2

Water Requirements of Crops

2.1. General

Every crop requires a certain quantity of water after a certain fixed interval, throughout its period of growth. If the natural rain is sufficient and timely so as to satisfy both these requirements, no irrigation water is required for raising that crop. In England, for example, the natural rain falling regularly throughout the year, satisfies both these requirements for practically all the crops, and, therefore, irrigation is not significantly needed in England. But in a tropical country like India, the natural rainfall is either insufficient, or the water does not fall regularly, as required by the crops. Since the magnitude as well as the frequency of the rainfall varies throughout a tropical country, certain crop may require irrigation in certain part of the country, and the same crop may not require any irrigation in some other part of the country. The area where irrigation is a must for agriculture is called the **arid region,** while the area in which inferior crops can be grown without irrigation is called a **semi-arid region.**

The term 'Water requirements of a crop' means *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 is very clear from the above discussion, that the water requirement, will vary with the crop as well as with the place. In other words, *different crops will have different water requirements, and the same crop may have different water requirements at different places of the same country* ; depending upon the variations in climates, type of soils, methods of cultivation, and useful rainfalls, etc.

2.2. Crop Period or Base Period

The time period that elapses from the instant of its sowing to the instant of its harvesting is called the *crop-period.* The time between the first watering of a crop at the time of its sowing to its last watering before harvesting is called the *Base period* or the *Base of the crop.* Crop period is slightly more than the base period, but for all practical purposes, they are taken as one and the same thing, and generally expressed in days. Hence, in future, the terms like *growth period, crop period, base period,* etc., will be used as synonyms, each representing crop period, and will be represented by *B* (in days).

2.3. Duty and Delta of a Crop

2.3.1. Delta. Each crop requires a certain amount of water after a certain fixed interval of time, throughout its period of growth. The depth of water required every time, generally varies from 5 to 10 cm depending upon the type of the crop, climate and soil. The time interval between two such consecutive waterings is called the **frequency of irrigation,** or **rotation period.** The rotation period may vary between 6-15 days for different crops. The summation of the total water depth supplied during the base period of a crop, for its full growth, will evidently represent the total quantity of water required by the crop for its full-fledged nourishment. *This total quantity of water required by the crop for its full growth* (maturity) may be expressed in hectare-metre (Acre-ft) or in million cubic metres (million cubic-ft) or simply as 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 is called its delta* (Δ).

Example 2.1. *If rice requires about 10 cm depth of water at an average interval of about 10 days, and the crop period for rice is 120 days, find out the delta for rice.*

Solution. Water is required at an interval of 10 days for a period of 120 days. It evidently means that 12 no. of waterings are required, and each time, 10 cm depth of water is required. Therefore, total depth of water required

$$\Delta = 12 \times 10 \text{ cm} = 120 \text{ cm}.$$

Hence Δ for rice = 120 cm. **Ans.**

Example 2.2. *If wheat requires about 7.5 cm of water after every 28 days, and the base period for wheat is 140 days, find out the value of delta for wheat.*

Solution. Assuming the base period to be representing the crop period, as per usual practice, we can easily infer that the water is required at an average interval of 28 days up to a total period of 140 days. This means that $\frac{140}{28} = 5$ no. of waterings are required.

The depth of water required each time = 7.5 cm.

$\therefore$ Total depth of water reqd. in 140 days $= 5 \times 7.5 \text{ cm} = 37.5 \text{ cm}$

Hence, Δ for wheat = 37.5 cm. **Ans.**

2.3.2. Delta for certain crops. The average values of deltas for certain crops are shown in Table 2.1. These values represent the total water requirement of the crops. The actual requirement of irrigation water may be less, depending upon the useful rainfall. Moreover, these values represent the values on field, *i.e.* 'delta on field' which includes the evaporation and percolation losses.

Table 2.1. Average Approximate Values of Δ for Certain Important Crops in India

S. No. (1)	*Crop* (2)	*Delta on field* (3)
1.	Sugarcane	120 cm (48″)
2.	Rice	120 cm (48″)
3.	Tobacco	75 cm (30″)
4.	Garden fruits	60 cm (24″)
5.	Cotton	50 cm (22″)
6.	Vegetables	45 cm (18″)
7.	Wheat	40 cm (16″)
8.	Barley	30 cm (12″)
9.	Maize	25 cm (10″)
10.	Fodder	22.5 cm (9″)
11.	Peas	15 cm (6″)

2.3.3. Duty of Water. The 'duty' of water is the relationship between the volume of water and the area of the crop it matures. It may be defined as the number of hectares of land irrigated for full growth of a given crop by supply of 1 m^3/sec of water continuously during the entire base period (B) of that crop. Thus, if water flowing at a rate of one cubic metre per second, runs continuously for B days, and matures 200 hectares, then the duty of water for that particular crop will be defined as 200 hectares per cumec to the base of B days. The duty is generally represented by the letter D.

2.3.4. Relation between duty and delta. Let there be a crop of base period B days. Let one cumec of water be applied to this crop on the field for B days.

Now, the volume of water applied to this crop during B days

$$= V = (1 \times 60 \times 60 \times 24 \times B)\ m^3$$
$$= \mathbf{86\,400\,B}\ \text{(cubic metre)}$$

By definition of duty (D), one cubic metre 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

$$= \frac{\text{Volume}}{\text{Area}} = \frac{86{,}400\,B}{10^4\,D} = \frac{8.64\,B}{D}\ \text{metres}$$

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

$$\therefore \qquad \Delta = \frac{8.64\,B}{D}\ \text{metres} \qquad ...(2.1)$$

or

$$\Delta = \frac{864\,B}{D}\ \text{cm.} \qquad ...(2.2)$$

where, Δ is in cm; B is in days ; and
D is duty in hectares/cumec.

Example 2.3. *Find the delta for a crop when its duty is 864 hectares/cumec on the field, the base period of this crop is 120 days.*

Solution.

$$\Delta\ \text{(cm)} = \frac{864\,B}{D}\ \text{where } B \text{ is in days and } D \text{ is in hectares/cumec}$$

In this question, $B = 120$ days and $D = 864$ hectares/cumec

$$\therefore \qquad \Delta = \frac{864 \times 120}{864} = \mathbf{120\ cm.} \quad \textbf{Ans.}$$

2.3.5. Duty at various places. In a large canal irrigation system, the water from its source, first of all, flows into the main canal ; from the main canal, it flows into the branch canal ; from the branch canal, it flows into the distributary ; from the distributary, it flows into the minor ; and then into the field channels (water-courses) ; and finally into the fields. A systematic layout of a canal system is shown in Fig. 2.1.

During the passage of water from these irrigation channels, water is lost due to evaporation and percolation. These losses are called Transit losses or Transmission or Conveyance losses in channels.

Duty of water for a crop, is the number of hectares of land, which the unit flow of water for *B* days can irrigate. Therefore, if the water requirement of a particular crop at a particular location is more, then lesser number of hectares of land it will irrigate. Hence, *if water consumed by a crop of a given base period is more, its duty will be less. It, therefore, becomes clear that 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 en-route as transit losses.* Applying the same reasoning, it can be established *that duty of water at the head of a minor will be less than that at the head of the water-course ; duty at the head of a distributary will be less than that at the head of a minor, duty at the head of a branch canal will be less than that at the head of a distributary, and duty at the head of a main canal will be less than the duty at the head of a branch canal.* Duty of water, therefore, varies from one place to another, and *increases* as one moves *downstream* from the head of the main canal towards the head of the branches or water-courses. *The duty at the head of water-course (i.e.* at the outlet point of the minor), is quite important, and is called the **outlet discharge factor.** This outlet point is generally the end point of Irrigation Department. The control of Irrigation Department finishes at the outlet point, and the water is carried into the fields through water-courses by the beneficiary cultivators themselves.

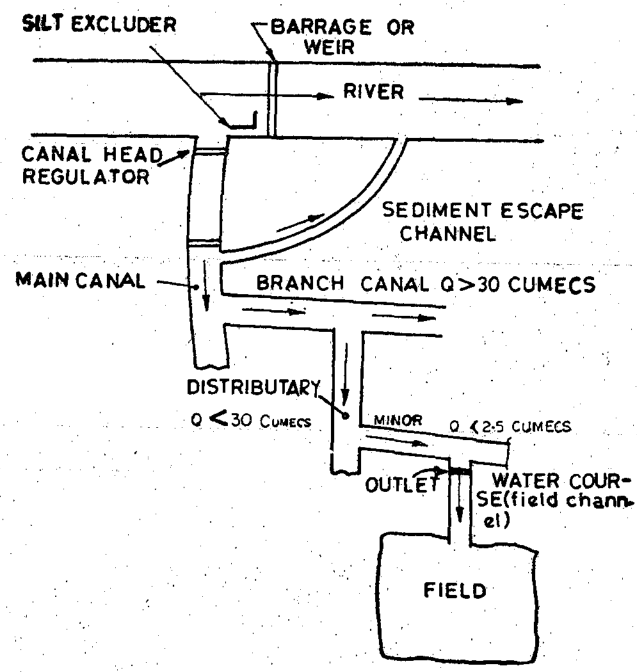

Fig. 2.1. Layout of a canal system.

2.3.6. Flow duty and Quantity duty. In direct irrigation, duty is always expressed in hectares/cumec. It is then called as *flow-duty* or duty.

In storage irrigation, duty may, sometimes be expressed in hectares/million cubic metre of water available in the reservoir. It eventually means that every million cubic metre of water available in the reservoir will mature so many hectares of a particular crop. Hence, the irrigation capacity of the reservoir is directly known. When duty is expressed in this manner, it is called *Quantity duty* or *Storage duty.*

2.3.7. Factors on which duty depends. Duty of irrigation water depends upon the following factors :

(*i*) *Type of crop.* Different crops require different amount of water, and hence, the duties for them are different. A crop requiring more water will have less flourishing acreage for the same supply of water as compared to that requiring less water. Hence, *duty will be less for a crop* requiring *more* water and *vice versa.*

(*ii*) *Climate and season.* As stated earlier, duty includes the water lost in evaporation and percolation. These losses will vary with the season. Hence, duty varies from season to season, and also from time to time in the same season. The figures for duties which we generally express are their average values considered over the entire crop period.

(*iii*) *Useful rainfall.* If some of the rain, falling directly over the irrigated land, is useful for the growth of the crop, then so much less irrigation water will be required to mature the crop. More the useful rainfall, less will be the requirement of irrigation water, and hence, more will be the duty of irrigation water.

(*iv*) *Type of soil.* If the permeability of the soil under the irrigated crop is high, the water lost due to percolation will be more and hence, the duty will be less. Therefore, for sandy soils, where the permeability is more, the duty of water is less.

(*v*) *Efficiency of 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. Cultivators should, therefore, be trained and educated properly to use irrigation water economically.

2.3.8. Importance of duty. It helps us in designing an efficient canal irrigation system. Knowing the total available water at the head of a main canal, and the overall duty for all the crops required to be irrigated in different seasons of the year, the area which can be irrigated can be worked out. Inversely, if we know the crops area required to be irrigated and their duties, we can work out the discharge required for designing the channel.

2.3.9. Duty for certain crops. The average values of duties for certain important Indian crops are tabulated in Table 2.2.

Table 2.2. Average Approximate Values of Duty for Certain Important Crops in India

Crop	*Duty in hectares/cumec*
Sugarcane	730
Rice	775
Other Kharif	1500
Rabi	1800
Perennials	1100
Hot fodder	2000

2.3.10. Measures for Improving duty of water. The duty of canal water can certainly be improved by effecting economy in the use of water by resorting to the following precautions and practices.

(1) *Precautions in field preparation and sowing :*

(*i*) Land to be used for cultivation should, as far as possible, be levelled.

(*ii*) The fields should be properly ploughed to the required depth.

(*iii*) Improved modern cultivation methods may preferably be adopted.

(*iv*) Porous soils should be treated before sowing crops to reduce seepage of water.

(*v*) Alkaline soils should be properly leached before sowing.

(*vi*) Manure fertilisers should be added to increase water holding capacity of the soil.

(*vii*) *Rotation of crops** should be preferred, as this will ensure increased crop yields with minimum use of water.

(2) *Precautions in handling irrigation supplies :*

(*i*) The source of irrigation water should be situated within the prescribed limits, and should be capable of delivering sufficient quantity of satisfactary quality of irrigation water.

(*ii*) Canals carrying irrigation supplies should be lined to reduce seepage and evaporation**, thereby reducing on field requirement of water and consequently improving the duty of water.

(*iii*) Water courses may preferably be lined ; or R.C.C. pipes may be used for the same to reduce on field requirement of water, thereby improving duty.

(*iv*) Free flooding of fields should be avoided and furrow irrigation method may preferably be adopted, if surface irrigation is resorted to.

(*v*) Sub surface irrigation and Drip irrigation may be preferred to ordinary surface irrigation.

(*vi*) 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.

(*vii*) Irrigation supplies should be economically used by proper control on its distribution, volumetric assessment, and by imparting proper education to the farmers.

2.4. Crop Seasons and Indian Agriculture

More than 70% of the Indian population is directly or indirectly connected with agriculture. The chief crops of India are rice, wheat, sugarcane, tea, cotton, groundnut, jute, coffee, rubber, garden crops (like coconuts, orange, etc), etc. Different types of soils are needed for raising different types of crops. For example, heavy retentive soil (40% clay) is favourable for raising crops like sugarcane, rice, etc., requiring more water. Light sandy soil (2 to 8% clay) is suitable for crops like gram, fodder, etc. requiring less water. Medium or normal soil (having about 10—20% of clay) is suitable for crops like wheat, cotton, maize, vegetables, oil seeds, etc. requiring normal amount of water.

From the agricultural point of view, the year can be divided into two principal cropping seasons, *i.e. Rabi* and *Kharif.* Normally, **Rabi** *starts from 1st October and ends on 31st March ; while* **Kharif** *starts from 1st April and ends on 30th September.* These dates are not rigid dead lines. The time may vary up to 1—3 months on either side. Sugarcane, which is an important cash crop, extends over both seasons.

The **Kharif crops** *are rice, bajra, jowar, maize, cotton, tobacco, groundnut, etc. The* **Rabi crops** *are wheat, barley, gram, linseed, mustard, potatoes, etc.* Kharif crops are also called 'Summer crops' and Rabi crops as 'Winter crops'. Kharif crops require about two to three times the quantity of water required by the Rabi crops.

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* explained in article 2.5.5.

** Water moving with higher velocity, will ensure reduced evaporation.

The above distinction of seasons is well applicable to North India, but in South India, there is no such marked distinction between the different seasons. In fact, in South India, there is no clear cut winter, spring, summer and autumn seasons, as they are in North India. Except Bombay-Deccan, where there are five crop seasons, there are only three crop seasons in the remaining parts of the country. These three classifications of seasons are :

(*i*) Hot weather or Kharif season. (*ii*) Monsoon season. (*iii*) Winter or Rabi season.

When a crop requires water for its crop season and also for some time in the beginning of the next crop season, allowance has to be made for this overlap. This allowance is known as **overlap allowance,** Sugarcane is an example of this kind of crop. Some important Indian crops, their periods of growth, water requirements, seed requirements, yields, etc. are shown in Table 2.3.

Table 2.3. Irrigation Requirements of Certain Important Indian Crops

S. No.	*Crop*	*Period of growth*	*Av. water depth reqd. (in cm)*	*Irrigation requirements and remarks*	*Average quantity of seed required in kg/hectare*	*Average quantity of yield obtained in kg/hectare*
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
	Kharif Crops					
(*i*)	Maize, high yielding	June to Sept.-Oct.	45	Four or five waterings. Sensitive to drought and floods. Responsible to fertilizers.	15	3,000
(*ii*)	Bajra (spiked millets, or Pearl millets), high yielding	July to Nov.	30	Water should not stand. Irrigation as required. Resistant to drought and flooding.	3.75	2,000
(*iii*)	Juar (Great millets), high yielding	Sown in July as fodder and cut green more than once.	30	Same as above.	12.5	3,000
(*iv*)	Ground-nut	May to Nov-Dec.	45	'Paleo' reqd. before sowing.	—	1,600
(*v*)	Cotton	May–June to Nov.–Jan.	25—40	Three or four irrigations are required. Damage up to the extent of 50% may be caused by flooding, rains, etc.	—	500
(*vi*)	Pulses like Arhar, etc.	July-Aug. to Nov.-Dec.	30	Irrigated when leaves get dried.	12.5	700
(*vii*)	Transplanted Rice (Paddy), high yielding	July to Nov.	125—150	Standing water of 5 to 8 cm gives best results.	30 to 35 kg of seed is sufficient to raise nursery to transplant one hectare	4500
(*viii*)	Til	July-Aug. to Oct.-Nov.	—	Generally not irrigated but better to irrigate once.	1.25	350

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Rabi Crops					
(i)	Wheat (ordinary)	Oct. to March–April	37.5	Three-four waterings of 7–10 cm depth.	80—100	1500
(ii)	High yielding Wheat	Oct. to March–April	45	Five-six waterings of 7—10 cm depth.	100—125	4000
(iii)	Gram (high yielding)	Sept.-Oct. to March	30	Irrigated when leaves get dry.	12.5	3500
(iv)	Barley	Oct. to Mar.-April	30	Two waterings ; one at jointing and another at booting stage.	120	1300
(v)	Potatoes	Sept.-Oct. to Feb.	60—90	Usually irrigated ; sown in high hills up to early April. Second crop in plains is sometimes, taken in Feb.-april.	15,000	35,000
(vi)	Tobacco	Oct.-Feb. to Feb.-May	60	Four to five waterings.		4,500
(vii)	Linseed *i.e.* Alsi	Oct.-Nov. to March	45—50	Irrigated at intervals of 15 days. Resistant to drought but damaged by frost and flooding.		700
(viii)	Mustard	Oct. to Feb.-Mar.	45	Watered at intervals of 7—10 days.	33	1000 to 1600
	Overlapping crop but generally classified under Rabi crop					
(i)	Sugarcane	Feb.-March to Dec.-March	90	5 or 6 waterings of 10 cm or more.	500	25,000—30,000

2.5. Certain Important Definitions

2.5.1. 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 is called, Kharif-Rabi ratio. This ratio is generally 1 : 2, *i.e.* Kharif area is one-half of the Rabi area.

2.5.2. 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, when the soil may be too dry to be sown easily. In such a case, the soil is moistened with water, so as to help in sowing of the crops. This is known as Paleo irrigation.

2.5.3. Kor-watering. The first watering which is given to a crop, when the crop is a few centimetres high, is called kor-watering. It is usually the maximum single watering followed by other waterings at usual intervals, as required by drying of leaves.

The optimum depth of kor-watering for different crops are different. *For example, the optimum depth of kor-watering for Rice is 19 cm., for Wheat (in U.P.) is about 13.5 cm, and for Sugarcane is 16.5 cm.*

The kor-watering must be applied within a fixed limited period, called *Kor-period.* If the plants fail to receive this water in time or in sufficient quantity, then they do suffer a significant loss. The kor-period depends upon the climate. It is less for humid climates and more for dry climates. The *kor-period for rice varies from 2 to 4 weeks, and that for wheat varies from 3 to 8 weeks.*

2.5.4. Cash crops. A cash crop may be defined as 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 crops. Crops like jute, tea, cotton, tobacco, sugarcane, etc. are, therefore, called cash crops. The food crops like wheat, rice, barley, maize, etc. are excluded from the list of cash crops.

2.5.5. Crops rotation. When the same crop is grown again and again in the same field, the fertility of land gets reduced as the soil becomes deficient in plant foods favourable to that particular crop. In order to enhance the fertility of the land and to make the soil regain its original structure, it is often found necessary and helpful to give some rest to the land. This can be achieved either by allowing the 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. This method of growing different crops in rotation, one after the other, in the same field, is called *Rotation of Crops.* A cash crop may be followed by a fodder crop, which, in turn, may be followed by a *soil-renovating crop* like gram, which being a **liguminous crop**, helps in giving nitrogen to the fields, thereby renovating the soil. The cultivators who are fond of sowing cash crops always, should be educated and made to understand the advantages of sowing crops in rotation.

The rotation of crops will help in extracting different foods from the soil, and thus avoiding the general deficiency of any particular type(s) of element(s). Moreover, if only one type of crop is grown in the same field, numerous insects and pests (of similar nature) will get developed. The crop rotation will also help in checking such growths. *Crop rotation will thus help in increasing the fertility of soil, and reducing the diseases and wastage due to insects, and hence increasing the overall crop yield.*

In general, the following rotations of crops may be adopted depending upon the soil conditions :

(*i*) Wheat—Juar—Gram

(*ii*) Rice—Gram*

(*iii*) Cotton—Wheat—Gram*— Fallow (up to July)

(*iv*) Cotton—Juar—Gram.

(*v*) Sugarcane (18 months) — Thadwa — Wheat or gram — Fallow (upto July).

2.6. Optimum Utilisation of Irrigation Water

If a crop is sown and produced under absolutely identical conditions, using different amounts of water depths, the yield is found to vary. The yield increases with water, reaches a certain maximum value and then falls down, as shown in Fig. 2.2. *The quantity of water at which the yield is maximum, is called the optimum water depth.*

Therefore, optimum utilisation of irrigation, generally means, getting maximum yield with any amount of water. The supplies of water to the various crops should be adjusted in such a fashion, as to get optimum benefit ratio, not only for the efficient use of available water and maximum yield, but also to prevent water-logging of the land

* After harvesting a heavy water consuming crop like Rice, a less water consuming short term crop like gram may be taken, which may come up on the remnant moisture and manure.

in question. To achieve economy in the use of water, it is necessary that the farmers be made acquainted with the fact that only a certain fixed amount of water gives best results. More than that quantity, as well as, less than that quantity, reduces the yield. Many cultivators, till today feel, that they can increase the crop yield by using more and more water. Hence, they try to supply more water to their fields by undue tapping at the outlets. This must be checked. Moreover, farmers should be encouraged to line their water courses, thereby saving at least 20% of the costly irrigation water, which can be used to irrigate extra additional fields.

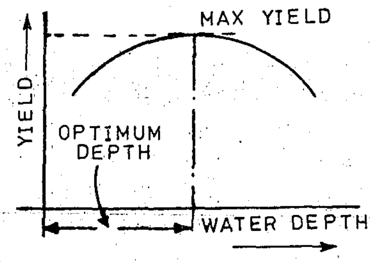

Fig. 2.2.

2.7. Irrigation Efficiencies

Efficiency is the ratio of the water output to the water input, and is usually expressed as percentage. Input minus output is nothing but losses, and hence, if losses are more, output is less and, therefore, efficiency is less. Hence, efficiency is inversely proportional to the losses. Water is lost in irrigation during various processes and, therefore, there are different kinds of irrigation efficiencies, as given below :

(*i*) **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 entering into the channel at its starting point. It may be represented by η_c. It takes the conveyance or transit losses into consideration.

(*ii*) **Efficiency of water-application.** It is the 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 called **on farm efficiency,** as it takes into consideration the water lost in the farm.

(*iii*) **Efficiency of water-storage.** It is the 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.

(*iv*) **Efficiency of water use.** It is the ratio of the water beneficially used, including leaching water, to the quantity of water delivered. It may be represented by η_u.

Example 2.4. *One cumec of water is pumped into a farm distribution system. 0.8 cumec is delivered to a turn-out, 0.9 kilometre from the well. Compute the conveyance efficiency.*

Solution. By definition,

$$\eta_c = \frac{\text{Output}}{\text{Input}} \times 100 = \frac{0.8}{1.0} \times 100 = 80\% \quad \textbf{Ans.}$$

Example 2.5. *10 cumecs of water is delivered to a 32 hectare field, for 4 hours. Soil probing after the irrigation indicates that 0.3 metre of water has been stored in the root zone. Compute the water application efficiency.*

Solution. Volume of water supplied by 10 cumecs of water applied for 4 hours

$$= (10 \times 4 \times 60 \times 60)\ \text{m}^3 = 1{,}44{,}000\ \text{m}^3$$
$$= 14.4 \times 10^4\ \text{m}^3 = 14.4\ \text{m} \times 10^4\ \text{m}^2 = 14.4\ \text{ha.m.}$$

($\because$ 10^4 m^2 = 1 hectare)

$\therefore$ Input = *14.4 ha.m* ...(*i*)

Output = 32 hectares land is storing water upto 0.3 m depth.

$\therefore$ Output = 32 × 0.3 ha.m = *9.6 ha.m* ...(*ii*)

$$\text{Water application efficiency } (\eta_a) = \frac{\text{Output}}{\text{Input}} \times 100 = \frac{9.6}{14.4} \times 100 = \mathbf{66.67\%} \quad \textbf{Ans.}$$

(*v*) **Uniformity coefficient or Water distribution efficiency**. The effectiveness of irrigation may also be measured by its water distribution efficiency (η_d), which is defined below :

$$\eta_d = \left(1 - \frac{d}{D}\right) \qquad \text{...(2.3)}$$

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.

The water distribution efficiency 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.

Example 2.6. *The depths of penetrations along the length of a boarder strip at points 30 metres apart were probed. Their observed values are 2.0, 1.9, 1.8, 1.6 and 1.5 metres. Compute the water distribution efficiency.*

Solution. The observed depths at five stations are 2.0, 1.9, 1.8, 1.6 and 1.5 metres, respectively.

$$\text{Mean depth} = D = \frac{2.0 + 1.9 + 1.8 + 1.6 + 1.5}{5} = \frac{8.8}{5} = 1.76 \text{ metres}$$

Values of deviations from the mean are (2.0 – 1.76), (1.9 – 1.76), (1.8 – 1.76), (1.6 – 1.76), (1.5 – 1.76) *i.e.*

0.24, 0.14, 0.04, – 0.16 and – 0.26.

The absolute values of these deviations from the mean, are 0.24, 0.14, 0.04, 0.16 and 0.26.

The average of these absolute values of deviations from the

$$\text{mean} = d = \frac{0.24 + 0.14 + 0.04 + 0.16 + 0.26}{5}$$

$$= \frac{0.84}{5} = 0.168 \text{ metre}$$

The water distribution efficiency

$$= \left(1 - \frac{d}{D}\right) = \left[1 - \frac{0.168}{1.76}\right] = 1 - 0.095 = 0.905$$

Hence, the water distribution efficiency = **0.905**. **Ans.**

Example 2.7. *A stream of 130 litres per second was diverted from a canal and 100 litres per second were delivered to the field. An area of 1.6 hectares was irrigated in 8 hours. The effective depth of root zone was 1.7 m. The runoff loss in the field was 420 cu. m. The depth of water penetration varied linearly from 1.7 m at the head end of the field to 1.1 m at the tail end. Available moisture holding capacity of the soil is 20 cm per metre depth of soil. It is required to determine the water conveyance efficiency, water application efficiency, water storage efficiency, and water distribution efficiency. Irrigation was started at a moisture extraction level of 50% of the available moisture.*

Solution.

(*i*) Water conveyance efficiency (η_c)

$$= \frac{\text{Water delivered to the fields}}{\text{Water supplied into the canal at the head}} \times 100$$

$$= \frac{100}{130} \times 100 = \mathbf{77\%} \text{ (say)} \quad \textbf{Ans.}$$

(*ii*) Water application efficiency (η_a)

$$= \frac{\text{Water stored in the root zone during irrigation}}{\text{Water delivered to the field}} \times 100$$

Water supplied to field during 8 hours @ 100 litres per second

$$= 100 \times 8 \times 60 \times 60 \text{ litres} = 2880 \text{ cu. m}$$

Runoff loss in the field = 420 cu. m.

∴ the water stored in the root zone

$$= 2880 - 420 = 2460 \text{ cu. m}$$

∴ Water application efficiency (η_a)

$$= \frac{2460}{2880} \times 100 = \mathbf{85.4\%} \quad \textbf{Ans.}$$

(*iii*) Water storage efficiency

$$= \frac{\text{Water stored in the root zone during irrigation}}{\text{Water needed in root zone prior to irrigation}} \times 100$$

Moisture holding capacity of soil

= 20 cm per m depth × 1.7 m depth of root zone = 34 cm.

Moisture already available in root zone at the time of start of irrigation

$$= \frac{50}{100} \times 34 = 17 \text{ cm.}$$

Additional water required in root zone

$$= 34 - 17 = 17 \text{ cm.}$$

$$= \frac{17}{100} \times (1.6 \times 10^4) \text{ cu. m} \qquad (i.e.\ \text{Depth} \times \text{Plot area})$$

$$= 2720 \text{ cu. m}$$

But actual water stored in root zone = 2460 cu. m

∴ Water storage efficiency (η_s)

$$= \frac{2460}{2720} \times 100 = \mathbf{90\%} \text{ (say)} \quad \textbf{Ans.}$$

(*iv*) Water distribution efficiency

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

where D = mean depth of water stored in the root zone

$$= \frac{1.7 + 1.1}{2} = 1.4 \text{ m.}$$

d is computed as below :

Deviation from the mean at upper end (absolute value)

$$= |1.7 - 1.4| = 0.3$$

Deviation from the mean at lower end

$$= |1.1 - 1.4| = 0.3.$$

d = Average of the absolute values of deviations

$$\text{from mean} = \frac{0.3 + 0.3}{2} = 0.30.$$

Using Eq. (2.3), we have,

$$\eta_d = \left(1 - \frac{0.30}{1.4}\right) = \mathbf{0.786 \text{ or } 78.6\%} \quad \textbf{Ans.}$$

2.8. Consumptive Use or Evapotranspiration (C_u)

Consumptive use for a particular crop may be defined as the total amount of water used by the plant in transpiration (building of plant tissues, etc.) and evaporation from adjacent soils or from plant leaves, in any specified time. The values of consumptive use (C_u) may be different for different crops, and may be different for the same crop at different times and places.

In fact, the consumptive use for a given crop at a given place may vary throughout the day, throughout the month and throughout the crop period. Values of daily consumptive use or monthly consumptive use, are generally determined for a given crop and at a given place. Values of monthly consumptive use over the entire crop period, are then used to determine the irrigation requirement of the crop.

2.9. Effective Rainfall (R_e)

Precipitation falling during the growing period of a crop that is available to meet the evapo-transpiration needs of the crop, is called *effective rainfall*. It does not include precipitation lost through deep percolation below the root zone or the water lost as surface run off. Average ratios, applicable to effective rainfall, are shown in Table 2.4.

Table 2.4. Average Ratios Applicable to Effective Rainfall

Average annual rainfall in cm.	*Per cent chance of occurrence*				
	50	*60*	*70*	*80*	*90*
10	0.84	0.72	0.61	0.50	0.38
20	0.90	0.81	0.71	0.62	0.51
30	0.93	0.85	0.78	0.69	0.58
40	0.95	0.88	0.81	0.73	0.63
50	0.96	0.90	0.83	0.75	0.67
60	0.97	0.91	0.84	0.78	0.70
70	0.97	0.92	0.86	0.80	0.72
80	0.98	0.93	0.87	0.81	0.74
90	0.98	0.93	0.88	0.82	0.75
100	0.98	0.94	0.89	0.83	0.76
120	0.98	0.94	0.90	0.85	0.78
140	0.99	0.95	0.91	0.86	0.80
160	0.99	0.95	0.91	0.87	0.82
180	0.99	0.95	0.92	0.88	0.84
200	0.99	0.95	0.92	0.89	0.85

2.10. 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

$$\text{C.I.R.} = C_u - R_e \qquad ...(2.4)$$

2.11. 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, N.I.R. $= C_u - R_e +$ Water lost as percolation in satisfying other needs such as leaching.

2.12. Factors Affecting Consumptive Use

Consumptive use or evapotranspiration depends upon all those factors on which evaporation and transpiration depend ; such as temperature, sunlight, humidity, wind movement, etc, as detailed in article 7.34.2.3.

Example 2.8. *The following table gives the values of consumptive uses and effective rainfalls for the periods shown against them, for a Jowar crop sown at Bellary in Karnataka State. The period of growth is from 16th October to 2nd Feb., i.e. (110 days). Determine the net irrigation requirement of this crop, assuming that water is not required for any other purpose except that of fulfilling the evapotranspiration needs of the crop.*

Table 2.5 (*a*)

Dates (1)	C_u *in mm.* (2)	R_e *in mm.* (3)
October 16—31	37.0	30.8
November 1—30	84.2	20.4
December 1—31	154.9	6.7
January 1—31	188.1	2.4
February 1—2	13.3	1.0

Solution. The given table is extended as shown in Table 2.5 (*b*). Values in col. (4) are obtained by subtracting values of col. (3) from values of col. (2).

Table 2.5 (*b*)

Dates (1)	C_u (2)	R_e (3)	$NIR = C_u - R_e$ (4)
October 16—31	37.0	30.8	6.2
November 1—30	84.2	20.4	63.8
December 1—31	154.9	6.7	148.2
January 1—31	188.1	2.4	185.7
February 1—2	13.3	1.0	12.3
			$\Sigma = 416.2$ mm **= 41.62 cm**

Hence, the net irrigation requirement = **41.62 cm. Ans.**

2.13. Estimation of Consumptive Use

Although various methods have been developed in order to estimate evapotranspiration (consumptive use) values of different crop in an area, or for areas vegetated with the same cropping pattern, but the most simple and commonly used methods are :

(1) Blaney-Criddle Equation, and

(2) Hargreaves class *A* pan evaporation method.

(3) Penman's equation.

They are described below :

2.13.1. Blaney-Criddle Formula. It states that the monthly consumptive use is given by

$$C_u = \frac{k \cdot p}{40}\left[1.8t + 32\right] \qquad ...(2.5)$$

where, C_u = Monthly consumptive use in cm.

k = **Crop factor,** determined by experiments for each crop, under the environmental conditions of the particular area.

t = Mean monthly temperature in °C.

p = Monthly per cent of annual day light hours that occur during the period.

If $\frac{p}{40}\left[1.8t + 32\right]$ is represented by f, we get

$$C_u = k \cdot f \qquad ...(2.6)$$

This formula has been extensively used throughout the world for estimating seasonal water requirements. However, it was found that the values of k based on seasonal determinations were too low for the short periods between irrigations. This led to further developments and finally the formula was expressed as

$$C_u = k\,\Sigma f \qquad ...(2.7)$$

where C_u = Seasonal consumptive use, *i.e.* consumptive use during the period of growth for a given crop in a given area.

The above formula involves the use of crop factor, the value of which is to be determined for each crop and for different places. At present, this information is not available in India. Moreover, this formula does not take into consideration the factors such as humidity, wind velocity, elevation, etc. on which consumptive use depends. Hargreaves class A Pan evaporation method is, therefore, generally used in India.

Example 2.9. *Wheat is to be grown at a certain place, the useful climatological conditions of which are tabulated below in Table 2.6 (a). Determine the evapotranspiration and consumptive irrigation requirement of wheat crop. Also determine the field irrigation requirement if the water application efficiency is 80%. Make use of Blaney-Criddle equation and a crop factor equal to 0.8.*

Table 2.6 (*a*)

Month	*Monthly temp. in °C, averaged over the last 5 years*	*Monthly per cent of day time hr. of the year computed from the Sun-shine Tables*	*Useful rainfall in cm, averaged over the last 5 years*
(1)	(2)	(3)	(4)
November	18.0	7.20	1.7
December	15.0	7.15	1.42
January	13.5	7.30	3.01
February	14.5	7.10	2.25

Solution. Blaney-Criddle equation is

$$C_u = k \cdot \Sigma f \qquad \text{where, } f = \frac{p}{40}\left(1.8\,t + 32\right);\ \text{and } k = 0.8 \text{ (given)}$$

Values of f are worked out in col. (5) of Table 2.6 (*b*).

Table 2.6 (*b*)

Month	t	p	R_e	$f = \frac{p}{40}(1.8t + 32)$
(1)	(2)	(3)	(4)	(5)
November	18.00	7.20	1.70	11.6
December	15.00	7.15	1.42	10.5
January	13.50	7.30	3.01	10.3
February	14.50	7.10	2.25	10.3
			Σ = 8.38 cm	Σ = 42.7 cm

$$C_u = k \cdot \Sigma f = 0.8 \times 42.7 = 34.16 \text{ cm.}$$

Hence, Consumptive use $C_u = 34.16$ cm. **Ans.**

Consumptive irrigation requirement = $C_u - R_e = 32.72 - 8.38 = 24.34$ cm. **Ans.**

Field irrigation requirement = C.I.R./$\eta_a = \frac{24.34}{0.8} = 30.43$ cm. **Ans.**

Example 2.10. *Determine the volume of water required to be diverted from the head works to irrigate area of 5000 ha using the data given in the table below. Assume 80% as the effective precipitation to take care of the consumptive use of the crop. Also assume 50% efficiency of water application in the field and 75% as the conveyance efficiency of canal*

Table 2.7 (*a*)

Month	*Temp F*	*Percentage hrs of sunshine*	*Rainfall mm*	*Consumptive coefficient or Crop factor (k)*
(1)	*(2)*	*(3)*	*(4)*	*(5)*
June	70.8	9.90	75	0.80
July	74.4	10.20	108	0.85
August	72.8	9.60	130	0.85
September	71.6	8.40	115	0.85
October	69.3	7.86	105	0.65
November	55.2	7.25	25	0.65
December	47.1	6.42	0	0.60
January	48.8	8.62	0	0.60
February	53.9	9.95	0	0.65
March	60.0	8.84	0	0.70
April	62.5	8.86	0	0.70
May	67.4	9.84	0	0.75

Solution. The given table 2.7 (*a*) is extended as shown in table 2.7 (*b*) to compute monthly values of consumptive use (C_u) by the Eqn. $C_u = k \cdot f$, where $f = \frac{p}{40}[1.8t + 32]$, where t is in °C. When t is in °F as given in col (2) of Table 2.7 (*a*), then the eqn. becomes

$$C_u = k\left(\frac{p}{40}t\right) \quad \text{where } t \text{ is °F.}$$

Monthly values of f are hence worked out in col (6) of Table 2.7 (*b*).

Table 2.7 (*b*)

Month	*Temp °F*	*Percentage hrs of sun shine p*	*Rainfall cm*	*Consumptive coefficient or Crop factor k*	$Cu = kf = \frac{k \cdot p}{40} \cdot t$ $\frac{\text{col(5)} \times \text{col (3)} \times \text{col (2)}}{40}$ *cm.*
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
June	70.8	9.90	7.5	0.80	14.02
July	74.4	10.20	10.8	0.85	16.13
August	72.8	9.60	13.0	0.85	14.85
September	71.6	8.40	11.5	0.85	12.78
October	69.3	7.86	10.5	0.65	8.85
November	55.2	7.25	2.5	0.65	6.50
December	47.1	6.42	0	0.60	4.54
January	48.8	8.62	0	0.60	6.31
February	53.9	9.95	0	0.65	8.71
March	60.0	8.84	0	0.70	9.28
April	62.5	8.85	0	0.70	9.68
May	67.4	9.84	0	0.75	12.44
Σ			55.8		124.09 cm

Total consumptive use = Σ col(6) = 124.09 cm.

Useful rainfall = 80% of total precipitation (given)

= 80% $\times$ 55.8 cm. = 44.64 cm.

$\therefore$ Net irrigation requirement

$$NIR = C_u - R_e = 124.09 - 44.64 = 79.45 \text{ cm.}$$

Field irrigation requirement $= FIR = \dfrac{N \cdot I \cdot R}{\eta_a} = \dfrac{79.45}{50\%} = \dfrac{79.45}{0.5} = 158.9$ cm

Gross irrigation requirement at headworks $= \dfrac{FIR}{\eta_c}$

where η_c = conveyance efficiency = 75% = 0.75

$$\therefore \quad GIR = \frac{158.9}{0.75} = 211.87 \text{ cm.}$$

Vol. of water required for 5000 ha area

$$= \frac{211.87}{100} \text{ m} \times (5000 \times 10^4 \text{ m}^2) = \mathbf{105.93\ M \cdot m^3}. \quad \textbf{Ans.}$$

Example 2.11. *The monthly consumptive use values for Paddy are tabulated in Table 2.8. Determine the total consumptive use. What is the average monthly consumptive use and peak monthly consumptive use ?*

Table 2.8

Dates			Rice (Loam Soil) C_u in cm
June	1–30	Nursery	26.69
July	1–12	Nursery	8.76
July	13—31		14.38
August	1—31		22.73
September	1—30		21.29
October	1—31		25.50
November	1—24		15.06

Solution. The summation of consumptive uses

$$= 29.69 + 8.76 + 14.38 + 22.73 + 21.29 + 25.50 + 15.06 = 137.41 \text{ cm}$$

Hence, total consumptive use for paddy = 137.41 cm. **Ans.**

Average daily consumptive use

$$= \frac{137.41}{\text{Period of growth in days}} = \frac{137.41}{30 + 31 + 31 + 30 + 31 + 24}$$

$$= \frac{137.41}{177} = 0.77 \text{ cm.} = 7.7 \text{ mm.} \quad \textbf{Ans.}$$

Average monthly consumptive use = 0.77 $\times$ 30 = 23.1 mm. **Ans.**

Peak monthly consumptive use

= **26.69 cm.** (Highest value given) **Ans.**

2.13.2. Hargreaves Class A pan evaporation method. In this method, evapotranspiration (consumptive use) is related to pan evaporation by a constant K, called *consumptive use coefficient.* The formula can be written as

$$\frac{\text{Evapotranspiration}(E_t \text{ or } C_u)}{\text{Pan evaporation } (E_p)} = K$$

or
$$\boxed{E_t \text{ or } C_u = K \cdot E_p} \qquad ...(2.8)$$

Consumptive use coefficient (K) is different for different crops and is different for the same crop at different places. It also varies with the crop growth, and is different at different crop stages for the same crop. The above relationship is now available for various crops from many countries such as Israel, Philippines, U.S.A. and India. Research stations constantly go on reporting more and more data. Where specific data are not available, average values can be used as recommended by Hargreaves, and given in Table 2.9. The crops have been divided into 8 groups and the coefficients have been suggested for average conditions of soil, etc.

(*i*) *Group A.* The important crops include :

Sugar, Beats, Maize, Cotton, Jowar, Bean, Peas, Potatoes, etc.

(*ii*) *Group B.* This group consists of deciduous fruits and some field crops. Important crops are :

Tomatoes, Hybrid Walnuts, Plumes, Olives, and some group A crops that fail to produce maximum vegetative cover and maximum growth ratios.

(*iii*) *Group C.* $\frac{E_t}{E_p}$ ratios are of the order of 0.6. It includes crops like Melons, Onions, Carrots, Hops, Grapes, etc.

(*iv*) *Group D.* The maximum $\frac{E_t}{E_p}$ ratio is about 0.90 and usually occurs at about 75 to 80% completion of crop vegetative cycle. The important crops are :

Wheat, Barley, Celery, Flax and other small grains, etc.

(*v*) *Group E.* Ratios of $\frac{E_t}{E_p}$ vary from 0.7 to 1.10. The model value being 0.90. The important crops are :

Pastures, Orchard with cover crop, Plantain, etc.

(*vi*) *Group F.* It includes citrus crops such as Oranges, Grape fruit, etc. The $\frac{E_t}{E_p}$ ratios are fairly constant throughout the year and average to a value of about 0.60.

(*vi*) *Group G.* $\frac{E_t}{E_p}$ values generally increase with crop and vary from 0.66 to 1.00. It includes *Sugarcane and Alfalfa.*

(*viii*) *Paddy or Rice.* $\frac{E_t}{E_p}$ increases from 0.80 to 1.30, with crop growth and then falls down, reaching its maximum value somewhere near 50% growth, as shown in Table 2.9.

The coefficients shown in Table 2.9 are only average values and care must be taken while using them. Local values when available should only be used. The factors which increase or decrease the evapotranspiration may be taken into consideration. For example, taller and more uneven vegetation tends to result in greater turbulence and more efficient utilisation of radiation in the production of water use. Dark green vegetation produces higher rate of absorption of solar energy, and hence, its evapotranspiration rate will be higher than that for light green vegetation. For this reason, the plant diseases, causing yellowing of the leaves of the plants, greatly reduce evapotranspiration.

Table 2.9. Hargreave's Average Values of Consumptive Use Coefficient K ($E_t = KE_p$)

Per cent of crop growing season	*Consumptive use coefficient (K) to be multiplied by class A Pan Evaporation (E_p), i.e. $E_t = K \cdot E_p$*							
	Group A	*Group B*	*Group C*	*Group D*	*Group E*	*Group F*	*Group G*	*Rice*
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*
0	0.20	0.15	0.12	0.08	0.90	0.60	0.50	0.80
5	0.20	0.15	0.12	0.08	0.90	0.60	0.55	0.90
10	0.36	0.27	0.22	0.15	0.90	0.60	0.60	0.95
15	0.50	0.38	0.30	0.19	0.90	0.60	0.65	1.00
20	0.64	0.48	0.38	0.27	0.90	0.60	0.70	1.05
25	0.75	0.56	0.45	0.33	0.90	0.60	0.75	1.10
30	0.84	0.63	0.50	0.40	0.90	0.60	0.80	1.14
35	0.92	0.69	0.55	0.46	0.90	0.60	0.85	1.17
40	0.97	0.73	0.58	0.52	0.90	0.60	0.90	1.21
45	0.99	0.74	0.60	0.58	0.90	0.60	0.95	1.25
50	1.00	0.75	0.60	0.65	0.90	0.60	1.00	1.30
55	1.00	0.75	0.60	0.71	0.90	0.60	1.00	1.30
60	0.99	0.74	0.60	0.77	0.90	0.60	1.00	1.30
65	0.96	0.72	0.58	0.82	0.90	0.60	0.95	1.25
70	0.91	0.68	0.55	0.88	0.90	0.60	0.90	1.20
75	0.85	0.64	0.51	0.90	0.90	0.60	0.85	1.15
80	0.75	0.56	0.45	0.90	0.90	0.60	0.80	1.10
85	0.60	0.45	0.36	0.80	0.90	0.60	0.75	1.00
90	0.46	0.35	0.28	0.70	0.90	0.60	0.70	0.90
95	0.28	0.21	0.17	0.60	0.90	0.60	0.55	0.80
100	0.20	0.20	0.17	0.60	0.90	0.60	0.50	0.20

Values of K for certain crops reported from India and U.S.A. are given in Tables 2.10 and 2.11 respectively.

Table 2.10. Values of K for Certain Indian Crops ; ($E_t = K \cdot E_p$)

% of crop growing season	*Wheat Ludhiana (India)*	*Wheat Poona (India)*	*Cotton Poona (India)*	*Maize Ludhiana (India)*
(1)	*(2)*	*(3)*	*(4)*	*(5)*
0	0.14	0.30	0.22	0.40
5	0.17	0.40	0.22	0.42
10	0.23	0.51	0.23	0.47
15	0.33	0.62	0.24	0.54
20	0.45	0.73	0.26	0.63
25	0.60	0.84	0.35	0.75
30	0.72	0.92	0.58	0.85
35	0.81	0.96	0.80	0.96
40	0.88	1.10	0.95	1.04
45	0.90	1.10	1.03	1.07
50	0.91	1.00	1.08	1.09
55	0.90	0.91	1.08	1.10
60	0.89	0.80	1.07	1.11
65	0.86	0.65	1.05	1.10
70	0.83	0.51	1.00	1.07
75	0.80	0.40	0.93	1.04
80	0.76	0.30	0.85	1.00
85	0.71	0.20	0.73	0.97
90	0.65	0.12	0.62	0.89
95	0.58	0.10	0.50	0.81
100	0.51	0.10	0.40	0.70
Seasonal value K	0.61	0.61	0.68	0.86

Table 2.11. Values of *K* for certain U.S.A. Crops ($E_t = K \cdot E_p$)

% of crop growing season	*Sugarcane* Hawaii (USA)*	*Rice Los Banos (USA)*	*Maize Albama (USA)*	*Jowar Albama (USA)*	*Sugarcane* Hargreaves*
(1)	(2)	(3)	(4)	(5)	(6)
0	0.34	1.00	0.40	0.42	0.48
5	0.37	1.02	0.40	0.44	0.50
10	0.40	1.03	0.43	0.46	0.53
15	0.44	1.05	0.46	0.48	0.55
20	0.50	1.07	0.52	0.50	0.60
25	0.60	1.09	0.59	0.52	0.67
30	0.72	1.11	0.67	0.56	0.75
35	0.86	1.13	0.76	0.59	0.80
40	0.93	1.16	0.85	0.64	0.85
45	0.98	1.18	0.93	0.71	0.87
50	1.02	1.20	1.02	0.79	0.89
55	1.05	1.21	1.09	0.92	0.90
60	1.07	1.22	1.14	1.01	0.90
65	1.10	1.22	1.19	1.07	0.85
70	1.13	1.21	1.21	1.09	0.75
75	1.16	1.19	1.23	1.09	0.71
80	1.19	1.16	1.22	1.05	0.68
85	1.20	1.10	1.16	0.99	0.59
90	1.20	1.03	1.06	0.91	0.51
95	1.19	0.96	0.95	0.82	0.50
100	1.19	0.86	0.75	0.70	0.50
Seasonal K	0.89	1.10	0.86	0.75	0.69

*Value of *K* for sugarcane reported from Hawaii and found by Hargreaves are compared in col. (2) and col. (6).

Class A pan evaporation (E_p) measurements. E_p can be experimentally determined by directly measuring the quantity of water evaporated from the standard class A pan. This pan is 1.2 m in diameter, 25 cm deep, and bottom is raised 15 cm above the ground surface. The depth of water is to be kept in a fixed range such that the water surface is at least 5 cm, and never more than 7.5 cm, below the top of the pan.

The pan evaporation (E_p) can also be determined by using the **Christiansen formula,** which states

$$E_p = 0.459\ R \cdot C_t \cdot C_w \cdot C_h \cdot C_s\ C_e \qquad ...(2.9)$$

where R = Extra-terrestrial radiation in the same units as E_p in cm or mm (Table 2.12),

C_t = Coefficient for temperature, and is given by

$$C_t = 0.393 + 0.02796\,T_c + 0.0001189\,T_c^2 \quad \text{...(2.10)}$$

where, T_c is the mean temperature in °C.

C_w = Coefficient for wind velocity, and is given as

$$= 0.708 + 0.0034\,W - 0.0000038\,W^2 \quad \text{...(2.11)}$$

where, W is the mean wind velocity at 0.5 metre above the ground in km/day.

C_h = Coefficient for relative humidity, and is given by

$$C_h = 1.250 - 0.0087H + 0.75 \times 10^4 H^2 - 0.85 \times 10^{-8} H^4 \quad \text{...(2.12)}$$

where H is the mean percentage relative humidity at noon or average relative humidity for 11 and 18 hours.

C_s = Coefficient for per cent of possible sunshine, and is given by

$$= 0.542 + 0.008S - 0.78 \times 10^{-4} S^2 + 0.62 \times 10^{-6} S^3 \quad \text{...(2.13)}$$

where S is the mean sunshine percentage.

C_e = Coefficient of elevation

$$= 0.97 + 0.00984\,E \quad \text{...(2.14)}$$

where E is the elevation in 100 metres.

Values of R for different latitudes are tabulated in Table 2.11.

Example 2.12. *(a) Determine the pan evaporation from the following data for the month of April, using Christiansen method.*

Latitude 15° 19′ N, Elevation + 449 metres

Month : April.

Mean Temperature 31.8°C.

Mean wind velocity at 0.5 m above the ground = 183 kilometres per day.

Mean relative humidity = 40%

Mean sunshine per cent = 89%

Use tables for extra-terrestrial radiation (Table 2.12). (b) What is the consumptive use for April in this country for a crop having a consumptive use coefficient equal to 0.80.

Solution. Find the value of R from Table 2.12 for the month of April and for a latitude of 15° 19′ N. It comes out to be about **47.3 cm**. Now, using eqs. (2.10) to (2.14), we get

$$C_t = 0.393 + 0.02796 \times 31.8 + 0.0001189\,(31.8)^2 = 1.403$$

Table 2.12. Mean Monthly Values of Extra-terrestrial Radiation R in cm.

Latitudes in degrees	*Jan.*	*Feb.*	*March*	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
North												
45	15.621	19.990	31.953	41.072	50.317	52.146	52.426	46.101	35.204	25.730	16.891	13.843
40	19.609	23.393	35.027	42.926	50.003	52.146	52.730	47.498	37.770	29.312	20.701	17.831
35	23.546	26.670	37.871	44.450	51.384	51.918	52.730	48.565	40.056	32.664	24.460	21.819
30	27.407	29.794	40.411	45.669	51.460	51.384	52.451	49.276	42.037	35.814	28.092	25.781
25	31.140	32.690	42.647	46.558	51.206	50.571	51.841	49.682	43.688	38.710	31.572	29.642
20	34.722	35.382	44.552	47.117	50.597	49.428	50.902	49.708	45.009	41.300	34.900	33.376
15	38.100	37.821	46.126	47.320	49.657	47.980	49.657	49.403	45.989	43.612	37.973	36.906
10	41.250	40.005	47.346	47.168	48.388	46.253	48.082	48.717	46.609	45.593	40.818	40.259
5	44.120	41.885	48.209	46.660	46.787	44.221	46.178	47.701	46.888	47.244	43.409	43.358
0	46.736	43.485	48.692	45.822	44.882	41.910	43.993	46.335	46.812	48.539	45.695	46.177

$$C_w = 0.708 + 0.0034 \times 183 - 0.0000038\,(183)^2 = 1.200.$$

$$C_h = 1.250 - 0.0087 \times 40 + 0.75 \times 10^4\,(40)^2 - 0.85 \times 10^{-8}\,(40)^4 = 1.000$$

$$C_s = 0.542 + 0.008 \times 89 - 0.78 \times 10^{-4}(89)^2 + 0.62 \times 10^{-6}(89)^3 = 1.073.$$

$$C_e = 0.97 + 0.00984 \times 4.49 = 1.014.$$

(*a*) Pan evaporation E_p is given by eq. (2.9) as :

$$\mathbf{E_p = 0.459\, R \cdot C_t \cdot C_w \cdot C_h \cdot C_s \cdot C_e}$$

$$= 0.459\,(47.3)\,(1.403)\,(1.200)\,(1.000)\,(1.073)\,(1.014)$$

$$= 39.8 \text{ cm.}$$ **Ans.**

(*b*) $E_t = K \cdot E_p = 0.8 \times 39.8 = 31.84$ cm

Hence, the required value of consumptive use = 31.84 cm. **Ans.**

Example 2.13. *Determine the consumptive use and net irrigation requirement for Jowar sown at Bellary (Karnataka) from the following data:*

Table 2.13 (*a*)

Dates and period of growth	*Pan evaporation E_p or P_e in cm*	*Consumptive use coefficient (K)*	*Effective precipitation in cm.*
(1)	*(2)*	*(3)*	*(4)*
Oct. 16—31	8.49	0.44	3.42
Nov. 1—30	15.57	0.54	2.19
Dec. 1—31	16.59	0.94	0.54
Jan. 1—31	19.10	0.99	0.15
Feb. 1—2	1.54	0.73	0.02

Solution.

Proceed as shown in Table 2.13 (*b*).

Table 2.13 (*b*)

Dates	*E_p (cm)*	*K*	*$K \cdot E_p = E_t = C_u$ in cm*	*R_e in cm*	*$C_u - R_e$ = N.I.R.*
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Oct. 16—31	8.49	0.44	3.74	3.42	0.32
Nov. 1—30	15.57	0.54	8.41	2.19	6.22
Dec. 1—31	16.59	0.94	15.59	0.54	15.05
Jan. 1—31	19.10	0.99	18.91	0.15	18.76
Feb. 1—2	1.54	0.73	1.12	0.02	1.10
			$\Sigma = 47.77$		$\Sigma = 41.45$

First of all, calculate the values of C_u as in col. (4) Table 2.13 (*b*) and then determine N.I.R. as in col. (6) of this Table. Table is otherwise self-explanatory.

Total consumptive use = **47.77 cm**
Net Irrigation requirement = **41.45 cm** } **Ans.**

Table 2.14. Sample Calculations for Determining Irrigation Requirement of Cotton Crop. (in cm)

Cotton (Oct. 11—Feb. 26 = 139 days)

Dates	*No. of days up to mid-point of interval*	*% of growing season = col.* $(2) \times \frac{100}{139}$	*Pan Evap.* $= E_p$	*K*	$E_pK = C_u$	*Effective rainfall* R_e	*N.I.R. in cm*	*F.I.R.* $= \frac{N.I.R.}{\eta_a}$	*GIR* $= \frac{FIR}{\eta_c}$
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*
Oct. 11—31	11	7.9	14.73	1.23	3.38	—	3.38	3.96	5.28
Nov. 1—30	35	25.2	18.85	0.36	6.78	—	6.78	7.98	10.65
Dec. 1—31	67	48.2	17.60	1.00	17.60	—	17.60	20.70	27.60
Jan. 1—31	98	70.5	19.63	0.99	19.43	—	19.43	22.86	30.48
Feb. 1—26	126	90.6	19.94	0.61	12.17	—	12.17	14.30	18.07
					$\Sigma = 59.36$		$\Sigma = 59.36$	$\Sigma = 69.80$	$\Sigma = 92.08$

FIR = Field Irrigation Requirement (in cm) $= \frac{\text{NIR}}{\eta_a} = \frac{\text{NIR}}{0.85}$

FIR includes percolation losses in the field water-courses, field channels and in field application of water.

GIR = Gross Irrigation Requirement (in cm) $= \frac{\text{FIR}}{\eta_c} = \frac{\text{FIR}}{0.85}$

i.e. GIR = FIR + Conveyance losses in distributaries up to the field.

Table 2.15

Sample Calculations for Determining Irrigation Requirement for Wheat Crop (in cm)

Wheat : Period of growth : 1 Nov. to 15 March (135 days)

Dates	*No. of days up to midpoint of interval*	*% of growing season = col.* $(2) \times \frac{100}{135}$	*Pan evaporation* (E_p) *in cm*	*Coeff. (K)*	$E_t = K \cdot E_p = C_u$ *Consumptive use in cm*	R_e *in cm*	*N.I.R.* $= C_u - R_e$ *cm*	*F.I.R.* $= \frac{NIR}{\eta_a} = \frac{NIR}{0.7}$
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*
Nov. 1—30	15	11	15	0.16	2.40	0.4	2.00	2.86
Dec. 1—31	46	34	12.8	0.46	5.89	1.6	4.29	6.13
Jan. 1—31	77	57	9.4	0.73	6.86	3.2	3.66	5.23
Feb. 1—28	106	78	15.4	0.90	13.86	2.2	11.66	16.66
March 1—15	128	95	10.1	0.60	6.06	Nil	6.06	8.66
					$\Sigma = 35.07$		$\Sigma = 27.67$	$\Sigma = 39.54$

Note : 1. The peak requirement during a month will be more than the average ; allowance should therefore, be made for this, while designing channel capacity.

2. Effective rainfall (R_e) should be taken from the previous records, and the mean value should not be taken. On the other hand, the values which are available in 75% to 80% of the years should be taken.

2.13.3. Penman's Equation. While the *Blaney Criddle equation* (1975) and the *Hargreaves class A pan equation using Christiansen formula* (1968) had been in use for the last many years for computing the consumptive use, C_u (*i.e.* evapotranspiration, E_t) values, and net irrigation requirements for different crops ; the *Penman equation* (1998) has, however, more recently been introduced for determing the consumptive use of different areas or different segments of a basin, depending upon the type of vegetation covering each sub-basin. The advantage with this equation lies in the fact that the different specified values of *coefficient of reflection* (*albedo*), a factor used in this equation, are available for different types of areas, which can be used in Penman's equation to compute consumptive use (*i.e.* Potential evapotranspiration, PAT) values for different segments of command area.

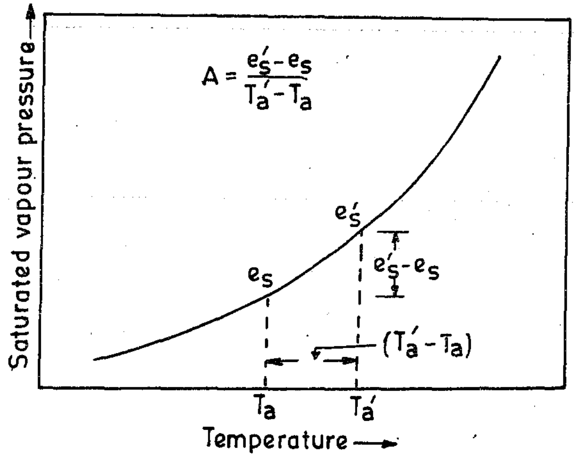

Fig. 2.3. Saturation vapour pressure *vs.* Temp. curve.

Penman's equation for computation of *PET* or C_u for an area, has a sound theoretical reasoning, and it is not a simple empirical equation. This equation has, in-fact, been derived by intelligently combining the *energy balance* and *mass transfer approaches* of the computations of transpiration and evaporation, respectively. Hence, although slightly complicated mathematical conceptual work is involved here, yet its use is becoming more and more popular, in today's modern computer age.

Penman's equation, incorporating some of the modifications suggested by other investigators, is given as:

$$E_t = \frac{A \cdot H_n + E_a \cdot \gamma}{A + \gamma} \qquad ...(2.15)$$

where E_t = Daily potential evapo-transpiration

A = Slope of the saturation vapour pressure V_s Temp. curve at the mean air temperature, as shown in Fig. 2.3, and values given in Table 2.16.

H_n = Net incoming solar radiation or energy, expressed *in mm of evaporable water per day**

* Since the energy required by water in evaporation equals 585 calories/gm = 585 calories/cc (1 gm = 1 cc), we have

Energy as 1 mm of evaporable water from an area of A hectares

$$= \left(\frac{1}{10}\text{ cm}\right)(A \times 10^8 \text{ cm}^2) \times 585 \text{ cal/cm}^3$$

$$= 585 \times 10^7 \text{ A calories}$$

E_a = A parameter including wind velocity and saturation deficit, as given by Eqn. (2.18) in mm/day

γ = psychromatic constant

= 0.49 mm of Hg/°C

The net radiation (H_n) in the above equation is the same, as used in the energy budget equation (7.46), and is estimated by the equation

$$H_n = H_c\,(1 - r)\left(a + b \cdot \frac{n}{N}\right) - \sigma \cdot T_a^{\,4}\,(0.56 - 0.092\sqrt{e_a}) \times \left(0.10 + 0.90\,\frac{n}{N}\right) \quad \text{...(2.16)}$$

where H_c = mean incident solar radiation at the top of the atmosphere on a horizontal surface, expressed in mm of evaporable water per day. This value is a function of latitude (ϕ) of the place and the period of the year, as per the mean monthly values given in table 2.18.

r = **reflection coefficient** (*albedo*) of the given area. Usual values of this coefficient for different types of areas are given in Table 2.17.

a = a constant depending upon the latitude (ϕ) and is given as

$$a = 0.29 \cos \phi \quad \text{...(2.17)}$$

b = a constant having average value

= 0.52

n = actual duration of bright sunshine in hours

N = maximum possible hours of bright sunshine (mean value). This value is a function of latitude (ϕ), and its values are given in table 2.19 for each month of the year

σ = *Stefan-Bolzman constant*

= 2.01×10^{-9} mm/day

T_a = mean air temperature in °K

= 273 + °C

e_a = actual mean vapour pressure in the air in mm of Hg.

The parameter E_a of Penman's equation (2.15) is estimated as :

$$E_a = 0.35\left(1 + \frac{V_2}{160}\right)(e_s - e_a) \text{ mm/day} \quad \text{...(2.18)}$$

where V_2 = mean wind speed at 2 m above the ground in km/day

e_s = saturation vapour pressure at mean air temperature in mm of Hg (Table 2.16)

e_a = actual mean vapour pressure of air in mm of Hg.

With the help of the above equation, and using the values of A, e, r, H_c and N from tables 2.16 to 2.19, E_t or C_u can be determined for the given area. This equation can also be used to compute the evaporation from a water surface (lake, etc.) by using $r = 0.05$. Due to its general applicability, this equation is widely used these days in India, the U.K., the Australia, and in some parts of U.S.A.

Table 2.16. Saturation Vapour Pressure (e_s), and Slope of Saturation Vapour Pressure Vs Temperature Curve (A)

Temperature (1)	Saturation vapour pressure (e_s) in mm of Hg (2)	Slope A in mm/°C (3)
0	4.58	0.30
5.5	6.54	0.45
7.5	7.78	0.54
10.0	9.21	0.60
12.5	10.87	0.71
15.0	12.79	0.80
17.5	15.00	0.95
20.0	17.54	1.05
22.5	20.44	1.24
25.0	23.76	1.40
27.5	27.54	1.61
30.0	31.82	1.85
32.5	36.68	2.07
35.0	42.81	2.35
37.5	48.36	2.62
40.0	55.32	2.95
45.0	71.20	3.66

Table 2.17. Values of Reflection Coefficient r (albedo)

Surface	Range of r values
Close grained crops	0.15 – 0.25
Bare lands	0.05 – 0.45
Water surface	0.05
Snow	0.45 – 0.90

Table 2.18. Mean Monthly Solar Radiation at Top of Atmosphere H_c in mm of evaporable water/day

North Latitude	Jan.	Feb.	March	April	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
0°	14.5	15.0	15.2	14.7	13.9	13.4	13.5	14.2	14.9	15.0	14.6	14.3
10°	12.8	13.9	14.8	15.2	15.0	14.8	14.8	15.0	14.9	14.1	13.1	12.4
20°	10.8	12.3	13.9	15.2	15.7	15.8	15.7	15.3	14.4	12.9	11.2	10.3
30°	8.5	10.5	12.7	14.8	16.0	16.5	16.2	15.3	13.5	11.3	9.1	7.9
40°	6.0	8.3	11.0	13.9	15.9	16.7	16.3	14.8	12.2	9.3	6.7	5.4
50°	3.6	5.9	9.1	12.7	15.4	16.7	16.1	13.9	10.5	7.1	4.3	3.0

Table 2.19. Mean Monthly Values of Possible Sunshine Hours (N)

North Latitude	*Jan.*	*Feb.*	*March*	*April*	*May*	*Jun.*	*July*	*Aug.*	*Sep.*	*Oct.*	*Nov.*	*Dec.*
0°	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1
10°	11.6	11.8	12.1	12.4	12.6	12.7	12.6	12.4	12.9	11.9	11.7	11.5
20°	11.1	11.5	12.0	12.6	13.1	13.3	13.2	12.8	12.3	11.7	11.2	10.9
30°	10.4	11.1	12.0	12.9	13.7	14.1	13.9	13.2	12.4	11.5	10.6	10.2
40°	9.6	10.7	11.9	13.2	14.4	15.0	14.7	13.8	12.5	11.2	10.0	9.4
50°	8.6	10.1	11.8	13.8	15.4	16.4	16.0	14.5	12.7	10.8	9.1	8.1

Example 2.14. *Compute the total consumptive use (C_u) from a drainage basin located near Gurgaon (Haryana) during the month of April by Penman's formula. The following data is given:*

Latitude of place = *28° N*
Elevation = *RL 220 m.*

Meteorologically observed data during April

Mean monthly temperature = *40°C*
Mean relative humidity = *35%*
Mean observed sun shine hours per day = *13h*
Mean wind velocity at 2 m height = *72km/day/(3km/h)*

Data available and obtained from standard charts

(i) Slope of the e_s Vs T° chart at 40°C = *2.95 mm of Hg/ °C*
(ii) Saturation pressure at 40°C = *55.32 mm of Hg*
Mean monthly solar radiation at top of atmosphere during April for 28°N latitude = *14.9 mm of evaporable water/day*
Mean monthly value of possible sunshine hours for April for 28°N latitude = *12.9 h*
Albedo for the area = *0.25*

Solution. Penman's equation (2.15) is given as:

$$E_t = C_u = \frac{A\,H_n + E_a \cdot \gamma}{A + \gamma}$$

where $A = 2.95$ mm of Hg/°C

H_n = to be computed by eq. (2.16)

E_a = given by eq. (2.18) as :

$$= 0.35\left(1 + \frac{V_2}{160}\right)(e_s - e_a) \text{ mm/day}$$

$$= 0.35\left(1 + \frac{72}{160}\right) \times (55.32 - 19.36)$$

$(\because\ e_a = (\text{R.H.})\, e_s$
$= 35\% \times 55.32 = 19.36$ mm Hg

$= 18.07$ mm/day

$\gamma = 0.49$ mm of Hg/°C

H_n is given by eqn. (2.16) as :

$$H_n = H_c (1 - r)\left(a + b \cdot \frac{n}{N}\right) - \sigma \cdot T_a^4 (0.56 - 0.092 \sqrt{e_a}) \times \left(0.10 + 0.90 \frac{n}{N}\right)$$

where H_c = mean monthly incident solar radiation at top of atmosphere

$= 14.9$ mm of evaporable water/day

$r = 0.25$

$a = 0.29 \cos \phi = 0.29 \cos 28° = 0.256$

$b = 0.52$

$n = 13$ h

$N = 12.9$ h

$\sigma = 2.01 \times 10^{-9}$ mm/day

$T_a = (40°C + 273) = 313°K$

$e_a = (R.H.)\ e_s = 35\% \times 55.32$

$= 19.36$ mm of Hg

Substituting values, we get

$$H_n = 14.9 (1 - 0.25)\left[0.256 + 0.52 \times \frac{13}{12.9}\right] - \left[\{2.01 \times 10^{-9} \times (313)^4\} \times \{0.56 - 0.092 \sqrt{19.36}\} \times \left\{0.10 + 0.90 \times \frac{13}{12.9}\right\}\right]$$

$$= 14.9 (0.75) (0.78) - (19.292) (0.155) (1.007)$$

$$= 8.716 - 3.011$$

$= \mathbf{5.705}$ mm of evaporative water/day

Now, $$C_u = \frac{AH_n + E_a\gamma}{A + \gamma}$$

$$= \frac{2.95 \times 5.705 + 18.07 \times 0.49}{2.95 + 0.49}$$

$$= \frac{49.648 + 8.854}{3.44} = \mathbf{17.01\ mm/day.}$$ **Ans.**

2.13.4. Comparison of Blaney-Criddle Equation, Hargreaves-Christiansen Equation and Penman's Equation. These three empirical equations have been developed by the various researchers over the last 40 years to estimate evapo-transpiration (E_t) values for different crops, or area segments vegetated with the same cropping pattern, under different climatic variables. Since the suggested empirical equations are often subjected to rigorous local calibrations, they can not have a global validity. It, however, becomes difficult to suggest as to which equation should be used in a particular case. A recent study made in Chandigarh region has, however, shown that the annual evapotranspiration values obtained from Penman's equation are quite close to the values obtained from the actual field observations made in pan evaporation method ; while the values obtained by Blaney-Criddle equation were on much higher side (about 30% higher), and the values obtained by Hargreaves-Christiansen equation were on lower side (about 15-20% lower). No definite conclusion can, hence, be drawn regarding the decision on the global use of a particular equation.

Although, use of Penman's equation is being largely advocated these days, yet since the equation needs elaborate data, it may not be always feasible to use this equation. Moreover, this equation can be used for generalised vegetated areas, and not for individual crops, since the value range of reflection coefficient *i.e. albedo* (*r*), as used in this equation, is given for areas having close grained crops, as to vary between 0.15-0.25 (Pl. see table 2.17)

2.14. Soil-Moisture-Irrigation Relationship

The water below the watertable is known as ground water and above the watertable as soil-moisture.

Extending down from the ground surface, is the soil zone or the root zone, which is defined as being the depth of overburden that is penetrated by the roots of vegetation, as shown in Fig. 2.4. This zone is the most important from irrigation point of view, because it is this zone, from which the plants do take their water supplies. When water falls over the ground, a part of it gets absorbed in this root zone, and the rest flows downward under the action of gravity and is called *gravity water.*

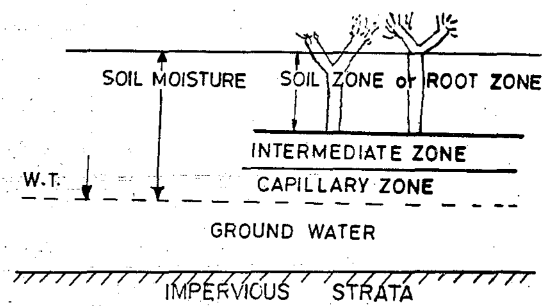

Fig. 2.4.

2.14.1. Field Capacity. Immediately after a rain or irrigation water application, when all the gravity water has drained down to the watertable, a certain amount of water is retained on the surfaces of soil grains by molecular attraction and by loose chemical bonds (*i.e.* adsorption). This water cannot be easily drained under the action of gravity, and is called the *field capacity.* The field capacity is thus the water content of a soil after free drainage has taken place for a sufficient period. This period of free gravity drainage is generally taken as 2 to 5 days.

The field capacity water further consists of two parts. One part is that which is attached to the soil molecules by surface tension against gravitation forces, and can be extracted by plants by *capillarity.* This water is called **capillary water.** The other part is that which is attached to the soil molecules by loose chemical bonds. This water which cannot be removed by capillarity is not available to the plants, and is called the **hygroscopic water.**

The field capacity water (*i.e.* the quantity of water which any soil can retain indefinitely against gravity) is expressed as the ratio of the weight of water contained in the soil to the weight of the dry soil retaining that water : *i.e.*

$$\text{Field Capacity} = \frac{\text{Wt. of water retained in a certain vol. of soil}}{\text{Wt. of the same volume of dry soil}} \times 100 \quad ...(2.19)$$

If we consider 1 m^2 area of soil and d metre depth of root zone, then the volume of soil is $d \times 1 = d$ cubic metres. If the dry unit wt. of soil is γ_d kN/m^3*, then the Wt. of d cubic metres of soil is $\gamma_d \cdot d$ kN. If F is the field capacity, then

* It is the unit wt. of the dried soil sample and not of the soil solids. It may sometimes hence be called as **apparent unit wt.**

$$F = \frac{\text{Wt. of water retained in unit area of soil}}{\gamma_d \cdot d}$$

or Wt. of water retained in unit area of soil $= \gamma_d \cdot d \cdot F \text{ kN/m}^2$

$$\therefore \text{ Vol. of water stored in unit area of soil} = \frac{\gamma_d \cdot d \cdot F \text{ kN/m}^2}{\gamma_w \text{ kN/m}^3}$$

or Total water storage capacity of soil in (m depth of water)

$$= \frac{\gamma_d \cdot d \cdot F}{\gamma_w} \text{ m}$$

where F = the field capacity m.c.
d = depth of root zone in m
γ_w = the unit wt. of water
γ_d = the dry unit wt. of soil.

Hence, the depth of water stored in the root zone in filling the soil upto field capacity

$$= \frac{\gamma_d \cdot \mathbf{d} \cdot \mathbf{F}}{\gamma_w} \textbf{ metres.} \qquad \text{...(2.20)}$$

The knowledge of field capacity is very important, because it is the field capacity water which can supply water for plant nourishment. The larger part of applied water drains down and joins the watertable and is thus a waste from irrigation point of view.

As expressed earlier, the total field capacity water cannot be utilised by the plants. The plants can extract water from the soil till the permanent wilting point is reached. The **permanent wilting point** is that water content at which plant can no longer extract sufficient water for its growth, and wilts up. It is the point at which permanent wilting of plants take place. *It, therefore, becomes evident that the water which is available to the plants, is the difference of field capacity water and permanent wilting point water. This is known as available moisture or maximum storage capacity of soil. Hence, the available water or* **available moisture** may be defined as the difference in water content of the soil between field capacity and permanent wilting point. The water left in the soil after the permanent wilting point is reached, cannot be removed, and is known as, unavailable moisture or *Hygroscopic water* (See Fig. 2.5).

2.14.2. Readily available moisture. It is that portion of the available moisture which is most easily extracted by the plants, and is approximately 75 to 80% of the available moisture.

2.14.3. Soil-moisture deficiency. The water required to bring the soil moisture content of a given soil to its field capacity is called the *field moisture deficiency* or *soil-moisture deficiency.*

2.14.4. Equivalent moisture. Just as the field capacity is the water retained by a saturated soil after being acted upon by gravity ; similarly, *equivalent moisture* is the water retained by a saturated soil after being centrifuged for 30 minutes by a centrifugal force of 1000 times that of gravity. Therefore, it is slightly less, or at the most equal to the field capacity.

2.15. Estimating Depth and Frequency of Irrigation on the Basis of Soil Moisture Regime Concept

Water or soil moisture is consumed by plants through their roots. It, therefore, becomes necessary that sufficient moisture remains available in the soil from the surface to the root zone depth. As explained earlier, the soil moisture in the root zone can vary between field capacity (upper limit) and wilting point moisture content (lower limit) as shown in Fig. 2.5.

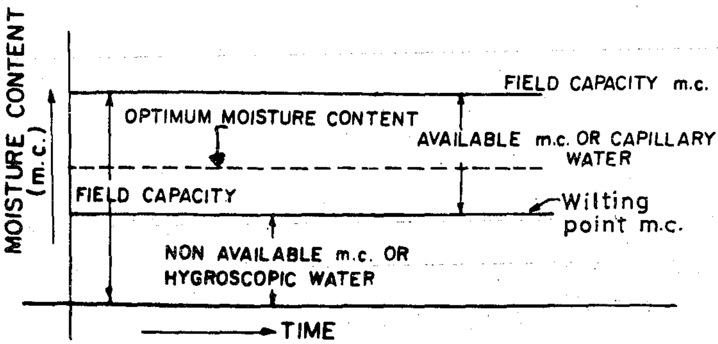

Fig. 2.5.

It is also evident from the previous discussion that the soil moisture is not allowed to be depleted up to the wilting point, as it would result in considerable fall in crop yield. The optimum level up to which the soil moisture may be allowed to be depleted in the root zone without fall in crop yield, has to be worked out for every crop and soil, by experimentation. *The irrigation water should be supplied as soon as the moisture falls up to this optimum level (fixing irrigation frequency) and its quantity should be just sufficient to bring the moisture content up to its field capacity, making allowance for application losses (thus fixing water depth).*

Water will be utilised by the plants after the fresh irrigation dose is given, and soil moisture will start falling. It will again be recouped by a fresh dose of irrigation, as soon as the soil moisture reaches the optimum level, as shown in Fig. 2.6.

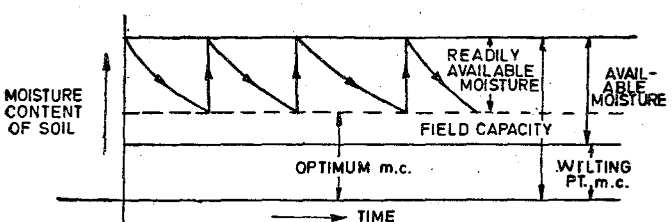

Fig. 2.6.

Example 2.15. *After how many days will you supply water to soil in order to ensure sufficient irrigation of the given crop, if*

(*i*) *Field capacity of the soil = 28%*

(*ii*) *Permanent wilting point = 13%*

(*iii*) *Dry density of soil = 1.3 gm/c.c.*

(iv) *Effective depth of root zone = 70 cm*

(v) *Daily consumptive use of water for the given crop = 12 mm.*

Assume any other data, not given. (*Engineering Services, 1974*)

Solution. We know, by definition of available moisture, that

the available moisture = Field capacity − Permanent wilting

$= 28 - 13 = 15\%$.

Let us assume that the readily available moisture or the optimum soil moisture level is 80% of available moisture.

i.e., Readily available moisture $= 0.80 \times 15\% = 12\%$

$\therefore$ Optimum moisture $= 28 - 12 = 16\%$

It means that the moisture will be filled by irrigation between 16% and 28%.

Depth of water stored in root zone between these two limits

$$= \frac{\gamma_d \cdot d}{\gamma_w}\left[\text{Field capacity m.c.} - \text{Optimum m.c.}\right]$$

$$\text{where } \frac{\gamma_d}{\gamma_w} = \frac{\rho_d \cdot g}{\rho_w \cdot g} = \frac{\rho_d}{\rho_w} = \frac{1.3 \text{ gm/cc}}{1.0 \text{ gm/cc}} = 1.3$$

$$d = 0.7 \text{ m (given)}$$

$$= 1.3 \times 0.70\left[0.28 - 0.16\right] \text{m}$$

$$= 1.3 \times 0.7 \times 0.12 \text{ m} = 0.1092 \text{ m} = 10.92 \text{ cm}.$$

Hence, water available for evapo-transpiration = 10.92 cm.

1.2 cm of water is utilised by the plant in 1 day

$\therefore$ 10.92 cm of water will be utilised by the plant in

$$= \frac{1 \times 10.92}{1.2} \text{ days} = \textbf{9.1 days} \text{ ; Say 9 days.}$$

Hence, after 9 days, water should be supplied to the given crop. **Ans.**

Example 2.16. *Wheat is to be grown in a field having a field capacity equal to 27% and the permanent wilting point is 13%. Find the storage capacity in 80 cm depth of the soil, if the dry unit weight of the soil is 14.72 kN/m³. If irrigation water is to be supplied when the average soil moisture falls to 18%, find the water depth required to be supplied to the field if the field application efficiency is 80%. What is the amount of water needed at the canal outlet if the water lost in the water-courses and the field channels is 15% of the outlet discharge ?*

Solution. Maximum storage capacity or Available moisture.

$$= \frac{\gamma_d \cdot d}{\gamma_w}\left[\frac{\text{Field capacity m.c.}}{100} - \frac{\text{Wilting pt. m.c.}}{100}\right]$$

$$\text{where } \gamma_d = 14.72 \text{ kN/m}^3$$

$$d = \text{depth of root zone} = 0.8 \text{ m}$$

$\therefore$ Max. storage capacity or max. Available moisture

$$= \frac{14.72}{9.81} \times 0.8\left[0.27 - 0.13\right] \qquad \left[\because \gamma_w = 9.81 \text{ kN/m}^3\right]$$

$$= 1.2\,[0.14] = 0.168 \text{ metres} = 16.8 \text{ cm.} \quad \textbf{Ans.}$$

Since the moisture is allowed to vary between 27% and 18%, the deficiency created in this fall

$$= \frac{14.72}{9.81} \times 0.8\,[0.27 - 0.18]$$

$$= 1.2 \times 0.09 = 0.108 \text{ metres} = \mathbf{10.8\ cm.}$$

Hence, 10.8 cm depth of water is the net irrigation requirement.

Quantity of water required to be supplied to the field (F.I.R.) $= \dfrac{\text{N.I.R.}}{\eta_a}$

or $$\text{F.I.R.} = \frac{\text{N.I.R.}}{0.80} = \frac{10.8}{0.80} = 13.5 \text{ cm.} \quad \textbf{Ans.}$$

Quantity of water needed at the canal outlet

$$= \frac{\text{F.I.R.}}{\eta_c} = \frac{13.5}{0.85} = 15.88 \text{ cm.} \quad \textbf{Ans.}$$

Example 2.17. *800 m³ of water is applied to a farmer's rice field of 0.6 hectares. When the moisture content in the soil falls to 40% of the available water between the field capacity (36%) of soil and permanent wilting point (15%) of the soil crop combination, determine the field application efficiency. The root zone depth of rice is 60 cm. Assume porosity = 0.4.* (*Civil Services, 1994*)

Solution. We have defined Field Capacity m.c. (F) as :

$$F = \frac{\text{Wt. of water contained in a certain vol. of soil}}{\text{Wt. of the same volume of dry soil (}i.e.\text{ wt. of dry soil retaining that water)}}$$

If a saturated soil contains volume equal to V, and the volume of its voids is V_v, then the weight of water contained in this soil $= \gamma_w \cdot V_v$; where γ_w is the unit wt. of water. The wt. of this soil of V m³ after it is oven dried to remove water and to fill the voids with air, is given by $\gamma_d \cdot V$; where γ_d is the *dry unit wt. of the soil.*

$$\therefore \quad F = \frac{\gamma_w \cdot V_v}{\gamma_d \cdot V} \qquad \text{But } \frac{V_v}{V} = n \text{ (porosity)}$$

$$\therefore \quad F = \frac{\gamma_w}{\gamma_d} \cdot n$$

$$\therefore \quad \frac{\gamma_d}{\gamma_w} = \frac{n}{F} = \frac{0.4}{0.36} = 1.11 \qquad \because \begin{array}{l} n = \text{Porosity} = 0.4 \\ F = \text{F.C.} = 0.36 \end{array} \text{(given)}$$

Max. quantity of water stored between field capacity (FC) and permanent wilting point (P.W)

$$= \left(\frac{\gamma_d}{\gamma_w}\right) d \cdot (w_F - w_P)$$

where d = root zone depth = 0.6 m (given)

$$= 1.11 \times 0.60\,[0.36 - 0.15] = 0.14 \text{ m.}$$

Deficiency of water created when irrigation is done

$$= 60\% \times 0.14 \text{ m} \left[\because \begin{array}{l} \text{irrigation water is applied when m.c. falls} \\ \text{to 40\% of m.c. available between F.C. and P.W.} \end{array}\right]$$

$$= \mathbf{0.084\ m}$$

Hence, irrigation water is supplied to fill up 0.084 m depth of water.

∴ Vol. of irrigation water required to fill up the created deficiency

$$= 0.084\ \text{m} \times (0.6\ \text{hect.})$$

$$= 0.084\ \text{m} \times (0.6 \times 10{,}000)\ \text{m}^2 = \mathbf{504\ m^3}. \quad ...(i)$$

Actual irrigation water supplied = $800\ \text{m}^3$ ...(*ii*)

∴ Efficiency of field application $= \frac{504}{800} = \mathbf{63\%}$ **Ans.**

Example 2.18. *Work out the irrigation schedule based on the soil moisture concept, given the following information. Also extract the data on the total depth of irrigation water required and the respective dates of irrigation water supply :*

(*a*) *The crop is grown in an appropriate soil with no restrictive layers within the top 1.5 m depth of soil.*

(*b*) *Normal root zone depth of the crop is 1.2 m.*

(*c*) *Bulk density of soil is 1.35.*

(*d*) *Field capacity is 18% and permanent wilting point is 7%.*

(*e*) *Moisture level in the soil is to be maintained at not less than one-third of available retention. Irrigation will then be done over a duration of 2 days at a uniform rate of supply and at a uniform rate of advance to fully and just compensate for the depletion.*

(*f*) *No extra water is ever required for leaching.*

(*g*) *Sowing is done on 1 November when the soil moisture is left just at field capacity in the entire root zone.*

(*h*) *For the crop, at the location, the average evapotranspiration rates are :*

1 Nov. — 30 Nov.	:	*1.1 mm/day*
1 Dec. — 31 Dec.	:	*1.7 mm/day*
1 Jan. — 31 Jan.	:	*2.4 mm/day*
1 Feb. — 28 Feb.	:	*1.5 mm/day*
1 March—25 March	:	*3.5 mm/day*

(*i*) *Harvesting is done on or after 26 March.*

(*j*) *There is expected an effective rainfall of 24 mm during 4 January to 19 January, both days inclusive, with uniform intensity.*

(*k*) *By the end of the crop growth season, only the minimum water needed to be left unused in the root zone.* (*Engineering Services, 1990*)

Solution.

Max. moisture retained by soil = Field capacity = 18%

Permanent wilting *i.e.* below which soil cannot extract water for plant's growth

$$= 7\%$$

∴ Max. moisture available for plant's growth *i.e. available moisture retention*

$$= 18 - 7 = 11\%$$

$\frac{1}{3}$ of available moisture $= \frac{11}{3}\% = 3.67\%$

∴ Moisture level at which irrigation must start = Minimum m.c. at which plants start wilting + $\frac{1}{3}$ of available moisture (given)

$$= 7\% + 3.67\% = 10.67\%.$$

This means that we will start irrigation as soon as m.c. falls to 10.67%, and will, thus, fill the soil with moisture till it rises to 18% (field capacity).

Irrigation water required to increase m.c. of soil in root zone from 10.67% to 18% is obtained by equation (2.15), as :

$$= \frac{\gamma d}{w}\left[\begin{matrix}\text{Upper limit m.c.}\\ \text{as fraction}\end{matrix} - \begin{matrix}\text{Lower limit m.c.}\\ \text{as fraction}\end{matrix}\right]$$

where γ = Unit wt. (Apparent) of soil

w = Unit wt. of water

∴ $\frac{\gamma}{w}$ = Density (apparent) of soil = 1.35 (given)

d = root zone depth = 1.2 m (given)

$$= 1.35 \times 1.2\left[\frac{18}{100} - \frac{10.67}{100}\right] = 1.35 \times 1.2\,[0.18 - 0.1067] = \mathbf{11.87\ cm.}$$

In other words, as and when this 11.87 cm depth of stored moisture gets consumed by evapotranspiration, irrigation water will be supplied.

From the given consumptive uses, we find that

Water consumed from 1st Nov. to 3 Jan. (when rains start)

= 1.1 mm/day × 30 days (*i.e.*, between 1 Nov. — 30 Nov.)

+ 1.7 mm/day × 31 days (*i.e.*, between 1 Dec.–31 Dec.)

+ 2.4 mm/day × 3 days (*i.e.*, between 1 Jan.–3 Jan.)

= 92.9 mm = **9.29 cm** ...(*i*)

Hence, water withdrawn from soil during Ist Nov. to 3 Jan. = **9.29** *cm* (< permissible 11.87 cm).

No irrigation is, thus, required till then.

During rains (between 4 Jan. to 19 Jan.), effective rain water received by soil per day

$$= \frac{2.4\ \text{cm}}{16\ \text{days}} = 0.15\ \text{cm/day}$$

Consumptive use of 0.24 cm/day during this period, means that an amount of 0.24–0.15 = 0.09 cm/day of moisture is only consumed from soil, *i.e.*

Additional water consumed from soil during 4 Jan. — 19 Jan.

= 0.09 cm/day × 16

= **1.44 cm** ...(*ii*)

Hence, water withdrawn from soil during 1st Nov.—19 Jan.

= (*i*) + (*ii*) = 9.29 + 1.44 = 10.73 cm.

Balance water left in soil to be withdrawn before irrigation

= 11.87 − 10.73 = 1.14 cm.

This is consumed @ 2.4 mm/day in x days,

$$\text{where } x = \frac{1.14}{0.24} = 4.75 \text{ days, say 4 days.}$$

Hence, Ist irrigation will be needed after 4 days from 20th Jan., i.e., on 24th Jan. This irrigation is to be done over 2 days (given), i.e., on 24 Jan. and 25 Jan.

First irrigation water required on 24 Jan. and 25 Jan.

$$= (10.73 + 4 \times 0.24) + \frac{2.4}{10} \text{ cm/day} \times 2 \text{ days}$$

(to compensate for depletion in 2 days)

$$= 11.69 + 0.48 = \mathbf{12.17\ cm.} \quad \textbf{Ans.}$$

With effect from 26 Jan., water is again consumed as below:

Between 26 Jan.–31 Jan.	$= 0.24 \text{ cm/day} \times 6 \text{ days}$	= 1.44 cm
Between 1 Feb.–28 Feb.	$= 0.15 \text{ cm/day} \times 28 \text{ days}$	= 4.20 cm
Between 1 March–25 March	$= 0.35 \text{ cm/day} \times 25 \text{ days}$	= 8.75 cm
	Total	= 14.39 cm > 11.87 cm

Hence, another water is required after x days of March, where

$$x = \frac{11.87 - (1.44 + 4.2)}{0.35} = 17.8 \text{ days } i.e., 17 \text{ days}$$

Hence, 2nd irrigation should start on **18th March** and water depth now required is only

$$= 14.39 - 11.87 = \mathbf{2.52\ cm.}$$

Thus, only 2.52 cm irrigation water is required at 2nd time.

Hence, *the required irrigation schedule is*

(*i*) 1st watering on 29th and 30 Jan. = 12.17 cm of water depth
(*ii*) 2nd watering on 18th March = 2.52 cm of water depth **Ans.**

Example 2.19. *A sandy loam soil holds water at 140 mm/m depth between field capacity and permanent witting point. The root depth of the crop is 30 cm and the allowable depletion of water is 35%. The daily water use by the crop is 5 mm/day. The area to be irrigated is 60 ha and water can be diverted at 28 l.p.s. The surface irrigation application efficiency is 40%. There are no rainfall and ground water contribution.*

Determine

(*i*) *allowable depletion depth between irrigations.*

(*ii*) *frequency of irrigation*

(*iii*) *net application depth of water*

(*iv*) *volume of water required*

(*v*) *time to irrigate 4 ha plot* (*Engineering Services 1999*)

Solution. Moisture holding capacity of soil = 140 mm/m depth

Depth of root zone = 30 cm = 0.3 m

∴ Moisture holding capacity of root zone

$$= 140 \frac{\text{mm}}{\text{m}} \times 0.3 \text{ m} = 42 \text{ mm} = \mathbf{4.2.\ cm}$$

Allowable depletion = 35%

(*i*) ∴ Available moisture depth or Allowable depletion depth between irrigations

$= 35\% \times 4.2 \text{ cm} = \mathbf{1.47 \text{ cm.}}$ Ans.

Daily use of water = consumptive use = 5 mm/day

(*ii*) ∴ Frequency of irrigation

$$= \frac{\text{Available moisture}}{\text{Moisture consumed per day}} = \frac{1.47 \text{ cm}}{0.5 \text{ cm/day}}$$

= 2.94 days., say **3 days. Ans.**

Net water depth to be applied while irrigating each time after 3 days

$= 3 \times 0.5 = \mathbf{1.5 \text{ cm}}$ **Ans.** (in place of 1.47 cm)

Field Irrigation requirement

$$= \frac{\text{Net irrigation requirement}}{\text{Efficiency of irrigation}} = \frac{1.5}{0.4} = 3.75 \text{ cm.}$$

(*iv*) ∴ Qty. of water reqd. in the fields

= 3.75 cm of water depth = 3.75 cm × Area of field

$$= 3.75 \text{ cm} \times 60 \text{ ha} = \frac{3.75 \text{ m}}{100} \times (60 \times 10^4) \text{ m}^2 = 22{,}500 \text{ m}^3$$

Hence, vol of water reqd. to irrigate 60 ha area, each time at 3 days interval

$= \mathbf{22{,}500 \text{ m}^3}$ **Ans.**

(*v*) *Time to irrigate 4 ha when irrigation water is supplied @ 28 lps :*

Vol. of water reqd. to irrigate 4 ha plot

$$= 3.75 \text{ cm} \times 4 \text{ ha} = \frac{3.75}{100} \times (4 \times 10^4) \text{ m}^3 = 1500 \text{ m}^3$$

Time during which 1500 m^3 of water can be supplied @ 28 lps.

$$= \frac{1500 \times 10^3 \text{ l}}{28 \text{ lps}} = \frac{1500 \times 10^3}{28} \text{ s}$$

$$= \frac{1500 \times 10^3}{28} \times \frac{1}{60 \times 60} \text{ hr} = \mathbf{14.88 \text{ hr}} \quad \textbf{Ans.}$$

Example 2.20. *Determine the field capacity of a soil for the following data :*

(*i*) *Depth of root zone = 1.8 m*

(*ii*) *Existing moisture = 8%*

(*iii*) *Dry density of soil = 1450 kg/m^3*

(*iv*) *Quantity of water applied to soil = 650 m^3*

(*v*) Water lost due to deep percolation and *evaporation* = 10%

(*vi*) *Area to be irrigated = 1000 m^3* (*AMIE 1999 (Summer) Exam.*)

Solution. Volume of total water applied = 650 m^3.

Water wasted = 10% of 650 m^3 = 65 m^3.

Water used in raising m.c up to field capacity = 650 – 65 = 585 m^3.

Depth of water used in raising m.c up to to field capacity from the existing 8%

$$= \frac{585 \text{ m}^3}{\text{Area} = 1000 \text{ m}^2} = 0.585 \text{ m}$$

But water depth required in root zone of depth *td* increase m.c, is given by eqn.

$$= \frac{\gamma_d}{w}\left[\text{ upper limit mc} - \text{lower limit mc, as fractions }\right]$$

$$\therefore \quad 0.585 = \frac{1.45\ t/\text{m}^3}{1\ t/\text{m}^3} \times 1.8 \text{ m}\left[F.C - 0.08\right]$$

or $(F.C - 0.08) = 0.224$

or $F.C = 0.224 - 0.08 = 0.144$

Hence, Field capacity = **14.4%** **Ans.**

PROBLEMS

1. (*a*) What is meant by 'Duty' and 'Delta' of canal water ? Derive a relationship between duty and delta for a given base period.

   (*b*) Find the delta for sugarcane when its duty is 730 hectares/cumec on the field and the base period of the crop being 110 days. (**Ans.** 130 cm)

   (*c*) Define and explain the following terms as used in relation to water requirements of crops :

   (*i*) Base period. (*ii*) Intensity of irrigation. (*iii*) Cash crops.

2. (*a*) What do you understand by 'Duty' of canal water and what is its importance ? Explain how does duty differs from that at the head of a water-course and that at the head of a canal bringing water to the watercourse.

   (*b*) Mention the approximate values of Duty and Delta for rice, wheat and sugarcane in your region.

3. (*a*) Define 'Duty' and 'Delta', and derive their relationship.

   (*b*) What are the factors on which duty depends ?

   (*c*) How can the duty be improved and what will be the gain ?

   (*d*) What is meant by 'Flow duty' and 'Quantity duty' ?

4. What is meant by 'duty' ?

   Enumerate the different terms by which duty can be improved.

   What are the factors affecting duty ?

   The base period of paddy is 120 days. If the duty for this crop is 900 hectares per cumec, find the value of delta. [**Ans.** 115 cm]

5. Describe briefly the factors affecting duty.

   Water is released at the rate of 5 cumecs at the head sluice. If the duty at the field is 100 hectares/cumec and the loss of water in transit is 30%, find the area of the land that can be irrigated. [**Ans.** 350 hectares]

6. What is meant by "Duty of water" ? Explain the influence of several factors which affect duty. What are the different ways in which duty can be expressed ?

   A reservoir with a live storage capacity of 300 million cubic metres is able to irrigate an ayacut of 40,000 hectares with 2 fillings each year. The crop season is 120 days. What is the duty ? [**Ans.** 691 hectares/cumec]

7. Name the principal kharif crops of your region, and detail the agricultural and climatic requirements for sowing, growth and harvesting of one of the principal ones. Give the normal requirement of seed per hectare and the average yield per hectare of the crop.

   Suggest ways to increase the "duty" in an irrigation system.

8. (*a*) Explain as how the following factors affect the 'duty' of a crop :

(*i*) Soil and sub-soil condition. (*ii*) Stage of growth.

(*iii*) Temperature. (*iv*) Rainfall.

(*b*) Compute the depth and frequency of irrigation required for a certain crop with data given below :

Root zone depth = 100 cm. Field capacity = 22%

Wilting point = 12% Apparent specific gravity of soil* = 1.50

Consumptive use = 25 mm/day Efficiency of irrigation = 50%

Assume 50% depletion on available moisture before application of irrigation water at field capacity.

[**Hint.** Follow example 2.14, and work out :

Readily available moisture = 5%, and finally work out :

Depth of water stored in root zone = 7.5 cm
Frequency of irrigation = 3 days] **Ans.**

9. Explain with neat sketch the layout of a modern canal system, carrying water from a barrage. Discuss as to how the duty of water increases as we move downstream from the head of the main canal towards the head of the watercourse.

10. Write short notes on :

(*i*) Optimum utilisation of irrigation water.

(*ii*) Crop rotation.

(*iii*) Consumptive use and its estimation.

(*iv*) Water distribution efficiency.

(*v*) Net irrigation requirement (NIR).

(*vi*) Outlet factor.

(*vii*) Estimating depth and frequency of irrigation on the basis of soil moisture regime concept.

(*viii*) Crop seasons in India and their principal crops.

11. Define and explain the following terms :

(*i*) Cash crops. (*ii*) Field capacity.

(*iii*) Available moisture. (*iv*) Soil moisture deficiency.

(*v*) Crop ratio. (*vi*) Overlap allowance.

(*vii*) Paleo irrigation. (*viii*) Kor water depth.

12. How will you proceed for determining the field irrigation requirement (FIR) for an important crop like wheat ? Explain with reference to a sample table, with assumed monthly values of pan evaporations. [**Hint.** Please see Table 2.15]

13. Name any two methods used for estimating consumptive use of water for a particular crop at a particular place. Explain in details the one which is most widely used in your region, and the reasons for preferring that particular method.

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* **Apparent sp. gr. of soil** $= \dfrac{\gamma_d}{\gamma_w}$, where γ_d is the dry unit wt. of soil (i.e. the soil containing air filled voids).

Actual sp. gr. (S_s or G) $= \dfrac{\gamma_s}{\gamma_w}$, where γ_s is the unit wt. of the soil solids.