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UKPSC – JE

Civil Engineering

Uttarakhand Public Service Commission (UKPSC)

Volume - 3

(Technical)

Irrigation & Transportation & Building Material

SIERRA INNOVATIONS

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1
CHAPTER

Water Requirements of Crops

THEORY

Irrigation

Three basic requirements of agricultural production are soil, seed, and water. In addition,fertilisers, insecticides, sunshine, suitable atmospheric temperature, and human labour are also needed. Of all these, water appears to be the most important requirement of agricultural production. The application of water to soil is essential for plant growth and it serves the following functions:

- o It supplies moisture to the soil essential for the germination of seeds, and chemical and bacterial processes during plant growth.
- o It cools the soil and the surroundings thus making the environment more favourable for plant growth.
- o It washes out or dilutes salts in the soil.
- o It softens clods and thus helps in tillage operations.
- o It enables application of fertilisers.
- o It reduces the adverse effects of frost on crops.
- o It ensures crop success against short-duration droughts

Water Requirements of a Crop

• The total quantity and the way in which a crop requires water, from the time it is sown to the time it is harvested

• It vary with the crop as well as with the place

• Depending on

o Climate

o Type of soil

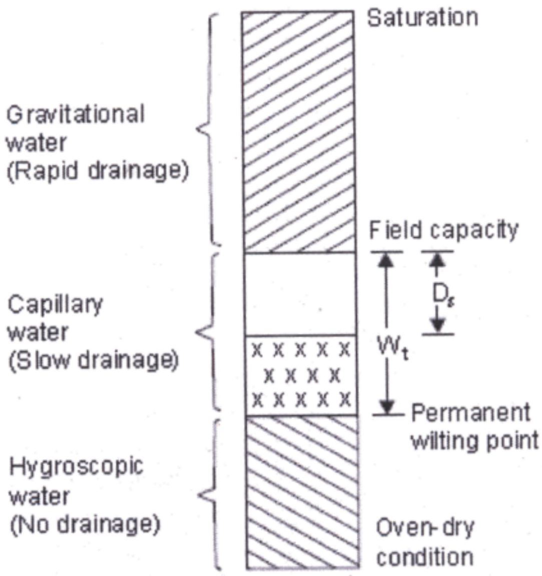
o Method of cultivation

o Useful rainfall

Classification of soil water

- **Gravitational water:** A soil sample saturated with water and left to drain the excess out by gravity holds on to a certain amount of water. The volume of water that could easily drain off is termed as the gravitational water. This water is not available for plants use as it drains off rapidly from the root zone.

- **Capillary water:** The water content retained in the soil after the gravitational water has drained off from the soil is known as the capillary water. This water is held in the soil by surface tension. Plant roots gradually absorb the capillary water and thus constitute the principle source of water for plant growth.
- **Hygroscopic water:** The water that an oven dry sample of soil absorbs when exposed to moist air is termed as hygroscopic water. It is held as a very thin film over the surface of the soil particles and is under tremendous negative (gauge) pressure. This water is not available to plants.



Soil water constants :

For a particular soil, certain soil water proportions are defined which dictate whether the water is available or not for plant growth. These are called the soil water constants, which are described below.

- **Saturation Capacity:** This is the total water content of the soil when all the pores of the soil are filled with water. It is also termed as the maximum water holding capacity of the soil. At saturation capacity, the ***soil moisture tension*** is almost equal to zero.
- **Field Capacity:** This is the water retained by an initially saturated soil against the force of gravity. Hence, as the gravitational water gets drained off from the soil, it is said to reach the field capacity. At field capacity, the macro-pores of the soil are drained off, but water is retained in the micropores. Though the soil moisture tension at field capacity varies from soil to soil, it is normally between 1/10 (for clayey soils) to 1/3 (for sandy soils) atmospheres.
- **Permanent Wilting Point:** Plant roots are able to extract water from a soil matrix, which is saturated up to field capacity. However, as the water extraction proceeds, the moisture content diminishes and the negative (gauge) pressure increases. At one point, the plant cannot extract any further water and thus ***wilts.***

Two stages of wilting points are recognized and they are:

- Temporary wilting point: this denotes the soil water content at which the plant wilts at day time, but recovers during right or when water is added to the soil.

- Ultimate wilting point: at such a soil water content, the plant wilts and fails to regain life even after addition of water to soil.

Crop Period or Base Period: The time period that elapses from the instant of its sowing to the instant of its harvesting

Base Period: The time between the first watering of a crop at the time of its sowing to its last watering before harvesting. It is represented by B (in days)

• Crop period is slightly more than the base period

• But for all practical purposes, they are taken as one and the same thing

Delta (Δ)

- Depth to which water would stand on the irrigated area if the total quantity supplied were to stand above the surface without percolation or evaporation
- This total depth of water (in cm) required by a crop to come to maturity.

Duty of Water

- It is the relationship between the volume of water and the area of the crop it matures
- A unit discharge flowing for a time equal to the base period of the crop., called Base of the duty
- If water flowing at a rate of one m^3/s, runs continuously for B days, and matures 200 hectares, then the duty of water for that particular crop will be defined as 200 hectares/cumec to the base of B days
- Duty is defined as the area irrigated per cumec of discharge running for base period B
- The duty is generally represented by D

Relationship Between Duty and Delta

– Let there be a crop of base period B days

– Let 1 cumec of water be applied to this crop on the field for B days

– Now, the vol. of water applied to this crop during B days

$= V = (1 \times 60 \times 60 \times 24 \times B)\ m^3$

$= 86400\ B\ (m^3)$

– By definition of duty (D), 1 m^3 supplied for B days matures D hectares of land

– Therefore this quantity of water (V) matures D hectares of land or 10^4 D sq. m of area

– Total depth of water applied on this land

$$\frac{\text{Volume}}{\text{Area}} = \frac{86400B}{10^4 D}$$

$$= \frac{8.64B}{D}\text{ meters} = \frac{864B}{D}\text{cm}$$

– By definition, this total depth of water is called delta (Δ)

– Therefore, $\Delta = \frac{8.64B}{D}$ metres

or

$$\Delta = \frac{864B}{D} \text{cm}$$

- Duty of water for a crop, is number of hectares of land which the water can irrigate
- Therefore, if the water requirement of the crop is more, less number of hectares of land it will irrigate
- If water consumed is more, duty will be less
- The duty of water at the head of the water course will be less than the duty of water 'on the field'; because when water flows from the head of the water course and reaches the field, some water is lost as transit losses (evaporation, percolation)

Commanded area (CA): This is defined as the area that can be irrigated by a canal system. CA may further be classified as under:

Gross command area (GCA): This is defined as total area that can be irrigated by a canal system on the perception that unlimited quantity of water is available. It is the total area that may theoretically be served by the irrigation system. But this may include inhibited areas, roads, ponds, uncultivable areas etc which would not be irrigated.

Culturable command area (CCA): This is the actually irrigated area within the GCA. However, the entire CCA is never put under cultivation during any crop season due to the following reasons:

- The required quantity of water, fertilizer, etc. may not be available to cultivate the entire CCA at a particular point of time. Thus, this is a physical constraint.
- The land may be kept fallow that is without cultivation for one or more crop seasons to increase the fertility of the soil. This is a cultural decision.
- Due to high water table in some areas of the CCA, irrigated water may not be applied as the crops get enough water from the saturation provide to the surface water table.

During any crop season, only a part of the CCA is put under cultivation and this area is termed as ***culturable cultivated area***. The remaining area which is not cultivated during a crop season is conversely termed as ***culturable uncultivated area***.

Intensity of irrigation

Intensity of irrigation is defined as the percentage of the irrigation proposed to be irrigated annually. Usually the areas irrigated during each crop season (Rabi, Kharif, etc) is expressed as a percentage of the CCA which represents the intensity of irrigation for the crop season. By adding the intensities of irrigation for all crop seasons the yearly intensity of irrigation to be obtained.

Factors on which duty depends

- **Type of crop :**
  - Duty will be less for a crop requiring more water and vice versa

- **Climate and season**

  – Duty includes the water lost in evaporation and percolation which vary with time, season and climate

- **Useful rainfall**

  – If some of the rain, falling directly over the irrigated land, is useful for the growth of the crop, then so less irrigation water will be required to mature the crop

- **Type of soil**

  – If the permeability of the soil under the irrigated crop is high, the water loss due to percolation will be more and hence, the duty will be less

  – Therefor sandy soils, the duty of water is less

- **Efficiency for cultivation method**

  – If the cultivation method (including tillage and irrigation) is faulty and less efficient, resulting in the wastage of water, the duty of water will naturally be less

  – If the irrigation water is used economically, then the duty of water will improve, as the same quantity of water would be able to irrigate more area

Measures for Improving Duty of water

- **Precautions in field preparation and sowing**

  – Land to be used for cultivation should, as far as possible, be levelled

  – The fields should be properly ploughed to the required depth

  – Improved modern cultivation methods may preferably be adopted

  – Porous soils should be treated before sowing crops to reduce seepage of water

  – Alkaline soils should be properly leached before sowing

  – Manure fertilisers should be added to increase water holding capacity of the soil

  – Rotation of crops should be preferred, as this will ensure increased crop yields with minimum use of water

- **Precautions in handling irrigation supplies**

  – The source of irrigation water should be situated within the prescribed limits, and be capable of good quality of water

  – Canals carrying irrigation supplies should be lined to reduce seepage and evaporation

  – Water courses may preferably be lined or RCC pipes may be used for the same

  – Free flooding of fields should be avoided and furrow irrigation method may preferably be adopted, if surface irrigation is restored.

  – Subsurface irrigation and drip irrigation may be preferred to ordinary surface irrigation

  – If canals are not lined, then two canals running side by side may be preferred to a single canal, as this will reduce the FSL, thereby reducing percolation losses.

  – Irrigation supplies should be economically used by proper control.

Type of Soils	Favourablve for raising crops	Water requirement
Heavy retentive soil (40% clay)	Sugarcane, rice, etc.	Require more water
Light sandy soil (2-8% clay)	Gram, fodder, etc.	Require less water
Medium or normal soil (having about 10-20% of clay)	Wheat, cotton. Maize, vegetables, oil seeds, etc.	Require normal amount of water

Types of irrigation methods

- Surface irrigation method
- Subsurface irrigation method
- Sprinkler irrigation system
- Drip irrigation system

SURFACE IRRIGATION METHOD

In this system of field water application the water is applied directly to the soil from a channel located at the upper reach of the field. It is essential in these methods to construct designed water distribution systems to provide adequate control of water to the fields and proper land preparation to permit uniform distribution of water over the field.

- One of the surface irrigation method is ***flooding method*** where the water is allowed to cover the surface of land in a continuous sheet of water with the depth of applied water just sufficient to allow the field to absorb the right amount of water needed to raise the soil moisture up to field capacity.
- The flooding method applied in a controlled way is used in two types of irrigation methods as under:
  - ***Border irrigation method***
  - ***Basin irrigation method***

Border irrigation method

- Borders are usually long uniformly graded strips of land separated by earth bunds (low ridges).
- The essential feature of the border irrigation is to provide an even surface over which the water can flow down the slope with a nearly uniform depth.
- Each strip is irrigated independently by turning in a stream of water at the upper end.

Basin irrigation method

- Basins are flat areas of land surrounded by low bunds.
- The bunds prevent the water from flowing to the adjacent fields.
- The basins are filled to desired depth and the water is retained until it infiltrates into the soil. Water may be maintained for considerable periods of time.

- Basin irrigation is suitable for many field crops. Paddy rice grows best when its roots are submerged in water and so basin irrigation is the best method for use with this crop

Furrow Irrigation

- Furrows are small channels, which carry water down the land slope between the crop rows.
- Water infiltrates into the soil as it moves along the slope.
- The crop is usually grown on ridges between the furrows.
- This method is suitable for all row crops and for crops that cannot stand water for long periods, like 12 to 24 hours, as is generally encountered in the border or basin methods of irrigation
- Furrow irrigation is suitable to most soils except sandy soils that have very high infiltration water and provide poor lateral distribution water between furrows.

As compared to the other methods of surface irrigation, the furrow method is advantageous as:

- Water in the furrows contacts only one half to one-fifth of the land surface, thus reducing puddling and clustering of soils and excessive evaporation of water.
- Earlier cultivation is possible

Subsurface irrigation methods

The application of water to fields in this type of irrigation system is below the ground surface so that it is supplied directly to the root zone of the plants.

- The main advantages of these types of irrigation is reduction of evaporation losses and less hindrance to cultivation works which takes place on the surface.
- There may be two ways by which irrigation water may be applied below ground and these are termed as:
  - Natural sub-surface irrigation method
  - Artificial sub-surface irrigation method

Sprinkler Irrigation System

- Sprinkler irrigation is a method of applying water which is similar to natural rainfall but spread uniformly over the land surface just when needed and at a rate less than the infiltration rate of the soil so as to avoid surface runoff from irrigation.
- This is achieved by distributing water through a system of pipes usually by pumping which is then sprayed into the air through sprinklers so that it breaks up into small water drops which fall to the ground.
- The system of irrigation is suitable for undulating lands, with poor water availability, sandy or shallow soils, or where uniform application of water is desired.
- No land leveling is required as with the surface irrigation methods.
- Sprinklers are, however, not suitable for soils which easily form a crust. The water that is pumped through the pump pipe sprinkler system must be free of suspended sediments.

Drip Irrigation System

- Drip Irrigation system is sometimes called trickle irrigation and involves dripping water onto the soil at very low rates (2-20 litres per hour) from a system of small diameter plastic pipes filled with outlets called emitters or drippers.
- Water is applied close to the plants so that only part of the soil in which the roots grow is wetted, unlike surface and sprinkler irrigation, which involves wetting the whole soil profile.
- With drip irrigation water, applications are more frequent than other methods and this provides a very favourable high moisture level in the soil in which plants can flourish.

Some Important Definitions

Kharif-Rabi ratio or Crop Ratio

• The area to be irrigated for Rabi crop is generally more than that for the Kharif crop.

• This ratio of proposed areas, to be irrigated in Kharif season to that in the Rabi season

• This ration is generally 1:2, i.e. Kharif area is one-half of the Rabi area

Paleo Irrigation

• Sometimes, in the initial stages before the crop is sown, the land is very dry.

• This particularly happens at the time of sowing of Rabi crops because of hot September.

• In such a case, the soil is moistened with water

Kor-watering

• The first watering which is given to a crop, when crop is few centimeters high

• It is usually the maximum single watering followed by other watering at usual intervals, as required by drying of leaves

• The optimum depth of kor-watering for different crops are different

• For example For wheat (in U.P.) is about 13.5 cm For sugarcane is 16.5 cm

• The kor-watering must be applied within a fixed limited period, called kor-period

Puddling -watering

• Preparation of land for transplantation

• Requires lump sum of water

• 200 mm at field level for rice crop

Cash Crop

- A crop which has to be encashed in the market for processing, etc. as it cannot be consumed directly by the cultivators
- All non-food crops, are thus, included in cash crop
- Examples, jute, tea, cotton, tobacco, sugarcane, etc.

Crop rotation

- The method of growing different crops in rotation, one after the other, in the same field
- When the same crop is grown again and again in the same field, the fertility of land gets reduced as the soil become deficient in plant foods favourable to that particular crop
- In order to enhance the fertility of the land and to make soil regain its original structure, allow land to lie fallow without any cultivation for some time, or to grow crops which do not mainly require those salts or foods which were mainly required by the earlier grown crop

Crop rotation will thus help in

- Increasing the fertility of soil
- Reducing the diseases
- Wastage due to insects
- Increasing the overall crop yield

Irrigation Interval: The time gap usually expressed in days, between two subsequent irrigations

Irrigation Period

- The time, usually expressed in days, that can be allowed for applying one irrigation to a given design crop area during the peak consumptive use period of crop
- Function of the peak-period consumptive use rate
- Considered for designing the irrigation system capacity and equipment
- Irrigation system must be so designed
- Irrigation period is not greater than the irrigation interval

$$\text{Irrigation period (days)} = \frac{\text{Depth of soil depletion in the design crop area just before irrigation, cm}}{\text{Peak period consumptive use rate of crop, cm}}$$

Design Irrigation Frequency

- It is same as the irrigation period
- The time, usually expressed in days, between two irrigations that is necessary to irrigate the design crop area during the period of peak consumptive use of the crop to be irrigated
- Used to decide the capacity of the irrigation system to be able to supply the required water to crops in the area
- The average consumptive use rate during this period is used for planning the system

$$\text{Design irrigation frequency(days)} = \frac{(F_c - M_b) \times A_s \times D / 100}{\text{Peak period consumptive use ratio of crop, cm}}$$

– Where, F_c is field capacity (%), M_b = soil water content just before irrigation(%)

A_s = apparent Sp. Gravity of soil or bulk density of soil

D = Depth of crop root zone, cm

Depth of Irrigation

- Function of the water retentive capacity of the root-zone soil and the extent of soil water depletion at the time of irrigation
- The depth to which the applied water would cover an area
- Ex. 10 cm depth of irrigation to a hectare of land means if the vol. of water is allowed to stand without any loss and infiltration into the soil would stand over one hectare area to a depth of 10 cm
- The net depth of irrigation is decided by the amount of water required to bring the soil water content just before an irrigation to field capacity in the root zone soil
- The water content of soil just before irrigation must be known to calculate the net depth of water required to be applied

$$d = \sum_{i=1}^{n} \frac{F_{ci} - M_{bi}}{100} \times A_{si} \times D_i$$

– Where, d = Net depth of water to be applied or net irrigation or net irrigation, cm

F_{ci} = Field capacity of the i^{th} layer of soil in % by weight.

M_{bi} = Water content of the i^{th} layer of soil just before irrigation, % by weight

A_{si} = Apparent sp. Gravity of i^{th} layer of soll, g/cm^3

D_i = Depth of i^{th} layer of soil in the root zone, cm

n = Number of soil layers in the root zone D

Consumptive use or Evapotranspiration (Cu)

- Quantity of water used by plant to perform its metabolic activities and that lost due to evaporation and transpiration.
- The total amount of water used by the plant in transpiration (building of plant tissues, etc.) and evaporation from the adjacent soils or from plants leaves, in any specified time
- It (Cu) may be different for different crops, and may be different for the same crop at different times and places
- Values of daily Cu or monthly Cu, are generally determined for a given crop and at a given place
- Values of monthly Cu over the entire crop period, are then used to determine the irrigation requirement of the crop

Method to fine consumptive use of plant:

Blaney-Criddle method

$ET_r = a + b \{P (0.46 T + 8.13)\}$

Where,

ET_r = Reference crop evaportranspiration in mm/day a & b = Calibration factors

P = Mean daily percentage of total annual daytime hours.

T = Mean daily air temperature in °C

$a = 0.0043\ RH_{min} - (n/N) - 1.41$

$b = ((0.82 - (0.0041RH_{mean}) + (1.07\ n/N) + (0.066U) - (0.006RH_{mean}n/N) - (0.0006RH_{mean}U)$

n/N = Mean ratio of actual to possible sunshine hours.

RH_{min} = Minimum daily relative humidity

U = Wind speed at a height of 2 m from ground surface $U_2 = U_x(2/x)^{(1/7)}$

Factors Affecting Consumptive Use

Consumptive Use or Evapotranspiration depends upon all those factors on which evaporation and transpiration depend such as:

o Sunlight

o Humidity

o Wind movement, etc

Effective rainfall (Re)

Precipitation falling during the growing period of the crop which is available to meet the evapotranspiration requirement of the crop

Consumptive Irrigation Requirement (CIR)

- It is the amount of Irrigation Water required in order to meet the evapotranspiration needs of the crop during its full growth
- It is, therefore, nothing but the consumptive use itself, but exclusive of effective precipitation, stored soil moisture, or ground water
- When the last two are ignored, then we can write

  CIR = Cu – Re

Net Irrigation Requirement (NIR)

- It is the amount of irrigation water required in order to meet the evapotranspiration need of the crop as well as other needs such as leaching
- Therefore,NIR = Cu – Re + Water lost as percolation in satisfying other needs such as leaching

Irrigation efficiencies

Efficiency is the ratio of the water output to the water input, and is usually expressed as percentage

Water is lost in irrigation during various processes and therefore, there are different kinds of irrigation efficiencies:

- Efficiency of water-conveyance

- Efficiency of water-application
- Efficiency of water-storage
- Efficiency of water-use

Efficiency of Water-Conveyance

• It is the ratio of the water delivered into the fields from the outlet point of the channel, to the water pumped into the channel at the starting point.

• It may be represented by η_c

• It takes the conveyance or transit losses into account

Efficiency of Water-Application

• Ratio of the quantity of water stored into the root zone of the crops to the quantity of water actually delivered into the field

• It may be represented by η_a

• It may also be termed as field efficiency

• As it takes into account the water lost in the field

Efficiency of Water-Storage

• Ratio of the water stored in the root zone during irrigation to the water needed in the root zone prior to irrigation (i.e. field capacity – existing moisture content)

• It may be represented by η_s

Efficiency of Water Use

• Ratio of the water beneficially used, including leaching water, to the quantity of water delivered

• It may be represented by η_u

Uniformity Coefficient or Water Distribution Efficiency

• The effectiveness of irrigation may also be measured by its water distribution efficiency η_d

$$\eta_d = \left(1 - \frac{d}{D}\right)$$

– Where,

– η_d = water distribution efficiency

– D = Mean depth of water stored during irrigation

– d = Average of the absolute values of deviations from the mean

• It represents the extent to which the water has penetrated to a uniform depth, throughout the field

• When the water has penetrated uniformly throughout the field, the deviation from the mean depth is zero and water distribution efficiency is 1.0.

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2 CHAPTER Design of Stable Channels

THEORY

The channel in which neither silting nor scouring takes place, are known as stable channels or regime channels. The flow velocity flow of water should be such that it does not produce local silt by erosion of bed & keeps the sediments present in water in suspension.

There are two theories for design of such channels.

(i) Kennedy's theory

(ii) Lacey's theory

Kennedy's theory

- From the observations on UPPER BARI DOAB CANAL, he concluded that silt supporting power in a channel cross-section was mainly dependent upon the generation of the eddies rising to the surface are generated due to the friction of the flowing water with the channel surface.
- If the velocity is suffecient of generate these eddies so as to keep the sediments just in suspension & silting will be avoided. Based upon this concept he defined the critical velocity (V_0) in a channel.
- Critical velocity V_0 in a channel is the mean velocity which will just keep the channel from free silting or scouring

  $V_0 = 0.55\ m.y^{0.64}$

  Where, y depth of flow (in meters)

  $m = CVR = V/V_0$

  Where, V_0 = critical velocity
- (i) For sands coarser than standard, the values of m = 1.0 to 1.2.

  (ii) For sands finer than the standard, the value of m lies between 1.0 to 0.7.

Type of silt value of m

Silt of indus (Pakistan), m = 0.7

North Indian rivers, m = 1.0

Debris of Hard soil, m = 1.3

DESIGN PROCEDURE

Step-1: Determine critical velocity by

$V_0 = 0.55 \text{ m } y^{0.64}$

Assuming a trial depth

Step-2: Calculate the area by

$$\text{Area} = \frac{\text{Discharge}}{\text{Velocity}} = \frac{Q}{V_0}$$

Step-3: Assume trapezoidal channel section with 1/2H : 1V slope of sides. Find B (width) as y (trial depth) is known and find wetted perimter P. Also find hydraulic radius R = A/P.

Step-4: Compute actual mean velocity V, by using;

1. Kutter's/chezy's formula:

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

2. Manning's formula:

$V = (1/n)R^{2//3}\, S^{1/2}$

Value of n depends upon Q and Channel conditions

Q	n
14 to 140 cumec	0.025
140 to 280 cumec	0.0225
≥ 280 cumec	0.020
Channel condition	n
Very good channel	0.0225
Good	0.025
Indifferent	0.027
Poor	0.030

- Use preferably kutter's equation

step 5: If the two velocities V and V_0 are equal, then assumed depth is all right, otherwise change it and repeat the procedure.

Note: Garret's diagram are Graphical solution of kennedy's equation and kutters equation and can be used for solution.

LACEY'S THEORY

Lacey's Regime Channels

- Kennedy stated that a channel is said to be regime, If there is neither silting nor scouring in the channel. But Lacey stated that even a channel showing no silting and no scouring, may actually not be in regime. He differentiated between 3 regime conditions.

  1. True regime

2. Initial regime

3. Final regime

- According to him a channel which is in initial regime is not a channel in regime and hence regime theory is not applecable to such. channels.
- Lacey's theory is applicable only to those channels which are either in true regime or in final regime.

True Regime

There can be only one channel section & one bed slope at which channel carrying a given discharge and one bed slope at which channel carrying a given discharge and a particular quantum type of silt would be in regime, hence an artificially constructed channel having a fixed section and a certain fixed slope can behave in regime only if the following conditions are satisfied.

1. Discharge is constant
2. Flow is uniform
3. The amount of silt is constant
4. Silt grade is constant (i.e., type & size of silt is always same).
5. Channel is flowing through a material which can be scoured as easily as it can be deposited. Such a silt is known as incoherent alluvium.

- In practice all above 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.

Initial Regime & Final Regime

- When only the bed slope of channel varies and its cross-section or wetted perimeter remains unaffected, even then the channel can exhibit no silting and no scouring properties.

  Such a condition is called initial regime.
- If there is no resistance from the sides and all the variables e.g. perimeter, depth, slope etc. are equally free to vary and finally get adjusted according to discharge & grade then the channel is said to have achieved permanent stability called final regime, Lacy's theroy is valid for such regime.
- The channels in which varables are equally free to vary, has tendency to assume a semi-elliptical section. The coarser the silt, the flatter is the semi ellipse i.e. greater is the width of water surface. The finer the silt, the more nearly the section attains semicircle.

Design Procedure (Lacey's theory)

Step-1: Calculate the velocity by

$$V = \left[\frac{Qf^2}{140}\right]^{1/6} \text{m/sec}$$

Where, f = silt factor

$$f = 1.75\sqrt{d_{mm}}$$

V = velocity in m/sec

Q = discharge in cumecs

Step-2: Find the hydraulic mean depth

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

Sssume trapezoidal channel with 1/2 H:

1 V stope.

Step-3: Find the area of channel section by

$$A = Q/V$$

Step-4: Find wetted perimeter by

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

Step-5: Find the bed-slope by

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

COMPARISON BETWEEN LACEY'S THEORY AND KENNEDY'S THEORY

Kennedy's theory

1. He considered trapezoidal section & neglected the eddies generated from sides.
2. He used depth that of flow for calculating critical veloicity.
3. He considered all the channels are in regime provided no silting and no scouring conditions exists.
4. He simply stated $m = V/V_0$ varies according to silt conditions.
5. He used kutter's formula for actual generated channel velocity, where n is again guess work.
6. Kennedy did not give any importance for bed width to depth ratio.
7. Kennedy did not fix regime slopes, although his diagrams indicate that steeper slopes are required for smaller channels.

Lacey's theory

1. Lacey considered semi-elliptical channel (cup shape) & entire wetted perimeter contributed to the generation of silt supporting eddies.
2. He used hydraulic mean radius in his regime velocity formula.
3. This theory is valid only in true regime & final regime conditions.
4. According to Lacey, grain size of silt is an important parameter, $f = 1.75\ \sqrt{d_{mm}}$.
5. Lacey produced general equation after applying huge data on regime condition for velocity $V = 10.8\ R^{2/3}\ S^{1/3}$.
6. Lacey has connected wetted perimeter P and area A with discharge. Lacey has fixed relationship between bed width & depth.

7. Lacey has fixed the regime slope

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

Defects in Kennedy's Theory

1. He did not suggest the equation for bed slope unlesss proper due is given, it is difficult to get a particular slope for a particular discharge.
2. He did not give his own flow equation. He used Kutter's equation, hence the limitations of Kutter's equation are also the limitations of Kennedy's theory.
3. Kennedy's theory is only applicable to average regime conditions for the channels and not for outlets and off takes on the given channel.
4. Kennedy did not take the eddies produced by sides.
5. He did not take into account silt concentration and bed load.
6. He did not give any importance to B/D ratio.
7. He did not define silt grade & silt charges.

Drawbacks in Lacey's theory

1. Physical aspects of the problem is not clearly described.
2. Lacey did not take into account the silt left in channel by water that is lost by absorption.
3. The effect of silt attrition is not accouted for.
4. Regime theory is not applicable to artificial channels.

LINING OF CANALS

Advantages of Lining

1. Seepage Control

   It has been emphasized that seepage losses are considerably reduced if the channels are lined. A lined canal costs about 2 to $2^1/_2$ times as much as unlined canal.
2. Prevention of water logging.
3. Increase in channel capacity.

   Less resistance to flow & more velocity can be maintained.

   n = 0.0225 For earthen channels

   n = 0.012 for cement mortar

   n = 0.015 for concrete

   n = 0.018 for brick lined canal.
4. Increase in commanded area.

   Steeper gradient can be provided as higher velocities are permitted.
5. Reduction in maintenance costs.
6. Elimination of flood dangers.

FINANCIAL JUSTIFICATIONAND ECONOMICS OF LINING

Annual benefits

- Let lrrigation water is sold to the cultivator at a rate Rs. R_1 per cumec. If m cumecs of water is saved by lining the canal annually. Money saved = m. R_1 rupees.
- Lining will also reduce maintenance cost. Let the rate of maintenance cost be R_2 rupees per year. If p is the % (fraction) of the saving achieved in maintenance cost by lining the canal, then amount saved = p. R_2 rupees.
- The total annual benefits = m. R_1 + p. R_2 {p = 0.4}.

Annual Costs

- If the capital expenditure required on lining is C rupees and the lining has a life of Y years, then annual depreciation charge = C/Y rupees.
- If r is the rate of interest (%). The lock of rupee C will earn C [r/100] annually as the interest charges. Since the capital value decreases from C to zero in Y years, the avg. Annual interest may be taken as C/2(r/100).
- Total annual costs of lining

$$= \frac{C}{Y} + \frac{C}{2}\left(\frac{r}{100}\right)$$

Benefit to cost ratio = $\dfrac{mR_1 + pR_2}{\dfrac{C}{Y} + \dfrac{C}{2}\left(\dfrac{r}{100}\right)}$

For project justification, benefit to cost ratio must be greater than unity.

DESIGN OF LINED IRRIGATION CHANNELS

- High velocity can be permitted by taking the advantage of hard wearing surface, so as to ensure hydraulically efficient channel.
- Generally two types of channel sections are adopted:

  1. Triangular section

  2. Trapezoidal section

1. Triangular section: These are used for smaller discharge (≤ **150 cumecs).**

• In order to increase R, the corners are rounded and attempts are made to use deeper section with limiting depths.

• Let central depth = Radius of circle = y