Module – 2
Introduction

Structure

2.0 Introduction:

A sewerage system is a system that contains pipes of several lengths and diameters which are very important to convey the wastewater, including domestic, residential, industrial and commercial treatment services. Sewerage system plays a critical role in that it supports public health and environmental protection. Normally, the wastewater flow in the sewerage system is directly related to human usage for all kind of activities.

Sewerage system is a main consideration in any residential, commercial, and industrial development because it can enhance the environment through the disposal of wastewater. Moreover, it also can prevent floods through removal of rain water.

2.1 Objectives

1. Understand sewerage network and influencing parameters.
2. Understand and design different unit operations involved in conventional and biological treatment process.
3. Evaluate self purification of streams depending on hydraulic and organic loading of sewage into receiving waters.

2.2 Design of sewers: After the determination of the quantity of sewage, variation in the quantity, the next step is to design the sewer section, which will be economical as well as can take the required discharge at self cleaning velocity.

Estimate of sanitary sewage: Sanitary sewage is mostly the spent water of the community draining into the sewer system with some ground water and a fraction into the sewer system with some ground water and a fraction of the storm runoff from the area, draining into it. The sewers should be capable of receiving the expected discharge at the end of design period. The provision however should not be much in excess of the actual discharge in the early years of its use to avoid depositions in sewers. The estimate of flow therefore requires a very careful consideration and is based upon the contributory population and the per-capita flow of sewage, both the factors being guided by the design period.

Design period: Since it is both difficult and uneconomical to augment the capacity of the system at a later date, sewers are usually designed for the maximum expected discharge to meet the requirements of the ultimate development of the area. A design period of 30 years for all types of sewers is recommended.

The future period for which the provision is made in designing the capacities of the various components of the sewerage scheme is known as the design period. The design period depends upon the following:

- Ease and difficulty in expansion,
- Amount and availability of investment,
- Anticipated rate of population growth, including shifts in communities, industries and
- commercial investments,
- Hydraulic constraints of the systems designed, and
- Life of the material and equipment.

Following design period can be considered for different components of sewerage scheme.

- Laterals less than 15 cm diameter : Full development
- Trunk or main sewers : 40 to 50 years
- Treatment Units : 15 to 20 years
- Pumping plant : 5 to 10 years

Population estimate: There are several methods for forecasting the population of a community. The most suitable approach is to base the estimation on anticipated ultimate density of population. Population is estimated based on the following methods.

- Arithmetical Increase Method
- Geometrical Increase Method
- Incremental Increase Method
- Graphical Method
- Comparative Graphical Method
- Master Plan Method
- Logistic Curve Method

Area: The tributary area for any section under consideration need to be marked on key plan. The topography, layout of buildings, legal limitations etc., determine the tributary area draining to a sewer section. The area is to be measured from the map.

Per capita sewage flow: Although the entire spent water of a community should contribute to the total flow in a sanitary sewer, it has been observed that a small portion is lost in evaporation, seepage in ground, leakage etc. Generally 80% of the water supply may be expected to reach the sewers. The sewers should be designed for a minimum of 150 lpcd.

Ground water infiltration: Estimate of flow in sanitary sewers may include certain flows due to infiltration of ground water through joints. The quantity will depend on the workmanship in lying of sewers and the height of ground water table, the material of sewer, nature of soil etc. However the following values may be assumed.

- 5000-50000 liters/day/hectare.
- 500-5000 litre/day/km of sewers/cm of diameter.

Self cleansing velocity: It is necessary to maintain a minimum velocity in a sewer line to ensure that suspended solids do not deposit and cause choking troubles. Such a minimum velocity is called as self cleansing velocity. Self cleansing velocity is determined by considering the particle size and specific weight of the suspended solids in sewage.
The velocity which can cause automatic self cleansing can be found out by the following formula given by Shield:

$$V = \sqrt{\left[\left(\frac{8K}{f}\right)\left(\frac{Ss - S}{S}\right) g\, d\right]}$$

Where:

f = Darcy's co-efficient of friction, 0.03
K = characteristics of solid particles
= 0.06 for organic and
= 0.04 for inorganic solids
Ss = specific gravity of particles
= 2.65 for inorganic and
= 1.2 for organic solids
S = specific gravity of sewage, 1.0
G = acceleration due to gravity
D = diameter of particle As per

Maximum Velocity or Non-scouring Velocity

The interior surface of the sewer pipe gets scored due to the continuous abrasion caused by suspended solids present in sewage. The scoring 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.

Sewer	**Material Limiting velocity, m/sec**
Vitrified tiles	4.5 – 5.5
Cast iron sewer	3.5 – 4.5
Cement concrete	2.5 – 3.0
Stone ware sewer	3.0 – 4.5
Brick lined sewer	1.5 – 2.5

2.3 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.

Regime velocity:

i. Channel should flow uniformly in "incoherent unlimited alluvium" of same character as that transported by the water;

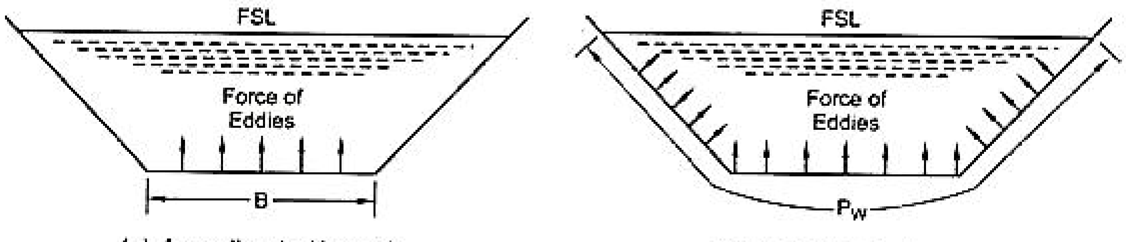
ii. Silt grade and silt charge should be constant; and

iii. Discharge should be constant.

These conditions are very rarely achieved and are very difficult to maintain in practice. Hence according to Lacey's conception regime conditions may be subdivided as initial and final. The definitions of these two terms are already given earlier.

In rivers achievement of initial or final regime is practically impossible. Only in bank full stage or high floods the river may be considered to achieve temporary or quasi-regime. The recognition of this fact can be utilised to deal with the issues concerning scour and floods.

Lacey also a state that the silt is kept in suspension solely by force of eddies. But Lacey adds that eddies are not generated on the bed only but at all points on the wetted perimeter. The force of eddies may be taken normal to the sides



(a) According to Kennedy (b) According to Lacey

Fig. 9.2. Lacey's theory

Obviously the vertical components of forces due to eddies are responsible for keeping the silt in suspension. Unlike Kennedy, Lacey takes hydraulic mean radius (R) as a variable rather than depth (D). So far as wide channels are concerned there is hardly any difference between R and D. When the channel section is semi-circular there is no base width and sides actually and hence assumption of ii as a variable seems to be more logical. From this point of view velocity is no more dependent on D but, rather depends on R. Consequently amount of silt transported is not dependent on the base width of a channel only.

$$\mathbf{V} = \boldsymbol{K}\, \boldsymbol{R}^{1/2}$$

Where, V = Regime velocity

R = hydraulic mean radius
K = constant.

2.4 Disposal of effluents by dilution
1. Dilution i.e., disposal of sewage to water.
2. Land disposal.

Both the methods are very simple. But these may be regulated carefully so that, the quantity of sewage discharged into water or applied to land is such that they are capable of receiving the organic load present in the effluent.

Dilution: Dilution is the disposal of sewage by discharging it into large bodies of water like sea, streams, rivers etc. This method is possible only when the natural water is available in large quantity near the town. Proper care should be taken while discharging sewage in water so that sewage may not pollute natural water and make it unfit for any other purposes like bathing, drinking, irrigation etc.

Conditions Favourable for Dilution:

1. Where sewage is fresh.
2. Where favourable currents exits in a stream.
3. Where sewage is almost free from floating/ settleable solids.
4. Where thorough mixing is possible.
5. Where diluting water has high quantities of dissolved oxygen.
6. When the city is situated near river or sea.

Conditions Essential for treatment before Dilution:

- Where wastewater is harmful to aquatic life
- Where wastewater is contains industrial wastes containing toxic substances
- Where receiving waters are used for inland navigation
- Where receiving water is a source for drinking
- Where wastewater is not fresh but is stale,
- Where wastewater is not likely to be dispersed easily due to tides, winds, cross-currents etc.

Self Purification Phenomenon:

Self Purification of Natural Streams: The automatic purification of natural water is known as self purification. The self purification of natural water systems is a complex process that often involves physical, chemical, and biological processes working simultaneously. When wastewater is discharged into a natural stream, the organic matter is broken down by bacteria to ammonia, nitrates, sulphates, carbon-dioxide etc. In this process of oxidation, the dissolved oxygen content of water is utilized. Due to this, deficiency of DO is created. As the excess organic matter is stabilized, the normal cycle will be re-established wherein the oxygen is replenished by its re-aeration. This process is known as Self-Purification. Also, the stabilized by products of oxidation mentioned earlier are utilized by plants, algae to produce carbohydrates and oxygen.

The amount of dissolved Oxygen (DO) in water is one of the most commonly used indicators of a river health. As DO drops below 4 or 5 mg/L the forms of life that can survive begin to be reduced. A minimum of about 2.0 mg/L of dissolved oxygen is required to maintain higher life forms.

Factors affect the amount of DO available in a river:

- Oxygen demanding wastes remove DO
- Plants add DO during day but remove it at night
- Respiration of organisms removes oxygen.
- In summer, rising temperature reduces solubility of while lower flows reduce the rate at which oxygen enters the water from atmosphere.

Factors Affecting Self Purification:

Dilution: When wastewater is discharged into the receiving water, dilution takes place due to which the concentration of organic matter is reduced and the potential nuisance of swage is also reduced. If C_S and C_R are the concentrations of an impurity such as organic content, BOD, suspended solids in the sewage and river having discharge rates Q_S and Q_R respectively, the resulting concentration C of the diluted mixture is given by,

$$C_S Q_S + C_R Q_R = C (Q_S + Q_R)$$

$$C = \frac{C_S Q_S + C_R Q_R}{Q_S + Q_R}$$

When the dilution ratio is quite high, large quantities of DO are always available which will reduce the chances of putrefaction (disintegration) and pollution effects. Aerobic condition always exists because of dilution. This will however not be there, if dilution ratio is small, i.e. when large quantities of effluent is discharged into a small stream.

Water Current: When strong water current is available, the discharged wastewater will be thoroughly mixed with stream water preventing deposition of solids. In small current, the solid matter from the wastewater will get deposited at the bed following decomposition and reduction in DO.

Temperature: The quantity of DO available in stream water is more in cold temperature than in hot temperature. Also, as the activity of microorganisms is more at the higher temperature, hence, the self-purification will take less time at hot temperature than in winter.

Sunlight: Algae produces oxygen in presence of sunlight due to photosynthesis. Therefore, sunlight helps in purification of stream by adding oxygen through photosynthesis.

Rate of Oxidation: Due to oxidation of organic matter discharged in the river DO depletion occurs. This rate is faster at higher temperature and low at lower temperature. The rate of oxidation of organic matter depends on the chemical composition of organic matter.

Zones of pollution in the stream:

The self-purification process of stream polluted by wastewater discharged into it can be divided into the following four zones:

1. **Zone of degradation**: This zone is situated below the outfall sewer when discharging its contents into stream. In this zone, water is dark and turbid, having the formation of sludge deposits at the bottom. The DO is reduced to 40% of the saturation values. There is an increase in CO_2 content and re-aeration is much slower than de-oxygenation. Though conditions are unfavourable for aquatic life, fungi at higher points and bacteria at lower points breed small which stabilizes the sewage sludge. The decomposition of solid matter takes place in this zone and anaerobic decomposition prevails.

2. **Zone of active decomposition**: This zone is just after the degradation zone and is marked by heavy pollution. Water in this zone becomes greyish and darker than previous zone. The DO concentration in this zone falls down to zero. Active anaerobic organic decomposition takes place, with the evolution of methane (CH_4), hydrogen sulphide (H_2S), carbon-dioxide (CO_2) and nitrogen (N_2), bubbling to the surface with masses of sludge forming black scum. Fish life is absent in this zone and, anaerobic bacteria at the upper end and aerobic bacteria at the lower end.

However, at the end of this zone, as the decomposition slackens, reaeration sets in and DO again rises to its original level 0f 40%.

3. **Zone of recovery**: In this zone, the process of recovery starts, from its degraded condition to its former condition. The stabilization of organic matter takes place in this zone. Due to this, most of the stabilized organic matter settles as sludge, BOD falls and DO content rises above the 40% value. Mineralization is active, with the resulting formation of products like nitrates (NO_4), sulphates (SO_4), carbonates (CO_3). Near the end of the zone, microscopic aquatic life reappears, fungi decreases and algae reappears.

4. **Clear water zone**: In this zone, the natural condition of stream is resorted with the result that

- Water becomes clearer and attractive in appearance,
- DO rises to the saturation level, and is much higher than BOD
- Oxygen balance is attained.

Thus recovery is said to be complete in this zone, though some pathogenic organisms may be present in this zone.

Indices of Self-Purification method:

The stage of self-purification process can be determined by physical, chemical and biological analysis of the water. Colour and turbidity are the physical indices, while DO, BOD and suspended solids are the chemical indices which can mark the stages of purification. Moreover, the biological growth present in the water can also indicate the stage of purification process, as different types of micro and macro organisms will exists in polluted water under different conditions.

2.5 Oxygen Sag Curve:

The oxygen sag or oxygen deficit in the stream at any point of time during self purification process is the difference between the saturation DO content and actual DO content at that time.

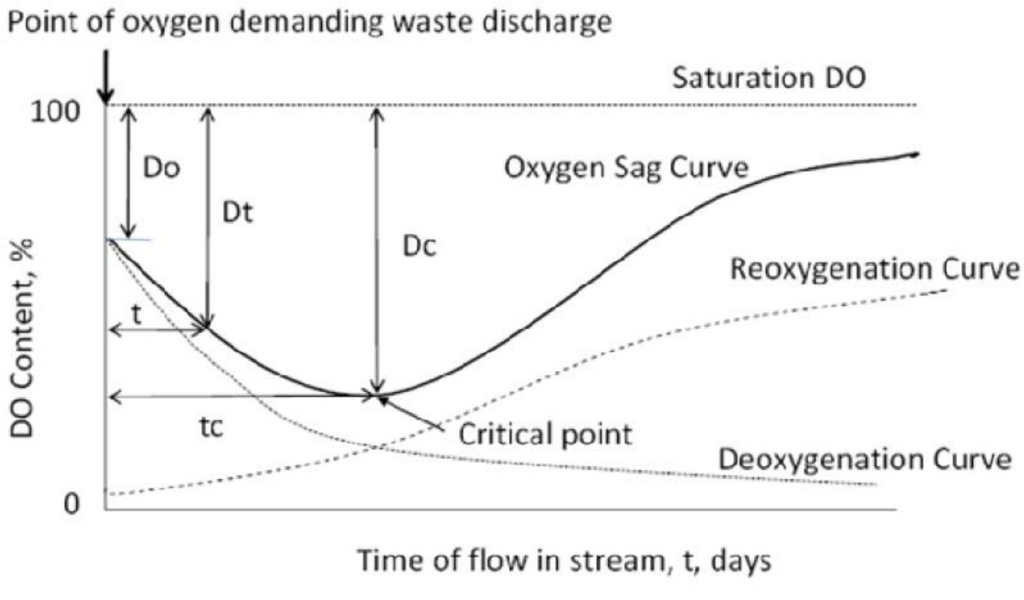
OR

The amount of resultant oxygen deflect can be obtained by algebraically adding the de - oxygenation and re -oxygenation curves. The resultant curve so obtained is called oxygen sag curve

Oxygen Deficit, D = Saturation DO – Actual DO

The saturation DO value for fresh water depends upon the temperature and total dissolved salts present in it and its value varies from 14.62 mg/L at 0oC to 7.63 mg/L at 30ºC, and lower DO at higher temperatures.

The DO in the stream may not be at saturation level and there may be initial oxygen deficit (D). At this stage, when the effluent with initial BOD load Lo, is discharged in to stream, the DO content of the stream starts depleting and the oxygen deficit (D) increases. The variation of oxygen deficit (D) with the distance along the stream, and hence with the time of flow from the point of pollution is depicted by the Oxygen Sag Curve. The major point in sag analysis is point of minimum DO, i.e., maximum deficit. The maximum or critical deficit (Dc) occurs at the inflexion points (as shown in fig) of the oxygen sag curve.



Deoxygenation, reoxygenation and oxygen sag curve

De-oxygenation and Re-oxygenation Curves:

De-oxygenation curve: The curve which represents (or) showing the depletion of D.O with time at the given temperature.

Re-oxygenation Curve: In order to counter balance the consumption of D.O due to the de – oxygenation, atmosphere supplies oxygen to the water and the process is called the re – oxygenation.

When wastewater is discharged in to the stream, the DO level in the stream goes on depleting. This depletion of DO content is known as de-oxygenation. The rate of de-oxygenation depends upon the amount of organic matter remaining (Lt), to be oxidized at any time t, as well as temperature (T) at which reaction occurs. The variation of depletion of DO content of the stream with time is depicted by the de-oxygenation curve in the absence of aeration. The ordinates below the de-oxygenation curve indicate the oxygen remaining in the natural stream after satisfying the bio-chemical demand of oxygen. When the DO content of the stream is gradually consumed due to BOD load, atmosphere supplies oxygen continuously to the water, through the process of re-aeration or re-oxygenation, i.e., along with de-oxygenation, re-aeration is continuous process.

Dilution into Sea:

The saturation concentration of the dissolved oxygen in water decreases with increase in salt content. Due to this reason, the saturation concentration in sea water is approximately 80% of that in water. In addition to this deficiency, the temperature of sea water is lower than sewage temperature, whereas the specific gravity is higher. Due to these reasons, when sewage is discharged into sea water, the lighter and warmer sewage will rise up to the surface, resulting in the spreading of the sewage at the top surface of sea in a thin film or sleek. Moreover, sea water contains a large amount of dissolved matter which chemically reacts with the swage solids, resulting in the precipitation of some of the sewage solids, giving a milky appearance to the sea water and resulting in the formation of sludge banks. These sludge banks and thin milky layer formed at the top of sea water produces offensive hydrogen sulphide gas by reacting with the sulphate rich water of the sea. The various chemical reactions and the prevailing dissolved matter in the sea water reduce its capacity to absorb more quantity of sewage. However, since the sea contains large volume of water, most of these deficiencies can be overcome if the sewage is discharged deep into the sea, much away from the coast line, with extreme care.

The following points should be kept in mind

1. The sewage should be discharged deep into the sea, preferably 1 to 1.5km away from the shore.
2. The outfall should be so designed such that there should be proper dilution of waste with seawater before waste tries to come to the surface.
3. The minimum depth of water at the outfall point should be 3 to 5m.
4. The sewage should be disposed off only during the low tides. For this purpose tanks of large size should be constructed near the shore during high tides and release the same during low tides.
5. While designing the position of outfall, the direction of wind velocity and direction of ocean currents should be considered.

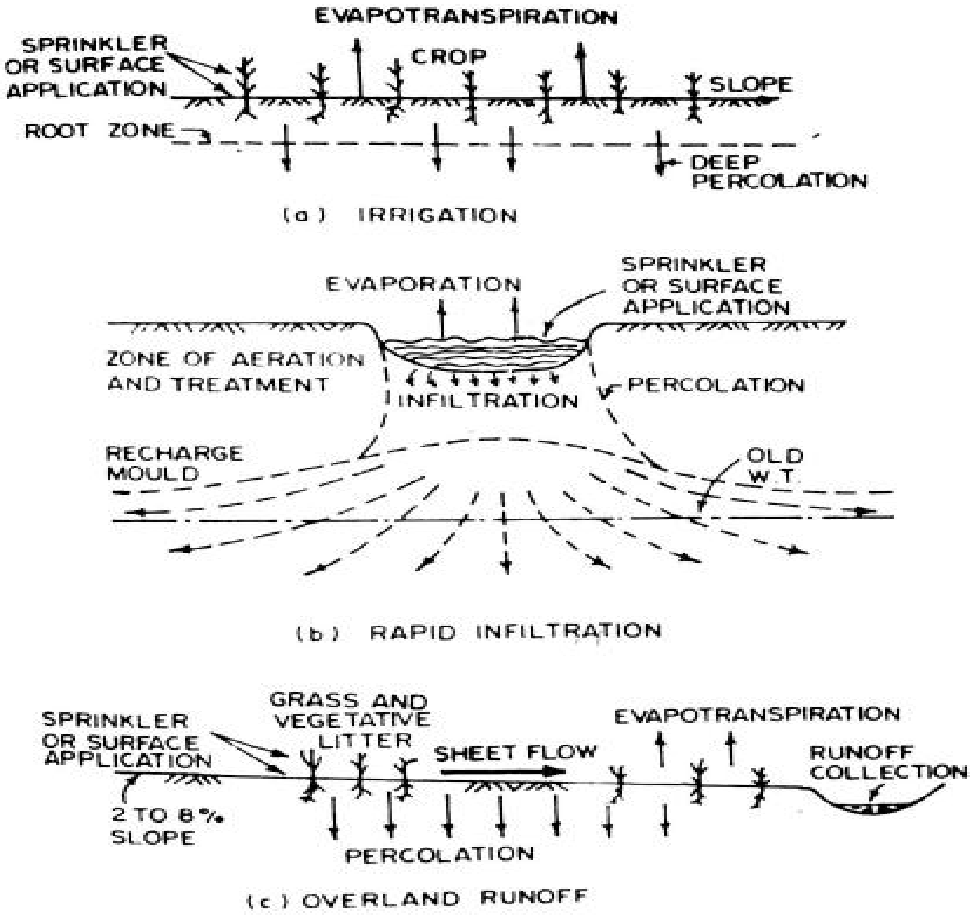
Disposal by land treatment:

When the wastewater, either raw or partly treated, is applied or spread on the surface of land, the method is called disposal by land treatment. Some part of the wastewater evaporates while other part percolates into the ground leaving behind suspended solids which are partly acted upon by the bacteria and partly oxidized by exposure to atmospheric actions of air, heat and light. The sewage adds to the fertilizing value of the land, and crops can be profitably raised on such land. Due to this, the disposal by land treatment is also known as sewage farming.

The three principal process of land treatment of wastewater are:

1. Broad irrigation or sewage farming
2. Rapid infiltration
3. Overland runoff

The first two processes depend upon the moving or percolating the water downward through the soil and thus are limited by infiltration and percolating capacity of the land. While the percolating capacity is a function of soil characteristics, the infiltration depends upon the degree of clogging at the soil surface. If the waste is sufficiently pretreated, clogging will be minimized and percolation will limit the rate at which liquid can be applied. For percolation of 6 to 25mm/min - rapid infiltration is practicable, for 2 to 6mm/min – broad irrigation is suited and below 2mm/min overland runoff should be adopted.



Rapid infiltration may be used for waste disposal, ground water recharge or both. For this process, wastewater is discharged into large basin underlined by soils and sands of high permeability. Bottom of the basin may be covered with grass which assists in removal of nitrogen gas and helps in maintaining the infiltration capacity of the surface.

The technique of overland runoff is applied when soils have low permeability. It is not a true disposal system since wastewater must be collected after passage over the soil. Plant or tree cover is essential to minimize and assist in nutrient removal. Thus for this purpose grasses are grown. The complex compounds in the sewage are thus converted into harmless mineral salts which serve as valuable fertilizers. The nutrients in the sewage like nitrogen, phosphorous and potassium along with the micro-nutrients as well as organic matter present in it could be advantageously employed for sewage farming to add the fertility of the soil.

Methods of application of wastewater:

- Sprinkler irrigation method
- Subsurface irrigation method
- Surface irrigation method

In sprinkler irrigation method, sewage is spread over the soil through nozzles which are fitted at the tips of pipes carrying sewage under pressure. The process, being costly is not preferred in India, although it gives very good results, like those of natural rainfall.

In sub-surface irrigation method, sewage is applied directly to the root zone of crops, though a system of properly laid open-jointed pipes. Sewage as it flows through these pipes, exfiltrates through the open joints and is distribute in the surrounding area by the action of capillarity.

Surface irrigation method is also known as Broad irrigation, where swage is applied over the surface of the land. There are different methods of application of sewage to the land are as follows:

i) **Border strip method**: In this method, agricultural field is divided into series of strips of width varying from 10 to 20m and length varying from 100 to 300m with a slope of 0.5 to 1.5%. Each strip is separated by means of borders or levels. Sewage is supplied between those borders from the main ditch through the inlet provided at the head of each strip and is made to flow in the form of sheets. The discharge to be supplied at the supply ditch depends on type of soil.

ii) **Free flooding**: This method is also known as irrigation by plots which are commonly used in India. In this method the entire field is divided into number of small plots which are relatively flat. The sewage is supplied from main ditch or supply ditch to subsidiary ditch to higher end of each plot. The supply is cutoff as soon as the plot receives sufficient depth of sewage

iii) **Basin flooding**: This method is used for irrigating orchards. In this method each tree or a group of tree is included by a circular channel, which is called as basin. These basins are supplied with sewage from the main ditch through field canals

iv)**Check flooding**: This method consists of applying sewage to check basins enclosed by a small size bunds (checks). The size of checks varies from 3mx3m to 30mx30m depending upon the type of soil and type of crop.

v) **Furrow irrigation method**: This method is adopted for row crops such as sugarcane, maize, tobacco and some variety of vegetables. In this method, sewage is supplied in furrows between crop rows. Sewage spreads laterally irrigating the area between two furrows. The width of furrow varies from 120-150 cm and the depth from 25-50 cm. The width of the ridge varies from 125-250 cm and length from 10-30 m. The percolated effluent is collected in underground drains flows towards natural drainage for disposal.

Advantages of Sewage farming:

1. Adds manure to land
2. Pollution of natural water courses is minimized.
3. Increase fertility of land.
4. Gives high calorific value to crops grown in sewage farms.
5. Does not require any installation of equipment involving high initial cost.
6. Crops could be grown and hence a return value is always possible to obtain.
7. Method specially suitable where large quantity of river water is not available at all times of the year.

Disadvantages of Sewage farming:

1. Difficult to get land during rainy and harvest seasons.
2. Additional land is required for reserve.
3. Sanitary reasons may not permit growing of crops on sewage farms.
4. More land area is required is sewage volume is greater since land capacity is limited.
5. If all precautions are not taken, sewage farming results in sewage sickness to land and health to life.

Conditions favourable for land treatment:

1) When natural rivers are not located near the town or city.
2) When river runs dry or have a small flow during summer, discharging sewage into them is out of question.
3) When plentiful land with sandy, loamy or alluvial soil overlying soft murram, sand or gravel is available, land treatment is favoured.
4) When climate is arid (means dry), land treatment is favoured.
5) Land treatment is favoured when subsoil water table is low even in wet season.
6) Land treatment is favoured when rainfall is low.
7) When large open areas are available near the locality, broad irrigation can be easily practiced.
8) Cash crops can be easily grown on sewage farms.

2.6 Sewage Sickness:

The phenomena of soil getting clogged and loses its capacity of receiving the sewage load when the sewage is applied continuously on a piece of land is called sewage sickness.

Sewage sickness can be prevented by adopting the following measures:

- **Pre-treatment of sewage**: By giving primary treatment to the sewage, the suspended solids are removed. Due to this measure, the pores of the soil will not get clogged quickly. Also, BOD load will be reduced by 30%.
- **Provision of extra land**: Extra land, as reserve or standby should be available so that the land with sewage sickness can be given rest. During the rest period, the sick land should be properly ploughed so that it is broken up and aerated.
- **Under Drainage of soil**: Subsoil drains should be provided to collect the percolated wastewater. This will minimize the possibility of sewage sickness.
- **Proper choice of land**: The land chosen for this purpose should be sandy or loamy, having higher permeability. Clayey soil should be avoided.
- **Rotation of crops**: Rotation of crops minimizes the chances of sewage sickness and prevents soil erosion and improves the fertility of land.
- **Shallow depth application**: Sewage should be applied in shallow depths. If sewage is applied at greater depths, chances of sewage sickness are increases.

2.7 Recommended Questions

1. Write a note on oxygen sag curve
2. Write a note on sewage sickness.
3. Explain the factors to be considered while designing sewers.
4. Explain the effects of variation on velocity.