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Irrigation Engineering

Civil Engineering

Comprehensive Theory *with* Solved Examples

Civil Services Examination

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Irrigation Engineering

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CHAPTER

Water Requirement of Crops

1.1 BASICS OF IRRIGATION

Water is the greatest resource of humanity. It not only helps in survival but also helps in making life from comfortable to luxurious. Besides various other uses of water, the largest use of water in the world is made for irrigating lands. Irrigation in fact is nothing but "a continuous and reliable water supply to the different crops in accordance with their different needs." When sufficient and timely water does not become available to the crops, the crop fade away, resulting in lesser crop yield, consequently creating famines and disasters. Irrigation can thus save us from such disasters.

1.1.1 Definition of Irrigation

Irrigation may be defined as the science of artificial application of water to the land, in accordance with the 'crop requirements' throughout the crop period for full-fledged nourishment of crops.

Crop yield and Productivity

The crop yield from irrigation is expressed as quintal/ha or tonne/ha. The productivity of the crop is expressed as crop yield per mm of water applied.

Increase of yield/productivity can be achieved by following method:

1. Land shaping or land levelling
2. Suitable crop rotations and crop planning.
3. Using high yielding varieties of seeds.
4. Using chemicals and fertilizers: inputs like MPK, FYM, green manure (nitrogen-rich crops).
5. Methods of irrigation such as sprinkler, drip, furrow, etc.
6. Lining of canals, distributaries and water courses by an economical lining material.
7. Drainage of irrigated land by surface and subsurface drainage.

1.1.2 Necessity of Irrigation in India

India is a tropical country with a vast diversity of climate, topography and vegetation. Rainfall in India varies considerably in its place of occurrence, as well as in its amount. Even at a particular place, the rainfall is highly erratic and irregular, as it occurs only during a few particular months of the year. Crops cannot therefore, be raised successfully, over the entire land, without providing artificial irrigation of fields.

1.1.3 Advantages & Disadvantages of Irrigation

Advantages:

1. **Increase in crop yield:** Good irrigation system helps in increasing crop yields.
2. **Optimum benefits:** Optimum utilization of water is made possible by irrigation.
3. **Avoidance of mixed cropping:** In the areas where irrigation is not assured, generally mixed cropping is adopted.

> **NOTE** By mixed cropping, we mean, sowing together of two or more crops in the same field. If the weather conditions are not favourable to one of the crops, they may be better suitable for the other; and thus the farmer may get at least some yield.

Mixed cropping, is thus, found necessary and also economical when irrigation facilities are lacking, and especially during periods of crash programmes in under developed countries. But if irrigation is assured, mixed cropping can be eliminated.

4. **General prosperity:** Revenue returns with well developed irrigation, are sometimes quite high, and helps in all round development of the country and prosperity of the entire nation and community.
5. **Generation of Hydro-electric power:** Cheaper power generation can be obtained from water development projects primarily designed for irrigation alone. Thus, dual purpose is served.
6. **Domestic water supply:** Development of irrigation facilities in an area helps in augmenting the water supply in nearby villages and towns, where other sources of water are not available.
7. **Facilities of communications:** Irrigation channels are generally provided with embankments and inspection roads. These inspection paths provide good roadways to the villagers for walking, cycling or motoring.
8. **Navigation:** Irrigation canals may be used for inland navigation. Inland navigation is useful for communication and transportation.

Disadvantages :

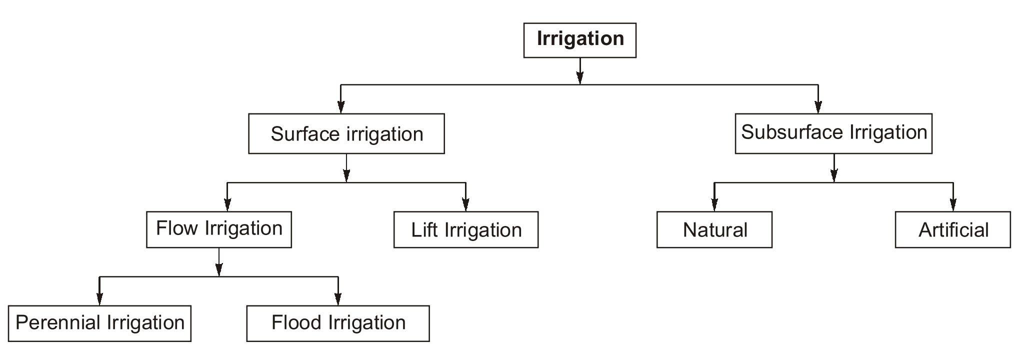
(i) **Wastage of irrigation water:** Abundant supply of irrigation water tempts the cultivators to use more than the required amount of water.

(ii) **Formation of marshy land:** Excessive seepage of water from irrigation canals may lead to formation of marshy lands along the course of the canals.

(iii) **Dampness in weather:** Temperature of the commanded area of irrigation project gets lowered considerably and the area may become damp. Dampness in the area lead to occurrence of diseases originating from dampness.

(iv) **Loss in valuable lands:** In various cases, valuable lands get submerged when storage reservoirs are formed on account of construction of weirs, barrages or dams.

1.1.4 Types of Irrigation



1. Surface irrigation

- In this method, irrigation water is distributed to the agricultural land through small channels which flood the area upto a required depth.
- Water is applied and distributed either by gravity or pumping.
- This method is good for soils with low to moderate infiltration capacities and lands with uniform terrain.

Surface irrigation: Flow irrigation / Lift irrigation

(a) **Flow irrigation:** When the water is available at a higher level, and it is supplied to lower level, by the mere action of gravity, then it is called flow irrigation.

(b) **Lift irrigation:** If the water available at lower level is lifted up by some mechanical or manual means, such as by pumps, etc. and then supplied for irrigation, then it is called lift irrigation. Use of wells and tube wells for supplying irrigation water fall under this category of irrigation. It is further subdivided into:

(i) **Perennial irrigation:** In perennial system of irrigation, constant and continuous water supply is assured to the crops in accordance with the requirements of the crop, throughout the 'crop period'. In this system of irrigation, water is supplied through canal distribution system taking-off from above a weir or a reservoir.

- When irrigation is done by diverting the river runoff into the main canal by constructing a diversion weir or a barrage across the river, then it is called as direct irrigation. Ganga Canal System is an example of this type of irrigation.
- But, if a dam is constructed across a river to store water during monsoons, so as to supply water in the off-taking channel during periods of low flow, then it is termed as storage irrigation. Ram-Ganga dam project in UP in an example of storage type of irrigation system.

(ii) **Flood irrigation:** This type of irrigation is also called Inundation Irrigation and uncontrolled irrigation.

- In this method of irrigation, soil is kept submerged and thoroughly flooded with water, so as to cause thorough saturation of the land.
- The moisture soaked by the soil, when occasionally supplemented by natural rainfall or minor watering, brings the crop to maturity.

2. Sub-surface irrigation

- In this method, water does not wet the soil surface.
- Water flows underground and nourishes the plant roots by capillarity.
- It is suitable for highly permeable soils.

(a) **Natural sub-irrigation:**

- Leakage water from channels, etc., goes underground, and during passage through the sub-soil, it may irrigate crops, sown on lower lands, by capillarity.
- Sometimes, leakage causes the water-table to rise up, which helps in irrigation of crops by capillarity.
- When underground irrigation is achieved, simply by natural processes, without any additional extra efforts, it is called natural sub-irrigation.

(b) **Artificial sub-irrigation:** When a system of open jointed drains is artificially laid below the soil, so as to supply water to the crops by capillarity, then it is known as artificial sub-irrigation. It is a very costly process and hence recommended only in some special cases with favourable soil conditions and for cash crops of very high return.

1.2 TECHNIQUES OF WATER DISTRIBUTION IN THE FARMS

Irrigation water can be applied to crop lands using one of the following irrigation methods :

(i) Surface irrigation

(a) Uncontrolled (or wild or free) flooding method,
(b) Border flooding
(c) Check flooding
(d) Basin flooding
(e) Furrow irrigation method.

(ii) Subsurface irrigation

(iii) Sprinkler irrigation

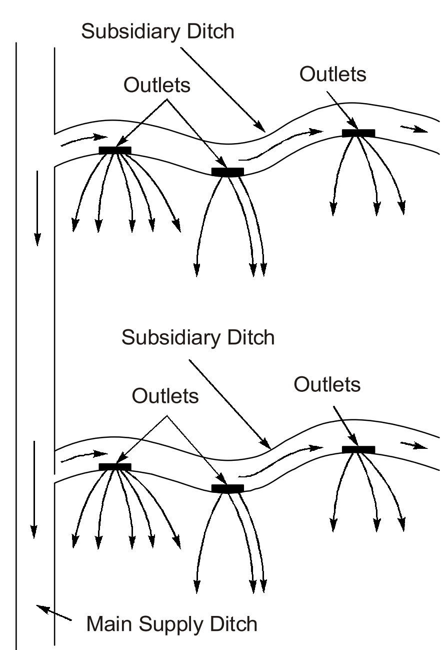
(iv) Trickle (Drip) irrigation

Each of the above methods have some advantages and disadvantages, and the choice of the method depends on the following factors:

(i) Size, shape, and slope of the field,
(ii) Soil characteristics,
(iii) Nature and availability of the water supply sub-system,
(iv) Types of crops being grown,
(v) Initial development costs and availability of funds and
(vi) Preferences and past experience of the farmer

1.2.1 Uncontrolled Flooding (Free flooding or Ordinary flooding)

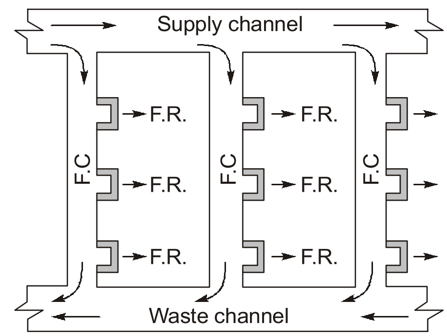
- Ditches are excavated in the field.
- Water from these ditches is allowed to flow across the field without any restriction by opening the field regulators.
- In case of controlled free flooding, surplus water flows through the waste water channel and is discharged into the river or drainage.
- In this method, cost of land preparation is low and cost of labour is high.
- The main disadvantage is that the water application efficiency is low (especially when flooding is not controlled).
- In this case, we have series of field channels connected to the main supply channel.
- This method may be used on rolling land (topography irregular) where borders, checks, basins and furrows are not feasible.



Free flooding

1.2.2 Border Flooding

- In this method, land is divided into a series of long, uniformly graded, narrow strips separated by low levees (i.e. small bunds).
- Here, levees guide the flow of water down the field.
- Usually, length of strips is in the range 100 to 400 m whereas width of strips is in the range 10 to 20 m
- This method is suitable when the area is levelled in direction perpendicular to the flow in order to prevent water from concentrating on either side of the border.
- Water is allowed to flow from supply ditch into each strip and during its travel water gets infiltrated into the soil.



F.C. = Field Channel
F.R. = Field Regulator

Border Flooding

- As soon as the water reaches the lower end of the strip, water supply to that strip is turned off.
- This is the most popular method of flooding.

REMEMBER If the land is not properly graded and there is cross slope, the irrigation water will not spread evenly over the field.

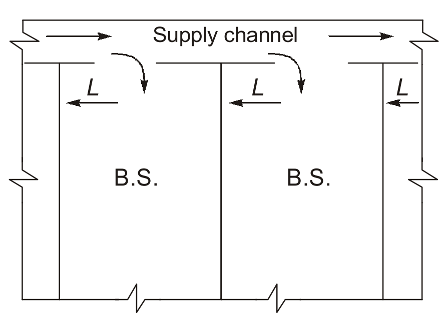
Time taken by irrigation water to irrigate an area:

Time required by irrigation water to irrigate an area can be given by following formula

$$t = 2.303\frac{y}{f}\log_{10}\left(\frac{Q}{Q - fA}\right) \quad ....(1.1)$$

where, Q = Discharge through the supply ditch
y = average depth of water flowing over the strip
f = rate of infiltration of the soil
A = area of the land irrigated

- Consider area dA which gets covered with water in time dt. If y is the water depth then volume of water for this area is $y.dA$.
- In same time dt, volume of water percolated into soil over the area A is $f.A.dt$.
- Total quantity of water supplied to the strip in time dt would be $Q.dt$.



B.S. = Border Strips
L = Leeves

$$\therefore \quad Q \cdot dt = y \cdot dA + f \cdot A \cdot dt \quad ...(i)$$

or $$dt = \left(\frac{y \cdot dA}{Q - f \cdot A}\right) \quad ...(ii)$$

Considering y, f and Q as constants, and integrating the above equation, we get

$$t = \frac{y}{f}\log_e\left(\frac{Q}{Q - f \cdot A}\right) + \text{a constant of integration } (K)$$

But at $t = 0$, $A = 0$

$$\therefore \quad K = \frac{y}{f}\log_e 1 = 0 \; (\because \log_e 1 = 0)$$

$$\therefore \quad t = \frac{y}{f}\log_e\left(\frac{Q}{Q - fA}\right)$$

or $$t = 2.3 \cdot \frac{y}{f}\log_{10}\left(\frac{Q}{Q - fA}\right),$$ which is the above given equation (1.1).

This equation can be further written as

$$\frac{t \cdot f}{2.3y} = \log_{10}\left(\frac{Q}{Q - fA}\right).\ \text{Now, let } \frac{t \cdot f}{2.3y} = x$$

Then, $$x = \log_{10}\left(\frac{Q}{Q - fA}\right) \text{ or } 10x = \frac{Q}{Q - fA}$$

or $$Q \cdot 10^x - f \cdot A \cdot 10^x = Q \text{ or } Q(10^x - 1) = f \cdot A \cdot 10^x$$

or $$A = \frac{Q(10^x - 1)}{f \cdot 10^x}$$

Further, considering the maximum value of $\frac{10^x - 1}{10^x} = 1$.

We get $$A_{max} = \frac{Q}{f} \quad ...(1.2)$$

This is the maximum area that can be irrigated with a supply ditch of discharge Q and for soil having infiltration capacity f.

EXAMPLE - 1.1

Determine the time required to irrigate a strip of land of 0.04 hectares in area from a tubewell with Q = 0.02 cumecs; f = 5 cm/hr and y_{avg} = 10 cm

where, Q = discharge through the supply ditch

y_{avg} = average depth of water flowing over the strip

f = infiltration rate of the soil

Also, determine the maximum area that can be irrigated from the tubewell.

Solution:

Given, $A = 0.04 \text{ ha} = 0.04 \times 10^4 \text{ m}^2 = 400 \text{ m}^2$

$$Q = 0.02 \text{ m}^3/\text{s}$$

$$f = 5 \text{ cm/hr} = \frac{0.05}{3600} \text{ m/s}$$

$$y = y_{avg} = 10 \text{ cm} = 0.1 \text{ m}$$

$$t = 2.303\frac{y}{f}\log_{10}\left(\frac{Q}{Q - fA}\right)$$

$$= 2.303\frac{0.10}{0.05/3600}\times\log_{10}\left(\frac{0.02}{0.02 - \frac{0.05}{3600}\times 400}\right)$$

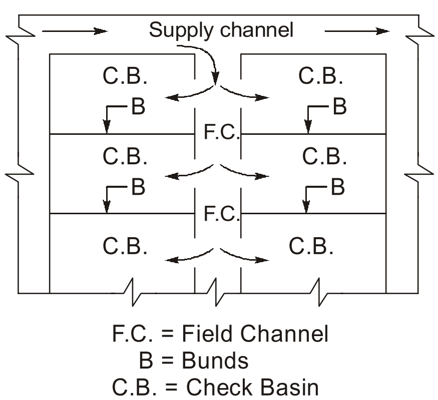
$$= 16581.6 \times 0.14 = 2343.46 \text{ s} = 39.06 \text{ min}$$

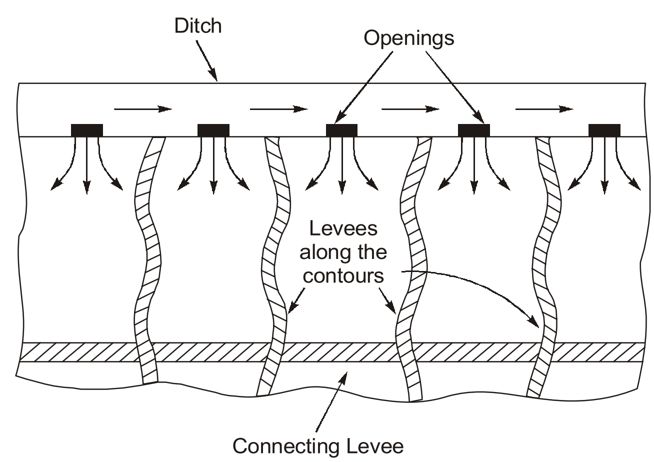
Maximum area that can be irrigated,

$$A_{max} = \frac{Q}{f} = \frac{0.02}{0.05}\times 3600 = 1440 \text{ m}^2$$

1.2.3 Check Flooding

- In this method, agricultural area is divided into small plots (known as checks) by surrounding the area with low and flat levees. These levees act as check bunds.
- Check bunds are generally constructed along the contours
- Water is supplied to the check basins through the field channels which are connected with the supply channel.
- Water is retained in these check basins for sometime to allow for infiltration into the soil.
- This method is suitable for both more permeable and less permeable soils.
- Close growing crops such as jowar or paddy are most preferred.
- Some loss of cultivable area occurs due to levees.

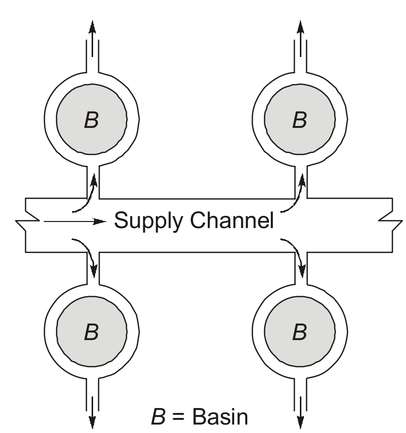




Check Flooding

1.2.4 Basin Flooding

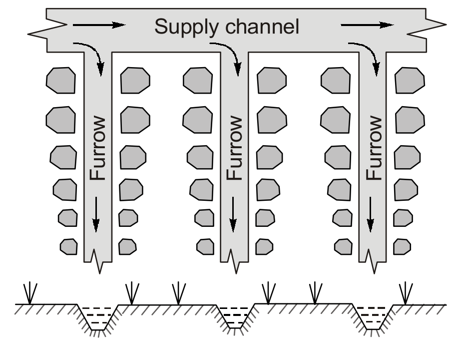
- This method is mainly employed for watering orchids.
- In this method, one or more trees are generally enclosed by circular channel through which water flows.
- This circular channel acts as a basin.
- Each basin is connected to the field channel while field channel is connected to the supply channel.
- This method is most suitable for crops that are unaffected by standing water present over long period of time.



Basin Flooding

1.2.5 Furrow Irrigation Method

- In this method, water is supplied to the land by digging narrow channels at regular interval.
- These narrow channels are called furrow.
- Water infiltrates through the wetted perimeter of the furrows and moves vertically and then laterally to saturate the soil.
- Usually, crops are grown on the ridges between the furrows.
- Depth of the furrows varies from 8 to 30 cm while length of furrows are around 400 m.
- This method is suitable for row crops like sugarcane, groundnut, potato, tobacco etc.
- Preferred on flat area or gentle slopes.



Furrow Irrigation

1.2.6 Subsurface Irrigation

Subsurface irrigation (or simply sub irrigation) is the practice of applying water to soils directly under the surface. Moisture reaches the plant roots through capillary action. The conditions which favor sub irrigation are as follows:

(i) Impervious subsoil at a depth of 2 meters or more,

(ii) A very permeable subsoil,

(iii) A permeable loam or sandy loam surface soil,

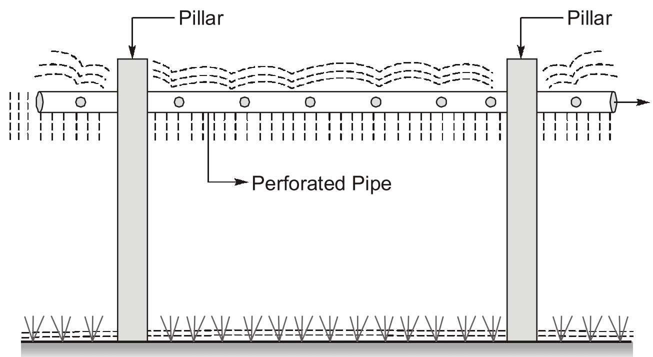
(iv) Uniform topographic conditions, and

(v) Moderate ground slopes.

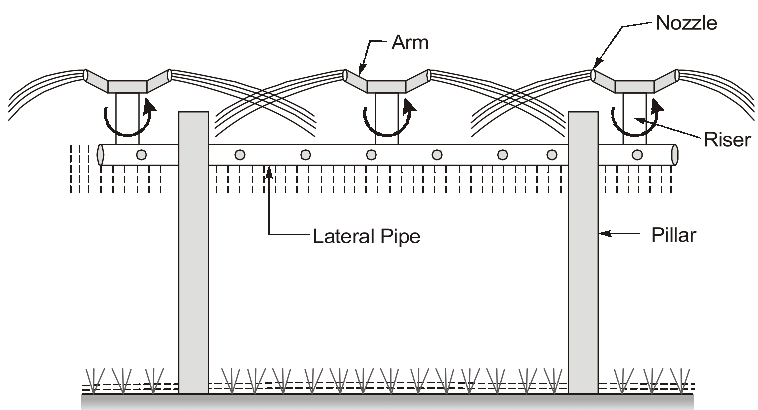
In natural sub irrigation, water is distributed in a series of ditches about 0.6 to 0.9 meter deep and 0.3 meter wide having vertical sides. These ditches are spaced 45 to 90 meters apart. Sometimes, when soil conditions are favorable for the production of cash crops (i.e., high-priced crops) on small areas, a pipe distribution system is placed in the soil well below the surface. This method of applying water is known as artificial sub-irrigation. Soils which permit free lateral movement of water, rapid capillary movement in the root-zone soil, and very slow downward movement of water in the subsoil are very suitable for artificial sub-irrigation. The cost of such methods is very high. However, the water consumption is as low as one-third of the surface irrigation methods. The yield also improves.

1.2.7 Sprinkler Irrigation Method

- In this method, irrigation water is applied to the land in the form of a spray.
- Water is sprayed by employing the network of main pipe, sub main pipes and lateral pipes.
- Lateral pipes may be perforated at the top and sides or it may contain series of nozzles through which water comes out as a fountain.
- In present scenario, mainly rotating sprinklers are being used.
- It is also sometimes known as overhead irrigation.
- The sprinkler irrigation can be used for all the crops except rice and jute and for almost all the soil except very heavy soils with very low infiltration rates.
- It is best suited for very light soils as deep percolation losses are avoided.



Perforated lateral pipes



Rotary sprinklers

Advantages of Sprinkler irrigation method:

- Can be efficiently used for wide range of topography, soils and crops.
- Erosion of soil can be controlled.
- Water as well as fertilisers are uniformly applied.
- 80% of water application efficiency achieved.
- Labour cost is reduced as no land preparation is required.
- No land levelling is required.

Disadvantages of Sprinkler irrigation method:

- System is a bit costly to install, operate and maintain.
- Continuous supply of power is required.
- Corners remain unirrigated.
- Under high wind condition and high temperature, application efficiency becomes poor.
- High saline water at higher temperature causes leaf burning.

1.2.8 Drip Irrigation Method (Trickle irrigation)

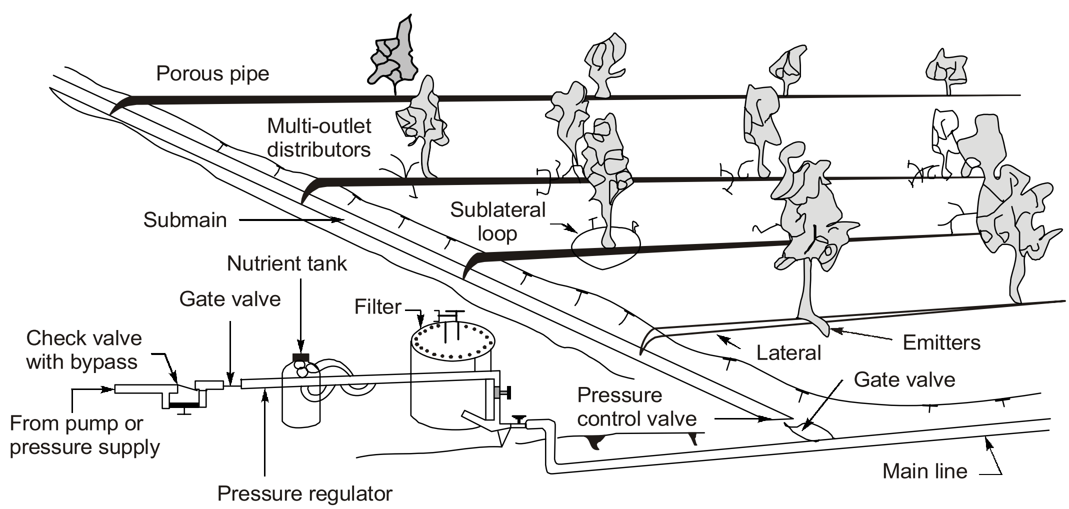
- It is the latest method of irrigation
- In this method, water and fertilizer are slowly and directly applied to the root zone of the plant in order to minimize the evaporation and seepage losses
- Specially designed emitters and drippers are used for this purpose.
- This method is best suited for row crops and orchards (e.g. tomatoes, grapes, corn, cauliflowers, cabbage etc.).
- Centrifugal pump is best suited for this method.

Advantages of drip irrigation:

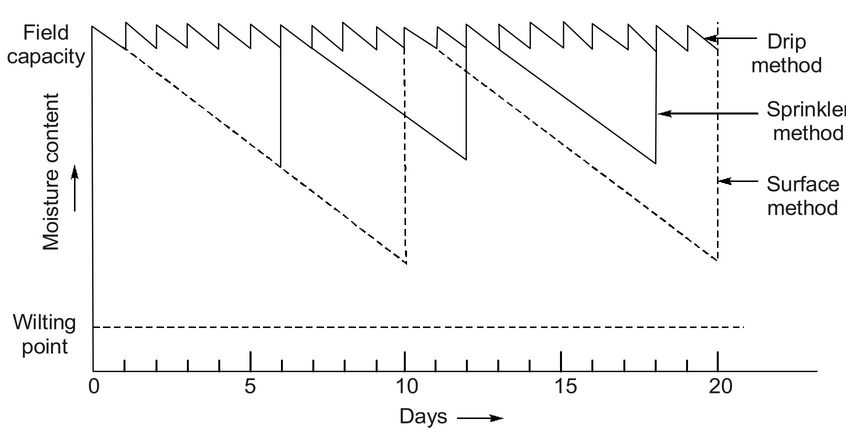
- Water requirement is minimal.
- Evaporation losses are close to negligible.
- Highest rate of vegetative growth is achieved in this method.
- Soil surface is least wetted and hence occurrence of diseases due to dampness decreases.
- No land levelling is required.
- No soil erosion takes place.
- Less labour is required.

Disadvantages of drip irrigation:

- Plastic pipes or drippers may get attacked by the rodents.
- Does not offer frost protection.
- Needs regular flushing and supervision.
- High skill is required in the design, installation, operation and maintenance.



Line sketch of a typical drip irrigation system



Moisture availability for crops in different irrigation methods

Capacity factor for the main canal

Kharif Season $\Sigma Q = 6 + 4 + 2 = 12$ cumecs

Rabi Season $\Sigma Q = 6 + 2.5 = 8.5$ cumecs

Summer Season $\Sigma Q = 6 + 1.6 = 7.6$ cumecs

$$\therefore \quad \text{Average discharge, } \bar{Q} = \frac{1}{3}(12 + 8.5 + 7.6) = 9.37 \text{ cumecs}$$

$$Q_{max} = 12 \text{ cumecs}$$

$$\text{Capacity factor } (C.F.) = \frac{\bar{Q}}{Q_{max}} = \frac{9.37}{12} = 0.78$$

Design discharge at the head of the main canal

$$Q_{max} = 12 \text{ cumecs}$$

Design discharge at the field outlet allowing for peak use and time factor,

$$Q_0 = \frac{1.2}{13/20} \times 12 = 22.15 \text{ cumecs}$$

NOTE

As time factor increases, canal runs more number of days and hence design discharge decreases. (i.e. we have to design for lesser value).

Design discharge at the head of the main canal (allowing conveyance losses)

$$Q_{max} = \frac{Q_0}{1-0.2} = \frac{22.15}{0.8} = 27.69 \text{ cumecs} \approx 28 \text{ cumecs}$$

PRACTICE QUESTIONS

Question : 1

Calculate the reservoir capacity for irrigating an area of GCA = 50000 ha. The cropping pattern is as follows:

Crops	Period	Base period (days)	Outlet factor (ha/cumec)	Intensity of cropping (%)	Crop ratio
Sugar-cane	Oct-Sep	360	1000	60	4
Cotton	May-Nov	180	1200	60	3
Wheat	Dec-April	120	1500	80	2
Gram	Dec-April	120	2000	80	3

The area has 40% non-culturable are:

Assume:

(i) Time factor = $\frac{7}{10}$

(ii) Extra allowance for period of peak water use = 20%

(iii) Conveyance losses = 20%

(iv) Reservoir losses = 10%

Also calculate design discharge and capacity factor of main canal.

Solution:

$$GCA = 50000 \text{ ha}$$

$$CCA = (1 - 0.4) \times 50000 = 30000 \text{ ha}$$

Sugar-cane: Area under irrigation (A_s) = Intensity × Crop ratio × CCA

$$= 0.6 \times \frac{4}{12} \times 30000 = 6000 \text{ ha}$$

$\because$
$$\Delta = \left(\frac{8.64B}{D}\right)$$

$$D = \text{duty (outlet factor) (ha/cumec)}$$

$$B = \text{Base period (days)}$$

$$\Delta = \text{Delta (m)}$$

$$\Delta_s = \frac{8.64 \times 360}{1000} = 3.11 \text{m}$$

$\therefore$ Volume required (V_s) = $A_s \times \Delta_s = 6000 \times 3.11 = 18660$ ha-m

Cotton: Area under irrigation (A_C) = $0.6 \times \frac{3}{12} \times 30000 = 4500$ ha

$$\Delta_C = 8.64\frac{B}{D} = 8.64 \times \frac{180}{1200} = 1.296 \text{ m}$$

Volume required, $V_C = A_C \times \Delta_C$

$$= 4500 \times 1.296 = 5832 \text{ ha-m}$$

Wheat: Area under irrigation (A_w) = $0.8 \times \frac{2}{12} \times 30000 = 4000$ m

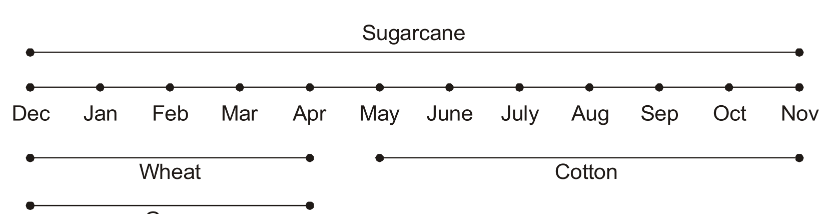
$$A_w = 8.64 \times \frac{120}{1500} = 0.691 \text{m}$$

$$V_w = A_w \times \Delta_w = 4000 \times 0.691 = 2764 \text{ ha-m}$$

Gram: Area under irrigation (A_g) = $0.8 \times \frac{3}{12} \times 30000 = 6000$ m

$$\Delta_G = 8.64 \times \frac{120}{2000} = 0.518 \text{ m}$$

$\therefore$
$$V_g = A_g \times \Delta_g = 6000 \times 0.518 = 3108 \text{ ha-m}$$



Peak water use = Maximum ($V_s + V_C$, $V_C + V_s + V_g$)

= Maximum (18660 + 5832 = 24492, 18660 + 2764 + 3108 = 24532)

= 24532 has-m

Due to 20% extra allowance $(V_{reqd}) = 1.2 \times 24532 = 29438.4$ ha-m

Given: $\eta_{conv.} = 0.8$

$\eta_{reservoir} = 0.9$

$\therefore$ Gross reservoir capacity needed $= \dfrac{29438.4}{0.8 \times 0.9} = 40886.67$ ha-m

Design discharge calculations:

$$q_{sugarcane} = \frac{A_s}{D_s} = \frac{6000}{1000} = 6 \text{ cumec}$$

$$q_{cotton} = \frac{A_c}{D_c} = \frac{4500}{1200} = 3.75 \text{ cumec}$$

$$q_{wheat} = \frac{A_w}{D_w} = \frac{4000}{1500} = 2.67 \text{ cumec}$$

$$q_{gram} = \frac{A_g}{D_g} = \frac{6000}{2000} = 3 \text{ cumec}$$

$$Q_{design} = \frac{\text{Max}\left[\text{Dec-April, May-Nov}\right]}{\text{Time factor}}$$

$$= \frac{\text{Maximum } (q_s + q_w + q_g, q_s + q_c)}{\text{Time factor}}$$

$$= \frac{\text{Maximum } (11.67, 9.75)}{0.7} = \frac{11.67 \text{ cumec}}{0.7}$$

$$Q_{design} = 16.67 \text{ cumec}$$

$$\text{Capacity factor} = \frac{Q_{mean}}{Q_{max}}$$

$$Q_{mean} = \frac{11.67 + 9.75}{2} = 10.71 \text{ cumec}$$

$$\therefore \quad CF = \frac{10.71}{11.67} = 0.918$$

Question : 2

A stream of 150 lps was delivered from a canal and 110 lps were delivered to the field. An area of 2.2 ha was irrigated in 8 hrs. The effective depth of root zone was 1.5 m. Runoff loss in the field was 445 m^3. Depth of water penetration varied linearly from 1.5 m at the head end of the field to 1.1 m at the tail end. Available moisture holding capacity of the soil is 200 mm per meter depth of soil. Determine the water conveyance efficiency, water application efficiency, water storage efficiency and water distribution efficiency. Given that irrigation was started at a moisture extraction level of 50%.