IRRIGATION

Irrigation may be defined as the process of supplying water to soil for rising crops, *or* is generally defined as the application of water to soil for supplying the moisture essential for plant growth.

1. Types of Irrigation

1. Surface irrigation
2. Subsurface irrigation

Surface irrigation can be further classified into

(*a*) **Flow irrigation:** In this types of irrigation, the supply of irrigation water available is at such a level that it is conveyed on to land by gravity flow.

(*b*) **Lift irrigation:** In this type of irrigation, the water is lifted up by mechanical means. Irrigation from well water is a example.

Flow irrigation is divided in two types :

(*i*) **Perennial system:** In this constant & continuous water supply is done to crops as per requirement during crop-period.

When perennial system of irrigation is carried out by canal system, it is called 'Direct Irrigation'.

When perennial system of irrigation is carried out by storage reservoirs, it is called 'Storage irrigation'.

(*ii*) **Flood irrigation:** In this soil is kept submerged & flooded with water. Moisture soaleed with occasional supplement of natural rainfall brings crops to maturity.

2. Sub surface irrigation : It is divided in two types.

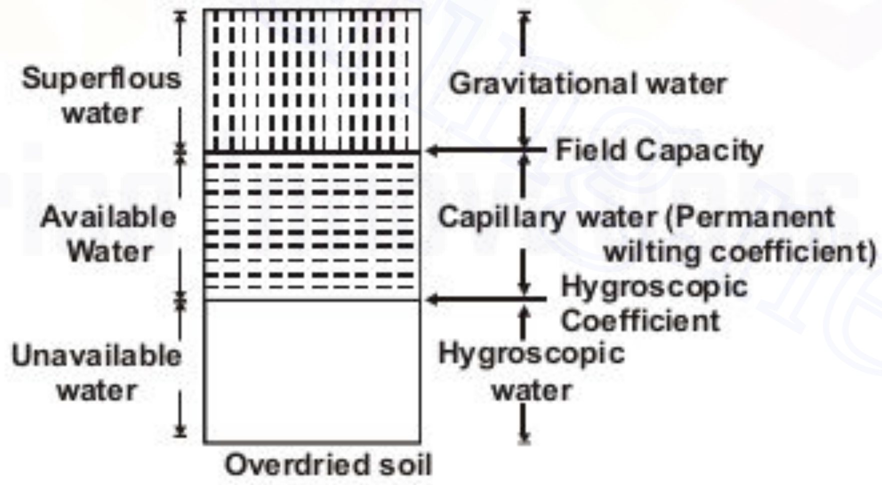
(*a*) **Natural sub irrigation :** Water leaked from channels causes rise of water lable, which in turn provides water to crops through capillarity is termed as natural sub irrigation.

(*b*) **Artificial sub irrigation :** When a system of open jointed drains is artificially laid below soil, so as to supply water to crops by capillarity, then it is known as Artificial sub surface irrigation.

CLASSIFICATION OF WATER PRESENT IN SOIL

1. Hygroscopic Water

When an oven dried sample is kept open in the atmosphere, it absorbs some amount of water from the atmosphere. This is called *hygroscopic water*, and is not capable of movement by the action of gravity or capillary forces.



2. Capillary Water

This is the part in excess of the hygroscopic water which exists in the pore spaces of the soil by molecular attraction

3. Gravitational Water

This is that part in excess of hygroscopic and capillary water which will move out of the soil if favourable drainage is provided.

SATURATION CAPACITY (or Maximum holding capacity/Total capacity)

It is the amount of water required to fill all the pore spaces between soil particles by replacing all air held in pore spaces.

It is the upper limit of possible moisture content when porosity of soil is known, the saturation capacity can be expressed as equivalent cm of water per meter of soil depth.

Field Capacity (F.C.)

It is the moisture content of the soil after free drainage has removed most of the gravity water.

Permanent Wilting Point/Wilting co-efficient (PWP)

It is the water content at which plants can no longer extract sufficient water from the soil for its growth.

$$\text{PWP} \approx \frac{\text{F.C.}}{2.0\, to\, 2.4}$$

It depends upon amount of silt in the soil.

or $$\text{PWP} \approx 1.5 \text{ Hygroscopic water (coefficient)}$$

$$\text{Available Water} = \text{F.C.} - \text{PWP}$$

Readily Available Water

It is that portion of available moisture that is most easily extracted by plants and is approximately 75% of the available moisture.

Moisture Equivalent

This is an artificial moisture property of the soil and is used as index of the natural properties.

It is the percentage of moisture retained in a small sample of wet soil 1 cm deep when subjected to a centrifugal force 1000 times as great as gravity.

Usually for a period of 30 minutes,

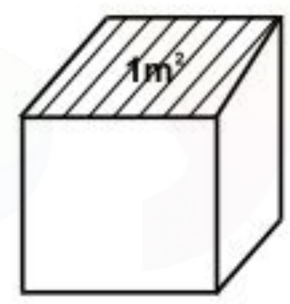
$$\begin{aligned} \text{moisture equivalent} &\approx \text{F.C.} \\ &\approx 1.8 \text{ to } 2 \text{ PWP} \\ &\approx 2.7 \text{ Hygroscopic water.} \end{aligned}$$

Soil moisture Deficiency / Field moisture Deficiency

This is the water required to bring the soil moisture content of the soil to its field capacity.

Depth of water stored in Root zone

Consider land area of 1m^2.



Let, d = root zone depth in m

γ_d = dry unit weight of soil

γ_w = unit weight of water

F_c = Field capacity of soil (expressed as % of dry weight of soil)

PWP = Permanent wilting point (expressed as % of dry weight of soil)

Now $$F_c = \frac{\text{water retained in the prism of soil}}{\text{dry weight of soil in the prism}} = \frac{\text{weight of water retained}}{\gamma_d.(1 \times d)}$$

$$\text{Weight of water retained} = \text{F}_c.\gamma_d.d$$

$$\text{Depth of water retained} = \frac{\text{F}_c.\gamma_d.d}{\gamma_w}$$

This depth will be available for evapo-transpiration.

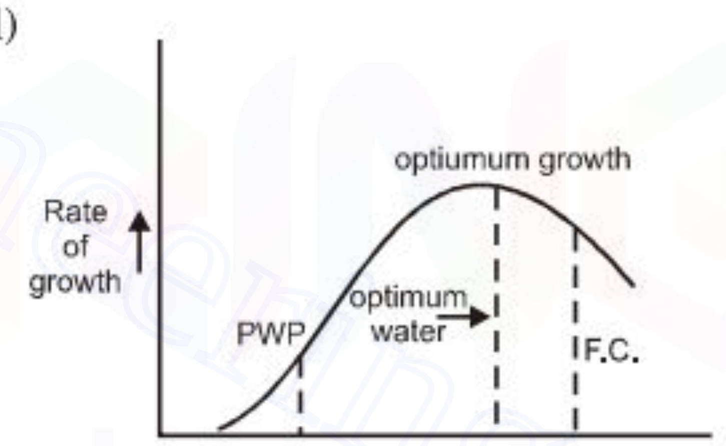


Fig. Limiting soil moisture condition

$$\text{Available water depth} = \frac{\gamma_d.d}{\gamma_\omega}[\text{F}_c - \text{PWP}]$$

$$\text{Readily available water depth} = \underset{\uparrow}{0.75}\frac{\gamma_d.d}{\gamma_w}[\text{F}_c - \text{PWP}]$$

It may be 0.7 to 0.8

$$\text{Depth of water during each watering}, d_W = \frac{\gamma_d\ d}{\gamma_w}[F_c - M_o]$$

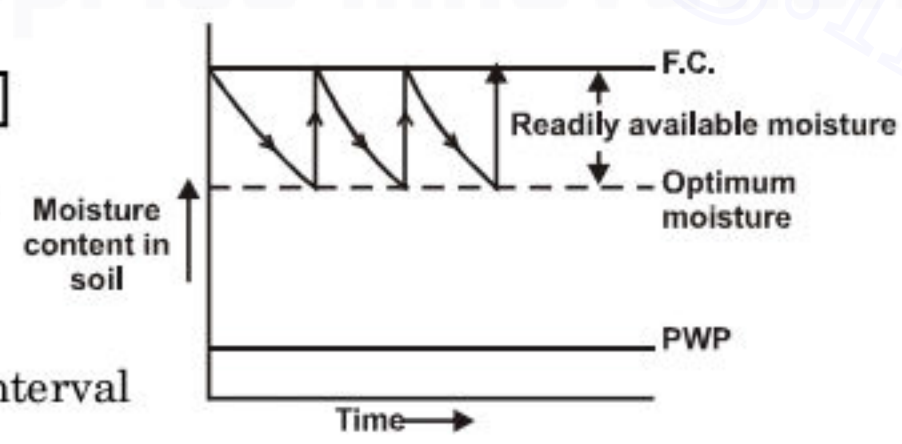


Fig. Depth and frequency (scheduling) of irrigation

If C_u is daily consumptive use rate of crop (mm/day), then interval between irrigation or frequency of water

$$f_w = \frac{dw}{C_u} \text{day}$$

DUTY (D)

Irrigation capacity of a unit of water, or it is the area irrigated in hectares by 1cumec of discharge flowing throughout the base period {hect/cumec}.

DELTA (Δ)

It is the total depth of water required by a crop during the entire period, the crop is in the field {cm or m}

BASE PERIOD (B)

It is the time interval in days between first watering given prior to sowing and the last watering before harvesting (days).

CROP PERIOD

It is the time interval between sowing and harvesting of crop (days).

Relation between Duty and Delta

Let Δ meter depth of water supplied to the field of D hectare, which require one cumec water for B days.

$$\therefore \quad \Delta = \frac{8.64\,B}{D}\ m$$

FACTORS AFFECTING DUTY

1. Method and System of Irrigation

(i) *Perennial or Permanent system* → high duty

Inundation system → low duty as wasteful use of water.

(ii) *Flow system* → low duty as conveyance losses are high.

Lift irrigation → high duty as commended area of each well is very near to it.

2. Mode of Applying Water

Flood irrigation → less duty than furrow system

Sub-irrigation → higher duty.

Basin irrigation and Uncontrolled flooding → low duty.

3. Method of cultivation

Land is made loose by ploughing → more duty

4. Time and Frequency of tilling

When soil is in good filth (structure), evaporation losses are less, soil becomes properly aerated → duty is high.

5. Type of crop

6. Base Period of crop

It's base period is high, duty is low and vice versa.

7. Climatic condition of the area

(i) *Temperature* → high temperature → low duty

(ii) *Wind* → high wind → low duty

(iii) *Humidity* → high humidity → high duty

(iv) *Rainfall* → increase duty

8. Quality of Water

(i) Harmful salt and alkali content decrease duty

(ii) Fertilizing matter in water increase duty.

9. Method of Assessment

(i) Volumetric method → more duty (economical use of water)

(ii) Crop rate or area basis → less duty (more water to be used)

10. Canal Condition

(i) *Earthern canal* → low duty due to more seepage and percolation losses.

Lined canal → high duty due to less losses

(ii) If canal is so aligned that irrigated areas are concentrated along it → duty will be higher and vice versa.

11. Character of soil and Sub soil of the canal

(i) *Coarse grained permeable soil* → less duty as more seepage and percolation.

(ii) *Fined grained soil* → losses are less, so high duty.

12. Character of soil and sub soil of the irrigation field

(i) *Coarse grained* – percolation losses are high, so less duty.

(ii) *Topography* : it also affects the duty.

Methods of Improving Duty

(1) Suitable method of applying water to the crop should be used.
(2) Land should be properly ploughed and levelled before sowing the crop. It should be given good filth (structure)
(3) The land should be cultivated frequently since frequent cultivation reduces loss of moisture, specially when the ground water is within capillary reach of ground surface.
(4) Canal should be lined. This reduces seepage, percolation losses and evaporation losses also.
(5) Parallel canal should be constructed so that F.S.L. will be lowered and thus losses will also be reduced.
(6) Idle length of canal should be reduced.
(7) Alignment of the canal either in sandy soil or in fissured rock should be avoided.
(8) Canal should be so aligned that the areas to be cultivated are concentrated along it.
(9) Source of water should be such that it gives good quality of water.
(10) Rotation of crops must be practiced.
(11) Volumetric method of assessment should be used.
(12) Farmers must be trained in the proper use of water so that they apply correct quality of water at correct timing.
(13) The land should be redistributed to the farmers so that they get only as much land as they are capable of managing it.
(14) Research stations should be established to study the soil, the seed and conservation of moisture.
(15) Canal staff should be efficient, responsible and honest.

Some Important Terms

- **Outlet discharge factor.** The duty at the head of water course (at outlet point of minor) is called 'outlet discharge factor'.
- **Kor depth.** It is the depth of water applying in first watering which is given to a crop.
- **Kor period.** It is the portion of the base period in which kor watering is needed
- **Time factor** = $\dfrac{\text{Number of days canal actually runs}}{\text{Number of days of irrigation period}}$
- **Capacity factor =** $\dfrac{\text{Mean supply (Average discharge)}}{\text{Full supply of a canal}}$
- **Cumec day.** Quality of water flowing for one day at the rate of perpendicular cumec. (= 8.64 hectare meter)
- **Paleo Irrigation.** At times of sowing crops particularly Rabi crops, land is very dry & needs to be moistened to help in sowing of crops. Irrigation carried out for this purpose is called Paleo irrigation.
- **Duty on capacity** = $\dfrac{\text{Area estimated to be irrigated during base period}}{\text{Design full supply discharge of channel at its head during maximum demand}}$
- **Nominal duty** = $\dfrac{\text{Area of which permit has been granted for the period}}{\text{Mean supply for the base period}}$
- **Open discharge** = $\dfrac{\text{Number of cumec days}}{\text{Number of days the canal has actually been used}}$
- **Root-zone depth.** It is the maximum depth in soil strata in which the crop spreads its roots system and derives water from the soil.

WATER REQUIREMENT OF CROPS

Field Capacity

Field capacity is defined as weight of water retained against the effect of gravity in the voids to the weight of soil drained.

$$\text{F.C} = \frac{wt.\ of\ water\ retained\ in\ voids\ against\ the\ effect\ of\ gravity}{wt.\ of\ soil\ drained} \times 100$$

Depth of root zone = d m

Area of field = 1 m^2

Density of soil = γ_s

Weight of soil drained (corresponding) = volume of soil present in root zone × density of soil

$$= A \times d \times \gamma_s = d.\ \gamma_s$$

Weight of water retained in the voids corresponding to F.C = F.C × weight of soil drained

$$= F.C. \times d.\ \gamma_s$$

Volume of water retained = F.C. $\dfrac{d\gamma_s}{\gamma_w}$

depth of water retained (corresponding to F.C.)

$$= F.C.\ \frac{d\gamma_s}{\gamma_w} \cdot \frac{1}{A} = F.C. \frac{d\gamma_s}{\gamma_w}$$

$$F.C. = \frac{wt. of\ water\ retained}{wt. of\ soil\ drained}$$

$$= \frac{Vol. of\ water\ retained}{Vol. of\ soil\ drained} \times \frac{\gamma_w}{\gamma_s}$$

if S = 1

& $V_w = V_v$

$$F.C. = \frac{Vol. of\ voids}{Vol. of\ soil} \times \frac{\gamma_w}{\gamma_s} = \frac{\gamma_w}{\gamma_s} \times \frac{V_v}{V_s}$$

$$F.C. = n \times \frac{\gamma_w}{\gamma_s} \left(\text{since } \frac{V_v}{v} = n = porosity \right)$$

Permanent Wilting Point

The entire water corresponding to the field capacity cannot be utilized by the crops for their growth. Plant can utilize the water from the soil only uptill permanent wilting point is reached. Permanent wilting point is defined as' the moisture content at which plant can no longer extract the water from the soil for their growth and finally wilts up' (dry off)

Available matrix = FC – φ

Depth corresponding to available moisture

$$= (FC - \varphi) \frac{d\gamma_s}{\gamma_w}$$

Readily Available Moisture

- It is the portion of the available water or moisture which should be present for the optimum growth of the crops. It approx. 75 to 80 % available water or moisture.
- Pending available moisture

  $$= F.C. - M_o = 0.75 \text{ to } 0.80\ (F_c - \varphi_o)$$
- Depth of water corresponding to RAM $= (F_c - M_o)$

Moisture content present in the soil to ensure the optimum growth of the crops is M_o

Frequency of Irrigation

If the consumption use of the crops is known, the frequency of water irrigation,

$$f = \frac{depth\ corrsponding\ to\ RAM}{C_u} = \frac{(F_c - M_o)}{C_u} \frac{d\gamma_s}{\gamma_w}$$

CONSUMPTIVE USE OF WATER (EVAPO-TRANSPIRATION)

It is the total depth of water consumed by transpiration from crop, evaporation from soil and water surface area, including the transpiration from accompanying weed growth.

The rain water and dew intercepted by leaves of plants and subsequently evaporating without entering the plant system also form part of consumption use.

$$\text{Transpiration ratio} = \frac{\text{weight of water transpired by the plant during its growth}}{\text{weight of dry matter produced by plant exclusive of roots}}$$

For wheat, transpiration ratio $\simeq$ 560

For rice, transpiration ratio = 680

Factor Affecting Consumptive Use of Water

(1) Evaporation ; which depends upon humidity.

(2) Mean monthly temperature.

(3) Growing season of crop and cropping patterns.

(4) Monthly precipitation in the area

(5) Irrigation depth.

(6) Wind velocity in the locality.

(7) Soil and topography.

(8) Irrigation practices and methods of irrigation.

Estimation of Consumptive use

(1) Tank and Lysimeter method.

(2) Field experiment method.

(3) Soil moisture studies.

(4) Integration method.

INFLOW AND OUTFLOW STUDIES FOR LARGE AREA

$$U = \{(I + P) + (G_b - G_e) - O\}$$

where, U = valley consumptive use (Hect-meter)

I = total inflow during 12 month year

P = yearly precipitation (Hect-meter)

G_b = ground water storage at the begining of the year.

G_e = ground water storage at the end of the year.

O = annual outflow rate

IRRIGATION EFFICIENCY

1. Water Conveyance Efficiency

$$\eta_c = \frac{W_f}{W_r} \times 100$$

where W_f = water delivered to the farm from outlet point of channel.

W_r = water delivered from the river or reservoir

2. Water Application Efficiency is also called 'Farm efficiency'

$$\eta_a = \frac{W_s}{W_f} \times 100$$

where, W_s = water stored in root zone during the irrigation

$$W_f = W_s + R_f + D_f$$

where, D_f = deep percolation losses.

R_f = surface run-off losses

3. Water use Efficiency

$$\eta_u = \frac{W_u}{W_d} \times 100$$

where, W_u = water used beneficially or consumptively including leaching water.

W_d = water delivered.

4. Water Storage Efficiency

$$\eta_s = \frac{W_s}{W_n} \times 100$$

where, W_s = water stored in the root zone during irrigation
W_n = water needed in the root zone prior to irrigation
= (field capacity – Available moisture)

5. Water Distribution Efficiency

It is also termed as uniformity coefficient. The effectiveness of irrigation may also be measured by water distribution efficiency.

$$\eta_d = 100\left[1 - \frac{y}{d}\right]$$

where, y = average deviation in depth of water stored from average depth stored during irrigation
d = average depth of water stored during irrigation

6. Consumption Use Efficiency

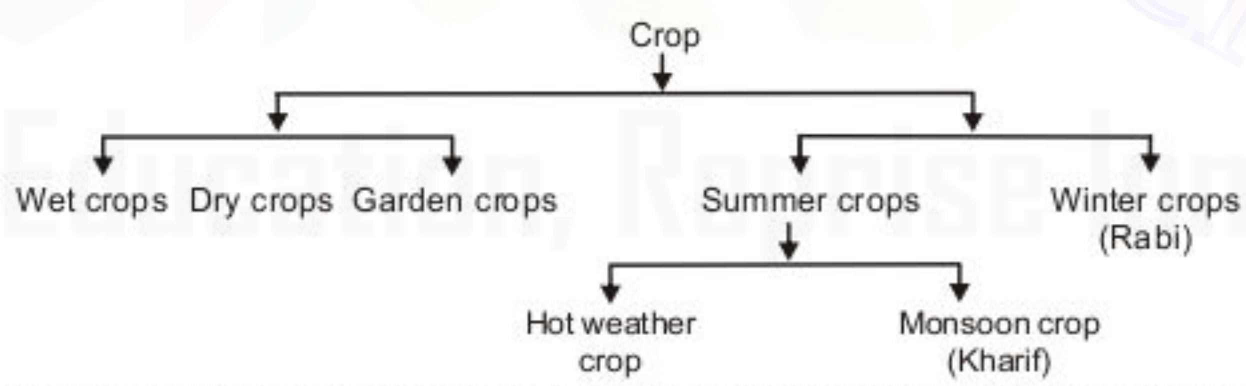
$$\eta_{Cu} = \frac{W_{cu}}{W_d} \times 100$$

where W_{cu} = nominal consumptive use of water
W_d = net amount of water depleted from root zone soil.

Factor Affecting Irrigation Efficiency

(1) Irregular land surface.
(2) Shallow soils underlain by gravels of light permeability.
(3) Either very small or excessively large irrigation stream.
(4) Non-attendance of water during irrigation
(5) Long irrigation runs.
(6) Wrong irrigation methods.
(7) Improper preparation of land.
(8) Compact impervious soil.
(9) Steep slopes of land surface.
(10) Excessive single application

PRINCIPLE CROPS



Kharif Crops : These are sown by the beginning of south west monsoon and are harvested in autumn.
Rabi crops : These are sown in autumn and are harvested in springs
Wet crop : These requires water for irrigation.
Dry crops : These does not require water for irrigation
Garden crops : These requires irrigation throughout the year.

Important Terms

- **Crop Ratio =** $\frac{\text{Area irrigated in Rabi Season}}{\text{Area irrigated in Kharif Season}}$
- **Crop Rotation.** It implies that nature of crop sown in a particular field is changed year after year.
- **Gross Commanded Area (G.C.A.).** It is the total area, bounded within the irrigation boundary of project, which can be economically irrigated without considering limitation of the quantity of available water. It includes cultivable and non cultivable area as well.

- **Culturable Commanded Area (C.C.A.).** It is that part of G.C.A., on which cultivation is possible. All of this area may not be sown or cultivated at a time.

  Pastures & fallow lands, which can be made cultivable, are included in this area but uncultivable populated areas including ponds, reserve forests, usar lands, roads are all excluded.

  $$\text{G.C.A.} = \text{C.C.A.} + \text{unculturable area.}$$

- **Unculturable Area.** It is the Unfertile barren land, alkaline soil, local ponds, village and other areas as habitation.
- **Intensity of irrigation (I.I.).** It is defined as ratio of actually irrigated area during a crop season to net cultivable commanded area.

DETERMINATION OF IRRIGATION REQUIREMENT OF CROPS

(i) Effective rainfall (Re)

(ii) *Consumptive irrigation requirement,* CIR = Cu – Re

where, Cu = consumptive use of water.

(iii) *Net irrigation requirement,* NIR = Cu–Re + water lost in deep percolation for purpose of leaching etc.

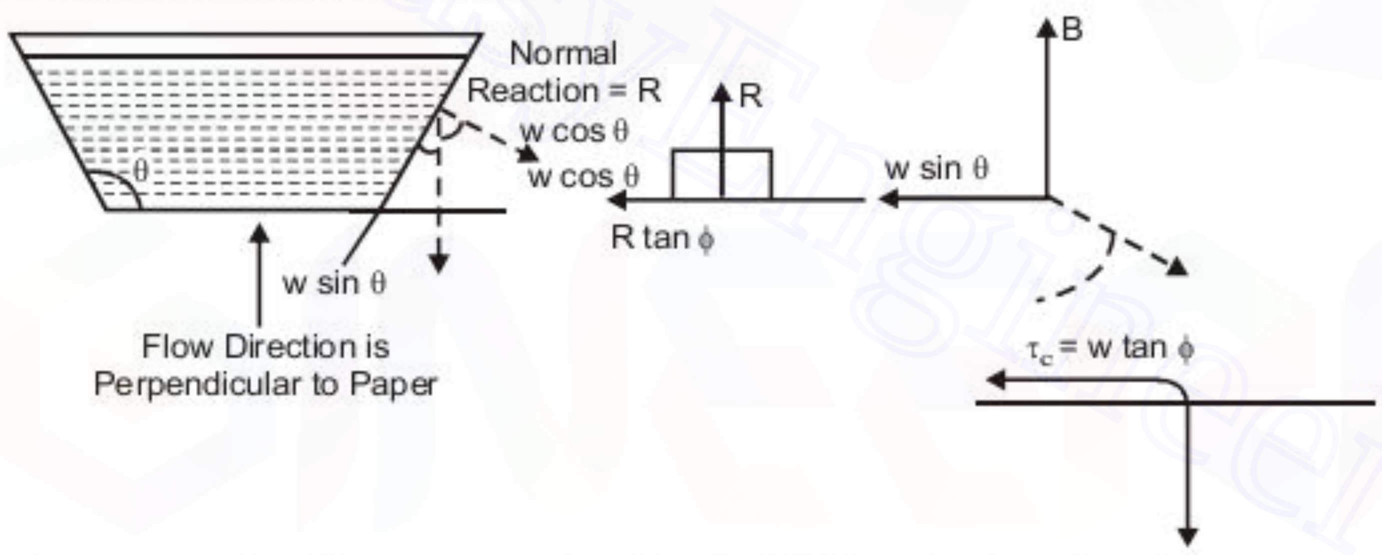
(iv) Field irrigation requirement, FIR = $\dfrac{\text{NIR}}{\eta_a}$

(v) Gross irrigation requirement, GIR = $\dfrac{\text{FIR}}{\eta_a}$

DESIGN OF CHANNELS

Stability of Channel Banks (Channels with Unprotected Banks)

Consider a grain on the side bank of a canal.



Let τ_0 be the shear stress required to move grain of weight W on the bank and τ_c represents critical shear stress or the shear stress required to move a similar grain on a horizontal bed.

Then $$\tau_0 = W\tan\phi \quad \text{and} \quad \frac{\tau_0}{\tau_c} = \sqrt{1-\frac{\sin^2\theta}{\sin^2\phi}}$$

This equation show that $\tau_0 < \tau_c$; which means that shear stress required to move a grain on the bank is less than the shear stress required to move the grain on bed.

On bed, average value of shear stress that will be generated by flowing water in a channel of given R and S is

$$\tau_0 = \gamma RS$$

while on banks $$\tau_0 = 0.75\,\gamma\,\text{RS}$$

In India, the channels are generally designed based upon empirical work done by Kennedy and Lacey.

Stable or Regime Channels

For proper functioning channel, it is designed such that neither silting nor scouring takes place. Such channels are called *stable channels or regime channels.*

A channel is said to be in the state of '*Regime*' if flow is such that '*silting and scouring*' need no special attention. Such a state is not easily possible in rivers, but in artificial channels, such a state can be obtained by properly designing the channel.

The basis for designing such an ideal, non- silting, non- scouring channel is that, whatever silt has entered the channel at its head is kept in suspension so that it does not settle down and deposit at any point of the channel. Moreover, velocity of the water should be such that it does not produce local silt by erosion of channel bed and banks.

Kennedy's Theory

According to Kennedy, silt supporting power in a channel cross-section was mainly dependent upon generation of the eddies, rising to the surface. These eddies are generated due to 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, thus keeping the sediment in suspension. So if velocity is sufficient to generate these eddies so as to keep the sediment just in suspension, silting will be avoided. Based upon this concept, he defined the critical velocity (V_0) in a channel as the mean velocity which will just keep the channel free from silting or scouring and related it to the depth of flow by the equation

$$V_0 = c_1 . y^{c_2}$$

where c_1 and c_2 are constant depending upon silt charge.

c_1 and c_2 were found to be 0.55 and 0.64 (in M.K.S. units), respectively.

$$\therefore \quad V_0 = 0.55\, y^{0.64}$$

Depending upon the type of soil, a factor **critical velocity ratio (C.V.R.)** and denoted by m is introluced, which depends upon silt grade.

$\therefore$ critical velocity in the channel in (m/sec), $V_0 = 0.55\, my^{0.64}$

where y is in metres

Recommended values of Critical Velocity Ratio (m)

S. No.	Type of silt	Value of *m*
1.	Silt of River Indus (Pakistan)	0.70
2.	Light sandy silt in North Indian Rivers	1.0
3.	Light sandy silt, a little coarser	1.1
4.	Sandy, loamy silt	1.2
5.	Debris of hard soil	1.3

Design Procedure

(1) Determince critical velocity V_0 assuming a trial depth

(2) Determine area by dividing discharge by velocity.

(3) Determine channel dimensions.

Compute actual mean velocity (V) that will prevail in the channel of this cross-section by using Kutter's formula, or Manning's formula, etc.

If two velocities V_0 and V work out to be the same, then assumed depth is all right, otherwise change it and repeat the procedure.

Kutter's formula :

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

Manning's formula : $$V = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$$

where V = velocity of flow in metres/sec

R = hydaulic mean depth in metres

S = bed slope of the channel

n = rugosity co-efficient, which depend upon channel condition and discharge.

Recommended values of Rugosity co-efficient n for unlined channels

Condition of Channel	Value of *n*
Very good	0.0225
Good	0.025
Indifferent	0.0275
Poor	0.030

Recommended values of n for different discharges by Central Board of Irrigation

Discharge in cumecs	Value of *n* for unlined channels
14 to 140	0.025
140 to 280	0.0225
280 and above	0.020

Chezy's formula $V = C\sqrt{RS}$

where, C = a constant depending upon shape and surface of the channel

R and S have the same meaning.

Mean actual velocity generated in the channel (V) can be computed by any of these three formulas, but generally Kutter's equation is used with Kennedy's theory.

Use of Garret's diagrams for Design of Irrigation channels

(1) Discharge, bed slope, rugosity coefficient, value of C.V.R. are given for the channel to be designed.

(2) Find out point of intersection of the given slope line and discharge curve. At this point of intersection, draw a vertcital line intersecting the various bed width curves.

(3) For different bed widthes (B), corresponding values of water depth (y) and critical velocity (V_0) can be read on the right hand ordinate. Each such pair of bed width (B) and depth (y) will satisfy Kutter's equation and is capable of carrying required discharge at the given slope and Rugosity coefficient. Choose one such pair and determine actual velocity of flow (V).

(4) Determine critical velocity ratio (V/V_0) taking V as calculated and V_0 as read.

(5) If value of C.V.R. is not the same as given in equation, repeat the procedure with other pairs of B and y.

The diagrams have been drawn for a trapezoidal channel with side slopes as $\frac{1}{2}$H : 1 V ($\frac{1}{2}$: 1) on the assumption that irrigation channels adopt approximately this shape even though they were constructed on different side slopes.

Lacey's Theory

On the basis of his research work, Lacey found many drawbacks in Kennedy's Theory and put forward his new theory.

Lacey's Regime Channels

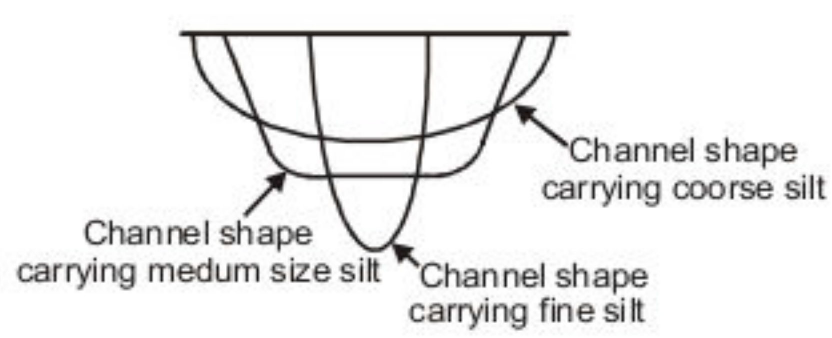
According to him, a channel which is under '*initial regime*' is not a channel in regime (though outwardly it appears to be in regime as there is not silting or scoruring) and hence, regime theory is not applicable to them. His theory is applicable only to channels which are in '*true regime*' or '*final regime*'.

1. Initial regime

When only bed slope of a channel varies and its cross-section or wetted perimeter remains unaffected, even then channel can exhibit no silting no scouring properties, called *initial regime*. When water flows through an excavated channel with some what narrower dimensions and defective slopes, then silt carried by the water gets dropped in the upper reaches, thereby increasing channel bed slope. Consquently, velocity is increases and a non-silting equilibrium is established, called *initial regime*. Sides of such channels are subjected to a lateral restraint and could have scoured if bank soil would have been a true alluvium. But in practice, they may either get grassed or be of clayey soil and, therefore, they may not get eroded at all. Hence, such channels will exhibit '*non-silting non scouring*' properties, and they will appear to be in regime, but in fact they are not. They have achieved only a working stability due to rigidity of their banks. Their slopes and velocities are higher and cross-sections narrower than what would have been if the sides were not rigid. Such channels are called *channels in initial regime and regime* theory is not applicable to them as they are infact, not the channels in alluvium.

2. Final regime

If there is no resistance from the sides and all the variables such as perimeter, depth, slope, etc are equally free to vary and finally get adjusted according to discharge and silt grade, then the channel is said to have achieved permament stability called *final regime*.



Regime theory is applicable to such channels only, and not to all regime channels (including initial regime) as was envisaged by Kennedy.

Such a channel in which all variables are equally free to vary, has a tendency to assume a semi-elliptical section. The coarser the silt, flatter is the semi-ellipse, *i.e.* greater is width of the water surface. The finer the silt, the more nearly the section attains a semicircle.

True Regime

A channel shall be in regime, if there is neither silting nor scouring. For this condition to be satisfied, the silt load entering the channel must be carried through by the channel section. Again, since there is only one channel section and one bed slope at which the channel carrying a given discharge will carry a particular type of silt. Hence, an artificially constructed channel having a certain fixed section and a certain fixed slope can behave in regime only if following conditions are satisfied :

(i) Dicharge is constant.

(ii) Flow is uniform.

(iii) Silt grade and silt charge is constant, *i.e.* amount and type of silt is the same.

(iv) Channel is flowing throught a material which can be scoured as easily as it can be deposited (such soil is called *incoherent alluvium* and is of the same type as is transported.

In practice, all these conditions can never be satisfied, and therefore artificial channels can never be in '*true regime*', they can either be in initial regime or final regime.

Design Procedure

(1) Calculate velocity from equation, $V = \left[\dfrac{Qf^2}{140}\right]^{\frac{1}{6}}$ in m/sec

Slit factor, $f = 1.76\sqrt{d_{mm}}$

where, d_{mm} = average particle size in mm.

Q = discharge in cumecs.

(2) Calculate hydraulic mean depth (R) from the equation,

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

Lacey's regime scoured depth, $R = 1.35\left(\dfrac{V^2}{f}\right)^{\frac{1}{3}}$

where, q = discharge per unit width

(3) Compute area of channel section $A = \dfrac{Q}{V}$

(4) Compute wetted perimeter. $P = 4.75\sqrt{Q}$

Knowing these values, channel section is determined.

Now, determine bed slope S by the equation,

$$S = \left[\frac{f^{5/3}}{3340Q^{1/6}}\right]$$

Comparison of Kennedy's and Lacey's Theories

(1) The concept of silt transportation is the same in both the cases. Both the theories agree that silt is carried by the vertical eddies generated by friction of the flowing water against the channel surface. Kennedy considered a trapezoidal channel section and, therefore, he neglected eddies generated from the sides. For this reason, Kennedy's critical velocity formula was derived only in terms of depth of flow (y). But Lacey considered that an irrigation channel achieves a cup-shaped section (semi-ellipse) and that entire wetted perimeter of the channel contributes to the generation of silt supporting eddies. He, thus, used hydraulic mean radius (R) as a variable in his regime velocity formulas instead of depth (y).

(2) Kennedy stated all the channels to be in a state of regim provided they did not silt or scour. But Lacey differentiated between two regime conditions, *i.e.* initial regime and final regime.

(3) According to Lacey, grain size of the material forming the channel is an important factor, and should need much more rational attention than what was given to it by Kennedy. Kennedy has simply stated that critical velocity ratio ($V/V_0 = m$) varies according to the silt conditions (i.e. silt grade and silt charge).

However, Lacey, connected grain size (d) with his silt factor (f) by the equation

$$f = 1.76\sqrt{d_{mm}}$$

Silt factor (f) occurs in all those Lacey's equations, which are used to determine channel dimensions.

(4) Kennedy has used Kutter's formula for determining actual generated channel velocity. The value of Kutter's rugosity coefficient (n) in again a guess work. Lacey, on the other hand, has produced a general regime flow equation, after analysing huge data on regime channels.

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

(5) Kennedy has not given any importance to bed width and depth ratio. Lacey has connected wetted perimeter (P) as well as area (A) of the channel with discharge, thus, establishing a fixed relationship between bed width and depth.

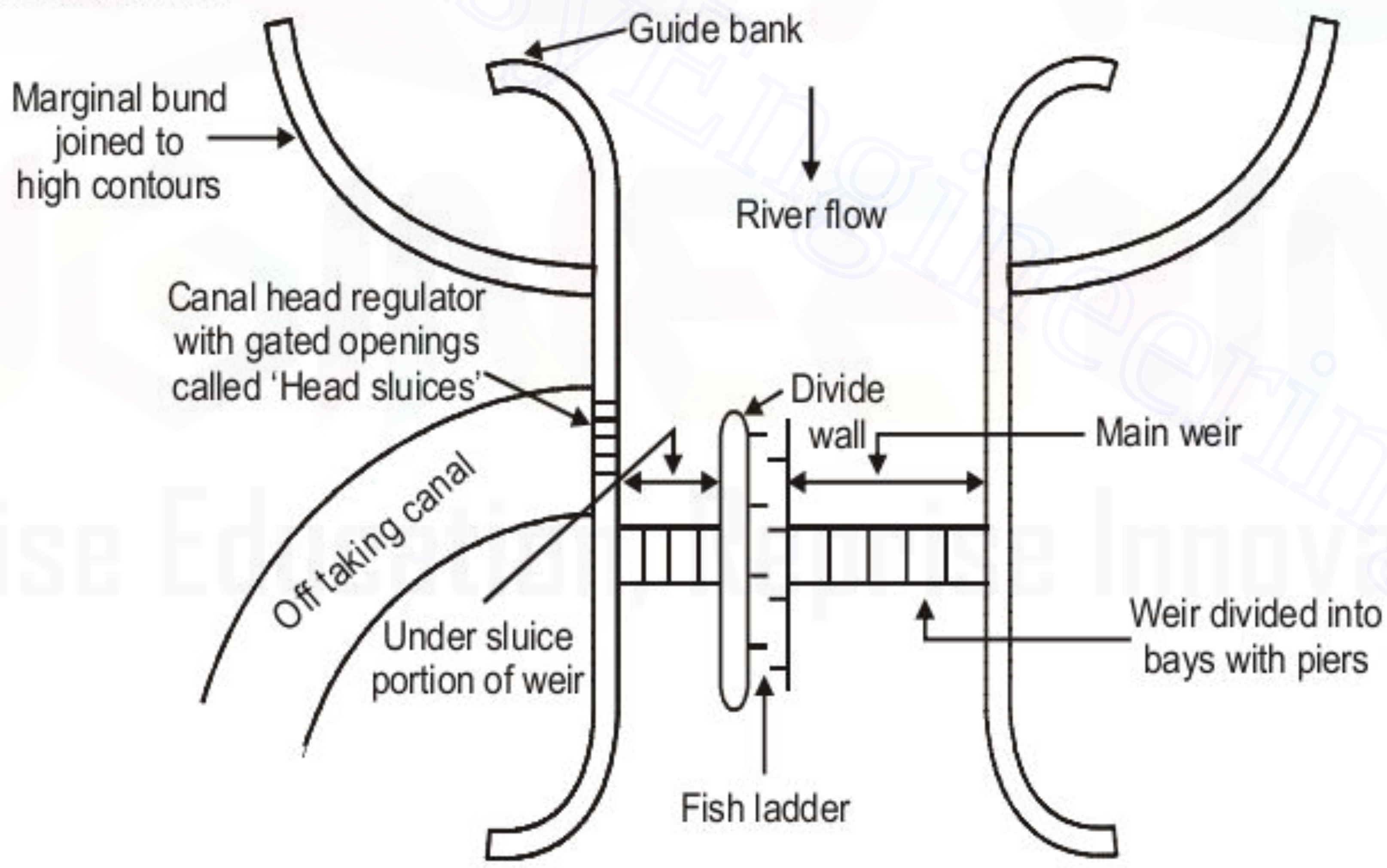
(6) Kennedy did not fix regime slopes for his channels, althought, his diagrams indicate that steeper slopes are required for smaller channels and flatter slopes are required for larger channels. Lacey, on the other hand, has fixed the regime slope, connecting it with discharge, by the original formula

$$S \propto \frac{f^{5/3}}{q^{1/3}}$$

This regime slope formula, given by Lacey, gives excessive slope values.

DIVERSION HEAD WORKS

The works, which are constructed at the head of the canal, in order to divert the river water towards the canal, so as to ensure a regulated continuous supply of silt-free water with a certain minimum head into the canal, are called *diversion head works*.



Layout of Diversion Head Works

1. Diversion Weir and Barrage

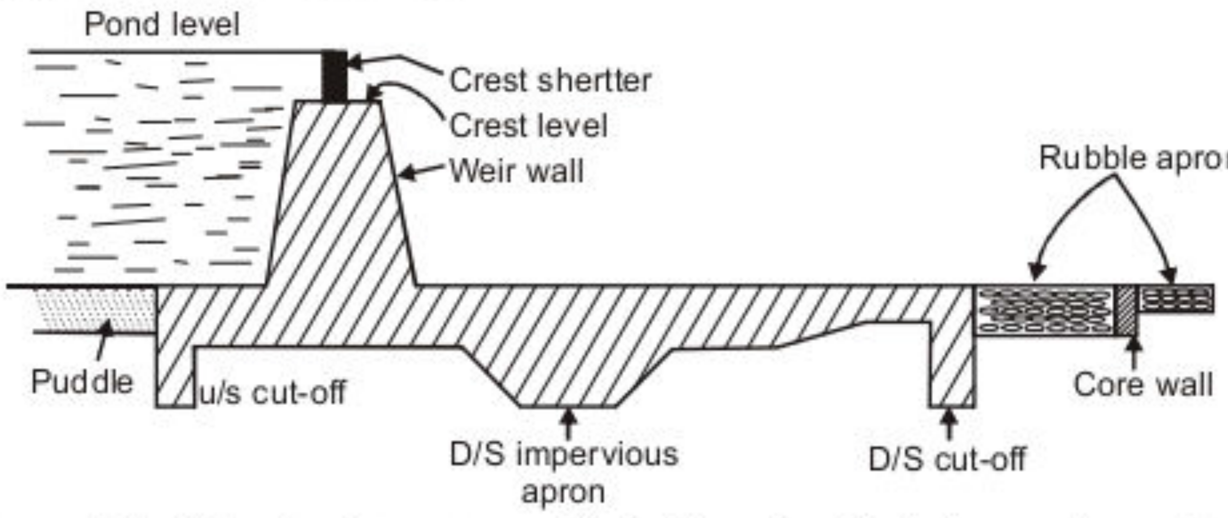
If major part or entire ponding of water is achieved by a raised crest and a smaller part or nil part of it is achieved by the shutter, then this barrier is called **weir**. If most of the ponding is done by gates and a smaller or nil part of it is done by the raised crest, then this barrier is called *barrage* or *river regulator*.

Barrage gives less afflux and a better control upon the river flow because inflow and outflow can be controlled to a much greater extent by a suitable manipulation of its gates.

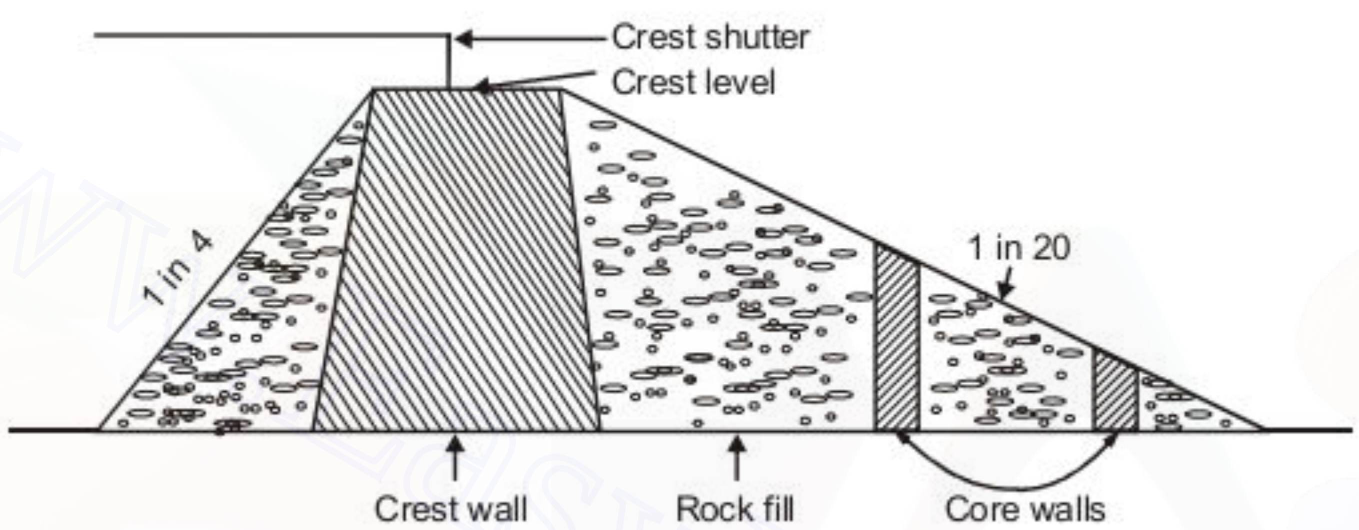
Diversion weir is a raised pucca structure with or without shutters and laid across the river width. Entire length of the weir is divided into a number of bays by means of divide piers so as to avoid cross-flow in floods.

Types of Weirs

(*i*) **Masonary weir with Vertical drop :** Particularly suitable for hard clay and consolidated gravel foundation. However, this type of weir is obsolete.



(*ii*) **Rock-fill weirs with Sloping aprons :** It is the simplest type of construction and is suitable for fine sandy foundations like those in alluvial areas in North India. However with the development of concrete glacis weirs, the above type also becomes obsolete.



(*iii*) **Modern concrete weirs with Sloping downstream glacis**

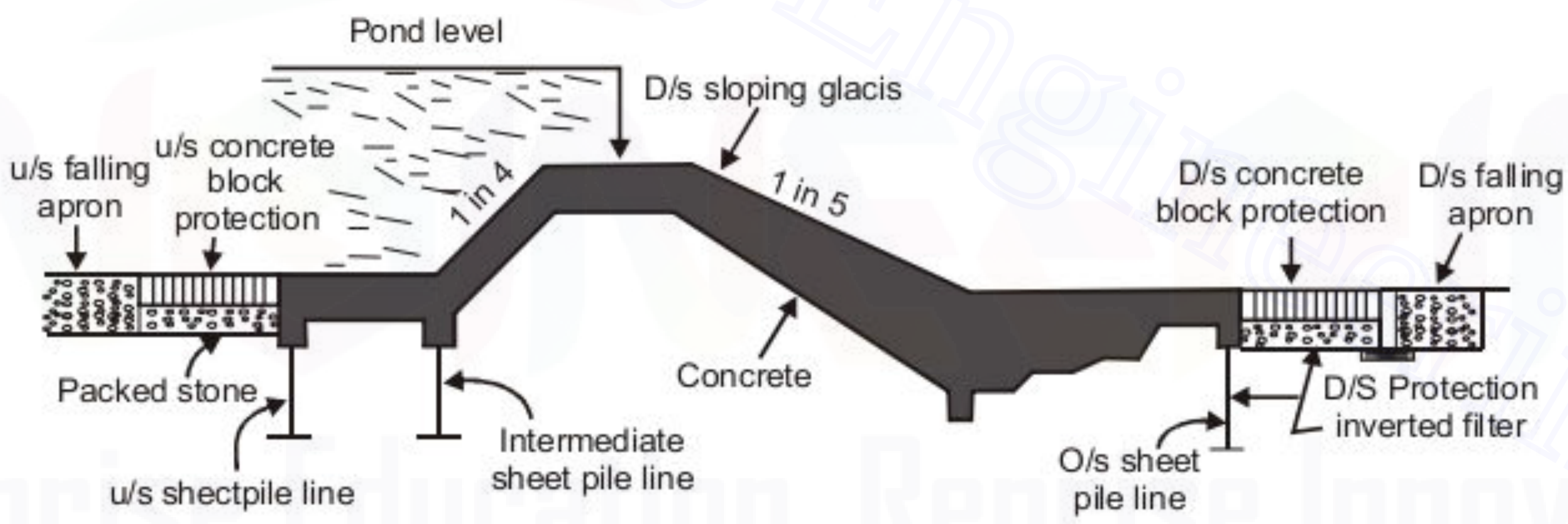


Fig. Modern concrete weir on permeable foundations.

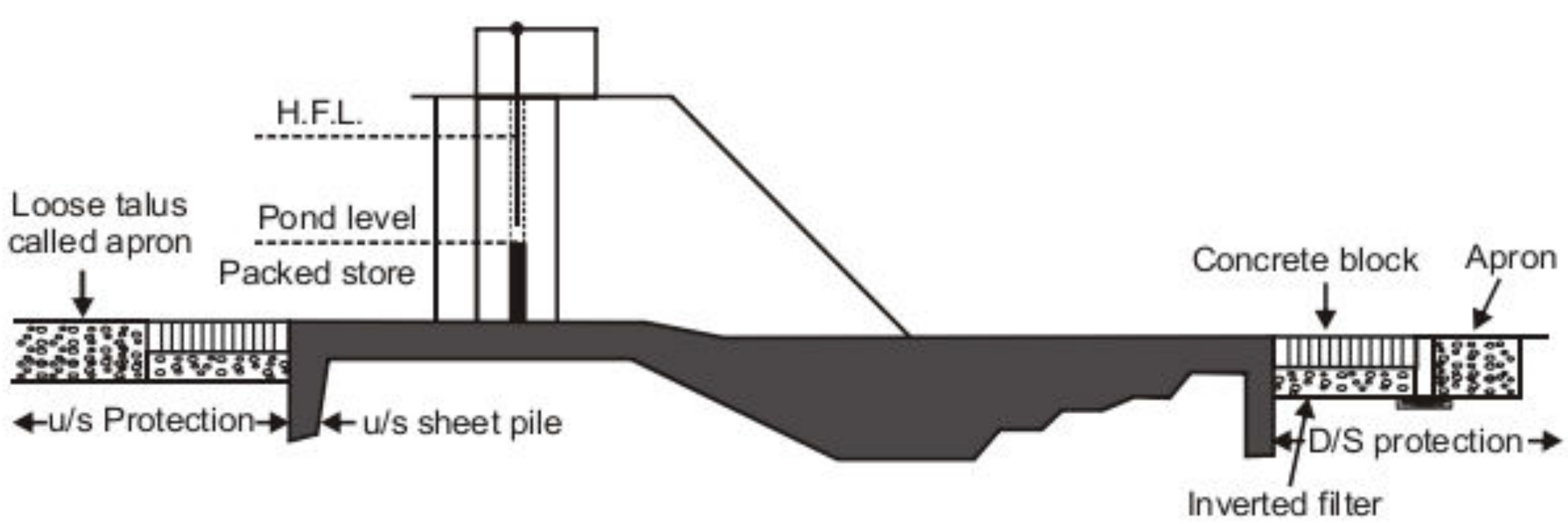


Fig. Barrage founded on pervious foundations

Weir of this type are of recent origin and their design is based on modern concepts of sub-surface flow (*i.e.* Khosla's theory). The hydraulic jump is formed on the downstream sloping glacis, so as to dissipate the energy of the flowing water.

This type of weirs are exclusively used, especially on permeable foundations, and are generally provided with a low crest and counter-balanced gates, thus, making it a barrage.

Afflux

Rise in the maximum flood level (HFL) upstream of the weir, caused due to construction of the weir across the river, is called *afflux*.

Pond level

Water-level required in the under-sluice pocket upstream of the canal head regulator, so as to feed the canal with the full supply, is called *pond level*.

Since weir crest is raised upto the pond level, a minimum water level equal to pond level is always maintained in the undersluice pocket, so as to ensure a continuous supply of water into the canal with its full supply level.

Thus available head at the canal head regulator is equal to difference of the pond level and canal FSL.

2. Under-Sluices or Scouring Sluices

These maintain a deep channel in front of the head regulator and dispose off heavy silt and a part flood discharge on the downstream side of the barrage.

Functions

(*i*) Preserve a clear and defined river channel approaching the regulator.
(*ii*) Control the silt entry into the canal.
(*iii*) Scour the silt deposited in the river bed above the approach channel.
(*iv*) Pass the low floods without dropping the shutter of the main weir.
(*v*) Provide greater water-way for floods, thus lowering the flood levels.

Design consideration

Silt of the under-sluice pocket is kept at or slightly above the deepest river bed and about 0.9 to 1.8 metres below silt of the canal head regulator.

3. Divide Wall or Groyne

Divide wall is a masonary or concrete wall constructed at right angle to the axis of the weir, and separates the weir proper from '*under-sluices*'. Divide wall extends on the upstream side beyond the beginning of the canal head regulator, and on the downstream side, it extends up to the end of loose protection of the under-sluices.

Functions

(*i*) It separates '*under-sluice*' from the weir proper, since crest level of the under-sluices is lower than that of the weir proper, the two must be separated, and this is being done by the divide wall.
(*ii*) It helps in providing a comparatively less turbulent pocket near the canal head regulator, resulting in deposition of silt in this pocket and, thus, help in entry of silt free water into the canal.

4. River Training Works

These are required near the weir site in order to ensure a smooth and *a axial flow of water*, and thus, to prevent the river from outflanking.

River training works required on a Canal Headworks :

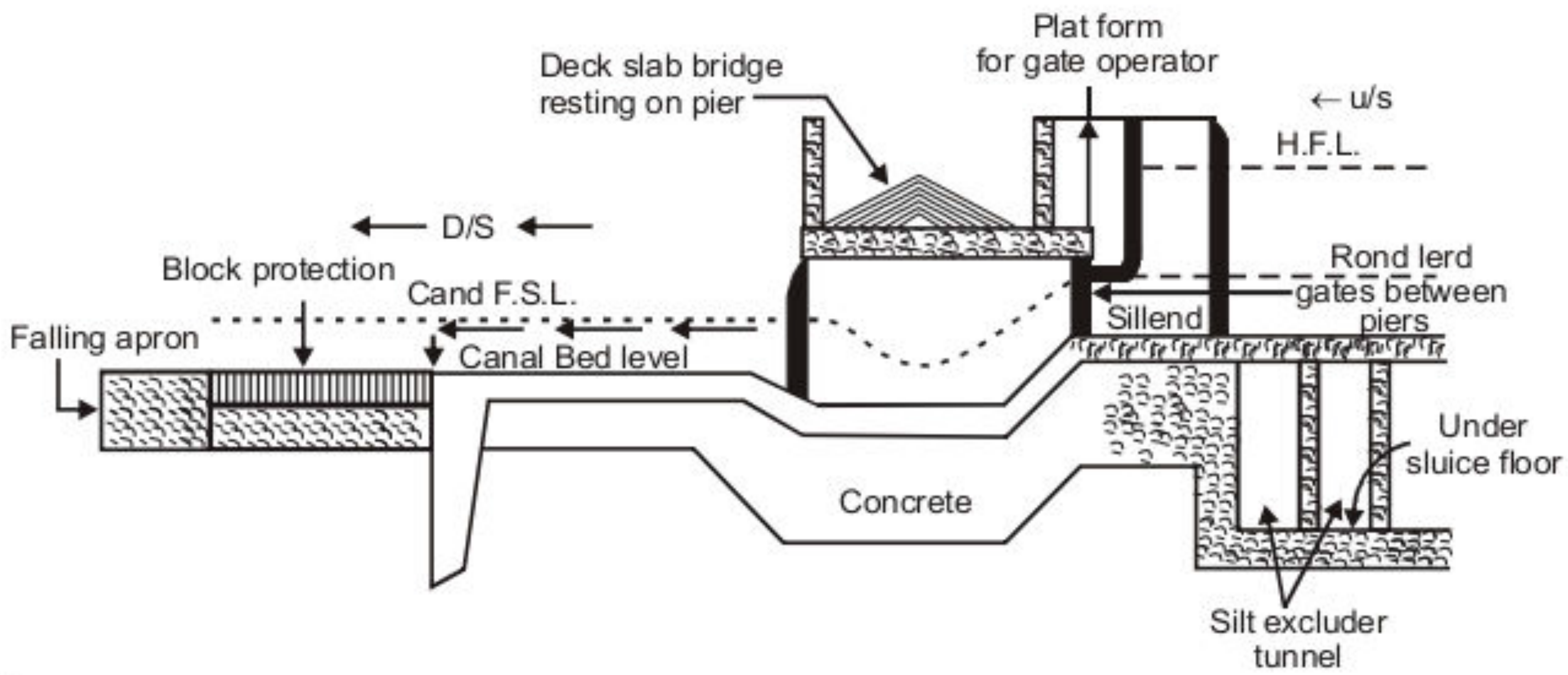
(*i*) *Guide Banks* : It forces the river into a restricted channel
(*ii*) *Marginal Bunds* : These are provided on the upstream side of the works in order to protect the area from submergence due to rise in HFL. These are nothing but earthen embankment, protected by groynes, wherever needed.
(*iii*) *Spurs or Groynes*

5. Fish Ladder

A structure which enables the fish to pass upstream is called *fish ladder*. It is a device by which flow energy can be dissipated in such a manner as to provide smooth flow at sufficiently low velocity, not exceeding 3 to 3.5 m/s. This object is generally accomplished by providing a narrow opening adjacent to the divide wall and provide suitable baffles or staggering device in it, so as to control the flow velocity.

6. Canal Head Regulator (CHR) or Head Sluices

This is provided at the head of the of-ftaking canal. A head regulator may consist of a number of spans separated by piers and operated by gates similar to that provided in a barrage.



Function

(*i*) It regulates supply of water entering the canal.

(*ii*) It controls entry of silt in the canal.

(*iii*) It prevents river floods from entering the canal.

Water from the under-sluice pocket is made to enter the regulator bays, so as to pass full supply discharge into the canal. Maximum height of these gated openings called *head sluice* will be equal to the difference of pond level and crest level of the regulator. The entry of silt into the canal is controlled by keeping crest of the head regulator by about 1.2 to 1.5 m higher than crest of the under-sluice.

Types of Regulations

There are two methods of regulation adopted at a head regulator to control entry of silt into the canal.

(*i*) **Still Pond Regulation :** In this method, the pocket sluices are entirely closed and canal draws water from the still pond in the pocket. The water in excess of the canal requirement is thus not allowed to escape under the sluice gates. Velocity of water in the pocket is very much reduced on account of excessive water way since only supply required for the canal enters the pocket. Thus silt is deposited in the pocket and clear water enters the canal. When silt deposited has a level about ½ to 1m below the crest level of the regulator, supply in the canal is shut off for about 24 hours and sluice gates are opened to scour deposited silt and discharge it downstream. The process is repeated.

(*ii*) **Open Flow Regulation :** In this system, under sluices may be kept open so that river supply in excess of the canal requirements is escaped. Top water passes into the canal while bottom water maintains a certain velocity in the pocket to keep the silt to remain in suspension. The advantage of this system is that the canal is not to be closed for scouring the silt.

7. Weir's Ancilary Works

8. Silt Control Devices

The entry of silt into a canal, which takes off from a head works, can be reduced by constructing certain special works, called *silt control works*.

Types of Silt Control Devices.

(*i*) **Silt Excluders :** These works are constructed on the bed of the river, upstream of the canal head regulation. Clear water enters the head regulator and silted water enters the silt excluder. Thus in this type of works silt is removed from the water before it enters the canal.

(*ii*) **Silt Ejectors or Silt Extractors :** These devices extract silt from the canal water after silted water has travelled a certain distance in the *off-taking canal*. Thus, these works are constructed on the bed of the canal, and a little distance downstream from the head regulator.

If friction can be reduced by constructing a smooth approach channel, more settlement of silt and its consequent removal, is possible. Again silt from the bottom layers can be removed by separating top layers and the bottom layers, without causing any disturbance to the flow. The chances of less disturbance and that of providing a smooth approach channel can be better attained in a canal rather than in the river bed. Hence, works which are constructed in the canal (*i.e.* silt ejectors) will definitely be superior and more effective than the works which are constructed in the river bed (*i.e.* silt excluders). Thus silt extractor is better than a silt excluder.

CANAL FALL

Whenever available natural ground slope is steeper than the designed bed slope of the channel, then difference is adjusted by constructing a some short of structure, called *canal fall* or *canal drop*.

Functions

(*i*) Lowering of water level structure
(*ii*) Energy decipiation device
(*iii*) Protection of bed in downstream side

Requirement for Design of Fall

(*i*) Velocity of approach should be minimum.
(*ii*) It should be able to admit variation of water level in canal.
(*iii*) Bed block and downstream portion of structure should be safe against erosion and damage due to excess energy of flow.

Site selection of Canal fall.

(*i*) Fall should be combined with road, rail to make it economical.
(*ii*) It should be combined with regulator.
(*iii*) Site of fall in distributaries and minor should be selected such that command is not effected.
(*iv*) Site of fall in main and branch canal should be such that earth work is minimum.
(*v*) Falls are provided on consideration of hydropower generation.

Main parts of Canal fall.

(*i*) Upstream approach channel
(*ii*) Throat
(*iii*) Downstream glacies
(*iv*) Downstream expansion
(*v*) Energy decipiation device

Types of Falls.

1. **Ogee fall :** The water was gradually led down by providing convex and concave curve
2. **Rapid fall**
3. **Stepped fall**
4. **Vertical fall**
5. **Sarda fall or Special fall.** It is a high crested fall, in which napple impignes into the water cushion below. There is no clear hydraulic jump and energy dissipation is brought about by the turbulent diffusion of the high velocity jet enters deep pivot of water downstream.
6. **Glacis fall**

SPILLWAYS

It is a structure constructed at a dam site, for effectively disposing of the dam surplus water from upstream to downstream.

It is a structure to divert excess water from upstream to downstream without causing any damage to the dam.

Requirements

It should fulfill following requirements :

(1) It should be able to pass the designed flood without raising the reservoir level above H.F.L.
(2) It should provide structural stability to the dam under all conditions of floods.
(3) Section of spillway should be economical.
(4) Operating of spillway should be efficient.

Location of Spillway

A spillway can be located either within the body of the dam or at one end of it or entirely away from it.

Controlled and Uncontrolled Spillway

The flow of water over a spillway may be controlled by installing gates over the spillway crest. In such a case, the spillway is called a *controlled spillway*, and if installing gate is not provided over a spillway crest then it is called *uncontrolled spillway*.

Cavitation

When operating head on the spillways is more than the designed head, lower nappe of the falling jet may leave the age probile, thereby generating negative pressure at the point and sepavate. The generation of negative pressure may be to formater of bubble on cavities in the mater. When cavities or bubble on bring downstream may enter the region of high pressure. When bubble coallapse then at the mean of boundaries abruptly increase very high pressure. This high pressure create fatigue of surface and rest cavit is formed. This process of formation of cavities is called *cavitation*. The action of *cavitation* is called *pitting*.

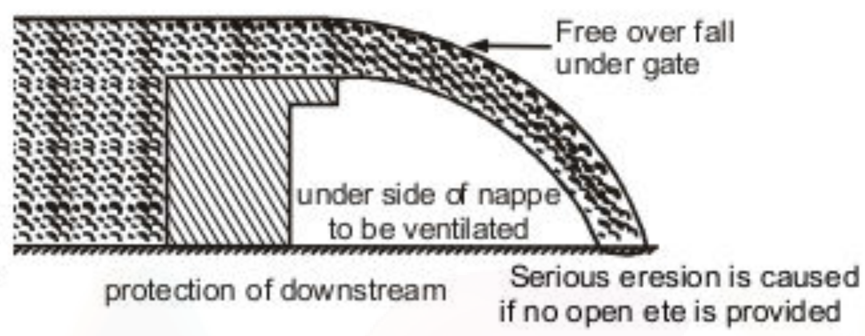
Classification of Spillways

1. Based on prominent feature, pertaining to either its control or discharge etc.

(*i*) Straight Drop Spillway or Overfall Spillway.

This is the simplest type of spillways, which may be constructed on small bends or on this arch dam.

The crest is sometimes extended in the form of an overhanging lip. The water falls freely from the crest under the action of gravity. Since vacuum get created in the under side portion of the falling jet,



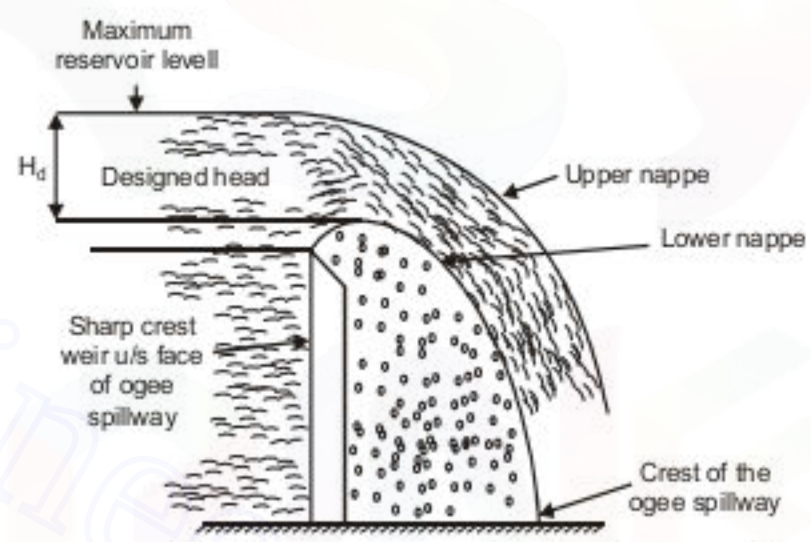
sufficient ventilation of the nappe is required in order to avoid pulsating and fluctuating effect of get.

(*ii*) Ogee Spillway or Overflow Spillway

It is an improvement upon the free overfall spillway.

It is widely used with concrete, masonary, arch and Buttress dam. It is least suitable for earthen dams.

But in practice actual head of water on the spillway crest called **operating head,** may be less or more than the designed head. If this operating head on the spillway is more than the designed head, lower napple of the falling jet may leave the ogee profile thereby generating negative pressure at the point of separation.



Structural design and stability requirement of ogee spillway are exactly the same as that of a gravity dam. Due to this reason, spillway is sometimes called *overflow portion of the dam*, and the real dam section is called *non-overflow section*.

Discharge passing over the ogee spillway is given by

$$Q = CL_e\, H_e^{3/2} = CL_e\, (H_d + H_a)^{3/2}$$

$$H_a = \frac{V_a^2}{2g}$$

where, V_a = velocity of approach = $\dfrac{\delta}{L \times (h + H_e)}$

L_e = effective length of the spillway

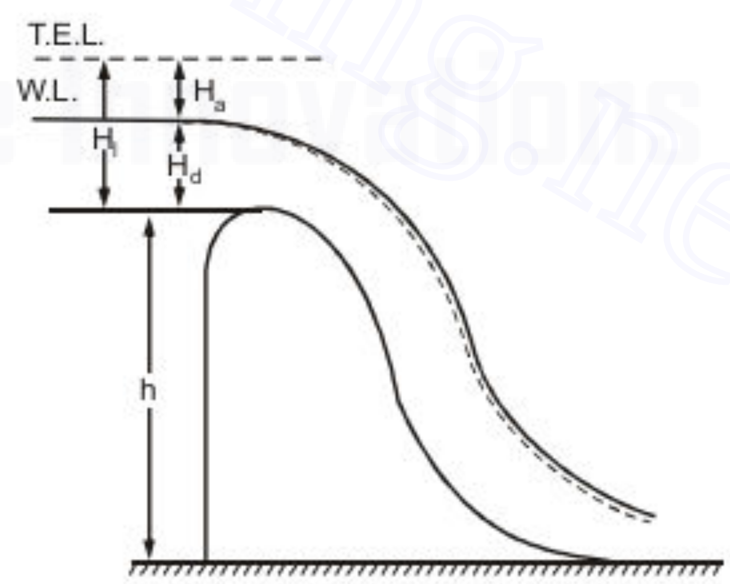
C = coefficient of discharge (2.2 for high spillway)

Q = discharge

H_e = total head over the crest including velocity head

= H_d for high ogee spillway

$$\frac{h}{H_d} > 1.33$$



Thus in a high spillway, effect of velocity head can be neglected.

$$\frac{h_d + d}{H_e} = \frac{H_e + h}{H_e} > 1.7$$

Discharge coefficient is not affected by tail water condition.

$$\text{Velocity of approach, } V_a = \frac{Q}{L \times (h + H_e)}$$

$$H_a = \frac{V_1^2}{2g}$$

Effective length (L_e) of Ogee spillway

$$L_e = L - 2\,[K_p N + K_a]\,H_e$$

where, L = net clear length of the spillway crest

K_p = pier contraction co-efficient

K_a = abutment contraction co-efficient

N = number of pier

H_e = total design head on the crest including velocity head

S. N	Pier Shape	K_p
1.	Square nosed piers without any rounding	0.1
2.	Square nosed piers with corners rounded on radius = 0.1 of pier thickness	0.02
3.	Rounded nose piers and 90° cut water nosed piers	0.01
4.	Pointed nose pier	0.0

S. N	Shape of abutment	K_a
1.	Square abutment with head wall at 90° to the direction of flow	0.2
2.	Roundex abutment with head wall at 90° to the direction of flow	0.1

Energy dissipation below Overflow spillway

Water flowing over the spillway acquires a lot of kinetic energy by the time it reaches near toe of the spillway (because of conversion of potential energy into kinetic energy). If arrangements are not made to dissipate this huge kinetic energy of the water, and if velocity of the water is not reduced, large scale scour can take place on the downstream side near toe of the dam and away from it. These arrangements are called *energy dissipation arrangements* or *energy dissipations*.

In general, kinetic energy of this super critical flow can be dissipated in two ways :

(*a*) By converting super critical flow into sub-critical flow by hydraulic jump.

(*b*) By directing flow of water into air and then making it fall away from the toe of the structure.

(*iii*) Chute Spillway or Trough Spillway

Chute spillway passes surplus discharge through a steep sloped open channel, called *chute or trough*, placed either along a dam abutment or through a saddle.

Their adaptability to almost any foundation condition and the overall economy often obtained by the use of large amounts of spillway excavation in the dam embankment.

Chute spillway can be adopted with ease on gravity as well as earthen dams.

In India, Bhakra dam is provided with **trough spillway** or **chute spillway**.

(*iv*) Side channel Spillway

In this spillway after passing over a weir or ogee crest, flow is carried away by channel running essentially parallel to the crest.

This spillway is suitable for earth or rock fill dams in narrow canyons and for other places where direct overflow is not possible.

(*v*) Shaft Spillway

This spillway has horizontally positioned lip through which water enters and then drops through a vertical or sloping shaft and then to a horizontal conduit which convey the water past the dam.

It can often be used where there is inadequate space for other types of spillway.

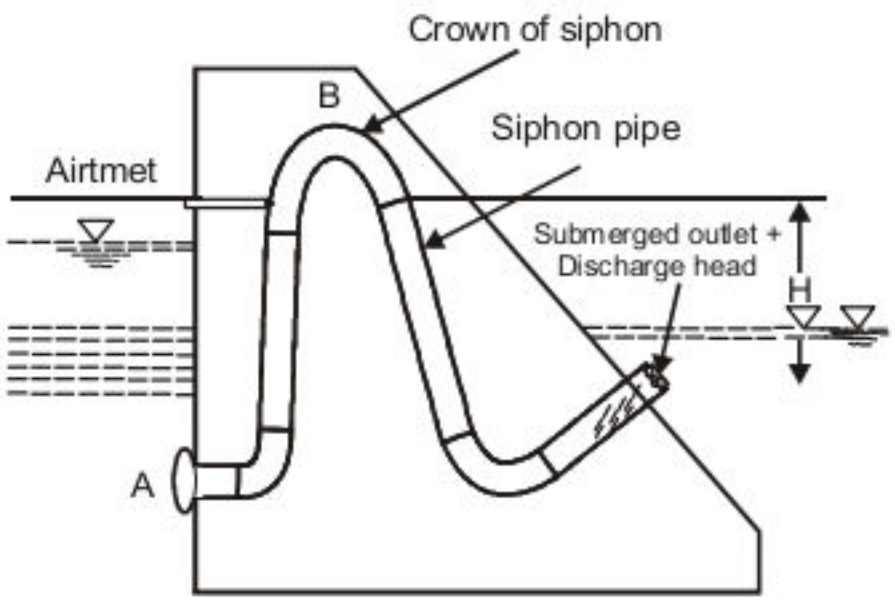
(*vi*) Siphon Spillway

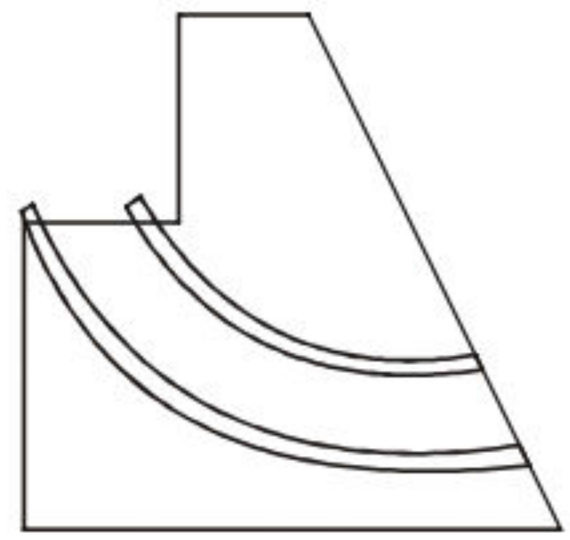
Instead of allowable water to spill over the crest of a dam or weir, surplus water may be discharged downward through a siphon spillway consisting of one or more siphon units. Siphon spillway utilizes siphonic action to discharge the surplus water.

These are of two types

(a) Saddle siphon spillway

(b) Volute siphon spillway





Discharge through saddle siphon , $Q = CA\sqrt{2gH}$

where , A = area of cross section at crown = L × *b,* where L is length and *b* is height of throat

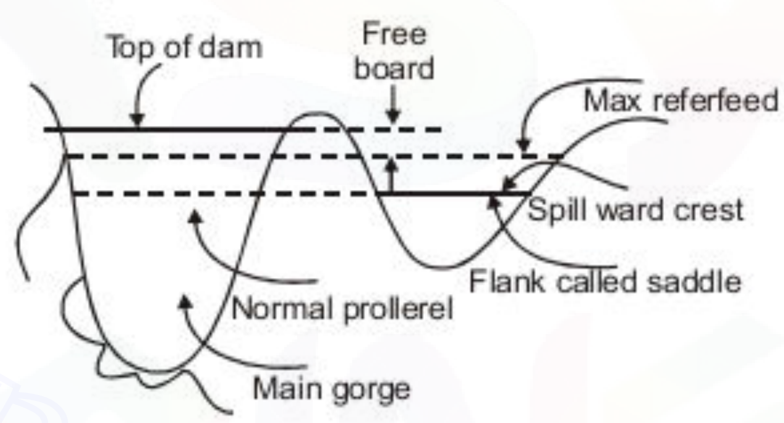
H = opening head

= Reservoir level – Centre of outlet, if outlet is discharged freely.

= Reservoir level – Downstream tailwater level, if outlet is submerged.

C = coefficient of discharge, the average value of which may be taken as 0.65.

2. Based on Utility



(*i*) Main Spillway

It is constructed to dispose off designed flood above the normal pool level and upto the maximum reservoir level. It is situated either **within the dam** or **at one end of it** or **independently** in a saddle away from the main dam.

A separate independent spillway is generally preferred for earthen dams.

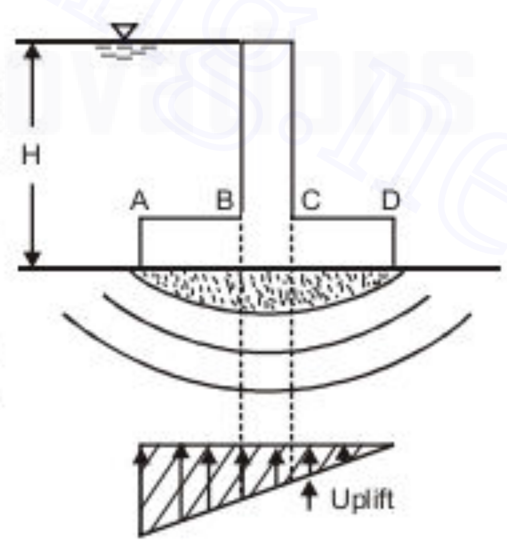
(*ii*) Emergency Spillway

DESIGN OF WEIRS AND BARRAGES

Failure of Hydraulic Structures Founded on Pervious Foundation

(1) Failure by Piping or Undermining

When seeping water retains sufficient residual force at the emerging downstream end of the work, it may lift up the soil particles. This leads to increased porosity of the soil by progressive removal of soil from beneath the found. The structure may ultimately subside into the hollow so formed, resulting in the failure of the structure.



Pressure diagram

(2) Failure by direct uplift

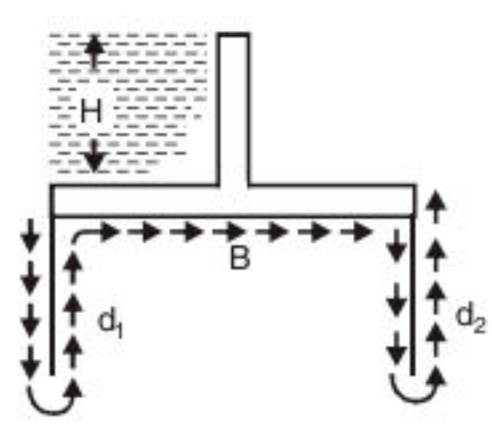
Water seeping below the structure, exerts an uplift pressure on the floor of the structure. If this pressure is not counterbalanced by weight of the concrete or masonry floor, the structure will fail by a rupture of a part of the floor.

(3) Failure by rupture of floor due to hydraulic jump

(4) Failure by scour on upstream and downstream of weir

Bligh's Creep Theory for Seepage Flow.

Bligh assumes that seeping water travels along vertical, horizontal and inclined path without making any distinction. Total length covered by percolating water till it emerges out at the down stream end is called *creep length.*



Here, Percolating length, $L = B + 2d_1 + 2d_2$

Head loss per unit length or hydraulic gradient $= \dfrac{H}{L} = \dfrac{H}{2d_1 + B + 2d_2}$

SAFETY OF HYDRAULIC STRUCTURES

(1) Safety against piping

Structure will be safe against piping when percolating water retains negligible upward pressure when it emerges out at down stream end.

$$L = CH$$

where, L = creep length

C = Bligh creep coefficient of soil

H = total head of water retained by the weir

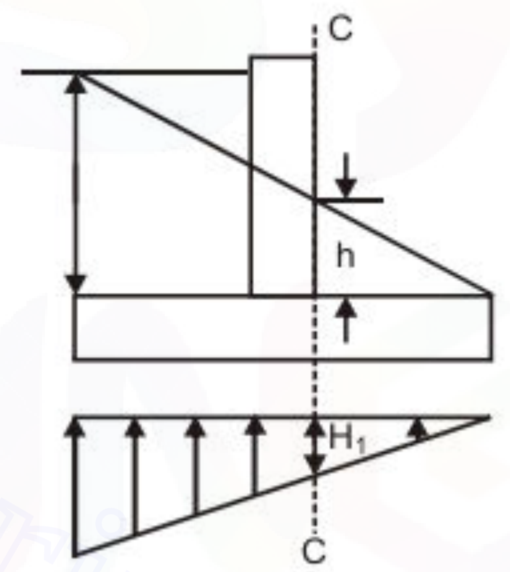
Values of Bligh's safe hydraulic gradients

S.No.	Type of soil	Value of C	Safe hydraulic gradient should be less than
1.	Silt and sandy soil	18	1/18
2.	North Indian river sand	15	1/15
3.	Coarse sand	12	1/12
4.	Sand mixed with boulder and gravel	5 – 9	1/5 to 1/9
5.	Loamy soil	5 – 9	1/5 to 1/9
6.	Gravel	5	1/5

For no piping, $$i = \frac{H}{L} \le \frac{1}{C}$$

i.e. $$\frac{\text{Head loss}}{\text{Creap length}} \le \frac{1}{C}$$

(2) Safety against uplift pressure



At critical section CC, uplift pressure = CH_1

Let t be the thickness of floor at critical section.

Downward pressure exerted by self weight of floor = $tG\gamma_w$

For stable condition, $\gamma_w H_1 = t\,G\gamma_w$

$\Rightarrow$ $H_1 = t\,G$

$\Rightarrow$ $H_1 - t = tG - t = t\,(G-1)$

$\therefore$ $$t = \frac{H_1 - t}{G-1} = \frac{h}{G-1}$$

where h = ordinate of uplift pressure above floor

Increase 33% so as to allow a suitable factor of safety (F.S.)

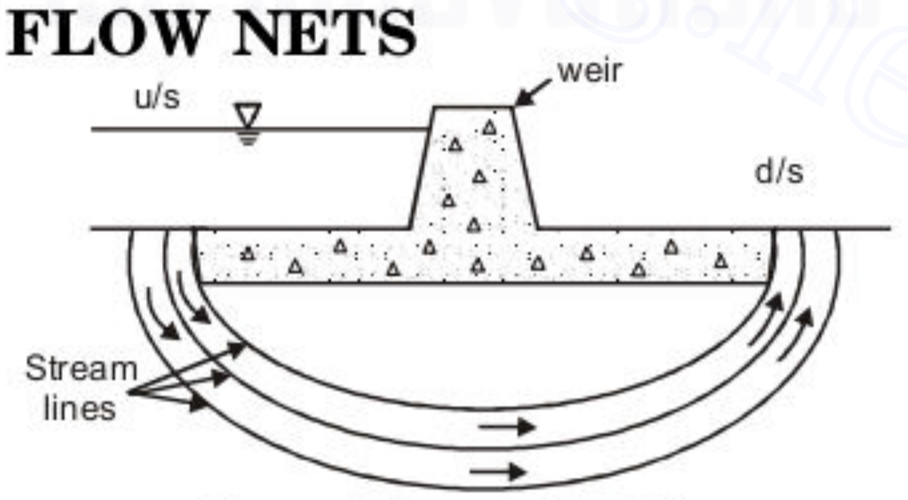
Taking factor of safety as 4/3, $$t = \frac{4}{3}\,\frac{H_1 - t}{G-1} = \frac{4}{3}\,\frac{h}{G-1}$$

KHOSLA'S THEORY AND CONCEPT OF FLOW NETS

Main principles

(1) The seeping water does not creep along the bottom contour of pucca floor as stated by Bligh, but this water moves along a set of streamlines. This steady seepage in a vertical place for a homogeneous soil can be expressed by Laplace equation.

$$\frac{d^2\phi}{dx^2} + \frac{d^2\phi}{dz^2} = 0, \quad \phi = kh$$



Seepage below weir Khosla theory

(2) This seepage water exerts a force at each point the direction of flow and tangential to the stream. For soil grains to remain stable, the upward component of this force should be counterbalanced by the sub-weight of the soil grain. This force has the maximum disturbing tendency at the exit end, because direction of this force at the exit point is vertically upward and hence full force acts as its upward component. The disturbing force at any point is proportional to the gradient of pressure of water at that point $\left(\frac{dp}{dl}\right)$. This gradient of pressure of water at exit is called **exit gradient**.

Critical Exit Gradient

Exit gradient is said to be critical when the upward disturbing force on the grain is just equal to the submerged weight of the grain at the exit.

$$I_e = \frac{I_c}{F \cdot S} = \frac{I_c}{4} \text{ to } \frac{I_c}{7}, \text{ so as to keep the structure safe against piping.}$$

Submerged weight of unit volume of soil, $W_{sub} = \gamma_{sub} \times 1 = \left(\frac{G-1}{1+e}\right)\gamma_w$

For critical condition occur at the exit point, $F = W_s$

where, F = pressure gradient at the point $= \frac{dp}{dl} = \gamma_w \frac{dh}{dl}$

$$\therefore \quad \gamma_w \frac{dh}{dl} = \left(\frac{G-1}{1+e}\right)\gamma_w$$

$$\therefore \quad I_C = \frac{dh}{dl} = \frac{G-1}{1+e}$$

Soil type	*F.S.*
Find sand	6 to 7
Coarse sand	5 to 6
Gravels	4 to 5

Take $e = 0.67$, and $G = 2.65$, $i_c = 1$

Values of Khosla's Safe Exit Gradient

Type of soil	Khosla's safe exit gradient
Shingles	0.25 to 0.20
Coarse sand	0.20 to 0.17
Fine sand	0.17 to 0.14

Hence safety against piping can not be obtained by providing sufficient floor length, as stated by Bligh, but can be obtained by keeping the **exit gradient well below the critical gradient.** The exit gradient may not be safe even in the average hydraulic gradient of Bligh (*i.e.,* $\frac{L}{C}$) is safe.

(3) The undermining starts only when the exit gradient is unsafe for the subsoil on which the weir is founded. It is therefore absolutely necessary to have a reasonably deep vertical cut off at the downstream end of the downstream pucca floor to prevent undermining.

The depth of this downstream vertical cut off is governed by two considerations:

(*i*) maximum depth of scour

(*ii*) safe exit gradient.

Note

(*i*) Weir or barrage may also fail due to surface flow.

(*ii*) Khosla's theory differs from Bligh's theory in all the above respects, but owing to the simplicity, Bligh's theory is still used for design of small works. A minimum practical thickness for the floor and a deep vertical cut off at the downstream end is, however always provided, in addition to the requirements of Bligh theory. However, on major works, Bligh's theory can never be used, as it would lead to expansive and erroneous designs.

DETERMINATION OF PRESSURE AND EXIT GRADIENT FOR SEEPAGE BELOW A WEIR BARRAGE

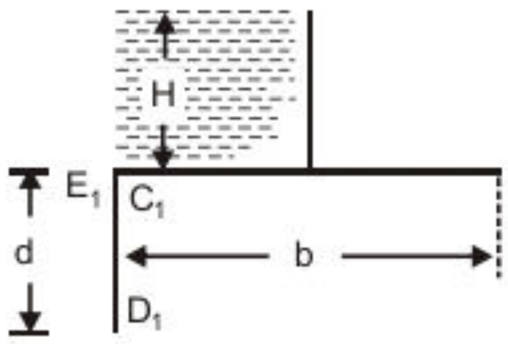
For designing hydraulic structure such as weirs barrage on previous foundations, Khosla has evolved a simple, quick and an accurate approach.

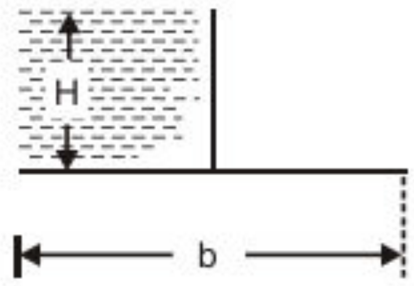
Khosla's method of independent variables

In this method, a complex profile is broken into a number of simple profiles, each of which can be solved mathematically. Mathematical solution of flow nets for these simple standard profiles have presented in the form of curves which can be used for determining the percentage pressures at the variables key points.

Most Useful Simple Profiles

(1) *Straight horizontal floor of negligible thickness with a sheet pile line on the upstream end and downstream end:*





$$\phi_{C_1} = 100 - \phi_E$$

$$\phi_{D_1} = 100 - \phi_D$$

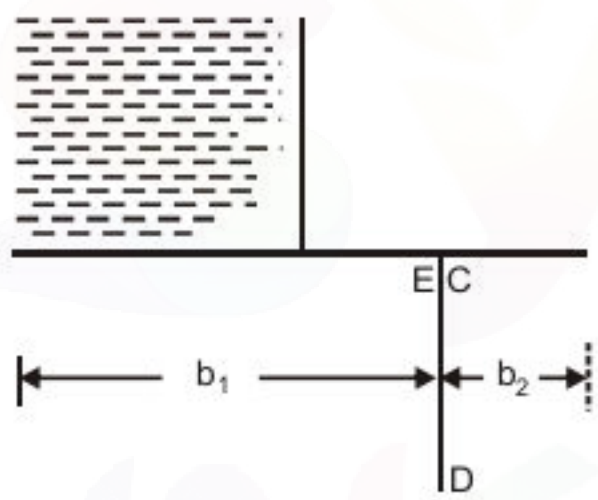
$$\lambda = \frac{b}{d}$$

$$\phi_E = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda - 2}{\lambda}\right)$$

$$\phi_D = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda - 1}{\lambda}\right)$$

$$\lambda = \frac{1 + \sqrt{1+\lambda}}{2}$$

(2) *Straight horizontal floor of negligible thickness with a sheet pile line at some intermediate point*



$$\phi_E = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda_1 - 1}{\lambda}\right)$$

$$\phi_D = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda_1}{\lambda}\right)$$

$$\phi_C = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda_2 + 1}{\lambda}\right)$$

where, $\lambda = \dfrac{\sqrt{1+\lambda_1^2} + \sqrt{1+\lambda_2^2}}{2}$, $\lambda_1 = \dfrac{\sqrt{1+\lambda_1^2} - \sqrt{1+\lambda_2^2}}{2}$

$\lambda_1 = \dfrac{b_1}{d}$, and $\lambda_2 = \dfrac{b_2}{d}$

(3) *Straight horizontal floor depressed below the bed but without any vertical cut-offs*

The percentage pressures at these key points for the simple forms into which the complex profile has been broken is valid for the complex profile itself, if corrected for

(*i*) mutual interference of piles

(*ii*) thickness of floor

(*iii*) slope of the floor.

These correction is applicable if Khosla's chart is used and also formula is used.

Correction for the mutual interference of piles

Correction C to be applied as percentage of head due to this effect, is given by

$$C = 19\sqrt{\frac{D}{b'}}\left[\frac{d + D}{b}\right]$$

where b' = distance between two pile lines.

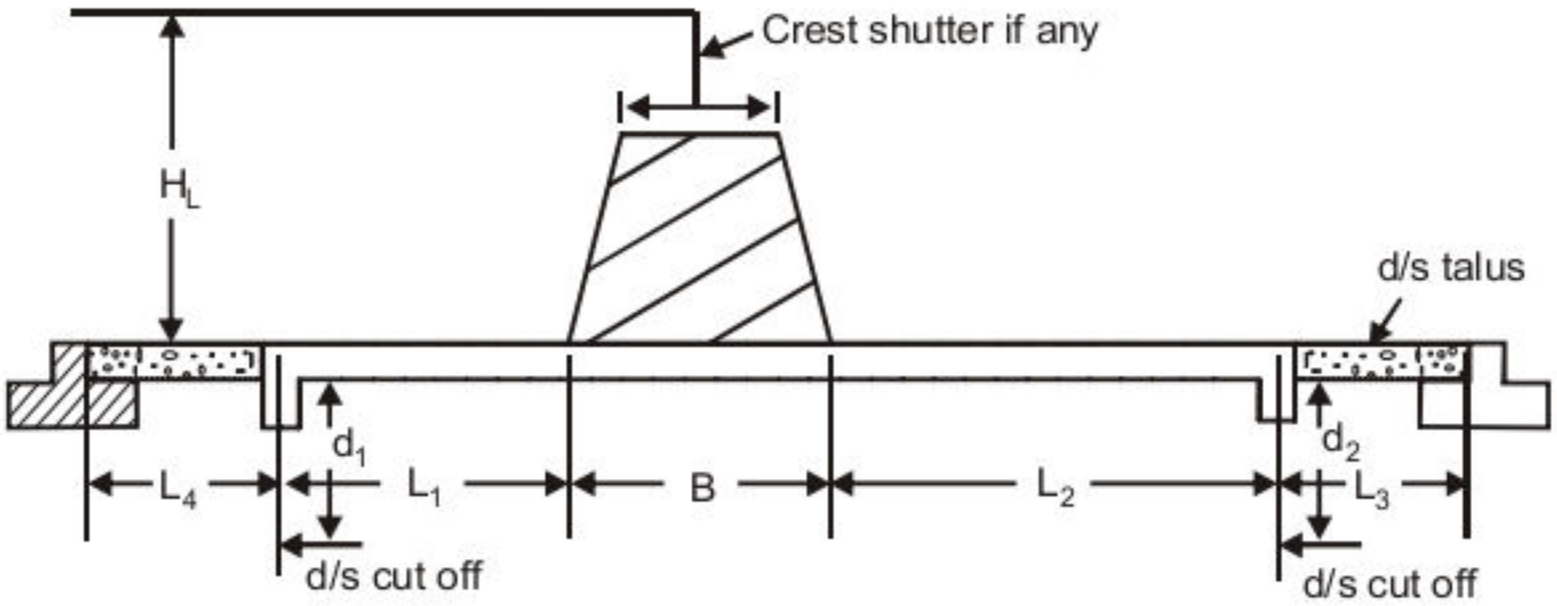
D = depth of the pile line, the influence of which has to be determined on the neighbouring piles of depth d. D is to be measured below the level at which interference is desired.

d = depth of the pile on which the effect is considered

b = total floor length.

Note : This correction is +ve for the points in the rear or back water and substrative for the points forward in the direction of flow. This equation does not apply to the effect of an outer pile on an intermediate pile, if the intermediate pile is equal to or smaller than the outer pile and is of a distance less than twice the length of the outer pile.

Pressure and Exit gradient for seepage below a weir or barrage on previous foundation



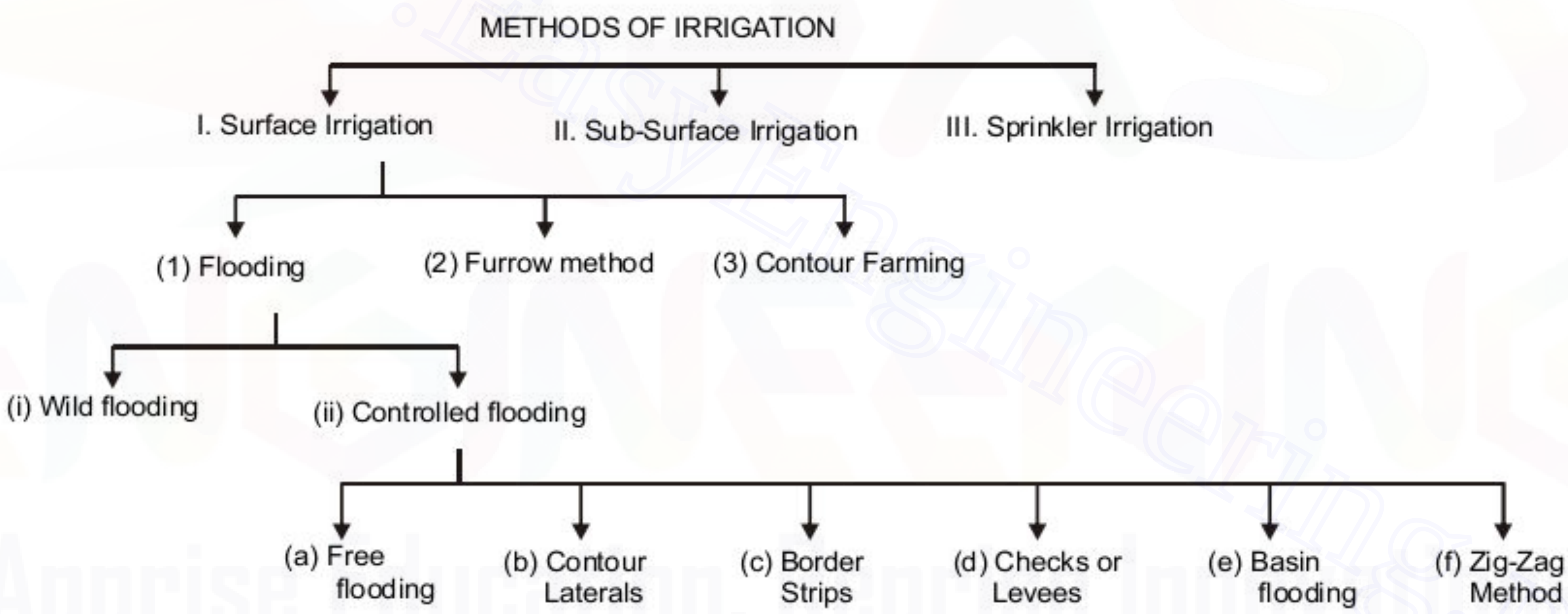
Drawback of Bligh theory:

(1) Bligh made no distinction between horizontal, vertical or inclined path of seepage.

(2) The idea of exit gradient has not been considered.

(3) The effect of varying length of sheet piles are not considered.

IRRIGATION METHODS



I. SURFACE IRRIGATION

1. Flooding

There are two types of flooding :

(*i*) Wild flooding

Water is spread on smooth flat land without much control or prior preparation.

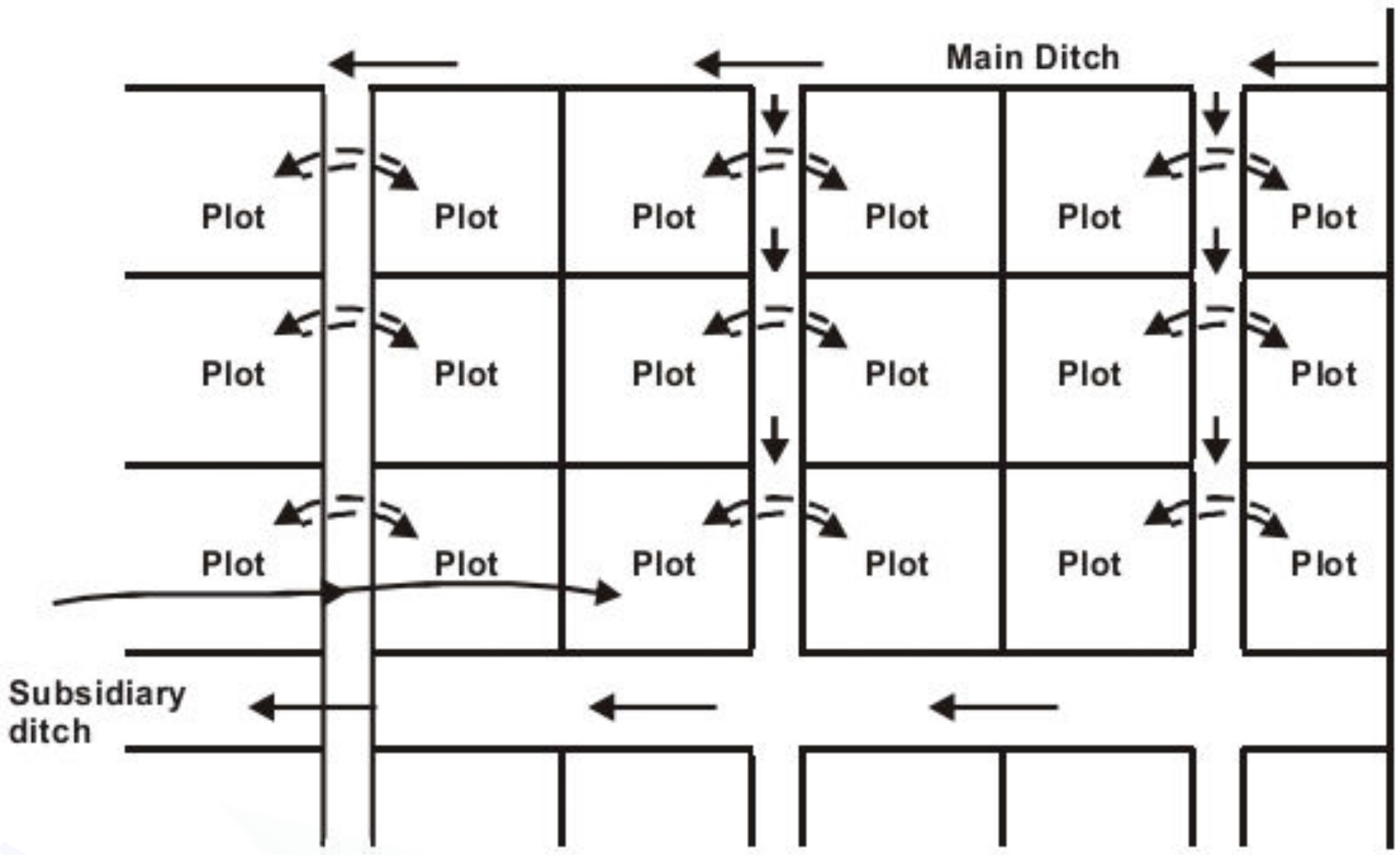
Used in inundation irrigation system.

(*ii*) Control flooding

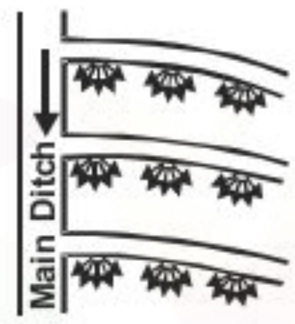
Water is spread over the land with proper methods to control the depth of application.

Methods of controlled flooding

(*a*) Free Flooding : In this method, field is divided into a number of small sized plots which are in level. Water is a admitted to those plots at a higher end and the supply is cutoff as soon as the lower part of plot with sufficient depth.

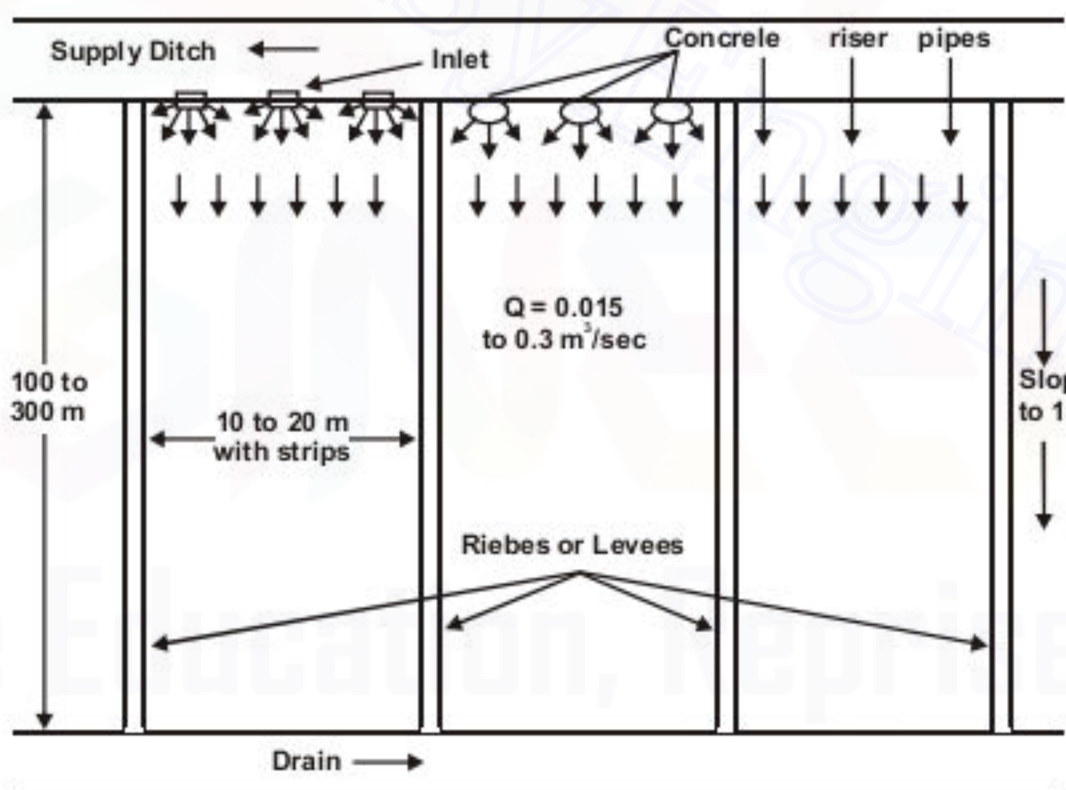


(*b*) Contour laterals



- This method is used in steeper field.
- The field is cut by dense network of small contour laterals.
- Spacing depends on grade of field, soil and uniformity of slopes.

(*c*) Borders strip method : Suitable for forage crops.



Length of strip depends upon

- Infiltration rate of soil
- Longitudinal slope of land
- Size of irrigation stream available

Length of strip	***Type of Soil***
1. 60-90m	For sandy soil
2. 90-150m	Medium silt loam
3. 150-300m	Clay loam or clayey soil

Method :

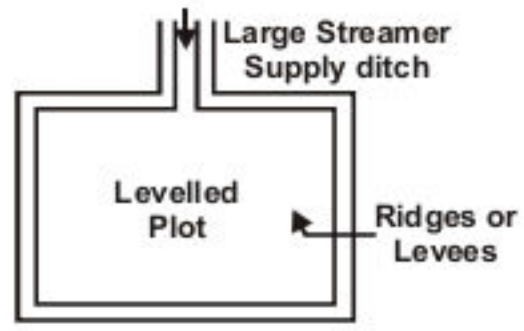
- Farm is divided into series of strips (10-20m wide and 100 to 300m long).
- These strips are separated by low levees or borders and run down to desired slope (0.5 to 1.5%).
- Water is turned from the supply ditch on to the head of border.

- Water advances-confined and guided by two borders in a thin sheet towards lower end of the strip.
- Surface is levelled between two borders so that advancing sheet of waters covers the entire width of the strip.

Advantages :

- Low investment
- Highest irrigation efficiency
- Lowest labour requirements
- Larger area can be irrigated within a short time

(*d*) Checks or Levees

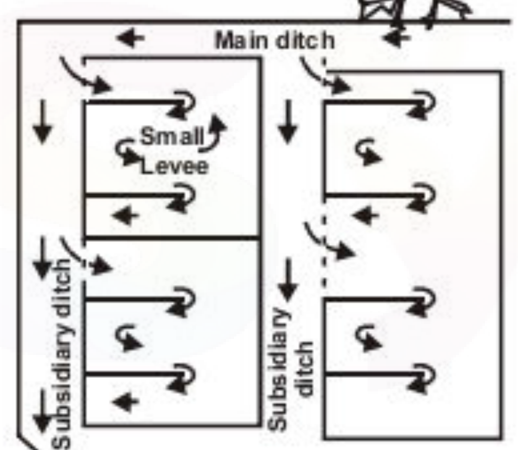


- A large stream discharges water into a relatively level plot surrounded by checks or levees.
- In a levelled ground, plots are generally rectangular but if ground has some initial slope; then checks may follow the contours.
- Suitable for pervious and impervious soils.

(*e*) Basin flooding

- This method is used in garden etc. or adopted to orchards.
- Basins are formed for each tree, one basin may be formed for 2 or more trees.
- Water is supplied to these basins through supply ditches.
- Portable pipes or large hoses may also be used in place of ditches.

(*f*) Zig-Zag method

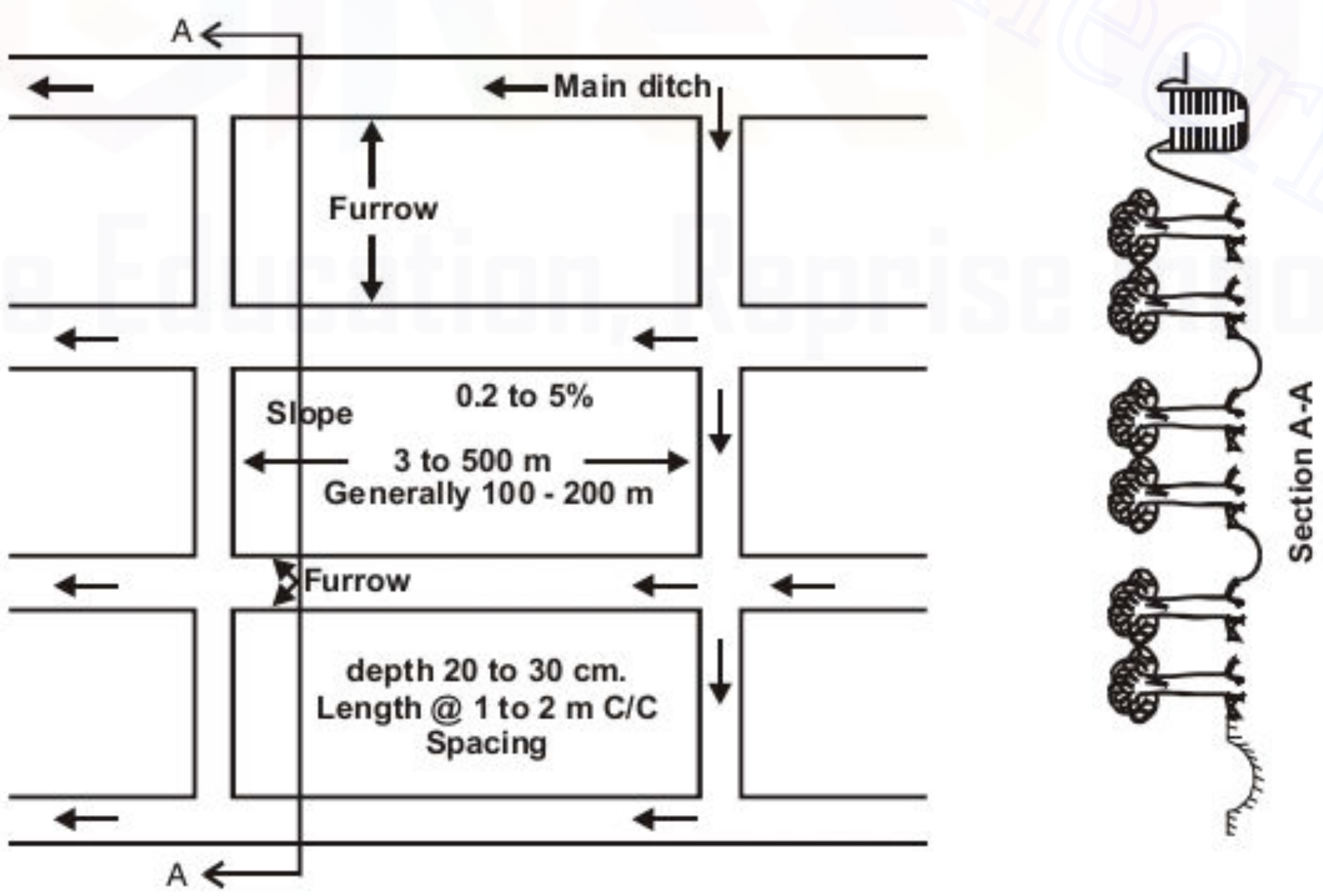


- Whole area is divided into a number of square or rectangle plots.
- Each plot is then sub-divided with the help of levees.
- This method is suitable for relatively level plots.

2. Furrow Irrigation

This method is very much used for raw crops like maize, jowar, sugarcane, cotton, tobacco, groundnut, potatoes etc.

Furrow consists of a narrow ditch between rows of plot. Furrows are sometimes made before planting, at time of planting or after plants have grown large enough not to be covered up.



Advantages

(*i*) Water contacts only $\frac{1}{5}$ to $\frac{1}{2}$ of the land surface, thereby reducing pudding and crushing of soil and evaporation losses.

(*ii*) Earlier cultivation is possible in heavy soil.

(*iii*) Labour requirements in land preparation and irrigation are very much reduced.

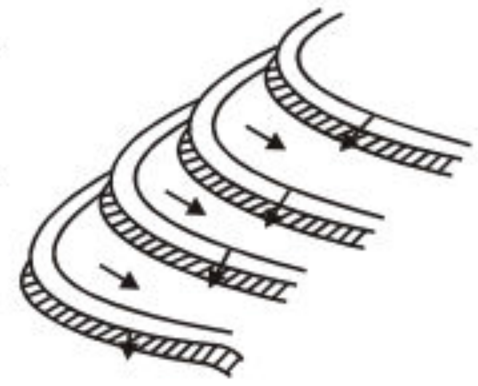
(*iv*) There is no wastage of land in field ditches.

(*v*) Specially suited for crops which may be injured (damaged) by contact with water.

3. Contour Farming

It is practised in hilly areas having steep slopes with quickly falling contours. It is the practice of conducting field operations such as ploughing, planting and cultivating land, across the slope rather than up and down hill.

Method



(*i*) Contour farming in practiced in hilly areas having steep slopes with quickly falling contours.

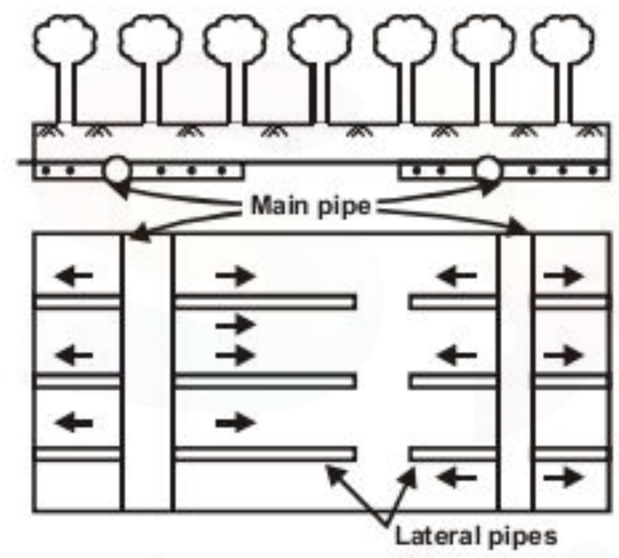
(*ii*) The area is divided into longitudinal curved plots, bends of the plots follow the contours.

(*iii*) The irrigation water stored in some depression higher up; flows between bunds.

(*iv*) Before starting contour farming, contour guidelines are established first.

(*v*) First contour should be laid about 1.2 to 1.5 m vertically below the top of the hill. Additional contour lines are located with the same spacing as the first.

II. SUB-SURFACE IRRIGATION



In this method water is supplied directly to the root zone of the crop.

Water is supplied to a series of ditches. Water flows at a slow rate and seeps into the ground to maintain water table at a height such that water from the capillary fringe is available to the crops.

Favourable condition for sub-surface irrigation:

(*i*) Impervious subsoil at depth 2 to 3 m or high water table.

(*ii*) Permeable soil in the root zone of the soil.

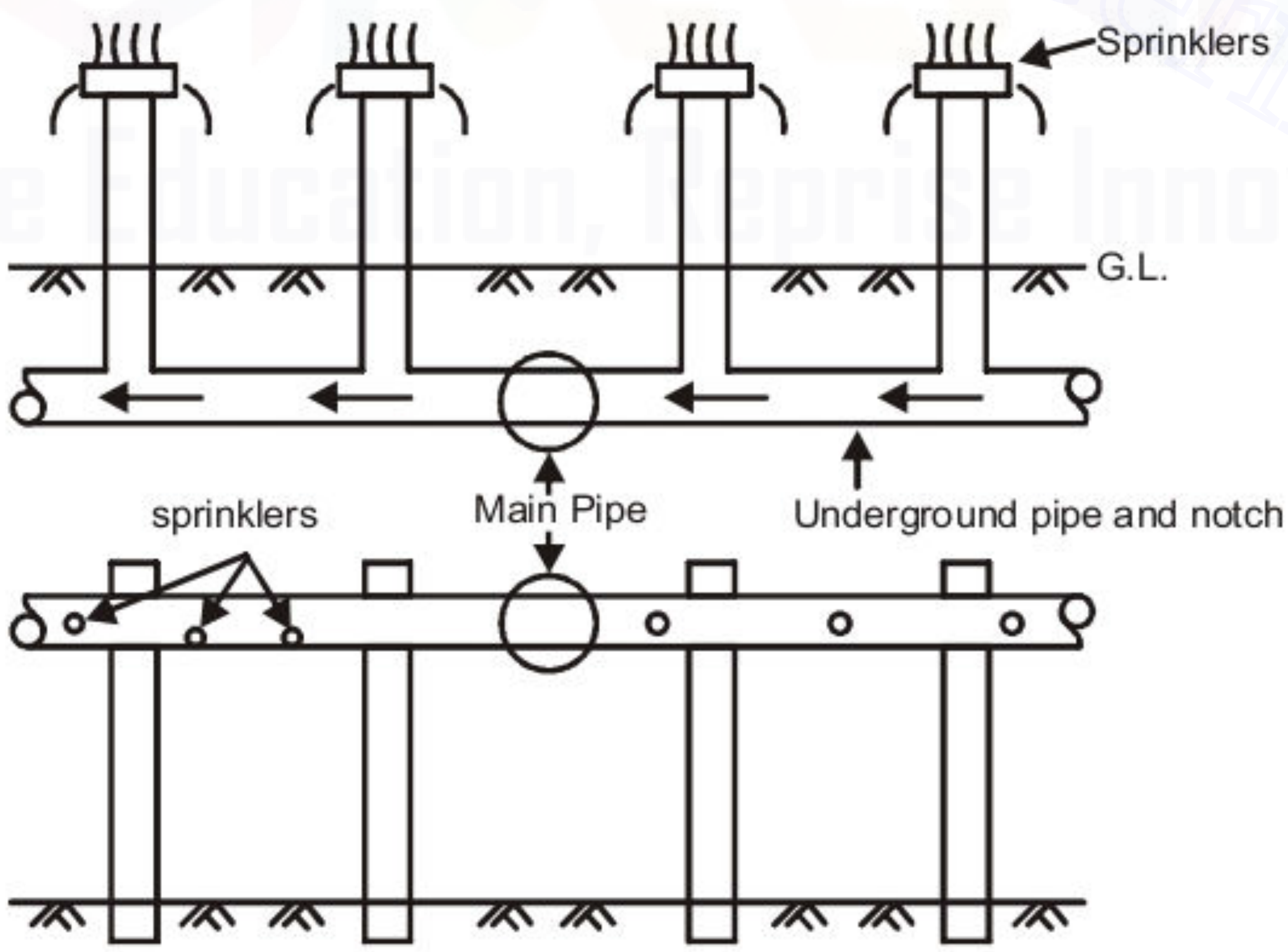
(*iii*) Uniform topographic condition

(*iv*) Good quality irrigation water.

III. SPRINKLER IRRIGATION

In this method, water is applying in the form of spray as in ordinary rain.

This method is used where surface irrigation method is not efficient.



Surface - Sprinkler pipe

Classification of Sprinkler Systems

1. **Permanent System**
   Pipes are permanently burried in such a way that they do not infer with tillage operation.
2. **Semi-permanent System**
   Main lines are burried while the lateral are portable.
3. **Portable System**
   This system has both portable main line and laterals.

This system is designed to be moved from around the farm from field to field.

A pump usually lifts the water from the source, pushes it through the distribution system and through the sprinkler nozzle on the sprinkler heads mounted on rising pipes attached to the laterals.

This method is more useful in following conditions

(*i*) Land cannot be prepared for surface methods.
(*ii*) Slopes are excessive.
(*iii*) Topography is irregular
(*iv*) Soil is erosive.
(*v*) Soil is excessive permeable or impermeable
(*vi*) Depth of soil is shallow over gravel or sand.

Advantages

(1) Erosion can be controlled.
(2) Uniform application of water is possible.
(3) Irrigation is better controlled.
(4) Land preparation is not required, labour cost is reduced, more land is available for cropping.
(5) Crop damage from frost can be reduced.
(6) Time and amount of fertilizer can be controlled.
(7) Small streams of irrigation water can be used efficiently.
(8) It is a stand by drainage pumping plant.
(9) Irrigation efficiency is high.
(10) Eliminates deep percolation losses.
(11) Used in undulating area and sandy soil area.

Limitations

(1) Wind may distort sprinkling pattern.
(2) A constant water supply is need for economical use of equipment.
(3) Water must be clean and free from sand etc.
(4) Initial investment is high.
(5) The power requirement is high.

WATER LOGGING AND DRAINAGE

Water Logging

An agricultural land is said to be water-logged, when its productivity gets affected by the high watertable. The productivity of land may become affected when root zone of plant gets flooded with water and thus become ill-aerated. Oxygen present in the air is not only needed by human beings, but is also needed by plants. The life of plants depend upon the nutrients like nitrates. The form in which the nitrates are consumed by the plants is produced by the bacteria, under a process called nitrification. These bacteria need oxygen for their survival. The supply of oxygen gets cut-off when the land becomes water-logged. Resulting in the death of these bacteria and fall in production of plants food (i.e. nitrates) and consequent reduction in plant growth, and hence, reducing crop yields.

Problems Created by Water-Logging

(1) Normal cultivation operations such as tilling, ploughing, etc. cannot be easily carried out in wet soils. In extreme cases, free water may rise above the surface of land, making the cultivation operations impossible. In ordinary language, such and land is called *swampy land*.

(2) Certain water loving plant like grass, weeds, etc. grow profusly and luxuriantly in water-logged lands, thus affecting and interfering with the growth of the crops.

(3) *Water-logging leads to salinity*

Causes of Water-Logging

(1) Over and intensive irrigation.

(2) Seepage of water from the adjoining high lands.

(3) Seepage of water through the canals.

(4) Impervious obstruction.

(5) Inadequate natural drainage.

(6) Inadequate surface drainage.

(7) Excessive rains.

(8) Submergence due to floods.

(9) Irregular or flat topography.

Water-Logging Control

It is evident that water-logging can be controlled only if quantity of water into the soil below is checked and reduced. To achieve this, the inflow of water into the underground reservoir should be reduced and the outflow from this reservoir should be increased.

Measures adopted for Water Logging Control

(1) Lining of canals and water courses.

(2) Reducing intensity of irrigation.

(3) Introducing crop-rotation.

(4) Optimum use of water.

(5) Providing intercepting drains.

(6) Provision of an efficient drainage system.

(7) Improving the natural drainage of the area.

(8) Introduction of lift irrigation.

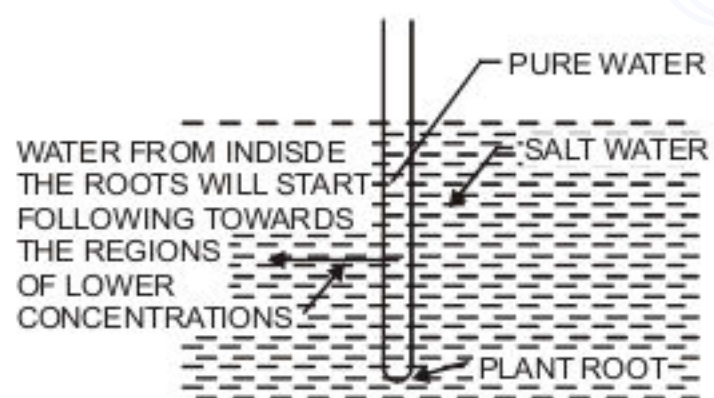
Saline Soil

Every agricultural soil contains certain mineral salts in it. Some of these salts are beneficial for plants as they provide the plant foods, while certain others prove injurious to plant growth. These injurious salts are called *alkali salts.*

e.g. NaCl, Na_2. SO_4 and Na_2CO_3. Na_2CO_4 is the most harmful and NaCl is the least harmful.

These salts are soluble in water. If water table rises up, or if plant roots happen to come within capillary fringe, water from the watertable starts flowing upward. The soluble alkali salts also move up with water and get deposited in the soil within the roots as well as on the surface of the land. This phenomenon of salts coming up in solution and forming a thin (5 to 7. 5 cm) crust on the surface, after the evaporation of water, is called *efforescence*. Land affected by *efforescence* is called *saline soil*. The salty water surrounding the roots of the plants reduces osmotic activity of plants.

Since plant roots act as semi-permeable membrane, so we have almost pure water on one side of the membrane, so we have almost pure water on one side of the membrane (*i.e.,* water already extracted by the roots) and highly concentrated salt solution on the otherside.



Water will start flowing out of the roots by *'osmosis'* and plant will die due to lack of water. Such a salt affected soil is unproductive and is called ***'Saline soil'.***

Alkaline Soil

If salt efforescence continues for a longer period, a base exchange reaction sets up, particularly if soil is clayey, thus sodiumising clay making it impermeable and, therefore, illaerated and highly unproductive. Such soils are called ***alkaline soils***. The reclamation of alkaline lands is more difficult.

Reclamation of Salt affected lands.

It is a process by which an unculturable land is made fit for cultivation. Saline and water logged lands given very less crop yields and are, therefore almost unfit for cultivation, unless they are reclaimed.

Efforescence can be avoided, if watertable is maintained sufficiently below the roots, so that capillary water is not able to reach the plant roots. Hence, all those measures which were suggested for preventing water-logging hold good for preventing salinity of lands also. An efficient drainag system consisting of surface drains as well as sub-surface drains must be provided in order to lower the watertable in saline lands. When high watertable has been lowered by suitable drainage, soil is freed from the existing salts by a process called *leaching*.

In leaching, land is flooded with adequate depth of water. The alkali salts present in the soil, get dissolved in this water, which percolate down to join the waterable or drained away by sub-surface drains. The process is repeated till salts in the top layer of land reduced to such an extent that some salt resistant crop can be grown. This process is called *leaching*. High salt resistant crops like rice or berseem are now grown on this leached land for one or two seasons or till the salinity is reduced to such an extent that an ordinary crop like wheat, cotton etc. can be grown. The land is then said to have reclaimed.

When sodium carbonate (Na_2CO_3) is present in the saline soil, gysum ($CaSO_4$) is generally added to the soil before leaching and thoroughly mixed with water. Na_2CO_3 reacts with $CaSO_4$ forming Na_2SO_4 which can be leached out.

LAND DRAINAGE

While designing a canal irrigation network, it is sometimes desirable to provide a suitable drainage system, so as to remove the excess water. This may be necessary in areas of high watertable and in river deltas, when irrigation facilities are extended to such areas. Drainage system is also required for draining out the strom water, and thus to prevent its percolation and to ensure easy disposal.

Types of Drainage

1. Surface Drainage or Open Drainage

It is the removal of excess water by using and constructing open ditches, field drains, land grading and related structures. When irrigation is extended to arid regions, drainage ditches are necessary to remove water required for leaching undesirable salts from the soil and to dispose of excess rainfall. The open drains, which are constructed in order to remove the excess irrigation water applied to the field, and the strom water, are broad and shallow and are called *shallow surface drains*. These drains carry runoff to the point of entrance to outlet ditches which are large enough to carry flood water and of sufficient depths to provide outlets for the underground drains. These outlet ditches may be called *Deep surface drains.* Surface drains constructed for removing excess irrigation water applied to the farms and the storm water, cannot and should not be deep enough as to interfere with agricultural operations. They are, therefore, designed as shallow surface drains.

Land grading, which resulting in continuous land slope towards the field drains, is an important part of a surface drainage system. *Shallow surface drains* are trapezoidal in cross-section. They should be designed to carry normal strom water, plus the excess irrigation water. Kutter's or Manning's equation may be used to design these drains keeping the velocity within the limits of critical velocity and thereby avoiding silting or scouring.

Deep surface drains or outlet ditches carry the seepage water coming from the tile drains, etc except during a storm. Thus, they are designed for the combined discharge. Generally, a *cunette* is provided in the centre of the drain-bed so as to carry the seepage water. A steeper slope is given to the cunette and it is lined so as to withstand higher flow velocities and thus to inhibit weed growth. The full section would be operative only during the storms.

Surface Inlet: The surface water from the pot holes, depressions, road ditches, farm steads, etc. may be removed either by connecting them with shallow surface drains called *Random field drains* or by constructing an intake structure called *open inlet* or *surface inlet*.

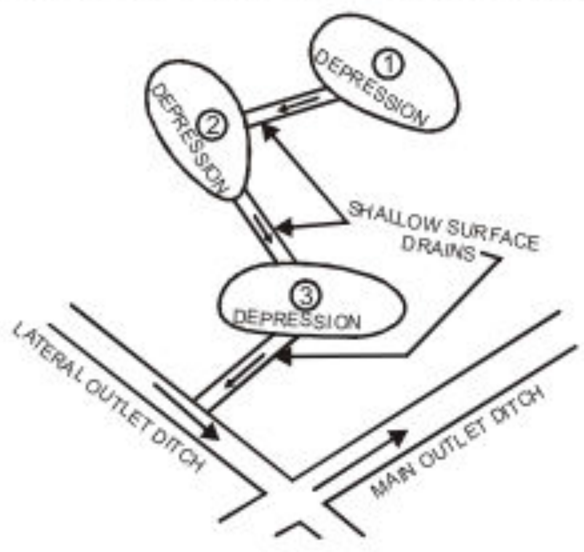


Fig. Random field-drain system for surface drainage

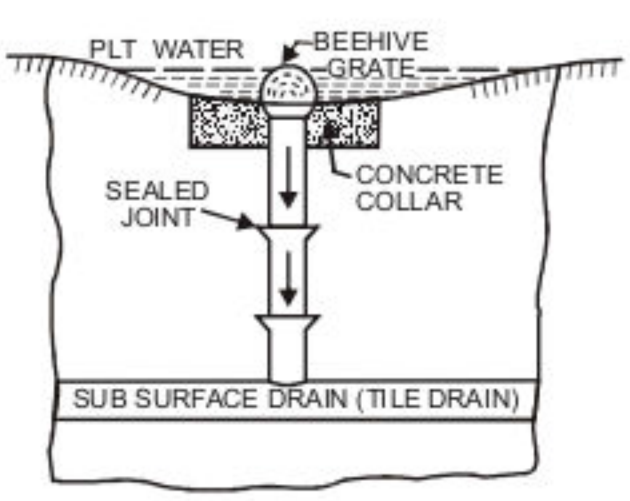
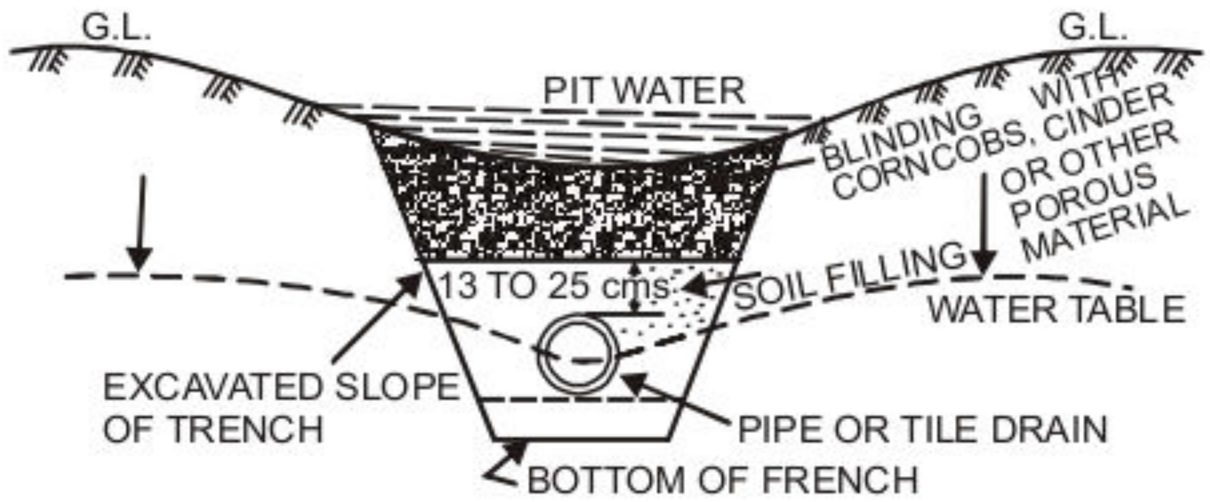


Fig. Surface inlet draining the surface water into a tile drain

Blend Inlet or French Drain : When quantity of water to be removed from pits or depressions is small, a blind inlet may be installed over the tile drain, called *blind inlet or French drain*. These are constructed by back filling the tile trench with graded materials such as gravel and coarse sand, or with corn cobs, straw and similar substances.



Bedding: It is a method of surface drainage which makes use of dead furrows. The area between two adjacent furrows is called *bed*. Depth of the bed depends on soil characteristics and tillage practices. In the bedded area, the direction of farming may be parallel or normal to dead furrows. Bedding is most parcticable on flat slopes of less than 15%, where soils are slowly permeable and the drainage is not economical.

Fig. Cross-section of bed showing method of construction

2. **Sub-surface Drainage or Tile Drainage**

   Sub-surface drain are required for soils with poor internal drainage and a high watertable. If no impervious layer occurs below the farm land and watertable is low, internal drainage may be sufficient and no tile drains needed. Thus for maximum productivity of most crops, both surface as well as sub-surface drains are essential.

   Tile drainage helps increasing crop yields by draining water or by lowering the watertable

   Water drained by the tile drains is discharged into some bigger ditches, called *deep surface drains*, either by gravity or by pumping.

Drainage Coeffcient (D.C.)

The rate at which the water is removed by a drain is called *drainage co-efficient*. It is expressed as the depth of water in cm. or meters, to be removed in 24 hours from the drainage area. *Drainage coefficient depends* upon rainfall but varies with the type of soil, type of crop, and degree of surface drainage, etc. Its recommended value is 1% of the effective rainfall of 24 hours. In irrigated areas, discharge through the tiles may vary between 10 to 50% of the total water applied. Since entire area is not irrigated at the same time, drainage area to be used to calculate tile flow is not the same as the entire tiled area, but is estimated from the area irrigated. A suitable value of dranage coefficient (DC) may be taken for calculations depending upon the local recommendations.

Values of DC been suggested for humid regions, by U.S. Soil Conservation Service :

- 1 cm/day to 2.5 cm/day for mineral soils
- 1.25 to 10 cm/day for organic soils for different crops

DRAINAGE AREA

The area actually drained by a tile drain is called its *drainage area*. Sometimes, surface water is also to be removed by the tile. In that case, watershed area will be the drainage area, even though it may not be entirely tiled.

SIZE OF TILE DRAINS

Tile drains are designed according to Manning's formula to carry a certain discharge decided by drainge coefficient and drainage area. Drains are laid on a certain longitudinal slope varying from 0.05 to 3% (say).

A desirable minimum working grade is 0.2%.

Where sufficient drainage area is available, the grade may be reduced to 0.1%.

Depending upon the available slope of the soil surface and the depth of the outlet, a suitable value of longitudinal slope can be given to the tiles. Their sizes can be easily evaluated from Manning's formula. 10 to 15 cm tiles are minimum recommended sizes. Minimum size for perforated tubing or pipes can be reduced, as in that case misalignment at joints or cracks is not a problem.

Drain Tile Material

(*i*) Clay (*ii*) Concrete (*iii*) Bituminous fibre (*iv*) Steel

EXERCISE – I

MCQ TYPE QUESTIONS

1. If kor depth for rice is 19cm and kor period is 14 days, then outlet factor for this will be
(*a*) 437 hectares/m^3/sec
(*b*) 637 hectares/m^3/sec
(*c*) 837 hectares/m^3/sec
(*d*) none of these

2. If wheat requires a total depth of 34.56 cm in 160 days, then outled factor will be
(*a*) 2000 hectares/m^3/sec
(*b*) 4000 hectares/m^3/sec
(*c*) 6000 hectares/m^3/sec
(*d*) 8000 hectares/m^3/sec

3. Index of wetness (x) and rainfall deficiency (y) at a place, are related by the equation
(*a*) $x = (100 - y)\%$ (*b*) $x = (10 + y)\%$
(*c*) $\frac{x}{y} = 100\%$ (*d*) none of these

4. Lime concrete lining is used
(*a*) when velocity of flow is below 2m/sec
(*b*) in irrigation channels with capacities upto 200 cumecs
(*c*) where economy is required
(*d*) all of these

5. Thickness of concrete lining, for discharge upto 200 cumes varies from
(*a*) 5 to 10 cm (*b*) 10 to 15 cm
(*c*) 15 to 20 cm (*d*) 20 to 30 cm

6. Forces cosidered for the analysis of an elementry profile of a gravity dam under empty reservoir condition are
(*a*) uplift pressure
(*b*) water pressure
(*c*) self-weight
(*d*) earthquake pressure

7. Uplift pressure acting on a dam is controlled by
(*a*) pressure grouting in foundation
(*b*) constructing drainage channels between dam and its foundation
(*c*) constructing cutoff under upstream face
(*d*) all of thene

8. In a gravity dam total force due to wave pressure acts at a height of
(*a*) $0.375\, h_w$ above the still water level
(*b*) $0.5\, h_w$ above the still water level
(*c*) $0.66\, h_w$ above the still water level
(*d*) $0.92\, h_w$ above the still water level
where h_w is height of wave

9. Horizontal acceleration due to earthquake results in
(*a*) hydrodynamic pressure
(*b*) inertia force into the body of the dam
(*c*) both (*a*) and (*b*)
(*d*) none of these

10. Vertical accleration due to earthquake results in
(*a*) increase in the effective weight of the dam
(*b*) a decrease in the effective weight of the dam
(*c*) both (*a*) and (*b*)
(*d*) none of these

11. Hydrodynamic pressure due to earthquke acts at a height of
(*a*) $\frac{3H}{4\pi}$ above the base
(*b*) $\frac{4H}{3\pi}$ above the base
(*c*) $\frac{4H}{3\pi}$ below the water surface
(*d*) $\frac{3H}{4\pi}$ below the water surface

12. In the elementary profile of a dam having empty reservoir condition, vertical stress at heels and toe respectively are given by

(*a*) 0 and $\frac{2W}{B}$ (*b*) $\frac{2W}{B}$ and 0

(*c*) $\frac{2B}{W}$ and 0 (*d*) 0 and $\frac{2B}{W}$

where B is base width and W is self-weight of unit length of dam

13. Base width of an elementary profile of a gravity dam, when uplift pressures is neglected, is given by

(*a*) $\frac{H}{\phi}$

(*b*) $\frac{H}{\sqrt{\phi}}$

(*c*) greater of $\frac{H}{\sqrt{\phi}}$ and $\frac{H}{\mu\phi}$

(*d*) lesser of $\frac{H}{\sqrt{\phi}}$ and $\frac{H}{\mu\phi}$

where H is depth of water, ϕ is specific gravity of dam material and is μ coefficient of friction

14. The focus of base parabola for a dam having a horizontal driange filter, is located from toe at distance of

(*a*) B/2 (*b*) *b*/2

(*c*) (B – *b*) (*d*) *b*

where B is base width of dams and b is width of horizontal drinage filter

15. In gravity dam, main overturning force is

(*a*) self weight of the dam

(*b*) wind pressure

(*c*) water pressure

(*d*) uplift pressure

16. On suitable foundation, earthen dam can be constructed upto a height of

(*a*) 50 m (*b*) 100 m (*c*) 150 m (*d*) 200 m

17. If *f* is allowable stress, w is unit weight of water, then limiting height of low gravity dam is taken as

(*a*) $\frac{f}{(f+c+1)}$ (*b*) $\frac{f}{(f-c+1)}$

(*c*) $\frac{f}{w(f-c+1)}$ (*d*) $\frac{f}{w(f+c-1)}$

18. In Ogee shaped spillway, discharge is proportional to

(*a*) H (*b*) $\sqrt{H}$ (*c*) $H^{3/2}$ (*d*) $H^{5/2}$

19. According to Lacey, depth of scour in case of a right angled bends is

(*a*) 1.414D (*b*) 1.667D

(*c*) 2D (*d*) 2.5D

20. Garrets diagrams are based on

(*a*) Lacey's theory (*b*) Kennedy's theory

(*c*) Khosla's theory (*d*) Bligh's theory

21. If base period for a particular crop is 50 days and duty of the canal is 500 hactares for per cumec, then depth of water will be

(*a*) 0.864 cm (*b*) 8.64 cm

(*c*) 86.4 cm (*d*) 864 cm

22. Value of Sodium Absorption Ratio for high sodium water lies between

(*a*) 0 to 10 (*b*) 10 to 18

(*c*) 18 to 26 (*d*) 26 to 34

23. The amount of irrigation water required to melt the evapotranspiration needs of the crop during its full growth is called

(*a*) effective rainfall

(*b*) consumptive

(*c*) consumptive irrigation requirement

(*d*) net irrigation requirement

24. Irrigation water having concentration of Na^+, Ca^{++} and Mg^{++} as 20, 3 and 1 milliequivalent per litre respectively will be classified as

(*a*) low sodium

(*b*) medium sodium water

(*c*) high sodium water

(*d*) very high sodium water

25. If electrical conductivity of water is in between 250 to 750 mho's/cm at 25°C, then its classified as

(*a*) low salinity water

(*b*) medium salinity water

(*c*) high salinity water

(*d*) very high salinity water

26. Total capacity of a reservoir is 25 million cubic metres and dead storage is 5 million cubic metres. If average volume of sediments deposition is 0.10 million cubic metre per year, then usefulness of the reservoir will start reducing after

(*a*) 50 years (*b*) 150 years

(*c*) 200 years (*d*) 250 years

27. A canal is 60 km long and has an average surface width of 15 m. If average evaporation measured in a standard VS weather Bureau class pan is 0.5 cm/day, then volume of water evaporation in the month of September is

(*a*) 136000 m^3 (*b*) 140000 m^3

(*c*) 94500 m^3 (*d*) 126000 m^3

28. In a triangular channel, top width and depth of flow were 2.0 m and 0.9 m respectively. Velocity measurements on the centre line at 18 cm and 72 cm below the free water surface indicated velocities of 0.6 m/s and 0.4 m/s respectively. The discharge in the channel is

(*a*) 0.54 cumecs

(*b*) 0.39 cumecs

(*c*) 0.45 cumecs

(*d*) 0.6 cumecs

29. The time required to irrigate a strip of area 0.203 hectare by a stream discharge of 0.043 cumec, for an average depth of 6.35 cm to the field is (assume average rate of infiltration to be 5 cm/h)

(*a*) 2.75 hour (approx.)
(*b*) 1.30 hour (approx.)
(*c*) 1.5 hour (approx.)
(*d*) 1.90 hour (approx.)

30. A soil has a field capacity of 35%, permanent wilting point of 25%, and specific weight of 14.0 kN/m^3. If root zone depth of the grown crop is 90 cm, then its available moisture holding capacity is

(*a*) 16.00 cm (approx.)
(*b*) 16.67 cm (approx.)
(*c*) 20.00 cm (approx.)
(*d*) 13.0 cm (approx.)

31. The area, on which crops are growing in a particular season, is called

(*a*) culturable commanded area (CCA)
(*b*) gross sown area
(*c*) net sown area
(*d*) none of these

32. If discharge required for different crops grown in a field is 0.3 cumecs, and capacity factor and time factor are 0.6 and 0.5, then design discharge for the distributary will be

(*a*) 0.60 cumecs (*b*) 0.15 cumecs
(*c*) 1 cumecs (*d*) 1.23 cumecs

33. The 6000 hectares of gross commanded area of an irrigation project includes 20% of reserved forests, user lands, roads etc. The pastures and fallow lands are 10%. If intensity of irrigation is 50%, then area to be irrigated is

(*a*) 6000 hectares (*b*) 3200 hectares
(*c*) 2200 hectares (*d*) none of these

34. An irrigation canal is to be designed to deliver 8.3 cumecs to meet the peak Rabi demand of a total of 8000 hectares of cropped area. The estimated canal losses are 25% of the head discharge. The duty an capacity of this canal will be

(*a*) 723.32 ha/cumecs (*b*) 800 ha/cumecs
(*c*) 594.64 ha/cumecs (*d*) 694.34 ha/cumecs

35. In order to ensure that no scouring takes place in the bed of a channel of bed slope S, constructed in an incoherent alluvium of size 'd' cm, the flow velocity should be restricted to

(*a*) $4.85 \times d^{\frac{1}{2}} \times S^{-\frac{1}{6}}$ (*b*) $4.85 \times d^{-\frac{1}{2}} \times S^{\frac{1}{6}}$

(*c*) $0.48 \times d^{\frac{1}{2}} \times S^{\frac{1}{6}}$ (*d*) $0.48 \times d^{\frac{1}{2}} \times S^{-\frac{1}{6}}$

36. In an earthen trapezoidal channel having side slopes of 1.5 H: 1 V, constructed in a non-cohesive soil, having D_{75} particle size of 'd' m, and angle $\phi = 37°$, no scouring will occur only when hydraulic mean depth (R) of the channel, is limited to

(*a*) $\dfrac{d}{33\,S}$ (*b*) $\dfrac{d}{11\,S}$

(*c*) $\dfrac{d}{21\,S}$ (*d*) none of these

37. Two irrigation channels, A and B, are designed on Lacey's theory to carry the same discharge. The alluvium through which canal A has to pass, however, is coarser than that for canal B. In such a design, we expect

(*a*) channel A to be deeper
(*b*) channel B to be deeper
(*c*) channel A to have larger wetted perimeter
(*d*) channel B to have larger crossed-sectional area

38. The meander belt for an alluvial stream is estimated to be 9 km. The peak discharge in this river will roughly be of the order of

(*a*) 40.60 cumecs
(*b*) 16.00 cumecs
(*c*) 13.77 cumecs
(*d*) 18.89 cumecs

39. If depth is 8.64 cm on a field over a base period of 10 days, then the duty is

(*a*) 10 hectarers per cu.m/s
(*b*) 100 hectarers per cu.m/s
(*c*) 864 hectarers per cu.m/s
(*d*) 1000 hectarers per cu.m/s

40. If Lacey's silt factor for a particular alhivium is 2.0, then this alluvium would comprise

(*a*) medium sand of size 0.5 mm
(*b*) coarse sand of size 0.75 mm
(*c*) medium bajri of size 1.3 mm
(*d*) coarse bajri of size 2.4 mm

41. The area between two isohytes 45 cm and 55 cm is 100 km^2, and that between 55 cm and 65 cm is 150 km. What is the average depth of annual precipitation over the basin of 250 km^2?

(*a*) 50 cm (*b*) 52cm
(*c*) 56 cm (*d*) 60 cm

42. The base width of a solid gravity dam is 25 m. The material of the dam has a specific gravity of 2.56 and the dam is designed as an elementary profile ignoring uplift. What is the approximate allowable height of the dam ?

(*a*) 64 m (*b*) 40 m
(*c*) 164m (*d*) 80 m

43. The moisture tension for a soil is 8 atmospheres. The soil is then at

(*a*) Permanent wilting point
(*b*) Field capacity
(*c*) Optimum moisture content
(*d*) Equivalent moisture

44. Consider the following terms relating to irrigation requirements :

1. Consumptive irrigation requirement
2. Net irrigation requirement
3. Field irrigation requirement
4. Gross irrigation requirement

For a given set up, which one of the following is the correct relation ?

(*a*) 1 > 2 > 3 > 4

(*b*) 1 < 2 < 3 < 4

(*c*) (1 = 2) < 3 < 4

(*d*) 1 < (2 = 3) < 4

NUMERICAL TYPE QUESTIONS

1. Fertility of soil is adversely affected, when the pH value is more than ______

2. Average delta of rice crop is nearly _____ cm

3. The duty of a crop is 432 hectares/cumec, when base period of the crop is 100 days. Delta for the crop will be _____

4. For economical design of a gravity dam, shear friction factor should be _____

5. Discharge coefficient of an Ogee-shaped spillway is ______

6. Out of 150 cm of water pumped into a canal 80 cum of water could be supplied to a field. If 60 cum of water in root zone while water required was stored in the root zone prior to irrigation was 80 cum, then storage efficiency of irrigation is _____ %

7. If average numerical deviation in the depth of water stored is 8 cm and average depth of water stored in root zone is 24 cm, then water distribution efficiency is ______ %

8. Cotton is grown in medium textured soil with available soil water of 100 mm/m depth of soil. If rooting depth is 1.5 m, fraction of available water is 0.65 and application efficiency is 0.65, then required depth of irrigation application will be equal to ______ mm

9. If a stream carrying a discharge of 4 cumecs per metre width is having a silt factor 2.0, then Lacey scour depth will be ______ m.

10. A channel designed by Lacey's theory has a mean velocity 1 m/s. If silt factor is unity, then hydraulic mean radius will be ______ m.

11. Following data were recorded from irrigated field :

Field capacity = 20%

Permanent wilting point = 10%

Permissible depletion of available soil moisture = 50%

Dry unit weight of soil = 1000 hgf/m^3

Effective rainfall : 25 mm

Based on these data, net irrigation requirement per metre depth of soil will be _____

12. During a flood in a wide rectangular channel it is found that at a section the depth of flow increases by 50 percent and at this depth the water surface slope is half its original value in a given interval of time. This marks an approximate change in the discharges of ________ %

13. A triangular direct run off hydrograph due to a storm has a time base of 80 hours, and a peak flow at 60 m^3/s occurring at 20 hours from the start. If the catchment area is 144 km^2, then rainfall excess in the storm was _____ m.

14. If concentration of Na^+, Ca^{++} and Mg^{++} in a water sample are 345, 60 and 18 mg/I respectively, then sodium absorption ratio (SAR) of this water will be _______

15. If irrigation efficiency at a 10 hectare field is 80%, and conveyance losses from the canal outlet is 10%, then volume of water required at the canal outlet, for supplying 10 cm water depth in the field, will be _______ kl

16. If in a certain irrigation project, and in a given year, 70% and 50% of the culturable command remained unirrigated in Kharif and Rabi seasons, respectively, then intensity of irrigation for that year and for that project, would be _____ %

17. The CCA for a particular state is 6 Mha; out of which, 4 Mha, is being shown in Rabi season and 3 Mha in Kharif season. These areas are being irrigated to the extent of 60% and 40% respectively. The annual intensity of irrigation for this state is _______ %

18. If a river in an alluvial plain has a dominant discharge of 8100 cumecs, the water way for this bridge in the absence of model testing, can be safely adopted, is equal to _____ m.

EXERCISE – II

(QUESTIONS FROM PREVIOUS GATE EXAMS)

MCQ TYPE QUESTIONS

2015

1. The two columns below show some parameters and their possible values

Parameter	Value
P. Gross Command Area	I. 100 hectares/cumec
Q. Permanent Wilting Point	II. 6°C
R. Duty of canal water	III. 1000 hectares
S. Delta of wheat	IV. 1000 cm
	V. 40 cm
	VI. 0.12

Which of the following options matches the parameters and the values correctly?

Codes :

	P	Q	R	S
(*a*)	I	II	III	IV
(*b*)	III	VI	I	V
(*c*)	I	V	VI	II
(*d*)	III	II	V	IV

2013

2. The transplantation of rice requires 10 days and total depth of water required during transplantation is 48 cm. During transplantation, there is an effective rainfall (useful for irrigation) of 8 cm. The duty of irrigation water (in hectares/cumec) is

(*a*) 612 (*b*) 216
(*c*) 300 (*d*) 108

2012

3. Wheat crop requires 55 cm of water during 120 days of base period. The total rainfall during this period is 100 mm. Assume the irrigation efficiency to bo 60%. The area (in ha) of the land which can be irrigated with a canal flow of 0.01 m^3/s is

(*a*) 13.82 (*b*) 18.85
(*c*) 23.04 (*d*) 230.40

2009

4. The depth of flow in an alluvial channel is 1.5 m. If critical velocity ratio is 1.1 and Manning's n is 0.018, the critical velocity of the channel as per Kennedy's method is

(*a*) 0.713 m/s (*b*) 0.784 m/s
(*c*) 0.879 m/s (*d*) 1.108 m/s

5. An agricultural land of 437 ha is to be irrigated for a particular crop. The base period of the crop is 90 days and the total depth of water required by the crop is 105 cm. If a rainfall of 15 cm occurs during the base period, the duty of irrigation water is

(*a*) 437 ha/cumec (*b*) 486 ha/cumec
(*c*) 741 ha/cumec (*d*) 864 ha/cumec

2008

6. A person standing on the bank of a canal drops a stone on the water surface. He notices that the disturbance on the water surface in not traveling upstream. This is because the flow in the canal is

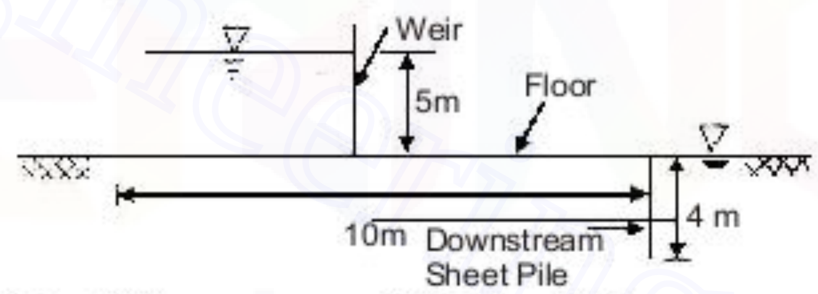
(*a*) sub-critical (*b*) super-critical
(*c*) steady (*d*) uniform

7. The base width of an elementary profile of gravity dam of height H is b. The specific gravity of the material of the dam is G and uplift pressure coefficient is K. The correct relationship for no tension at the heel is given by

(*a*) $\frac{b}{H} = \frac{1}{\sqrt{G-K}}$ (*b*) $\frac{b}{H} = \sqrt{G-K}$

(*c*) $\frac{b}{H} = \frac{1}{G-K}$ (*d*) $\frac{b}{H} = \frac{1}{K\sqrt{G-K}}$

8. A weir on a permeable foundation with downstream sheet pile is shown in the figure below. The exit gradient as per Khosla's method is



(*a*) 1 in 6.0 (*b*) 1 in 5.0
(*c*) 1 in 3.4 (*d*) 1 in 2.5

9. An outlet irrigates an area of 20 ha. The discharge (l/s) required at this outlet to meet the evapotranspiration requirement of 20 mm occurring uniformly in 20 days neglecting other field losses is

(*a*) 2.52 (*b*) 2.31
(*c*) 2.01 (*d*) 1.52

2007

10. The consumptive use of water for a crop during a particular stage of growth is 2.0 mm/day. The maximum depth of available water in the root zone is 60 mm. Irrigation is required when the amount of available water is 50% of the maximum available water in the root zone. Frequency of irrigation should be

(*a*) 10 days (*b*) 15 days
(*c*) 20 days (*d*) 25 days

2006

11. In a cultivated area, the soil has porosity of 45% and field capacity of 38%. For a particular crop, the root zone depth is 1.0 m, the permanent wilting point is 10% and the consumptive use is 15 mm/*d*. If the irrigation efficiency is 60%, what should be the frequency of irrigation such that the moisture content does not fall below 50% of the maximum available moisture ?

(*a*) 5 *d* (*b*) 6 *d*

(*c*) 9 *d* (*d*) 15 *d*

NUMERICAL TYPE QUESTION

2014

1. Irrigation water is to be provided to a crop in a field to bring the moisture content of the soil from the existing 18% to the field capacity of the soil at 28%. The effective root zone of the crop is 70 cm. If the densities of the soil and water are 1.3 g/cm^3 and 1.0g/cm^3 respectively, the depth of irrigation water (in mm) required for irrigating the crop is ________

ANSWERS

EXERCISE – I

MCQ Type Questions

1. (*b*)	**2.** (*b*)	**3.** (*a*)	**4.** (*d*)	**5.** (*b*)	**6.** (*c*)	**7.** (*d*)	**8.** (*a*)	**9.** (*c*)	**10.** (*c*)
11. (*b*)	**12.** (*b*)	**13.** (*c*)	**14.** (*d*)	**15.** (*c*)	**16.** (*d*)	**17.** (*c*)	**18.** (*c*)	**19.** (*c*)	**20.** (*b*)
21. (*c*)	**22.** (*c*)	**23.** (*c*)	**24.** (*b*)	**25.** (*b*)	**26.** (*a*)	**27.** (*c*)	**28.** (*c*)	**29.** (*b*)	**30.** (*d*)
31. (*d*)	**32.** (*c*)	**33.** (*d*)	**34.** (*a*)	**35.** (*d*)	**36.** (*c*)	**37.** (*b*)	**38.** (*c*)	**39.** (*d*)	**40.** (*c*)
41. (*c*)	**42.** (*b*)	**43.** (*a*)	**44.** (*c*)						

Numerical Type Questions

1. (11)	**2.** (120)	**3.** (200)	**4.** (0.65)	**5.** (2.2)	**6.** (75)	**7.** (66.67)
8. (150)	**9.** (2.7)	**10.** (2.5)	**11.** (125)	**12.** (39)	**13.** (6)	**14.** (10)
15. (13,800)	**16.** (80)	**17.** (60)	**18.** (684)			

EXERCISE – II

MCQ Type Questions

1. (*b*)	**2.** (*b*)	**3.** (*a*)	**4.** (*b*)	**5.** (*d*)	**6.** (*b*)	**7.** (*a*)	**8.** (*c*)	**9.** (*b*)	**10.** (*b*)
11. (*c*)									

Numerical Type Question

1. (91 to 91)

EXPLANATIONS

EXERCISE – I

MCQ TYPE QUESTIONS

21. $\Delta = 864\,\frac{B}{D} = 864 \times \frac{50}{500} = \mathbf{86.4\ cm}$

22.
$$SAR = \left[\frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}\right]$$

$$S_1 = 0 - 10$$
$$S_2 = 10 - 18$$

all crops except sensitive to sodium

$$S_3 = 18 - 26$$
$$S_4 > 26$$

23. It is equal to consumptive use-effective rainfall.

24. Sodium absorption ratio

$$= \left[\frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}\right] = \left[\frac{20}{\sqrt{\left(\frac{3+1}{2}\right)}}\right] = 14.14$$

which lies between 10 and 18

S_2 : (10 – 18) which is medium salinity

25. C_1: (100 – 250) mhos/cm–all crops low salinity

C_2: (250 – 750) mhos/cm–can be used when moderate amount of leaching occurs.

C_3: (750 – 2250)mhos/cm–only high salt tolerant soil

C_4: 2250 and above mhos/cm–unsuitable for irrigation

26. Dead storage = 5 million m^3

Average volume of sediments deposited = 0.10

$$\text{Usefulness} = \left[\frac{5}{0.1}\right] = 50 \text{ years.}$$

27. Actual evaporation from canal during September month

= (Area of canal) × Evaporation rate × Number of days × Pan coeff.

$$= (60 \text{ km} \times 15 \text{ m})\left(\frac{0.5 \text{ m}}{100 \text{ day}} \times 0.7\right) \times 30 \text{ days}$$

$$= \left[60000 \times 15 \times \frac{0.35}{100} \times 30 \text{ m}^3\right] = \mathbf{94500\ m^3}$$

28. Velocity at 0.2 y depth

= – velocity at 0.18 m depth = 0.6 m/s

Velocity at 0.8 depth

= velocity at 0.72 m depth = 0.4 m/s

$$\text{Average mean velocity} = \frac{0.6 + 0.4}{2} = 0.5 \text{ m/s}$$

$$\text{Area of channel, A} = \frac{1}{2} \times (2.0 \text{ m} \times 0.9\text{m}) = 0.9 \text{ m}^2$$

Discharge, Q = V . A

= 0.5 m/s × 0.9 m^2 = 0.45 m^3/s = **0.45 cumecs**

29.
$$T = 2.3 \times \frac{y}{f} \log_{10}\left(\frac{Q}{Q - f.A}\right)$$

where, A = 0.203 ha = 2030 m^2

Q = 0.043 cumecs = 0.043 × 60 × 60 m^3/h

= 154.8 m^3/h

f = 5 cm/hr = 0.05 m/h

y = 6.35 cm = 0.0635 m

$$\therefore \quad T = 2.3 \times \frac{0.0635}{0.05} \log\left(\frac{154.8}{154.8 - 0.05 \times 2030}\right)$$

= **1.30 h**

30. Specific weight means unit weight = 14.0 kN/m^3

Unit weight of water = 9.8 kN/m^3

Available moisture holding capacity of root zone

$$= \frac{yd}{w}(\text{F.C. } m.c. - \text{ wilting point m.c.})$$

$$= \frac{\left[\dfrac{14.0\, k\text{N}/\text{m}^2}{g}\right]}{\dfrac{9.8 \text{ kN}/\text{m}^2}{g}} \times (0.9 \text{ m})\,[35\% - 25\%]$$

= 1.5 × (0.9 m) × 10% = 0.130 m = **13.0 cm**

31. Such an area may be called *seasonal cropped area*, or *seasonal sown area*, such as Rabi area or Kharif area.

Net sown area is the total cropped area (which is only cropped once) in the entire year, *i.e.* in both the seasons.

32. Required discharge (mean) in the field = 0.3 cumecs Peak discharge required

$$= \frac{\text{Mean discharge}}{\text{Capacity factor}} = \frac{0.3}{0.6} \qquad \left[\because \text{CF} = \frac{Q_{mean}}{Q_{peak}}\right]$$

= 0.5 cumecs

Since channel runs for lesser days than the crop days, the required channel discharge should be more.

∴ Design discharge for distributary

$$= \frac{\text{Required discharge for crops}}{\text{Time factor}}$$

$$= \frac{0.5}{0.5} = \mathbf{1\ cumecs.}$$

33. CCA = GCA – reserve forests

= 6000 – 20 × 6000/100 = 4800 hect.

Area under irrigation

= CCA × Intensity of irrigation

= 4800 × 0.5 = **2400 hectares**

34. Discharge required at head of canal

$$= \frac{8.3 \text{ cumecs}}{0.75} = 11.06 \text{ cumecs}$$

Area irrigated = 8000 hectares

Duty on capacity

$$= \frac{\text{Area to be irrigated during base period}}{\text{Design full supply discharge at its head during peak demand}}$$

$$= \frac{8000}{11.06} = \mathbf{723.32\ ha/cumecs.}$$

35. For non-scouring

$$R_{max} = \frac{d}{11S}$$

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

$$\text{But} \quad N = \frac{1}{24}d^{1/6}$$

$$\therefore \quad V = \frac{24}{d^{1/6}} \times R^{2/3}.S^{1/2}$$

$$V_{max} = \frac{24}{d^{1/6}} \times R^{2/3}{}_{max} \times S^{1/2}$$

$$= \frac{24}{d^{1/6}} \times \left(\frac{d}{11\,S}\right)^{2/3} \times S^{1/2}$$

$$= \frac{24}{(11)^{2/3}} \times d^{2/3 - 1/6} \times S^{1/2 - 2/3}$$

$$= 4.85\, d^{1/2} \times S^{-1/6} \text{ where } d \text{ is in } m$$

When d is in cm, then

$$V_{max} = 4.85\left(\frac{d \text{ cm}}{100}\right)^{1/2} \times S^{-1/6}$$

$$= 0.485\, d^{1/2} \times S^{-1/6}$$

$$\Rightarrow \quad V_{max} \approx 0.48\, d^{1/2} \times S^{-1/6}$$

36. For 1.5 H : 1V, $\tan\theta = \frac{y}{n} = \frac{1}{1.5}$

$$\sin\theta = 0.554$$

$$\frac{\tau_c'}{\tau_c} = \sqrt{1 - \frac{\sin^2\theta}{\sin^2\theta}}$$

$$= \sqrt{1 - \left(\frac{0.554}{\sin 37^\circ}\right)^2} = \sqrt{0.153} = 0.391$$

For stability on banks,

$$0.75\,\text{yRS} \le 0.391\,\tau_c \le 0.391\,(\text{yRS})$$

For stability on bed, $\text{RS} = \frac{d}{11}$

$$\therefore \quad 0.75\,y\,\text{RS} \le 0.391\,.\,y\frac{d}{11}$$

$$\Rightarrow \quad \text{RS} \le \frac{0.391}{11 \times 0.75}d$$

$$\Rightarrow \quad \text{RS} \le \frac{d}{21}$$

$$\Rightarrow \quad \text{R} \le \frac{d}{21\text{S}}$$

37. *Given* : $Q_A = Q_B, f_A > f_B$

Now since, $V = \left(\frac{Qf^2}{140}\right)^{1/6}$,

and $P = 4.75\sqrt{Q}$

$\therefore \quad V_A > V_B$

$P_A = P_B$

Since Q in same,

$A_A < A_B$

and since $R = \frac{A}{P}$

$R_A < R_B$ or $R_B > R_A$

i.e. channel B has more hydraulic radius for the same wetted perimeter, and this happens only when the channel has more depth (deeper channels are more hydraulically efficient).

$\therefore \quad y_b > y_A$

Hence, choice (*b*) is the correct choice.

38. Meander belt, $M_B = 9\text{ km} = 9000\text{ m}$

Also $M_B \approx 150\sqrt{Q_{\text{dominant}}}$

$$\therefore \quad 9000 = 150\sqrt{Q_{\text{dominant}}}$$

$$\Rightarrow \quad \sqrt{Q_{\text{dominant}}} = \frac{9000}{150} = 60$$

$$\Rightarrow \quad Q_{\text{dominant}} = 7.745\text{ cumecs}$$

$$\therefore \quad Q_{\max} = \frac{16}{9} \times 7.745 = \mathbf{13.77\ cumecs}$$

39. Duty, $D = \frac{8.64\,B}{\Delta} = \frac{864 \times 10}{8.64} = 1000$

40. $f = 1.76\sqrt{d}$

$\Rightarrow \quad d = 1.3\text{ mm}$

41. Given, area between two isohytes 45 cm and 55 cm is 100 km²

$$P_1 = \frac{(45+55)}{2} = 50\text{ cm}$$

$$P_2 = \frac{(55+65)}{2} = 60\text{ cm}$$

Hence average depth of annual precipitation over the basin of 250 km²

$$P = \frac{\Sigma A_p}{\Sigma A} = \frac{(50 \times 100 + 60 \times 150)}{(100+150)} = 56\text{ cm}$$

42. Base width of dam, $b = \frac{H}{\sqrt{G}}$

$\Rightarrow \quad H = b\sqrt{G} = 25\sqrt{2.56} = 40\text{ m}.$

NUMERICAL TYPE QUESTIONS

6. Storage efficiency of irrigation,

$$w_s = \left[\frac{\text{water stored in root zone}}{\text{water needed prior irrign}}\right] \times 100$$

$$= \frac{60}{80} \times 100 = \mathbf{75\%}$$

7. Average deviation in water depths = 8 cm

Average depth of water stored in root zone = 24 cm

Water distribution efficiency

$$= \left[1 - \frac{d}{D}\right] \times 100 = \left[1 - \frac{8}{24}\right] \times 100 = 66.67\%$$

8. Depth of application $= \frac{0.65 \times 100 \times 1.5}{0.65} = \mathbf{150\ mm}$

9. Laceys scour depth, $R = (1.35)\left(\frac{q^2}{f}\right)^{1/3}$

10. Scour depth $= \frac{5}{2}\left[\frac{V^2}{f}\right] = \mathbf{2.5}$

12. For wide rectangular channel

$$Q = \frac{1}{n}.\,A.\,R^{2/3}\sqrt{s_f} = \frac{1}{n}(B \cdot y)\cdot(y)^{2/3}\cdot\sqrt{s_f}$$

$$\Rightarrow \quad Q = \frac{1}{n}\cdot y^{5/3}\cdot\sqrt{s_f}$$

$$\therefore \quad \frac{Q_2}{Q_1} = \frac{{y_2}^{5/3}}{{y_1}^{5/3}}\frac{\sqrt{s_{f_2}}}{\sqrt{s_{f_1}}}$$

But $\quad y_2 = 1.5\,y_1$

$$\therefore \quad s_{f_2} = \frac{1}{2}s_{f_1} = 0.5\,s_{f_1}$$

$$\therefore \quad \frac{Q_2}{Q_1} = \frac{(1.5)^{5/3} \times {y_1}^{5/3} \times \sqrt{0.5} \times \sqrt{s_{f_1}}}{{y_1}^{5/3} \times \sqrt{s_{f_1}}}$$

$$= (1.5)^{5/3} \times \sqrt{0.5} = 1.39$$

Percentage change in discharge

$$= \frac{Q_2 - Q_1}{Q_1} \times 100 = \left(\frac{Q_2}{Q_1} - 1\right)100$$

$$= (1.39 - 1)\ 100 = 39\%$$

13. Volume of water contained in the unit hydrograph

$$= \frac{1}{2} \times 60\, m^3/s \times 80 h$$

$$= 2400 \times 3600\ S/s = 8.64 \times 10^6\ m^3$$

$$\text{Depth of water} = \frac{\text{volume of water}}{\text{C.A.}}$$

$$= \frac{8.64 \times 10^6\ m^3}{144 \times 10^6\ m^3} = 0.06\ m = \mathbf{6\ cm}$$

14. $\text{Combining weight} = \frac{\text{atomic weight}}{\text{valency}}$

$\therefore$ Combining weight of Na $= \frac{23}{1} = 23$

Combining weight of Ca $= \frac{40}{2} = 20$

Combining weight of Mg $= \frac{24}{2} = 12$

$$Na^+ = \frac{\text{Na in Mg / I}}{23} = \frac{345}{23}$$

= 15 milli equivalent per litre

$Ca^{++} = \frac{60}{20}$ = 3 milli equivalent per litre

$Mg^{++} = \frac{18}{12}$ = 1.5 milli equivalent per litre

$$\therefore \quad SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}} = \frac{15}{\sqrt{\frac{3 + 1.5}{2}}} = \mathbf{10}$$

15. Water depth required at canal

$$= \frac{\text{water depth required in the field}}{n_a . n_c}$$

$$= \frac{10\ cm}{0.8 \times 0.9} = 13.8\ \text{(approx.)}$$

$\therefore$ Volume of water required for 10 hectare ($10 \times 10^4\ m^2$) field

$$= \frac{13.8}{100} m \times 10^5 m^2$$

$$= 13{,}800\ m^3 = 13{,}800\ kl\ \text{(approx)}$$

16. Intensity of irrigation for Kharif

= 100 – 70 = 30%

Intensity of irrigation for Rabi

= 100 – 50 = 50%

Total Intensity of irrigation

= 30% + 50%

= **80%**

17. G.I.A. $= 4 \times 0.6 + 3 \times 0.4$

$= 2.4 + 1.2 = 3.6$ Mha

$$\text{A.I.I.} = \frac{\text{G.I.A}}{\text{C.C.A}} = \frac{3.6\ \text{Mha}}{6} = 0.6 = \mathbf{60\%}$$

18. Waterway required $= 1.2 \times 4.75 \times \sqrt{Q_{max}}$

where 1.2 is safety factor of Lacey's regime width

$$\text{But } Q_{max} = \frac{16}{9} Q_{dom}$$

$$\therefore \text{Waterway required} = 1.2 \times 4.75 \times \sqrt{8100 \times \frac{16}{9}}$$

$$= 1.2 \times 4.75 \times \frac{4}{3} \times 90 = \mathbf{684m}$$

EXERCISE – II

MCQ TYPE QUESTIONS

1. The unit of Gross Command Area is hectares Permanent Wilting Point is the moisture content and is given in %

$\therefore$ 12% or 0.12.

The unit of duty is hectares/cumec

The unit of delta is cm.

2. Duty $D = \frac{864B}{\Delta}$

where, Δ is in cm, B is in days,

then get duty is in hectare/cumecs

B = 10 days

Total depth of water required during transplantation of rise = 48 cm

effective rainfall (usefull for irrigation) = 8 cm

So, actual depth of water required = 48 – 8 = 40 cm

$$\therefore \quad D = \frac{864 \times 10}{40} = 216\ \text{hectare/cumecs}$$

4. Critical velocity ratio, m = 1.1

D = 1.5 *m* $\quad n = 0.018$

From Kennedy method

$V_0 = 0.55\ mD^{0.64} = 0.55 \times 1.1 \times (1.5)^{0.64} = 0.784$ m/sec

5. Effective rainfall = Total required rainfall

Required depth = 105 – 15 = 90 cm

Volume of water required

$= \text{Area} \times \text{depth required} = 437 \times 10^4 \times 0.90$

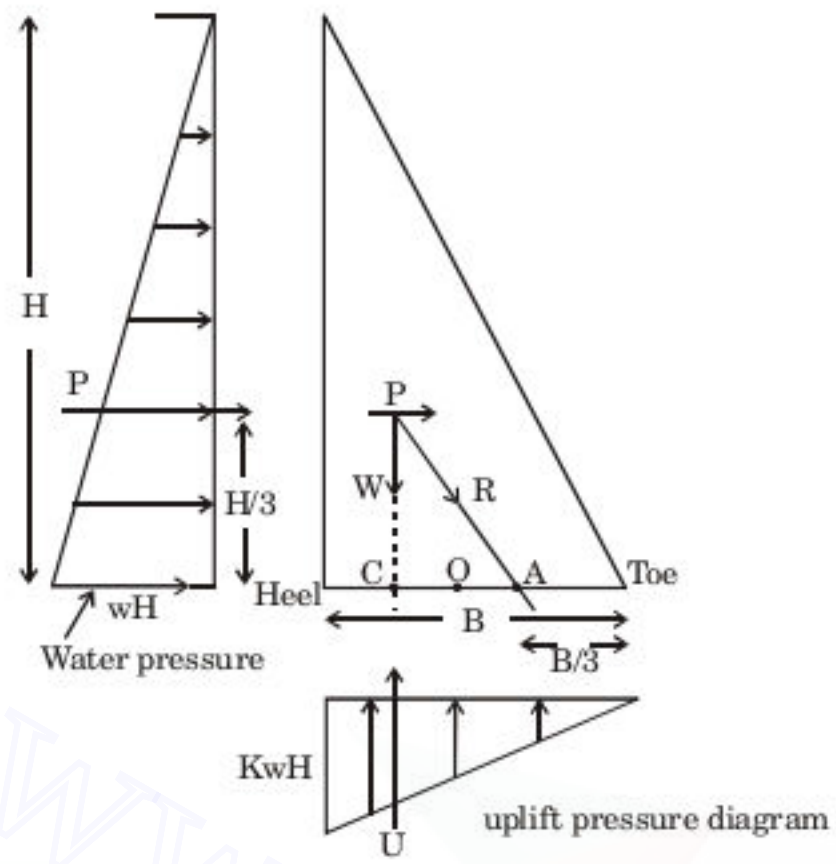
$$\therefore \quad \text{Discharge, } Q = \frac{v}{t}$$

$$= \frac{437 \times 10^4 \times 0.90}{90 \times 24 \times 60 \times 60} = 437\text{ha}$$

$\therefore$ Duty = Area irrigation by unit discharge

$$= \frac{437}{Q} = 864\ \text{ha.cm/sec}$$

6. **Super critical** because in supercrifical state of flow, the velocity is much high, that will prevent the propogation of water surface wave.

7. 

For no tension at heal, the resultant R must pass through middle third.

$\therefore$ OA = $\frac{b}{6}$ and AC = $\frac{b}{3}$

Also OC = $\frac{b}{6}$

Let W = Self weight of dam = wG

Now taking moments of all forces about A

$$W\left(\frac{b}{3}\right) - U\left(\frac{b}{3}\right) - P\left(\frac{H}{3}\right) = 0$$

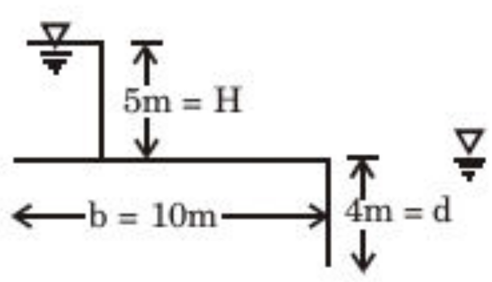
$$\Rightarrow \quad \frac{1}{2}\text{ b.H.Gw. } \frac{b}{3} - \frac{1}{2}\text{ kwH. b. } \frac{b}{3} - \frac{1}{2}\text{ wH.H. } \frac{H}{3} = 0$$

Solving, we get

$$b^2 (G - k) = H^2$$

$$\frac{b}{H} = \frac{1}{\sqrt{G-k}}$$

8. Here, H = 5m,
b = 10m,
d = 4m.



$$\therefore \quad \alpha = \frac{b}{d} = \frac{10}{4} = 2.5$$

and $\lambda = \frac{1+\sqrt{1+\alpha^2}}{2} = \frac{1+\sqrt{1+2.5^2}}{2} = 1.846$

According to Khosla's method, exit gradient is given by

$$G_E = \frac{H}{d}.\frac{1}{\pi\sqrt{\lambda}} = \frac{5}{4}.\frac{1}{\pi\sqrt{1.846}}$$

$$= \frac{1}{3.41}\text{, i.e. 1 in 3.4}$$

9. $$\text{Duty, D} = \frac{8.64\text{ B}}{\Delta}\text{ ha./cumec}$$

Here, Δ = 0.02m (20×10^{-3} m.)
B = base period
= 20 days.

$$\therefore \quad \text{Duty} = \frac{8.64 \times 20}{0.02} = 8640\text{ ha/cumec}$$

Now, Outlet discharge = $\frac{\text{Area}}{\text{Duty}}$

$$= \frac{20\text{ ha.}}{8640\text{ ha / cumec}}$$

$= 2.31 \times 10^{-3}$ cumec = 2.31 litre/sec

10. Consumptive use of water for a crop
= 2mm/day.

Maximum depth of available water in root zone
= 60 mm.

Irrigation required when depth of available water in root zone = 0.5×60 = 30 mm

Water aviable for crop = 60 – 30 = 30 mm.

Frequency of irrigation (f)

$$= \frac{\text{Water available for crop}}{\text{consumptive use of water}}$$

$$= \frac{30}{2} = 15\text{ days}$$

NUMERICAL TYPE QUESTION

1. The depth of irrigation water required = $\frac{\gamma \cdot d}{\gamma_\omega}$

[Field capacity available – Moisture content]

d = effective depth of root zone
= 70 cm = 700 mm

Field capacity = 28%

Available moisture constent = 18%

density of soil = 1.3 gm/cm^3 = γ

density of water = γ_ω = 1.0gm/cm^3

$\because$ Depth of irrigation water required

$$= \frac{1.3 \times 700[0.28 - 0.18]}{1.0} = 91\text{ mm}$$

■■