5 WASTEWATER AND STORM WATER COLLECTION SYSTEM

Sewage is a general term used to define municipal wastewater and storm runoff. Sewerage is the system that is used for collecting sewage. Municipalities should be provided with adequate and effective sewerage systems to protect the safety and health of the people and the environment. Lack of access to sanitation facilities is one of leading problems in many developing countries.

5.1. Sources and quantities of sewage

Sewage consists of liquid wastes produced in residences, commercial establishments, and institutions, liquid wastes discharged from industries, and any subsurface, surface, or storm water that enters the sewers. Liquid wastes that originate from residential, commercial and institutional areas are commonly called *sanitary or domestic sewage* whereas liquid waste from industrial establishments is referred to as *industrial wastewater*. *Infiltration* is groundwater entering sewers through defective joints, and broken or cracked or broken pipes and manholes. *Inflow* is water discharged into sewer pipes from such sources as foundation drains, roof leaders, cellar and yard area drains, cooling water from air conditioners, and other clean water discharges from industrial and commercial establishments. Surface runoff that is caused by rainfall is called storm sewage. Figure 5.1 depicts the sources and routes of the different sewages.

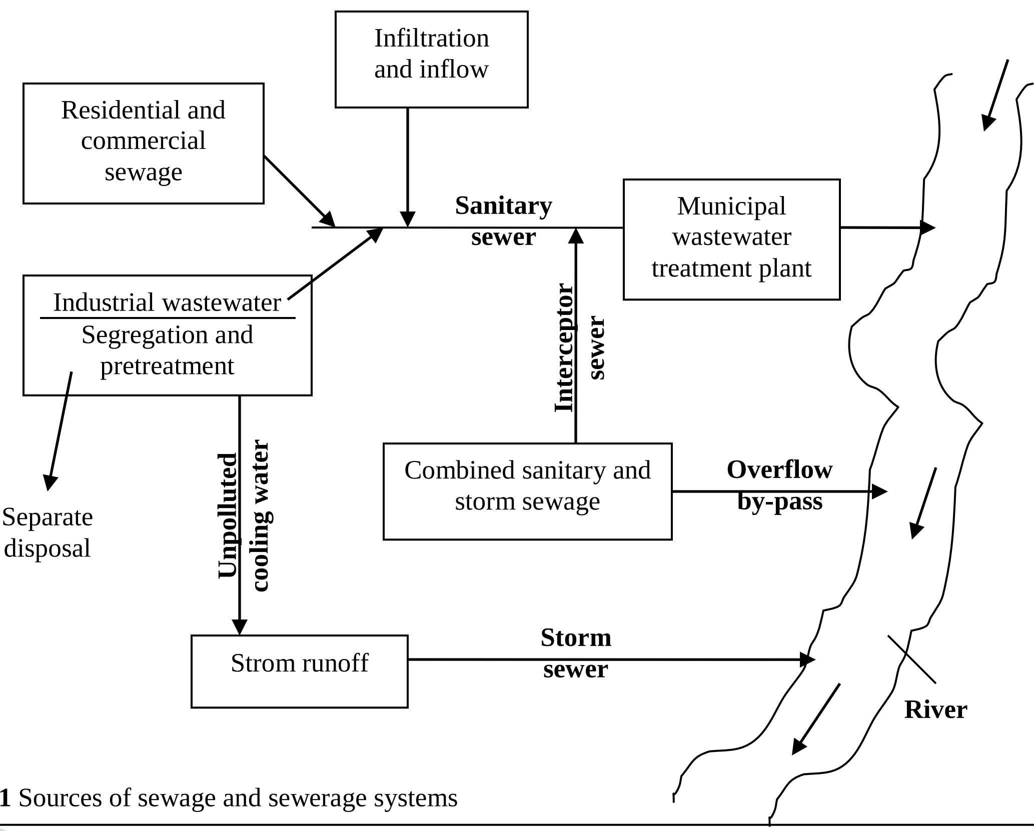

Fig. 5.1 Sources of sewage and sewerage systems

The domestic and industrial sewage discharge that has to pass through a sewer must be estimated as correctly as possible; otherwise the sewers may either prove to be inadequate, resulting in overflow, or may prove to be unnecessarily big, resulting in wasteful investments. *Sanitary sewage and industrial wastewater* are derived principally from the *water supply*. For this reason estimation of sewage flow should be based on study of both present and future water consumption. The proportion of water supplied, which will reach the sewers, depends in large part upon local conditions.

Domestic sewage

The principal sources of sanitary sewage in a community are the residential and commercial districts. Other important sources include institutional and recreational facilities. The accounted water supplied to the public through the public distribution system is not necessarily the only water consumed by the public. Some private wells and tube-wells may sometimes be used by the public for their domestic needs; and similarly, certain industries may utilize their own sources of water. The quantity of water that appears as sewage from such area should be added to the total sewage quantity; it is usually referred as additions due to unaccounted private water supplies.

Infiltration should also be accounted in the determination of total sewage quantity. Wherever the sewer pipes are laid below the ground water table, certain amount of ground water generally seeps into them, through faulty leaky joints or cracks formed in the sewers. The quantity of the ground water entering these sewer pipes depends mainly upon the level of the water table above the sewer invert, and the nature and extent of faults and cracks present in the sewer pipes. However, if the ground water table is well below the sewer, infiltration can occur only after rain, when water is moving down through the soil. In this case, the infiltration quantity depends upon the permeability of the soil. Since these factors cannot be precisely computed, the exact quantity of ground water infiltrating into the sewer pipes cannot be estimated precisely. Only certain nominal allowance, based upon some experimental results may be made because of this factor.

The water lost, due to leakage in the distribution system and house connections of the water supply scheme, does not reach the consumers, and hence, never appear as sewage. In addition certain amount of water may be used by the public and industries for such uses that may not produce any sewage at all. These two categories of water quantity should be subtracted from the total sewage quantity computation as subtractions due to water losses for the first case and subtractions due to water not entering the sewerage system.

The net quantity of sewage produced will be equal to the accounted quantity of water supplied from the water-authority plus the additions due to unaccounted private water supplies and due to infiltration minus the subtractions due to water losses and water not entering the sewerage system. This net value may vary 70 to 130 percent of accounted water supplied from the water authority.

Industrial waste water

If the water requirements for the industries are known, wastewater flow projections can be based on water flow projections. For industries without internal reuse programs about 85-95% of the water used in the various operations and processes will probably become wastewater. For large industries with internal water reuse programs separate estimates must be made. Average wastewater contributed from industrial activities may vary from 30 - 95 l/capita/d.

Infiltration/inflow

During dry season infiltration may be non-existent. During wet period infiltration may be greatly increased as ground water levels rises and may be augmented by inflow. Sewers that are constructed in or close to streambeds are especially likely to have high infiltration. The amount of infiltration, to be expected will depend up on the care with which the sewer system is constructed the height of the ground water table, and the characteristics of the soil. Special types of joints tend to reduce infiltration. A soil that heaves with varying water content will pull joints apart and so permit water to enter. A pervious soil permits easy travel of percolating water to the sewers where it will travel along them until it reaches a crack or open joints. Infiltration rates are likely to vary from 35 to 115 m^3/km.4d. Infiltration and Inflow should be reduced as much as possible. Otherwise they demand additional cost of collection and treatment.

Storm sewage

Estimation of the amount of storm sewage is done by using hydrological analysis. The maximum rate of storm run-off, popularly called peak drainage discharge that is produced from a particular catchment depends upon numerous factors such as the type of precipitation, the intensity and duration of rainfall, the rainfall distribution, the soil moisture deficiency, the direction of the prevailing storm, the climatic conditions, the shape, size and type of catchments basin, etc. Rational method, the SCS technique, hydrograph technique and computer simulation techniques (e.g. SWMM) are the most widely used methods' worldwide to estimate the peak rate run-off or peak drainage discharge.

Fluctuations in sewage flow

The flow and strength of sewage varies throughout the day. The peak flow is several times the mean flow and the hydraulic capacity of sewerage systems must be designed on the basis of this peak flow. The magnitude of the peak flow relative to the mean flow depends on the size of the contributing population; the larger the population, the lower the peaking factor since flow fluctuations are smoothed out during the time of travel in the sewer.

There is also change in the sewage quantity if the city has seasonal industries such as sugarcane crushing, fruit canning, brewing, etc. Peaking factors for different sewers are given in Table 5.1.

Table 5.1: Common values of hourly variation in sewage flow.

Types of Sewer	Ratio of Max/Avg flow
Small size sewers including laterals	4
Sewers up to 25 cm in diameter	4
Branch sewers up to 50 cm in diameter	3
Main sewers up to 100 cm in diameter	2
Trunk sewers up to 125 cm in diameter	1.5

The flow in sewers is minimum during nights. The effect of this flow is maximum in the laterals connected direct to the houses and minimum to the main trunk sewer. It could be seen that the minimum flow in laterals is below 30% of average flow while in trunk sewers it may be 60-70% of the average. The overall variation in the sewage is maximum in the smaller size sewers and goes on reducing as the size of the sewer increases.

5.2. Sewerage systems

Two major sewerage systems are well known.

Combined system*:* a system composed of sewers that carry both domestic, with or without industrial wastewater, and storm sewage.

Separate system*:* a system composed of sewer that segregates the storm water from sanitary sewers. *A sanitary sewer* carries sanitary sewage and is designed to exclude storm sewage, infiltration, and inflow. Industrial waste may be carried in sanitary sewers, depending upon its characteristics. *A storm sewer* carries storm sewage and any other wastes that may be discharged into the streets or onto the surface of the ground.

Sometimes, a part of drainage water especially that originating from the roofs or paved courtyards of buildings, is allowed to be admitted into the sewers; and similarly sometimes, the domestic sewage coming out from the residences or institutions, etc., is allowed to be admitted into the drains, the resulting system is called *a partially separate system.*

In the modern days, 'separate system' is generally preferred to a 'combined system' although each individual case should be decided separately on merits, keeping the following points into consideration:

- A separate system requires laying of two sets of conduits; where as, a combined system requires laying of only one set of big-size conduit, thus making the former system expensive. Moreover, the separate conduits cannot be laid in congested streets and localities, making it physically infeasible.
- The sewer pipes in the combined system are liable to frequent silting during the non-monsoon season (when the flows in them are quite less) unless they are laid at sufficiently steeper slopes, which, in turn, will make them deeper, requiring more excavation and pumping, thereby making them costlier.
- In a combined system, the less-foul drainage water gets mixed with the highly foul sewage water, thus necessitating the treatment of the entire flow, needing more capacity for the treatment plant, there by making it costly. Where as, in the separate system, only the sewage discharge is treated and the storm sewage is disposed of without any treatment.
- In case, flooding and backing up of sewers or drains occur due to excessive rains, more flow and unsanitary conditions will prevail in case of combined sewers than in the case of storm drainage alone.
- Since the sewer lines are generally laid deep and at steeper slopes, as compared to storm water surface drains, pumping of sanitary sewage is required in a separate system. Whereas, the entire sewage has to be pumped, if the sewage and storm discharges are mixed together; this makes the combined system more costly.

The economy of the two systems must be worked out for each individual project, and the economical system should be adapted, if physically feasible.

A conventional sewerage system consists of the following lines.

- A ***house sewer***- a pipe conveying wastewater from an individual structure to a common sewer or other point of disposal.

- *A **lateral sewer***- is a common sewer collects flow from house sewers.
- *A **submain sewer***- collects sewage *from* one or more laterals as well as house sewers.
- *A **main or trunk sewer-*** collects flow from several sub-mains as well as laterals and house sewers.
- ***Force mains-*** pressurized sewer lines, which convey sewage from a pumping station to another main or to a point of treatment or disposal.
- ***An intercepting sewer-*** separates dry weather flow and conveys it to a wastewater treatment plant
- *A **relief sewer-*** a sewer, which is built to carry a portion of the flow in a system with inadequate capacity.
- *An **outfall sewer***- a sewer, which carries the collected waste to a point of treatment or disposal.

5.3. Design periods for sewage system components

Based on the life of the material used and the ease for replacement or expansion of the element, components of a sewage system have different design periods.

- Sewer pipes- have long useful life and are difficult to replace
  - Design period- indefinite, i.e., ultimate development potential of an area is considered
  - Design capacity- peak flow with sewer flowing full
- Sewage pumping- easy to expand
  - Design period- 10 years
  - Design capacity- requires knowledge of anticipated minimum, average, and maximum flows
- Sewage treatment facilities- can be expanded
  - Design period- 15-20 years
  - Design capacity- peak flow; minimum flow is also required to check the minimum velocity

5.4. Sewer materials and Appurtenances

Improperly management of sewage may cause adverse effects both to the community and to the environment. To transform these potentially harmful sewages into non-harmful effluents there should be a proper collection and transportation as well as treatment and disposal systems.

The liquid wastes must be collected and conveyed from domestic, commercial, industrial and storm water sources. Materials that can be used for theses purposes are presented below.

Sewer Pipe Materials

Each type of sanitary sewer pipe, and its advantages and limitation, should be evaluated carefully in the selection of pipe materials for given applications.

Various factors are involved in the evaluation and selection of materials for sewer construction and are dependent on the anticipated conditions of services. Factors that may be involved and should be considered are:

- intended use-type of wastewater
- scour of abrasion conditions
- installation requirements-pipe characteristics and sensitivities
- corrosion conditions-chemical, biological
- flow requirements-pipe size, fitting and connection requirements, laying length
- cost-effectiveness-materials, installation, maintenance, life expectancy
- physical properties-crush strength for rigid pipe, pipe stiffness of stiffness factor for flexible pipe, soil conditions, pipe beam loading strength, hoop strength for force main pipe, pipe shear loading strength, pipe flexural strength
- handling requirements-weight, impact resistance

No single pipe product will provide optimum capability in every characteristic for sanitary sewer design conditions. Specific application requirements should be evaluated prior to selecting or specifying pipe materials.

Commonly available sewer pipe materials are listed below alphabetically within the two commonly accepted classifications of rigid pipe and flexible pipe:

1. Rigid pipe
    a. Concrete pipe
    b. Vitrified clay pipe (VCP)
2. Flexible pipe
    a. Ductile iron pipe (DIP)
    b. Thermoplastic pipe
        i. Acrylonitrile-butadiene-styrene (ABS)
        ii. ABS composite
        iii. Polyethylene (PE)
        iv. Polyvinyl chloride (PVC)
    c. Thermoset plastic pipe
        i. Reinforced plastic mortar (RPM)
        ii. Reinforce thermosetting resin (RTR)
    d. Steel pipe

Rigid pipe

Sewer pipe materials in this classification derive a substantial part of their basic earth load carrying capacity from the structural strength inherent in the rigid pipe wall.

Concrete pipe

Reinforced and nonreinforced concrete pipe and polymer concrete pipe are used for gravity sewers. Reinforced concrete pressure pipe and prestressed concrete pressure pipes are used for pressure sewers and force mains as well as sanitary gravity sewers. nonreinforced concrete pipe is available in nominal diameters from 100 through 900 mm. reinforced concrete pipe is available in nominal diameters from 300 mm through 5 m. pressure pipe is available in diameters from 300 mm through 3 m. Polymer concrete pipe used for gravity sewers is available in diameters from 150 mm through 3.6 m.

Potential advantages of concrete pipe include:

- wide range of structural and pressure strengths.
- wide range of nominal diameters
- wide range of laying lengths generally 1.2 to 7.4 m
- allows direct installation for microtunnelling (without casing)

Potential disadvantages of concrete pipe include:

- high weight
- susceptible to corrosion where acids are present

Vitrified Clay Pipe (VCP)

VCP is used for gravity sanitary sewers. The product is manufactured from clay and shale. clay pipe is vitrified at a temperature at which the clay mineral particles become fused. The product is available in diameters from 75 through 900 mm and in some are up to 1 m. clay fittings are available to meet most requirements, with special fitting manufactured on request. The pipe is manufactured in lengths up to 3 m.

Potential advantages of VCP include:

- High resistance to chemical corrosion
- high resistance to abrasion
- wide range of fittings available

Potential disadvantages of VCP include

- limited range of sizes available
- limited range of sizes available
- high weight
- susceptible to shear and beam breakage when improperly handled or bedded.

Flexible pipe

Sewer pipe materials in this classification derive load carrying capacity from the interaction of the flexible pipe and the embedment soils affected by the deflection of the pipe to the pipe of equilibrium under load.

Ductile iron pipe (DIP)

DIP is used for gravity and pressure sanitary sewers and force mains. DIP is manufactured by adding cerium if magnesium to cast (gray) iron just prior to the pipe casting process. The product is available in nominal diameter from 75 mm through 1350 mm and in lengths of 6 m. Cast iron (gray iron) or ductile iron fittings are used with DIP.
Potential advantages of DIP include:

- long laying lengths
- high pressure and load-bearing capacity
- high impact strength
- high beam strength

Potential disadvantages of DIP include

- susceptible to corrosion where acids are present
- susceptible to chemical attack in corrosive soils
- high weight

Acrylonitrile-Butadiene-Styrene (ABS) Composite pipe

ABS composite pipe is used for gravity sanitary sewers. The product is available in nominal diameters from 200 through 375 mm and in lengths from 2 to 4 m. ABS fittings are available for the product. The jointing systems available include elastomeric gasket joints and solvent cemented joints.
ABS composite pipe is manufactured by extrusion of ABS plastic material with a series of truss annuli that are filled with filler material such as lightweight Portland cement concrete.
Potential advantages of ABS composite pipe include:

- light weight
- long laying lengths
- ease in field cutting

Potential disadvantages of ABS composite pipe include:

- limited range of sizes available
- susceptible to environmental stress cracking
- susceptible to rupture when improperly bedded
- susceptible to attack by certain organic chemicals
- susceptible to surface change effected by long-term ultraviolet exposure

Polyethylene (PE) Pipe

PE pipe is used for gravity and pressure sewers and force mains. Nonpressure PE pipe, primarily used for sewer relining, is available in nominal diameters from 100 mm through 1200 mm. PE fittings are available. Jointing is primarily accomplished by butt-fusion or flanged adapters; with bell and spigot sometimes used. PE pipe is manufactured by extrusion of PE plastic material. Nonpressure PE pipe is produced at this time in accordance with individual manufactures' product standards.
Potential advantages of PE pipe include:

- long laying lengths

- light weight
- high impact strength
- ease in field cutting

Potential disadvantages of PE pipe include:

- relatively low tensile strength and pipe stiffness
- limited range of diameters available
- susceptible to environmental stress cracking
- susceptible to excessive deflection when improperly bedded and haunched
- susceptible to attack by certain organic chemicals
- susceptible to surface change effected by long-term ultraviolet exposure
- special tooling required for fusing joints

Polyvinyl Chloride (PVC) Pipe

PVC pipe is used for both gravity and pressure sewers. Non pressure PVC sewer pipe is available in nominal diameters from 100 through 1220 mm. PVC pressure and non-pressure fittings are available. PVC pipe is generally available in lengths up to 6 m. Joining is primarily accomplished with elastomeric seal gasket joints, although solvent cement joints for special applications are available.

PVC pipe is manufactured by extrusion of the plastic material.

Potential advantages of PVC pipe include:

- light weight
- long laying lengths
- high impact strength
- ease in field cutting and tapping

Potential disadvantages of PVC pipe include:

- subject to attack by certain organic chemicals
- subject to excessive deflection when improperly bedded and haunched
- subject to surface changes effected by long-term ultraviolet exposure

Corrugated Steel Pipe

Steel pipe is rarely used for sanitary sewers. When used, it usually is specified with interior protective coatings or linings (polymeric, bituminous, asbestos, etc.). It is not recommended for use in sanitary sewer systems.

Steel pipe is fabricated in diameters from 8 through 120 inches (200 mm through 3 rn). Appurtenances include tees, wyes, elbows, and manholes fabricated from steel. Various linings and coatings arc available. Steel is generally manufactured in lengths up to 12.2 m.

Potential advantages of steel pipe include:

- Light weight.
- Long laying lengths (in some situations).

Potential disadvantages of steel pipe include:

- Susceptible to corrosion where acids are present.
- Susceptible to chemical attack in corrosive soils.
- Difficulty in making lateral connections.
- Poor hydraulic coefficient (unlined corrugated steel pipe).
- Susceptible to excessive deflection when improperly bedded or haunched.
- Susceptible to turbulence abrasion.

Steel pipe is specified by size, shape, wall profile, gage or wall thickness, and protective coating or lining.

Sewer Pipe Joints

A substantial variety of pipe joints are available for the different pipe materials used in sewer construction. A common requirement that must be imposed on the design of all sanitary sewer systems, regardless of the type of sewer pipe specified is the use of reliable, tight pipe joints.

A good pipe joint must be:

- watertight,
- root-resistant,
- flexible,
- durable, and
- Easily assembled in the field.

Water infiltration/exfiltration testing or air exfiltration testing is commonly specified for typical nonpressure sanitary sewer system construction to demonstrate that infiltration/exfiltration is within acceptable limits.

Types of Pipe Joints

Commonly specified sanitary sewer pipe joints are described in the following subsections.

1. Gasket Pipe Joints

Gasket joints effect a seal against leakage through compression of an elastorneric seal or ring. Gasket pipe joint design is generally divided into two types: push-on pipe joint and mechanical compression pipe joint.

1.1. Push-on Pipe joint

This type of pipe joint uses a continuous elastomeric ring gasket that is compressed into an annular space formed by the pipe, fitting or coupler socket, and the spigot end of the pipe, thereby providing a positive seal when the pipe spigot is pushed into the socket. When using this type of pipe joint in pressure sanitary sewers, thrust restraint may be required to prevent joint separation under pressure. Push-on pipe joints (fittings, couplers, or integral bells) are available on nearly all pipe products mentioned.

1.2. Mechanical Compression Pipe joint

This type of pipe joint uses a continuous elastomeric ring gasket that provides a positive seal when the gasket is compressed by mean s of a mechanical device. When using this type of pipe joint in pressure sanitary sewers, thrust restraint may be required to prevent joint separation under pressure. This type of pipe joint may be provided as an integral part of DIP. When incorporated into a coupler, this type of pipe joint may be used to join two similarly sized plain spigot ends of any commonly used sewer pipe materials.

2. Cement Mortar Pipe Joint

This type of pipe joint involves use of shrink-compensating cement mortar placed into a bell-end-spigot pipe joint to provide a seal. The use of this joint is discouraged in that reliable, watertight joints are not assured. Cement mortar joints arc not flexible and may crack due to any pipe movement. This type of joint is used on concrete gravity and pressure pipe to protect otherwise exposed steel.

3. Elastomeric Sealing Compound Pipe Joints

Elastorneric sealing compound may be used in jointing properly prepared concrete gravity sewer pipe. Pipe ends must be sandblasted and primed for elastomeric sealant application. The sealant-athixotropic, two -compound elastomer-is mixed on the job site and applied with a caulking gun and spatula. The pipe joint, when assembled with proper materials and procedures, provides a positive seal against leakage in gravity sewer pipe.

4. Solvent Cement Material Pipe Joints

Solvent cement pipe joints may be used in jointing thermoplastic pipe materials such as ABS, ABS composite, and PVC pipe. This type of pipe joint involves bonding a sewer pipe spigot into a sewer pipe bell or coupler using solvent cement. Solvent cement joints can provide a positive seal provided the proper cement is applied under proper ambient conditions with proper techniques. Required precautions should be taken to ensure adequate trench ventilation and protection for workers installing the pipe. Solvent cement pipe joints may be desired in special situations and with some plastic fittings.

5. Heat Fusion Pipe Joints

Heat fusion pipe joints are commonly specified for PE sanitary sewer pipe and are now being used on some PVC pipe. The general method of jointing PE sanitary sewer pipe involves butt fusion of the pipe lengths, end-to-end. After the ends of two lengths of PE pipe arc trimmed and softened to a melted state with heated metal plates.

Sewer Appurtenances

The major sewer appurtenances, which are required for proper functioning of sewer systems include manholes, street inlets, catch basins, junctions, sand, grease and oil traps, inverted siphons, overflow structures, etc.

Manholes*:* are used to allow a means of access into a sewer system for inspection, repair and cleaning. They are placed at changes in direction, pipe size, grade and elevation, and at junctions. They are also required on straight sections at intervals of 90-120 m for sewers up to 1 m in size, and at large spacing or none for pipes large enough for a man to enter. Where laterals or submains join in a deeper sewer, excavation will be saved by keeping the upper sewer at a reasonable grade and making a vertical drop at the manhole. This is known as a Drop manhole and construction is as shown in fig below. Note that if the sewage drops in the vertical pipe, the sewer line intersects the manhole wall so that the branch can be rodded for cleaning. If the drop is less than 0.6 it is usually cared for by increasing the sewer grade instead of using a drop manhole.

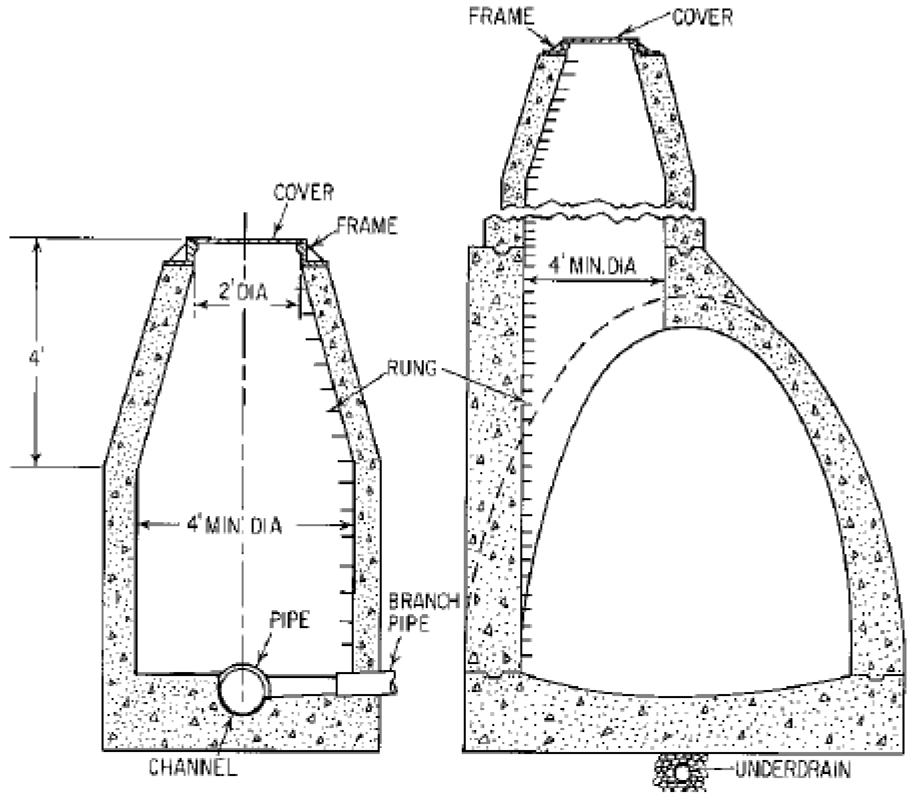

Figure 5.2 Manhole

***Street Inlets**:* An inlet is an opening into a storm or combined sewer for entrance of storm runoff. These inlets discharge into the storm sewer or into catch basins that are intended to intercept or settle out the refuse and sediments flushed from the street surfaces. Street inlets are placed at intersections and where these are far apart, inlets are placed at intervals of 100 to 150 m. Inlets can be classified as to whether they are of the *grated* type, the *curb opening* type, the *combination* type consisting of both a grate and a curb opening, and the *slotted drain* type. For each of these four types, inlets can also be described as either *continuous grade* inlets or *sag* inlets. A sag inlet is one constructed in the low point of a vertical curve (for instance), where water drains to the inlet from all directions. On the other hand, a continuous grade inlet is one where surface water can flow away from the inlet opening in one or more directions.

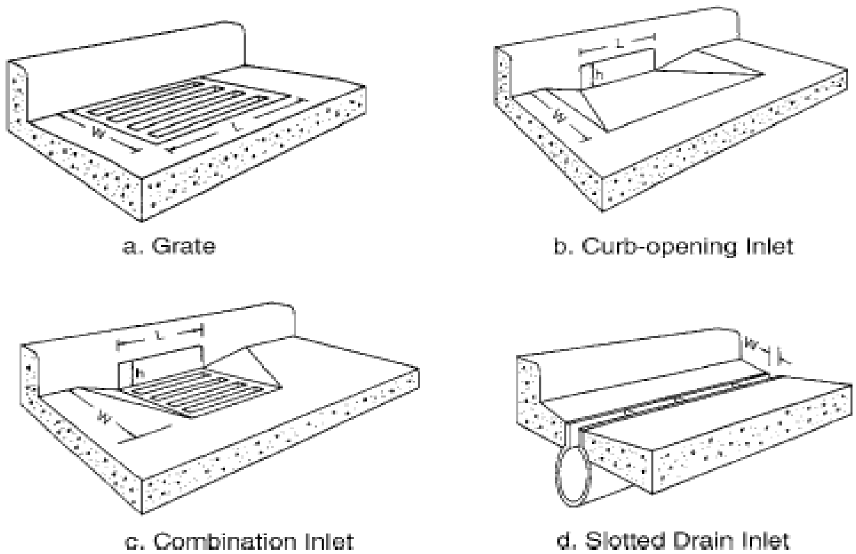

Figure 5.3. street inlet types

***Catch Basins**:* These are inlets with a Basin, which allow debris to settle out. Catch basins were formerly considered necessary to prevent stoppages of storm and combined sewerage with sand and grit. Present practice, however, emphasizes good self-cleaning sewer grades with simple inlets.

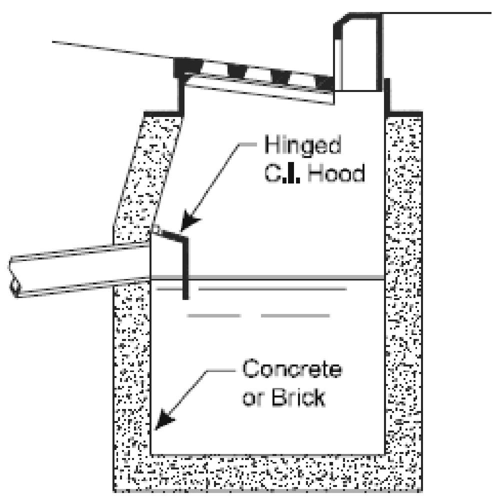

Figure 5.4 Catch basin

Sand, Oil and Grease Traps: Sewage from large kitchens may contain Grease, and from garages it may contain Grease, oil and sand. Waste lines from such sources are provided with traps so that the lines will not be clogged-with proper cleaning regularly.

5.5. Design of sanitary sewer systems

In designing a sewer system, the designer must

- conduct preliminary investigations,

- review design considerations and select basic design data and criteria,
- design the sewers which include preparation of a preliminary sewer system and design of individual sewers, and
- prepare contract drawings and specifications.

Comprehensive preliminary investigations of the area to be sewered are required not only to obtain the data needed for design and construction but also to record pertinent information about the local conditions before construction begins. These are

- Maps and other drawings of the area;
- Locations of streets, alleys, railways public parks and buildings, ponds, streams, drainage ditches and other features and structure which may be influenced or influence the sewer systems;
- A bench mark on each block of every street;
- If possible contours at suitable intervals, high and low points and changes in surface slopes;
- Local rainfall and runoff data, if any, otherwise measurements in the field should be taken;
- Character of the soil in which the sewers are to construct; and
- Local wages of unskilled and skilled labor.

Designing a sanitary sewer involves estimation of waste flow rates for the design data and evaluation of any local conditions, which may affect the hydraulic operation of the system; the selection of the hydraulic-design equation, alternative sewer pipe materials and minimum and maximum sizes, minimum and maximum velocities and slopes; the evaluation of alternative alignments or designs.

Design flow: Peak hourly flow and peak infiltration allowances for the entire service area are used for the design of new sanitary sewers.

Hydraulic design equation: Manning equations are commonly used.

Sewer Material and sizes: To avoid clogging sewers not less than 200 mm should be used. Obviously the smallest sewers should be larger than the building sewer connection in general use. In no case less than 100 mm is used.

Minimum and Maximum Velocity:

- ✓ The usual practice is to design the slope for sanitary sewers to ensure a minimum velocity of 0.6 m/s with flow at one half- full or full depth.
- ✓ To prevent deposition of mineral matter such as sand and gravel a mean velocity of 0.75 m/s is generally adequate in storm sewers.
- ✓ In depressed sewers (Inverted siphons) where access for cleaning is difficult the minimum velocity should be about 0.9 m/s.
- ✓ The erosive action of the material suspended in wastewater depends not only on the velocity, at which it is carried along the invert of a sewer but also on its nature. In general, maximum mean velocities of 2.5 to 3.3 m/s at the design depth of flow will not damage the sewer.

Design Procedures

Layout the sewer: Draw a line to represent the proposed sewer in each street or alley to be served. Near of on the line; indicate by an arrow the direction in which the wastewater is to flow. Except in special cases, the sewer should slope with the surface of the street. It is usually more economical to plan the system so that the wastewater from any street will flow to the point of disposal by the most direct (and, consequently; the shortest) route. In general, the laterals connect with the mains and these; in turn connect with the trunk sewer, which leads to the point of discharge or to an intercepting sewer.

Locate the manholes: Locate a manhole at:

(1) Changes in direction;

(2) Changes in slope;

(3) At pipe junctions with the exception of building connections;

(4) At the upper end and ends of all laterals for cleansing and flushing the lines; and

(5) At intervals from 90 to 120 m or less, as required. Give each manhole an identification number.

Establishing the limits of the service area: Sketch the limits of the service areas. Search the limits of the service area for each lateral. If a single lateral will be required to accommodate an area larger than can be served by the minimum size of sewer with the minimum slope the area should be subdivided further. Where the streets are laid out assume that the limits are midway between them. If the street layout is not shown on the plan, the limits of the different service areas cannot be determined as closely and the topography may serve as a guide.

Determine the area of each service area. Measure the area of each service area by using a scale, and enter the value on the map.

1. Summarize the basic design criteria.
    a. Design period (usually saturation period used);
    b. Population density;
    c. Residential wastewater flow (Obtain the peaking factor);
    d. Infiltration allowances;
    e. Inflow allowances
    f. Hydraulic design equation;
    g. Minimum pipe size ;
    h. Minimum velocity; and
    i. Minimum cover.

Prepare tabulation form to record the data and steps in the compilations for each section of sewer between Manholes.

N.B. If sewer changes direction in a manhole without change of size, a drop of 30 mm should be provided in the manhole. If the sewer changes size, the crowns of the inlet and outlet sewers should be at the same elevation. Branches coming into manholes should have their crowns at the same elevation as that of the large sewer. Drop manholes are used only if the invert of the branch is 0.6 m or more above what its location would be when following the rule just stated.

Example 5.1 A 40 hec drainage basin containing 24 hec net residential area with average 5 dwelling units per hec with 4 residents, and 16 hec zoned commercial area. Determine the design flow for a sewer servicing this area.

Take wastewater generation for
Residential = 300 l/capita/day
Commercial = 1800 l/hec/day
Peak I & I allowance = 9000 l/hec/day

Solution

ADF for residential area = (24 hec x 5 DU/hec x 4 Res./DU x 300 l/Res) = 144m^3/day

ADF for commercial area = (16 hec x 1800 l/Hec) = 288 m^3/day

ADF from Res. And Comm area = 144 m^3/day + 288 m^3/day = 432 m^3/day

Calculate peaking factor

PF= 15.05 $Q^{-0.167}$ =15.05x $(432)^{-0.167}$ = 5.45

Calculate PDF

PDF = 5.45 x 432 + I & I = 2354.4 + 9 x40=2714.4 m^3/day= 0.0314m^3/sec = 1.885 m^3/min

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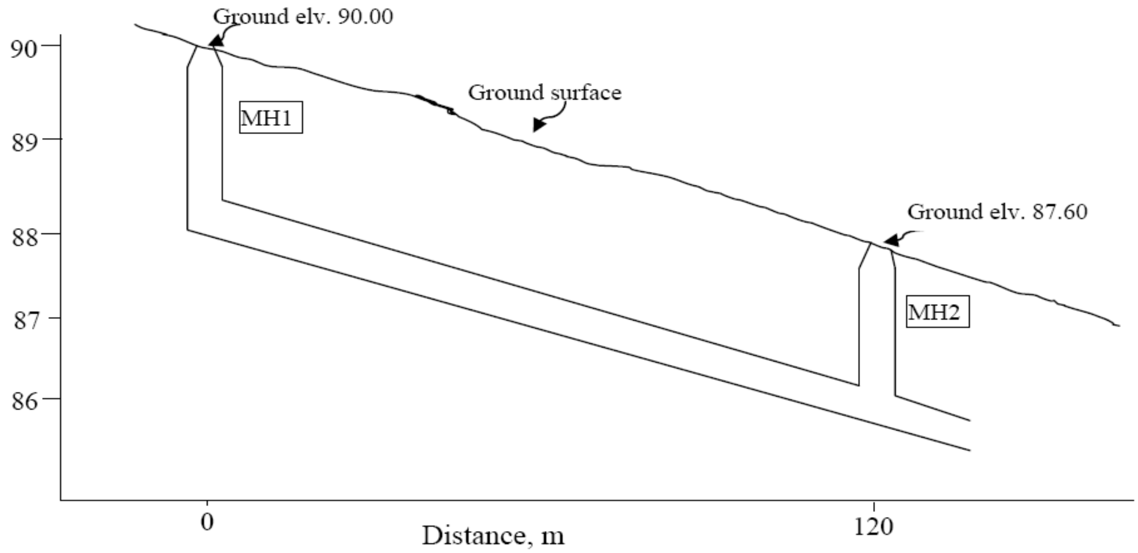
Example 5.2. A 120 m reach of sewer is to be designed with a flow capacity of 100 L/s. The street elevation at the upper manhole is 90.00 m and the lower manhole is 87.60 m, as shown below. Determine an appropriate pipe diameter and slope for this reach, and establish the pipe invert elevations at the upper and lower manholes. Assume a minimum earth cover of 2 m above the crown of the pipe.



Solution

ground slope = (90 – 87.6)/120 = 0.02

Enter the Manning's monograph with s = 0.02 and Q = 100 L/s

We read d = 260 mm → take standard dia. of 250mm → but the slope has to be steeper, about 0.03 to have a capacity of 100 L/s

If the slope is 0.03 the drop will be 0.03 x 120 = 3.6 m which means extra cover of 3.6 – 2.4 =1.2 m

∴ select a larger dia. Of 300 mm at 0.02 slope → full-flow capacity would be 135 L/s.

→ we have partial flow condition

→ q/Q_f =100/135 = 0.74 → we read d/D = 0.63 from partial flow diagram → d = 0.63 x 300 = 190 mm of depth of flow

The full flow velocity = 1.95 m/s

For d/D = 0.63 → v/v_f = 1.06 → v = 1.06 x 1.95 = 2.1 m/s

∴ **select 300 mm dia. at 0.02 slope**

Calculate the invert elevation

Upper invert elevation = ground elv. - cover - pipe diameter

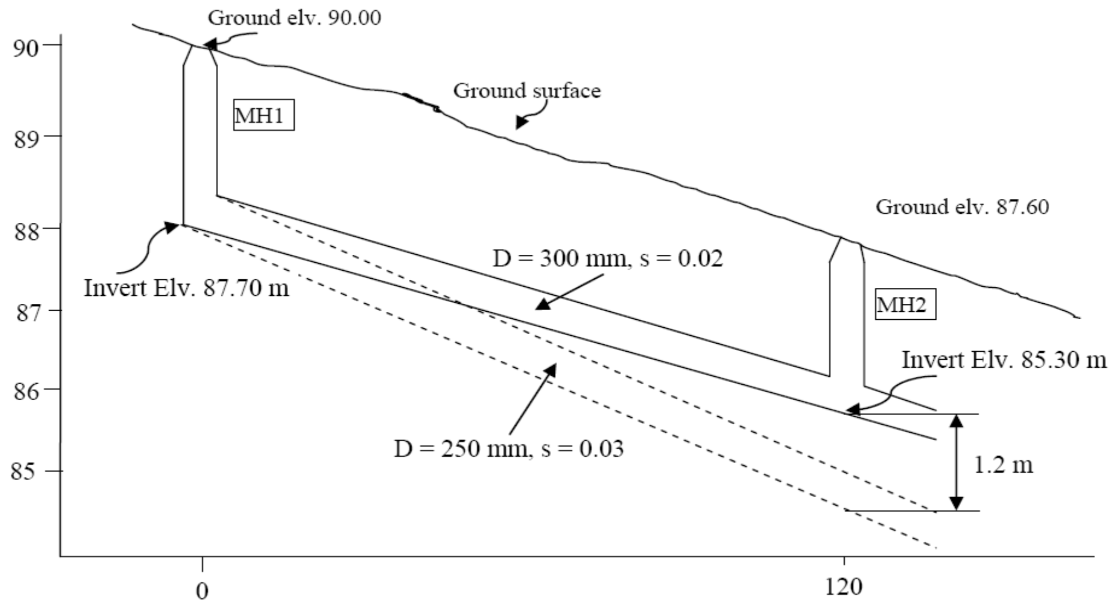
= 90.00 - 2.00 - 0.3 = 87.70 m

Drop in the elevation of sewer

Fall of sewer = 0.02 x 120 = 2.40 m

∴ lower invert elevation = Upper invert elevation – fall of sewer

= 87.70 - 2.4 = 85.30 m



5.6. Design of storm sewers

Generally, storm sewers are designed to provide safe passage of vehicles, and to collect, convey and discharge for frequently occurring, low-return-period storms.

Storm sewer design involves estimation runoff from an area design of the sewer and other hydraulics structures in the drainage system.

Design flow

Design flow is the maximum flow that can pass through a specified structure safely. In determining this design flow the possibility of occurrence has be fixed. Once this is fixed the design flow magnitude can be determined.

Generally, a design frequency is selected to match the facility's cost, amount of traffic, potential flood hazard to property, expected level of service, political considerations, and budgetary constraints, considering the magnitude and risk associated with damages from larger flood events.

The frequency with which a given flood can be expected to occur is the reciprocal of the probability or chance that the flood will be equaled or exceeded in a given year. If a flood has a 20 percent chance of being equaled or exceeded each year, over a long period of time, the flood will be equaled or exceeded on an average of once every five years. This is called the **Recurrence Interval**(RI). Thus the exceedence probability equals 100/RI.

Generally, to design drainage facilities the recurrence interval shown in table 5-1 can be used.

Table 5-1 Return Period Based on Type of Structures.

Drainage Type	Return Period
Side Ditch	10
Pipe Culvert	10
Slab/Box Culvert	25
Bridge	50/100

The commonly used hydrologic methods used to estimate are the following:

• **Rational Method** - only for drainage areas less than 50 hectares (0.5 kilometer^2);

• **SCS and other Unit Hydrograph Methods** - for drainage areas greater than 50hectares;

• **Suitable Computer Programs** - such as HYDRAIN's HYDRO, HEC 1, and TR-20 will be used to facilitate tedious hydrologic calculations.

Rational Method

Runoff from an area can be determined by the Rational Method. The method gives a reasonable estimate up to a maximum area of 50 ha (0.5 Km^2.)

The rational method makes the following assumptions:

- Precipitation is uniform over the entire basin.
- Precipitation does not vary with time or space.
- Storm duration is equal to the time of concentration.
- A design storm of a specified frequency produces a design flood of the same frequency.
- The basin area increases roughly in proportion to increases in length.
- The time of concentration is relatively short and independent of storm intensity.
- The runoff coefficient does not vary with storm intensity or antecedent soil moisture.
- Runoff is dominated by overland flow.
- Basin storage effects are negligible.

$$Q = kCiA$$

Where,
Q = runoff [m3/s]
C = runoff coefficient which can be given for a land use or surface type (Table 5.2)
i = design rainfall intensity [mm/min]
A = area [m^2]

k = unit conversion constant

If an area that drains to a manhole consists of n land uses, the combined C value needs to be calculated by

$$C = \frac{\sum_{i=1}^{n} CiAi}{\sum_{i=1}^{n} Ai}$$

Table5.2: Runoff coefficients for various surfaces.

Type of surface	C
Watertight roofs	0.70-0.95
Asphalted cement streets	0.85-0.90
Portland cement streets	0.80-0.95
Paved driveways and walks	0.75-0.85
Gravel driveways and walks	0.15-0.30
Lawns, sandy soil	
2% slope	0.05-0.10
2-7% slope	0.10-0.15
>7% slope	0.15-0.20
Lawns, heavy soil	
2% slope	0.13-0.17
2-7% slope	0.18-0.22
>7% slope	0.25-0.35

Determination of the design rainfall intensity requires knowledge of the return period, and the duration of rainfall (which equals the time of concentration). A rainfall with 2-5 years return period can be used for residential areas; 5-15 years return period may be used business and high value areas.

The time of concentration refers to the time at which the whole area just contributes runoff to a point. T

$$t_c = t_e + t_f$$

Where,

t_c = time of concentration

t_e = time of entry to the inlet (usually taken as 5 – 10 min)

t_f = time of flow in the sewer

Time of concentration is made up of inlet time (over land flow) and channel flow time.

Time of entry (inlet time or overland flow): is the time required for water to reach a defined channel such as a street gutter, plus the gutter flow time to the inlet.

Channel flow time: is the time of flow through the sewers to the point at which rate of flow is being assessed.

The channel flow time can be estimated with reasonable accuracy from the hydraulic characteristics of the sewer. The channel flow time is then determined as the flow length divided by the average velocity.

The inlet time is affected by numerous factors, such as rainfall intensity, surface slope, surface roughness, flow distance, infiltration capacity, and depression storage. Because of this, accurate values are difficult to obtain. Design inlet flow times of from 5 to 30 min are used in practice.

Kirpich's equation can also be used to calculate inlet time as

$$t_e = \frac{0.00032L^{0.77}}{S^{0.385}}$$

Where

t_e= Time of concentration (hr)

L = Maximum length of travel (m)

S = Slope equal to H/L, where H is the difference in elevation between the remotest point to the basin and the outlet in outlet (m)

If two or more time of concentrations are possible for a point, the greater of the time of concentrations should be used for the determination of intensity. The rainfall intensity can be read from the IDF curve (see fig. 5.2) or calculated by using a relevant formula.

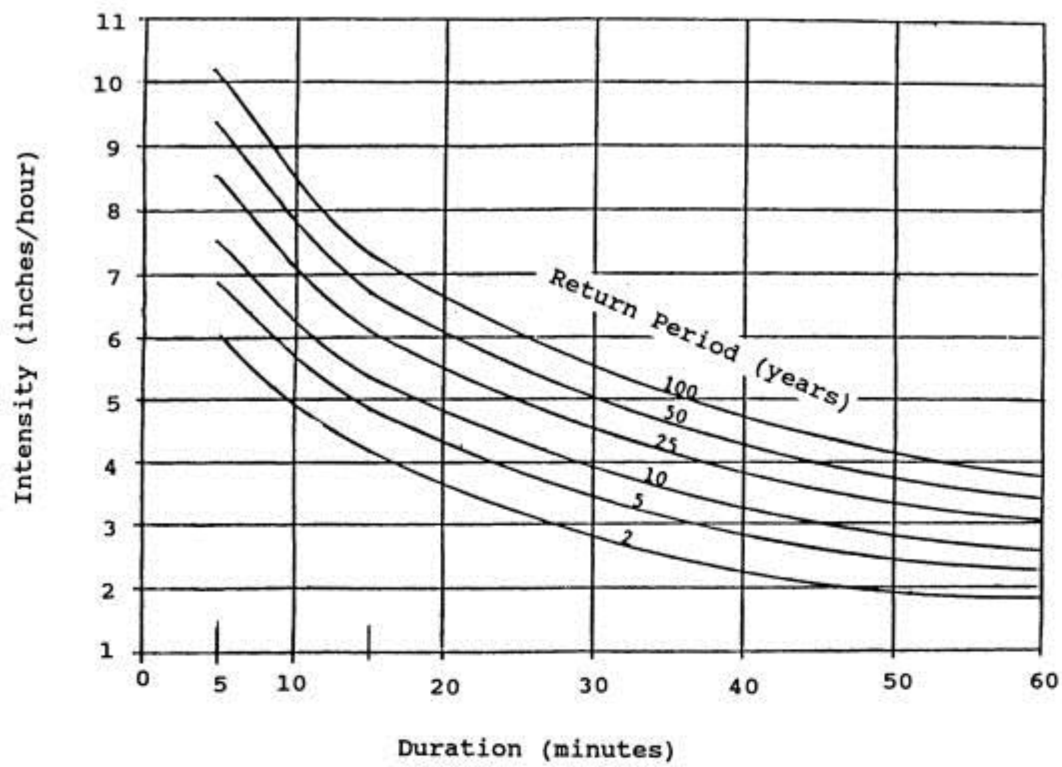
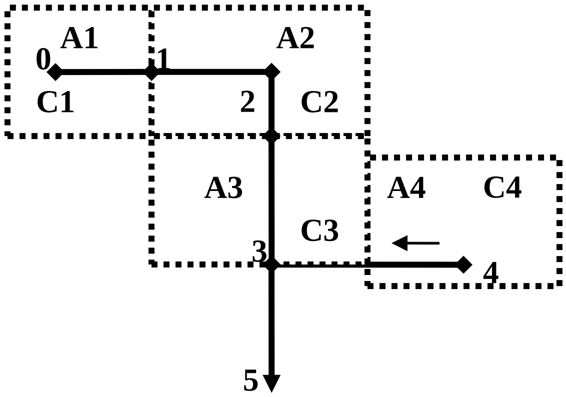


Figure 5.2 Typical IDF curve



Line 2-3

Area, A = A1 + A2

C = $(C_1A_1 + C_2A_2)/(A_1 + A_2)$

t_{c2} = greater of ($t_{eo} + t_{f0\text{-}2}$ or t_{e2})

i = intensity corresponding to t_{c2}

Line 3-5

Area, A = A1 + A2 + A3 + A4

C = $(C_1A_1+C_2A_2+C_3A_3+C_4A_4)/(A_1+A_2+ A_1+A_2)$

t_{c3} = greater of ($t_{eo}+t_{f0\text{-}3}$, t_{e3} or $t_{e4}+t_{f4\text{-}3}$)

i = intensity corresponding to t_{c3}

The sewer design procedure is as follows

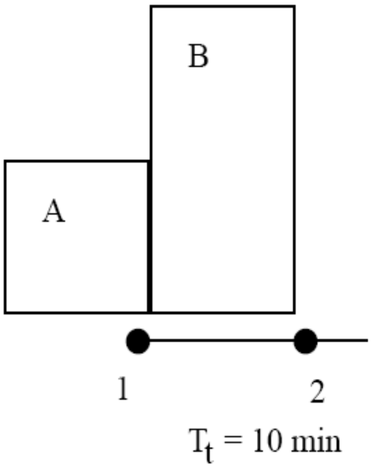
- Establish the layout of the storm sewer
- Estimate the design runoff by the Rational Method
- Determine the sewer size by the Manning formula

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

- Check for velocity; if not in the range change the sewer diameter
- Determine sewer invert elevations

Example 5.3. A storm sewer is proposed to drain a 12 hectares drainage area shown in the figure below. With given data in the table below determine the design discharge needed to convey 5-year peak discharge.

Site	Area (ha)	C	Inlet time (min)
A	4	0.8	10
B	8	0.5	30



Solution

Upstream Area (Manhole 1):

A = 4 ha

C = 0.8

t_c = 10 min

i = 2700/(10+15) = 108 mm/hr

$Q_p = CiA/360$ = (0.8)(108)(4)/360 = 0.96 m^3/sec

Downstream Area (Manhole 2):

A = 4 +8 = 12 ha

C = (0.8 x 4 + 0.5 x 8)/ 12 = 0.6

Time from A – 1 – 2 = 10 + 10 = 20 min

Time from B – 2 = 30 min (**max**)

t_c = 30 min

i = 2700/(30+15) = 60 mm/hr

$Q_p = CiA/360$ = (0.6)(60)(12)/360 = 1.2 m^3/sec

Example 5.4. From a topographic map and field survey, the area of the drainage basin upstream from the point in question is found to be 35 hectares.Determine the maximum rate of runoff for a 10-year and check a 25-year return period. The following data were measured:

Length of overland flow = 45 m Average overland slope = 2.0%
Length of main basin channel = 700 m
Slope of channel = 0.018 m/m = 1.8 %
Estimated Manning's n Roughness coefficient (n) of channel is, n = 0.090
Hydraulic radius = A/P, can be approximated by average depth, = 0.6m
Land Use and Soil Data
From existing land use maps, land use for the drainage basin was estimated to be:
Residential (multi-units, attached) 40%
Undeveloped (2.0% slope),with lawns,heavy soil cover 60%
For the undeveloped area the soil group was determined from field analysis to be:

Lawns, heavy soil100%
The land use for the overland flow area at the head of the basin was estimated to be:
Undeveloped, (Lawns, heavy soil, 2.5% slope) 100%
$I_{10} = 375/(12.61+5)^{0.71}$

Solution

Overland Flow

The runoff coefficient (C) for the overland flow area from Table 4-2 is 0.12-0.17, use 0.14.

Time of Concentration

FromKirpich'sformula with an overland flow length of 45 m, slope of 2.0 % and a C of 0.14, the inlet time can be calculated as:

$$t_e = \frac{0.00032L^{0.77}}{S^{0.385}}$$

$$t_e = 0.00032 x 45^{0.77}/0.02^{0.385}$$

$$t_e = 0.027 \text{ hr} = 1.6 \text{ min}$$

Channel flow velocity is determined from Manning's formula:
$V = (1/n)R^{2/3}S^{1/2}$
Using n = 0.090, R = 0.6 m and S = 0.018m/m, V = 1/1 m/s. Therefore,
Flow Time = (700 m)/(1.1 m/s)(60 s/min) = 10.61 min
and t_c = 1.6 + 10.61 = 12.21 min

Rainfall Intensity

From the equation given with a duration equal to 12.61 minutes,
$I_{10} = 375/(12.61+5)^{0.71}$= 49 mm/hr

Runoff Coefficient

A weighted runoff coefficient (C) for the total catchment area is determined in the following table by using the values from Tables 4-1

Land use	Area	Coefficient	Weighed coefficient
Residential (multi-units, attached)	40%	0.68	0.27
Undeveloped	60%	0.14	0.08
		Total Weighted Runoff Coefficient	0.35

.

Peak Runoff

From the rational equation:
Q_{10}= CIA/360 =0.35 x 49 mm/h x 35 ha/360 = 1.67 m^3/s