Canal Irrigation

It is one of the types of irrigation where in the reservoir water is carried to the field through channels having specific shape and bed channel slope. The shape is generally trapezoidal or triangular with side slopes based on soil types.

Types of canals

Canals are classified into different types based on different criteria:

- ***Classification based on Size:***

Based on size, canals are classified into following types:

1. Main canal*: The main canal is the largest canal in the system. It takes off directly from the canal headworks. Generally, there are two main canals, each taking off from either side. Sometimes there are two or more main canals on either side. No direct irrigation is normally done from a main canal.*

2. Branch canal*: A branch canal takes off from the main canal or another branch canal. The discharge capacity of a branch canal is usually more than 5 cumecs. Generally, no direct irrigation is done from a branch canal.*

3. Major distributary*: A major distributary takes off from a main canal, a branch canal or another distributary and supplies water to minor distributaries and water courses. The discharge capacity is usually between 0.25 to 5 cumecs and these channels are generally used for direct irrigation.*

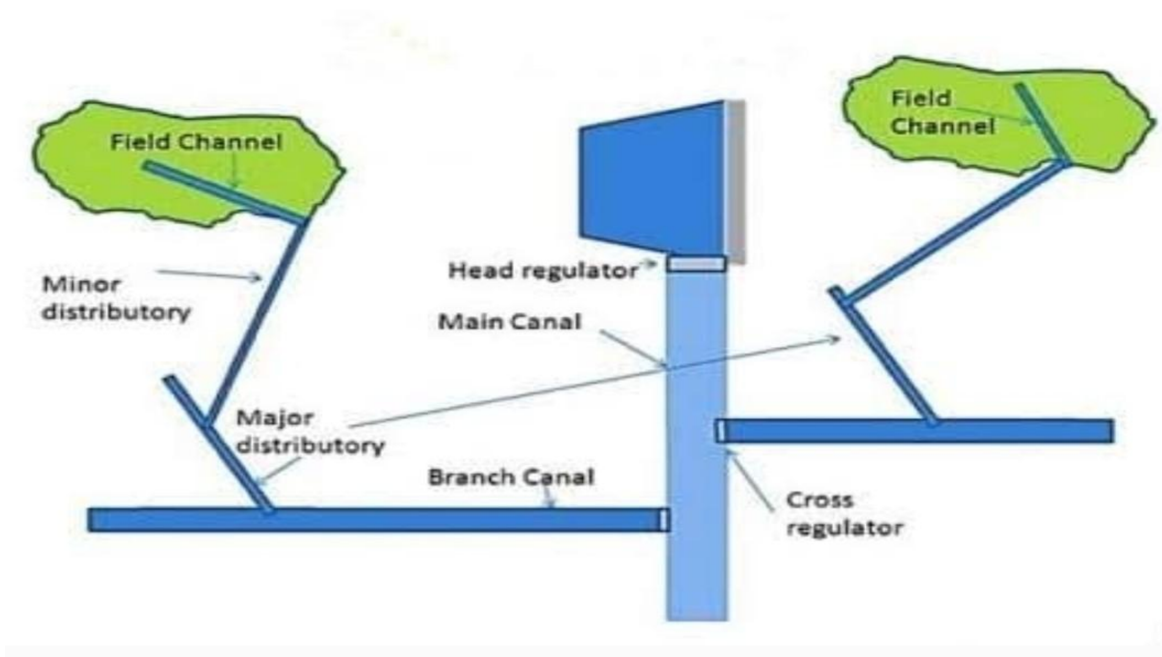

Figure 1 Different canals Based on size

***4. Minor distributary**: A minor distributary also takes off from a main canal, a branch canal or another distributary and supplies water to water courses, but its discharge capacity is usually less than 0.25 cumecs. The minor distributaries are also used for direct irrigation.*

***5. Water courses (or field channels):** Water courses are small channels which take water from a branch canal, a major distributary or a minor distributary and supply it to the agricultural fields. The water courses are owned, constructed and maintained by cultivators.*

➢ Classification based on alignment

Based on alignment, canals are classified into following types:

***1. Watershed (or Ridge Canals):** The canal which is aligned along a watershed (or ridge) is called a watershed canal. As far as possible, a canal should be aligned on a ridge line so that it can irrigate on both sides of the ridge by gravity, and hence, has a large commanded area.*

- ✓ *The dividing line between the catchment areas of two streams is called the watershed or Ridge.*
- ✓ *Watershed canals are suitable for plain areas, where slopes are relatively flat and uniform.*
- ✓ *Watershed canals have minimum number of cross-drainage works, because most of the drainages originate from the ridge and do not cross the canal.*

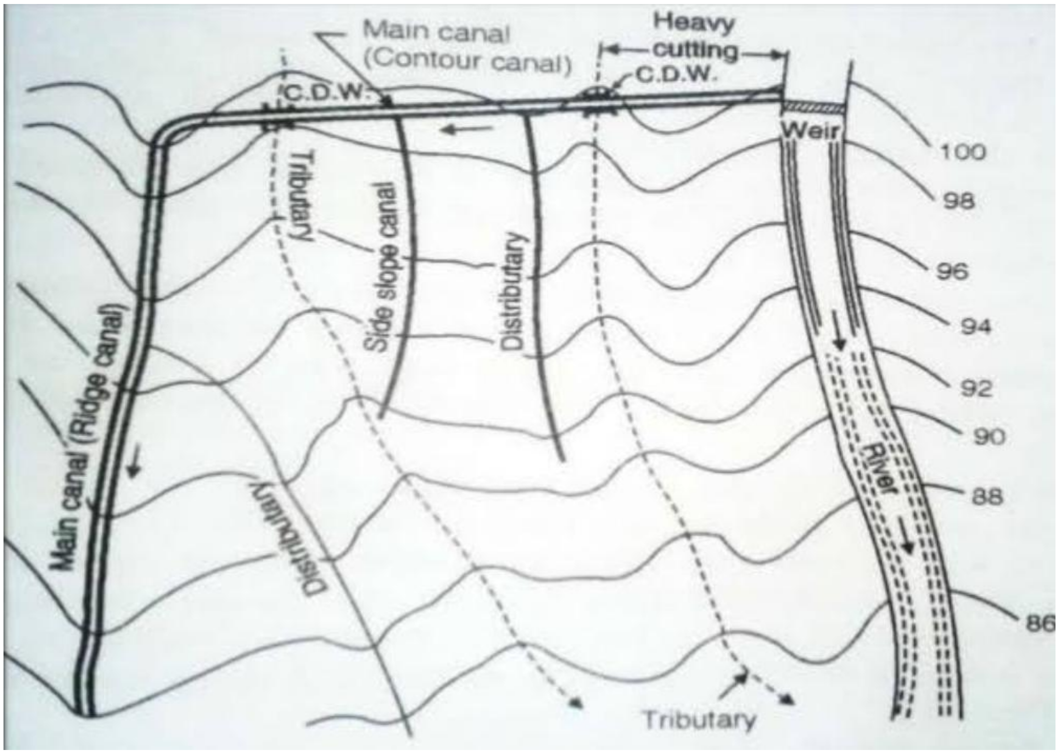

Figure 2 Different canals based on alignment

2. Contour canals: *A contour canal is aligned almost parallel to the contours of the terrain.*

- ✓ *A contour canal cannot be exactly parallel to the contours because it requires some drop in the bed level to have a longitudinal slope required for the gravity flow.*
- ✓ *A contour canal can irrigate only on one side because the land on the other side is higher.*
- ✓ *They are aligned generally when canals take off from river.*
- ✓ *In a contour canal, there are a large number of cross-drainage works because all the drainages are at right angles to the contours.*

3. Side-Slope canal*: A side-slope canal is aligned at right angles to the contours.*

- ✓ *Because drainages also run at right angles to the contours, a side-slope canal does not normally intercept drainages, and therefore, no cross-drainage work is required.*
- ✓ *It can irrigate only on one side.*

➢ ***Classification based on canal surface***

Based on the canal surface, canals are classified into following types:

1. Lined canal*: A lined canal is the one which has its surface lined with an impervious material on its bed and sides to prevent seepage of water. Also, in lined canals, high velocity can be permitted and hence the cross-sectional area is less.*

***2. Unlined canal**: An unlined canal is the one which has the surface of the natural material through which it is constructed and it is not provided with a lining on its surface. These are further of two types:*

- ***Alluvial canals:** These canals are constructed through the alluvial soils deposited by rivers. The alluvial soils are incoherent silty soils which can be easily scoured as well as deposited. These canals are designed so that there is neither scouring nor silting. The velocity in these canals is quite low and therefore, the cross-sectional area is large.*
- ***Non-alluvial canals:** These canals are constructed through hard soils or disintegrated rocks. Since the canal surface is hard, scouring normally does not occur, hence, the velocity in these canals is high.*

➢ Classification based on Purpose

Based on the purpose served, canals are classified into following types:

*1**. Irrigation canals:** An irrigation canal is the one which is constructed for carrying the water for irrigation.*

***2. Power canals**: A power canal is the one which is constructed for carrying the water for hydropower generation. It is also called a hydel canal.*

***3. Navigation canals**: A navigation canal is constructed to provide inland navigation. Small ships and steamers can ply in these canals.*

***4. Water supply canal**: A water supply canal provides water for drinking purposes and industrial use.*

***5. Feeder canals**: A feeder canal is constructed to feed water to another canal. It is located outside the commanded area of the canal system.*

***6. Carrier canals:** A carrier canal carries water for another canal and is also used for irrigation.*

***7. Multipurpose canal**: A multipurpose canal serves two or more purposes, such as irrigation, water supply, hydropower and navigation.*

➢ Classification based on financial returns

Based on the financial returns, canals are classified into following types:

***1. Protective canals**: A Protective canal is constructed to protect the areas most prone to famines. These canals do not give any revenue to the state.*

***2. Productive canals**: These are such canals which yield revenue to the state. When fully developed. A productive canal yields enough revenue to cover up its maintenance and running cost as well as a minimum rate of return (6% to 8%) on the initial cost. Thus the entire cost is recovered in 12 to 16 years.*

Parts of a Canal Irrigation system

A large number of structures are constructed on the canals for various purposes which are classified as:

1. Conveyance structures

2. Regulatory structures

***1. Conveyance structures**: A canal conveying water from the source has to run for large distances and has to maintain the water levels appropriately. The water which enters the **main canal** is distributed into **branches** and **distributaries** and ultimately reaches the agricultural fields through **water courses**. The canal has to cross terrain of different slopes as well as some obstacles such as natural water bodies or railway lines, roads, etc. For this purpose, cross-drainage works are required. The **cross-drainage work** is required to dispose of the drainage water so that the canal supply remains uninterrupted. The canal at a cross-drainage work is generally taken either over or below or at the same level as the drainage. Depending upon the relative positions of the canal and the drainage, the cross-drainage works may be broadly classified into 3 categories:*

a) Canal over the drainage:

- ***Aqueduct:** It is a structure in which the canal flows over the drainage and the flow of the drainage below is open channel flow. It is provided when the canal bed level is higher than the HFL of the drainage.*
- ***Syphon aqueduct:** In a siphon aqueduct also the canal is taken over the drainage, but the flow in the drainage is under pressure. It is constructed when the HFL of the drainage is higher than the canal bed level.*

b) Canal below the drainage:

- ***Superpassage:** It is a structure in which the canal is taken below the drainage and flow in the canal is open channel flow. It is required when the canal FSL is below the drainage bed level.*
- ***Canal Syphon:** A canal syphon is a structure in which the canal is taken below the drainage and flow in the canal is pipe flow (i.e. under pressure). It is constructed when the canal FSL is above the drainage bed level.*

c) Canal at the same level as drainage:

- ***Level crossing:** A level crossing is provided when the canal and the drainage are practically at the same level. In this case, the drainage water is admitted into the canal at one bank and is taken out at the opposite bank.*
- ***Inlet and outlet:** An inlet-outlet structure is provided when the drainage and the canal are almost at the same level, and the discharge in the drainage is small. The drainage water is admitted into the canal at a suitable site and the excess water is discharged out through an outlet provided on the canal at some distance downstream of the junction.*

2. Regulatory structures: *Different types of structures are constructed on the canal in order to regulate and control the discharge, velocity, etc. in the canal. These structures are called Regulatory structures. These include:*

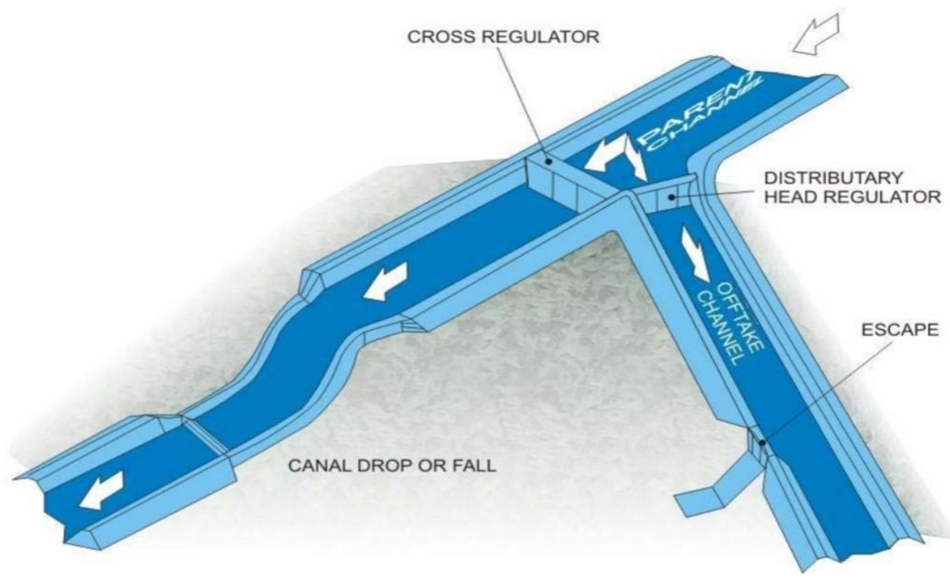

Figure 3 Canal structures for flow regulation and control

a) Distributary head regulator*: It is provided at the head of each distributary and branch canal. It controls the entry of water into the offtaking channels.*

b) Cross Regulator: *It is provided on the parent channel just downstream of the offtake point of the offtaking channel to raise water level in the parent channel, so that the full supply can be taken into the offtaking channel even when the parent channel is running partly full. Canal regulators are also provided on the downstream of the canal escape and various other locations.*

c) Canal falls: *When the slope of the natural ground is much steeper than the slope of the canal, a sudden drop in the channel bed is provided. This sudden drop is known as the canal fall. The location of the fall has to be decided judiciously such that there should be a balance between the quantities of excavation and filling.*

d) Canal escapes: *These are the structures which are designed to remove the water from the canal when excess rainfall occurs or when breaches occur in the canal downstream. They are a sort of safety valves in the canal system to remove the excess water or to empty the canal at the times of emergency or for repair works.*

Channel alignment

The alignment is the feasible path or route from a source location to the desired destination. A canal has to be aligned in such a way that it covers the entire area proposed to be irrigated with the *shortest possible length, and at the same time, its cost including the cost of cross drainage works is minimum. While aligning a canal, following points should be considered:*

1. A canal should be aligned on a watershed (or ridge) as far as possible because it ensures irrigation on both sides of the canal and it avoids cross drainage works.

2. Attempts should be made such that the main canal mounts the ridge in as small length as possible from the point of offtake.

3. The canal should run straight even when the watershed makes a sharp loop.

4. The alignment should be such that the number of cross drainage works is minimum.

5. The length of the canal should be as small as possible. The smaller the canal, the less are the absorption and seepage losses and the lower is the maintenance cost.

6. The canal alignment should avoid inhabitated areas, religious places, valuable property and other important monuments.

7. As far as possible, the canal should run through the heart of the commanded area to keep the cost of distribution system to a minimum.

8. As far as possible, curves in the canals should be avoided.

9. The canal should avoid sandy or alkaline or waterlogged areas and also the soil should not be hard to excavate.

10. The canal should be aligned such that its crossings with the road, railway lines and drainages are at right angles.

11. The canal should have a balanced depth of cutting as far as possible so that the soil excavated from the cutting is used for filling. This ensures the minimum cost of earthwork.

12. The canal should not be in heavy cutting as it would be uneconomical and the flow irrigation would not be possible.

Some Basic definitions

- ***Time factor:*** *Time factor is the ratio of the number of days the canal actually runs during a watering period to the total number of days of the watering period.*

  For example, if a canal runs for 7 days out of 14 days of watering period, the time factor is 7/14.

- ***Capacity factor:*** *The ratio of the mean discharge of a canal during a certain period to the maximum discharge is defined as the capacity factor. Thus*

  Capacity Factor = $\frac{Mean\ Discharge}{Max.\ Disharge}$

- ***Outlet Discharge Factor (O.D.F.)****: The outlet discharge factor is the duty of water of a crop at the outlet of the canal.*
- ***Nominal Duty:*** *Nominal duty is the ratio of the authorized area to be irrigated (for which the permit is granted by the govt.) to the mean supply discharge for the base period.*
- ***Full Supply Coefficient:*** *The full supply coefficient (also called duty on capacity) is the ratio of the area to be irrigated during the base period to the design full supply discharge at the head of the canal.*

$$\text{Full Supply Coefficient} = \frac{Area\ to\ be\ irrigated}{Design\ full\ supply\ discharge\ at\ the\ canal\ head}$$

- ***Crop Ratio:*** *Crop ratio is the ratio of areas under different crops to be irrigated during a year. 1t is usually expressed as the ratio of Rabi crops area to the Kharif crops area. The crop ratio is usually selected such that the discharge required is approximately the same in both crops. Because the water requirements for Kharif crops are approximately twice those for Rabi crops, the Rabi crop area is kept about twice the Kharif crop area. In other words, the crop ratio is about 2.*
- ***Overlap Allowance:*** *The extra discharge required for a crop when it overlaps the other crop period is known as the overlap allowance. There is an extra demand of water during the overlapping period of the two crops, and, therefore, the canal discharge has to be correspondingly increased*.

For example, if a Rabi crop extends to the hot weather period, it would require overlap allowance, and the canal for the hot weather season will have to be designed for the water required for the hot weather crops plus the overlap allowance of the Rabi crop. Overlap allowance is usually taken as 5 to 10 per cent of discharge.

- ***Kor Period :*** *The kor period is the critical growth period of a crop during which the water demand is a maximum. For most crops, the Kor period varies between 2 and 4 weeks .*
- ***Kor Watering:*** *The watering done during the kor period is called Kor watering. The kor watering is usually the second watering from the sowing of the crop.*
- ***Paleo****: Paleo is the watering applied to the land prior to the sowing of a crop. Paleo is required if the soil is dry. It adds sufficient water to unsaturated soil for the initial growth of the crop.*
- ***Capacity of Canal:*** *The capacity of canal is equal to the full supply discharge of the canal.*
- ***Frequency of irrigation:*** *Frequency of irrigation is the number of waterings applied to a crop throughout the base period.*
- ***Water Allowance:*** *Water allowance is defined as the authorized discharge in cumecs per thousand hectares of the culturable commanded area.*

Methods for determination of quantity of water required:

The following methods are commonly used for the determination of the quantity of water required for a given culturable commanded area, the cropping pattern and the water requirements of different crops.

- *Inductive methods*
- *Critical growth period method*
- *Consumptive use method.*

1. *Inductive methods*: *Inductive methods are based on the experience and judgment of the irrigation engineer. Generally, standard tables of duties of different crops prepared on broad zonal basis are used for the determination of the quantity of water required. However, these methods are empirical, as they do not take into account the physical and chemical properties of soils and the climatic conditions. Different inductive methods are prevalent in various states. Broadly speaking, these methods can be subdivided into 3 types:*

1. Water allowance method

2. Outlet discharge factor method

3. Standard duties method.

- ***Water allowance method:*** *In this method, a suitable water allowance is fixed for the entire culturable commanded area after considering the percentage of the cropped area under different crops and their water requirements.*

For example, for the Nangal Hydel Channels, the following values of water allowance were adopted:

(a) Perennial areas: 0.168 cumecs per 1000 hectares of CCA.

(b) Non- Perennial areas: 0.213 cumecs per 1000 hectares of CCA.

For preparing irrigation projects, sometimes the discharge at the head of the canal is estimated from the duty at the head. The following are the typical values for North India: Sugarcane and Rice = 600 ha/cumec, Rabi = 1800 ha/cumec and Kharif = 1200 ha/cumec.

- ***Outlet discharge factor method:*** *The Outlet discharge factor is the duty of water at the outlet. The Outlet discharge factors have been standardized by various agencies for different types of crops. Knowing the irrigated area and the outlet discharge factor, the discharges required in the Kharif and Rabi seasons are calculated, and the channel is designed for the greater of the two discharges.*

- ***Standard duties method:*** *In this method, the discharge required month-wise is calculated from the standard duties of various crops and the areas irrigated. The channel is then designed for the maximum of discharge in any month.*

2. Critical growth period method: Crops at their different stages of the growth require different quantities of water. It has been found that the water requirements of a crop are usually the maximum during the flowering stage. This critical growth period is known as Kor period. The crop requires a certain depth of water for its growth during the kor period. This depth of water is Known as the Kor depth. The watering done during the kor period is called the kor watering. It is the maximum single watering. If the crops are not given a suitable kor watering during the kor period, the growth and yield are considerably decreased.

$$\text{Outlet discharge factor (O.D.F)} = \frac{864 \times Kor\ period}{Kor\ depth}$$

In the critical growth period method, the channel is designed for the maximum discharge computed from the outlet discharge factor (O.D.F) based on the Kor period. Thus

$$\text{Outlet discharge} = \frac{Area\ to\ be\ irrigated}{Outlet\ discharge\ \ factor}$$

3. Consumptive use method: The consumptive use of water for different crops depends mainly on the meteorological factors. Therefore, the water requirements for various crops depend on the length of the growth period and the seasonal changes. The nature and type of soil affects only the frequency and depth of irrigation. A shallow soil requires more frequent irrigation as compared to a deep soil. However, the total amount of water required for a crop remains practically the same if the meteorological conditions remain the same. The field irrigation requirements (FIR) are determined from the consumptive use and application efficiency.

For each month, the discharge required for different crops is found from the monthly consumptive use and the irrigated area from the relation,

$$\text{Discharge} = \frac{Area\ to\ be\ irrigated}{8.64\ B/\Delta}$$

where B is equal to 30 days and & Δ is the field irrigation requirement of the crop in that month.

The total discharge required for the month is obtained by adding up the discharges required for different crops. The channel is designed for the maximum of monthly discharges, after making a suitable allowance for the conveyance efficiency.

Channel losses

Water enters the main canal at the headworks through the head regulator and flows through the branches, distributaries and the water courses and finally reaches the field. Throughout its journey, there are continuous water losses which have to be accounted for the design of channels. These losses are considerable, especially in unlined canals. The losses in irrigation in irrigation channels are mainly of the following types:

***1. Absorption losses:** Absorption losses occur because of absorption of water by the soil surface at the canal wetted perimeter. When the water table is at a considerable depth below the canal bed, the water infiltrating the soil below the canal bed is unable to reach the ground water reservoir below the* *water table. The soil layer which is in immediate contact with the channel section is completely saturated due to the absorbed water. It forms a bulb of saturated soil below the channel. The soil layer below the saturated bulb is not fully saturated. Thus the extent of saturation goes on reducing with from the ground level. Above the water table, there is also a small zone of saturation due to capillary action. Above that zone, there is also a zone of partial saturation in which the degree of saturation decreases as the distance from the water table increases. Thus there exists a zone of unsaturation between the soil saturated by canal water and that by the capillary action from the water table. Therefore there is no chance of continued and constant flow from the canal to the groundwater reservoir.*

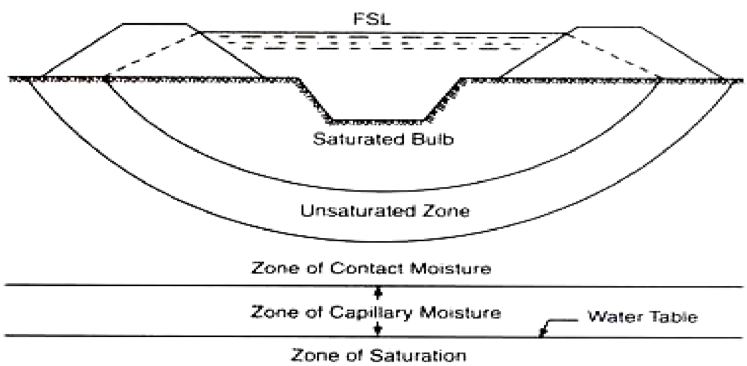

Figure 4 Absorption losses

Absorption losses are independent of the seepage head (difference of water level of the canal and the level of ground water table). These losses depend upon the water head from the water level of the canal to the bottom of the saturated zone and the capillary head for the soil at the boundary of the saturated zone. In general, Absorption losses depend upon the depth of water in the canal and the type of soil.

2. Percolation (or seepage) losses*: When the water table is close to the canal bed, Percolation (or seepage) occurs from the canal to the water table. There is a direct flow from the canal to the ground water reservoir. Almost all the water which seeps from the channel joins the ground water reservoir. The seepage losses mainly depend upon the total seepage head (difference between canal water level and water table level) and the type of soil and are independent of the depth of water in the channel. Percolation losses are generally much greater than absorption losses. They may be as high as 3 times or more of the absorption losses.*

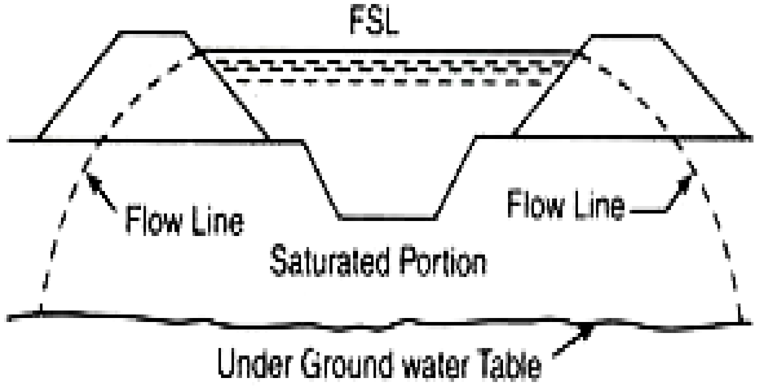

Figure 5 Percolation losses

Absorption and percolation losses from the canal mainly depend upon the following factors:

- ✓ ***Permeability of soil:*** *Greater is the Permeability of soil in the bed and banks of the cannel, greater are the losses.*
- ✓ ***Depth of water:*** *Greater is the depth of water in the canal, greater is the losses.*
- ✓ ***Velocity of water:*** *The losses decrease with an increase in the velocity of flow in the channel.*
- ✓ ***Amount of silt:*** *The losses decrease with an increase in the amount of silt carried by the canal water.*
- ✓ ***Temperature of water:*** *The losses increase with an increase in temperature of water because viscosity decreases and the permeability of soil is increased.*
- ✓ ***Age of the channel:*** *The losses are large in newly constructed channels and they reduce as silt gets deposited with the passage of time and a relatively impervious silt layer is formed.*
- ✓ ***Level of the channel bed:*** *The losses are more when the canal is in heavy filling than when in cutting.*
- ✓ ***Position of the water table:*** *The losses depend upon the Position of the water table with respect to the canal bed. The losses are more when the water table is high.*

3. Evaporation losses*: As canal water is exposed to the atmosphere at the surface, loss due to evaporation is obvious. Evaporation losses depend upon the water surface area of the canal, relative humidity, wind velocity, temperature and various other factors. Generally, evaporation losses are less than 1% of the total water entering the canal head.*

4. Transpiration losses*: Transpiration losses occur through the vegetation and weeds in the canal. These losses are usually a small percentage of the total losses in an unlined channel. These losses can be considerably decreased by keeping the canal banks free of vegetation.*

Estimation of channel losses

The transmission losses are usually estimated based on experimental data obtained from the existing channels. Some useful methods for measuring channel losses are:

1. Inflow and Outflow method: *The losses in the channel can be measured by a simple method, known as Inflow and Outflow method. A long reach of the channel is selected for the experimental study. Discharge measurements are made at the beginning and the end of the reach. The outlets or offtaking channels within the reach should be completely closed during the observation period. The difference between the discharge entering and that leaving the reach is equal to the total loss occurring in the reach.*

2. Permeameters and Seepage meters: *Permeameters measure permeability of a canal bed or lining. The depth of water in permeameter should be approximately equal to the normal depth of water in the canal.*

Seepage meter consists of a metal cylinder which is dome shaped at the top. A valve is fixed on the dome to remove the entrapped air and a plastic bag is attached to the cylinder which is filled with water. The whole meter remains below the water surface and the seepage occurs which causes a corresponding reduction in the water content of the plastic bag. The rate of reduction in the water content gives the seepage rate. However, the area under the test is very small and hence several readings are to be taken in order to get reliable results.

3. Ponding method: *This method gives isolation of a section of a canal by means of a temporary cross bunds. The enclosed area is filled with water and the decrease in the volume over a certain period of time is noted. Then rate of loss is calculated. Proper allowance is made for rainfall.*

Empirical formulae:

Unlined canals

- *In U.P. the following empirical formula is used for the determination of canal losses:*

$$\Delta Q = \frac{1}{200}(B+D)^{2/3}$$

Where ΔQ *is total loss in cumecs per km length of channel*
B is bed width of the channel (m)
D is the depth of water (m)

- *In Punjab, the following empirical formula is used.*

$$K = 1.6\, Q^{0.0625}$$

Where *K is the total loss in cumecs per million square metre of wetted perimeter*
Q is the discharge in cumecs.

- *According to Central Water Commission, the transmission losses are given as:*

S.No.	*Channel surface*	*Transmission losses*

		(cumecs/Mm^2)
1	Rock	0.91
2	Black cotton soil	1.83
3	Alluvial soil	2.74
4	Decayed rock, gravel	3.00

Lined canals

- *In Punjab, following formula is used to determine total losses in cumecs per Mm^2 of wetted perimeter of the lined canal.*
  $K = 0.349Q^{0.056}$

Where Q is the discharge in cumecs.

- *As per the recommendation of CWC, the transmission losses in the lined canals are taken as 0.60 cumecs/Mm^2 of the wetted perimeter.*

Design of channels

The design discharge of an irrigation channel is fixed and depends upon the irrigated areas of crops in different seasons and the water requirements of crops. The design of the canal is mainly governed by the quantity of silt in the water and the type of boundary surface of the channel. Depending upon these factors, the irrigation channels can be broadly classified into following types:

1. Non-alluvial channels: *These are excavated in Non-alluvial soils such as loam, clay, moorum, boulder, etc. There is no silt problem in these channels and they are relatively stable.*

2. Rigid boundary channels: *In the Rigid boundary channels, the surface of the channel is lined. In such channels, relatively high velocity can be permitted which does not allow the silt to get deposited; hence, the problem of silt does not exist.*

3. Alluvial channels: *These are excavated in alluvial soils, such as silt. In such channels, the quantity of silt may vary from section to section along the reach. The silt content may increase due to scouring of bed and sides of the channel and it may decrease due to silting at some sections. If velocity is high, scouring occurs and if velocity is low, silting may occur. Such channels should be designed for a non-scouring and a non-silting velocity called the* ***critical velocity****.*

Design of Non-alluvial channels

*Non-alluvial channels are considered stable as there is no silt problem in such channels. These channels are usually designed on the basis of the **maximum permissible velocity** which the channel boundary surface can resist without scouring.*

The side slopes of the channel excavated in clay are generally kept 1:1 in cutting and 1.5:1 in filling. For the channels in grit, soft rock and hard rock, the safe side slopes are usually taken as 0.5:1, 0.25:1 and 0.125:1 respectively. In hard rock, the sides may even be kept vertical.

The design of non- alluvial channels is done by Chezy's equation or Manning's formula:

- ***Chezy's equation***

$$V = C\sqrt{RS}$$

where *C is Chezy's coefficient, given by*

$$C = \frac{87}{1+\frac{K}{\sqrt{R}}}$$

where *K is Bazin's coefficient, which depends upon the surface of the channel.*

R is hydraulic radius

S is longitudinal slope.

- ***Manning's formula***

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

where *N is Manning's coefficient and depends upon the type of surface.*

Procedure for design: *The following procedure is used for the design of a non- alluvial channel by Manning's formula. Similar procedure can be used for the design by Chezy's equation.*

Given: Discharge (Q), maximum permissible velocity (V), Manning's N, Bed slope (S) and the side slope (r: 1) are given.

Steps: 1. Determine the area of cross-section from the continuity equation.

$$Q = AV \text{ or } A = Q/V$$

2. Determine the hydraulic radius R from the manning's formula.

$$V = \frac{1}{N}R^{2/3}S^{1/2} \quad \text{or } R = \left(\frac{VN}{S^{1/2}}\right)^{3/2}$$

3. Determine the wetted perimeter from the relation, $P = A/R$

4. Determine the depth D and bed width B from the values of A and P by solving the equations given below.

$$(B + r\,D)\,D = A$$

$$B + \left(2\sqrt{1+r^2}\right) D = P$$

Example 1: Design an irrigation channel in a non-erodible material to carry a discharge of 15 cumecs when the maximum permissible velocity is 0.8 m/s. Assume bed slope = 1 in 4000, side slope = 1:1 and Manning's N = 0.025.

Solution: $A = Q/V = 15/0.8 = 18.75\ m^2$

$$R = \left(\frac{VN}{S^{1/2}}\right)^{3/2} = \left(\frac{0.8\times 0.025}{(\frac{1}{4000})^{1/2}}\right)^{3/2} = 1.42\ m$$

$P = A/R = 18.75/1.42 = 13.20\ m$

Now $(B + D)\,D = 18.75$ *and* $B + \left(2\sqrt{1+1^2}\right) D = 13.20$

Or $B + 2.828\,D = 13.20$

Solving these equations, ***D = 1.95 m and B = 7.69 m***

Example 2: An earthen canal has to irrigate 24,000 ha of Rabi (wheat). If duty at head is 400 ha/cumec, determine the dimensions and the bed slope of the canal by Manning's formula. Assume (B/D) ratio as 6, N = 0.025, side slope = 1.5: 1 and permissible velocity of 0.80 m/s.

Solution: *Discharge required at head = 24000/40 = 60 cumecs*

Area of flow = $Q/V = 60/0.80 = 75\ m^2$

Now $(B + 1.5\,D)\,D = 75$

Or $(6D + 1.5\,D)\,D = 75$ *or* ***D = 3.16 m, B = 18.96 m***

$P = B + \left(2\sqrt{1+r^2}\right) D = 18.96 + \left(2\sqrt{1+1.5^2}\right) \times 3.16 = 30.37\ m$

$R = A/P = 75/30.37 = 2.47\ m$

Now $V = \frac{1}{N} R^{2/3} S^{1/2}$ *or* $0.8 = \frac{1}{0.025} 2.47^{2/3} S^{1/2}$

S = 1 in 8347

Design of Lined canals

A lined canal is rigid boundary channel. It can withstand much higher velocity as compared to an unlined, non-alluvial channel or alluvial channel. The design is similar to the design of non-alluvial channels. However, the maximum permissible velocity is relatively high.

Cross-section of lined canals: *From the practical considerations, a channel of trapezoidal section or triangular section is usually selected. The corners of these sections are rounded to increase the hydraulic radius.*

- *Triangular section: It is adopted when the discharge in the channel is less than 85 cumecs. The radius of the bottom is equal to the depth of water (D). The angle subtended at the centre is equal to 2θ where θ is the angle which the sides make with the horizontal.*

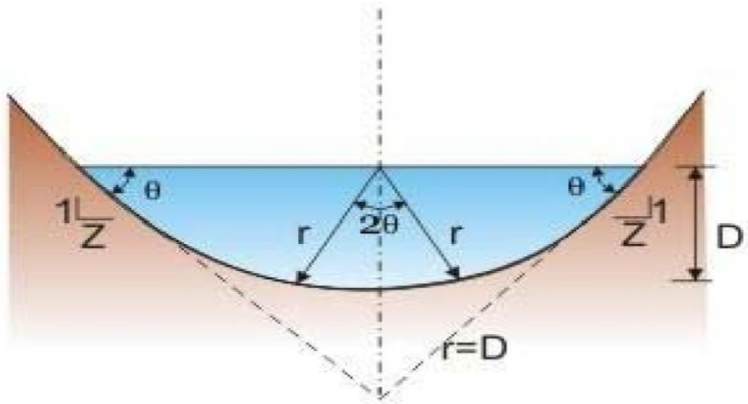

Figure 6 Triangular section of a canal

The geometrical properties of the section are as follows:

$$A = (\pi D^2)\,(2\theta/2\pi) + 2\left(\tfrac{1}{2}D^2 cot\theta\right)$$

Or $\quad A = D^2(\theta + \cot\theta)$

Also $\quad P = 2\pi D\,(2\theta/2\pi) + 2D\,cot\theta$

Or $\quad P = 2D\,(\theta + \cot\theta)$

For side slopes of 1: 1 $(\theta = 45° = \pi/4)$, $\quad A = 1.785\,D^2$ *and* $\quad P = 3.570\,D$

- *Trapezoidal section: For the lined channels with a discharge greater than 85 cumecs, a trapezoidal section is adopted. The radius of the corners is equal to the depth of water (D). The angle subtended at the water surface by the corner is equal to θ.*

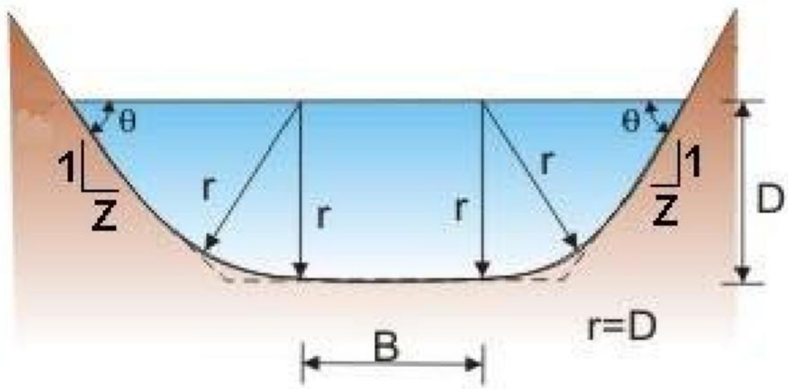

Figure 7 Trapezoidal section of a canal

The geometrical properties of the section are as follows:

$$A = BD + (\pi D^2)\,(2\theta/2\pi) + 2\left(\frac{1}{2}D^2 cot\theta\right)$$

Or $A = BD + D^2(\theta + \cot\theta)$

Also $P = B + 2D\,(\theta + \cot\theta)$

For side slopes of 1: 1 ($\theta = 45° = \pi/4$), $A = BD + 1.785\,D^2$ *and* $P = B + 3.570\,D$

Design procedure for a trapezoidal lined channel:

Given: *The following data should be collected or assumed.*

- ✓ *Bed slope (S)*
- ✓ *Side slope or the angle* θ
- ✓ *Rugosity coefficient N*
- ✓ *Limiting velocity V.*

Steps:

- *Determine the area of flow,* $A = Q/V$
- *Determine the hydraulic radius,* $R = \left(\frac{VN}{S^{1/2}}\right)^{3/2}$
- *Determine the wetted perimeter,* $P = A/R$.
- *Determine the values of B and D from the computed values of A and P by utilizing the geometries given above for the section.*

Alternative method: *If instead of the limiting velocity V. the B/D ratio is given, the following procedure is used. Let B/D = x.*

Steps:

- *Determine*

$$V = \frac{Q}{A} = \frac{Q}{BD + D^2(\theta + \cot\theta)}$$

Or
$$V = \frac{Q}{D^2\left[\frac{B}{D} + (\theta + \cot\theta)\right]} = \frac{Q}{D^2[x + (\theta + \cot\theta)]}$$

- *Determine the hydraulic radius.*

$$R = \frac{A}{P} = \frac{BD + D^2(\theta + \cot\theta)}{B + 2D(\theta + \cot\theta)}$$

Or
$$R = \frac{D^2[B/D + (\theta + \cot\theta)]}{D[B/D + 2(\theta + \cot\theta)]}$$

Or
$$R = \frac{D^2[x + (\theta + \cot\theta)]}{D[x + 2(\theta + \cot\theta)]}$$

- *Write down Manning's formula as:*

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

$$\frac{Q}{D^2[x + (\theta + \cot\theta)]} = \frac{1}{N}\left[\frac{D^2[x + (\theta + \cot\theta)]}{D[x + 2(\theta + \cot\theta)]}\right]^{2/3} S^{1/2}$$

Determine D from above equation.

- *B = xD.*

Example3. Design a lined channel to carry a discharge of 50 cumecs. Assume bed slope as 1 in 8100, N as 0 015 and side slope as 45⁰.
Solution*. Let us adopt a triangular section.*

For $\theta = \frac{\pi}{4}$, *A= 1.785* D^2 *and* *P = 3.570 D*
From Manning's formula

$$V = \frac{1}{N} R^{2/3} S^{1/2} \text{ or } Q = AV = \frac{A}{N} R^{2/3} S^{1/2}$$

Or
$$50 = \frac{1.785\, D^2}{0.015}\left(\frac{1.785\, D^2}{3.570\, D}\right)^{2/3}\left(\frac{1}{8100}\right)^{1/2}$$

Solving, **$D = 4.64$ m.**

Example 4. Design a lined channel to carry a discharge of 120 cumecs. The velocity of flow may be taken as 2 m/s. Take side slope as 1: 1. Assume N as 0 018 bed slope as 1 in 3000.

Solution: $A = 120/2 = 60\ m^2$

$$R = \left(\frac{VN}{S^{1/2}}\right)^{3/2} = \left(\frac{2\times0.018}{(\frac{1}{3000})^{1/2}}\right)^{3/2} = 2.77\ m$$

$P = 60/2.77 = 21.66\ m$

Now $BD + D^2(\pi/4 + \cot 45°) = A$

$BD + 1.785\ D^2 = 60$

Now $B + 2D\ (\pi/4 + 1) = P = 21.66$

$B + 3.57\ D = 21.66$

Solving above two equations, we get **$D = 4.28$ m** *and* **$B = 6.38$ m.**

Assignment:1. Design the most efficient cross-section of a lined trapezoidal canal to carry a discharge of 15 cumecs when the maximum permissible velocity is 2 m/s. Assume the side slope as 1: 1. Also, determine the bed slope for the canal if the Chezy's coefficient C is 60.

Design of Alluvial channels

ln the case of alluvial channels, the channel surface consists of alluvial soil which can be easily scoured. Moreover, the velocity is low which encourages silting. Therefore, in an alluvial channel, scouring and silting may occur if the channel is not properly designed. The quantity of silt transported by water in an alluvial channel varies from section to section due to scouring of bed and sides as well as due to Silting (or deposition). If the velocity is too high, scouring may occur. On the other hand, if the velocity is too low, silting may occur.

The command of an irrigation channel decreases if the scouring occurs because the fall supply level falls. The discharge capacity is decreased if the silting occurs because the cross-section is reduced. Therefore the alluvial channel should be designed such that neither scouring nor silting occurs. The velocity at which this condition occurs is called the critical velocity. Such an alluvial channel is called a stable channel. Therefore, a stable channel is one in which banks and bed are not scoured and also in which no silting occurs. Even if there is some minor scouring and silting, the bed and banks of a stable channel remain more or less unaltered over a long period of time.

Several investigators have studied the problem and suggested various theories. These are known as Silt theories. The most commonly used theories are:

1. Kennedy's silt theory ***2. Lacey's silt theory***.

Kennedy's silt theory

R.G Kennedy, an executive engineer of Punjab PWD, carried out extensive investigations on some of the canal reaches in the Upper Bari Doab canal system. He selected some straight reaches of the canal section which had not posed any silting and scouring problems during the previous 30 years. He considered the canal in those reaches as stable. Kennedy gave his theory, in 1895, based on the investigations carried out on those reaches of the canal.

From the observations he concluded that the silt supporting power in a channel cross-section was mainly dependent upon the generation of the eddies rising to the surface. These eddies are generated due to the friction of the flowing water with the channel surface. The vertical component of these eddies try to move the sediment up while weight of the sediment tries to bring it down. So if the velocity is sufficient to generate eddies so as to keep the sediment just in suspension, silting will be avoided based on the concept critical velocity. Eddies generated at the sides were neglected by Kennedy because such eddies are horizontal for the greater part and therefore have very little silt supporting power. Therefore, the eddies generated only at the bed of the channel are effective for transportation of the silt. Thus, the silt supporting power is proportional to the bed width (and not the wetted perimeter). Kennedy therefore, selected the relevant parameter as the depth of flow D (and not the hydraulic radius R) for the critical velocity.

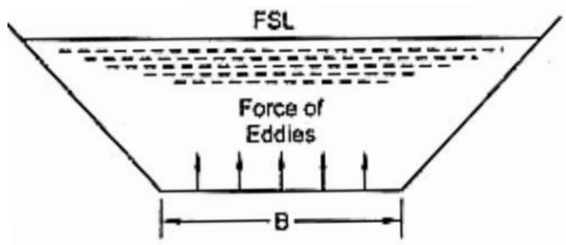

Figure 8 Generation of eddies (according to Kennedy)

According to Kennedy, the critical velocity V_c in a channel may be defined as the mean velocity of flow which will just keep the channel free from silting or scouring.

He gave his equation as: $V_0 = 0.55\ D^{0.64}$

Later he recognized that the grade (or size) of silt played an important role in the silt-carrying capacity of the channel and introduced another factor, called the critical velocity ratio (m). the equation was thus modified as:

$$V = 0.55\ m\ D^{0.64}$$

m = critical velocity ratio = 1.1 to 1.2 for coarse sand

= 0.8 to 0.9 for fine sand

Kennedy's method of design: Kennedy used 3 basic equations, namely:

1. Continuity equation: $Q = A\,V$

2. Flow equation (Kutter's equation):

$$V = \left[\frac{\frac{1}{N} + \left(23 + \frac{0.00155}{S}\right)}{1 + \left(23 + \frac{0.00155}{S}\right)\frac{N}{\sqrt{R}}}\right]\sqrt{RS}$$

3. Kennedy's critical velocity equation: $V = 0.55\,m\,D^{0.64}$

Generally, discharge Q, Manning's coefficient N and the C.V.R (m) are given or assumed. Still there are 4 unknowns, namely A, V, R and S. Since there are only 3 equations and 4 unknowns, the complete solution is not possible. To obtain the complete solution, either bed slope or B/D ratio is assumed.

Design Procedure:

1. When the bed slope is given:

Given: *Q, m, N and S.*

Steps:

- *Assume a trial value of the depth D.*
- *Calculate the velocity V using* $V = 0.55\,m\,D^{0.64}$
- *Determine the cross sectional area,* $A = Q/V$
- *Assuming a side slope of 0.5: 1, compute the bed width.*

  $A = BD + 0.5\,D^2$ *or* $B = \dfrac{A - 0.5D^2}{D}$
- *Compute the wetted perimeter for the assumed depth and computed bed width.*

  $P = B + D\sqrt{5}$
- *Compute the hydraulic radius from the relation*

  $$R = \frac{A}{P} = \frac{BD + 0.5\,D^2}{B + D\sqrt{5}}$$
- *Calculate the actual mean velocity V from Kutter's equation*

$$V = \left[\frac{\frac{1}{N} + \left(23 + \frac{0.00155}{S}\right)}{1 + \left(23 + \frac{0.00155}{S}\right)\frac{N}{\sqrt{R}}}\right]\sqrt{RS}$$

If the velocity computed now is same as found by Kennedy's method, the design depth is correct. Otherwise, repeat the above steps by assuming different depth of flow. If the Velocity from Kennedy's equation is less than that from Kutter's equation, a greater value of D is assumed for the next trial and vice versa.

2. Design procedure when B/D is given:

Given: *Q, m, N and B/D.*

Steps:

- *Calculate the area in terms of D.*

$A = BD + 0.5\,D^2 = D^2\,(B/D + 0.5)$

or $A = D^2\,(x + 0.5)$

- *Write the continuity equation and substitute Kennedy's equation for the velocity.*

$$Q = AV = D^2\,(x + 0.5)\ 0.55\ m\ D^{0.64}$$

- *Calculate the value of D from above equation.*
- *Determine the bed width.* $B = x\,D$
- *Compute the hydraulic radius.*

$$R = \frac{BD + 0.5\,D^2}{B + D\sqrt{5}}$$

- *Determine the velocity V from the relation*

$$V = 0.55\ m\ D^{0.64}$$

- *Compute the slope from Kutter's equation. (for the first trial, the term 0.00155/S may be neglected).*

Example 5. Design an irrigation channel by Kennedy's theory to carry a discharge of 5 cumecs. Take m = 1.0, N = 0.0225 and B/D = 4.4.

Solution: $A = D^2\,(B/D + 0.5) = D^2\,(4.4 + 0.5) = 4.9\,D^2$

$Q = AV = 4.9\,D^2\,(0.55 \times 1.0 \times D^{0.64})$ or $5.0 = 2.695\,D^{2.64}$

We get $\mathbf{D = 1.26\ m}$

$B = 1.26 \times 4.4 = \mathbf{5.54\ m}$

$$R = \frac{BD + 0.5\,D^2}{B + D\sqrt{5}} = \frac{5.54 \times 1.26 + 0.5\,(1.26)^2}{5.54 + 1.26\sqrt{5}} = 0.93\ m$$

$V = 0.55 \times 1.0 \times (1.26)^{0.64} = 0.64\ m/s$

Neglecting the term 0.00155/S,

$$0.64 = \left[\frac{\frac{1}{0.0225} + 23}{1 + (23)\frac{0.0225}{\sqrt{0.93}}}\right]\sqrt{0.93 \times S}$$

Hence, $\mathbf{S = 0.0002288}$

Example 6: Design an irrigation channel by Kennedy's theory to carry a discharge of 15 cumecs. Take m = 1.0, N = 0.0225 and S = 1 in 5000.

Solution: *Assume a depth of 1.74 m.*

$$V = 0.55\, m\, D^{0.64} = 0.55 \times 1 \times (1.74)^{0.64} = 0.78\ m/s$$

$$A = Q/V = 15/\,0.78 = 19.13\ m^2$$

$$BD + 0.5\,D^2 = 19.13$$

$$B = \frac{19.13 - 0.5 \times (1.74)^2}{1.74} = 10.12\ m$$

Now $P = B + D\sqrt{5} = 10.12 + 1.74\sqrt{5} = 14.01\ m$

$$R = A/P = 19.13/14.01 = 1.37\ m$$

$$V = \left[\frac{\frac{1}{N} + \left(23 + \frac{0.00155}{S}\right)}{1 + \left(23 + \frac{0.00155}{S}\right)\frac{N}{\sqrt{R}}}\right]\sqrt{RS} \quad or \quad V = \left[\frac{\frac{1}{0.0225} + \left(23 + \frac{0.00155}{0.0002}\right)}{1 + \left(23 + \frac{0.00155}{0.0002}\right)\frac{0.0225}{\sqrt{1.37}}}\right]\sqrt{1.37 \times 0.0002}$$

Or *V = 0.782 m/s which is same as above.*

Hence, ***D = 1.74m, B = 10.12m.***

Assignment: 1.Design an irrigation channel to carry 50 cumec of discharge. The channel is to be laid at a slope of 1 in 4000. The C.V. R for the soil is 1.1. use Kutter's rugosity coefficient as 0.023.

2. Design an irrigation channel to carry 40 cumec of discharge, with B/D ratio as 2.5. The C.V.R is 1.0. Assume a suitable value of Kutter's rugosity coefficient and use Kennedy's method.

Drawbacks of Kennedy's theory:

i) In the absence of B/D relation the Kennedy theory do not provide easy basis for fixing channel dimensions uniquely.

ii) Perfect definitions of silt grade and silt charge are not given.

ii) Complex phenomenon of silt transportation is not fully accounted and only critical velocity ratio (m) concept is considered sufficient.

iv)There is no provision to decide longitudinal slope under the scope of the theory.

v) By use of Kutter's formula inherent limitations therein remain applicable in Kennedy's channel design procedure.

Lacey's Regime theory

Lacey, an eminent engineer of U.P irrigation department carried out extensive investigations on the design of stable channel in alluviums. On the basis of his research work he found many drawbacks in Kennedy's theory and he put forward his new theory .He differentiated between three regime conditions:

1. True regime *2.initial regime* *3.final regime*

Three regimes – true, initial and final:

True regime: *A channel will be in true regime if these conditions are satisfied:*

1. Discharge is constant
2. Flow is uniform
3. Silt charge is constant
4. Silt grade is constant

Initial regime: *It is the first stage of regime attained by an artificial channel. The channel when excavated has somewhat a smaller width and a flatter slope. As the channel comes in operation and flow takes place, the bed slope of the channel is increased due to deposition of silt on the bed of the channel when the channel throws down its incoherent silt on the bed. It increases the velocity of flow in the channel which allows the given discharge to flow through the channel of the smaller width. With an increase of bed slope, the depth of channel may also change. However, the width of the channel does not change because the sides of the channel are usually cohesive and they resist erosion. If the soil in banks is clay, the sides may resist erosion almost indefinitely.*

The channel in an alluvial soil achieves equilibrium, called the initial regime after running for some time. This is achieved by change in bed slope and depth when discharge, silt grade, silt charge and width remain constant. However, this stability is only temporary because the width of the channel has so far not been adjusted to suit the requirement of a regime channel.

Final regime: *It is the ultimate regime attained by an alluvial channel when in addition to bed slope and depth, the width of the channel has also been adjusted. After a long time, because of continuous action of water, the resistance of the sides of the channel is overcome and finally gets adjusted according to discharge and silt grade, then the channel is said to have permanent stability called final regime.*

Lacey's Basic regime equations:

Lacey found that the silt is kept in suspension by the vertical component of eddies, but he also considered the eddies generated at the sides of the channel which have vertical components and hence support the silt. Lacey, therefore, considered the hydraulic radius R as the characteristic parameter rather than the depth of flow D considered by Kennedy.

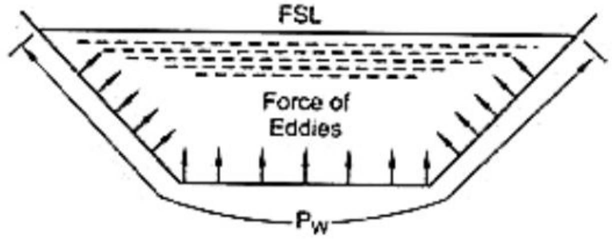

Figure 9 Generation of eddies (according to Lacey)

Lacey's fundamental equations:

Lacey gave four basic equations:

1. Silt factor: *This is similar to C.V.R (m) as introduced by Kennedy. The silt factor was related to the average particle size of the silt. The silt factor depends upon the average size of the channel boundary material and its density. Since the specific gravity of all the transported material is same (about 2.65), the difference in density is ignored, hence the silt factor is related only to the particle size. Lacey gave the following equation for silt factor:*

$$f = 1.76\sqrt{m}$$

m is the average particle size in mm.

2. Relation between mean velocity (V) and hydraulic radius (R):

$$V = \sqrt{\frac{2}{5} f R}$$

3. Relation between cross-sectional area (A) and mean velocity (V):

$$Af^2 = 140\, V^5$$

4. Flow equation: $V = 10.8\, R^{2/3}\, S^{1/3}$

Lacey's derived equations:

Following equations are derived from the Lacey's basic or fundamental equations as:

1. Velocity equation: $Af^2 = 140\, V^5$

Multiplying both sides by V: $(AV)f^2 = 140\, V^6$

$$Qf^2 = 140\, V^6$$

Or $V = (Qf^2/140)^{1/6}$

2. Wetted perimeter equation:

$$V = \sqrt{\frac{2}{5} fR} \qquad or \qquad V^4 = \frac{4}{25} f^2 R^2$$

Also $\qquad Af^2 = 140\, V^5 \qquad or \qquad f^2 = 140 \frac{V^5}{A}$

Eliminating f^2 *from above equations:* $V^4 = \frac{4}{25}\left(140 \frac{V^5}{A}\right) R^2$

Or $\qquad \frac{25}{4}\left(\frac{AV}{R^2}\right) = 140\, V^2$

Writing R = A/P, we have $\frac{25}{4}\left(\frac{Q}{A^2/P^2}\right) = 140\, V^2$ *or* $P^2 Q = \left(\frac{140 \times 4}{25}\right) V^2 A^2$ *or* $P^2 Q = \left(\frac{140 \times 4}{25}\right) Q^2$

Solving: $P = 4.75\sqrt{Q}$

3. Hydraulic radius equation: $V = \sqrt{\frac{2}{5} fR}$ *or* $R = \frac{5}{2}\frac{V^2}{f}$

Also $\qquad V^2 = (Qf^2/140)^{1/3}$

Solving these, $\qquad R = \frac{5}{2}\frac{(Qf^2/140)^{1/3^2}}{f}$

Or $\qquad R = 0.481\, (Q/f)^{1/3}$

Generally, this constant is taken as 0.47. Therefore, $\qquad R = 0.47\, (Q/f)^{1/3}$

4. Slope equation: $\qquad V = 10.8\, R^{2/3}\, S^{1/3}$

$$Or\ V^3 = 1260\, R^2 S$$

Also $\qquad V^3 = \left(\frac{2}{5}\right)^{3/2} f^{3/2} R^{3/2}$

Therefore, $\qquad 1260\, R^2 S = \left(\frac{2}{5}\right)^{\frac{3}{2}} f^{\frac{3}{2}} R^{\frac{3}{2}}$ *or* $S = \frac{f^{3/2}}{4980\, R^{3/2}}$ ———————*(a)*

Or $\qquad S = \frac{0.0002\, f^{3/2}}{R^{3/2}}$

Alternative equation: $\qquad V = \sqrt{\frac{2}{5} fR}$

Also $V = (Qf^2/140)^{1/6}$

$$\sqrt{\frac{2}{5}fR} = \left(\frac{Qf^2}{140}\right)^{\frac{1}{6}}$$

Or $R^{1/2} = \left(\frac{5}{2f}\right)^{1/2} (Qf^2/140)^{1/6} = \left(\frac{Q}{8.96\ f}\right)^{1/6}$

Substituting the value of $R^{\frac{1}{2}}$ *from equation* (a):

$$\frac{f^{\frac{3}{2}}}{4980\ S} = \left(\frac{Q}{8.96\ f}\right)^{\frac{1}{6}}$$

Or $S = \dfrac{0.0003\ f^{5/3}}{Q^{1/6}}$

Design of channels by lacey's equation:

Procedure:

Given: *Discharge Q and silt factor* f.

Steps:

- *Determine the velocity.* $V = (Qf^2/140)^{1/6}$
- *Calculate the area of flow.* $A = Q/V$
- *Compute the wetted perimeter.* $P = 4.75\sqrt{Q}$
- *Knowing the area of flow and wetted perimeter, determine the depth D and width B from the geometrical relations given below, using a side slope of 0.5:1.*

  $A = BD + 0.5\ D^2$ *and* $P = B + D\sqrt{5}$
- *Determine the bed slope:* $S = \dfrac{0.0003\ f^{5/3}}{Q^{1/6}}$

Example 7: The bed slope of a regime channel is 1 in 5800. Determine the channel section and discharge. The average particle size is 0.323 mm.

Solution: $f = 1.76\sqrt{m} = 1.76\sqrt{0.323} = 1.00$

$$S = \frac{0.0003\, f^{5/3}}{Q^{1/6}} \quad or \quad \frac{1}{5800} = \frac{0.0003}{Q^{1/6}}$$

Or $Q = 27.67$ *cumecs*

Now discharge and silt factor are known, the section can be designed.

$V = (Qf^2/140)^{1/6} = (27.67 \times 1/140)^{1/6} = 0.76\ m/s$

$A = Q/V = 27.67/\ 0.76 = 36.41\ m^2$

$P = 4.75\sqrt{Q} = 4.75\sqrt{27.67} = 24.99\ m$

$A = BD + 0.5\ D^2$ *and* $P = B + D\sqrt{5}$

$BD + 0.5\ D^2 = 36.41$ *and* $B + D\sqrt{5} = 24.99$

Solving, we get ***D = 1.64 m*** *and* ***B = 21.32 m.***

Comparison of Kennedy's and Lacey's theory:

Kennedy's theory	***Lacey's theory***
1. It states that the silt carried by the flowing water is kept in suspension by the vertical component of eddies which are generated from the bed of the channel.	*1. It states that the silt carried by the flowing water is kept in suspension by the vertical component of eddies which are generated from the entire wetted perimeter of the channel.*
2. Relation was given between V&D.	*2. Relation was given between V& R.*
3. Critical velocity ratio 'm' is introduced to make the equation applicable to different channels with different silt grades.	*3. Silt factor f is introduced to make the equation applicable to different channels with different silt grades.*
4. Kutter's equation is used for finding the mean velocity.	*4. This theory gives an equation for finding the mean velocity.*
5. This theory gives no equation for bed slope.	*5. This theory gives an equation for bed slope.*
6. In this theory, the design is based on trial and error method.	*6. This theory does not involve trial and error method.*

Drawbacks in Lacey's theory:

- *The concept of true regime is only theoretical and cannot be achieved practically.*
- *The various equations are derived by considering the silt factor, which is not constant at all.*
- *The concentration of silt is not taken into account.*
- *The silt grade and silt charge are not clearly defined.*
- *The equations are empirical and based on the available data from a particular type of channel.*
- *The characteristics of regime of channel may not be same for all cases.*

Canal Linings

Canal Lining is an impermeable layer provided for the bed and sides of canal to improve he life and discharge capacity of canal. Canal Linings are provided in canals to resist the flow of water through its bed and sides. 60 to 80% of water lost through seepage in an unlined canal can be saved by construction canal lining. These can be constructed using different materials such as compacted earth, cement, concrete, plastics, boulders, bricks etc. The main advantage of canal lining is to protect the water from seepage loss.

Types of Canal Linings:

Canal linings are classified into three major types based on the nature of surface and they are:

1. Earthen type lining *2. Hard surface lining* *3. Buried membrane lining*

1. Earthen Type lining

Earthen Type linings are again classified into two types and they are as follows:

- *Compacted Earth Lining*
- *Soil Cement Lining*

Compacted Earth Lining:

Compacted earth linings are preferred for the canals when the earth is available near the site of construction or In-situ. If the earth is not available near the site then it becomes costlier to construct compacted earth lining.

Figure 10 Compacted Earth Lining

Compaction reduces soil pore sizes by displacing air and water. Reduction in void size increases the density, compressive strength and shear strength of the soil and reduces permeability. This is accompanied by a reduction in volume and settlement of the surface. Proper compaction is essential to increase the stability and frost resistance (where required) and to decrease erosion and seepage losses.

Soil Cement Lining:

Soil-cement linings are constructed with mixtures of sandy soil, cement and water, which harden to a concrete-like material. The cement content should be minimum 2- 8% of the soil by volume. However, larger cement contents are also used. In general, for the construction of soil- cement linings following two methods are used.

- *Dry-mix method*
- *Plastic mix method*

Figure 11 Soil Cement lining

For erosion protection and additional strength in large channels, the layer of soil-cement is sometimes covered with coarse soil. It is recommended that the soil-cement lining should be protected from the weather for seven days by spreading approximately 50 mm of soil, straw or hessian bags over it and keeping the cover moistened to allow proper curing. Water sprinkling should continue for 28 days following installation.

Hard Surface Canal Linings:

It is sub divided into 3 types and they are:

- *Cement Concrete Lining*
- *Brick Lining*
- *Boulder Lining*

Cement Concrete Lining:

Cement Concrete linings are widely used, with benefits justifying their relatively high cost. They are tough, durable, relatively impermeable and hydraulically efficient. Concrete linings are suitable for both small and large channels and both high and low flow velocities. They fulfill every purpose of lining. There are several procedures of lining using cement concrete.

- ✓ *Cast in situ lining*
- ✓ *Shotcrete lining*
- ✓ *Precast concrete lining*
- ✓ *Cement mortar lining*

Figure 12 Cement Concrete lining

Brick Lining

In case of brick lining, bricks are laid using cement mortar on the sides and bed of the canal. After laying bricks, smooth finish is provided on the surface using cement mortar.

Figure 13 Brick lining

Boulder Lining

This type of lining is constructed with dressed stone blocks laid in mortar. Properly dressed stones are not available in nature. Irregular stone blocks are dressed and chipped off as per requirement. When roughly dressed stones are used for lining, the surface is rendered rough which may put lot of resistance to flow. Technically the coefficient of rugosity will be higher. Thus the stone lining is limited to the situation where loss of head is not an important consideration and where stones are available at moderate cost.

Figure 14 Boulder lining

3. Buried membrane linings:

It is sub divided into 3 types and they are:

- *Plastic lining*
- *Asphaltic membrane lining*
- *Road oil lining*

Plastic Lining

Plastic lining of canal is newly developed technique and holds good promise. There are three types of plastic membranes which are used for canal lining, namely:

- ✓ *Low density poly ethylene*
- ✓ *High molecular high density polythene*
- ✓ *Polyvinyl chloride*

The advantages of providing plastic lining to the canal are many as plastic is negligible in weight, easy for handling, spreading and transport, immune to chemical action and speedy construction.

The plastic film is spread on the prepared sub-grade of the canal. To anchor the membrane on the banks 'V' trenches are provided. The film is then covered with protective soil cover.

Figure 15 Plastic lining

Asphaltic membrane Lining

This type of lining consists of prefabricated asphaltic membranes available in rolls. The membrane is spread directly on the prepared subgrade and covered with protective earth. It is quite flexible and readily adjusts to the settlements in subgrade. There is no need of special equipment and skilled workers in this case. Prefabricated asphaltic membranes are quite durable.

Road oil lining

In this type of lining road oil is sprinkled over the subgrade in a thickness of about 1.5 mm. the oil penetrates to a depth of 5 to 8 cm into the subgrade. The subgrade is then compacted so that oil fills the soil pores and makes the subgrade somewhat impervious.

Advantages of Canal lining:

1. Seepage Reduction

2. Prevention of Water Logging

3. Increase in Commanded Area

4. Increase in Channel Capacity

5. Less Maintenance

6. Safety against Floods

1. ***Seepage Reduction:*** *The main purpose behind the lining of canal is to reduce the seepage losses. In some soils, the seepage loss of water in unlined canals is about 25 to 50% of total water supplied. The cost of canal lining is high but it is justifiable for its efforts in saving of most of the water from seepage losses. Canal lining is not necessary if seepage losses are very small.*

2. Prevention of Water Logging: *Water logging is caused due to phenomenal rise in water table due to uncontrolled seepage in an unlined canal. This seepage affects the surrounding ground water table and makes the land unsuitable for irrigation. So, this problem of water logging can be surely prevented by providing proper lining to the canal sides.*

3. Increase in Commanded Area: *Commanded area is the area which is suitable for irrigation purpose. The water carrying capacity of lined canal is much higher than the unlined canal and hence more area can be irrigated using lined canals.*

4. Increase in Channel Capacity: *Canal lining can also increase the channel capacity. The lined canal surface is generally smooth and allows water to flow with high velocity compared to unlined channel. Higher the velocity of flow greater is the capacity of channel and hence channel capacity will increase by providing lining. On the other side, with this increase in capacity, channel dimensions can also be reduced to maintain the previous capacity of unlined canal which saves the cost of the project.*

5. Less Maintenance: *Maintenance of lined canal is easier than unlined canals. Generally there is a problem of silting in unlined canal which removal requires huge expenditure but in case of lined canals, because of high velocity of flow, the silt is easily carried away by the water.*

In case of unlined canals, there is a chance of growth of vegetation on the canal surface but not in case of lined canals. The vegetation affects the velocity of flow and water carrying capacity of channel. Lined canal also prevents damage of canal surface due to rats or insects.

6. Safety against Floods: *A line canal always withstand against floods while unlined canal may not resists and also there is chance of occurring of breach which damages the whole canal as well as surrounding areas or fields. But among all, concrete canal linings are good against floods or high velocity flows.*

Factors Affecting Selection of Good Canal Lining

Following are the factors affecting selection of canal lining:

1. Economy

2. Durability

3. Maintenance

4. Stability

5. Erosion resistance

6. Impermeability

7. Hydraulic efficiency

1. Economy: *The lining selected for a particular canal should be economical. The economy of canal lining project generally depends upon many factors such as the type of material used for construction, availability of materials, labor availability, construction equipment, the period of construction etc. A canal lining is said to be economical when the repair and maintenance costs are inexpensive along with the initial construction cost.*

2. Durability: T*he canal lining should be durable in such a way that it should survive in peak flow conditions, canal empty condition, all weather conditions, against temperature changes, chemical actions etc. The lining should be inspected periodically to prevent the growth of rodents, weed, etc. which affects the durability of the structure.*

3. Maintenance: *The maintenance of good canal lining is always easy and economical. A canal lining constructed using bricks or concrete tiles or stone boulders can be easily repaired. Cast in situ concrete lining is difficult to repair when it is damaged. But however, cast in situ concrete lining requires less maintenance than other because of its structural stability.*

4. Stability: *There are various pressures that act on a canal lining. Soil behind the lining may get saturated due to rainwater or seepage and exerts severe pressure on the lining. Sometimes cavities can form behind the lining and create problems. The canal lining should survive against these types of pressures. So, the lining provided should be heavy, strong and stable.*

5. Erosion resistance: *The canal lining material should have good resistance against erosion. Erosion occurs due to abrasion of sediments present in the water with canal surface. If the canal water contains sediments in a considerable amount, the concrete lining or stone boulder lining is preferred since they are good in erosion resistance.*

6. Impermeability: *The main reason behind the provision of lining for the canal is to protect the water from seepage losses. Hence, the canal lining should be efficiently impermeable. However, some types of linings like compacted earth lining, soil cement lining are provided to reduce the seepage losses up to a considerable limit.*

Concrete lining, plastic lining etc. are more impermeable but uneconomical. The type of lining with respect to seepage losses is selected based on different factors such as percentage of seepage, water demand, population intensity etc.

7. Hydraulic efficiency: *The hydraulic efficiency of the canal gradually decreases with time. When the lining surface is continuously exposed to water flow, the surface becomes rough and erosion occurs which reduces the hydraulic efficiency of a canal.*