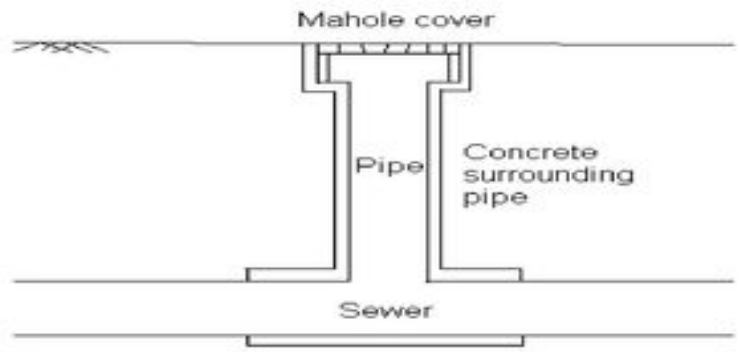
Manholes


Cover
Ground surface
Sewer or house drain
Backdrop
Slope
Main sewer



Lamp Hole

It is an opening or hole constructed in a sewer for purpose of lowering a lamp inside it. It consists of stoneware or concrete pipe, which is connected to sewer line through a T-junction. The pipe is covered with concrete to make it stable. Manhole cover of sufficient strength is provided at ground level to take the load of traffic. An electric lamp is inserted in the lamp hole and the light of lamp is observed from manholes. If the sewer length is unobstructed, the light of lamp will be seen. It is constructed when construction of manhole is difficult. In present practice as far as possible the use of lamp hole is avoided. This lamp hole can also be used for flushing the sewers. If the top cover is perforated it will also help in ventilating the sewer, such lamp hole is known as fresh air inlet.

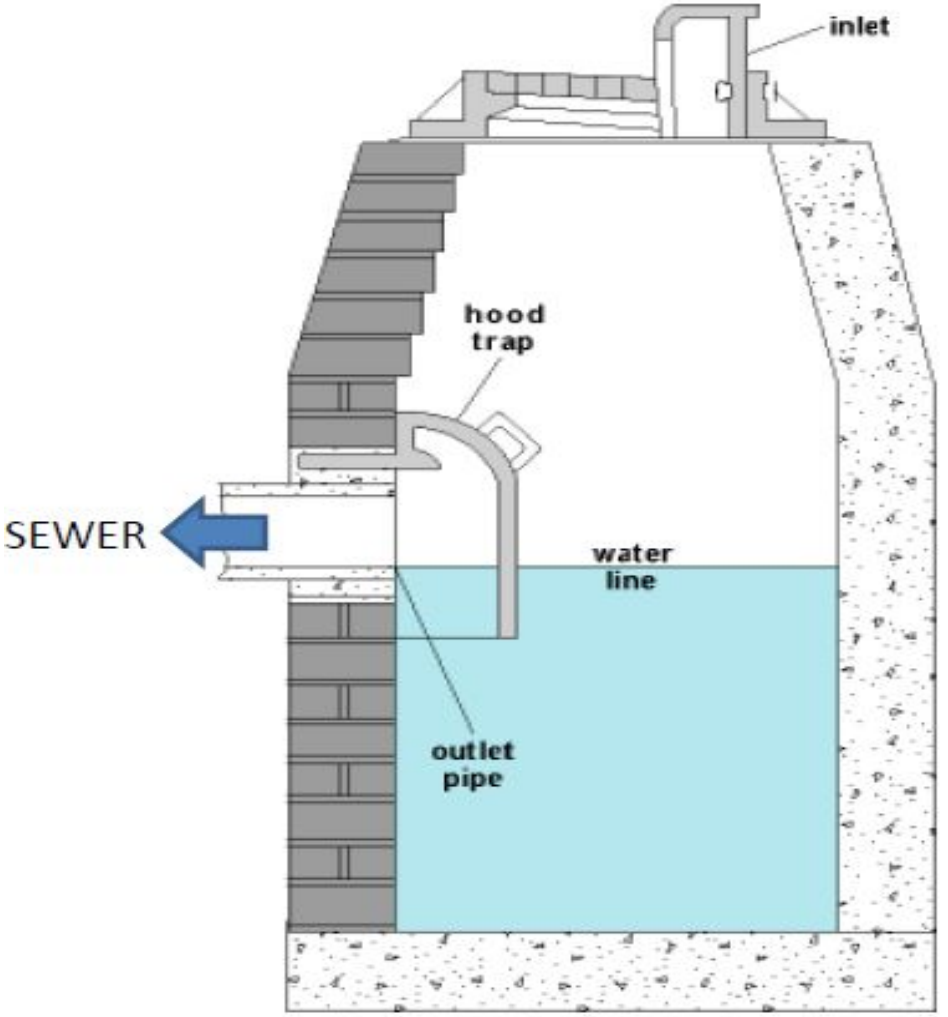


STORMWATER INLETS

Storm water inlets are provided to admit the surface runoff to the sewers. These are classified in three major groups viz. curb inlets, gutter inlets, and combined inlets. They are provided either depressed or uniform slope flush with respect to the elevation of the pavement surface. The structure of the inlet is constructed with brickwork with cast iron grating at the opening. Where the traffic load is not expected, fabricated steel grating can be used. The clear opening shall not be more than 25 mm. The connecting pipe from the street inlet to the sewer should be minimum of 200 mm diameter and laid with sufficient slope. A maximum spacing of 30 m is recommended between the inlets, which depends upon the road surface, size and type of inlet and rainfall.

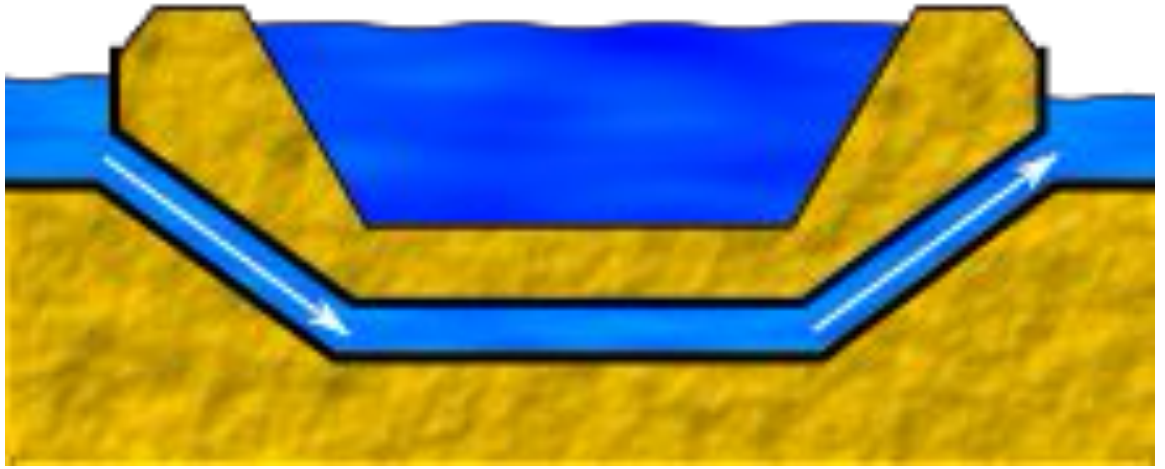


Catch Basins: Catch basins are small settling chambers of diameter 60 - 90 cm and 60 - 75 cm deep, which are constructed below the street inlets. They are provided to stop the entry of heavy debris present in the storm water into the sewers and allow grit, sand, debris to settle in the basin. At the bottom of the basin space is provided for the accumulation of impurities. Perforated cover is provided at the top of the basin to admit rain water into the basin.





Inverted Siphons: Inverted siphons are pipes that allow wastewater to flow under obstructions or low-lying areas, such as rivers, utilities, or highways. They are used when gravity flow is not possible. The pipe is lowered below the obstacle, then rises back to its original level. The liquid in the pipe is completely filled and flows under pressure.



SEWAGE PUMPING STATIONS

These are required to elevate and transport wastewater when Continuation of gravity flow is no longer feasible due to any obstacle lies in the path of sewer (e.g. river, canal etc) and/or receiving stream is higher than the sewer.

Pumps for Sewage:

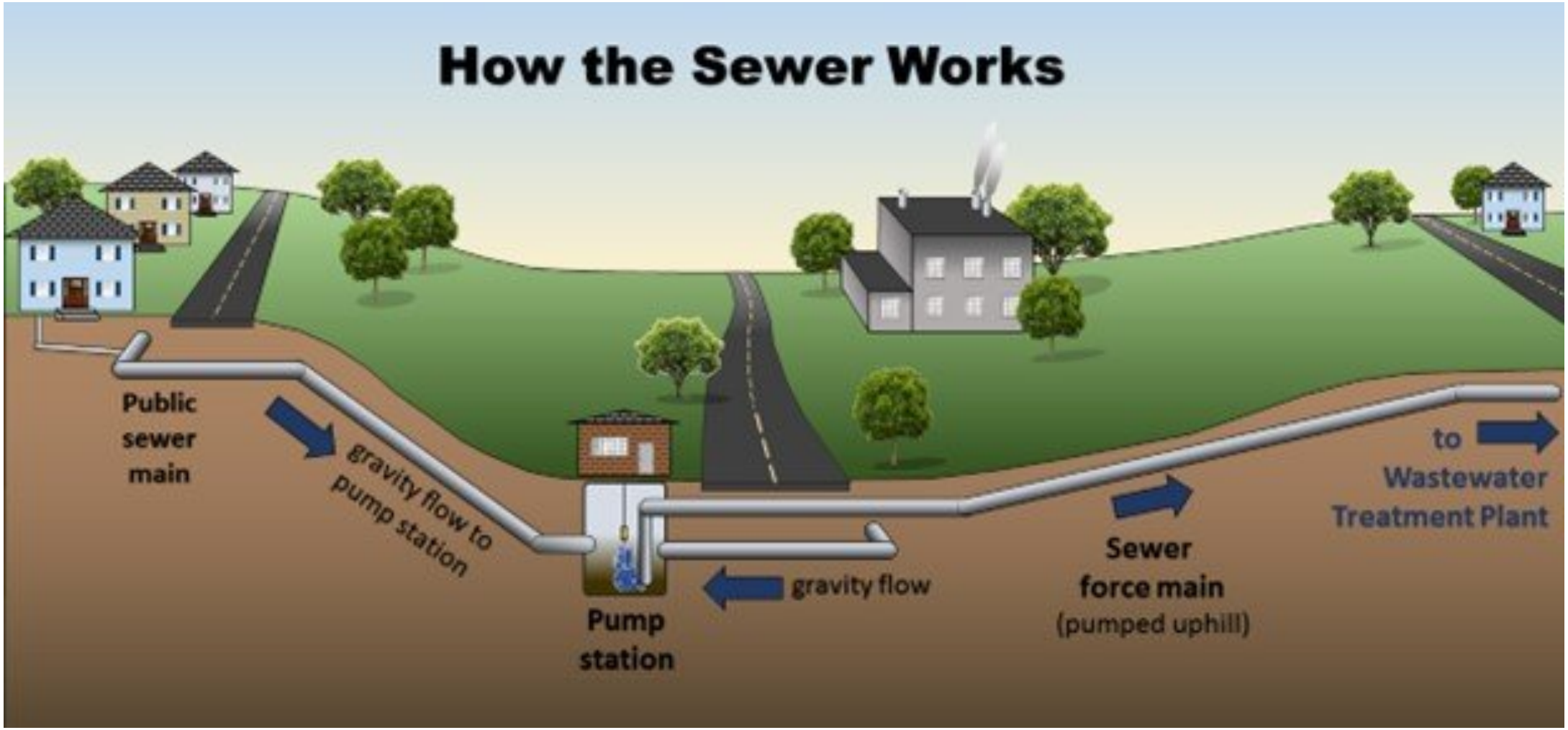
Centrifugal, single suction, non-clogging type pumps are normally used. They have impellers

Having two or three vanes. Pump suction pipe is usually larger than the discharge pipe by about 25%. Smallest discharge pipe =75mm ,while smallest suction pipe =100 mm.

Components of Sewage Pumping Station

Screens: To screen out large floating matters which can damage the pumps
Dry well: To house the pump and **Wet well:** for receipt of wastewater.

i. More than one pump should be provided to cope with variable discharge. Two pumps for small Pumping Station and more than two for large Pumping Station should be used.


How the Sewer Works
Public sewer main
gravity flow to pump station
Pump station
gravity flow
Sewer force main
(pumped uphill)
to Wastewater Treatment Plant

Module 7:
Hydraulic Design of Sewers and Storm Water Drains

Lecture 8:
Hydraulic Design of Sewers and Storm Water Drains (Contd.)

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7.8 Effect of Flow Variations on Velocities in a Sewer

The discharge flowing through sewers varies considerably from time to time. Hence, there occur variation in depth of flow and thus, variation in Hydraulic Mean Depth (H.M.D.). Due to change in H.M.D. there occur changes in flow velocity, because it is proportional to $(H.M.D.)^{2/3}$. Therefore, it is necessary to check the sewer for minimum velocity of about 0.45 m/sec at the time of minimum flow (1/3 of average flow) and the velocity of about 0.9 to 1.2 m/sec should be developed at a time of average flow. The velocity should also be checked for limiting velocity i.e. non-scouring velocity at the maximum discharge.

For flat ground sewers are designed for self-cleansing velocity at maximum discharge. This will permit flatter gradient for sewers. For mild slopping ground, the condition of developing self-cleansing velocity at average flow may be economical. Whereas, in hilly areas, sewers can be designed for self-cleansing velocity at minimum discharge, but the design must be checked for non-scouring velocity at maximum discharge.

Example: 1

Design a sewer for a maximum discharge of 650 L/s running half full. Consider Manning's rugosity coefficient of n = 0.012, and gradient of sewer S = 0.0001.

Solution

$Q = A.V$

$0.65 = (\pi D^2/8)\,(1/n)\,R^{2/3}\,S^{1/2}$

$R = A/P$

Solving for half full sewer, $R = D/4$

Substituting in above equation and solving we get D = 1.82 m.

Comments: If the pipe is partially full it is not easy to solve this equation and it is time consuming.

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7.9 Hydraulic Characteristics of Circular Sewer Running Full or Partially Full

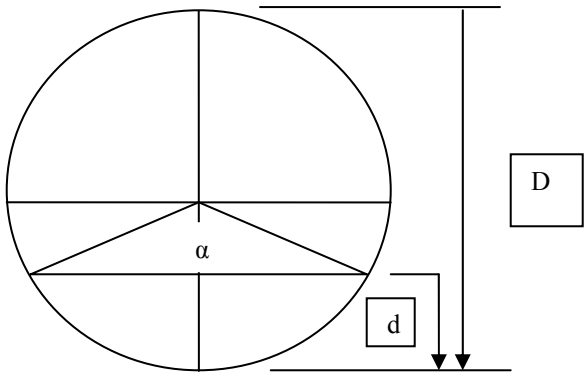


Figure 7.1 Section of a circular sewer running partially full

a) Depth at Partial flow

$$d = \left[\frac{D}{2} - \frac{D}{2}\cos\left(\frac{\alpha}{2}\right)\right]$$

b) Therefore proportionate depth

$$\frac{d}{D} = \frac{1}{2}\left[1 - \cos\left(\frac{\alpha}{2}\right)\right]$$

c) Proportionate area

$$\frac{a}{A} = \left[\frac{\alpha}{360} - \frac{Sin\alpha}{2\pi}\right]$$

d) Proportionate perimeter: $\frac{p}{P} = \frac{\alpha}{360}$

e) Proportionate Hydraulic Mean Depth

$$\frac{r}{R} = \left[1 - \frac{360 Sin\alpha}{2\pi\alpha}\right]$$

f) Proportionate velocity = $\frac{v}{V} = \frac{N}{n}\frac{r^{2/3}}{R^{2/3}}$

In all above equations except 'α' every thing is constant. Hence, for different values of 'α', all the proportionate elements can be easily calculated. These values of the hydraulic elements can

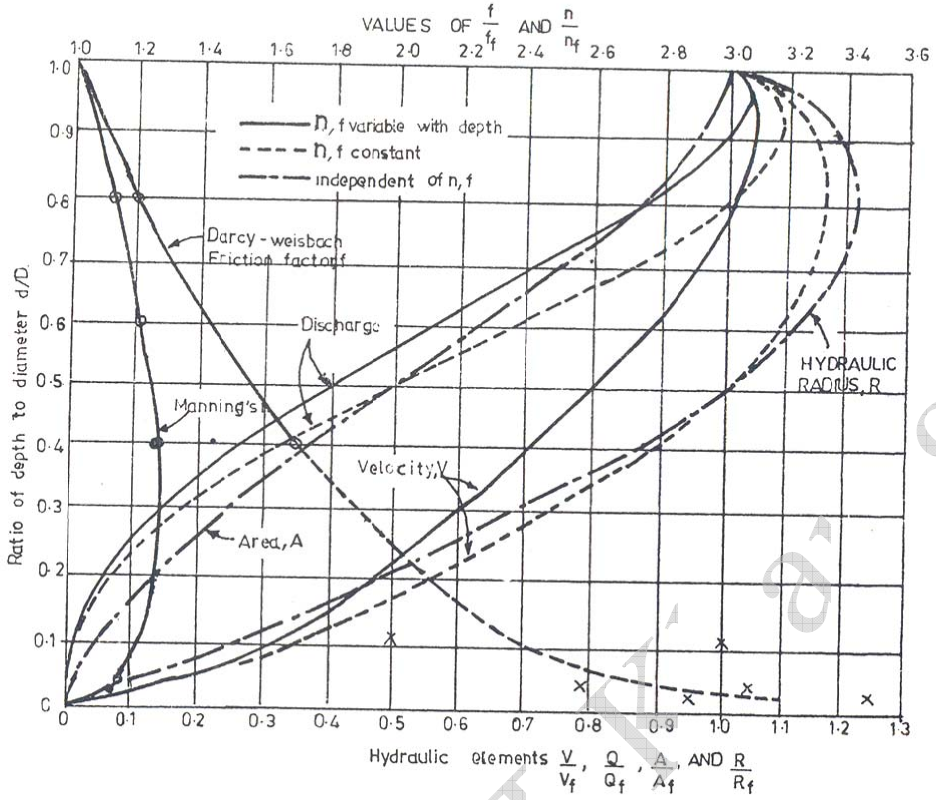
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be obtained from the proportionate graph prepared for different values of d/D (Figure 7.2). The value of Manning's n can be considered constant for all depths. In reality it varies with the depth of flow and it may be considered variable with depth and accordingly the hydraulic elements values can be read from the graph for different depth ratio of flow.

From the plot it is evident that the velocities in partially filled circular sewer sections can exceed those in full section and it is maximum at d/D of 0.8. Similarly, the discharge obtained is not maximum at flow full condition, but it is maximum when the depth is about 0.95 times the full depth.

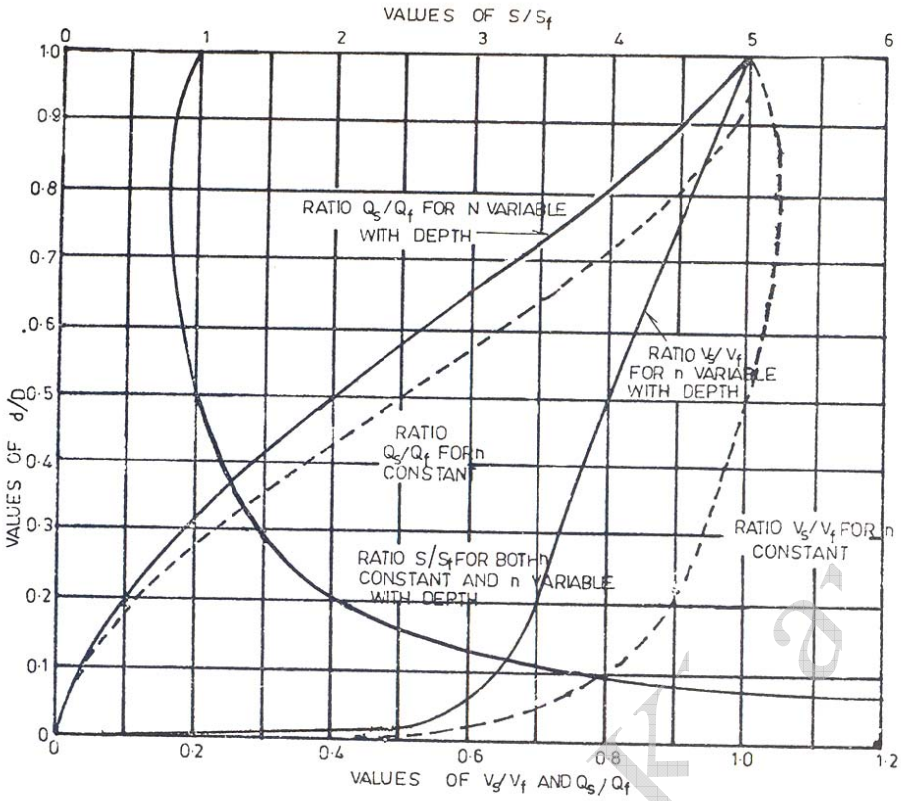
The sewers flowing with depths between 50% and 80% full need not to be placed on steeper gradients to be as self cleansing as sewers flowing full. The reason is that velocity and discharge are function of tractive force intensity which depends upon friction coefficient as well as flow velocity generated by gradient of the sewer. Using subscript 's' denoting self cleansing equivalent to that obtained in full section, the required ratios v_s/V, q_s/Q and s_s/S can be computed as stated below:

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(a) Hydraulic elements for circular sewer

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(b) Hydraulic elements of circular sewer possessing equal selfcleansing properties at all depths

Figure 7.2 Proportionate graph for circular sewer section (CPHEEO Manual, 1993)

Consider a layer of sediment of unit length, unit width and thickness 't' is deposited at the invert of the sewer. Let the slope of the sewer is θ degree with horizontal. The drag force or the intensity of tractive force (ι) exerted by the flowing water on a channel is given by:

$$\iota = \gamma_w \, . \, R. \, S$$

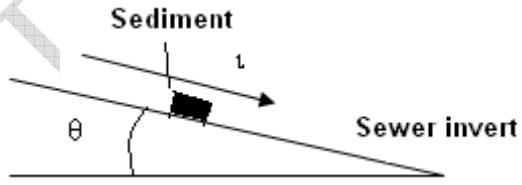


Figure 7.3 A sediment particle moving on the sewer invert

Where,

γ_w = unit weight of water

R = Hydraulic mean depth

S = slope of the invert of the sewer per unit length

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With the assumption that the equality of tractive force intensity implies equality of cleansing, i.e., for sewers to be same selfcleansing at partial depth as full depth:

$\iota = T$

Therefore,

$\gamma_w \cdot r \cdot s_s = \gamma_w \cdot R \cdot S$

Hence,

$$s_s = (R/r)\, S$$

Or $$\frac{s_s}{S} = \frac{R}{r}$$

Therefore,

$$\frac{v_s}{V} = \frac{N}{n}\left(\frac{r}{R}\right)^{2/3}\left(\frac{s_s}{S}\right)^{1/2}$$

OR, by substituting $r/R = S/s_s$

$$\frac{v_s}{V} = \frac{N}{n}\left(\frac{r}{R}\right)^{1/6}$$

And

$$\frac{q_s}{Q} = \frac{N}{n}\frac{a}{A}\left(\frac{r}{R}\right)^{1/6}$$

Example: 2

A 300 mm diameter sewer is to flow at 0.3 depth on a grade ensuring a degree of self cleansing equivalent to that obtained at full depth at a velocity of 0.9 m/sec. Find the required grade and associated velocity and rate of discharge at this depth. Assume Manning's rugosity coefficient n = 0.013. The variation of n with depth may be neglected.

Solution:

Manning's formula for partial depth

$$v = \frac{1}{n} r^{2/3} s^{1/2}$$

For full depth

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

Using V = 0.90 m/sec, N = n = 0.013 and R = D/4 = 75 mm = 0.075 m

$$0.90 = \frac{1}{0.013} 0.075^{2/3} S^{1/2}$$

S = 0.0043 This is the gradient required for full depth.

and, Q = A.V = $\pi/4\ (0.3)^2$ x 0.90 = 0.064 m^3/s

At depth d = 0.3D, (i.e., for d/D = 0.3) we have a/A = 0.252 and r/R = 0.684 (neglecting variation of n)

Now for the sewer to be same self cleansing at 0.3 m depth as it will be at full depth, we have the gradient (s_s) required as $s_s = (R/r)S$

Therefore, $s_s = S / 0.684$

$= 0.0043 / 0.0684 = 0.0063$

Now, the velocity v_s generated at this gradient is given by

$$v_s = V \frac{N}{n} \left(\frac{r}{R} \right)^{1/6}$$

$= 1 \text{ x } (0.684)^{1/6} \text{ x } 0.9$

$= 0.846$ m/s

The discharge q_s is given by

$$q_s = Q \frac{N}{n} \frac{a}{A} \left(\frac{r}{R} \right)^{1/6}$$

$q_s = 1 \text{ x } (0.258) \text{ x } (0.939) \text{ x } (0.064)$

$= 0.015\ m^3/s$

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Plumbing System

Introduction

Plumbing is the system of pipes, drains, fittings, valves, and fixtures installed for the distribution of potable water for drinking, heating and washing in a building, and drainage of wastewater and storm water from the building.

The water supply system 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 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 from the drainage system into the house must be prevented.

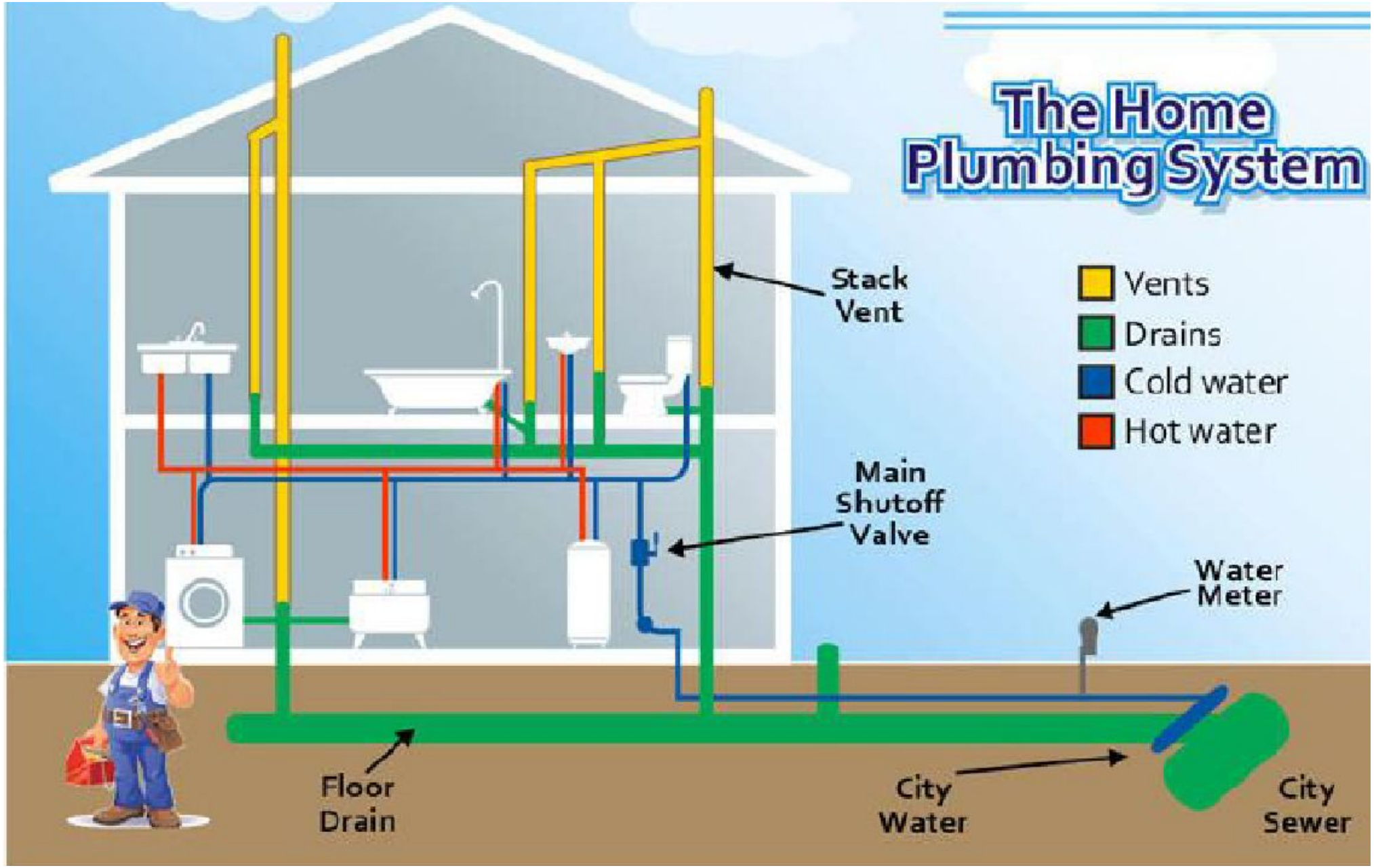
History of Plumbing



Indus Valley Drainage System (3000 BC)

Roman Aqueducts




The Home Plumbing System
Stack Vent
Vents
Drains
Cold water
Hot water
Main Shutoff Valve
Water Meter
Floor Drain
City Water
City Sewer





Scope of Plumbing

- Water supply system related
- Waste disposal related.
- Storm water management related.
- Gas supply related.

Scope of Plumbing

Water supply system related

- Cold water supply.
- Hot water supply.
- Chilled water supply.
- Water treatment for building occupants.
- Pump selection, installation and maintenance.
- Steam and hot-water boiler selection and related works.
- Fire suppression system.
- Garden hydrant system
- Fountain, cascade and water fall.
- Swimming pool water supply, treatment **and** conditioning.
- Interior-scape irrigation: Manual and automatic.

Scope of Plumbing

Waste disposal related.

- Plumbing fixture, pipe equipment selection, installation and maintenance.
- Soil, waste and vent piping system.
- Building sewer.
- Basement drainage and pumping.
- Sewage pump selection and installation.
- Swimming pool, fountain, water body drainage.
- Wastewater recycling and reuse.

Scope of Plumbing

Storm water management related.

- Rainwater collection, storage, disinfection, and distribution.
- Storm water drainage.

Gas supply related.

- Fuel gas supply in building.

Governing principles of plumbing system in a building

1) should be sufficient water pressure available to serve each fixtures.
2) should be no opportunity for backflow of water.
3) Wastewater/liquid waste should be quickly removed with minimum possibilities of stoppage of drains or leakage.
4) Entrance of sewer gases, foul odour inside the building should be prevented.
5) should not any risk involved in the contamination of water supply for domestic purpose by x-connection between watersupply pipe and drainage pipe.
6) The facilities and storage for fire fighting should be provided.
7) The pipes should be protected from possible damages while lying underground or even over the ground.

Governing principles of plumbing system in a building

8) The pipes should be laid as straight as possible to minimize the frictional loss.
9) The pipes and fittings should be fully protected against corrosion and frost.
10) The pipes layout should be such as to admit of easy inspection and repair.
11) The pipes and fittings should be thoroughly water-tight due to prevent the damage for leakage.
12) The changes in diameter and direction of pipe should be gradual to avoid undue loss of water-head.
13) Installation is not done so as to impair the structural safety of the building.
14) Each stack should be suitably covered on top above roof.

Design Approach

- Safety
- Sanitation
- Good environment
- Convenience
- Comfort
- Economy
- Durability
- Legality

Types of pipes used in Plumbing System

Materials	Galvanised iron pipes	Cast iron pipes	Unplasticsized PVC pipes	Rigid PVC pipes
Diameter	used for small diameter	Up to 60 mm	Ranging from 16 mm to 315mm	Ranging from 32 to 315 mm
Property	Best for services and internal connections	they don't echo when water moves through	Corrosion resistant , Chemical resistance	Same as Unplasticsized PVC Pipes



Galvanised iron pipes



Cast iron pipes



Unplasticsized PVC pipes



Rigid PVC pipes

Sanitary Drainage Systems

- There are basically two types of drainage systems - *sanitary drainage system and storm water drainage system.*
- The system that drains waste water from sinks, tubs, showers, lavatories, and soil matter from toilets is known as the *sanitary drainage system*, and the other system that collects storm water from roofs, yards, and areaways is known as the *storm water drainage system.*
- These systems may be used separately, each draining into a public sewer, a private cesspool, or septic tank. When both systems are combined, they are known as a *combined drainage system.*

Wastewater Removal

1. Wastewater is carried to the sanitary sewer or septic tank through the building drainage system consisting of horizontal and vertical pipes.

2. These pipes are isolated from the water supply system and must be sized for sufficient capacity, have the proper slope and venting, and have provisions for cleanouts.

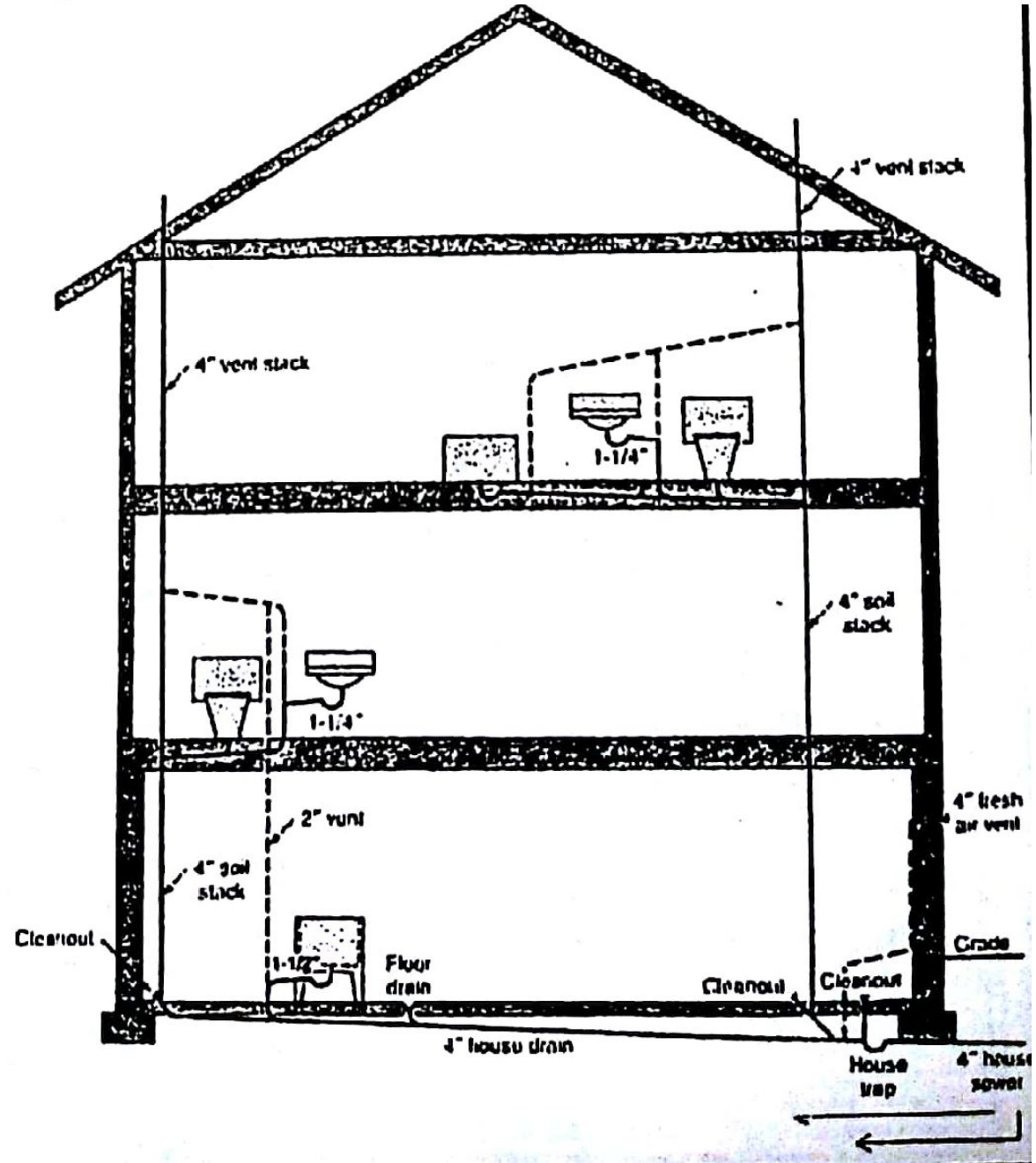
3. Typically it is practical to drain as many of the fixtures as possible into a single main drain.

4. The drainage system is not under pressure and depends on gravity to carry the wastewater to the sewer.

Wastewater Drainage System

The piping that makes up a sanitary system is generally as follows:

House sewer
House drain
Soil, waste, vent stacks
Fixture branches
Fixture traps
Fixtures
Fixture vents



HOUSE SEWER :

1. The house sewer is that portion of pipe that extends to the public sewer pipe in the street to about 3 to 5 ft from the house.
2. The minimum pipe diameter for the house sewer is 3 in. Larger sizes are of course required when serving a greater number of fixtures.

HOUSE DRAIN :

The house drain is the horizontal pipe inside the house into which the vertical soil and waste stacks discharge.

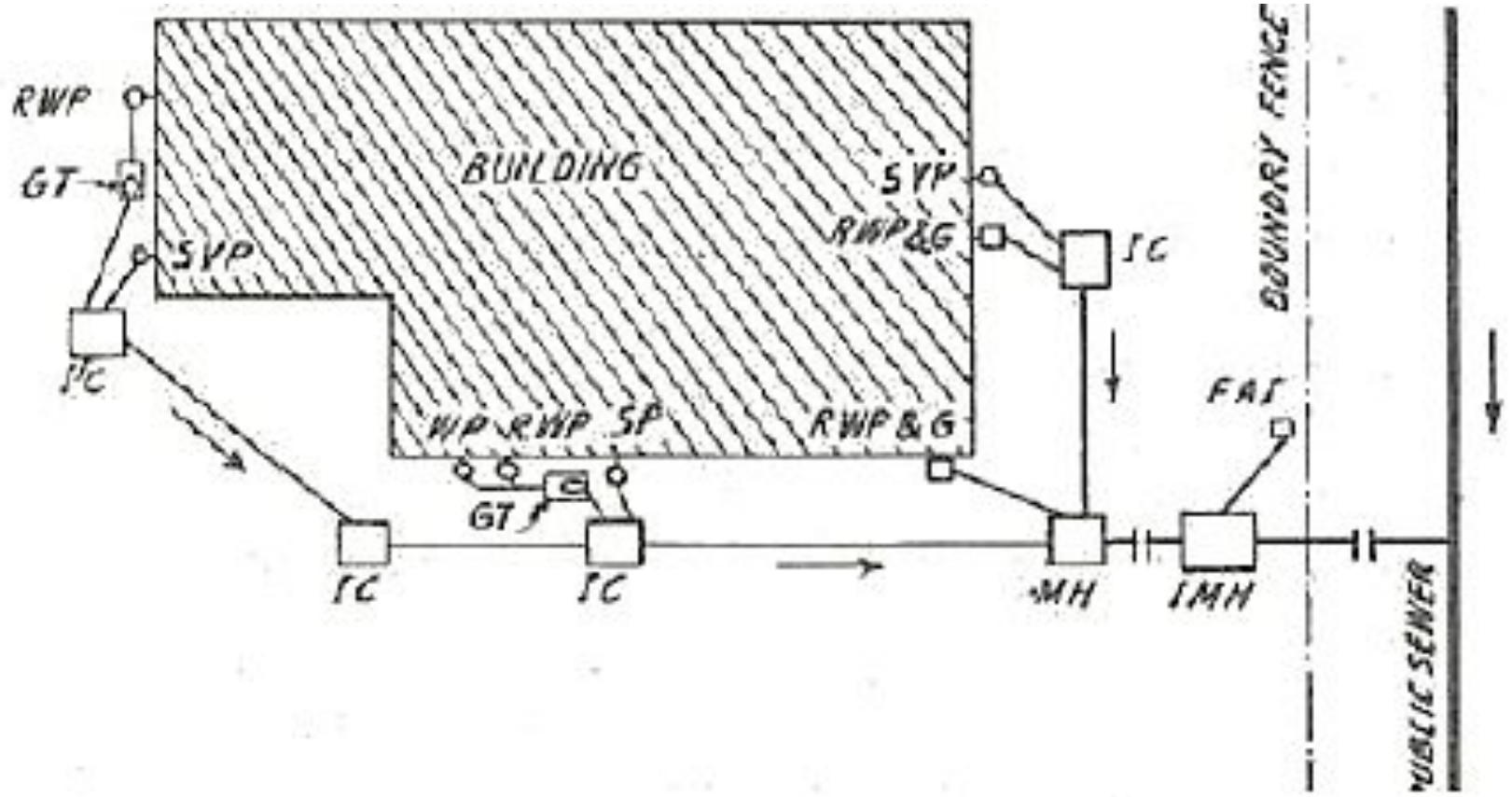
SOIL, WASTE, AND VENT STACKS :

1. Soil, waste, and vent stacks are the vertical pipes of the drainage system.
2. The soil stack receives the soil matter from the water closets and urinals.
3. The waste stack receives wastewater from all types of fixtures except water closets and urinals.
4. If a stack receives both soil matter and sullage, it is termed as a soil stack.
5. Vent stacks are used only to allow movement of air through the system.

FIXTURE BRANCHES AND BRANCH VENTS :

1. The fixture branch is the horizontal pipe running from the fixture trap to the vertical soil or waste stacks.
2. The fixture branch vents are the horizontal piping that run from near the fixture trap, then overhead of the fixture to the vent stack. Branch vents are arranged so that waste matter flowing through the fixture branch cannot clog and foul the vents.

Grades of Horizontal House Sewer Drainage pipes should have a minimum slope of ¼ inch per ft toward the point of disposal. Where this is not practicable due to depth of a street sewer or the arrangement of the structural features, pipes 4 inch or larger dia may have a slope of not less than 1/8 inch per ft should be provided.

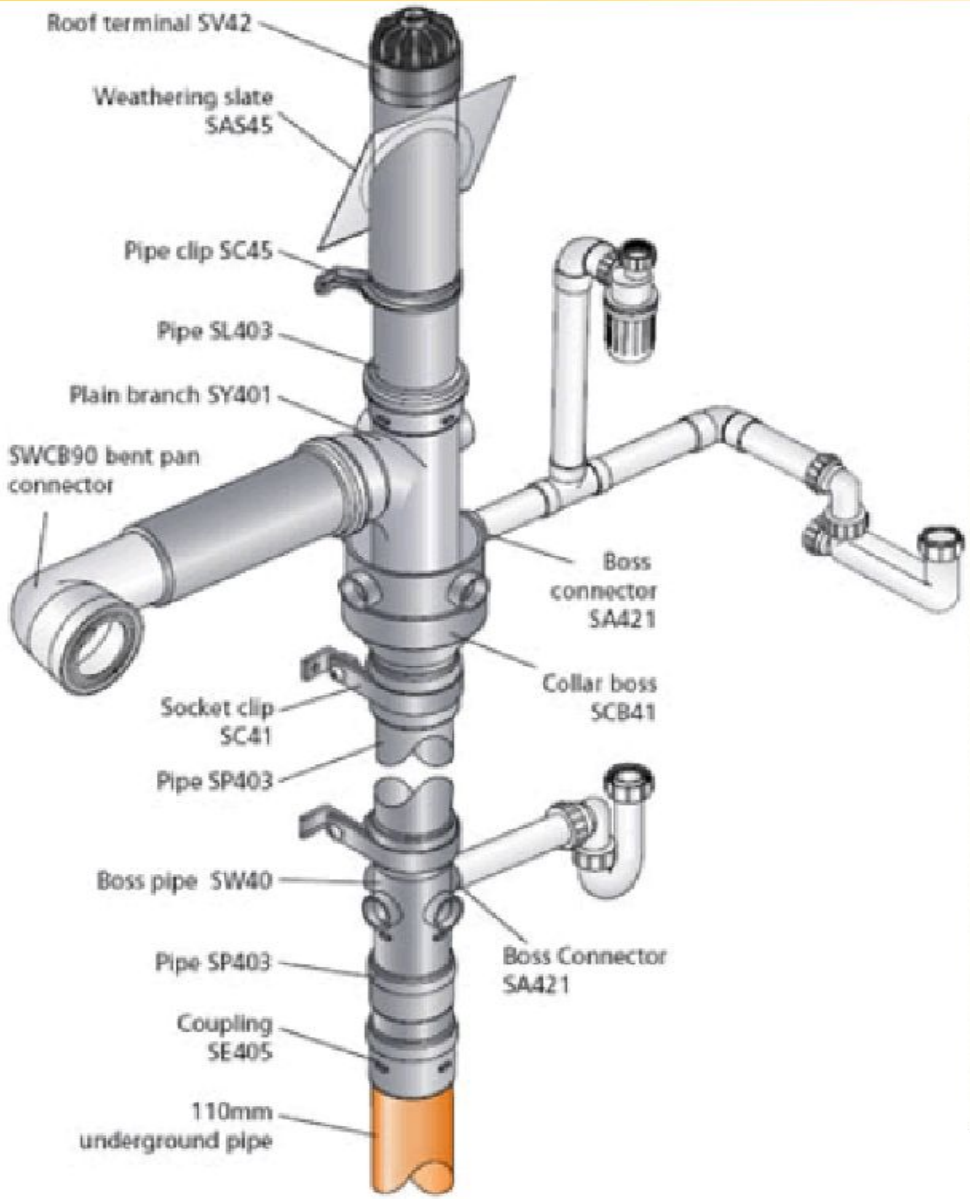


Conventions

SP	=	Soil pipe	GT	=	Gully Trap
WP	=	Waste pipe	MH	=	Manhole
SVP	=	Soil vent pipe	IC	=	Inspection chamber
RWP	=	Rain water pipe	IMH	=	Intercepting manhole
RWP & G	=	Rainwater pipe and gully	FAI	=	Fresh air inlet

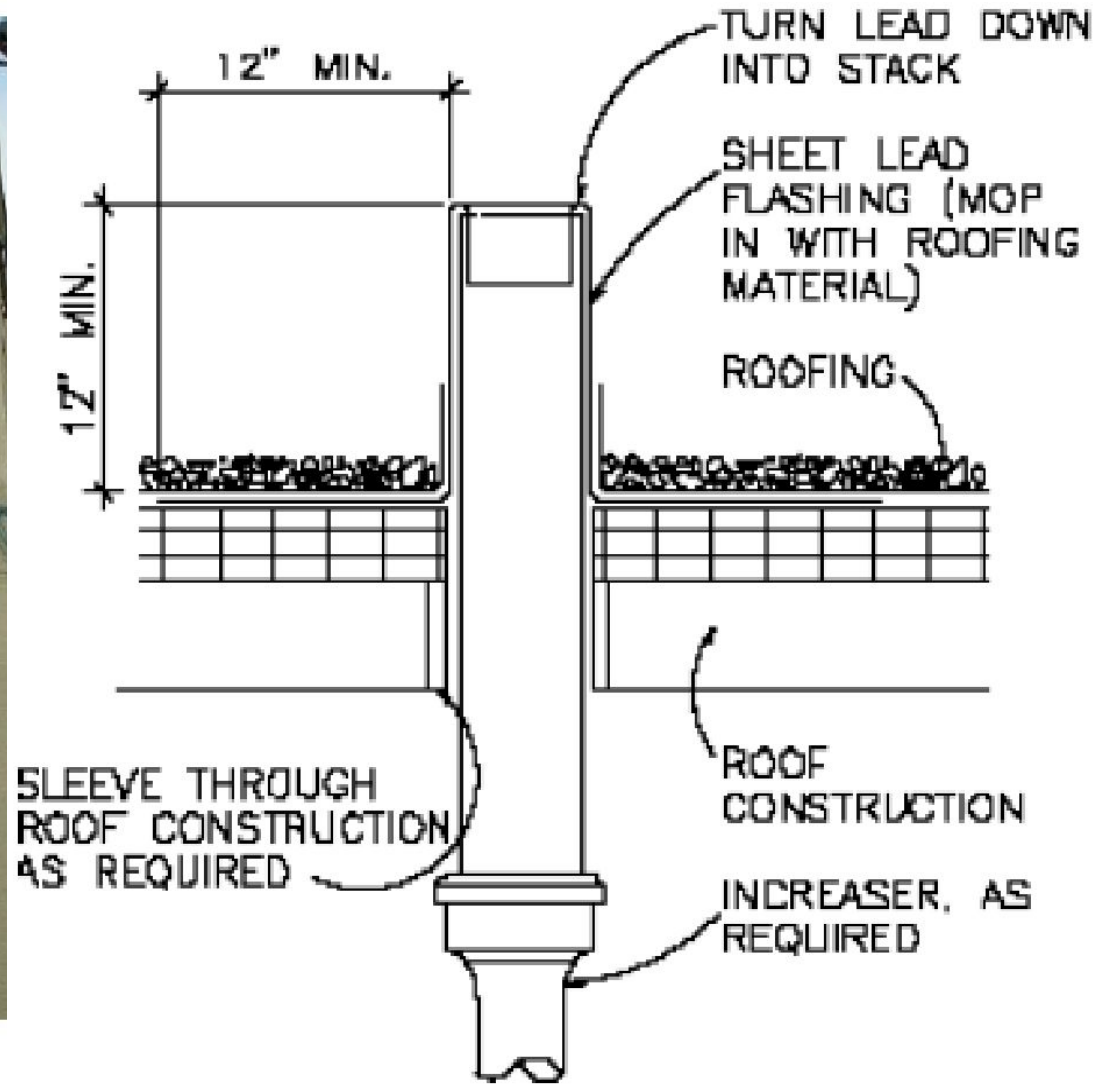
Fig. 1.18. Typical Lay-out of House Drainage System.

SOIL TACK



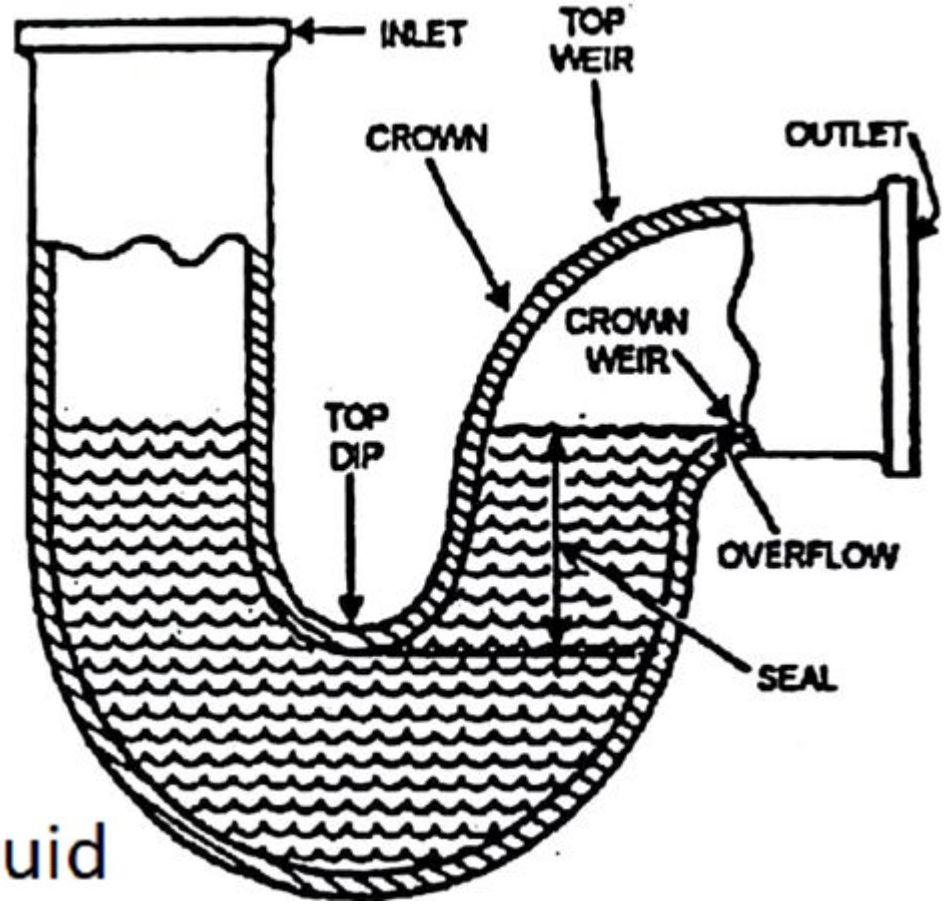


VENTS



Traps

Traps are fittings placed in drainage pipes, which prevent the passage of foul air or gases through drains, waste or soil pipes and thus prevent their entry into the interior of the houses or buildings. This is possible because traps are equipped with water seals having a minimum depth of 25 mm.



Trap Seal is the maximum vertical depth of liquid that a trap will retain, measured between the crown weir and the top of the dip of the trap.

Traps

Quality of the traps:

Good Traps should have following Qualities:

- ✓ Should provide enough water seal or trap seal (around 50 mm) with large surface area.
- ✓ Interiors surface should be smooth so that the flow is not obstructed which enables self cleansing.
- ✓ An access door should be provided for cleaning the trap.
- ✓ It should be made of non- adsorbent material.

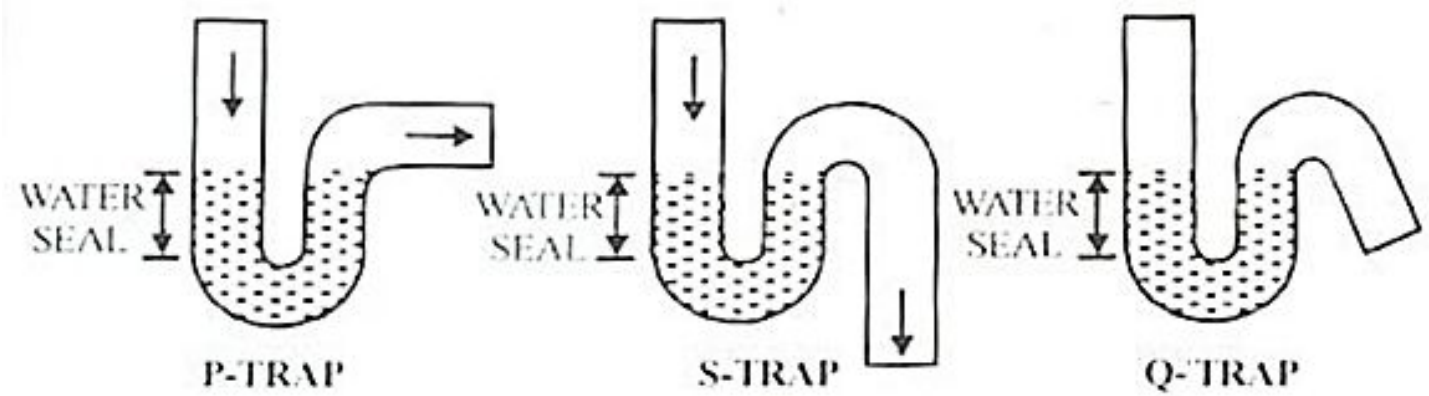
Strength of a trap:

The strength of a trap is the ability of its water seal to resist the passage of air or gas through it. The strength of a trap is determined by the vertical height to which water in the trap can raise above the dip.

Types of Traps

- According to shape
  - P Trap
  - Q Trap
  - S Trap
- According to use
  - Floor trap
  - Gully Trap
  - Intercepting Trap

Types of Traps





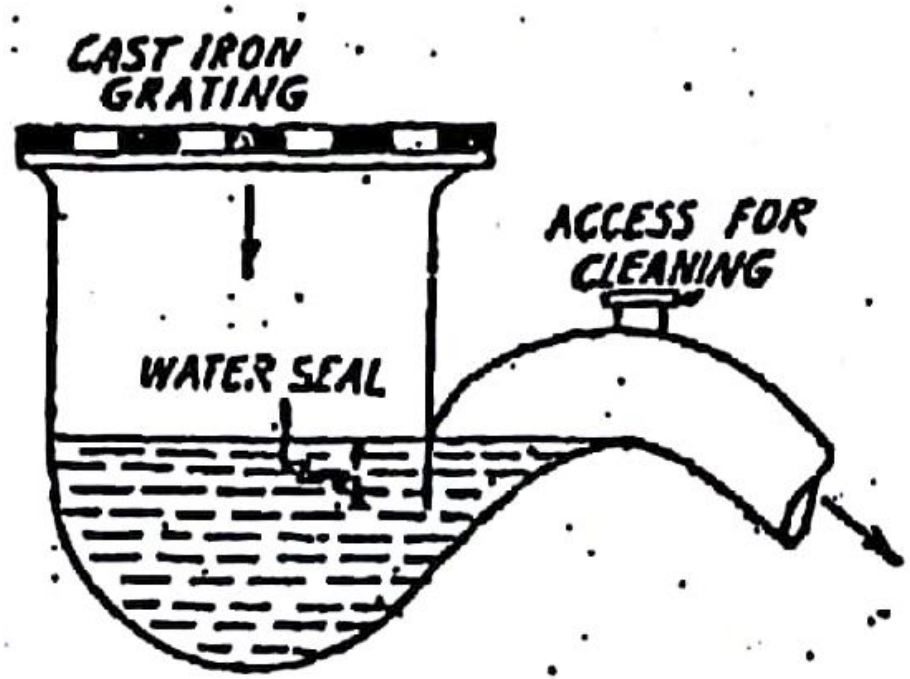
A P-trap is a bend in a drain and waste pipe which contains a pocket of water, blocks toxic, foul-smelling sewer gases (like methane) from traveling through the pipe inside home.

S-traps are a type of plumbing trap that blocks sewer gases in sinks and other plumbing fixtures which traps wastewater before it drains to the sewer line, creating a water seal that prevents gases from flowing up through the drain.

Q-trap is a common SWR fittings used in combination with Push fit & Solfit Pipes. It prevents transmission of unfavorable odors from the washroom to the living area. Commonly used in shower areas and WC drain areas.

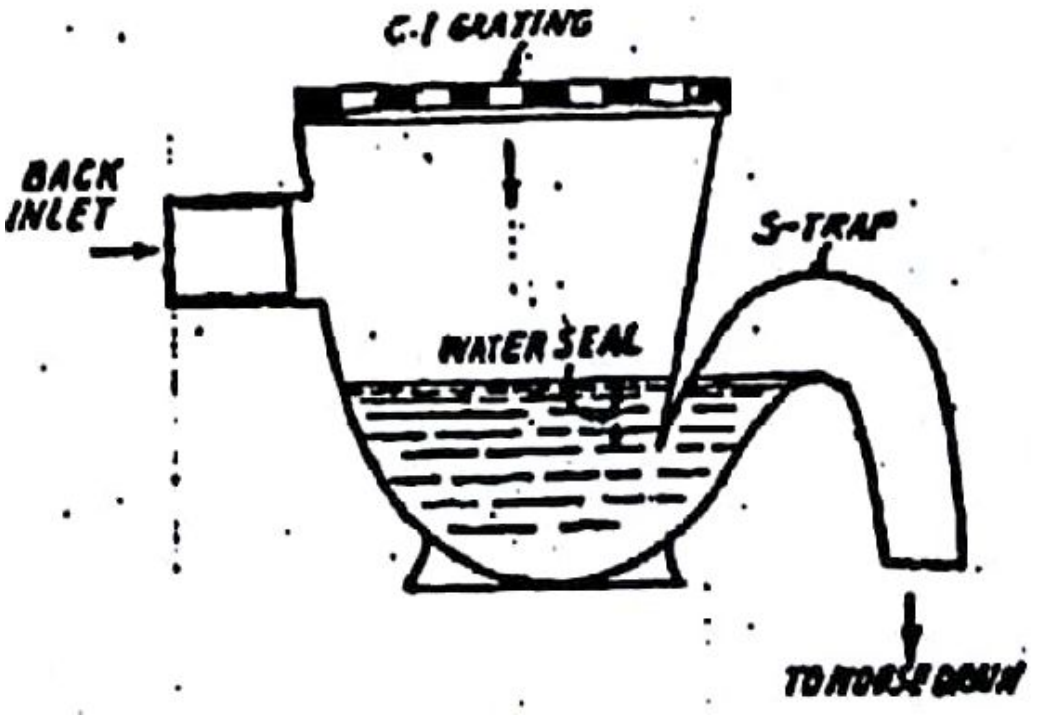
Floor Traps

- Used primarily for admitting surface wash or wastewater from floors of baths and kitchen.
- A grating is provided at the top of the trap to exclude coarse solid matter.



Gully Traps

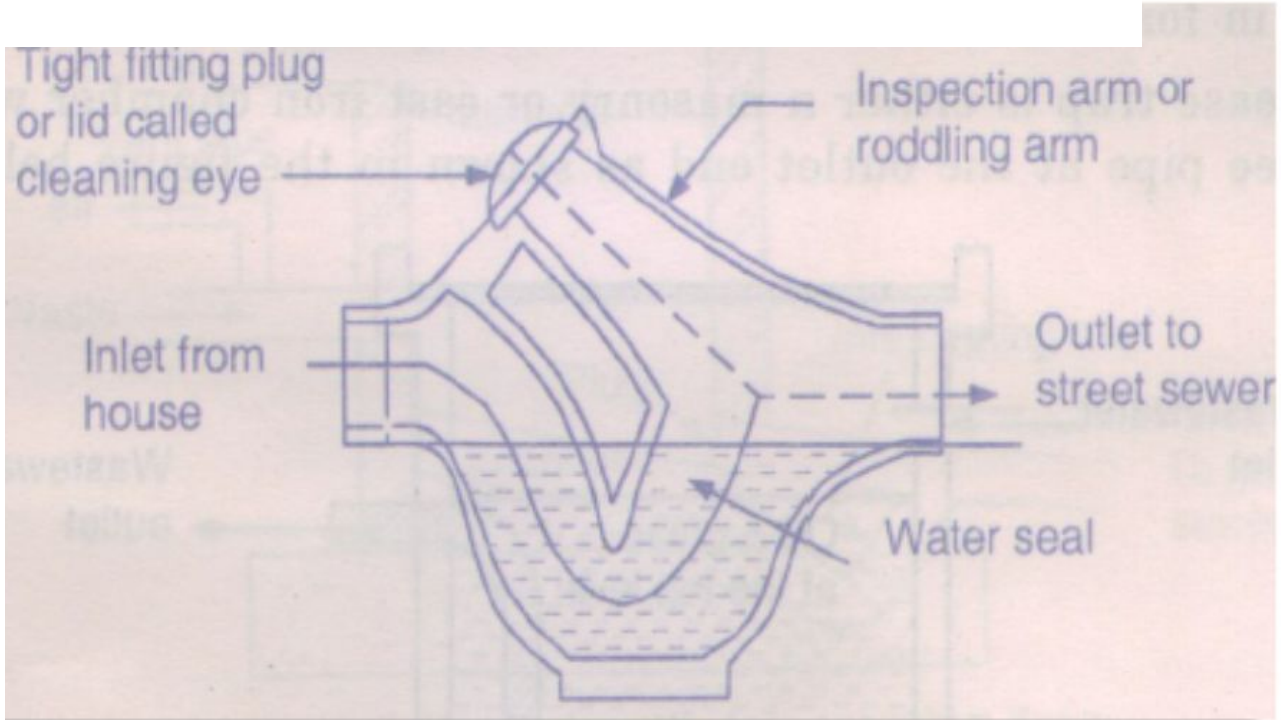
- Also called GULLIES.
- Used for reception of wastewater from baths, sinks and wash basins. Also collects stormwater.
- May have P-trap or S-trap.
- Water seal depth is 50-75 mm.
- A grating is provided at the top of the trap to exclude coarse solid matter.



Intercepting Traps

- Used at the junction of the house drain and house sewer.
- Primary objective is to prevent the foul gases entry from public/municiple sewer.
- Harmful pathogens are not entered in house drains.
- Well designed and constructed interceptors can quickly remove foul matter of house drain to municipal sewers
- Water seal is sufficiently deep as much as 75 mm.
- Has an opening at the top called rodding arm or inspection arm or cleaning eye for periodically cleaning.

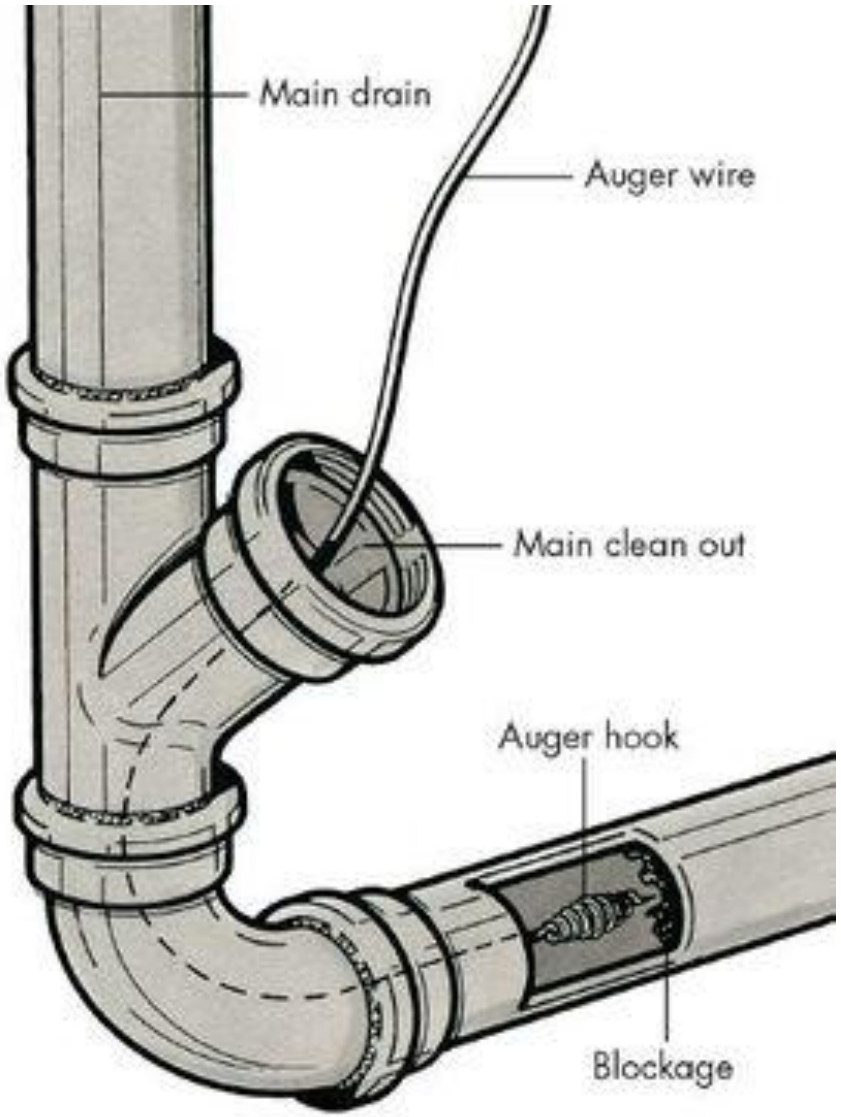




Cleanouts

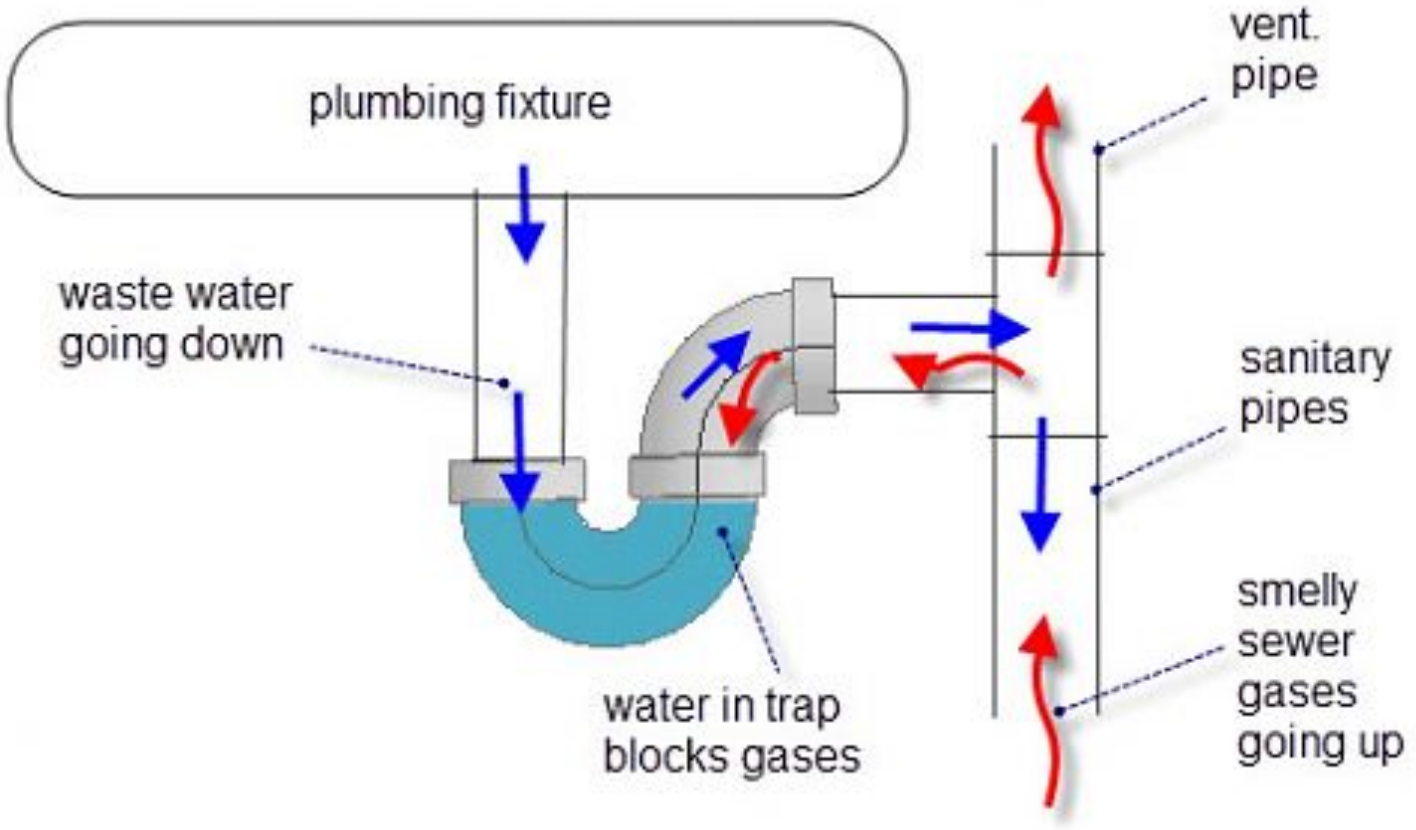
A plumbing cleanout is a cleanout fitting with a removable plug that is found in a building drainage system. It is designed to help keep clear any type of debris that could cause any type of stoppage in the water drain lines.

Cleanouts are usually placed at the connection point between the sewer lines and the drain lines where the base is located of a vertical stack and at all places were the pipe direction changes at 90 degrees.



Water Seal

Sewer gas is prevented by the back-flow prevention of the **water seal** in bottom of the trap (It “traps” the water). Sewer gas can contain many smells and odors and may smell like rotten eggs, but can also be poisonous. The traps installed in the plumbing lines help to form a seal of water within the plumbing trap.

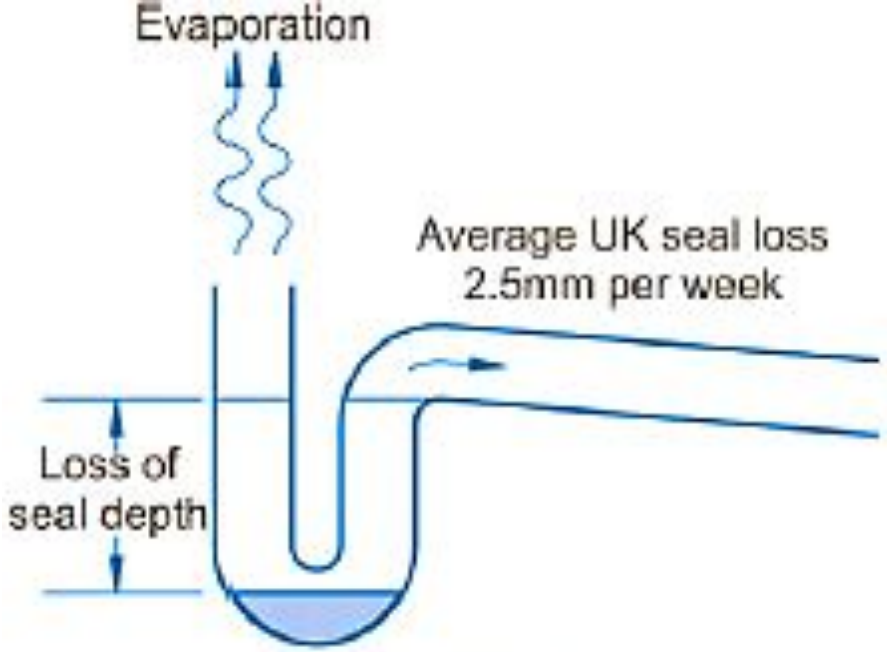


Loss of Trap Seals

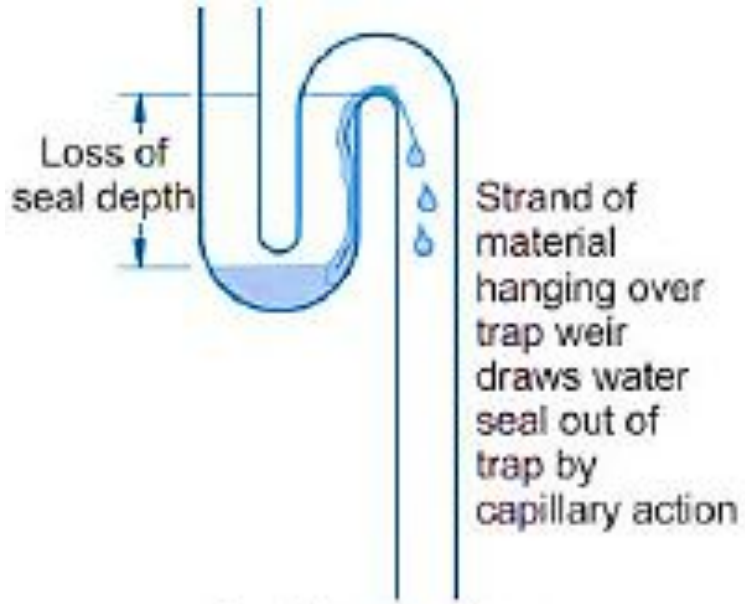
- Trap seal loss occurs **when the seal of the trap is lost as a result of poor practice** and by not following the regulations with regard to sanitation pipework installation. If a trap seal losses, smells from the sanitary appliances would enter the building.
- The main reasons of losing the water seal are:
  - Evaporation
  - Capillary action
  - Momentum
  - Leakage
  - Wind effect
  - Compression or back pressure
  - Induced siphonage
  - Self siphonage

Loss of Trap Seals

- ***Evaporation:*** Trap seals can be lost due to evaporation when fixtures are not used for long periods of time. This is especially true in warm or hot climates. When a trap seal evaporates, you can replenish the water seal by running water into the fixture. If this is not possible or convenient, then the drain opening may be sealed with a cap to prevent sewer gases from entering the structure. The rate is approximately 2.55 mm per week, so a 25 mm seal would last for 10 weeks.
- ***Capillary action:*** This is another rare occurrence which happens in 'S' trap when a piece of porous material being caught over the bend of a trap absorbs water and deposits it down the waste discharge pipe.



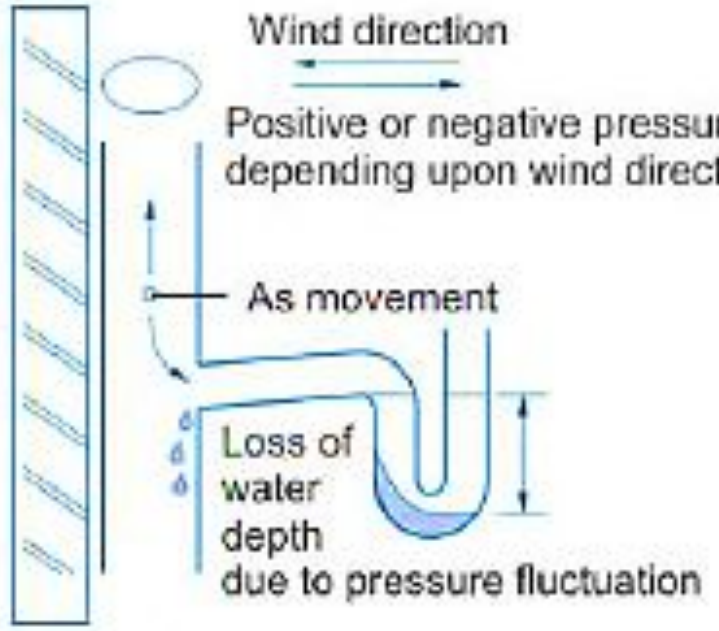
Evaporation



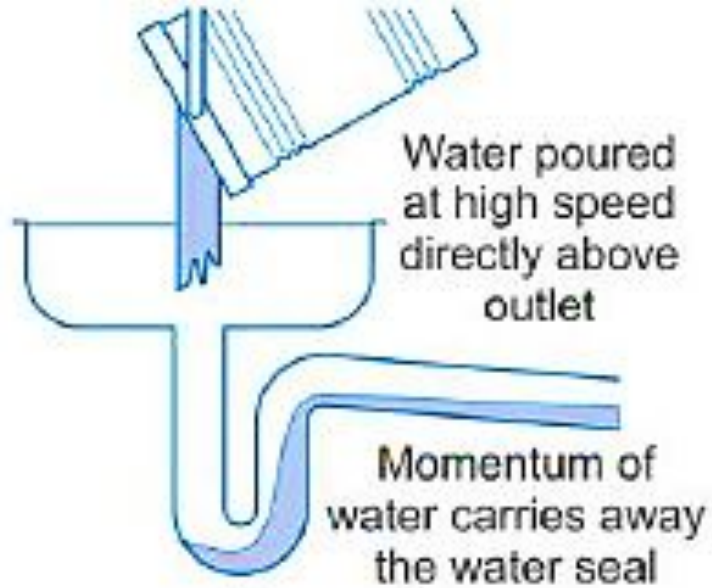
Capillary action

Loss of Trap Seals

- ***Wind Effect:*** This is caused by the effect of the wind which passes over the top of the ventilation pipe and thus causes pressure fluctuations.
- ***Momentum:*** This is caused by a sudden discharge of water from a bucket. Due to velocity water is discharged and it shoots around the trap bend and goes down the waste pipe, leaving no seal.



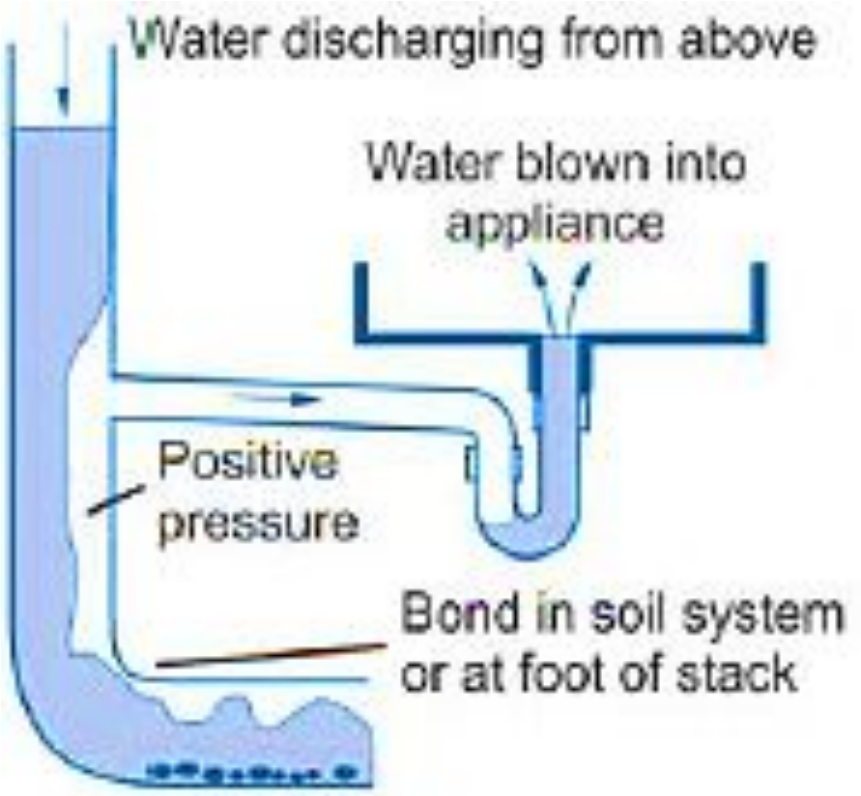
Wind effect (wavering out)



Momentum

Loss of Trap Seals

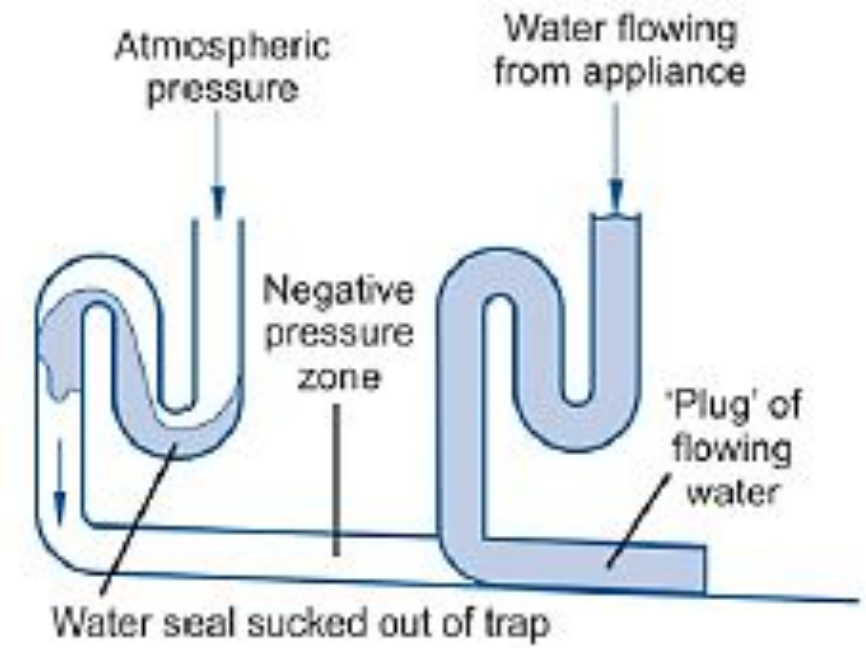
- ***Leakage:*** It is caused by a fault in the trap or plumbing installation and water on the floor would be apparent.
- ***Compression or back pressure:*** This occurs in high rise buildings. When water is discharged down to the main discharge stack, air is compressed at the base of the stack. A waste pipe connected to the stack in the pressure zone may have the seal of the trap lost by the compressed air forcing out the water. Detergent foam increases the risk of compression.



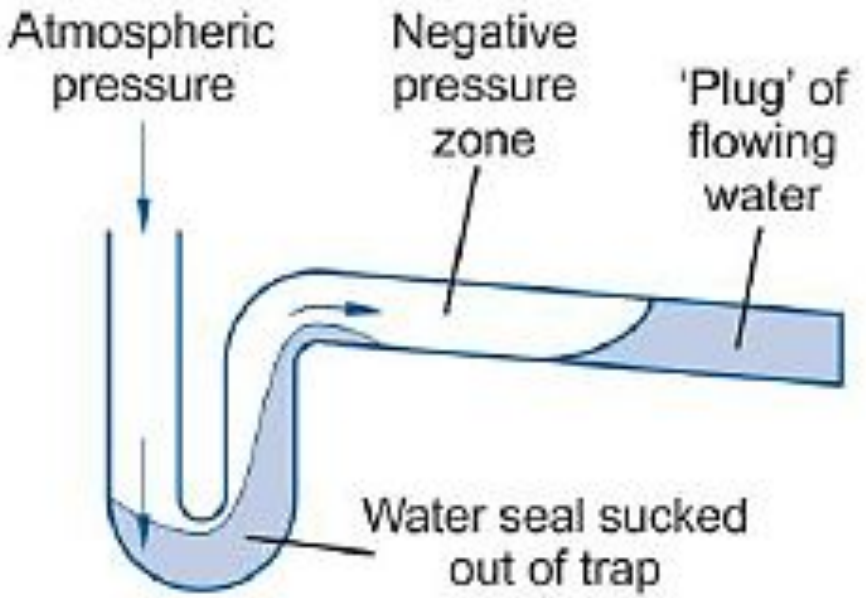
Compression

Loss of Trap Seals

- ***Induced siphonage:*** This is caused by discharge of water from another sanitary appliance connected to the same discharge pipe. In either a vertical or horizontal main waste pipe, as water flows down the pipe and passes the branch pipe connected to it, it draws air from it, thus creating a partial vacuum and subsequently siphonage of the trap takes place.
- ***Self Siphonage:*** This is caused by appliances such as wash basins and other small appliances, due to their curved shape, and is caused by a moving plug of water in the waste pipe. A partial vacuum is created at the outlet of the trap, thus causing siphonage action takes place.



Induced siphonage



Self siphonage

Building Drainage System

- Two Pipe System
- One Pipe System
- Single Stack system
- Partially ventilated Single Stack system

Plumbing systems: Types

Two pipe system:

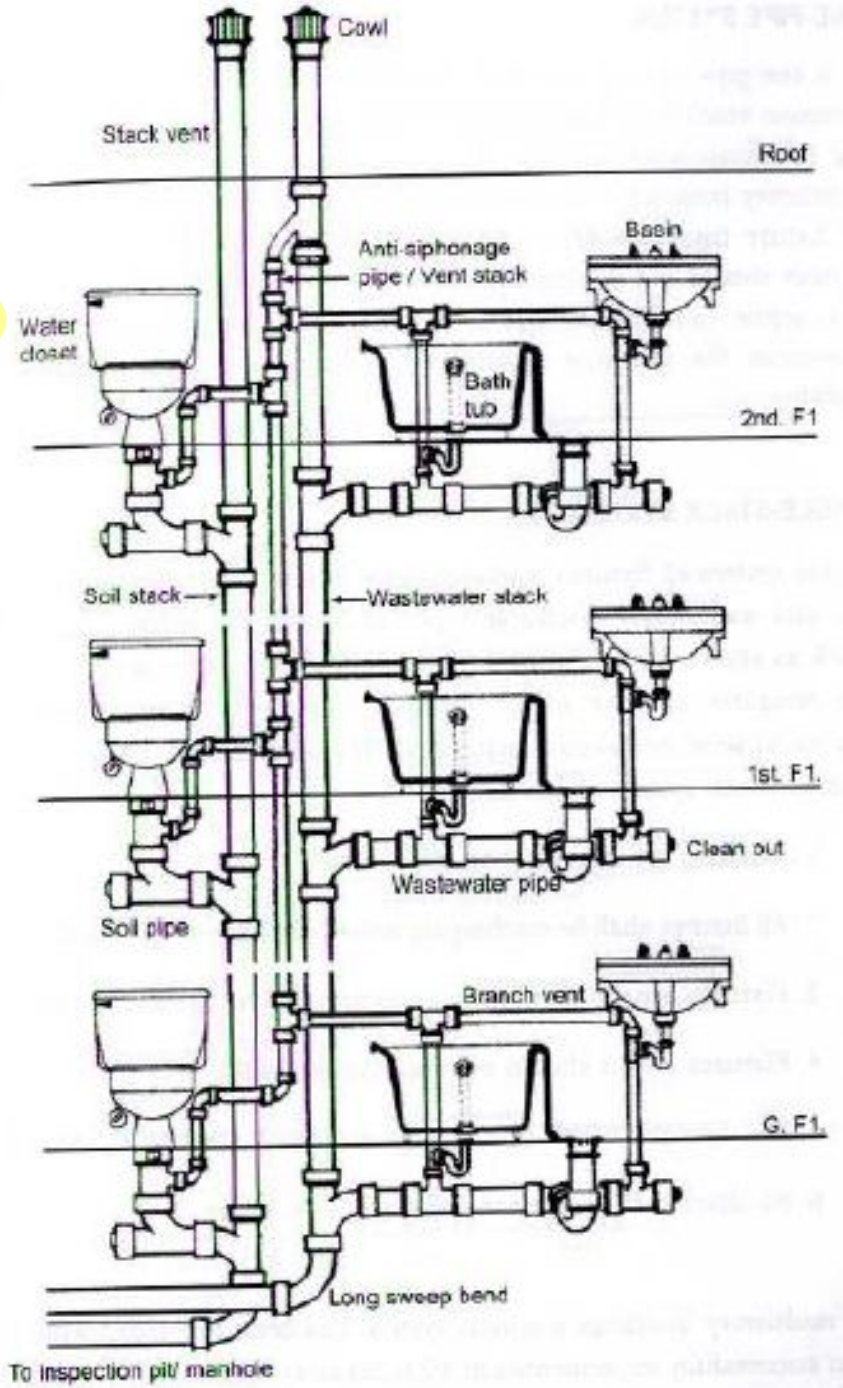
In two-pipe system, two separate piping and stacks are installed for conveyance of wastes generated from building.

Elements:

- Soil pipe
- Waste pipe
- Anti siphonage Pipe

Advantages of Two pipe system:

- Ensures segregation of the foul sewage from waste water
- No danger of back flow of sewage into waste fittings in case of blockage of soil pipe
- Separate waste stack permits arrest of solids from kitchen in gulley traps thus preventing from entering the sewer
- Reduce waste load for septic tank where there is no public sewer



Plumbing systems: Types

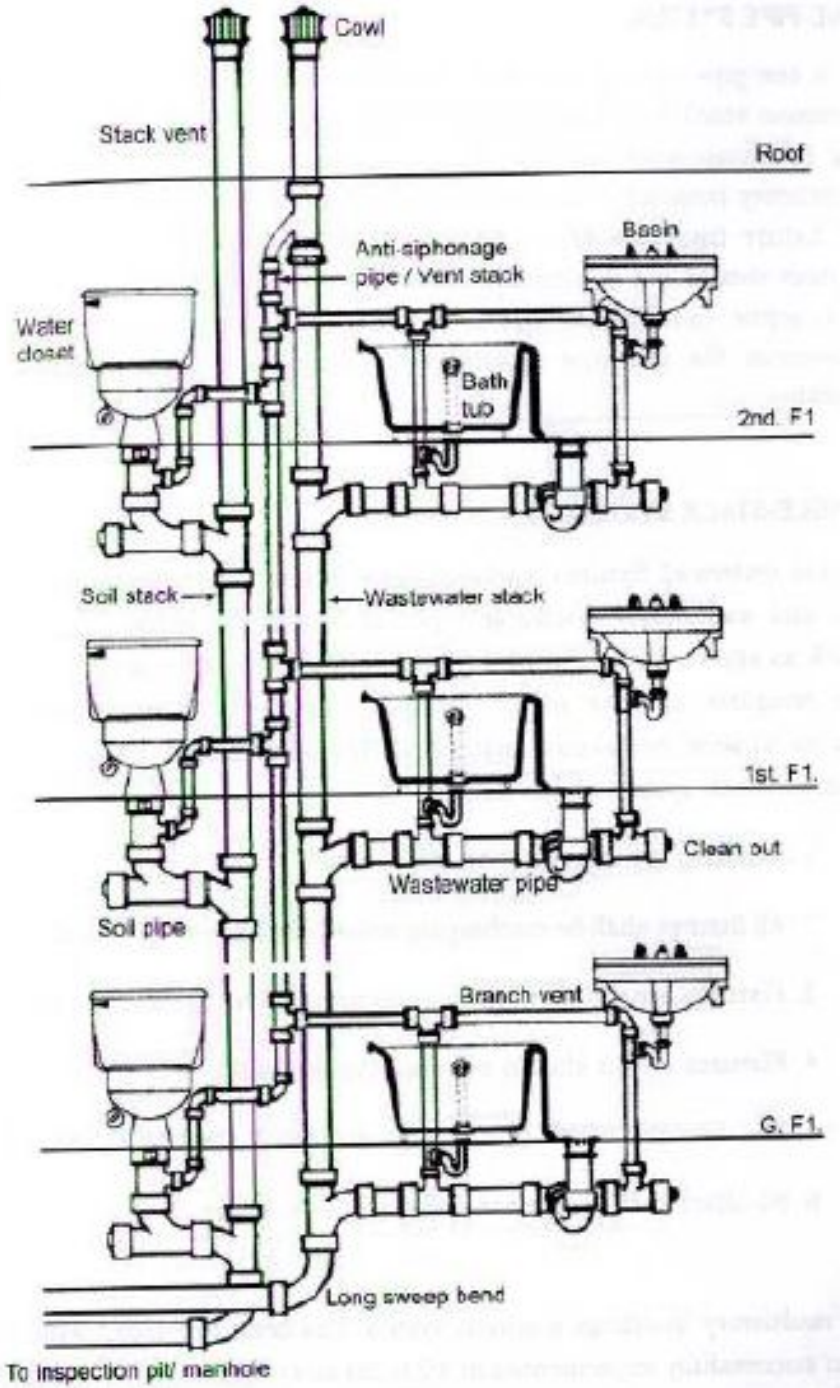
Disadvantages of Two pipe system:

– Requires comparatively more pipes so it is not economical

– Long external horizontal runs are required to reach external walls and lines connected to the sewer.

– Requires more space

– Installation of more pipes needs more joints. So probability of leakage through joints increases



Plumbing systems: Types

One pipe system:

In one-pipe system, both soil and waste fittings are discharged into a common stack with the addition of trap ventilation pipes.

Advantages of One pipe system:

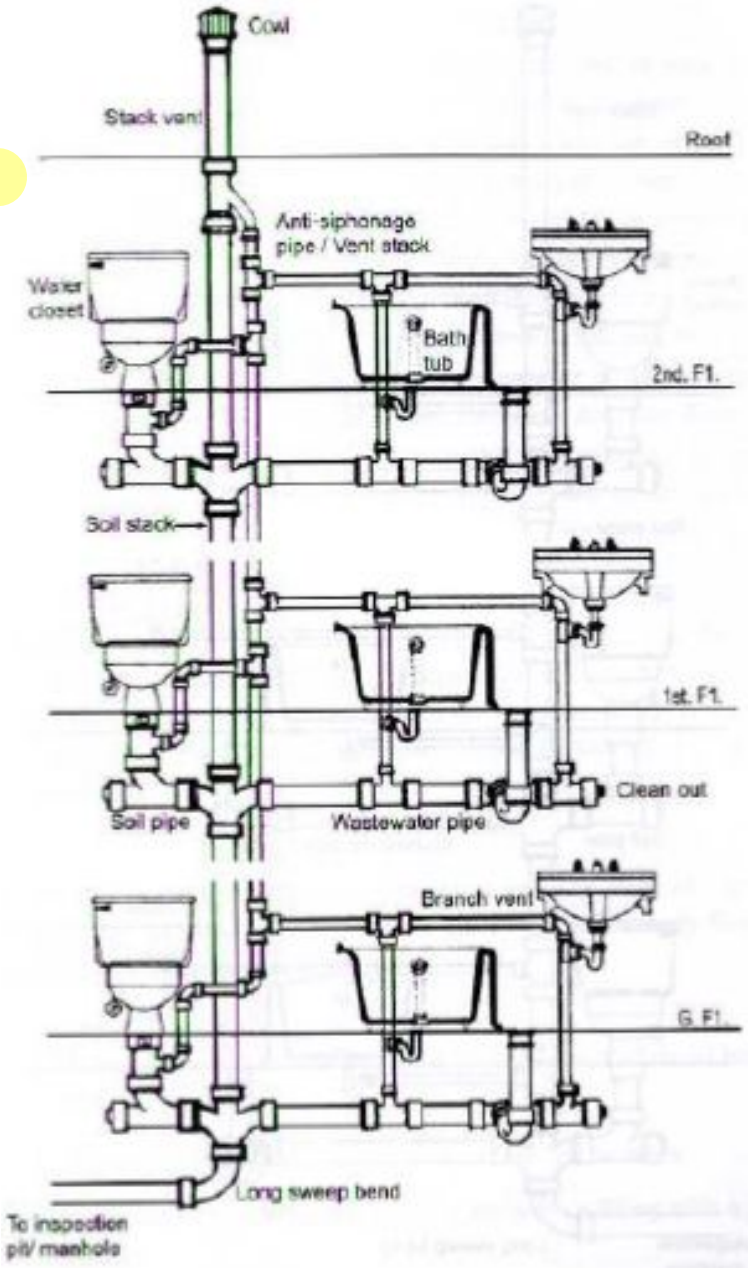
– Now widely used in modern multistoried building

– High quality of pipes, fittings and installation techniques ensures reduction of blockage problem

– Requires lesser space in pipe shafts and ducts

Disadvantages of One pipe system:

– Costlier than single stack system



Plumbing systems: Types

Single stack system:

In this system, all fixtures discharge directly into a common stack.

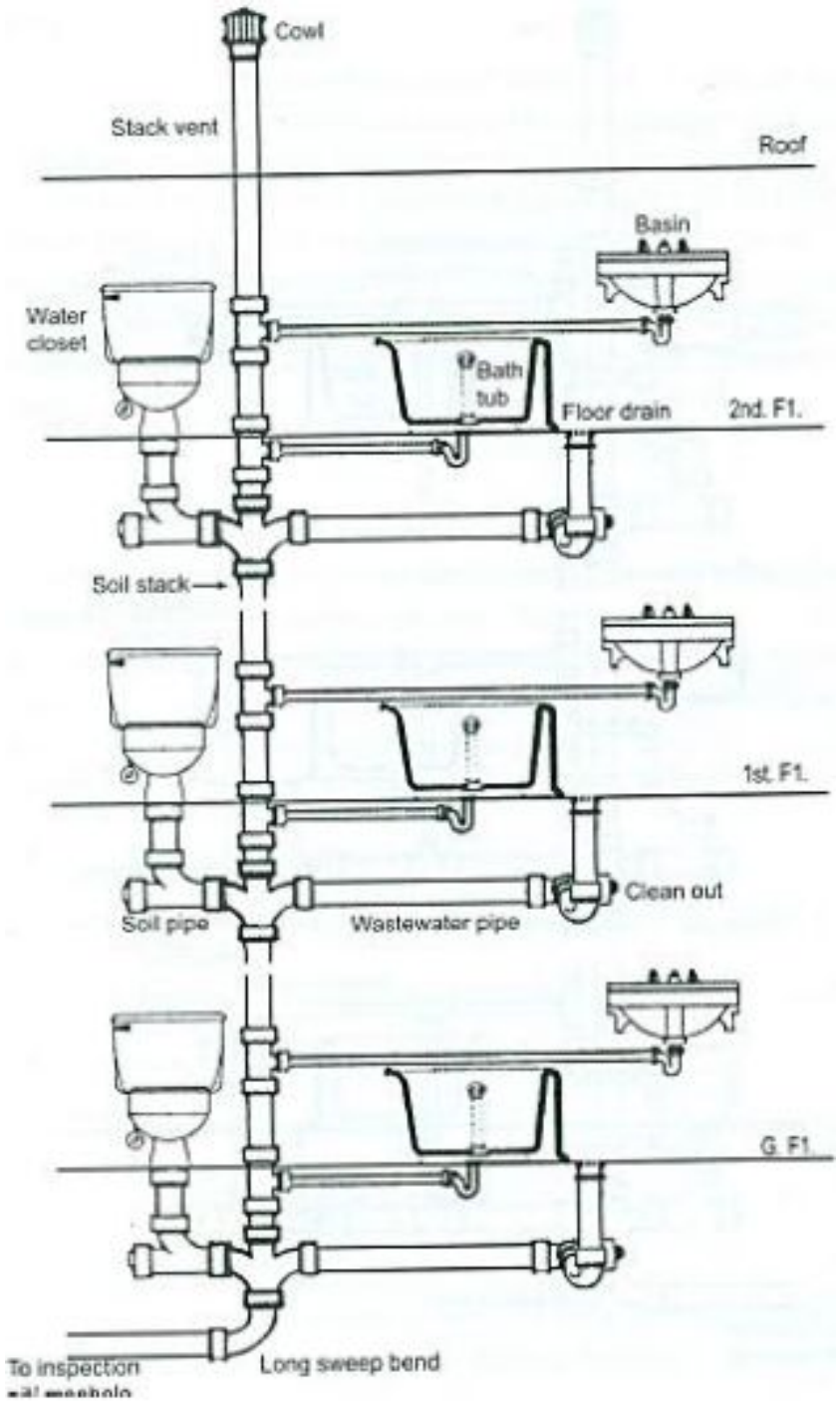
-No ventilation pipe

Advantages of single stack system:

– Simplicity in lay out, design, plumbing of the sanitary fixtures
– Improved external appearances
– More compact system

Disadvantages of single stack system:

– Air and waste from drainage pipes may be forced up through traps by back pressure due to blockage or bad design
– Water in the seal may be evaporated in dry season or in absence of flushing for a long time
– Self siphonage due to sudden discharge from appliance sucking away its own trap seal, due to discharge of another appliance in the system.



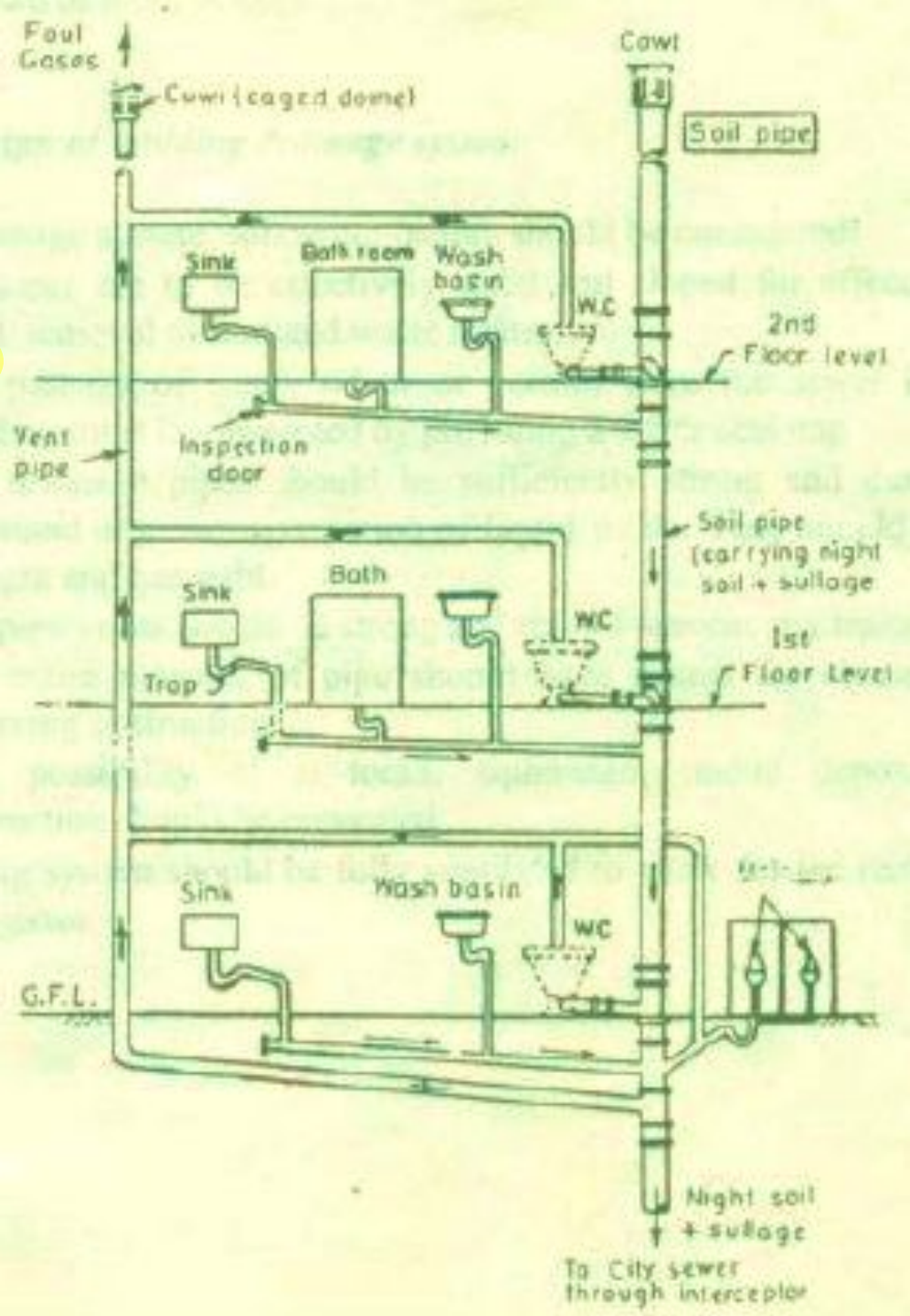
System	Types of Pipes	Advantages	Disadvantages
Dual Pipe	1. Waste single stack pipe 2. Soil single stack pipe	1. More effective drainage	1.Require two types of pipe 2. Complicated installation work
Single Pipe	1. Waste and soil single stack pipe 2. Vent pipe	1. Require only one main pipe 2. Easier to install	1. Vent pipe installation is complicated 2. Require more pipelines for vent pipe
Single Stack	1. Waste and soil single stack pipe	1. Require only one single stack pipe	1. Ventilation is less efficient

Plumbing systems: Types

Partially Ventilated Single Stack System:

A modification of one-pipe system is the partially ventilated one-pipe system. In this, the vent pipe ventilates only the traps of the water closets while the soil pipe discharges sewage and waste matter from sanitary fixtures as in the case of single stack system. As such it is more economical and has a simple arrangement of plumbing.

- Improved form of single stack system
- Traps of WC are separately ventilated by relief vent pipe.
- Sullage fixtures are not connected to the vent pipe.
- Less costly



SYSTEMS MOST PREVALENT IN WORLD

- US - ONE PIPE SYSTEM SINCE 1934.
- UK - ONE PIPE SYSTEM
- EUROPE - ONE PIPE SYSTEM
- INDIA - TWO PIPE MOSTLY

BANGLADESH - ??

Water Distribution System

- The layout of water distribution piping is basically a combination of horizontal or vertical piping arrangements designed to supply water from a source to points of use at different locations.
- Depending upon the location of supply in respect to the source of water, the distribution system is termed as up feed or down feed system.

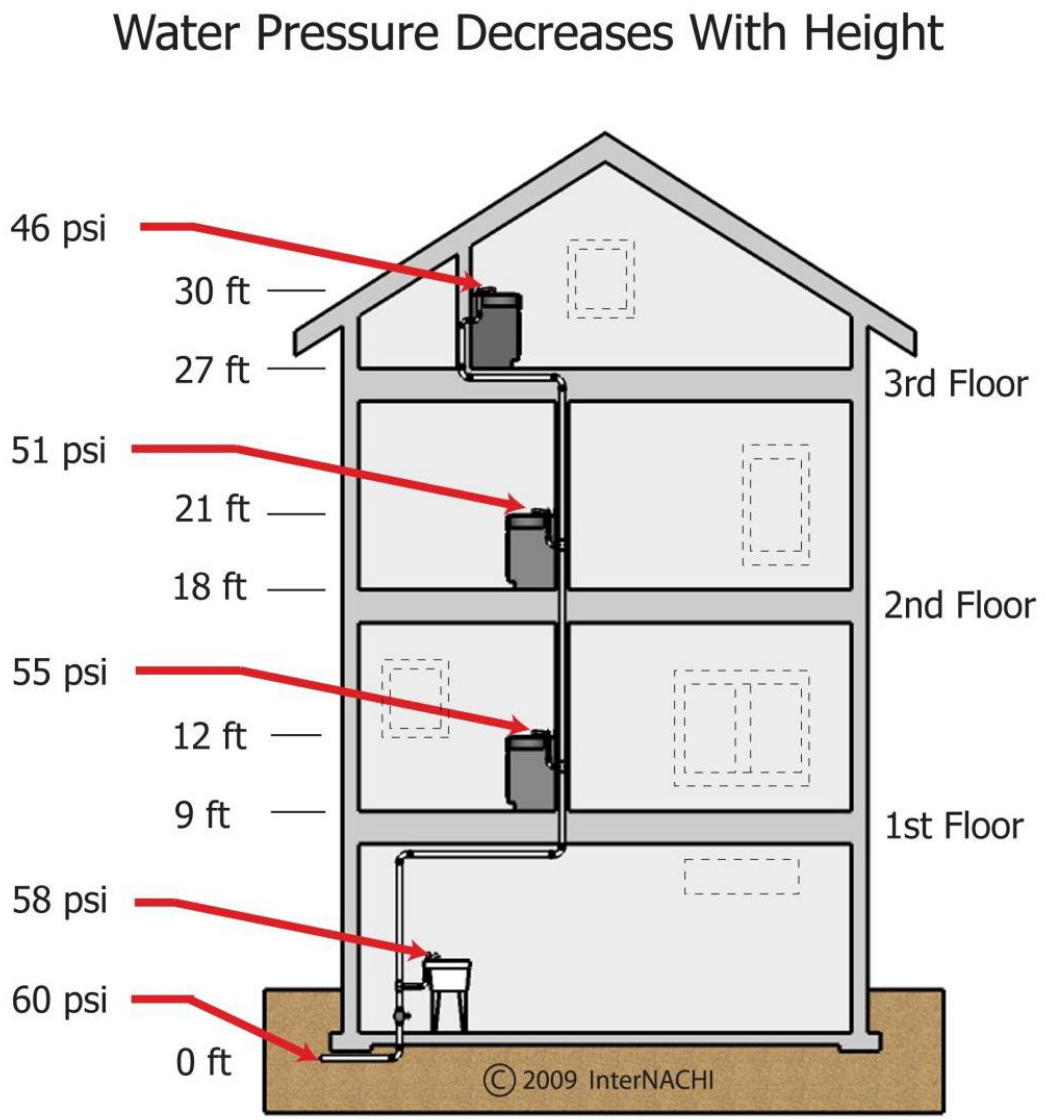
Types of Distribution System

- Up feed system
- Down feed system

Up Feed System

System with piping above the main or pressure tank is called up feed system.

- In this system, as water is forced to rise from the main or reservoir, pressure is lost in overcoming the static head and friction offered to water flow.
- At the uppermost and furthest outlet, enough pressure must be ensured to operate the faucet.



Up Feed System

Advantages of Up Feed System

- It requires the least floor space
- It generally has low initial cost
- It is the most flexible system in terms of available flow and pressure to meet a variety of distribution requirements
- The installation does not impose a large weight on the structure.

Up Feed System

Disadvantages of Up Feed System

- It has high operating and maintenance cost
- Sophisticated control system and knowledgeable maintenance staff is required
- Water supply is interrupted due to power failure
- Instantaneous pressure fluctuation may be greater

Up Feed System

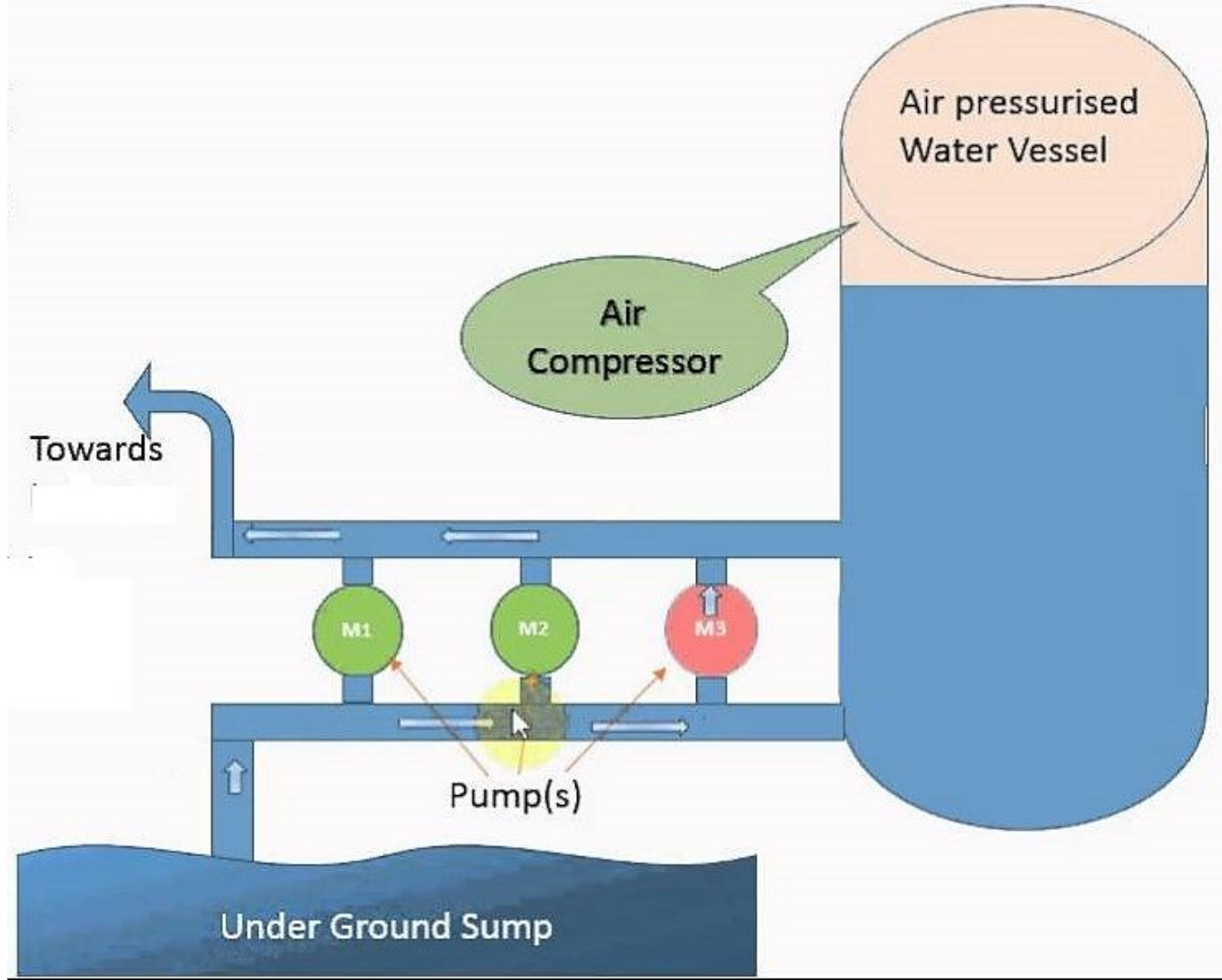
Generally two systems are adopted in a building for an up feed distribution.

Booster Pump System direct push

- A booster pump system is generally employed when pressure in water supply main is insufficient and variable. Booster pump draws water from the supply main or underground reservoir and supplies water at desired pressure, directly to the points of uses.

Hydro Pneumatic Tank System Compressed air → push

- Hydro Pneumatic tank system consist of a pneumatic water tank used in connection with a water pump. The pneumatic tank is simply a water tank partly filled with air. It acts as an equalizer of the water demand. Air volume in the tank is maintained supplying air by an air compressor.

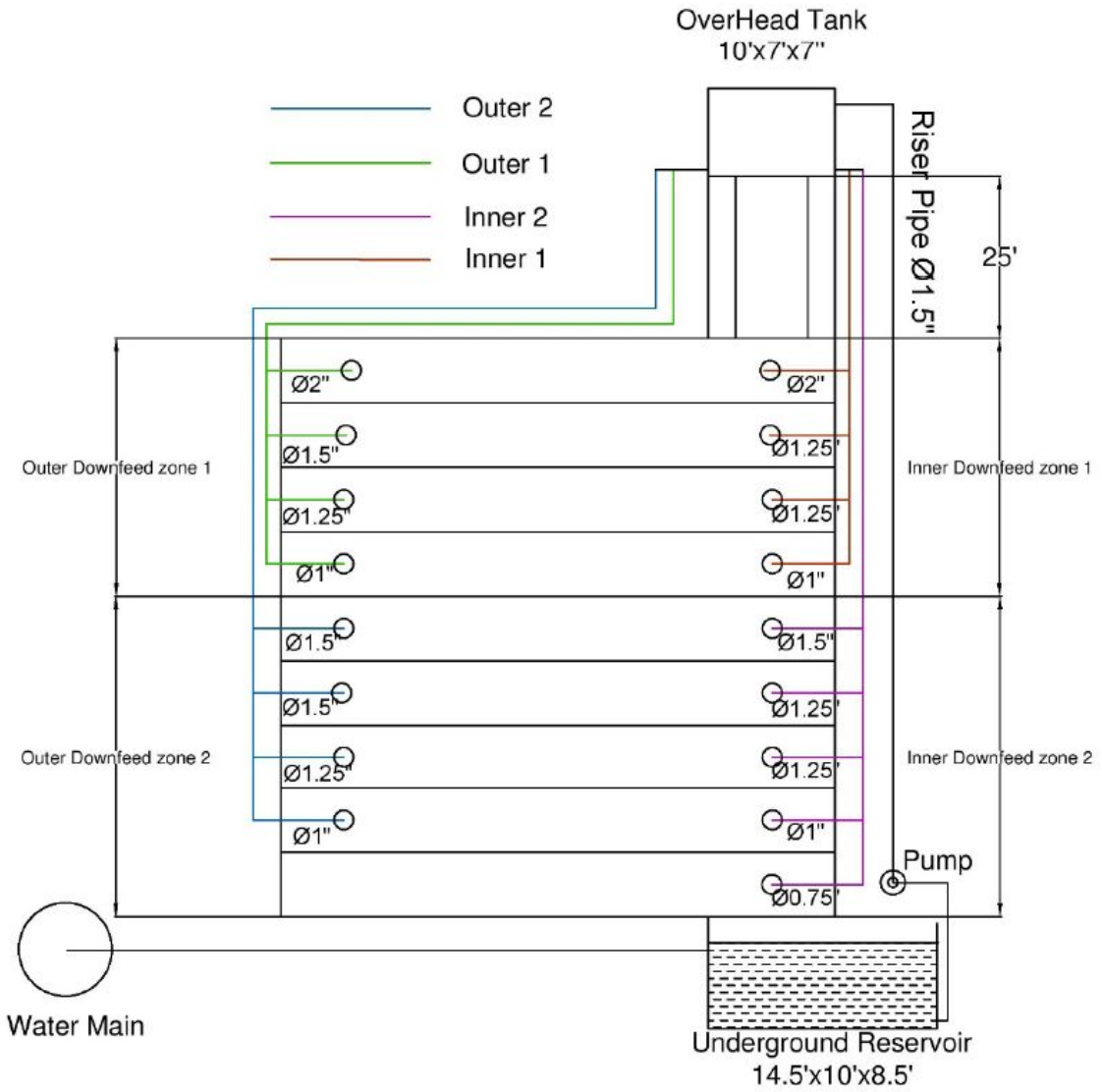


Hydro Pneumatic Tank System

Down Feed System

When the source is located at an elevated position than the points of use then the supply system is called a down feed system

- In this system static head is available for overcoming friction to flow through piping and for obtaining adequate delivery pressure at faucets.
- Water distribution from overhead tanks to faucets in the lower floors is the down feed system



Down Feed System

Advantages of Down Feed System

- Provides a reserve against failure of the mains supply
- Reduce possibility of mains pressure dropping and back siphonage of water from sanitary appliances into the main
- Reduce pressure on the installation which minimizes noise and wastage
- Not affected by power interruption
- Time needed to replace broken parts does not affect water supply

Down Feed System

Disadvantages of Down Feed System

- Water is subject to contamination
- High maintenance cost
- Occupies valuable space
- Requires stronger foundation and other structure to carry additional load of tank and water

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 commonly included in toilet and kitchen are:

- Lavatory
- Sink
- Bathtub
- Water Closet
- Sink
- Faucet

FIXTURES

There are different types of fixtures available such as washbasins , taps ,etc .



WC with Q Trap



Wall Hung WC



Wash Basin



WC with S Trap



Taps



Plumbing fixtures

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 not a flow rate unit but a design factor.

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

Flush tank vs Flush valve





Rate of flow and required pressure during flow for different fixtures

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
WC FV, 1 inch @ 15psi	15	27
WC FV, $^{3}/_{4}$ inch @ 15psi	15	15
Urinal, Flush valve	15	15
Garden hose, 50 feet and sill cock	30	5.0

Demand weight of fixtures in fixture units

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

Sustainable Plumbing Practices

"Sustainable plumbing practices reduce water and energy consumption, minimize waste, and promote eco-friendly living."

Water Conservation

- Low-flow showerheads and faucets
- Dual-flush toilets
- Rainwater harvesting systems

Energy Efficiency

- Solar water heaters
- Efficient pumps and motors
- Insulated pipes

Sustainable Plumbing Practices

Waste Reduction

- Greywater reuse systems
- Composting toilets
- Biodegradable cleaning products

Eco-Friendly Materials

- Recycled pipes and fittings
- Sustainable materials (bamboo, recycled plastic)
- Lead-free and low-lead products

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.
- Zoning of water distribution

- Lower floors can be up feed from the service main pressure.
- Upper floor must be supplied by down feed risers from elevated tank.

Design of Water Supply System of a Building

b. Determination of Up feed Zone (from the service main)

- In an up feed 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 up feed zone, ft.

f = fixture pressure, psi

- Pressure drop through 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 up feed zone.
- Pressure drop through water meter will be obtained from manufacturer's data

Design of Water Supply System of a Building

c. Determination of Down feed 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 down feed zone, ft.

Design of Water Supply System of a Building

d. Check the available pressure allowable to overcome friction loss (Up feed 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 up feed zone, ft.

f = maximum fixture pressure, psi

b =fixture branch pressure, psi (usually 1 psi)

Design of Water Supply System of a Building

e. Check the available pressure allowable to overcome friction loss (Down feed 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 down feed zone (ft)

f = maximum fixture pressure, psi

b =fixture branch pressure, psi (usually 1 psi)

Plumbing System

Example Problem

Example Problem

Given:

- 25 storey building, 10 ft floor to floor
- 50 psi at public main
- Men's and women's toilets on alternate floors
- 3 water closets or 1 water closet and 2 pedestal urinals and 2 lavatories on each floor.
  Flush valve fixtures except on 24th and 25th floors where flush-tank fixtures are used.
- Maximum pressure at any fixture is not to exceed 50 psi

Required:

Riser pipe sizes

Solution:

Determine a reasonable zoning. The lowest floors can be upfeed from main pressure. Upper floors must be supplied by downfeed risers from elevated tanks. The maximum number of floors to be served by a downfeed zone depends on the maximum pressure to be permitted at the lowest fixture.

Rate of flow and required pressure during flow for different fixtures

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
WC FV, 1 inch @ 15psi	15	27
WC FV, $^3/_4$ inch @ 15psi	15	15
Urinal, Flush valve	15	15
Garden hose, 50 feet and sill cock	30	5.0

In an upfeed zone, the pressure available at the main must equal the frictional pressure loss through piping and equipment plus the static head loss plus the required pressure at the top fixture.

Expressing this mathematically, we obtain

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

where P = service main pressure, psi;

p = pressure drop through piping and equipment, psi;

h = height from main to fixture, ft;

f = minimum permissible fixture pressure; psi.

In order to estimate friction drop, especially through a water meter, we must establish a tentative water service pipe size.

The probable rate of flow in the pipe is found as follows:

On each typical floor, the fixture unit load is

3 water closets, or 1 water closet and 2 urinals (flush valve)	30
2 lavatories	4
TOTAL	34 FU

And on the 24th and 25th floors, it is

3 water closets, or 1 water closet and 2 urinals (flush tank)	15
2 lavatories	4
TOTAL	19 FU

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,	Public	Flush valve	5
Stall or wall urinal,	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

The load on the service pipe is

23(34) +2(19) = 820 FU

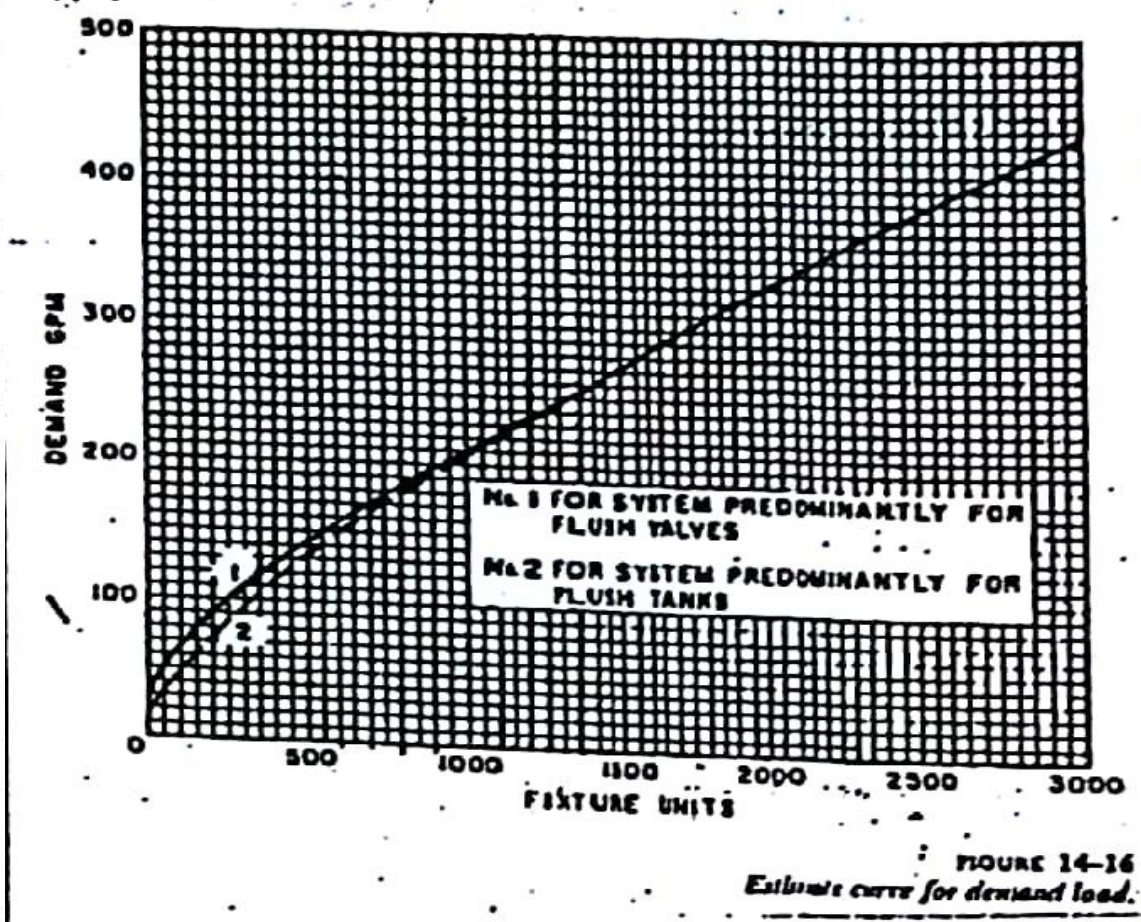


FIGURE 14-16
Estimate curve for demand load.

According to Fig. 14-16, the probable maximum demand is 184 gpm

If we use iron pipe, Fig. 14-19 indicates a 3-inch main for a drop of 6 psi per 100 ft or a 4-inch main for a drop of 1.4 psi per 100 ft.

Let us tentatively select the 4-inch main to conserve pressure for the upfeed zone.

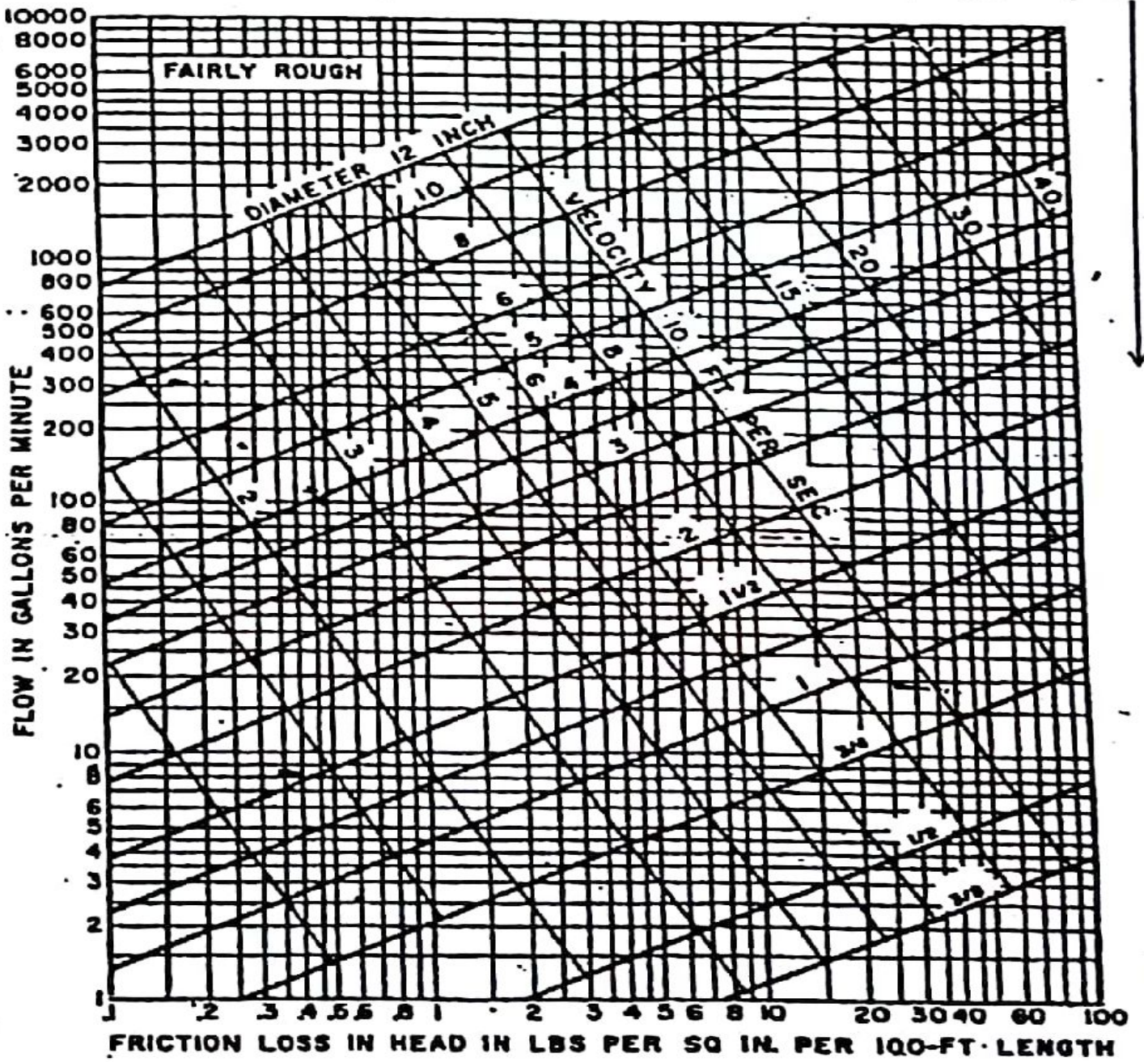


FIGURE 14-19
Friction losses in fairly rough iron pipe.

Figure 14-20 shows that about 3.5 psi drop occurs at a 4-inch meter when the flow is 184 gpm.

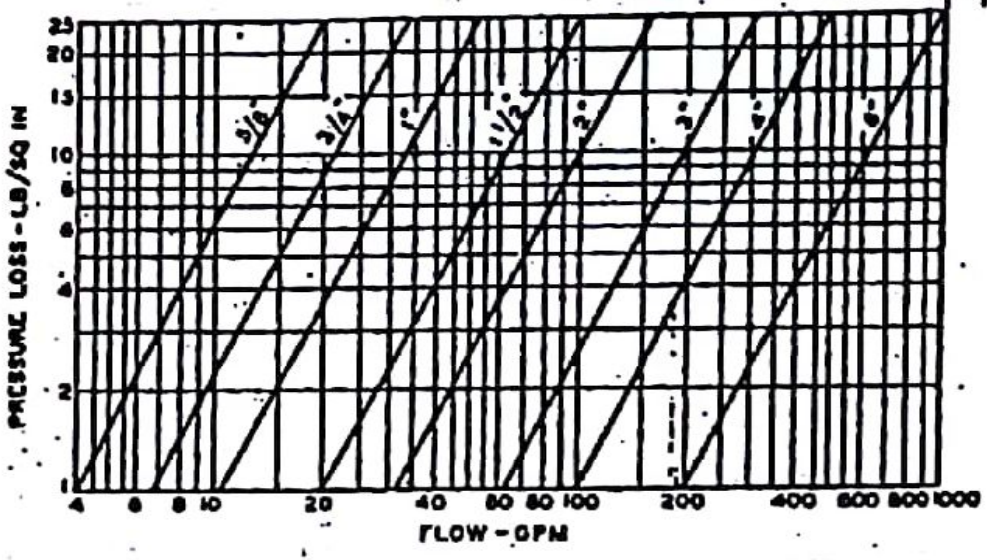
In Eq. (14-1), let us allow 1 psi drop in branch from the riser and calculate the friction loss through the service pipe, riser and fittings. For fitting friction, 50% extra length is considered as initial approximation. Therefore, the height of the upfeed zone is found from the equation

$$50 = 3.5 + 1.5\,(70 + h)\,(1.4 / 100) + 0.434h + 15 + 1$$

$$h = 29.03 / 0.455 \approx 64 \text{ ft}$$

water main to service pipe ~ 70'

min fixture press



(See manufacturer's data for exact value for meter used)

FIGURE 14-20
Pressure losses in disk-type water meters.

If the floor-to-floor height is 10 ft, 6 stories are indicated for the height of the upfeed zone.

We must remember that 64 ft is from main to top fixture. Therefore, a deep water main would limit us to 5 floors.

Now we should check the maximum height of a downfeed zone.

The maximum pressure on the lowest fixture occurs when all water flow is off and it is the static head obtained from the roof tank elevation.

Obviously, when water flows, frictional resistance lessens the pressure at the bottom of a riser. If the maximum pressure for a fixture is 50 psi, the maximum vertical distance from tank to fixture is 50/0.434= 115 ft.

Allowing a little extra height of the roof tank above the top-most flush tank fixture for overcoming friction loss through piping and fittings, about 20 to 25 ft of height between the top fixture and the roof tank is required, only 91 ft (= 115 – 24) is left to use for the floor-to-floor distances served by the riser. Hence, for 10-foot floor-to-floor heights, the maximum downfeed zone is 9 floors.

For our 25-story building, the use of two downfeed zones of 9 floors requires that the upfeed zone be (25 – 18) or 7 floors. But we found 5 floors as the maximum for the upfeed zone.

We have the choice between

(i) increasing the downfeed zones to three or

(ii) raising, slightly our maximum fixture pressure for a downfeed zone.

The latter alternative would take less equipment while the former would lessen the sizes of the units used.

If the maximum fixture pressure allowed is increased by 10 (0.434) or 4.34 psi.

Raising our 50 psi to 54.34 or, 55 psi is not objectionable.

Hence, we choose:

(i) Zone # 1
a 5-floor upfeed zone
(1st floor- 5th floor)

(ii) Zone # 2
a 10-floor downfeed zone
(15th floor – 6th floor)

(iii) Zone # 3
a 10-floor downfeed zone
(25th floor – 16th floor)

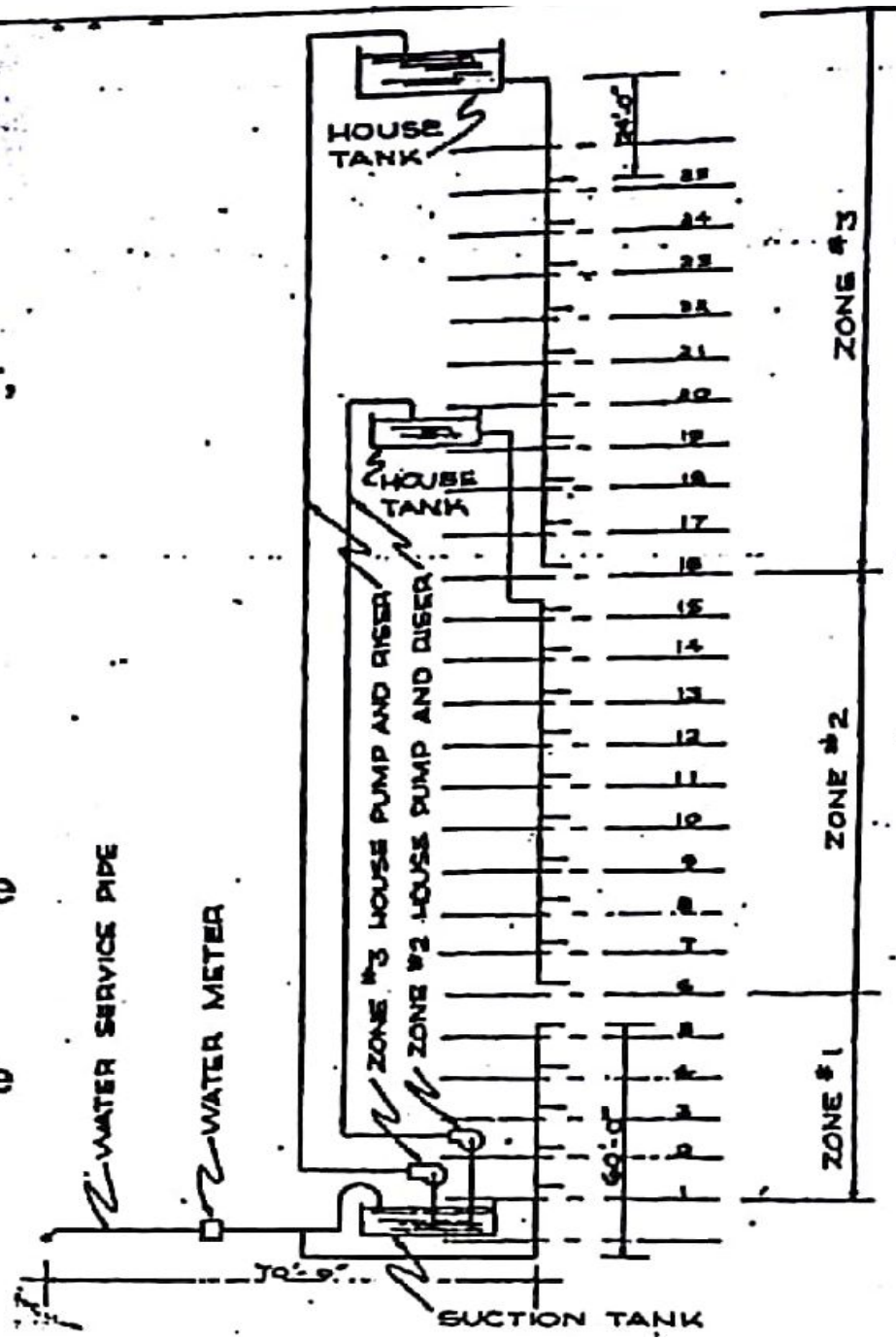


FIGURE 14–21
Water supply for a tall building.

Design of the Upfeed Zone

- First let us find the total pressure available for overcoming friction to flow in piping and fittings.
- It will be the main pressure less the sum of water meter pressure drop, static head loss, and minimum fixture pressure including pressure drop in branches from the riser for which allow 1 psi, or

$$p = 50 - [3.5 + 60\ (0.434) + 15 + 1] = 4.46 \text{ psi}$$

assuming that the top fixture is 60 ft above the main.

- The pressure of 4.46 psi can be utilized to overcome friction caused by flow through piping and fittings.

- We evaluate 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.

At the moment, we do not know pipe or fitting sizes, hence, an estimate of equivalent length must be made.

The riser is a straight vertical run, and a low increase in actual length to allow for fittings is reasonable. If the measured length of pipe from main to foot of riser is 70 ft and the riser is 60 ft, the total actual length is 130 ft.

Let us add 50% for fittings. The total equivalent length is 130(1.5)= 195 ft.

Therefore, the pressure loss per 100 ft is

$$p = \frac{(4.46)(100)}{195} = 2.3 \text{ psi per } 100 \text{ ft}$$

The tabulation of the information for sizing the upfeed zone is given in Table 14-5.

Table 14–5. Pipe sizes for upfeed zone of water supply system.

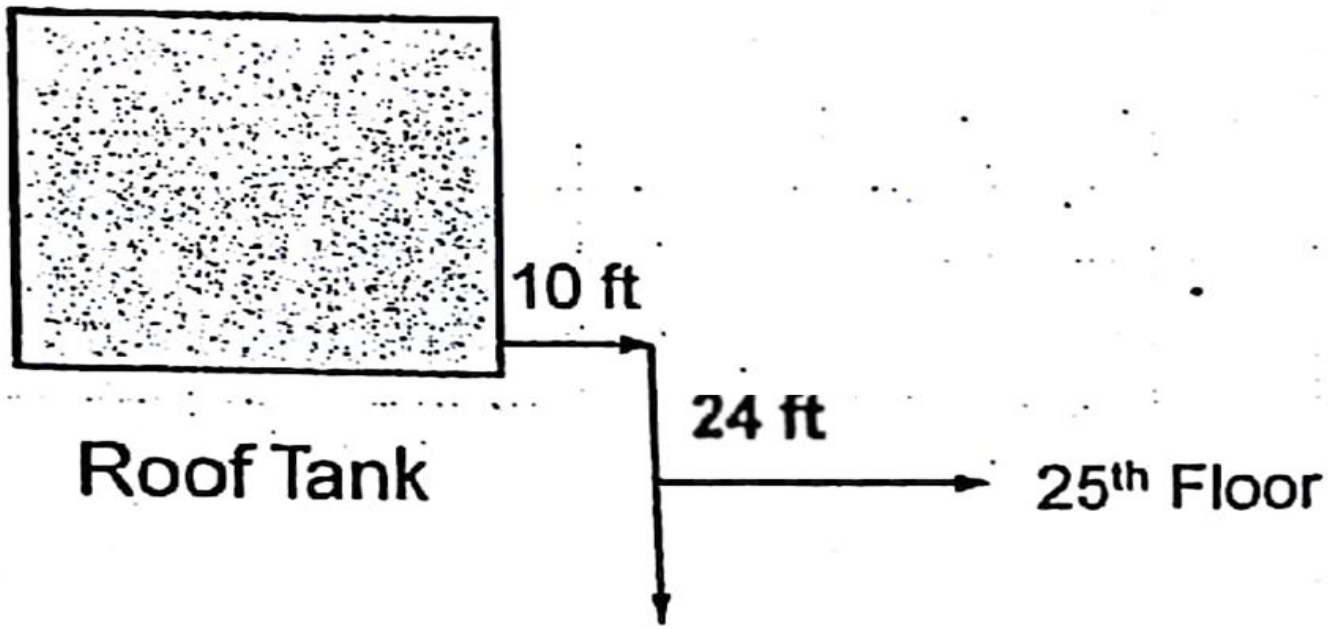
Floor	Fixture units	Accumulated fixture units	Demand flow (gpm)	Pipe size (in.)
Service pipe		820[a]	184	3½
1	34	170	85	3
2	34	136	77	2½
3	34	102	68	2½
4	34	68	58	2½
5	34	34	43	2

[a] Includes F.U. from zones 2 and 3.

- Each floor is listed.
- Then, the fixture unit load as previously determined is given to each floor. Calculate the accumulated fixture units corresponding to each floor.
- The rate of flow for each floor corresponding to the fixture unit demand load is determined from curve 1 of Fig. 14-17 for installations having flush-valve fixtures. From these rates of flow and a permissible drop of 2.3 psi per 100 ft, we can read the pipe sizes from Fig. 14-19.

Design of the Downfeed Zones

- Now, let us size downfeed zone 3.
- The problem is rather different from upfeed sizing. Two special conditions are to be satisfied
  - (i) We must limit pressure loss at the top of the zone so that top fixtures will receive their minimum pressure.
  - (ii) Lower down, we can size piping so that friction due to flow just balances the static gain.



- Let us set our tank at 24 ft vertically above the top fixture with 10 ft of horizontal pipe also required in the first section.
- Now, the permissible pressure drop in the pipe from the tank to the top floor is the static gain less the fixture pressure, 8 psi, and the fixture branch pressure, 1 psi.

- Therefore, $p = 24(0.434) - 8 - 1 = 1.4$ psi

- Assuming the fitting friction to be equal to a 50% increase in actual length, the drop per 100 ft is

$$\frac{1.4 \times 100}{1.5 \times 34} = 2.80 \text{ psi}$$

- We must remember that at the 23rd floor the minimum pressure for flush-valve fixture and branch is 15 + 1= 16 psi. Let us find the pressure drop from the 25th to the 23rd floor to obtain the 16 psi required at the 23rd floor.
- The static head gained is 10 + 10 = 20 ft or 20(0.434) = 8.68 psi. Therefore, 9 + 8.68 – 16 = 1.68 psi is available for overcoming friction.

↳ 8+1

- The permissible pressure drop per 100 ft is

$$\frac{1.68 \times 100}{1.5 \times 20} = 5.60 \text{ psi}$$

- This pressure drop can be used to size the riser for the 23rd and 24th floors.
- From this point on, all piping can be sized to use up the entire static head gain. In other words, once we have 16 psi available, any additional gain from static head can be used to overcome friction.
- Permissible pressure loss, $p = 16 + 10 \times 0.434 - 16 = 4.34$ psi
- Thus, at each floor the gain is $10(0.434) = 4.34$ psi, and the loss per 100 ft is

$$\frac{4.34 \times 100}{1.5 \times 10} = 28.9 \text{ psi}$$

- Table 14-6 illustrates a convenient tabular form for the riser pipe sizing. We find the fixture unit loads present at each floor and the accumulated load on the riser at each floor using Table 14-3 as we did for the upfeed zone. From the fixture unit loads, we find the corresponding probable flow rates from Figs. 14-16 and 14-17.

Table 14-6. Pipe sizes for downfeed zone 3 of water-supply system.

Floor	Fixture units	Accumulated fixture units	Demand flow (gpm)	Actual pipe length (ft)	Equivalent length due to fittings (ft)	Total equivalent length (ft)	Pressure drop (psi/100 ft)	Pipe size (in.)
25	19	310	110	34	17	51	2.80	3
24	19	291	107	10	5	15	5.60	2½
23	34	272	103	10	5	15	5.60	2½
22	34	238	98	10	5	15	28.90	2
21	34	204	92	10	5	15	28.90	2
20	34	170	85	10	5	15	28.90	2
19	34	136	77	10	5	15	28.90	2
18	34	102	68	10	5	15	28.90	1½
17	34	68	58	10	5	15	28.90	1½
16	34	34	43	10	5	15	28.90	1¼

(i) Calculate the permissible pressure loss per 100 ft in the riser pipe of the topmost floor of a seven storied building from the following data:

- the water supply is intermittent
- the fixture pressure ranges from 5 psi to 10 psi
- floor to floor height is 10 ft

Assume reasonable value for any missing data.

(ii) In a down-feed zone of water supply, the pressure available in the riser at a certain floor is 8 psi. Calculate the permissible pressure drop per 100 ft of riser to supply for a floor 22 ft floor below where the pressure requirement is 14 psi.

(iii) The roof tank of a 30 storied tall building is placed 26 ft above the top-most fixture whose pressure requirement is 9 psi. The maximum fixture pressure requirement of the two top-most floors is 9 psi. The top-most zone covers 8 floors and the floor to floor height is 10 ft. The maximum fixture pressure requirement of each floor is 16 psi except the two top-most floors. Calculate the permissible pressure drops in the concerned riser pipe. Assume reasonable value of any missing data if required.

(iv) Given:

* 30-story building 12 ft floor to floor.
* 55 psi at public main.
* Flush-valve fixtures except on 29th and 30th floors where flux-tank fixtures are used.
* Maximum pressure at any fixture is not to exceed 55 psi.
* Minimum permissible fixture pressures vary from 5 psi to 8 psi for flush-tank fixtures.
* Minimum permissible fixture pressures vary from 7 psi to 14 psi for flush-valve fixtures.
* Pressure loss in the water meter is 4 psi.
* Public main is 50 ft away from the foot of the riser.
* The pressure loss is 7 psi/100 ft for a 3-inch main and that is 1.6 psi/100 ft for a 4-inch main.

Assume reasonable values for missing data if required.

Determine zoning of the tall building.

(v) You need to design the water distribution system of a 4-storied Apartment building by downfeed system. The main pressure is 40 psi and the minimum fixture pressure is 5 psi.

Each storey has the following fixtures:

Bathtub 1, Water Closet 3, Shower 2, Tap 4, Kitchen Sink 1

(i) Determine the minimum height of the Roof Tank of the building.

(ii) Determine the water distribution pipe sizes of the building.

(Table, Graph, Nomographs are attached).

Table: Fixture Unit values

Type of Fixture	Fixture Unit Value	
	Private	Public
Lavatory	1	2
Bath tub	2	4
Water Closet (Flush tank)	3	5
Water Closet (Flush valve)	6	10
Urinal	----	5
Shower	2	4
Kitchen Sink	2	4
Hand wash basin	2	4
Ablution Tank	1	1

(c) Calculate the height of up-feed zone of a tall building form the following data.

Floor to floor height = 10 ft

Service main pressure = 55 psi

Pressure loss in water meter = 3.5 psi

Pressure loss in service pipe = 4.5 psi per 100 ft

Fixture pressure varies from 4 psi to 10 psi

Length of pipe form street water main to the foot of riser = 45 ft

Assume reasonable value of any missing data if required.

(d) Calculate the available pressure loss to supply water to the top most floor of a 7 storied building from the following data:

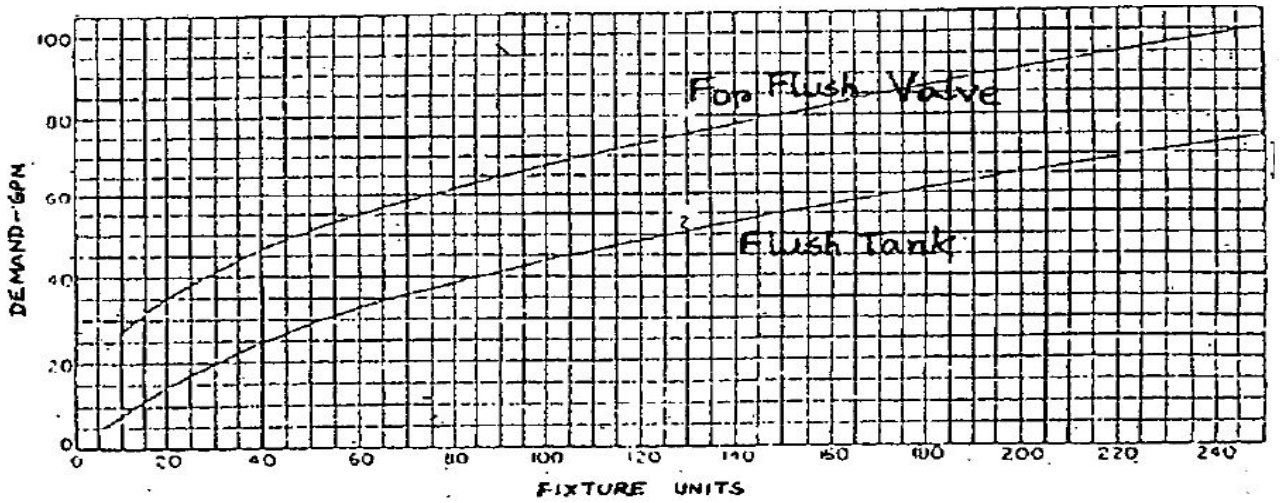
Water supply in the street main is intermittent.

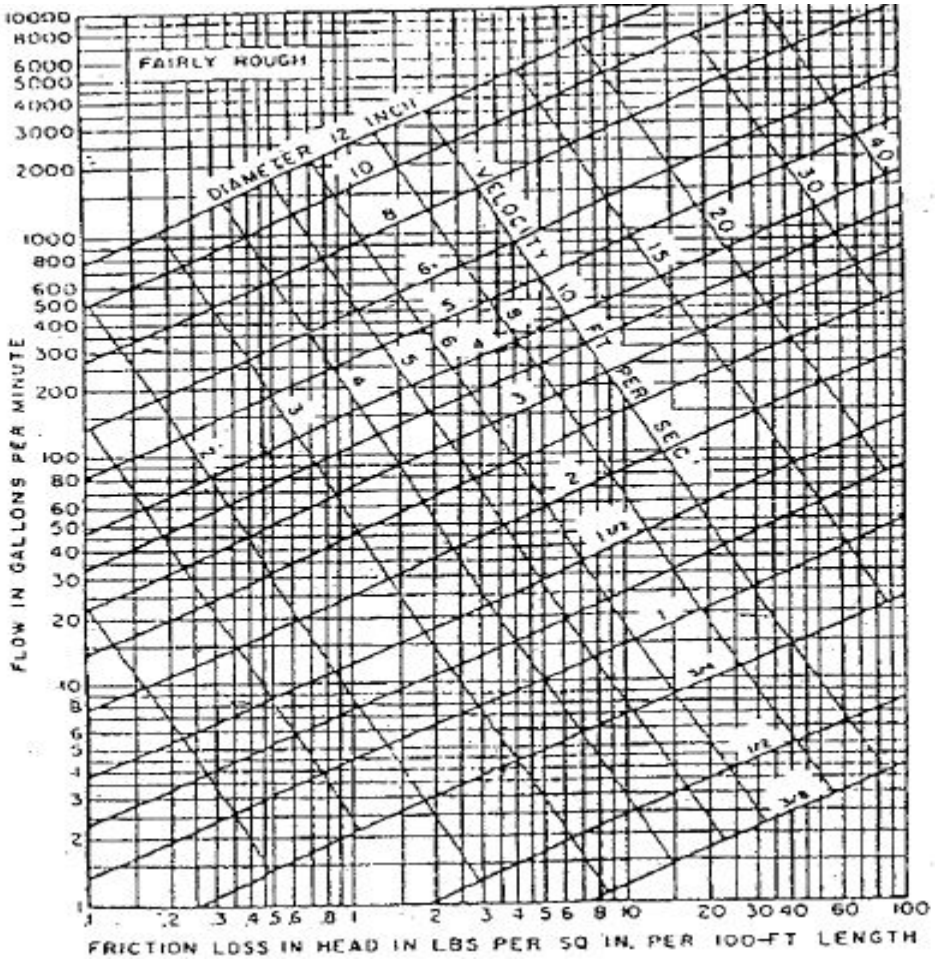
Service main pressure = 40 psi

Floor to floor height = 9.5 ft

Fixture pressure varies form 4 psi to 7 psi

Assume reasonable value of any missing data if required.


For Flush Valve
Flush Tank
DEMAND - GPM
FIXTURE UNITS
0
20
40
60
80
100
120
140
160
180
200
220
240


FAIRLY ROUGH
DIAMETER IN INCH
VELOCITY IN FT PER SEC
FLOW IN GALLONS PER MINUTE
FRICTION LOSS IN HEAD IN LBS PER SQ IN. PER 100-FT LENGTH



Sustainability of Water and Sanitation Services

SDG 6: Ensure Access to Water and Sanitation for All



Target 6.1: Safe and affordable drinking water

UN definition: By 2030, achieve universal and equitable access to safe and affordable drinking water for all.

Target 6.2: End open defecation and provide access to sanitation and hygiene

UN definition: By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations.

Target 6.3: Improve water quality, wastewater treatment and safe reuse

UN definition: By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.

SDG 6: Ensure Access to Water and Sanitation for All



Target 6.4: Increase water use efficiency and ensure freshwater supplies

UN definition: By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.

Target 6.5: Implement integrated water resources management

UN definition: By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate.

Target 6.6: Protect and restore water-related ecosystems

UN definition: By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes.

SDG 6: Ensure Access to Water and Sanitation for All



Target 6.7: Expand water and sanitation support to developing countries

UN definition: By 2030, expand international cooperation and capacity-building support to developing countries in water and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies.

Target 6.8: Support local engagement in water and sanitation management

UN definition: Support and strengthen the participation of local communities in improving water and sanitation management.

What are the challenges?

In 2024, 2.2 billion people still lacked safely managed drinking water; 3.4 billion people lacked safely managed sanitation,; and 1.7 billion lacked basic hygiene services at home.

Sustainability



The definition of sustainability with respect to water supply or sanitation system indicates:

- Provides an efficient and reliable service at a level which is desired.
- Can be financed or co-financed by the users with limited but feasible external support and technical assistance.
- Is being used in an efficient effective way, without negatively affecting the environment.

Sustainability



- Communities or households must be convinced of the desirability of new water sources, or particularly new excreta disposal facilities, in the first place.
- The financial costs which communities are expected to rise as a contribution to capital or recurrent expenses must be acceptable, affordable, or practicable.
- Communities must have felt ownership of the new infrastructure, so that repairs and maintenance should be taken place.
- Benefits promised at the outset of projects (e.g. dramatically improved health) must be materialized.

Sustainability



- Community education (e.g. hygiene education) and the attitudinal and behavioral change expected to be achieved by it.
- Full community participation or management should be planned in from the start, community-level committees and caretakers should be trained.

6 CLEAN WATER AND SANITATION

Water services are sustainable if

- the infrastructure operates and is used effectively and efficiently
- the benefits of the service continue to be realised over a prolonged period of time where the quality, quantity, level of service, affordability, reliability, health, and economic spin-offs do not decrease over time
- the infrastructure is maintained in a condition which ensures a reliable and adequate water supply
- all O&M and replacement costs are covered
- water consumed is not over-exploited
- the management of the services is institutionalised (Water services provider in place)
- there is access to sufficient support
- there are no negative effects to the environment
- there are no unplanned external interventions.

6 CLEAN WATER AND SANITATION

Hard ware and soft ware

- Sustainability is about systems that last – both 'hardware' and 'software'
- **Hardware** is the 'hard' or physical infrastructure such as pumps, pipes, taps and toilets which provide water and sanitation services
- **Software** includes all the systems, structures and activities to ensure that the services function. This includes community awareness and mobilisation, hygiene awareness, establishing management structures, putting in place systems for operations, maintenance and revenue collection, ensuring access to support (especially to community management structures)

Water Sources Hardware

- Rainwater Harvesting
- Field Trenches
- Sand Dams and Subsurface Dams
- Conjunctive Use
- Controlled Drainage
- Fog Drip
- Rivers, Lakes, Springs
- Man-made Reservoirs
- Dug Well, Manual pumping
- Desalination, Water source protection
- Retention basin
- Groundwater Recharge

Water Sources Software

- Creating Policies and a Legal Framework
- Strengthening Enforcement Bodies
- School Campaigns
- Empowering Young People as Promoters
- Media Campaigns - Internet and Email
- Creating Information Material
- Corporate Social Responsibility
- Social Marketing
- Water Charges
- Water Resources Assessment
- Water Allocation

6 CLEAN WATER AND SANITATION

Key sustainability factors

- Ongoing operation and maintenance
- Financial sustainability (management and cost recovery)
- Appropriate infrastructure choice and design
- Community awareness, responsibility and willingness to pay
- Effective advocacy and communication
- Sound and sustainable institutional arrangements
- Integrated water, sanitation and hygiene services
- Local economic opportunities
- Improved health
- Integrated development planning



Sustainability: social issues

- Community participation and decision making
- Improved health and hygiene
- Effective communication and customer relations
- Involvement of women
- Training and capacity building
- People-centered, developmental approach
- Household responsibilities are understood

6 CLEAN WATER AND SANITATION

Sustainability: governance issues

- Good policy in place
- WSA fulfills its roles and functions
- Participatory WASH development planning
- Appropriate WSP selected
- Clear roles and responsibilities
- Bylaws and contracts to regulate provision of services
- Monitoring and evaluation for sustainability
- Necessary support in place

6 CLEAN WATER AND SANITATION

Sustainability: financial issues

- Awareness of all the costs in providing services (life cycle costs)
- Effective use of tariffs, transfers and taxes to ensure that all costs are covered
- Affordable tariff structuring
- Financial bylaws and provisions in place
- Appropriate billing and tariff collection system in place
- Accountability and transparency to customers
- Clear, enforced sanctions for non-payment

6 CLEAN WATER AND SANITATION

Sustainability: technical issues

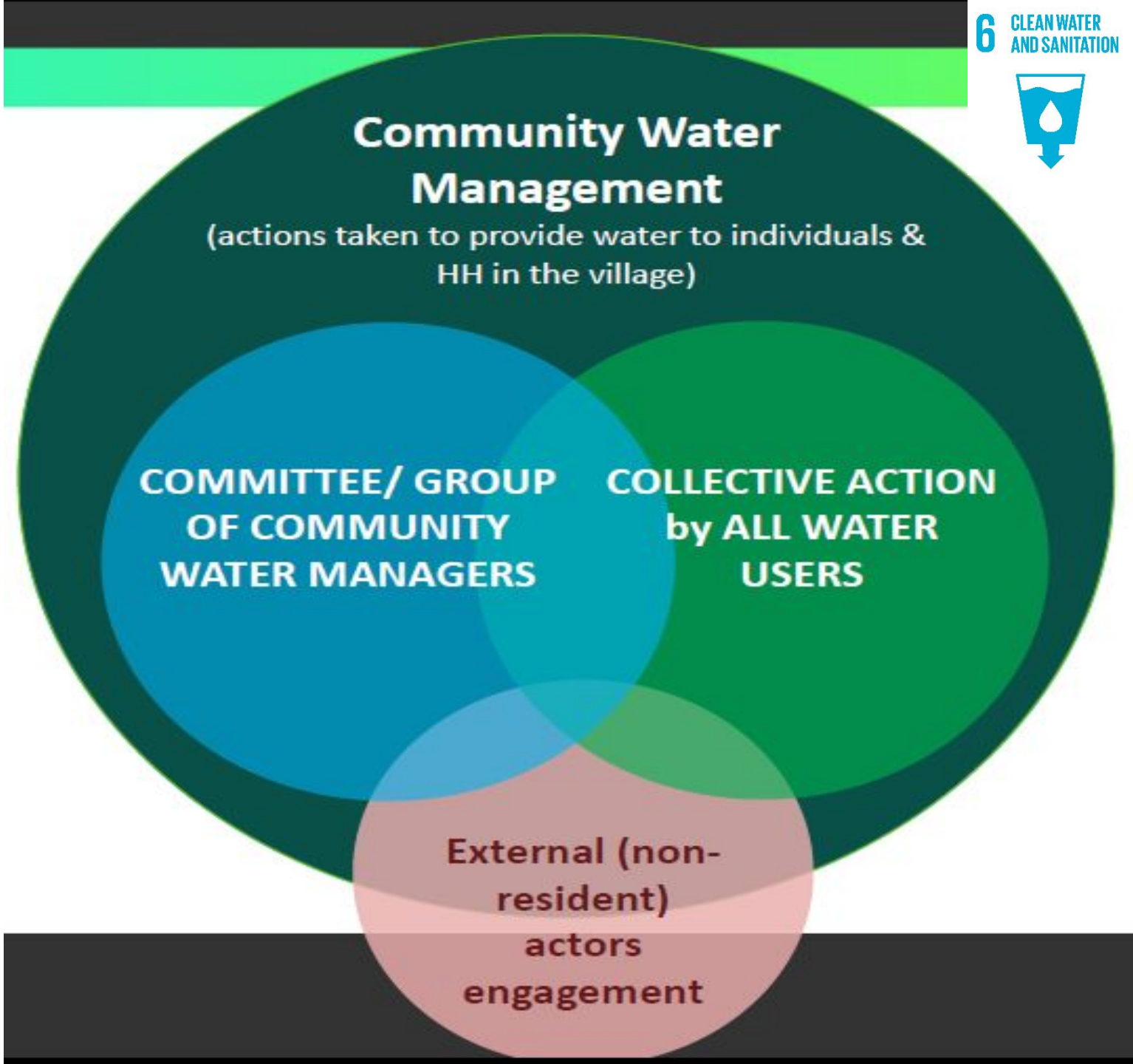
- Appropriate infrastructure choice and design
- Affordable technology
- Good quality implementation
- Ongoing operations and maintenance
- Supply chain management
- Access to technical support
- Integration with institutional and social development issues
- Ensure environmental sustainability

Community



- Group of people with common but also conflicting interests and ideas and different socio-economic and cultural background living in one geographic area.
- Water supply and sanitation systems can be common interest but at the same time source of conflict.
- As example at the community level part of it uses latrines whereas others use the open air.
- A very clear understanding of problems and potential solutions has to be shared by all involved.

"Good" community water management?



6 CLEAN WATER AND SANITATION

COMMITTEE/ GROUP OF COMMUNITY WATER MANAGERS

1. **Maintenance** (proactive, timely, innovative)
2. Managing / encouraging **WQ Risk management** (mitigate hazards e.g. promote sanitation, maintenance, treatment/promoting HH treatment of poor water)
3. **Planning and managing supply** (multiple sources, storage capacity, plan for future demand and changes)
4. Managing **demand** (supply strategies with multiple water sources, awareness activities, community messaging about why, when and how to conserve water)
5. Efforts to achieve **inclusion** – physical accessibility, participation of gender, youth, vulnerable, all parts of village
6. Use of **policies and rules** (formal, informal)
7. **Managing finances** transparently and competently
8. **Monitoring** to guide improvements and report to community, support finances
9. **Consulting with and Reporting to community** for transparency and accountability
10. **Coordination and leverage between community committees/groups**
11. Ways, means and capacity to **access external support**
12. **Motivate and coordinate collective action**

COLLECTIVE ACTION by ALL WATER USERS

(By individuals, families, communities)

- Financial contribution
- Other direct action - maintenance, (reporting, doing), operations: conserving water use & using multiple sources

External (non-resident) actors engagement

- Technical advice (suited to current and future context) – planning, designing, construction, managing
- Finance – capital
- Spare parts
- Maintenance support
- Monitoring

Community Management- Water Supply

Community-managed water supply systems are decentralized, participatory approaches where local users operate and maintain water infrastructure to ensure safe, sustainable access.

Rainwater reservoir and ponds

- managed by individual or groups
- regular cleaning and desilting is needed to avoid contamination

Handpumps

- placed on shallow and deep wells
- maintained by users, mechanics and DPHE

Community water points

- piped system
- user group chooses a small committee to oversee proper water use and collect money

Community Management- Water Supply

Group taps

- used by taking one private connection and share the bill
- needs good facilitation and overall management structure

Vending Kiosks

- water is sold per bucket at public vending points
- elected water committee employ kiosk holders
- manages fund and takes care of maintenance and repair







Community Water Points

Community Management- Water Supply

Local Distribution Net

- communities buy water from the urban utility
- install metered connection or fills reservoir
- local community distributes to user

Small Autonomous Water Supply

- an elected management committee involves in treatment by multi-stage filtration

6 CLEAN WATER AND SANITATION



Local Distribution Net

Community Management- Sanitation

Community-led sanitation management empowers local communities to take responsibility for, design, and maintain sanitation facilities.

On-site sanitation systems

- usually constructed by the users
- latrines (Home made, Ventilated Improved Pit, Water Seal) require maintenance
- communal collection for the disposal of latrine pits content

Shared sanitary facilities

- group of families living in the same cluster share one sanitary latrine
- user committee involves in locating and organizing its proper maintenance (fund collection, keep latrines clean)

Community Management- Sanitation

The condominial system

- a shallow sewerage system
- sewer pipes are installed in backyard's of the house and connect to main sewer lines
- community involves in waste collection and recycling

Pay and use latrines

- leased and managed by private sector
- maintenance and upkeep are ensured from revenues

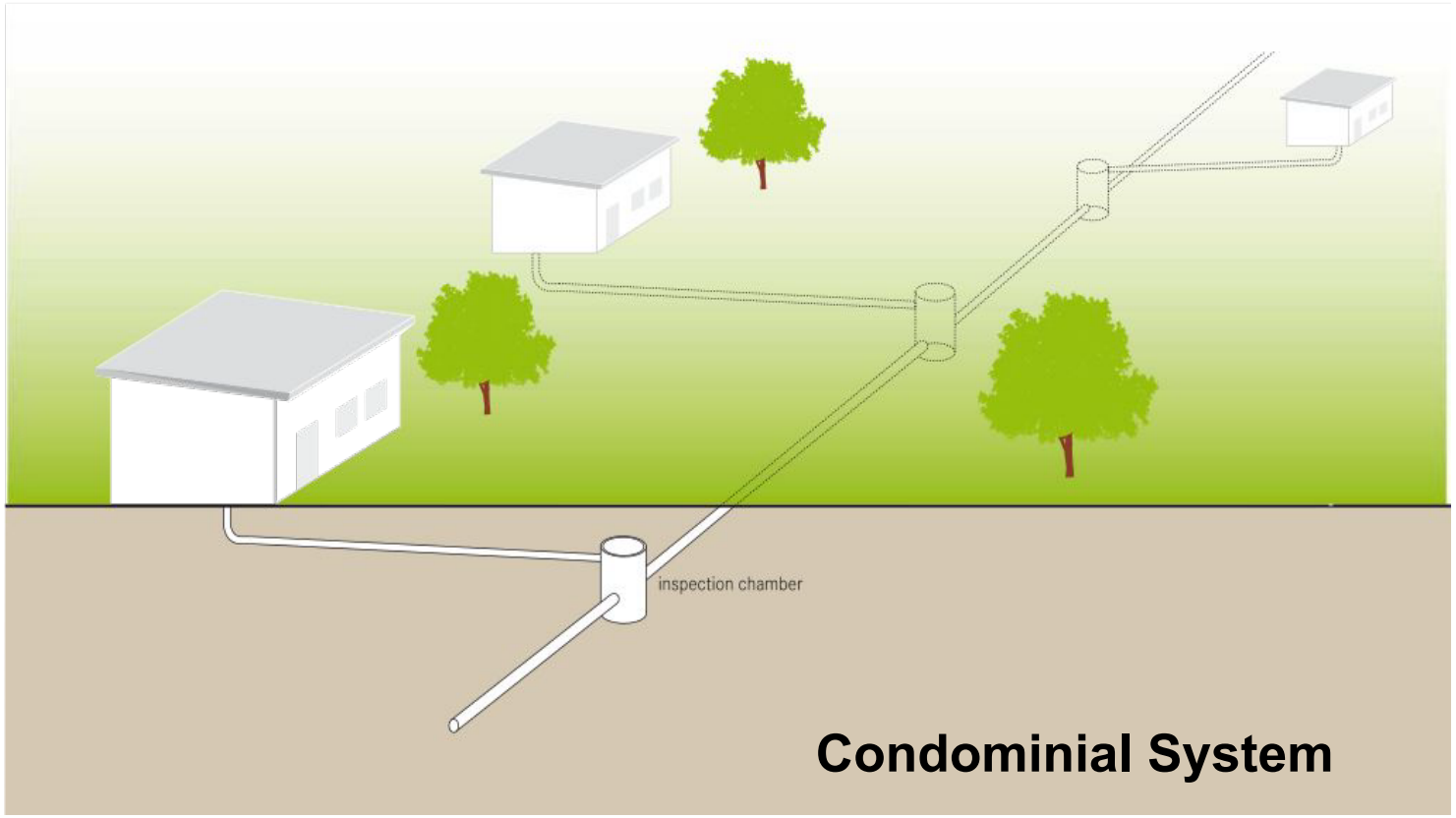
6 CLEAN WATER AND SANITATION



Shared Latrine



6 CLEAN WATER AND SANITATION



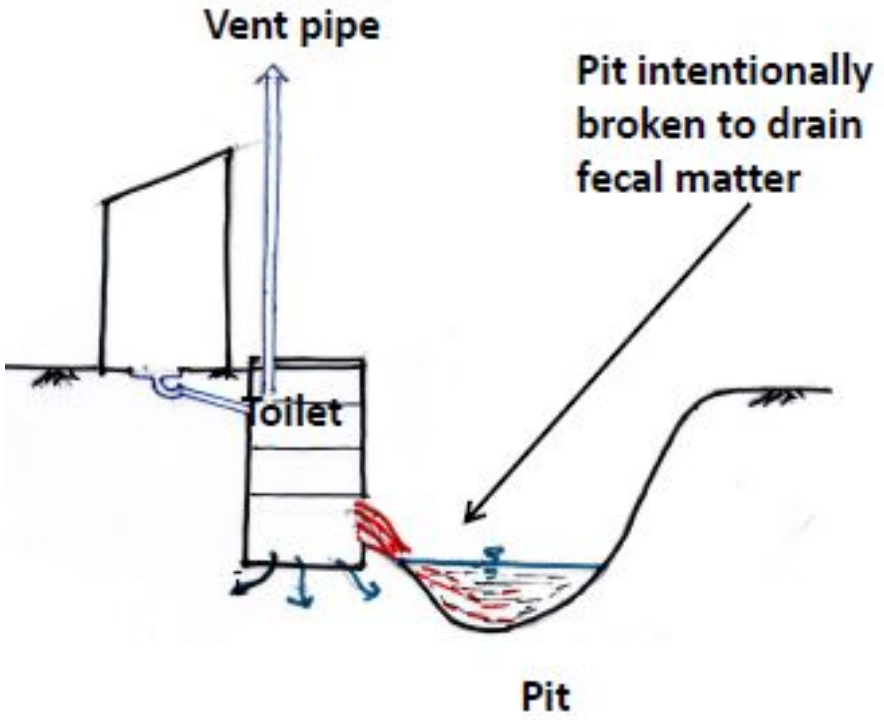

THESDGREPORT2025
PROGRESS IN WASH SERVICES
(2015–2024)
74%
68%
58%
48%
80%
66%
SAFELY MANAGED DRINKING WATER
SAFELY MANAGED SANITATION
BASIC HYGIENE SERVICES
6 CLEAN WATER AND SANITATION
United Nations
Department of Economic and Social Affairs
FOR FULL REPORT
UNSTATS.UN.ORG/SDGS/REPORT/2025

Fecal Sludge Management (FSM)

Fate of Fecal Sludge …….

- Pits are mostly emptied manually, **at great risk to the manual emptiers**, endangering public health. Media reported **31 deaths of sweepers while cleaning septic tanks in 2015.**
- In the absence of proper emptying services, the pit/septic tank-contents are often drained into the surrounding low-lying areas, or into storm drainage system.
- Even if the pits are emptied, the **emptied fecal matter are discharged into nearby drains/water bo**dies.

Fate of Fecal Sludge ……..





Fate of Fecal Sludge ……..



Fate of Fecal Sludge ……..



Fate of Fecal Sludge ……..



Fate of Fecal Sludge ……..





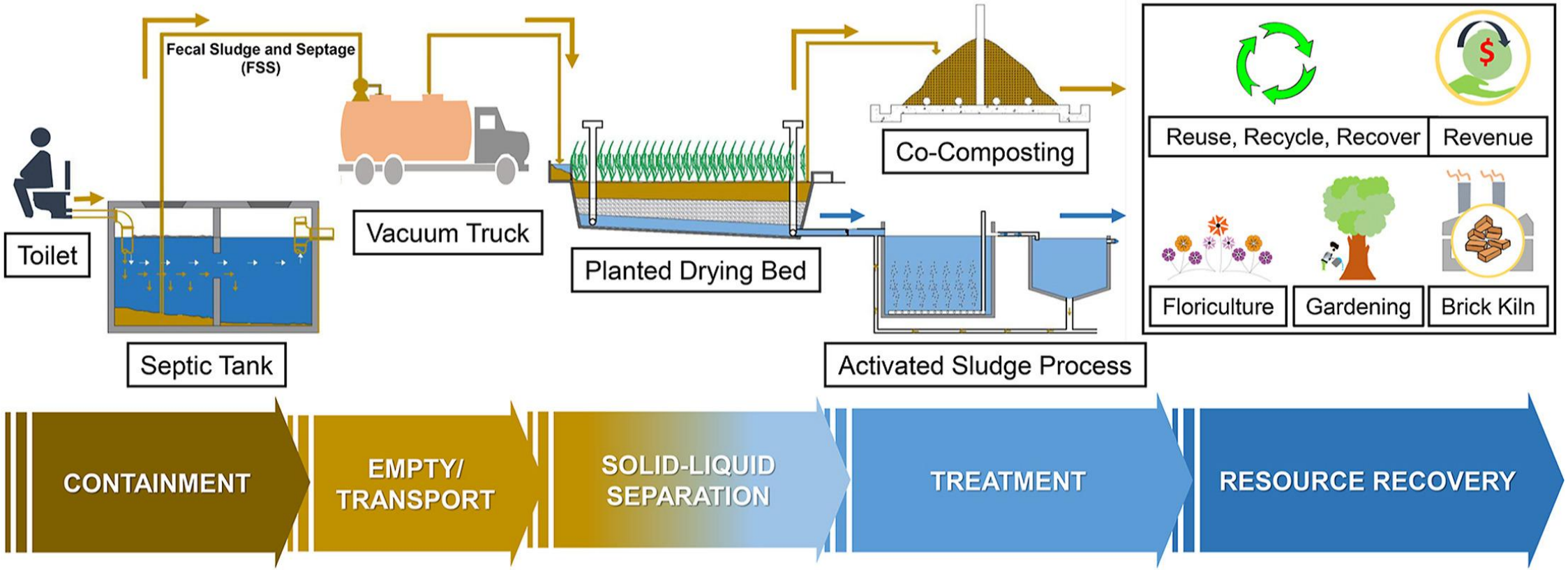




Fecal Sludge Management (FSM)

- Fecal Sludge Management (FSM) refers to a “systems approach” that includes technologies and mechanisms for containment, emptying, collection, transportation, treatment, disposal and/or enduse of sludge produced in onsite sanitation systems such as septic tanks and pit/pour-flush latrines.
- Conventional sewerage system is not included in a FSM system.

Fecal Sludge Management (FSM)



FSM System Elements: Important Issues

- **User**: Raise awareness of users regarding FSM
- **Containment**: Proper design for effective containment and easy emptying of fecal matter.
- **Emptying**: Sufficient access for mechanical desludging, particularly in slums and low income communities.
- **Collection**: Align collection vehicle size with available access to OSS facilities.
- **Transport**: Include transfer stations for cost-effective transport of fecal sludge up to treatment plants.
- **Treatment**: Ensure availability of land for establishment of fecal sludge treatment plants.
- **Disposal/ reuse**: Implement quality assurance of treatment and of treated FS for enduse.

Containment & on-site treatment

- The “containment” refers to small-scale treatment options for domestic wastewater treatment in which FS is contained for collection.
- Through good FS containment, the discharge of pathogens into the environment is significantly reduced.
- Within any technical containment option, wastewater is also automatically treated to some extent.
- The treatment process may consist of sedimentation, filtration (mechanical treatment), anaerobic and/or aerobic digestion (biological treatment) or a combination of mechanical and biological treatment processes.

Containment & on-site treatment

- Pit systems fall under the category of “basic sanitation” and do allow for an underground collection of feces.
- A conventional septic tank falls under the containment category of “improved sanitation” in which domestic wastewater from toilets is collected.



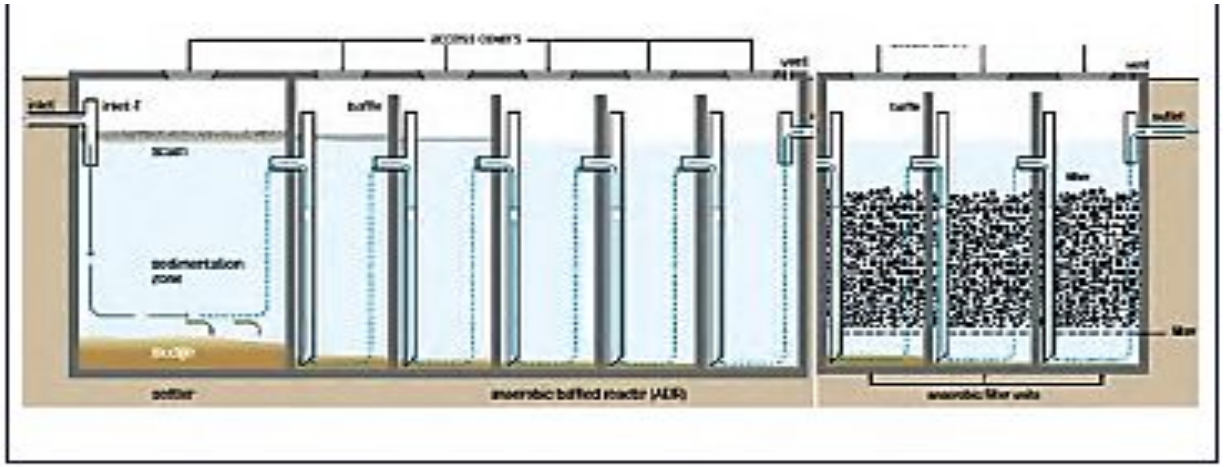
Pit System



Conventional Septic Tank



Prefabricated Septic Tank

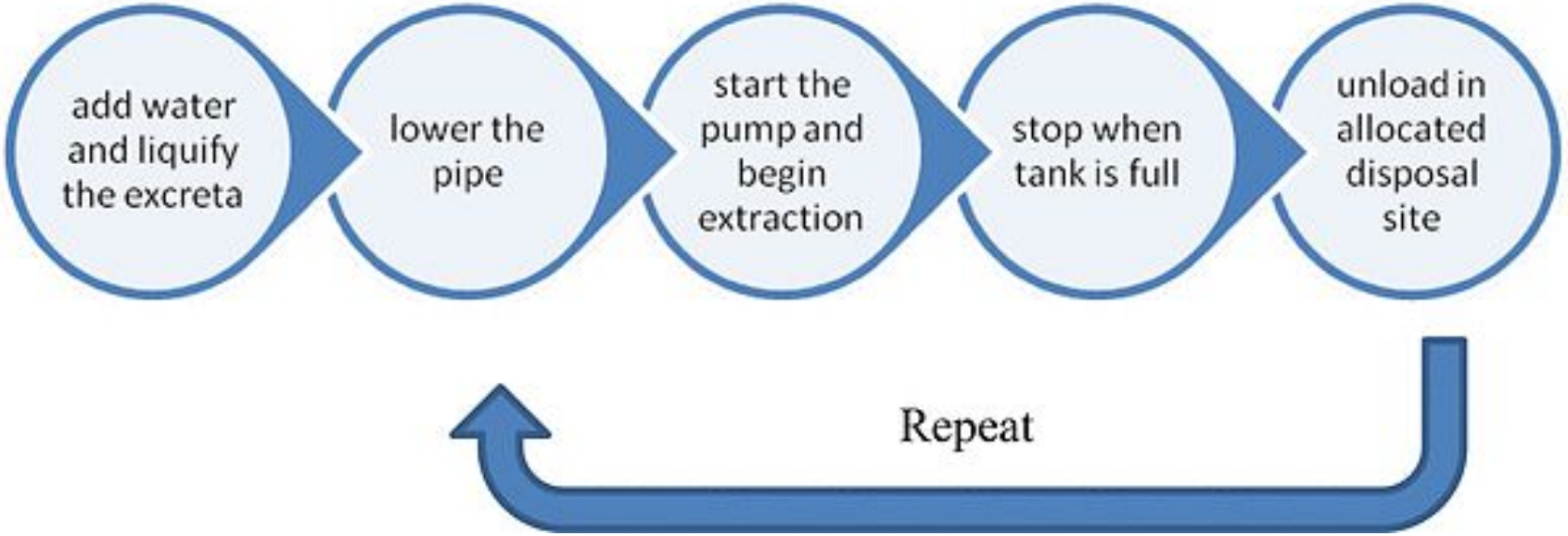


Anaerobic Baffled Reactor

Emptying

- The "emptying and collection" component within the FSM refers to different manual and mechanical means by which fecal sludge is collected from different types of containment structures for transport to fecal sludge treatment plants (FSTP).
- Human powered tools, Manually powered pumps, Wastewater Pumps, Vacuum tugs etc. are used for emptying fecal sludge from containment.

Mechanical Emptying Procedure



Emptying/Collection of Fecal Sludge in Bangladesh

- Mechanical emptying service was first introduced in Dhaka by **DSK** in the year 2000, with support from **DWASA** and **Water Aid,** using a vacuum tanker (**vacutugs**).
- This service is still continuing. Emptied sludge is discharged in DWASA sewer network.



Emptying and Collection of FS







Emptying/Collection of FS



Mechanized Gulper

Capacity: 60 Liters/min



Motorized Gulper

Capacity: 90 Liters/min



Vacutug Mark II

Capacity: 120 Liters/Min

Transport

- The transport process of fecal sludge is often directly linked to its prior collection.
- Manual emptying services may operate push-carts or wheel-barrows, mechanical pumps are mounted on different kinds of vehicles
- “Vacuum truck" is literally a combination of different pieces of technical equipment - a vacuum pump connected to a large vessel that is mounted on a truck.
- Major limitations of the transport component are the size of vehicles, the size and volume of mounted FS collection containers (smaller containers must be emptied more frequently which does consume valuable time) and the location of the fecal sludge treatment plant (FSTP).

Transportation of Fecal Sludge



Transport by manually driven vehicle



Mechanized Transporter (Mounted on Tri-Wheeler Diesel Engine Driven Vehicle); Capacity: 1000 Liters



Mechanized transport of fecal sludge

Transportation of Fecal Sludge



Vacutug Mounted on Pickup

Capacity: 250 Liters/Min



Vacutug with a capacity of 2000 Liters



Truck-mounted Vacutug

Characterization of Fecal Sludge

Parameter	Range of values (manual emptying)	Range of values (mechanical emptying)
Physical and Chemical characteristics		
Total solids (mg/L)	19,420 to 57,272	12,778 to 72,694
Suspended solids (mg/L)	17,868 to 55,484	10,852 to 70,896
COD (mg/L)	300 to 672	480 to 678
BOD (mg/L)	118 to 306	266 to 447
COD : BOD ratio	2.01 to 2.54	1.65 to 1.93
NH_4 – nitrogen (mg/L)	20 to 1,100	130 to 1,900
Total nitrogen (mg/L)	30 to 10,700	200 to 1,400
Total phosphorus (mg/L)	170 to 900	120 to 200
Microbiological characteristics		
E. coli (MFC media) (cfu/100ml)	1.6×10^4 to 6.4×10^4	6.1×10^3 to 8.0×10^3
E. coli (EMB media) (cfu/100ml)	1.4×10^4 to 4.2×10^4	1.8×10^4 to 5.4×10^4
Total helminth eggs (No/L)	267 to 781	408 to 562

Treatment

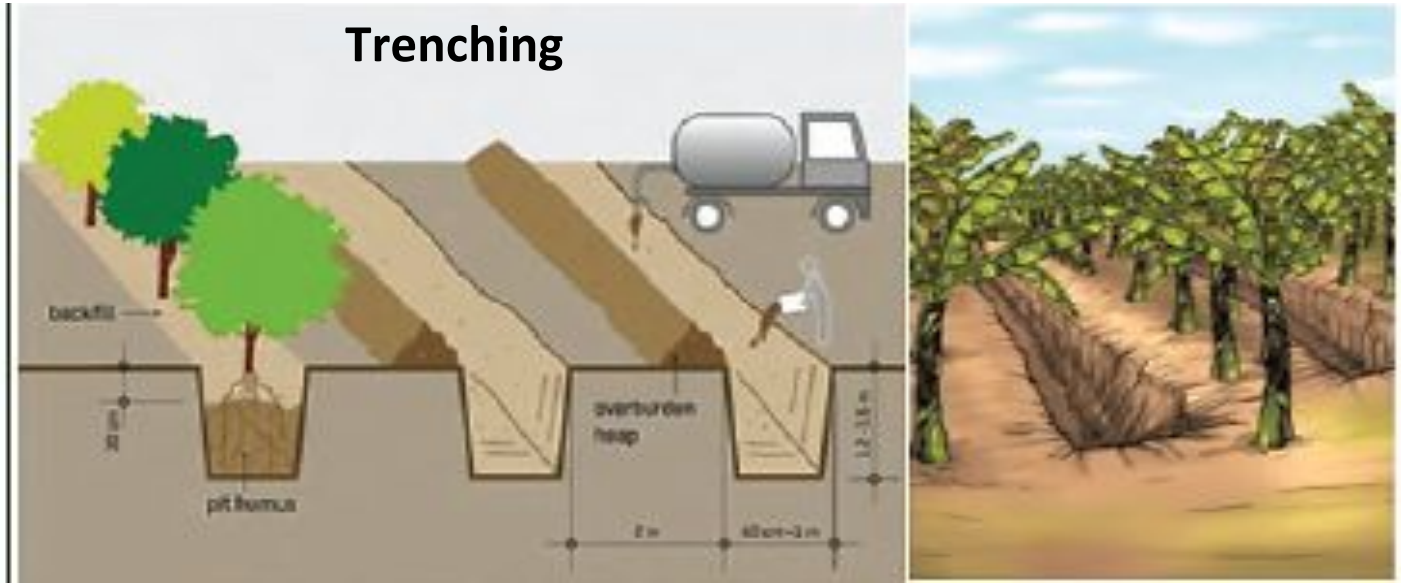
- Safe treatment of fecal sludge for disposal or reuse is the ultimate component within the FSM service chain.
- **Trenching** of FS is being promoted as (temporary) solution for safe disposal of fecal sludge.
- **Open lagoon**, pond or tank systems for fecal sludge treatment of various sizes are well known throughout the world.
- As part of an early liquid/solid separation during the treatment process of an FSTP, fecal sludge is discharged onto a **sand-bed**.
- **Geobags** or geotubes, which are made from engineered geotextiles, are an alternative technical option to sand-beds for dewatering of fecal sludge.

Treatment

- Technical processes of anaerobic **sub-surface FSTP**s are based on the principles an early liquid/solid separation, anaerobic sludge stabilization / digestion and flow of liquids by gravity.

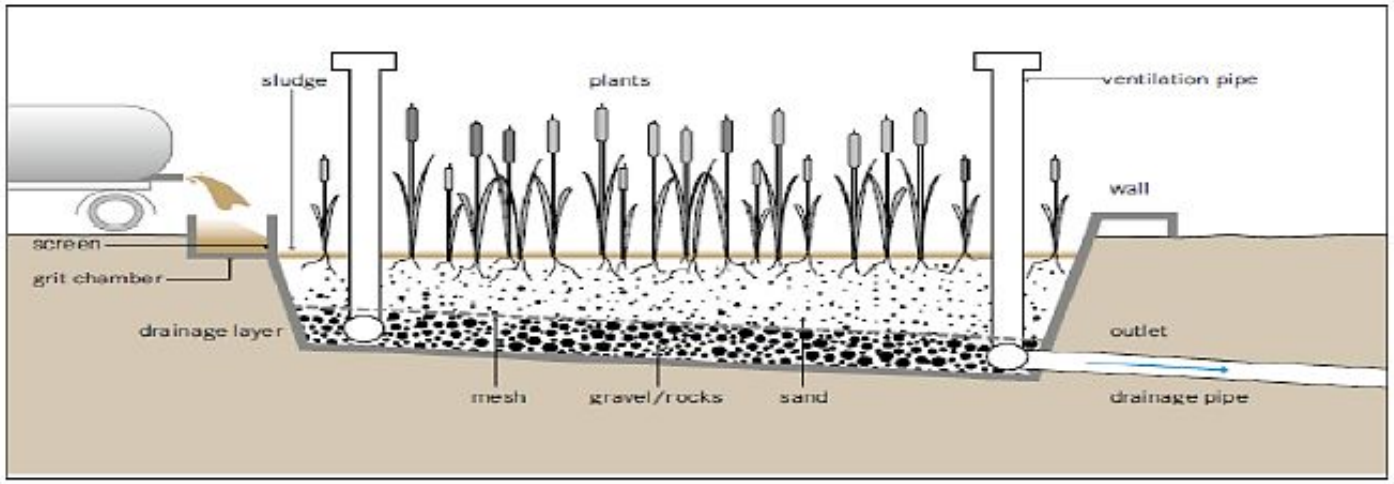
Treatment objectives

- Dewatering
- Pathogen inactivation
- Harnessing nutrients for beneficial use
- Stabilization–organic matter and nutrients
- Safe end-use or disposal



Advantage • Low-cost solution to dispose fecal sludge safely in sparsely populated rural areas with low ground water as well as in arid and semi-arid areas

Disadvantage • Unsuitable for densely populated urban regions • Risk of contamination of water resources during monsoon • Risk of public health hazards if open trenching is practiced



Planted Drying Bed

Advantage • Easy to operate (no experts, but trained community required) • Can be built and repaired with locally available materials • Relatively low capital costs; low operating costs • Fruit or forage growing in the beds can generate income •No electrical energy required

Disadvantage • Requires a large land area • Odors and flies may be noticeable • Requires expert design and construction supervision • Leachate requires further treatment



Large size lagoon system with splitter box, liquid /solid separation, facultative and aerobic ponds



Pond Systems

Advantages • Tested and robust sludge treatment systems • Low-operation and maintenance costs as no skilled personnel and equipment is needed • Long lifetime of 20+ years if properly constructed and maintained

Disadvantages • Large requirement of space especially for lagoon type plants • Compact tank/ pond plants are prone to hydraulic overloading • Potentially disturbing for nearby residents due to odors and overflow during rainy season



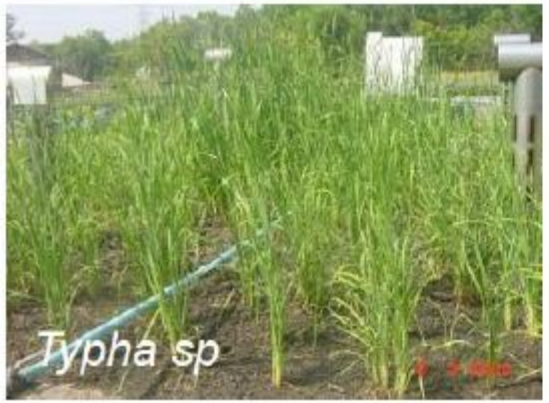
Geobags

Advantages • Less space requirement than sand drying-bed based FSTP • Less odor emissions than FS sand drying-bed based FSTP • No energy required for drying

Disadvantages • Continuous replacement of geobags required • Used geobags produce large amounts of solid waste • Short lifetime and subsequently high CO_2 footprint.


Echinochloa sp


Phragmites sp


Typha sp


Papyrus sp


HIGH COUNTRY
GARDENS



INNOVATION – Onsite dewatering systems



A mobile sludge dewatering truck is used to pump septic tanks, separate the faecal sludge from the liquids, and send the liquids back to the tank. High capital cost, but much more efficient in transferring solids than regular vacuum trucks.

Resource Recovery

- A reuse of treated fecal sludge as safe organic fertilizer and subsequent recovery of fertilizing nutrients in agriculture.
- Utilization of sludge as a source of renewable fuel.
- May require further refinements in addition to dewatering of sludge during its treatment.
- Solar drying and composting reduces the pathogen content for safe application in agriculture and will allow for easier packaging and efficient transport of sludge.
- Further processes such as sieving, nutrient enrichment and pelletizing are recommended for better sales and marketing of fecal sludge based organic fertilizers.

Resource Recovery

- In addition to produce fertilizer, the use of professional pelletizing equipment may also allow a combustion of sludge based organic materials as renewable source of fuel.

Resource Recovery

production of animal feed



soil conditioner



production of biogas





solid biofuel



component in building materials